India Smart Grid Forum

India SMART UTILITY Week 2022

COMPENDIUM OF TECHNICAL PAPERS

ISUW 2022

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INDIA SMART UTILITY WEEK 2022

02 - 04 March 2022
Digital Platform

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Preface

India Smart Grid Forum (ISGF), a public private partnership initiative of Government of India with the mandate of accelerating smart grid deployments across the country. With 180+ members comprising of ministries, utilities, technology providers, academia and research, ISGF has evolved as a Think-Tank of global repute on Smart Energy and Smart Cities. Mandate of ISGF is to accelerate energy transition through clean energy, electric grid modernization and electric mobility; work with national and international agencies in standards development and help utilities, regulators and the industry in technology selection, training and capacity building.

Since 2016, ISGF invites Technical Papers on the latest themes related to Power Sector to recognize the best Technical Papers in the industry as part of its annual flagship event India Smart Utility Week (ISUW) an International Conference and Exhibition on Smart Energy and Smart Mobility. The authors of the top 25 technical papers selected by an expert jury panel get the opportunity to present their papers at India Smart Utility Week (ISUW) which witnesses participation of Visionary Leaders, Utility CEOs, Regulators, Policy Makers and Subject Matter Experts from 50+ Countries every year. Top 50 Authors get the opportunity to get their technical papers published with renowned publishing house/ISGFs Portal.

The themes for Technical Papers 2022 were:

- Evolving Architecture of the 21 st Century Grid with Two Way Power Flows
    - Planning And Design of Transmission Grid
    - Planning And Design of Distribution Grid with Prosumers and Electric Vehicles and Distributed Energy Resources
    - Communication Systems and Technologies for Fast Response- 1/50 OR 1/60 Seconds
    - Climate Proofing of Future Grids
- Electric Mobility
    - Electric Vehicle Charging Infrastructure (EVCI) and Distribution Grid Upgrades
    - Vehicle Grid Integration (VGI)
    - Electricity Tariff for EV Charging
    - New Infrastructure Planning with Integrated EVSE
    - EVs as Virtual Power Plants (VPP)
    - Smart Charging of EVs
    - Business Models for EV Charging Stations
- Foundational Blocks for Smart Grids
    - Learnings from Smart Grid Projects
    - Smart Microgrids for Campuses, Railway Stations, Sea Ports, Airports, Industrial Parks, Military Bases, Hotels, Hospitals, Slums and Commercial Complexes
    - Cyber Physical Security of the Critical Infrastructure
    - Standards and Interoperability of Equipment and Systems
    - Communication Solutions for Smart Grids and Smart Cities

  - Flexibility in Power Systems
  - Energy Storage Systems - Applications and Business cases
  - 250 Million Smart Meters in India – Rollout Strategies and Business Models
- Disruptive Innovations for Utilities
  - Artificial Intelligence and Robotics, Drones
  - Virtual Reality, Augmented Reality, and Mixed Reality Technologies for the Smart Grids and Smart Cities
  - Machine Learning
  - Wearable Devices
  - Blockchain Applications for Utilities
  - Robotic Process Automation (RPA) for Utilities
  - "Paper-less" and "Contact-less" Operations
  - Digitalization, New Services and Revenue Streams
  - Voice of the Customer - What the Digital Customers Wants?
  - Customer Engagement Strategies and Social Media for Utilities - Customer Portal, Chat-bot, Voice-bot
  - Grid Interactive Buildings and Campuses
- Smart Grids for Smart Cities
  - Common Automation and IT Layer for Smart City Infrastructure Domains
  - Unlocking the Value of Street Light Poles for Multiple Smart City Applications
  - Smart Home and Smart Appliances
  - Smart Grid as Anchor Infrastructure for Smart Cities
  - Smart Energy Communities
  - Distributed Generation
  - Combined Billing and Customer Care Systems for all Utilities in a Smart City
  - Common GIS Map for all Domains in a Smart City
  - Digital Twins
- New and Emerging Technologies and Trends
  - Green Hydrogen
  - District Cooling System
  - Electric Cooking
  - Urban Air Mobility Systems (UAM)
- Regulations for the Evolving Smart Energy Systems
  - 100% Renewables
  - Flexibility Solutions
  - Retail Competition
  - Green Power Markets
  - Ancillary Services
- Smart Water
  - Smart Solutions for Water Production, Transmission and Distribution
  - Smart Technologies to Address India's Urban Water Crisis
- Smart City Gas Distribution
- Solutions for Gas Transmission and Distribution Networks

- Cyber Security for the Digitalized Grids

For the year 2022, total of 180 abstracts were received out of which 106 abstracts were shortlisted by esteemed Jury Panel for full technical paper submission. As per the guidelines given by Jury Members, 76 Full Papers were further evaluated by Jury Members out of which 57 Papers were shortlisted this year. Top 25 Papers were given an opportunity to present at ISUW 2022, organized from 02 – 04 March 2022. Top 57 selected Technical Papers are published in this compendium of Technical Papers.

Esteemed Jury Members
ISUW 2022 Technical Papers

Jury Members	Brief Profile of Jury Members
 Dr Faruk Kazi Chair of ISGF Working Group on Digital Architecture and Cyber Security Professor and Dean of Research and Development, VJTI, Mumbai	Faruk Kazi received his Ph.D. degree from Systems & Control Engineering of Indian Institute of Technology (IIT) Bombay, in 2009. He is currently a Professor and Dean of Research & Development at VJTI, Mumbai, India.
 Mr N Murugesan Former Director General, CPRI, 38 Years of experience in Power Systems, SCADA, Substation, Distribution Automation and Smart Metering	N.Murugesan holds MSc (Engg) and MBA. He has more than 38 years of experience in the area of Smart Metering, Smart Grid, Advanced Metering Infrastructure (AMI), Power Systems, Transmission & Distribution system, SCADA, Substation & Distribution Automation, Switchgear testing & Certification (Low & High voltage equipment) as per National & International standards.
 Mr Ravi Seethapathy Ambassador Americas, Global Smart Grid Federation, Honorary Member and WG Chair, ISGF and Chairman, Biosirus Inc. Canada	After 35+ year career in Electric Utilities/Power Systems, Ravi Seethapathy is now an Advisor to the Utility/Industry, and sits on the Boards of Power Transmission & Distribution (IC) Division of Larsen & Toubro, India; Biosirus Inc., Canada; Smart Grid Canada, and India Smart Grid Forum. His current international activities include (1) “Ambassador for the Americas”, Global Smart Grid Forum; (2) CIGRE Convener WGC6.28-Remote Grids; (3) IEA PVPS Taskforce 14 – Large Scale Solar Integration; (4) IEC TC 120 – Energy Storage; (5) IEC SEG4-LVDC; and (6) Chair, India Smart Grid Forum WG 5-RE & Micro-grids.

 Mr BP Singh Former Member Delhi Electricity Regulatory Commission (DERC)	Mr. BP Singh is a graduate in Mining Engineering from Indian School of Mines, Dhanbad and has over 40 years of experience in the power & energy sector. He was a Former Member in DERC (Delhi Electricity Regulatory Commission). He has issued three successive Tariff Orders for the period 2014 to 2018, being consumer friendly, were highly acclaimed at all levels. He has been part of numerous high-level committees constituted by the Government of India for formulation of Plan proposals and Policies including Energy Policy, pricing of Coal etc.
 Mr Vijay Sonavane Former Member, MERC	Shri Vijay Sonavane is Former member to Maharashtra Electricity Regulatory Commission (MERC). He retired as a Member, MERC in August 2014. Sh. Sonavane is BE / ME (ELECTRICAL) from Pune University. He is the Member of the Committee set up by Govt. of India for preparing Regulations for Smart Grids.
 Mr Girish Ghatikar Technical Executive, Senior Program Manager, EPRI, California, USA	Mr Girish Ghatikar leads the information and communication technologies (ICT) program at the Electric Power Research Institute (EPRI) in the United States. Ghatikar's research identifies, creates, and transfers digital energy solutions for the electric industry, emphasizing the remote management of distributed energy resource technologies (demand response, electric vehicles, energy storage, and distributed generation) and services.
 Mr Reji Kumar Pillai President, ISGF Chairman, GSGF	Reji is the President of India Smart Grid Forum since its inception in 2011 and is also the Chairman of Global Smart Grid Federation since November 2016. He is an internationally renowned expert with over three decades of experience in the electricity sector in diverse functions covering the entire value chain and across continents. He is spearheading a mission to leverage technology to transform the electric grid in India and light every home at affordable cost through sustainable developmental models.

 Ms Reena Suri Executive Director, ISGF	Reena Suri, Executive Director with India Smart Grid Forum (ISGF) since 2013, brings over 19 years of experience in the Energy Sector. She is responsible for the research projects, advisory services, business development, training and capacity building programs, customer outreach activities, members relations and finances of ISGF.

ISGF Team

Please refer to the below table to know the details of ISGF Team Members involved in the ISUW 2022 Technical Papers Secretariate.

ISGF Team	Brief Profile
 Sneha Singhania Manager - Digital Communications and Marketing, ISGF	Sneha Singhania is currently working as Manager- Digital Communications and Marketing at India Smart Grid Forum (ISGF). she is currently in-charge of managing overall Marketing Activities, Digital and Corporate Communications and Media Outreach. She also manages ISGF Social Media Communications, Press Release and Press Conferences, Media Partnerships and Engagement, Traditional and Non-Traditional Media Advertisements and Marketing Collaterals development and Annual Reports. She plays a key role as part of the organizing committee of ISGF's annual Flagships Events – India Smart Utility Week (ISUW), ISGF Innovation Awards and Distribution Utility Meet (DUM).
 Parul Shribatham Research Analyst, ISGF	Parul is a Research Analyst at ISGF. Her current research interests are Advance metering Infrastructure (AMI), Communications in Smart Grid Technologies, Electric Vehicles, Artificial Intelligence in Energy, Smart Metering, Micro grids and Smart grids. She has a Post-Graduation Diploma (PGDC) in Smart Grid Technologies from National Power Training Institute (NPTI), Faridabad and a Bachelor's degree in Electronics and Communications. Parul has also worked for organizing and successfully managing various workshops and events for ISGF.

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Validation of smart metering technology

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***Abstract:* Planned and proper validation of new technologies, including driving the correct inference from the validation test results, can help both the service provider and utility to avoid surprises and regrets at a later date. It is recommended to spend time and resources on validation rather than feeling helpless or frustrated later, advises Rajesh Bansal, CEO of BSES Rajdhani Power Limited.**

Keywords: Smart Meter, Utility, Inference, Solar Panel

I. INTRODUCTION

The world over, the power distribution scenario is changing. The greater integration of renewable energy, growth in rooftop solar and need for electric vehicle charging are all leading to larger variation and unpredictability in the net power demand curve. With this, management is now the biggest concern and challenge for the utility.

Further, with the higher levels of engagement, meeting the expectations of consumers and other stakeholders is becoming another big challenge. With this changing scenario, utility objectives are also changing. To address these issues, concerns and expectations, utilities are opting for smart grid technology, with smart metering one of its key components.

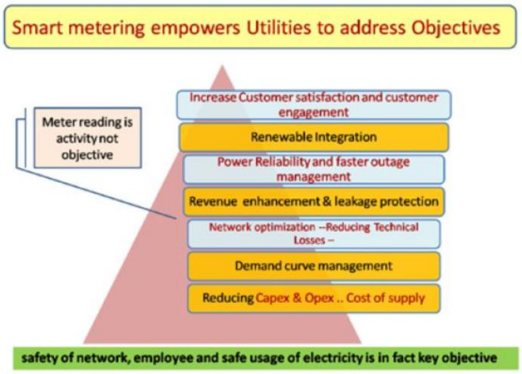

Figure 1: Roles of Smart Meters in Meeting Utility Objectives

II. NEED FOR SMART METERING VALIDATION

Smart metering is one of the most desirable technologies for utilities and most of them are going for large scale implementation. It is important to note that smart metering is a tool, not a solution; and is also an integrated system, not a standalone product. The key question is how to ensure that the chosen 'smart metering integrated system tool' is effective and is the right one with the required capabilities to empower the utility to achieve its desired objectives. The only way, ahead of mass installation, is the process of 'validation'.

A smart metering system is totally different from a standalone static energy meter. As an integrated system, the validation of a smart metering system is not merely the testing of the meter alone, but far more than that. Before going further, let us refer to some experiences encountered in the past:

1. When an LV CT meter and the LV CT box were tested individually, they were accurate, but when coupled, the composite accuracy was out. In other words, the standalone and integrated behaviours can be different.
2. When a 'disconnect' command was given, many meters did not disconnect. The reason was that the meter feeding power to the network went off first and affected the travel of the command to the remaining meters.
3. At a particular location, a smart meter was found malfunctioning with intermittent functioning of load relay. The fault continued even after the meter was replaced and was later tracked to a powerful magnet in the speaker, impacting the performance.
4. At a utility, many customers suddenly lost supply. This was tracked to a server having given a command to switch off but the 'why' and 'how' need investigation.
5. A meter reader reported, 'No display/ display not working'. When checked, the audit team

found it working, indicating an intermittent behaviour.

6. A smart fire sensor connected to the server was found less effective compared to a conventional sensor connected directly to the relay. Time is critical in protection with delays due to signal travel from sensor to server to the switchgear RTU.

From these incidents, we can conclude that validation of the product alone is not sufficient and needs testing far beyond the applicable standard or specification.

Meters and other components of a smart metering system can experience conditions not covered in the standard. While compliance with a standard can ensure a product works normally in defined conditions, the product should be checked in the conditions that may be experienced in the field. The validation engineer has to imagine the extreme scenario-based on field experience and plan the validation process accordingly.

The limit when a meter/system can malfunction or fail should be identified. This will help to understand the limitation of the system and to compare different product offers. The performance level, e.g. signal response time, can vary with the objective. Validation should be done keeping the objective in consideration.

Utilities are highly staked on their metering systems. Validation should be planned taking this aspect into consideration. An error in a bill can be a headline in the next day's newspaper.

Finally, there are many parameters of meters, which the utility has no plan to use. A typical metering system life is 10 years and tests related to these parameters should be done. They may be needed at a later date. Cyber and data security are equally critical and should be part of the validation.

Validation is one of the most critical aspects to ensure the success of a smart metering project. It should cover all aspects of system. Any malfunctioning or undesirable behaviour in an integrated system or any lack of features, when found at a later date, may be too costly to rectify.

III. Role of Smart Apps

Smart phones are popular as they are frequently used and their popularity can be traced to the 'smart apps' which bring benefits to users. Similarly, in order to leverage the maximum benefit from a smart metering system, smart apps are needed to carry out the various functions (Figure 2). Thus, it is equally critical to validate the smart apps

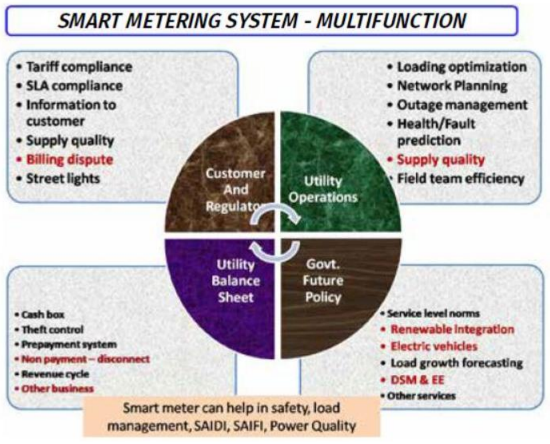

Figure 2: Smart Meter Functionalities

IV. Planning Smart Metering System Validation

For planning and preparation of the validation process, ask four questions:

1. What should be validated? Validation is a process to ensure functioning of the system to meet the objectives without failure or malfunctioning in any field condition and to ensure the 'return on investment' and no regrets about the technology.
2. How should validation be done? A series of steps are recommended, starting with understanding the objectives, both short term and long term, of the project:
    - The first step is to define the process and strategy as to how the technology will be used to address the objectives. This mainly covers the data required and their frequency; logics for events, alerts, etc.; the processing, analysis and storage of data; and then inferring and planning actions.
    - The probable conditions for when and what can go wrong should be identified and the system behaviour during extreme conditions checked.
3. Who should do the validation? Validation should not be done entirely alone but in partnership with others such as vendors, independent test labs and other utilities. Their data can also be used to validate and certify the smart metering system. As the utility holds the biggest stake, the involvement of the utility engineer is a must in the entire validation process.

4. What initial preparation is required? Three basic preparations are recommended:
    - Manpower training – to understand the objectives, product, process and strategy.
    - Test setup – in general not many instruments are required and rather than simulating field conditions in the lab, validation should be undertaken in real field conditions.
    - Interpretation of validation results – to check compliance with the plan and understand behaviour under extreme conditions. These need to be analysed, reviewed and then inferences drawn. This also includes analysis and driving conclusions from similar tests done or actual field experience of other users.

Validation of smart meters

- Such validation should be done by both the meter company and utility.
- Basic knowledge helps on measurement methodology, how measurements are done, meter standard, influence parameters and basic meter architecture.
- Meter tampering is nothing but exposing the meter to certain abnormal conditions, and basic knowledge about theft science helps to understand methodology.
- Validation against 'theft methodology' for system immunity, logging, impact.
- Malfunctioning under extreme conditions is expected. Key is whether these can be detected or not and the impact on utility basic operations.

Sr No	Validation test
1	Effect on abnormal conditions on alerts, events and measurement of parameters.
2	To use unauthorised means to change data, memory content, software, settings.
3	Failure of susceptible meter components/ subassembly.
4	Wrong alerts, events and alarm generations.
5	Malfunctioning of latching relay or communication module.

Validation chart – smart meters

Validation of communication network and head-end system/ data acquisition system

- Such validation should be done by both system integrator and utility.
- Response time is very important for certain utility objectives/ applications.
- Reliability if not ~100%, need to be studied against impact on application.
- Cyber security is a specialised field. If immunity is not assured than ensure to have alerts/logging of event. If required, can take service of experts.
- Interoperability should be in true means. Regarding functionality it should not behave as if proprietary. It is important to validate how other makes can be integrated with the system.

Sr No	Validation test
1	Effect on signal fidelity, time response with population (of communicating simultaneously).
2	Impact of failure/power outage of other (say neighbouring) meter, DCU etc. on communication.
3	Response for a command to get a particular data set from a meter vs actual data received.
4	Meter behaviour if a command in form of spurious data is sent to meter.
5	Adequacy of command generation security system, based on criticalness of command and its impact.
6	Interoperability at meter, module, communication media, HES command level

Validation chart – communication system and head-end/data acquisition system

Validation of meter data management system (MDMS) and smart apps:

- Such validation should be done by smart app developers, system integrator & utility.
- Response time & accessibility of data is important to leverage maximum benefits
- Smart apps should be validated end to end, i.e. from data processing to data analysis to recommending action and if possible generating commands and taking feedback.
- System should have enough capacity and flexibility for future applications and increase in nodes/devices.
- Data should be secure from all threats.

Sr No	Validation test
1	Accessibility of stored data for processing or needed in any application modules.
2	Validation of smart apps whether developed as per philosophy planned to achieve objective.
3	Availability of data to run any smart apps. If apps works on online data, check response time.
4	Simulating conditions due to which one can change data or can corrupt data.
5	Ease to make own logic, queries for analysis.

Validation chart – MDMS and smart apps

Conclusion

Smart metering system validation is a specialised job and should be carried out before mass installation. The utility should have a dedicated team, which is well trained, and the required resources should be allocated.

For validation of the communication network, HES/DAS, computer system, data storage, MDMS, the services of field experts/vendors can be taken. However, the utility should be directly involved in validation of the smart meter and smart apps.

This description is just a skeleton structure on how to make validation roadmap, with guideline charts to prepare the validation process. Incidentally, there is no complete, structured roadmap is available. To prepare an effective validation process, basic knowledge about meters, the study of abnormal behaviour as observed by utilities and knowledge on how to use data to address objectives is a must.

Based on his past experience with static meters, data usage applications software and on the feedback and experiences of other utilities, the author is preparing a validation roadmap for the smart metering system, detailing a set of validation tests, test methodology and data collection chart and process.

Are Indian homes ready for electric cooking?

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***Abstract*—Electric cooking (eCooking) can help counter India's growing import dependency for liquified petroleum gas (LPG), and support the low-carbon transition. However, there exists limited understanding about the prevalence and consumer perception towards eCooking in India. This paper tries to fill these critical knowledge gaps using the nationally representative data from India Residential Energy Survey 2020 that covered 14,850 urban and rural households from 21 most populous states. We find that only five per cent of Indians (mostly wealthier households from urban India) use eCooking devices. The factors that influence the adoption of eCooking include differences in lifestyle choices and culinary habits, and power tariff rates. We estimate that at the current LPG refill prices, households using electricity at a tariff lesser than INR 7.4 (USD 0.10) per kWh would find eCooking cheaper. However, households harbor concerns about the feasibility of preparing all dishes in an affordable and timely manner through eCooking. Therefore, eCooking promotion at scale would require efforts on multiple fronts, including research and development of energy-efficient, low-cost devices, provision of suitable financing solutions, and reliable electricity services, and in-depth studies to capture the household experience and perception of eCooking under diverse social contexts. We also estimate that even if 25% of Indian households transition exclusively to eCooking in 2030, it could increase peak demand by 101 GW (14% of the overall estimated capacity in 2030). Hence, the policy discourse on the role of electricity in India's clean-cooking journey must reflect on future power demand, and our ability to service that through renewables.**

Keywords*—*peak demand, demand management, electric cooking, eCooking, clean cooking, household energy access, LPG

Disclaimer—This paper draws from our recent study at CEEW – *Are Indian Homes Ready for Electric Cooking?: Insights from the India Residential Energy Survey (IRES) 2020* [1]**. Fig. I, Fig. II, Fig. III, and Fig. IV in this paper are completely borrowed from the above report.**

I. Introduction

On the back of government efforts including the recent *Ujjwala* scheme, nearly 85% of Indian households now have access to liquified petroleum gas (LPG) connections [2]. However, India's reliance on LPG as its mainstay clean cooking fuel poses some concerns in the long term. With a growing dependency on LPG and rising crude prices in the international market, India's LPG import bill has been on the rise (India spent more than USD 10 billion worth of foreign exchange in 2021 alone). Rising LPG use also contributes to the country's emission footprint. Further, many Indian households struggle to afford regular LPG consumption (due to high prices for LPG refill).

Availability of surplus power generation capacity and near universal access to electricity (along with improved power supply situation) present a significant opportunity to explore electric cooking (eCooking) as an alternative clean cooking option in India. But there exists limited evidence on the current extent of eCooking adoption and usage in India, its cost-effectiveness compared to other clean alternatives, households' perception of switching to eCooking from their prevalent cooking fuels, and its potential impact on the grid.

II. Method and Data

Between late 2019 and early 2020, Council on Energy, Environment and Water (CEEW), in partnership with the Initiative on Sustainable Energy Policy, undertook a nationally representative survey—India Residential Energy Survey (IRES) 2020—to capture the state of energy access and use in Indian homes [3]. IRES 2020 covered 14,850 urban and rural households across 152 districts from 21 most-populous states of India.[1] This paper uses data from IRES 2020 to fill the critical knowledge gaps related to eCooking use in India, and its implications in terms of increased demand for power.

III. Findings

A. *Extent of eCooking adoption in India*

As per IRES 2020, only 5% of Indian households use eCooking devices, with a higher prevalence in urban areas (10.3%) than rural areas (2.7%).[2] Induction cookstoves and

[1] Refer to [3] for details on survey design and data collection.

[2] To estimate the extent of eCooking use, we only considered appliances used for heating or cooking the food and excluded kitchen appliances like refrigerators, juicers, etc.

rice cookers are the most popular devices, each used by nearly 40% of the eCooking users, followed by microwave ovens (Fig. 1). We find that 85% of eCooking users belong to the top-five wealth deciles, suggesting that households' economic situation plays a vital role in the adoption of eCooking.[3] eCooking penetration rates also vary significantly across states. While Tamil Nadu and Delhi have the highest proportion of eCooking users (17%), perhaps because of lower state level electricity tariffs for residential consumers and presence of wealthier households, most northern, western, and eastern states have very low penetration.[4] This also suggests that the pace of transition to eCooking is likely to be higher among wealthier households in urban areas and in states with lower power tariffs.

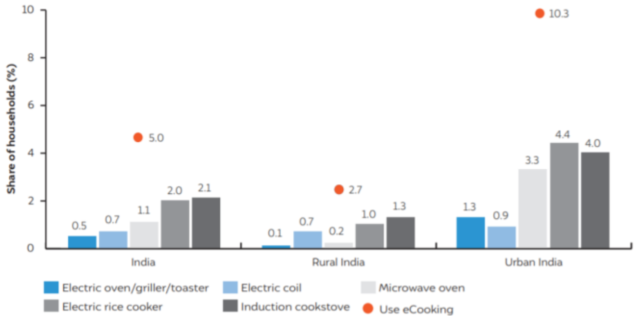

Fig. 1. Induction cookstoves and rice cookers are the most commonly used electrical appliances for cooking in Indian homes

B. *Is exclusive use of eCooking cheaper or expensive compared to that of LPG and PNG?*

Affordability of any cooking fuel is one of the most critical factors in its adoption and use [4], [5]. Therefore, we estimate and compare the expenses of a typical Indian household to meet its entire cooking energy requirement through the exclusive use of electricity, LPG and PNG.

As per IRES, a typical household in urban India—that relies exclusively on LPG for cooking—consumes eight large LPG refills (of 14.2 kg each) in a year [2]. This is equivalent to 2.95 gigajoules of useful cooking energy. At the January 2022 refill price of INR 900 (USD 12.3) per cylinder (unsubsidised), household expenses on exclusive LPG use would amount to INR 600 (USD 8.2) per month.[5] Assuming that an equivalent amount of useful cooking energy will be required for cooking exclusively with electricity, households would need to spend INR 446 per month (USD 6.1), assuming a power tariff of INR 5.5 per (USD 0.075) kWh.[6]

In fact, at an unsubsidised LPG refill cost of INR 900 (USD 12.3) per cylinder, eCooking would be operationally cost-effective for households paying tariffs less than INR 7.4 (USD 0.09) per kWh. Further, PNG is the cheapest cooking energy option for households, but it is currently accessible only in a few Indian cities. TABLE I. summarises the key assumptions and results.

TABLE I. ESTIMATION OF OPERATIONAL COST OF USING LPG, INDUCTION COOKSTOVE, AND PNG TO MEET ALL THE COOKING NEEDS FOR A TYPICAL INDIAN HOUSEHOLD

		Fuel type		
		LPG	**Electricity (induction cookstove)**	**PNG**
Standard measuring unit		14.2 kg refill	1 kWh	1 SCM
Calorific value per standard unit	**kCal**	1,54,354	860	9,000
	Gj (kCal/ 239,006)	64582x10^(-5) per refill	360x10^(-5) per kWh	3766x10^(-5) per SCM
Appliance efficiency		57%	84%	57%
Useful calorific value after adjusting for relative efficiencies (in Gj)		36812x10^(-5) per refill	302x10^(-5) per kWh	2146x10^(-5) per SCM
Cost per standard unit (in INR)		900 per refill	5.5 per kWh	30 per SCM
Number of units required for exclusive use in cooking (annual)		8 LPG refills (113.6 kg)	974 units (kWh)	137.2 SCM
Annual cost of using the fuel exclusively for cooking (in INR)		7,200	5,357	4,116
Monthly cost of using the fuel exclusively for cooking (in INR)		600	446	343

Source: CEEW analysis

Note for TABLE I: The above comparison is only based on the energy costs of the LPG, electricity and PNG, and does not consider capital cost, one-time fixed charges for connection and maintenance costs. Further, we only consider the lower heating value (LHV) for all three cooking fuels. LHV is also known as net calorific value (NCV) or lower calorific value (LCV).

[3] To assess household economic status, we use a wealth index based on principal component analysis of 11 indicators spanning house characteristics, and ownership of various consumer durables and motorised vehicles. Based on the relative values of this wealth index, households are divided into 10 wealth deciles. Refer to [3] for further details

[4] Households consuming up to 100 units in two months receive free of cost electricity in Tamil Nadu [7]. Similarly, in Delhi, households consuming less than 200 units per month receive a 100 per cent subsidy, while those with 200–400 units per month get a 50 per cent subsidy [8], [9].

[5] We use a currency conversion factor of INR 73/USD.

[6] In India, household electricity tariffs vary widely (range: INR 0-11.5 per kWh) across states and consumption slabs, progressively increasing for households with higher consumption.

C. Despite being operationally cheaper, households do not use eCooking as their primary cooking fuel

From IRES, we also found that most eCooking appliance owning households use it only to supplement their cooking energy needs. For instance, around 93% of the households that use eCooking, use LPG or piped natural gas (PNG) as their primary cooking fuel. Further, one-fourth of the eCooking users use eCooking devices as a backup only when other alternatives are unavailable, while another fourth use these occasionally. Only around half of them reported using it daily for some of their cooking needs (Figure 2). Such variation in eCooking appliance usage patterns will have a significant bearing on how the uptake of eCooking interplays with future demand for electricity.

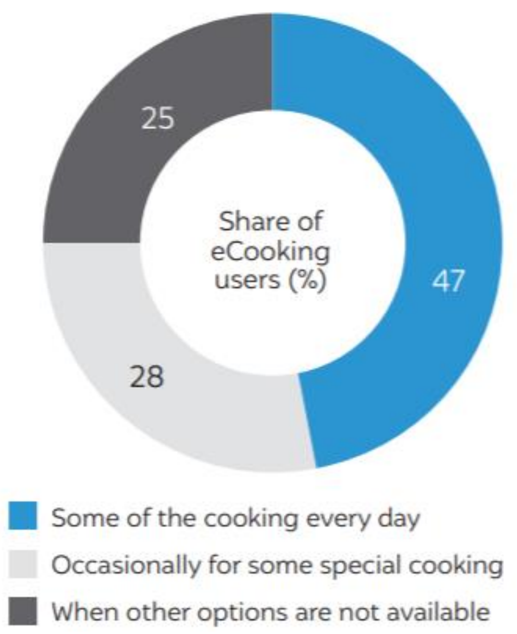

Fig. 2. Around half of the eCooking users use it every day

D. Household preferences about shifting to exclusive eCooking use

When asked if it would be feasible to meet all their cooking needs using eCooking, nearly 60% of the eCooking users agreed with it. An equal share believes that eCooking would be faster than the alternatives. However, only a third of the users find eCooking cheaper than the alternatives, perhaps because most eCooking users are high-income households, who also pay higher electricity tariffs (falling in higher consumption slabs) (Fig. 3).

Among non-users of eCooking, a significantly higher proportion of households are either sceptical or uncertain about their benefits, perhaps because they are unsure about the benefits of eCooking, and it also requires high upfront investment for purchasing eCooking devices and compatible utensils. This is also reflected in Fig. 4 which shows that wealthier non-users of eCooking are relatively more optimistic about the technology. This again suggests that high-income thouseholds would most likely be the first to switch to eCooking.

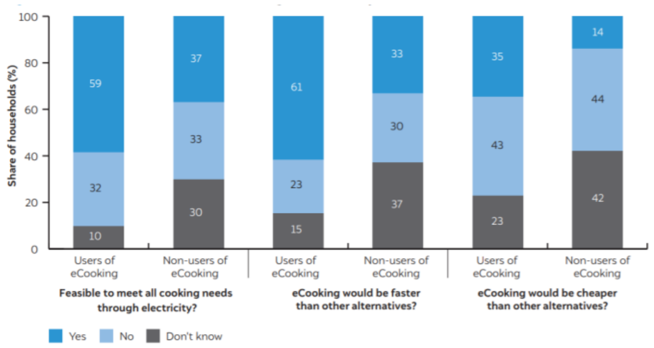

Fig. 3. Few Indian households think eCooking would be cheaper than other alternatives

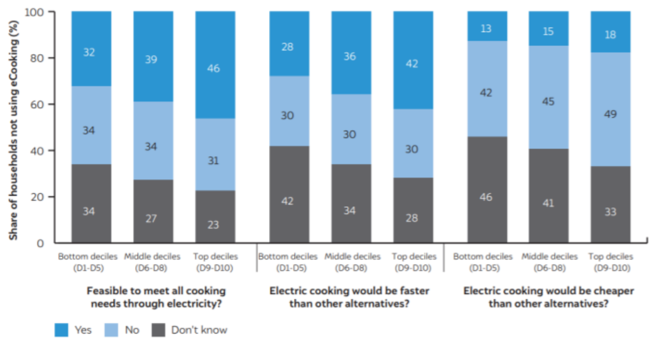

Fig. 4. Among the non-users, perception towards eCooking improves with household economic status

E. Implications of Indian households switching to eCooking on power demand

With increase in awareness about the eCooking appliances, changing lifestyles and access to reliable and quality power supply, more and more households will adopt eCooking. In a scenario with an aggressive shift of households to eCooking as their exclusive cooking fuel (25% in 2030, 50% in 2040 and 100% in 2050), we estimate that associated power demand would rise by 82 TWh in 2030 and by 359 TWh in 2050.

While the additional energy demand would be ~3.6% of total estimated power demand in 2030, the additional peak demand of 101 GW (14% of total estimated installed capacity in 2030) may have substantial implications for grid stability and flexibility.[7] This will increase to an additional electricity demand and generation capacity of 174 TWh and 215 GW in 2040 and 359 TWh and 442 GW in 2050, respectively (TABLE II). Given the installed capacity of 370 GW in 2019-20, it will need to be almost doubled in 2050 to account for additional load from eCooking alone.

[7] Spencer et. al (2020) [10] estimate India's electricity generation and installed capacity to be 2260 TWh and 705GW in 2030.

TABLE II. POTENTIAL IMPACT OF ELECTRIC COOKING ADOPTION ON GRID DEMAND IN 2030, 2040 AND 2050

Year	2030	2040	2050
Yearly electricity consumption on eCooking (kWh) per household	974	974	974
Total estimated population (in million)	1,504	1,593	1,639
Total number of households (in million)	338	358	367
Share of households exclusively relying on eCooking (%)	25	50	100
Number of households using eCooking (in millions)	84	179	368
Additional electricity consumption required in a year (in TWh)	82	174	359
Additional peak demand (in GW)	101	215	442

Source: CEEW analysis

Note for TABLE II: We use population growth projection from the United Nations (also used in [6]) and assume an average household size of 4.45 from Census 2011 to arrive at the number of households in 2030, 2040 and 2050. We also assume that efficiency of eCooking appliances will remain the same, and exclusive use of eCooking will continue to require 974 kWh of electricity per year in all these years.

IV. CONCLUSION AND RECOMMENDATIONS FOR FUTURE RESEARCH

This paper indicates that, although the adoption of eCooking is critical from the point of view of energy security, the presence of significant cost and perception barriers limit its uptake in India. High-income urban households would most likely be the first to switch to eCooking, predominantly to supplement their cooking energy needs. Promotion of eCooking at scale would require efforts on multiple fronts, including research and development of energy-efficient, low-cost devices, provision of suitable financing solutions, and reliable electricity services, and in-depth studies to capture the household experience and perception of eCooking under diverse social contexts.

The future research on the role of electricity in India’s clean-cooking journey must also reflect on its implications on future electricity demand and our ability to service the same through renewable sources. With growing adoption and use of eCooking, we will also need to continuously assess our electricity infrastructure as Indians cook roughly at the same time (morning and evening hours) as peak demand for electricity. This will help in addressing the problem of limited grid capacity to service the additional peak demand due to eCooking.

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Peer to Peer Trading using Blockchain

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***Abstract*—Tata Power DDL and Power Ledger have collaborated with India Smart Grid Forum (ISGF) to roll out live Peer-to-Peer (P2P) solar energy trading using Blockchain. Under the project, about 150 sites that include TPDDL's locations, as well as their actual customers with solar generation (prosumers), are using the platform to sell their excess energy to other residential and commercial sites in a dynamic pricing environment. Consumers can choose which seller (prosumer) to buy electricity from, with Power Ledger's blockchain audit trail of energy transactions providing near-time settlement and complete transparency throughout the entire process. Commercial and Industrial Consumers may get comparatively cheaper power from local prosumers than from DISCOM. For consumers with energy consumption band in the lower category, P2P will support DISCOM in reducing the Cross Subsidy charges and will help State Regulator to comply with National Tariff Policy, 2016. For any DISCOM, the average Power Procurement cost is significantly higher than the energy charges levied for consumers in the lower power consumption band. This benefit holds greater significance during the COVID-19 pandemic as most of the industrial and commercial units were shut down due to national wide lockdown. Prosumers may earn higher profits if they choose to sell power to consumers whose monthly energy consumption is in the medium to the higher range of category. This project also enables the development of an integrated ecosystem of grid-connected, distributed energy resources including Electric vehicle charging stations and battery energy storage systems that can directly participate in the P2P marketplace.**

Keywords—Blockchain, Peer 2 Peer, Prosumer, International Solar Alliance

I. INTRODUCTION

Tata Power Delhi Distribution Limited [Tata Power-DDL] is a joint venture between Tata Power and the Government of NCT of Delhi with the majority stake being held by Tata Power Company (51%). To ensure reliable power supply and to provide best in class service to its consumers, Tata Power–DDL has implemented several world-class technologies. The company has also rolled out live peer-to-peer (P2P) Solar Energy Trading, a first of its kind pilot project in Delhi. The project will bolster India's rapid adoption of renewable energy; powered by Power Ledger and India Smart Grid Forum (ISGF).

Ministry of New and Renewable Energy, Govt. of India has set up an ambitious target of adding 40 GW of the solar rooftop by 2022. Although, India has achieved ~ 6 GW of installed capacity as of the end of 2021. It is expected that govt. will continue to push the solar rooftop segment through various policy incentives and DBT schemes, more than being done presently.

The shift towards decentralization through empowerment of end consumers by adopting conducive policy given by Govt. of India for Rooftop Solar installation also brings uncertainty to the grid. So as more and more consumers becomes prosumers and injects power back to the grid, an interactive and real-time technological platform solution is required to move from a centralised system to a distributed one. One of the most important solutions for the adoption of decentralised generation is to introduce some viable commercial settlement mechanism such as Peer-to-Peer (P2P) trading. Accordingly, the idea is to utilise the existing metering & transmission infrastructure with minimal changes and develop a new settlement mechanism based on some technology (e.g., Blockchain technology, AMR based solution etc) and establish a local peer to peer market along with net & gross metering and fill the gap in the value chain.

II. OPPORTUNITY AND SOLUTION

The P2P model creates an online marketplace where prosumers and consumers can trade electricity, with or without an intermediary, at their agreed price. Further, P2P trading has the potential to enable the following for a utility: -

a) Local consumption of energy among peers
b) Peak Shaving
c) Congestion Management
d) Demand Side Management
f) Reduction in AT&C losses

The distribution company or a service provider can further facilitate local generation by providing financial support as a lender to the consumers for setting up the infrastructure under OPEX or CAPEX model and develop End to End, Fool-Proof and acceptable centralised mechanism for commercial settlement of power produced locally via setting up peer-to-peer (P2P) Trading and Settlement.

III. POSSIBLE P2P TRADING OPTION

A. Fixed Price Trading

It ensures P2P trading at a fixed price. This will guarantee each user certainty over the price they will receive for their energy traded through P2P. If no excess energy is available in a P2P network, then the consumer's energy needs will be met by DISCOM. Similarly, if no buyer is available for the P2P then it will be sold back to DISCOM.

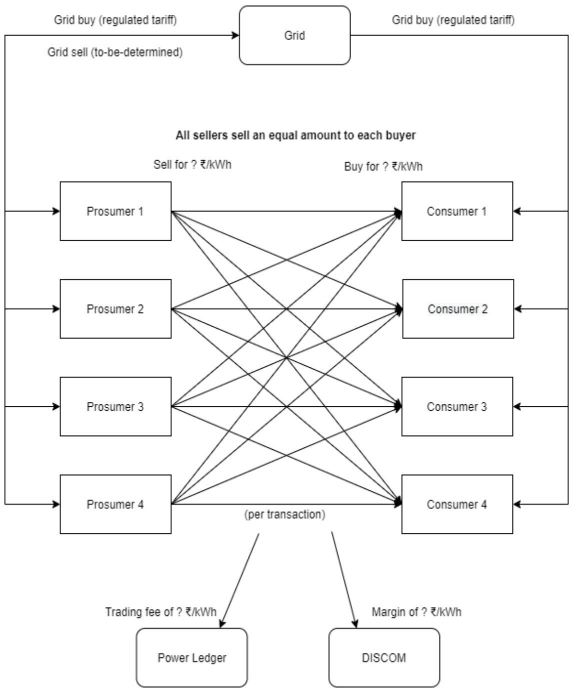

Fig. 1. Fixed Price Trading Model

B. Dynamic Price Trading

The dynamic trading option involves prosumers and consumers trading with each other, setting their own prices. There can be numerous ways of finalizing the trade which may be decided as per the Regulatory environment/framework. The cleared price can be the highest price being offered by the buyer, the lowest price being offered by the seller, an average of buyer- seller price or market-determined price by any other methodology.

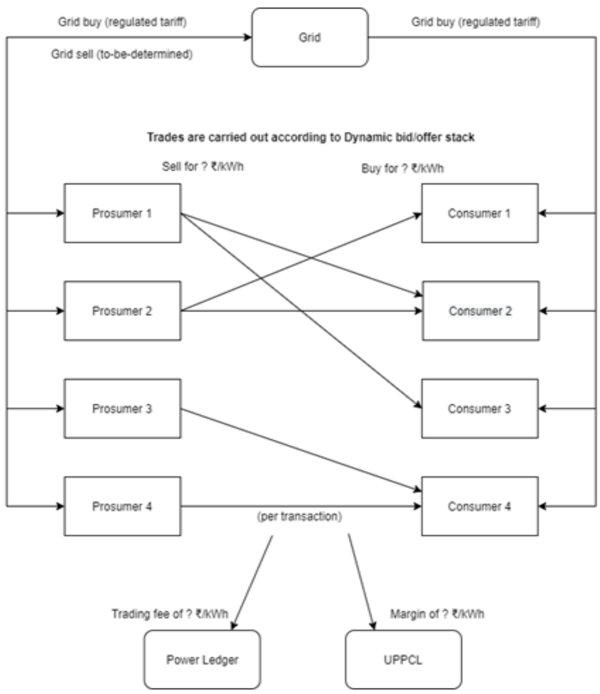

Fig. 2. Dynamic Price Trading Model

C. Dynamic Price Trading with Preferential Trading

In this case, the prosumer can also be given a choice to identify its preferred consumer and is termed as preferential trading. This rule allows prosumers to choose a consumer and offer them a percentage of their excess energy at a specific price, or any other mutually negotiated tariff this trade will be carried out before any other trading occurs, meaning that prosumers can choose their preferred off-taker.

In diagram below, dashed lines indicate a preferential trade, which is carried out before all other P2P trades:

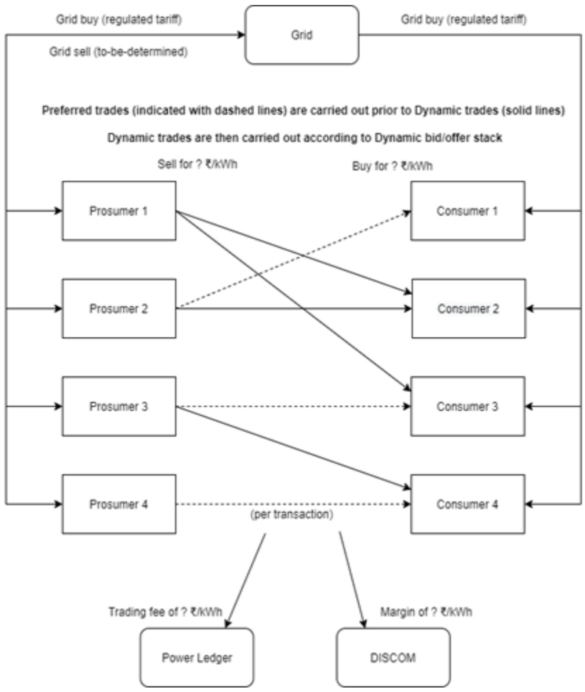

Fig. 3. Dynamic Price with Preferential Trading Model

IV. BENEFITS OF P2P

Tata Power Delhi Distribution Limited (TPDDL) has collaborated with Power Ledger to launch Peer-to-Peer solar power trading on a pilot basis. The study has been carried out between Feb'21 and Sep'21 on Power Ledger's block chain based P2P platform using 14 virtual prosumers (TPDDL own Rooftop) and 41 virtual consumers (TPDDL own offices) and 41 real prosumers and 21 real consumers. An ecosystem was created for these consumers to trade solar power among themselves and using the P2P platform.

A summary of energy transaction is given in table below:

Month	**Energy Transaction - P2P**	
	Kwh	***Amount (Rs)***
Feb'21	20846	150147
Mar'21	28327	205060
Apr'21	32665	234985
May'21	28834	214565
Jun'21	30213	227323
Jul'21	24689	185100
Aug'21	17768	133305
Sep'21	19424	145885

Fig. 4. Energy Transaction through P2P

A. *Benefits to Consumers*

Block chain enabled P2P platform empower consumers with solar rooftop to sell their excess energy to the consumers of their choice at their preferred price. The P2P platform provides consumers with 3 different model to trade their excess energy. It also provides an opportunity to consumers to buy cheap and green power from their locality's prosumers at preferential or fixed price model.

Month	Energy Purchased from Grid		Energy Sold to Grid	
	Kwh	Rs	Kwh	Rs
Feb'21	42885	298806	2685	15576
Mar'21	48086	340345	9170	53185
Apr'21	65636	458667	7731	44841
May'21	77112	539043	5572	32313
Jun'21	109322	760172	1095	6349
Jul'21	120520	850000	604	3500
Aug'21	93495	659574	745	4323
Sep'21	121666	867681	1254	7274

Fig. 5. Energy Transaction through Grid using P2P

- 41 Prosumers & 21 consumers traded 2,02,766 kwh among themselves and further sold 28,856 kwh to Tata Power DDL between Feb'21 to Sep'21
- Freedom for the consumer to choose a supplier. An amount of Rs 49,41,649 has been settled successfully between prosumers and consumers under P2P
- Prosumers have monetized Rs 1,63,631 by selling their excess solar units to Tata Power DDL between Feb'21 to Sep'21
- There is a provision of incentive from DISCOM upon participation in TOD & DSM.
- The settlement has been done in the same billing cycle as the trading of units occurred
- In the dynamic pricing model, the prosumers have the option to set their prices in a given range. However, it was observed that prosumers are not inclined to set the price daily and are interested in contracting it to DISCOM with a small commission
- For prosumers, faster monetization of rooftop solar asset through P2P than feed-in-tariff and for consumers without generation capacity, availability of low-cost local renewable energy supply as per requirement

B. *Benefits to DISCOM*

P2P trading of surplus solar power between prosumers and consumers connected to the same Distribution Transformer will lead to deferral of CAPEX for Network augmentation and hence, financial and operational efficiency for all stakeholders. It will give an opportunity to DISCOM to earn revenue through transaction fee, wheeling charges, etc and save capital on RPO compliance.

- RPO fulfilment for DISCOM: A total of 28,856 kW of energy was generated during Feb'21 to Sep'21 by Rooftop Solar under P2P pilot study which contributed in RPO fulfilment for TPDDL
- Increased generation from rooftop solar deferred CAPEX investment on a system upgrade and ultimately helped in reducing Regulatory overhang for DISCOM
- Reduction in the procurement of excess rooftop solar energy from consumers by DISCOMs by enabling Roof Top Photo Voltaic (RTPV) energy to be traded directly between prosumers & consumers
- New revenue streams for the utility: (a) Wheeling charges; (b) Billing and transaction fees. DISCOMs can levy wheeling charges and billing and transaction fees for the energy traded on the P2P trading platform within their distribution network
- Smart meters and Blockchain technology would ensure a simplified and secure billing process (efficiency, transparency) and faster switching times. A Blockchain solution identifying the energy source, at what unit price and any mark-up passed to the consumer would result in more competitive pricing and better integrity from public perception
- Balancing local generation and demand - to enable prosumers / consumers to coordinate their energy usage and prepare the buy and sell orders to balancing the demand and supply within the community
- High level of engagement of end users with their electricity will ensure load shifting and will help to deal with peak problems on the grid. It will help grid resiliency and defer the need for network upgrade
- Voltage & capacity constraint management - to prevent over-voltage & reverse power flow issues

V. P2P TRADING SCENARIO

The Electricity Act, 2003 empowers the entity to set up its generation unit and the New Draft on Electricity Amendment Act, 2020, has replaced the Distribution Licensee with Distribution Company. The intent of the Ministry of Power, Govt. of India is progressive and is intended to give the right to every individual to participate in Power Sector Reform. For large consumers, the CERC and respective State Regulatory Commission have already laid down guidelines to buy / sell electricity through the Open Access platform. For small residential prosumers with Net Metering, the P2P trading concept with Blockchain Technology has been proposed to empower them to get the best price for their investment done in setting up of Solar Infrastructure.

As the quantum of energy transactions will increase substantially with the introduction of P2P trading, Blockchain Technology will provide faster, reliable, secure, immutable, and transparent settling of all transactions accounts (energy charges, UI charges, Reactive Power billing, Transmission charges, Wheeling charges, and other surcharges).

The excess energy generated in an intra-DISCOM P2P network can be tagged and consumer/ obligated entity can utilize it for its RPO. Any further residual generation after fulfilment of RPO can be sold in Green-Term Ahead Market (G-TAM) or other options for green power by DISCOM.

For Inter-State P2P trading, the SLDC of the prosumer's state will determine the capacity available in the transmission system and the operational constraint. It will also include the capacity available in the Distribution System network. Preference will be given on first-come-first-serve basis with a long-term P2P contract.

In the event of augmentation of generation capacity by prosumer, a new request will be submitted to DISCOM for better management of Network Capacity.

VI. CONCLUSION

India's rapid adoption of renewable energy has been bolstered with the rollout of the first live solar energy trading project in Delhi, spearheaded by Tata Power-DDL, a leading power distribution utility, and Australian technology company Power Ledger in collaboration with India Smart Grid Forum (ISGF). This project enables development of an integrated ecosystem of grid-connected, distributed energy resources including EV Charging Stations and Battery Energy Storage Systems that can directly participate in the P2P marketplace. The Project is aligned with the vision of International Solar Alliance as it will incentivize prosumers by giving them access to the market where they can sell their surplus energy. This will further scale up adoption of grid connected Roof Top Photo Voltaic among customers.

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Aggregated Demand Side Flexibility: A Suitable and Cost-Effective Solution for Stabilizing the Power Grid

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***Abstract*—Electrical energy systems all over the world are changing towards decentralized renewable generation – the Indian power sector is also undergoing this massive transformation. At the same time, there is a prominent increase in variability, both in electricity output from renewables, and in consumption due to the rapid emergence of electromobility and air-conditioners along with electrification of industrial processes. The provision of balancing services by traditional large-scale power plants is increasingly reaching the limits of technical possibilities and economic viability. There is increasing recognition that management of loads in addition to generation will be useful in energy balancing and ensure stable operation of the electric grid.**

This paper will introduce the concept of aggregated demand side flexibility as a cost-efficient source of balancing power. It focuses on the growing, yet underutilized potential that demand-side assets can offer to maintain the balance of load and generation in the grid, a service that has so far been provided by large-scale thermal power plants. To achieve a sizeable impact on the network, combining several loads to act as a single large controllable system ('aggregation') is needed. For all distributed systems to be able to provide their services reliably and expediently, controlled activation through an aggregator is required. The concept of aggregators providing ancillary services to support grid reliability is not new and has been successfully established in recent years, in different markets worldwide. This paper presents business models and cases where aggregated demand response supports in congestion management, balancing services, and consequently grid stability.

Keywords—ancillary services, demand response, demand side flexibility, aggregator, energy balancing, congestion management, frequency reserve

I. The Growing Need For Flexibility

Over the past decade there has been an exponential growth in the decentralization and electrification of electrical system worldwide. The power grid is expected to experience significant penetration of variable renewable energy (RE) sources at both bulk and distributed levels. The government of India targets integration of 175 GW of renewable capacity by 2021-22, which will result in 36% share of RE in the total installed capacity [1]. At the same time, increased electrification in sectors like transport, building, industrial, etc. has caused an overall increase in electricity consumption with more loads connected to the grid. Many of these loads are interruptible, like electric vehicle charging, heating and cooling, and industrial automation leading to spurts of electricity demand. These two trends towards decentralization and electrification, are leading to major issues on the power system, which was built with the idea of a centralized generation and a rather stable demand.

Electric utilities need to address issues like decreasing system inertia, increasing volatility of generation, less predictability of demand and more congestion at lower voltage level. In such scenario, it becomes essential to identify and enable new sources of flexibility that can support balancing of the electrical system in combination with the traditional power plant. The demand-side assets, earlier perceived as passive elements of the network, exhibit high potential of providing flexibility for grid stabilization but have remained highly untapped.

The integration of energy storage and flexible demand resources will be integral for the growth of RE sources and grid stability. Furthermore, evolution of intelligent loads with communication and higher responsiveness provides opportunity for the demand-side assets to participate in energy balancing service. Therefore, there exists an opportunity to assess and unlock the flexibility potential from demand side resources capable of providing a multitude of benefits both at the transmission and distribution level.

Reforms in the distribution system operation are critical as India is set to experience a significant increase in electricity demand [2]. Under suitable techno-economic conditions, flexible demand through load management and integrating distributed resources at the distribution grid level can supplement supply side flexibility [3]. For this transformation to happen, there is a need to review the existing regulatory ecosystem to allow the participation of demand aggregators in various market services.

II. The Current Status Of Balancing Services In India

Load and renewable forecast, unit commitment, generation scheduling, manual frequency control, ancillary services, automatic secondary and primary frequency control, inertial response and interconnection strength are all essential components of frequency control of any grid. The electrical system in India has been kept in balance by using all control strategies, in different time, to intervene systems failures. While primary frequency control is already mandated by the Indian electricity grid code on several generators, slow tertiary frequency control as an ancillary service for manually changing the schedules of thermal generators was introduced in 2016 [4].

An overview of the current suite of solutions that the Indian electric utilities are using to maintain a secure and reliable grid is described hereafter.

A. Scheduling Mechanism

In India, the grid operations are regulated by Central Electricity Regulatory Commission (CERC) with standardized interaction process between distribution companies (DISCOMs) and generating companies (GENCOs). Scheduling is carried out in a coordinated manner in a centralized process, to forecast the daily region-wise and all India demand on day-ahead basis by aggregating demand forecast by the states. DISCOM forecasts and schedules the power demand for 15-minute time blocks [5] each hour with total of 96 blocks in a day. The scheduled power withdrawal from the grid is collated by State Load Dispatch Centres (SLDC) and sent to regional load dispatch center (RLDC), which passes that over to GENCOs for planning of power injection schedule. The schedules prepared by national load dispatch centre (NLDC) for inter-regional and cross-border exchange of power is on the basis of net requirement of the regions and of the country respectively.

B. Deviation Settlement Mechanism

As matching supply with demand is vital for maintaining grid stability, Deviation Settlement Mechanism (DSM) has been established to account for grid balancing process, based on the variation between actual demand and supply. The balancing energy mechanism is guided by the Deviation Settlement Regulations at central and state level. Both GENCOs and DISCOMs are allowed to make changes in their schedule within a certain time limit, beyond which they face penalties in case of deviation from their generation/drawal schedule. These penalties are in proportion to the frequency deviation in a particular time block and is linked with the clearance prices in the power exchange. The cost of the grid balancing is accounted under a DSM pool maintained by NLDC [6].

C. Ancillary Services

Ancillary services are the support services that complement the grid's operational reliability and becomes critical for grid support [7]. The ancillary services are currently derived from supply side i.e., from the requisitioned surplus power of all generating stations, whose tariff is determined by CERC. NLDC is responsible for implementation of ancillary services at inter-state level through RLDC. NLDC prepares a merit order stack of all ancillary providers based on the variable cost of generation.

Recent developments pertaining to market-based Ancillary Service Regulations (2021) are pivotal, as they permit the participation of energy storage and demand-side assets into the wholesale markets. These regulations mark the beginning of ancillary services as a market product and showcases a market-based procurement of Secondary Reserve Ancillary Service (SRAS) and Tertiary Reserve Ancillary Service (TRAS) [8]. For SRAS the minimum capacity for eligibility of resources is 1 MW and has to respond to the signal within 30 seconds, provide service within 15 minutes, and sustain it for at least the next 30 minutes. The TRAS resource needs to provide service within 15 minutes and sustain the service for at least the next 60 minutes. There is no market mechanism defined for demand-side flexibility as a primary reserve in the draft regulations.

D. Real Time Market for Energy Balancing

For a long time, all power system imbalances were managed through DSM and ancillary services. The practice of dependence on DSM for 'real-time energy' was identified as a challenge to grid security. Hence a real-time energy market was established in India, in June 2020, creating a clear distinction between 'energy balancing' and 'system imbalance' management. DISCOMs can make last minute procurement or sale of balancing energy from the Real Time Market (RTM) mechanism. GENCOs, with surplus power, not tied to any power purchase agreements, are also allowed to participate in the RTM. State Commissions are implementing Scheduling, Metering, Accounting and Settlement of Transactions in Electricity (SAMAST) in the states to let intrastate entities participate in the RTM. The RTM has 48 auction sessions during the day, opens every 30 minutes, and is based on double-sided anonymous auction with uniform price [9].

E. Involuntary Load Shedding

As variability at demand side grows, it becomes difficult to manage and maintain the stability of the grid, which leads to power outages and load shedding. Rising demand puts an added burden on the aging distribution infrastructure leading to increased number of outages. Furthermore, the high costs of power during high demand periods makes the procurement of peaking power uneconomical for DISCOMs, which in turn triggers load shedding [3].

F. Draft National Electricity Policy, 2021

The electricity market mechanism in India does not have any product which enables demand participation. Acquiring flexibility from the industrial, commercial or residential sectors require revisiting the regulatory framework to enable aggregation of demand, as the capacity from single resource would be inadequate to provide grid level services.

The recently published Draft National Electricity Policy 2021 issued by Ministry of Power emphasizes the importance of energy conservation and demand side management [10]. Section 7.18 (Distribution) requires all State Electricity Regulatory Commissions (SERCs) to devise suitable incentives for demand response and consumers must be given a choice to offer part or full load reduction for interruption during exigencies in the grid in lieu of lower tariff. Additionally, the participating consumers must have smart meters installed with appropriate functionalities and features.

CERC has initiated the conversation for demand participation in ancillary markets through their recent Ancillary Service Regulations, 2021 [8]. The draft regulations permit demand-side assets and energy storage participation in SRAS and TRAS.

The regulations are still in their draft stages and are yet to be finalized. Therefore, given the current regulatory environment, there is a need to assess the role and responsibility of an aggregator to participate in wholesale electricity markets and provide the services to DISCOMs at local level and the grid at bulk level, thereby facilitating a sustainable network operation.

III. Flexible Demand As A Cost Efficient Solution

Flexibility is the ability of electrical generators and consumers to alter their output or consumption when triggered. Increase in digitalisation and decentralisation are enabling a larger range of assets and asset classes to provide flexibility. It is in this context that Demand Side Flexibility (DSF), or (automated) demand response, is becoming increasingly important.

DSF has huge potential to deliver cost-efficient solution for energy balancing, grid stability, and decarbonization of power sector. Unlocking DSF can lower carbon footprint, become more sustainable and enable the global shift to renewables. DSF in India could reduce total system electricity supply costs by up to 5% on average, while improving the quality of supply. If India achieves higher levels of flexibility, it will significantly increase the rate of deployment of renewable energy at little or no extra cost [3].

DSF is the response to a price signal or dispatch instruction for assets on a consumer site, to deviate from planned or forecast consumption, generation, or storage, to alleviate transmission or distribution system congestion. Often, DSF offers a cheaper and cleaner way of providing balancing services. The cost of avoiding or displacing consumption is in most cases lower than the cost of additional fuel, and it is certainly lower than the investment required to build a new power plant as a reserve capacity. For this reason, DSF should be seen as the cheapest source of flexibility [11].

In the United States, DSF (most commonly referred to as demand response), is already participating in multiple energy and balancing markets for the past 15 years. In 2019, the European Commission published the Clean Energy Package (CEP), a set of eight legislative acts covering energy performance of buildings, energy efficiency, renewable energy, electricity market design, and governance. The CEP focuses, for a greater part, on the centrality of the consumers and the need for enabling a more active participation of the demand in electricity sector. As part of the implementation of the CEP, all European member states are amending their Energy Policies to allow the participation of DSF in energy and balancing markets.

The rise in the digitalization is pivotal to the increase in the number of resources being available and suitable to deliver DSF. Smaller and decentralized assets can now play a major role in the balancing of the grid. Flexibility can be found both in commercial and industrial sites as well as in the domestic environment. This is extremely beneficial, as it can help fill the gap left by the inadequacies of the limited centralised thermal generation. It is also a more efficient way of handling intermittencies since it does not compromise on the efficiencies of the thermal power plant.

The issue with the participation of smaller assets is that the system operator would have to monitor and control a much larger number of assets, which it may not be equipped to do. It would be much easier for the utility to interface with a few stakeholders that manage an aggregation of assets. In this context, the role of a demand response aggregator was born. In the CEP, the European Commission has also identified the independent aggregators as an integral stakeholder of this new energy system, and it has defined the role and responsibilities of such an entity.

IV. Role Of An Aggregator

Frequently, distributed assets are not able or incentivized to provide flexibility services on their own due to multiple reasons: for example, complicated market rules, a small installed capacity, or the lack of technical capabilities. Aggregators can pool distributed assets together, irrespective of their size, enabling them to participate collectively in the market and therefore increasing accessibility. Aggregators are entities that combine software, hardware, and flexibility expertise, providing an end-to-end solution to the grid operators and to end consumer that stabilises energy grids, and offers real-time monitoring and balancing of electricity supply and demand.

Aggregators typically have a direct relationship with the end customer, tailoring their services to specific assets and use cases. Aggregators commonly target distributed resources (e.g., energy storage, electric vehicle charging) and large industrial loads to enter the market, as these can be connected to the pool at a cheaper marginal price. However, in highly profitable markets, the participation of smaller assets can also be financially viable.

Aggregator can be a DISCOM or an independent entity. The independent status allows them to collaborate with any end user, can easily adapt to local conditions and work more efficiently with regional authorities and energy regulators. An independent aggregator could collaborate with many DISCOMs at the same time, providing the flexibility services and creating additional value to the companies. In turn, this enhances market competition and efficiency. The CEP defines in detail the responsibilities and the benefits deriving from the participation of independent aggregators in the energy and balancing markets.

V. Aggregators' Flexibility Platform And Services

A demand response aggregator needs to perform a series of activities to enable the participation of demand flexibility in energy market. These activities can all be performed by a single party or by collaboration of more parties. When a single aggregator owns the responsibility of all the activities that are part of the DSF value chain, it can be referred to as a virtual power plant operator [12]. The different activities are summarized below:

A. Customer Acquisition

This activity is performed in combination by sales managers and sales engineers that need to persuade two stakeholders on the customer side, i.e., the management team and the operations team. Generally, sales managers interact with the management team, in particular with the financial officer, which is interested in understanding the potential revenue deriving from the participation in flexibility markets. Sales engineers, instead, need to convince the operations managers of different production sites that the participation in demand response would not affect the core production process. To gain customer trust, sales engineers need to be familiar with the production process that the customer runs to identify the right assets that shall provide flexibility services.

B. Asset Monitoring And Control

Flexible assets are connected to the flexibility platform via the use of either hardware or software solutions. Depending on the market requirements, the data transmitted to the platform can vary in type, speed, granularity and accuracy. A control equipment is installed, most of the time, in order to control the asset remotely, without the need of human interaction. Control equipment can be either digital, i.e. a signal to turn on or off the asset, or analog i.e. signals that control the asset's set points.

C. Aggregation

The flexibility (cloud-based) platform has functionalities that allow the aggregator to pool together the loads of multiple customers and rank their availability according to their own requirements. Some markets are dispatched multiple times per day and this may be impossible for some customers to sustain. In such cases, the aggregator creates selection logic based on bidding strategy and asset restrictions. The aggregator will transmit data and signals to the market operator in an aggregated way, so that the response of multiple customers is perceived as a single response.

D. Optimisation

The flexibility platform will forecast the aggregated available controllable capacity (that is flexible and available for specific time frame) and will send it as an input for the bidding strategy. This forecast can be generated in different ways based on the available input (historical metering data, customer's availability preferences, and asset restrictions). If there is enough historical data, the platform can assess different forecasting models which will generate automated forecasts. Because the bidding process is such a crucial part of the revenue making process, operation teams are able to review and adjust the forecast if needed (with the automatically generated forecast as a fall back option). The bidding strategy for each market is defined in order to optimize for maximum revenue for the single asset as well as the aggregated load.

E. Interface With Value Streams

The aggregator needs to connect to the market operator via different interfaces that are available to communicate with the market. Ancillary services are the most open value streams for DSF. The aggregator sends out the bids and receives the bid results, which will be passed on to the platform to be able to deliver the service accordingly when there are activations.

F. Billing And Settlement

The flexibility platform is usually equipped with a customer interface that shows the number of dispatches per day, the length of the dispatch, the activated energy, and the associated revenue to the end customer. The aggregator may need to send to the market operator performance reports, based on which the billing will be performed.

VI. BUSINESS MODEL

The business model of demand response aggregators can differ depending on which of the activities, listed in Section V, are performed.

Some aggregators provide their flexibility platform in exchange of a monthly service fee. The fee can be a fixed amount per month or proportional to the amount of flexible capacity connected to the platform or to the number of transactions that take place on the platform. In these cases, it is said that the aggregator provides a software as a service.

Some other aggregators offer, on top of the flexibility platform, all the services that are needed to integrate the flexible asset in the aggregated pool. Such companies usually have a revenue sharing model, which is based on sharing the generated market revenue between the asset owner and the aggregator.

In some countries such as Spain, Sweden, and Norway, aggregators are not allowed to participate in the market as individual entities and need to partner with energy retailers. In those cases, the market revenue is shared between the asset owner, the aggregator, and the energy retailer.

VII. VALUE OF DEMAND RESPONSE

With more variable RE integration and increased electrification with intermittent loads, the electric grid requires flexibility to balance supply and demand. In the US and Europe, this role is increasingly being offered by small, distributed assets instead of large thermal generators. Aggregators have developed virtual power plants because these smaller assets individually often do not meet the requirements for market entry. Aggregation enables a larger range of assets to play into value streams.

Flexibility from dispatchable demand could be controlled by the aggregator. Large commercial and industrial users are traditionally considered best suited to provide dispatchable flexibility due to the large quantum of loads. With the advent of Internet of Things (IoT) and smart loads, residential and small commercial consumers can also be economically tapped into for DSF.

Heating, ventilation, and air-conditioning (HVAC) systems in residential and commercial buildings are well-suited to load shedding and shifting on timescales of seconds to minutes. HVAC systems, motors, chillers, and other non-essential loads across diverse industries are utilized as flexible loads through aggregation. Behind the meter resources like energy storage and electric vehicles are few of the upcoming sources of demand flexibility. Moreover, building automation technologies and domestic electrical water heaters are emerging trends in aggregation of residential assets.

Allowing DSF to participate in energy and balancing markets can be highly beneficial for numerous stakeholders described in sections below.

A. The Asset Owner

Industrial scale flexibility offered on the demand side can be used for several markets or services, depending on the grid topology, the market design and involved organizations. Load interruption for peak shaving or load shifting for peak curtailment, of non-critical loads as identified by the owner, are well known examples in this direction. This reduces the power purchase costs of the industrial client and hence reduce energy bills.

In some cases, asset owners generate revenues by unlocking flexibility in their assets and processes to be used in different energy markets (day-ahead, real-time market, imbalance market and reserve markets) [13]. Immediate incentivization, from participating in demand response may include energy savings (thus lower carbon footprint), lower electricity bills (by avoiding peak power costs), lower deviation penalties, and custom built user interface for asset monitoring and control.

B. Flexibility For Distribution Network

The concept of DSF goes a step further by addressing the challenges the electric utility faces and helping it to overcome them. With more assets, appliances and more distributed RE resources connected to the distribution grid, managing variability and congestions, and balancing the grid becomes increasingly important. By optimizing the operation patterns, assets can not only positively affect the industry's energy costs, but it can also help utility to reduce the peak demand and result in cost savings from availing their services.

A promising application could be the grid balancing mechanism to avoid paying DSM charges. Penalties for over or under drawing from the drawal schedule are applied for every 15 min time slot. By aggregating a suitable number of flexible loads, the DISCOM's load curve can be influenced and slightly shaped in such a way, that the forecasted demand can be achieved, and overdrawing can be reduced.

DSM is just one example of a balancing method for which aggregated flexibility could provide a benefit. Additional value streams could be found through the provision of other ancillary services and participation in reserve power markets. Stacking of value streams is possible and unveils the total benefit of aggregated flexibility on the demand side. Since the cost of unlocking the demand side potential does not depend on the asset's power rating, overall, it is always more cost-effective to tap the flexibility of electric assets than to ensure a power reserve on the generation side.

Since DISCOMs have a direct link with the end-users of electricity, therefore, there is a logical sense in obtaining flexibility at the local level by way of creating a retail market mechanism for it. DISCOMs can utilize the flexibility for alleviating network congestion, reduce peak power purchase cost, lower the losses incurred through deviation charges, improve reliability indices, network upgrade deferral. DISCOMs may choose to procure the flexibility by having more consumers participate through an apt incentive based demand response program that entail investments in the form of technological interventions, like IoT enables devices required for efficient control of demand side assets.

C. Flexibility For Bulk Grid Level

Conventional flexibility methods include automatic generation control, commonly thermal or hydro power, to match the demand. While hydro power is inherently flexible, the coal-based power plants, which is the mainstay of thermal generation in India, is not flexible in nature. To operate the grid in a stable manner with highly variable supply and demand sources, India is making investments to make the thermal power flexible, and to integrate grid scale storage along with variable RE generation. As the supply side integrates more RE sources, demand-side flexibility, which is more economical, is the need of the hour.

Aligning the demand levels with the available supply output is an economically viable option. DISCOMs, being the natural aggregators of demand, may facilitate demand side resources to provide flexibility to the grid through energy, capacity, ancillary or balancing mechanisms as required by the grid operator. They can either do it directly or through aggregators. If done directly, they may need to take up more responsibility themselves, because of additional tasks. If done through aggregators, they can outsource some of these tasks.

Independent aggregators may choose to participate in the wholesale energy, capacity, ancillary or balancing markets for economic benefits while also providing services to the grid. The economic benefits could then be passed on to the consumers as performance-based incentive payments. Subsequently, independent aggregators may also choose to provide the services directly to transmission system operator or independent system operator through competitive bidding mechanism. This will be extremely relevant in case of emergency situations.

One recent event to be observed occurred on 8 January 2021, when the synchronous area of Europe interconnected grid was separated into two parts (North-West and South-East) caused due to outages of several transmission network elements in a very short time, which almost led to a large-scale blackout. Due to the separation of the electricity grid the frequency in North-West grid had dropped to 49.74Hz, whereas the frequency of the South-East grid increased to more than 50.5Hz for a short time. Such situations require immediate measures and fast response for grid stabilization through staggered activation of various reserves. DSF is ideally suited to support traditional power control, as distributed resources are readily available and can be activated quickly, for both FCR (frequency containment reserve) and FRR (frequency restoration reserve), to mitigate critical conditions and maintain grid safety.

VIII. BENEFITS OF AGGREGATED FLEXIBILITY

There are multiple benefits of enabling flexibility market for the Indian electricity ecosystem:

- DSF acts as an additional source of revenue for domestic, industrial, and commercial customers with flexible loads as well as energy storage asset owners. Especially, energy intensive industries can benefit from reduced electricity costs.
- DSF can maximize RE and energy storage integration into the energy mix which helps in decarbonization of electricity.
- DSF is estimated to be one of the cheapest sources of ancillary services for grid stabilization. Experts agree that aggregated demand-side flexibility will make a valuable contribution to a sustainable and cost effective energy system.
- Electric utilities can optimize their CAPEX and defer the network capacity additions required to meet peak load demand.
- The possibility to comply with the parameters of the distribution network by immediate load reduction leads to an increased quality of service, and better System Average Interruption Duration Index

(SAIDI) and System Average Interruption Frequency Index (SAIFI) reliability indices.

- DSF can help DISCOMs in congestion management and reduce the deviation penalties. The solution helps in reliable and secure operations in real-time for both the distribution network and the grid itself.
- With the proposed market mechanism for ancillary services that enables demand participation, DISCOMs can focus on their core duties, at the same time providing new revenue for private players to act as aggregators.
- The increasing use of DSF to keep the balance between demand and supply will determine a decrease in the use of fossil plants for the purposes of balancing the grid and hence more efficient operation of these plants. This has a direct effect on the ecological impact of stabilizing the grid.

IX. CONCLUSION

Transitioning to an energy system exclusively based on renewable energy sources require different options to maintain the balance between electricity generation and demand. It make sense to harness the inherent flexibility of electrical assets, thanks to new capabilities of cloud-based communication technologies, and make them available to the energy system of tomorrow in a cost-effective way. In this paper, the concept of aggregated DSF is discussed, and various existing value-streams are mentioned.

Because the challenges in the present electrical systems vary from country to country, not all aspects of demand-side management are equally applicable. However, experts agree that without including the DSF, the rapid phase-out of fossil-fuel power generation, while maintaining grid stability and the quality of supply is difficult to achieve.

Flexibility is the key to powering a successful energy transition and achieving a 100% renewable energy system. Recent events reflect the need to exploit aggregated DSF for energy balancing and power grid stability. At the same time, revisiting the regulatory framework to enable nation-wide aggregation of demand is essential to realize the benefits and lay the foundation for a sustainable power grid. Developments in Europe and the U.S. demonstrate the superior cost-effectiveness of demand-side flexibility for various use cases. Independent aggregators take on the responsibility of tapping into the potential and generate new value-added opportunities for utilities, grid operators, and asset owners.

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Regulatory intervention on Distribution Reform

Recently Ministry of Power initiated four major reforms in the distribution sector to make it customer focussed and bring it out from recurring financial losses through adoption of professional management. They are,

i) MOP published Electricity (Rights of Consumers) Rules, 2020 on 31st December 2020 and numbers of amendments from time to time the latest draft on 30th September 2021.

ii) Ministry of Power (MOP) vide their OM dated 20th July 2021 has issued detailed guidelines for states which seek to implement reform-based result-linked power distribution program over the next five years, in exchange for financial support from central government.

iii) MOP has prepared draft Electricity (Amendment) Bill, 2021 for presentation in the parliament for enactment of Electricity (Amendment) Act,2021 for delicensing distribution among others.

iv) MOP vide letter dated 1st September has advised all state governments for bringing 33 kV system under the State Transmission Utility (STU)

Delicensing of distribution will encourage entry of various service providers to the electricity distribution business and will provide more choices to consumers and bring higher efficiency in the sector. The Bill seeks to de-license the power distribution business and allow other operators to set up and run distribution companies without any restriction. The proposal does not envisage building numerous networks alongside each other. Instead, it means that various private distribution companies will sign up customers, procure bulk power for them, and deliver it to their customers using the available low voltage distribution lines. Private companies will be managing their own customer relationships, billing, repairs, etc. The existing distribution operator will have to "provide non-discriminatory access to their distribution network (low voltage grid) to all operators registered with the Regulator within the same area of supply", in return for receiving wheeling charges from those other distribution operators, as determined by state power regulators.

The Bill also proposes state governments to create a 'universal service obligation fund' where "any surplus with any operator on account of cross subsidy or cross subsidy surcharge or additional surcharge shall be deposited.

Due to its delivery through a physical network (cables, wires, poles, distribution transformers etc), dependence on a monopoly carrier has been considered a must for reaching electricity to the end consumers from the generating stations.

For delicencing of distribution sector, it is essential to remove or at best minimize the monopoly ownership of the existing carrier and they should not have the sole right to sell and purchase electricity in line with other services like telecom, etc.

Subsequently MOP vide letter dated 1st September has advised all state governments for bringing 33 kV system under the State Transmission Utility (STU). This is intended for improvement of performance of 33 kV networks including Robust network planning/network re-configuration, Network reconditioning use of higher capacity conductor, Predictive Maintenance, adoption of modern technology for improvement of reliability like indoor Switchgear/GIS switchgear panel, auto switched (Thyristor controlled) capacitor Bank, Low Loss power Transformers, SCADA based Substation Automation System (SAS), etc.

On implementation of this MOP proposal, the existing network infrastructure which are currently assigned to the Distribution Licensee, will be split into High Tension Distribution (HTD) asset up to 33Kv including sub stations and this portion will be transferred to the State Transmission company. All other assets from 11kV onwards will be retained by the distribution licensee. This is a way to retain state ownership and give control over the asset to the State Transco, which will henceforth become responsible for delivery of trouble-free power up to the 33/11 kV Distribution Transformer. Similarly, DISCOM will be responsible from 33/11 kV transformer and onwards including L T Distribution Transformer up to consumer premises.

This proposed separation of HT assets from the distribution company will create the right enabling environment for microgrids and other local operators, as they will be able to use the common (expanded to include 33kV) transmission network for sale of surplus power at an agreed tariff and also source additional power/draw grid power to meet their deficit.

AT&C losses in this 33kV segment will reduce by 2-3% thus further reducing the cost of power.

To make the delicensing more competitive with consumer focus, a separate project implementation company like EESL (as indicated in MOP OM dated 20/07/2021) may be considered for owning and leasing the smart meters which may not be changed with the change of operator, and all new operators may opt for this facility of leasing the smart meters.

Consumers will be relaxed even with the change of operator as the electricity meter does not change depending on their selected distribution service provider. This also minimizes the investment of the new operator, as in most of cases LT distribution transformer with wire (consumer asset) including Smart meter will be made available to the new operator. Thus, the changeover will become painless with better quality service at competitive rate.

Ministry of Power (MOP) vide their OM dated 20th July 2021 has issued detailed guidelines for states which seek to implement reform-based result-linked power distribution program over the next five years, in exchange for financial support from central government.

The program aims to improve the quality and the reliability of power supply to consumers through a financially sustainable and operationally efficient distribution sector by providing central financial assistance to state DISCOMs for installation of Smart meter (pre-paid), strengthening of their supply infrastructure, reduction of AT&C losses (12-15%), capacity build-up of the DISCOM employees and better financial management through better billing & realization including narrowing down the ACS & ARR gap to zero. This will be based on meeting pre-qualifying criteria and achieving basic minimum benchmarks in reforms in order to access central funds, which will be administered through PFC and REC.

One set of actions alone will not be sufficient. In fact, a combination of all the initiatives listed here, such as (i) Reform-based result-linked power distribution program of MOP over the next five years (ii) bringing 33kV systems under STU along with delicencing of distribution along with (iii) Direct Benefit Transfer (DBT) and voltage wise tariff irrespective of consumer category, and stringent implementation of SOP by Regulator will be able to address most of the critical areas which are likely to bring substantial improvement if they are properly implemented with required political will.

In the draft notification of the amendment of Electricity (Rights of Consumers) Rules, 2020 on 30th September 2021the followings have been envisaged.

a) Distribution Licensee shall ensure 24x7 uninterrupted power supply to all the consumers, so that there is no requirement of running the Diesel Generating sets. Accordingly, the State Commission shall give trajectory of System Average Interruption Frequency Index (SAIFI) and System Average Interruption Duration Index (SAIDI) for the cities.
b) The State Commission may consider a separate reliability charge for the Distribution company, if they require funds for investment in the infrastructure for ensuring the reliability of supply to the consumers. The State Commission shall also make a provision of penalty in case the standards laid down are not met by the distribution company.
c) Consumers, who are using the Diesel Generating sets as essential back up power, shall endeavour to shift to

cleaner technology such as RE with battery storage etc in five years from the date of the publication of this amendment or as per the timelines given by the State Commission for such replacement based on the reliability of supply by the distribution company in that city.

d) The process of giving temporary connections to the consumers for construction activities or any temporary usage etc shall be simplified by the distribution licensee and given on an urgent basis and not later than 48 hours. This will avoid any use of DG sets for temporary activities in the area of the distribution licensee. The temporary connection shall be through a prepayment meter only.

DISCOMs are likely to be future-ready to face market competition which may arise on delicencing of distribution and ignite India’s growth to become a 5-trillion-dollar economy in future. Competitive pressures will force DISCOMs to address the consumer’s requirements through better service at affordable rate and freedom from bondage to a single monopoly service provider.

As these initiatives of MOP address different shortcomings of DISCOMs including their financial health, once successfully implemented, it can be expected that DISCOMs will become willing players in clean energy transformation. For example, once DISCOMs are financially sound, they are likely to encourage integration of Roof Top Solar (RTS), along with generation of power from agricultural residue, etc. These initiatives will help in ensuring availability of power at lower cost to the consumers through distributed generation and creation of employment opportunity for the local youths.

This will accelerate the semi urban and rural growth and improve the quality of life.

We should put our best effort to make these initiatives successful with political, regulatory and government support as an and when required.

Electricity Act 2003 specifies the following responsibilities of State Regulators

a) Introduction of competition gradual reduction in cross subsidy (+/- 20% of average cost of supply), Progressive reduction in Cross-subsidy surcharge for open access.

b) To specify and enforce the standards with respect to quality, continuity, and reliability of service. Issue licenses for intra state transmission, distribution, and trading

c) Promote competition, efficiency and economy in power markets, protects the interests of consumers, and promotes investments in power sector.

d) In pursuit of these objectives the Commission also to reorganization and restructuring of electricity industry in the State.

Now let us see the actions likely to be taken by the Regulators,

i) Get actively involved in the implementation of reform-based result-linked power distribution program over the next five years, in exchange for financial support from central government to ensure that licensee takes the best advantage of the programme and fulfil all the milestones set by MOP within the specified timeline.

ii) Ensure smooth transfer of all 33Kv assets from Distribution licensee to STU within specified timeline.

iii) Similarly identify and separate all assets created by deposit work of consumers from the remaining assets of the Distribution licensee so that these assets are separately accounted and maintained.

v) Ensure implementation of Standard Of Performance (SOP) regulation as envisaged in the Electricity (Rights of Consumers) Rules, 2020 published on 31st December 2020 and subsequent amendments the latest on 30th September 2021.

vi) As and when the Electricity (Amendment) Bill, 2021 gets enactment to Electricity (Amendment) Act,2021 for delicensing distribution get licensee, state government and MOP in developing the detailed action plan for ensuring smooth transaction to multiple operators as envisaged in the act.

Data Analytics enabled Inertia Volatility Assessment of Smart Grid in Enhancing Grid Resiliency in Presence of DER

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Abstract— **The significant percentage penetration of Distributed Renewable Energy (DRE) sources in the generation mix has been continuously increasing, for more than a decade. These RE generators differ with conventional generators having large inertia, in terms or either low or with non inertial generation. RE generators are located at distribution level, distributed throughout the network. Even there is significant increase in the customers /prosumers, installing roof top solar PV generation in the cities.**

Increased percentage of these RE generation in the grid introduces challenges of reduced rotational inertia and random fluctuations in the available power at any instant. The reduced inertia introduces very high rate of change of frequency (RoCoF) along with frequency overshoot or frequency dip (nadir). Such variations may result in the mal-operation of frequency dependant protection system and hence initiate tripping of the generators or shedding of loads, which further initiates chain reaction, perhaps resulting in blackout, before primary control system gets activated.

The paper aims to demonstrate the potential of data driven analytics in enhancing grid resiliency. In turn that enables Power system engineers to know the inertia-profile, Perturbation Sustainability level-(PSL) of system, aggregated system inertia. These insights are very instrumental for control engineers to provide mechanisms to provide the required inertia support at sensitive nodes to limit RoCoF to specified magnitude as per the standards.

The vitality of the latest digital tools of Analytics and Intelligent Insights increases the visibility of smart grid, ensures the improved operational Efficacy and Efficiency through continuous assessment and evaluation of inertia of grid and provision of inertia support. The very important practical challenge of Grid resiliency faced by power utilities across globe, embarking on green energy journey is discussed in this paper with results and observations.

Keywords— Data Analytics, DER, Grid Resiliency , Inertia, Smart grid

I. Introduction

Embarking on the journey of sustainability, with an objective of Net Zero Carbon, Utilities across globe have been aggressively investing into renewable generation, fulfilling load demand. Digitalization, decarbonization and deregulation have open up many opportunities to business stakeholders of Electricity Utility to embrace green technologies and develop affordable, efficient, modular digital interventions across the value chain. The biggest advantage of having deploying advanced metering infrastructure and integration of all data sources, is enabling Utility industry to get clear visibility of grid and functions. The big data generated at grid level is cross leveraged for multiple business functions and for proactive decision making.

The objective of paper is to discuss about the Data driven opportunities in leveraging the present digital enablers to address two major dimensions of Grid. The first aspect is inertia of Grid in presence of large penetration of renewable generation and second aspect is resiliency of grid.

The inertia of system provides real-time energy stored in the system in the form of kinetic energy of rotating masses as a buffer. The switching of load or generator results in instantaneous mismatch between load and generation (ΔP). Inertia takes care of this mismatch by changing its kinetic energy during first few seconds before primary control (governor) takes over. The kinetic energy ($\frac{J\omega^2}{2}$) in rotating masses (inertia), adjusts itself to either absorb extra generation or supply extra load. For about 10 seconds the system dynamics is inertia driven before primary control (Governor) takes over.

Today's smart grid, with large penetration of power from renewable sources has node-dependant, time-varying and more volatile "inertia", compared to the one post few decades. The involvement of citizen in the carbon neutrality mission has added new dimension to the opportunities as well as operational challenges.

This paper articulates the global challenge of utilities in maintaining grid resiliency and how availability of diverse data of renewable generation, system load variation enable the assessment of inertia volatility and in turn the susceptibility of grid towards any perturbation.

In the following paragraphs, using representative grid data, insights are provided in terms of impact of DER on inertia of grid, its ability to absorb perturbation/ fault, vulnerability of grid and indicative grid support to mitigate the threat of the mal-functioning of protective switchgear.

II. Inertia and Grid Resiliency Visuailization

The transformation of utilities in adapting digitalization and deployment of SCADA, IOT, AMI, PMU etc have enabled access to the real time DATA of grid, giving opportunity to be able to apply analytics to get the trend of behavior of grid, unlocking the potential solutions for techno-economical vulnerabilities.

The benefits of data driven insights are well appreciated by the stakeholders as there is significant increase in accuracy of decision making and improved operational excellence , grid security, reliability and resiliency.

However, to be able to achieve these key outcomes, understanding of data is a must before applying any analytical approach.

By knowing rate of change of frequency, it is possible to assess the grid inertia.

For example, when power grid is subjected to any step change of load ie perturbation, the system frequency will alter as a function of time as shown in Fig 1.

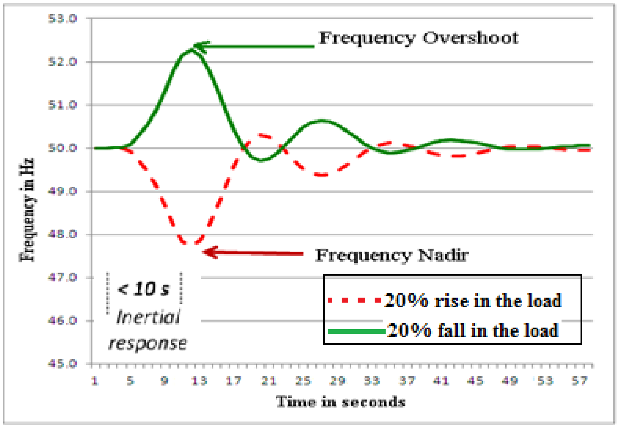

Fig.1. System frequency after a step-change of load

It is observed through available Data that grid with significant penetration of renewable generation has overall reduced inertia, influencing the system dynamics. It introduces frequency overshoot, frequency nadir and high rate of change of frequency for first few seconds. Hence this assessment is important to avoid possible relay mal-operation and de-synchronization.

The maximum Rate of Change of Frequency (RoCoF) occurs immediately after perturbation. As pointed out in section –II each node has different inertia and hence with the same perturbation, RoCoF of each node will be different. To get the total view of the network it is necessary to monitor inertia-profile, the way perturbation can penetrate through network, , Perturbation Sustainability Level (PSL) at each node and total system Aggregate Sustainability Level.

These attributes provide insights about the required inertia support to strengthen the grid and provide prescriptive guidelines on providing virtual inertia support or by adding a conventional inertia generation.

This has become very important task for network operators to enhance grid performance.

III. Data Analytics for Inertia Volatility and Grid Resiliency Assessment

As introduced in the previous section, the enablement of data is the success in getting clear visibility of grid and initiate analytics to derive insights to perform techno-commercial tasks. Representative grid system is used for demonstration of concept in the paper, where the proposition can be scaled up to a lager grid.

The demo-grid has nine generators and total capacity of 600MVA and load 590 MVA, as presented in Fig. 2.

To demonstrate the effect of RE generation, two different cases are investigated. In first case all generators are assumed conventional generators with inertia constant as per their type. In second case four generators, out of nine generators are replaced by Solar/Wind generators. In both cases, inertia-profile, Perturbation Sustainability Level, Aggregate system inertia, Aggregate Sustainability Level, Inertia availability status, RoCoF, Inertia Support-profile are calculated.

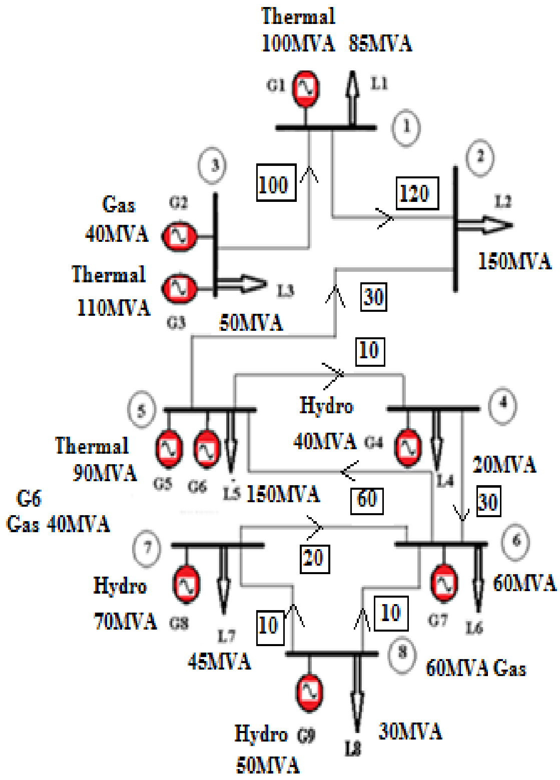

Fig.2. Representative Reference Grid

A. Inertia Profile of Grid

Using free body diagram, inertia at each node is calculated based on the network connectivity, showing one example in Fig. 3.

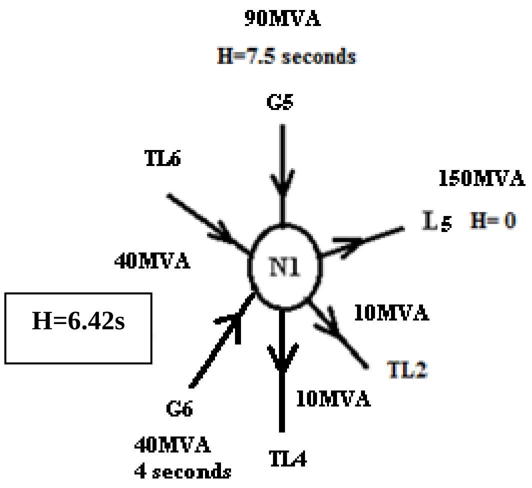

Fig. 3 Isolated Node Free Body Diagram

As shown in figure, in any perturbation condition at a node, power from transmission link is assumed to be constant, with the presence of conventional generator possessing high inertia. Generation-Load imbalance is taken care by inertia of the system for first few seconds. Analytically the inertia can be calculated using equation 1.

Inertia of node is $H = \frac{\sum_{i=1}^{n} H_i * S_i}{\sum_{i=1}^{n} S_i}$ (1)

Where H_i –Inertia of i^{th} node, S_i –MVA at i^{th} node,
n- Number of links.
The inertia profile of the representative grid is shown in Fig. 4

Inertia of node 2 is zero as it is only load bus. Inertia of remaining nodes is 4 or more than 4. These values ensure robustness of grid making it a strong inertia system, with a clear picture on variability associated with inertia offered at various junctions across grid.

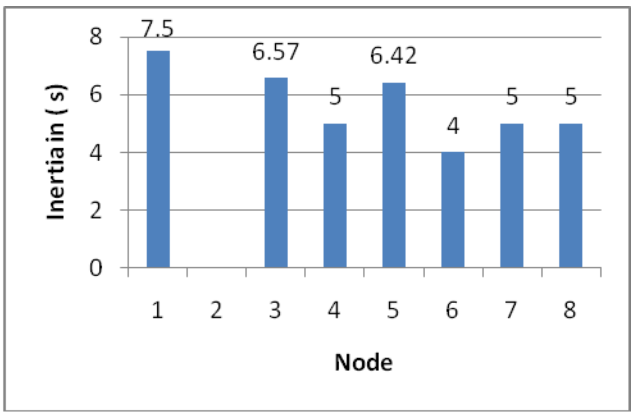

Fig. 4 Inertia profile of the Strong Inertia Power Grid

This insight about inertia profile is used further to calculate the resiliency of grid which is explained in next section.

B. Inertia Profile of Grid with DER

In case 2, out of nine generators, five conventional generators and four RE generators are used. Generation capacity of the system is 600MVA and connected load is 590MVA. It is assumed that RE generators are inertia-less generators.

Inertia profile of the system:

Inertia of each node is calculated by using same procedure that used is case 1. Inertia profile of the system is as shown in Fig. 5.

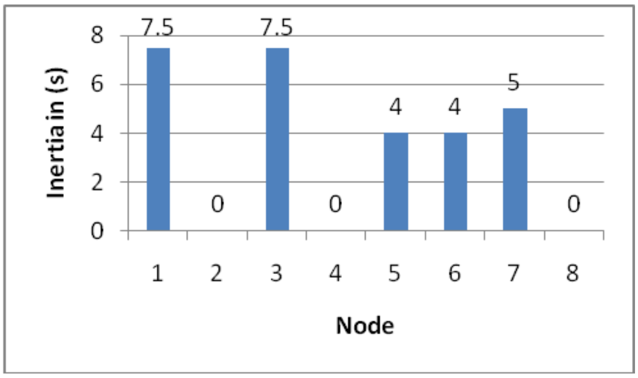

Fig. 5 Inertia profile of the test system.

Node 2,4and 8 have zero inertia due to presence of RE generators.

C. Resiliency of Grid

The resiliency of grid is dependent on the property of all the upstream and downstream assets of grid, deciding the behavior of grid under normal as well as contingency situations. The load dynamics used to be the main governing actor, creating generation-load unbalance in the system, but today, in presence of generation from renewable sources , the dynamicity at the generation side is introduced. There is need for including generation intermittency as an additional factor while assessing the resiliency of grid.

In this paper, three parameters are introduced to assess the fault/perturbation absorption ability of grid under two cases such that case one has major conventional generation sources and second with significant amount of renewable generation along with conventional generation.

1) Perturbation Sustainability Level (PSL) of each node

It is the ability of node to sustain perturbation. To evaluate Perturbation Sustainability level, rate of change of frequency is assumed to be 0.2Hz/sec as per standard. [1] At each node Perturbation Sustainability Level(PSL) is calculated using equation (2) and presented in TABLE I

$$\frac{df}{dt} = \frac{f\,\Delta P}{2HS} \quad (2)$$

Where ΔP - Perturbation level in MW, H- node inertia in seconds, S-Node MVA, $\frac{df}{dt}$- rate of change of frequency in Hz/sec, f-system frequency in Hz. For Case 1- with only conventional generation at grid, PSL value at each node is presented in TABLE I.

TABLE I. PERTURBATION SUSTAINABILITY LEVEL AT NODE –CASE 1

Node	Node inertia(s)	Perturbation Sustainability ΔP (MW)
1	7.50	6.00
2	0	0
3	6.57	7.88
4	5.00	1.6
5	6.42	6.68
6	4.00	1.92
7	5.00	2.8
8	5.00	2

As presented in above table, based on the network topology with presence of downstream, upstream assets connected, each node has different capability to sustain the perturbation. Node 3 is the strongest node due to connection of large capacity thermal and gas generators, whereas, node 4 is the weakest node due to connection of small capacity hydro generator. Node 4 is most sensitive towards perturbations resulting in high RoCoF.

Next paragraph shows the observations of PSL for a grid with renewable generation penetration

TABLE II. PERTURBATION SUSTAINABILITY LEVEL AT NODE –CASE 2

Node	Node inertia(s)	Perturbation Sustainability ΔP (MW)
1	7.50	6.00
2	0	0
3	7.5	6.60
4	0	0
5	4	2.88
6	4	1.92
7	5	2.8
8	0	0

2) System Aggregate Inertia:

To understand the overall system performance, aggregate system inertia is calculated for both cases as “with conventional generation” and with “Conventional plus DER”.
The aggregated system inertia is 6.02 seconds as calculated using formula given below.

$$H = \frac{\sum_{i=1}^{n} H_i * S_i}{\sum_{i=1}^{n} S_i} = 6.02 \text{ seconds}$$

with conventional generation , whereas it is 4.21sec, with significant presence of DER.

3) System Perturbation Sustainability Level (S-PSL)

Every node has different Perturbation Sustainability Level, the system also exhibits its aggregated S-PSL as **4.81MW** which is calculated at 100MVA base, in first case, and S-PSL is 3.37 MW in the second case of DER presence.

4) Key Observations -

It is observed that,

1. With increased penetration, the inertia of the node to which RE is connected is reduced. This also affects the aggregate system inertia level.
2. The rate of change of frequency profile is decided by the profile of the inertia. RoCoF is different at each node and increases with RE penetration as can be seen from node 3,4,5 and 8.
3. More inertia support is required at nodes where there is no or less inertia generation.

IV. INERTIA SUPPORT TO MAINTAIN GRID RESILIENCY

As detailed out in the previous paragraphs, all mentioned insights are useful in calculating the required inertia support to make grid resilient under any perturbation. For better understanding this aspect is discussed for both the cases.

A) Case 1- Grid with Conventional Generation

Assuming the occurrence of perturbation of 4.81MW, the requirement of inertia at each node is calculated to sustain the perturbation. For the same, it is required to know the inertia availability status across the grid and RoCoF. TABLE III provides indicative reference for the controlling actions to be taken.

TABLE III. INERTIA AVAILABILITY STATUS, ROCOF –CASE 1

Node	Node inertia (seconds)	Inertia required to Sustain perturbations (s)	Inertia availability status (s) -deficit, +Excess	RoCoF (Hz/s)
1	7.50	6.01	+1.49	0.16
2	0	High	0	fast
3	9.86	4.01	+5.85	0.12
4	2.00	15.03	-13.03	0.60
5	8.35	4.63	+3.72	0.14
6	2.4	10.02	-7.62	0.50

7	3.5	8.59	-5.09	0.34
8	2.5	12.03	-9.53	0.48

For example, node 4 being a sensitive node, requires 15.03 seconds inertia support which is large compare to remaining node. Similarly for node 8 inertia requirement is 12.03 seconds.

Once the inertia requirement is known, the presence of inertia in the system can be leveraged as given below.

To control RoCoF to required magnitude, inertia support of 13.03seconds is required.

Excess inertia of node 1,3 and 5 can be utilized to give support to weak nodes if required along with additional inertia support measures. Inertia availability status is shown in Fig. 5.

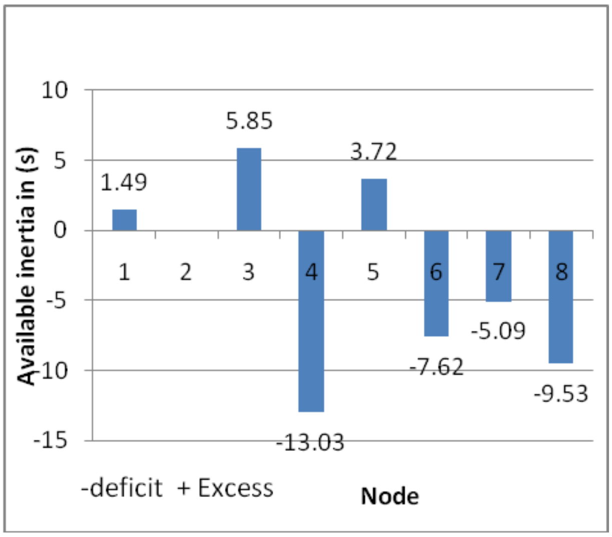

Fig. 5 Inertia availability status

B) Case 2- Grid with DER plus Conventional Generation

As an example, the occurrence of perturbation of 3.37MW is assumed and the requirement of inertia at each node to sustain the perturbation, is calculated along with inertia availability status and RoCoF, given in Table IV.

TABLE IV. INERTIA AVAILABILITY STATUS, ROCOF –CASE 2

Node	Node inertia (seconds)	Inertia required to Sustain perturbations (s)	Inertia availability status (s) -deficit, +Excess	RoCoF (Hz/s)
1	7.50	5.88	+1.62	0.16
2	0	Large	0	Fast
3	8.25	5.34	+2.91	0.13
4	0	Large	0	Fast
5	3.6	6.53	-2.93	0.36
6	2.4	9.79	-7.39	0.82
7	3.5	8.39	-4.89	0.48
8	0	Large	0	Fast

It is observed that along with zero inertia node (2,4,8) node 5,6 and 7 are more sensitive. RoCoF of these three nodes is high and inertia support is required to maintain RoCoF within the standard limit. In the system only two nodes have sufficient inertia due to connection of only conventional generators.

Hence, this is critical to maintain grid resiliency when DER is present with significant percentage. In such situations, following are few examples on how to provide inertia support.

It is observed from above two cases that node 4 and node 8 are very sensitive nodes as their inertia is less due to connection of only RE generators. In case 2, if it is possible to give inertia support to these nodes, it will limit ROCOF to standard value (0.2Hz/sec). Following methods can be used to provide inertia support.

1) Transfer of inertia from one node to other connected node:

Inertia support to node 4 is given by transferring inertia of node 5 to node 4 as interconnected through transmission line. The effective inertia is calculated treating 4 and 5 as a single node and presented in table IV. Connection diagram is shown in Fig. 6.

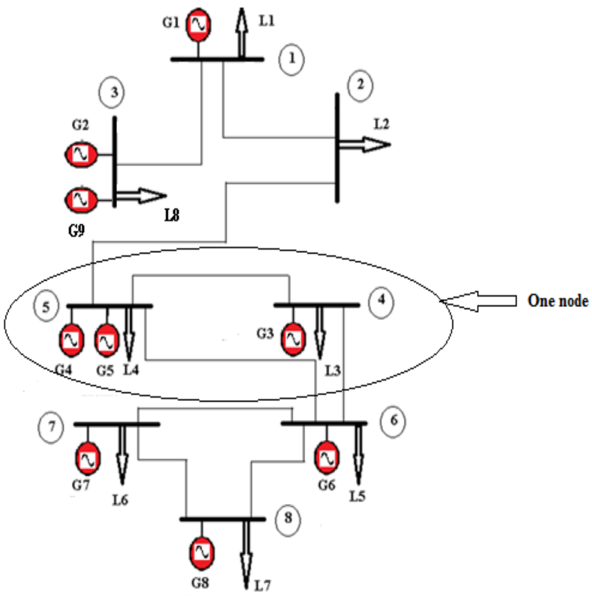

Fig. 6 Transfer of inertia from node 5 to node 4 by connection

TABLE V. PERFORMANCE OF SYSTEM WITH INERTIA SUPPORT

Node	Node Inertia H before support (s)	Node Inertia H after support (s)	RoCoF before support Hz/s	RoCoF after support Hz/s
4	2	6.09	0.6	0.2
5	8.35		0.14	

Inertia of node 4 and 5 when independent was 2s and 8.35s respectively becomes 6.09s after connections. Similarly rate of change of frequency (RoCoF) at node 4 and 5 when independent was 0.6 Hz/s (very fast) and 0.14Hz/s is within the standard limit after connections.

2) Utilizing inertia of Renewable generators:

Solar PV and wind generators are used as RE sources. Inertia from these sources can be utilized for inertia support to node 8

I] Solar PV: If battery is used for storage in Solar PV generation, then battery can be utilized as a fast acting inertia support to the system.

II] For wind generators, if induction types of generators are used then inertia support is available due to direct connection. For DFIG type, inertia is isolated by means of Power Electronic converters. Here inertia can be emulated from DFIG by controlling firing angle of the power electronic devices.

3) Installation of new transmission line

Excess inertia of node 3 can be provided along with other inertia support to node 8. Hence new line can be installed from node 3 to node as shown by dotted line as shown in Fig. 7.

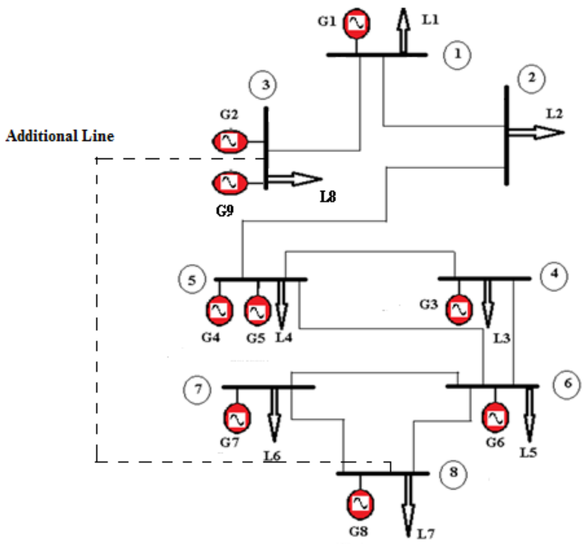

Fig. 7 Inertia support by installation of new transmission line

CONCLUSION

With green energy encouragement from regulatory commissions as well as governments, utility across globe have been strategically investing into DER since a decade. With digital transformation roadmap, Utilities are becoming smarter , in accessing, integrating and leveraging data across the grid for all techno-commercial decision making. This paper is articulated to present the potential of analyzing data to enhance the grid resiliency. As a known fact, penetration of RE generation not only reduces the inertia of the power system but results into node-dependent and time- variant inertia. Reduced inertia results in fast frequency dynamics. Hence an attempt is made in demonstrating how to create visibility and identify locations with high as well as low inertia in the grid. The frequency dynamics , RoCoF can be improved by harnessing inertia support within the system along with external inertia support. For interconnected nodes, inertia support can be given from high inertia node to low inertia node.

All the observations presented in the paper are very value added and relevant to Utilities in achieving real time secure operation of grid.

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Methodology of smart planning of Distribution transformers with Smart Meters Data and Enhancement of life using Active Power Filter

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Abstract - **Distribution transformers are one of the critical equipment in our power distribution system and smart analysis & planning along with any development in performance of distribution transformer results in drastic improvement in the power quality and reliability as well as in huge saving of CAPEX budget. In this paper, we would like to share the methodology of optimized planning of Distribution Transformers of rating 100 kVA to 1600 kVA with smart meter data analysis in Tata Power-DDL and method to reduce Harmonics and unbalance current using Active Power Filter (APF). We have successfully witness a record peak after COVID recovery.**

Index Terms - ***Overload, Smart Meter, APF (Active power filter); DT (Distribution transformer); DSP (Digital signal processing); EV (Electric vehicle); AT&C (Aggregate technical and commercial losses); SAIDI (System average interruption duration index); SAIFI (System average interruption frequency index); STATCOM (Static compensator); ABR (Average billing rate)***

I. INTRODUCTION

It has been now two Decades since the un-bundling of generation, transmission and Distribution in Delhi. Distribution Business were given in the Hands of Private Players on Public Private Partnership (PPP) Model. Tata Power Delhi Distribution Limited was amongst who was awarded License for operation in north and North West Delhi. TATA Power-DDL span over an area of 510 sq. km., serving about 1.86 million consumers [6]. TATA Power-DDL has always been an early implementer of latest technologies & procedures in India and has perhaps most number of standalone and integrated platforms in use. These procedures have also been instrumental in improving the overall operational efficiency & performance of the company and also been able to deliver business benefits in terms of return on capitalization of assets and improving reliability. TPDDL's competence in adaptation of latest technologies makes it very appropriate to achieve high standards in optimization of resources in Project Execution, maintenance and management of Grid networks.

Major problems associated with high neutral current, harmonic distortion and unbalance are –

- Failure of Transformer HT windings
- High Neutral to Ground voltage
- Unwanted heating can lead to Fire Hazards
- Reduced life of transformer
- Nuisance tripping of relays
- Voltage Unbalance
- Underutilization of transformer
- Low power factor

Distribution Transformer plays a vital role in connecting Power Distribution network to consumer. Its operating conditions directly affect security and stability of power system. With the continuous development of economy and the improving people's living standards, peak load is increasing along with increase in non-linear load which usually led to unbalancing and injection of Harmonics. Any development or adoption of new technology or practice for the improvement of performance transformers gives rise to a significant money saving (Cai, Wang, IEEE 2018). To continually monitor the Peak Load experienced by Distribution Transformers (DTs), Tata Power-DDL has installed Smart Meter on DTs. This is one of the steps in moving forward to Smarter DISCOM. Smart Meter measures energy consumption of DTs and periodically transmits its readings to the Servers of Tata Power-DDL. Data collected by smart meters have been regarded as having potential to change the way of Planning of Distribution Transformers level, since they can be used, for example, to obtain a more detailed view of the Loading pattern of DTs. However, smart meters generate data at a rate and volume that outpaces the capabilities of many traditional systems. As a result, much of the data is collected, but not analysed. One of the most important challenges for Tata Power-DDL is to use the smart meter data beyond its core function. Tata Power-DDL has developed a use case of analysing smart Meter data for Planning of Distribution Transformers either for load projection, maintenance or Asset Management.

Data collected from smart meters can also be used to for Better Asset Utilisation (especially DTs) as it gives the insight of actual loading and loading patterns of different ratings of transformers on single Platform.

Along with the Asset utilisation, power quality is now becoming a significant issue. Poor quality and inefficient usage of power can increase losses and lead to increased AT&C losses and impact the Life of the Transformer (Moses, P. S., & Masoum, M. A.2012). Moreover, poor power quality, high harmonic distortions and high neutral current conditions lead to increased failure resulting in unintended and expensive downtimes. These problems will be more prominent in future when there will be considerable non-linear loads in the network (EV charging stations and integration of renewables in the network) (Zynal and Yass, 2012) (Zhou and Wang, 2014).

In this Paper, smart planning of Distribution Transformers and method to improve the Power Quality along with Data Analysis of Distribution Transformers in Tata Power – DDL License area has been discussed.

Research problem:

- To study the methods to reduce transformer losses
- To study the methods to improve power factor and reduce neutral current in transformer.
- To determine the impact of integrating renewable energy sources into the grid and its effects on power quality.

- To explore methods to mitigate over heating of DT winding due to 3n harmonics get trapped in delta winding.
- To explore methods to optimize planning of distribution transformers using smart meter data analysis.
- To eliminate instances where meter reading does not represent true values.

A. *ACTIVE POWER FILTERS*

APF are based on Static Compensator (STATCOM) technology which consists of an IGBT inverter capable of generating current waveform of any shape or size. The versatility of the technology makes this the only solution which can simultaneously correct all current related issues like reactive demand, harmonic distortions, high unbalance, and high neutral. Due to the advanced micro-processor and fast switching of the IGBT inverter topology, we can achieve ultra-fast reaction time of < 200 micro seconds. A STATCOM produces three-phase AC Voltage from a DC Bus using Pulse Width Modulation (PWM) technique. The STATCOM generated voltage is coupled to the source voltage through a coupling reactor. By varying the magnitude of AC terminal voltage of the STATCOM, power exchange takes place between filter and the AC Source. Just by manipulating the voltage at the output terminal of the STATCOM, the device can be programmed to generate current waveform of any shape, size or phase.

APF uses an advanced DSP micro-processor which analyses various network parameters every 100 micro seconds and adjusts the output voltage of the STATCOM every 200 micro seconds. The ultra-fast sensing and advanced control algorithm ensures step less correction and instantaneous compensation. The output can simply be controlled just be customizing the control algorithm in the DSP micro-processor. This flexibility makes the system infinitely configurable and customizable which ensures the optimum utilization of available capacity.

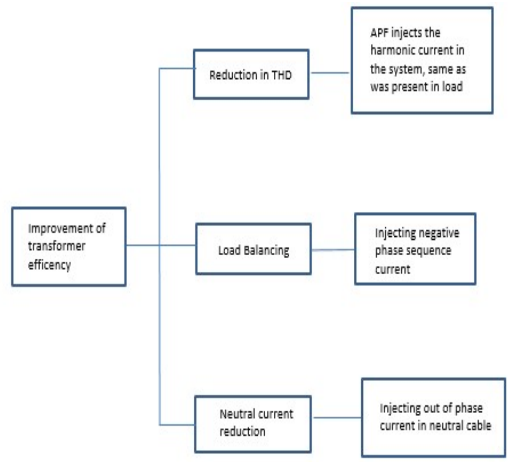

Fig.1. Methods to improve transformer's efficiency

The APF can be programmed simultaneously to address all current related issues and helps in improving transformer's efficiency as shown in Fig1, making their application universal.

Hypothesis made:

H1. Reduction in transformer losses.
H2. Reduction in Total Harmonic Distortion.
H3. Improvement in power factor.
H4. Mitigate problems related to unbalancing.
H5. Neutral current reduction.

Working principle - Active Power Filter (APF) is commissioned on secondary (LT side) of transformer. Current transformer is installed on each phase and its output is given to APF. Microprocessor of APF analyses the current waveforms, and injects feedback current (I_F) in main line to enhance power quality as shown in Fig2.

$$I_s + I_f = I_L$$

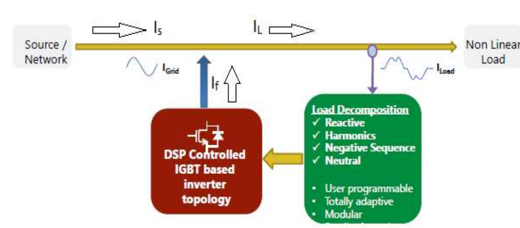

Fig.2. Schematic diagram of closed loop system

APF has been designed to perform mainly three functions, as explained below –

1. **Harmonic compensator –** By Injecting harmonic current in the system, same as was present in load current.
2. **Neutral compensator-** By injecting the same current 180^o out of phase into the neutral.
3. **Load balancing:** Phase current is decomposed into the Positive Sequence and the Negative Sequence current by the DSP micro controller. It then supplies the negative sequence current component so that the corrected waveform only has the Positive Sequence current left.

Mathematical model for Analysis-

Assumptions made while doing analysis are mentioned below-

- All of the stray losses is assumed to be winding eddy current losses.
- Magnetizing current has been neglected to make the calculation easier.
- Total load losses increase by 13.26% for non-linear load (Zynal and Yass, 2012).
- Transformer assumed to be on tap position number 3.
- HT winding resistance = 1.55 Ohm; LT winding resistance = 1.15 mOhm.(Data taken from TWS)
- Average billing rate (ABR) assumed to be Rs. 7/unit.

Equivalent diagram of transformer is used for analysis. HT side impedance is shifted to LT side.

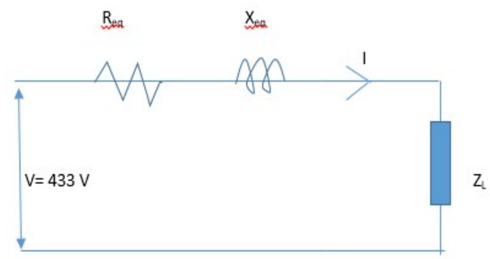

Fig3. Equivalent Diagram

Req = 1.15*10^-3 + 1.55*(433/11000)^2=3.55 mOhm

Full load current of 630 KVA DT = 630*10^3 /(1.732*433) = 840 A

R_{eq}	0.003552	Ω
Full load current -		
I	840.0493	A
Load loss at full load (Linear load) -		
I^2R_{eq}	2506.387	W
For 3-phase system-		
3 X I^2R_{eq}	7519.16	W
For non-linear load-		
Total load losses	8516.201	W
Δ Change	997.0406	W
Yearly saving	60301.02	Rs.

Yearly savings of Rs. 60301 is estimated if only harmonics are removed from supply.

Scenario Analysis-

Scenario analysis performed by considering different loading percentage of transformer. Average billing rate (ABR) assumed to be Rs. 7/unit. Loading scenarios were considered as per winter, summer and actual loading patterns. Annual monetary benefits and energy savings were computed whose details are given below-

Amount saved when transformer is 60% loaded (Actual)			
	KVA	KW	Power factor
Unit is OFF	385.71	378	0.98
Unit is ON	378	378	1
Improvement in transformer utilisation	2.00%		
Total KVAh saved (Annually)	66651.42		
Monetary benefit (Annually)	₹ 4,66,560		
Reduction in current	2%		
Reduction in I^2R losses	-4.12%		

Table 1. Amount saved when transformer is 60% loaded

Amount saved when transformer is 40% loaded (winter estimation)			
	KVA	KW	Power factor
Unit is OFF	257.142	252	0.98
Unit is ON	252	252	1
Improvement in transformer utilisation	2.00%		
Total KVAh saved (Annually)	44434.28		
Monetary benefit (Annually)	₹ 3,11,040.		
Reduction in current	2%		
Reduction in I^2R losses	-4.12%		

Table 2. Amount saved when transformer is 40% loaded

Amount saved when transformer is 80% loaded (Peak load estimation)			
	KVA	KW	Power factor
Unit is OFF	514.28	504	0.98
Unit is ON	504	504	1
Improvement in transformer utilisation	2.00%		
Total KVAh saved (Annually)	88868.57		
Monetary benefit (Annually)	₹ 6,22,080		
Reduction in current	2%		
Reduction in I^2R losses	-4.12%		

Table 3. Amount saved when transformer is 80% loaded

As shown in above tables, APF gives monetary benefit of around 4.5 Lac annually.

II. METHODOLOGY

Tata Power – DDL has around 5000 Sets of Distribution Transformers of ratings ranging from 100 kVA to 1600 kVA and are equipped with smart meters. The data of smart meter i.e, Current, Voltage etc. is communicated and stored in Master Data Management System (MDM).

B. PLANNING OF DISTRIBUTION TRANSFORMERS

Data from MDM Database is moved to DT Dashboard and processed into report format. DT Dashboard is in-house Web Application of Tata Power-DDL to automatically convert Data of MDM into report format. Report on DT Dashboard contains 2 hrs Sustained peak loading details having following parameters:-

Reading Date	District	Zone	Meter No	DT No
DT Name	Consumer Count	Sanction Load	DT Capacity	MF
Peak KVA { Persistent Basis }	% DT Loading { Persistent Basis }	% DT Loading Band	Slot	Max Peak Slot
No of Available Slots	Peak KVA { Day Wise }	% DT Loading { Day Wise }	VR Day Peak	VY Day Peak
VB Day Peak	IR Day Peak	IY Day Peak	IB Day Peak	Criteria 1
Criteria 2	Criteria 3	Meter Reading Status	% Unbalance Current	Unbalance Band

Peak KVA (Persistent Basis) means 2 Hrs Sustained Peak on rolling basis.
Ix – Phase Current
Vx- Phase Voltage

There are some instance where meter reading does not represent true values. These may be due to some kind of events such as CT missing, CT reverse, Phase current missing, voltage missing, Unbalancing on phase currents or any other event. So, these reading has been flagged as abnormal in dashboard as per below criterion and based on these Meter Reading Status is updated.

Criteria 1 - Max of IR, IB and IY greater than 50 A and Min of IR,IB and IY less than 10 A.
Criteria 2 - Max of IR, IB and IY greater than 50 A and Percentage unbalance current more than 100%.
Criteria 3 - Min of VRN, VYN, VBN is less than 180 V.

Calculation of % Unbalance Current is –

% Unbalance Current = { Max(IR,IY,IB) – Average(IR,IB,IY) } / Average (IR,IY,IB) []

Report generated from DT Dashboard is used to identify and mitigate overloaded DTs in current Summer and forecasting of DT Loading for X+1 year and X+2 year (X is current year) and mitigation of overloaded DTs which gets overloaded in X+1 year and X+2 year.

In Tata Power – DDL, overloading of Distribution transformer means 2 Hrs Sustained peak of Distribution is more than 90% of its capacity.

Load on DT is forecasted using the below Formula –
$(\text{Peak KVA})_{x+i}=(\text{Peak kVA})_{x}(1+\%LG)^{i}$
X - Current Year
i - ith Year
LG – Calculated Load Growth

Below is the Flow Chart for DT Analysis-

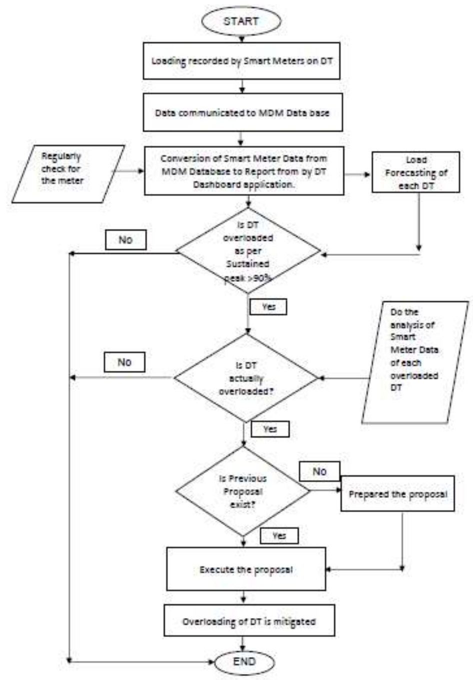

Fig. 4. Flow chart of DT Analysis

In DT Dashboard, there is also a feature of Load Curve Analysis and comparative analysis of DTs. This feature shall is very helpful in filtering DT which were not actually overloaded. By identifying, whether DT is actually overloaded or not w.r.t any erroneous data or temp. load shifting, significant capacity addition in network shall be avoided which in turn will help in capex savings.

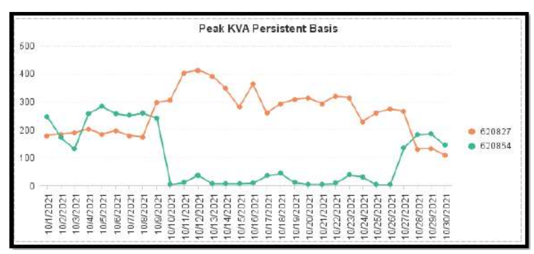

Fig.5. Sample Comparative Analysis

DT Dashboard also generates a table with Loading Band. This Table helps in Asset Management and helps in movement of Lightly Loaded DTs to overloaded Pockets. By virtue of this, significant amount of capex savings has been achieved.

District	0-40	40-70	70-90	90-100	>100	Abnormal	Grand Total
BDL	140	49	2	0	0	18	209
BWN	116	65	2	0	0	19	202
CVL	339	28	0	0	0	21	388
KPM	261	46	2	1	0	11	321
KRR	65	86	18	3	2	19	193
MDT	238	17	0	0	0	23	278
MGP	149	81	7	0	1	21	259
MTN	304	46	1	1	0	14	366
NRL	246	70	8	1	1	31	357
PPR	385	40	0	0	0	20	445
RHN	844	40	1	0	0	39	924
SMB	340	101	3	0	0	31	475
Grand Total	3,427	669	44	6	4	267	4,417

Fig.6. Sample Table for DT Loading Band

III. RESULTS

By using smart meter data in planning of Distribution Transformers, significant amount of savings has been achieved in H1 of FY21-22.

Activity	MVA Saved	Cost Per MVA (Cr.)	Total Savings
Cost saving DT Swapping in H1	12.21	0.2	2.44
Cost saving by identifying erroneous data and Temporary Load Shifting	11.91	0.2	2.38
Total	**24.12**	**0.2**	**4.82**

Table 4: Savings in H1 in DT Planning

After commissioning of APF on 630 KVA Distribution transformer, power quality meter was installed on LT side of transformer. Following observations were recorded with APF in switched ON and OFF condition as shown in table 5.

S.No.	Feeder Name	Active filter	Cases	Arms (A)				Aunb	iTHD(%)			Urms (V)			Vrms (V)				vTHD(%)			Power			PF
				R	Y	B	N		R	Y	B	R	Y	B	R	Y	B	N	R	Y	B	kW	kVAr	kVA	Mean
ransformer(630kVA),Active filter-150A(p2p-415-apf4-150)																									
1	Main LT Incomer	OFF	I	393	411	361	74	7	5	5	6	415	416	418	243	237	242	3	1	2	1	276	44	280	0.98
			II	399	379	301	104	9	6	5	8	421	423	424	246	240	245	3	2	2	1	261	31	265	0.98
		ON	I	422	414	409	36	1	3	2	3	419	422	422	245	239	245	4	1	1	1	302	-8	303	1.00
			II	397	388	369	22	3	3	2	5	418	421	421	244	239	244	4	1	1	1	280	-5	280	1.00

Table 5: Post installation data

While APF was switched ON it showed improvement in power factor from 0.98 to 1.00, reduction in total harmonic distortion from 5% to 3% and reduction in neutral current from 74 A to 36 A.

IV. CONCLUSION

- Reduction in Transformer load or copper Losses. Hence H1 hypothesis is supported.
- Harmonic reduction in Transformer. Also eddy current losses are reduced (Eddy current losses are function of harmonics). Hence H2 hypothesis is supported.
- Reduction in tripping and reduced heating of transformer HT winding due to high neutral current. Hence H5 hypothesis is supported.
- Harmonic impact reduction of Photo voltaic and EV charging station for long term sustenance.
- Improved power factor and capacity utilization of transformer which can be used to service more connections. Hence H3 hypothesis is supported.
- Active load balancing resulting in uniform loading of all phases is not possible. Hence H4 hypothesis is not supported.
- Effective DT planning & analysis based on loading trend and enhanced Asset sweating.
- Maximization of DT utilization factor with swapping of lightly & over loaded DTs.

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Power Quality Assessment at Customer Level

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***Abstract*— In recent years, Power quality (PQ) has become a major concern for both utilities and customers due to advancement in sensitive process controls and electronic equipments. It is necessary to know the level of disturbances in order to have appropriate preventive measures to avoid equipment malfunction. Power Quality assessment surveys play a major role in achieving that. The objective of this paper is to showcase results obtained through power quality assessment conducted at industrial sites by Tata power Delhi Distribution Limited. For the study carried out in this paper, power quality monitoring equipments were installed at five different category of industrial sites to record the data. The recorded data is analyzed, compared and presented in detail. Observed PQ parameters are also compared with relevant standards to understand their severity levels. The parameters considered under this study are voltage and current waveform distortions, power factor, voltage and current harmonics, unbalance, voltage events while the measurements were carried out by Portable PQ meters.**

Keywords*— *Power Quality, Harmonics, THDI, THDV, TDD, Sag/Swell, IEEE 519-2014, Flicker

I. Introduction

Tata Power Delhi Distribution Limited is a joint venture between Tata Power and the Government of NCT of Delhi with the majority stake being held by Tata Power Company (51%). Total distribution area is of 510 sq.km and population served is around seven millions. Peak load served as on date is 2106 MW and this load demand is increasing every year. With introduction of non-linear loads in this increasing load trend new power quality issues have surfaced. Thus, it is necessary to perform power quality study, so that inferences brought out from these studies will serve as the inputs to utility to take necessary action to ensure reliable operation of power system network and for industrial customers to improve their installation and also input to equipment manufacturer to enhance their design and robustness to withstand under such PQ environment.

The PQ study is performed for multiple consumers of five different categories of industrial sites. The duration of the analysis is one week for each location. To carry out this study, the power quality analyser is connected to the Low Voltage (LV) side of the step-down transformer, which provides supply to industry. Using the logging feature of the analyser as mentioned earlier, variation of PQ issues like voltage harmonics, current harmonics, and power factor, events such as voltage sag, swell, and interruption is recorded in the memory at an interval of three seconds [1]. Further analysis of the recorded events are performed using relevant software.

II. Power Quality study details based on real time measurements

A. System Description

This Power Quality Study is carried out at nineteen industrial sites of five different category industries mentioned below. This survey is carried out during May 2021 to January 2022.

- Petrol Pump
- Commercial hubs
- Food Processing Industry
- Plastic Moulding & Packaging Industry
- Cold Storage

B. Data Analysis

The most common PQ events observed at the sites are Current harmonics, sag, swell. In addition to these events, the PQ analyser recorded other parameters such as flicker, supply frequency, unbalance, K-factor continuously with three seconds sampling rate.

a) Current Harmonics: The increased use of nonlinear loads like adjustable speed drives, switched-mode power supplies in computers, uninterrupted power supplies in industries have caused current harmonics. The total harmonics distortion of currents recorded at each industry site is shown in Table I & Figure I. For each site, average current THD (Total Harmonic Distortion) and harmonic index cumulative 95 percentile (CP95) [2], is shown for all three phases. It can be seen in Table I that all the industries except cold storage have high current distortion values.

The Total Harmonic distortion (TDD) values are calculated for each site as shown in table II and figure II. The TDD limits are decided by calculating Isc/IL ratio as defined in IEEE 519-2014 standard [2].

TABLE I. PERCENTAGE CURRENT THD

INDUSTRY	SITE NO.	PERCENTAGE CURRENT THD					
		PHASE A		PHASE B		PHASE C	
		AVG.	CP95	AVG.	CP95	AVG.	CP95
PETROL PUMP	1	31.89	45.68	29.64	41.70	28.10	39.71
COMMERCIAL HUBS	1	18.94	36.26	8.21	17.61	7.19	16.77
	2	15.04	29.21	15.41	23.33	9.66	14.62
	3	23.67	31.84	30.61	42.65	29.22	38.04
	4	21.44	30.87	27.28	41.67	23.63	32.68
	5	14.05	21.40	19.38	35.35	11.04	16.38
FOOD PROCESSING INDUSTRY	1	14.57	18.12	18.58	23.69	14.63	18.27
	2	4.38	6.36	4.63	7.83	5.56	8.33
	3	5.32	10.22	6.02	10.44	6.72	13.08
	4	5.62	7.60	6.13	8.33	6.06	8.71
	5	45.54	51.90	41.19	45.02	46.48	53.37
	6	10.62	15.79	12.95	18.50	12.97	19.45
PLASTIC MOULDING & PACKAGING INDUSTRY	1	23.22	33.89	23.37	39.57	20.54	31.29
	2	6.37	19.73	6.73	12.85	6.98	12.59
	3	24.52	34.38	23.09	33.12	25.97	36.55
	4	18.82	24.53	16.99	20.90	16.16	28.52
	5	15.63	25.74	13.56	19.66	14.02	21.40
	6	22.78	34.30	25.89	40.69	19.57	30.61
COLD STORAGE	1	1.99	4.33	2.45	8.32	2.36	6.50

TABLE II. PERCENTAGE CURRENT TDD

INDUSTRY	SITE NO.	PERCENTAGE CURRENT TDD			
		LIMIT	PHASE A	PHASE B	PHASE C
PETROL PUMP	1	8.00	34.55	32.44	31.52
COMMERCIAL HUBS	1	8.00	4.51	5.23	6.02
	2	8.00	6.71	7.46	5.75
	3	12.00	14.74	14.84	14.68
	4	12.00	7.14	9.51	10.05
	5	12.00	7.12	6.95	5.86
FOOD PROCESSING INDUSTRY	1	8.00	3.21	4.29	5.16
	2	8.00	5.08	4.49	5.84
	3	8.00	4.18	5.21	5.63
	4	8.00	9.22	10.22	9.46
	5	12.00	14.51	13.28	14.94
	6	8.00	8.50	8.68	8.52
PLASTIC MOULDING & PACKAGING INDUSTRY	1	8.00	16.02	16.81	16.10
	2	8.00	5.04	16.69	16.81
	3	8.00	19.95	18.64	17.69
	4	12.00	9.77	12.04	13.23
	5	8.00	13.12	11.87	11.45
	6	8.00	7.58	8.55	7.73
COLD STORAGE	1	8.00	1.77	1.74	1.74

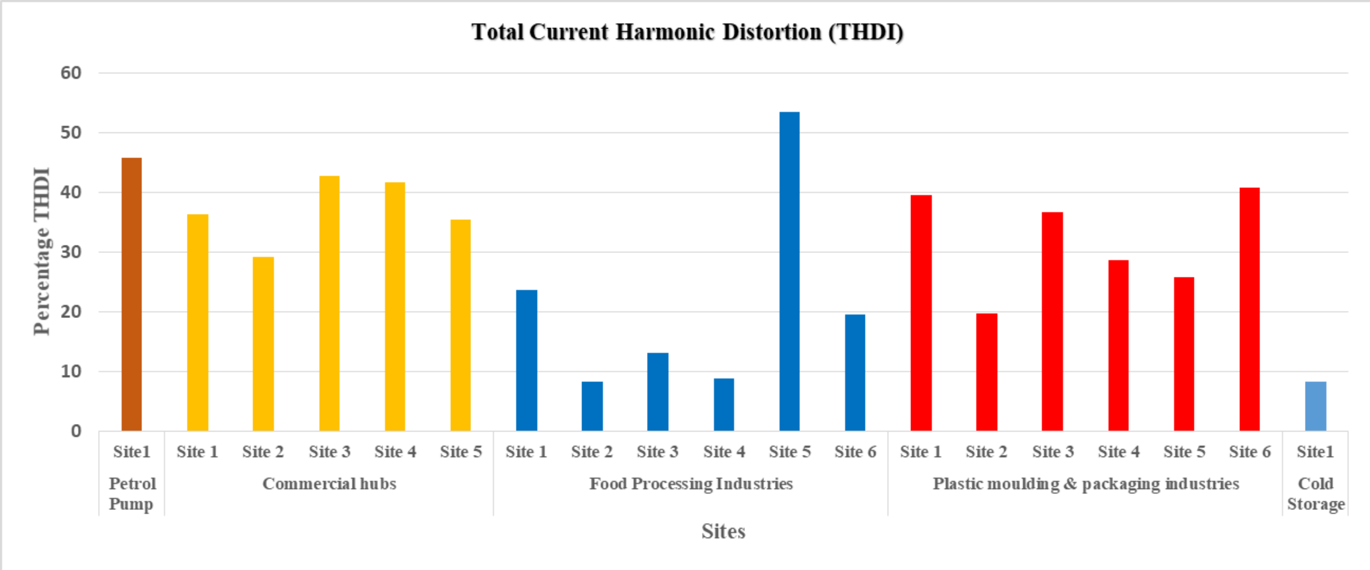

Fig. I. Total Current Harmonic Distortion

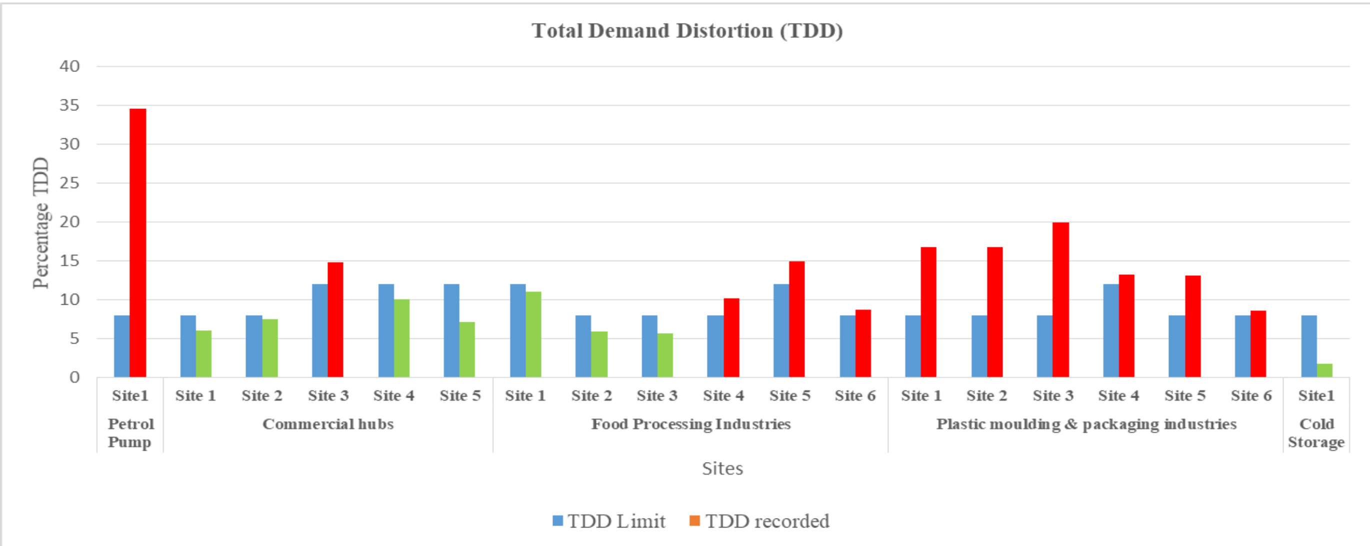

Fig. II. Total Demand Distortion

It is observed from figure II that total demand distortion (TDD) is more than the limits specified in IEEE 519-2014 standard in petrol pump, some sites of commercial hubs, food processing industry and all the sites of plastic moulding & packaging industry.

Individual current harmonics of odd order up to 11th harmonic and even order up to 4th harmonic is given in table III.

b) Voltage Harmonics: Harmonic voltages are present at the distribution system due to the interaction of harmonic currents drawn by nonlinear loads with the impedance of the network. Table IV shows the voltage THD measured at each site [3]. It can be witnessed from the measurements that the highest voltage THD is recorded at site 1 of petrol pump. However, the voltage THDs at all sites are well within the limit of 8% imposed by IEEE 519-2014 standard.

c) Voltage Disturbances: The voltage sag and swell events, which are short-time changes in Root Mean Square (RMS) value of supply voltage lasting from milliseconds up to a few seconds, are generally caused by faults and other external disturbances to power systems. Sudden changes in the load may also yield it [4]. Voltage sags, swells and momentary interruptions are the main power quality concern for an ever-increasing group of customers, especially in industries with variable speed drives and other voltage-sensitive electronic loads. Voltage-related events such as voltage sag, swell, interruptions, over/under voltages are recorded by the PQ analyser for each monitoring period and discussed in the subsequent study. The summary of voltage events that were recorded for each site is shown in Table V. Voltage events observed at these sites are classified into three categories as Instantaneous (I), Momentary (M) and Temporary (T) [5].

TABLE III. INDIVIDUAL CURRENT HARMONICS

Harmonic No.		Petrol Pump	Commercial HUBS	Food Processing Industry			Plastic Moulding & Packaging Industry					
		Site 1	Site 3	Site 4	Site 5	Site 6	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
2	Limit	1.75	2.50	1.75	2.50	1.75	1.75	1.75	1.75	2.50	1.75	1.75
	Recording	0.58	0.42	0.27	3.08	0.28	0.25	3.48	0.20	0.35	2.06	0.21
3	Limit	7.00	10.00	7.00	10.00	7.00	7.00	7.00	7.00	10.00	7.00	7.00
	Recording	6.33	4.25	2.60	4.25	0.97	2.65	14.93	2.99	10.49	9.02	1.07
4	Limit	1.75	2.50	1.75	2.50	1.75	1.75	1.75	1.75	2.50	1.75	1.75
	Recording	0.20	0.16	0.18	2.62	0.08	0.24	1.25	0.11	0.14	0.51	0.13
5	Limit	7.00	10.00	7.00	10.00	7.00	7.00	7.00	7.00	10.00	7.00	7.00
	Recording	27.89	12.50	9.87	12.16	8.11	13.73	5.75	19.29	6.07	9.52	7.29
7	Limit	7.00	10.00	7.00	10.00	7.00	7.00	7.00	7.00	10.00	7.00	7.00
	Recording	15.85	6.79	2.81	5.89	3.07	9.22	2.63	7.41	5.64	3.22	4.34
9	Limit	7.00	10.00	7.00	10.00	7.00	7.00	7.00	7.00	10.00	7.00	7.00
	Recording	3.64	1.06	1.60	2.25	0.45	1.18	0.77	1.37	3.36	2.69	0.80
11	Limit	3.50	4.50	3.50	4.50	3.50	3.50	3.50	3.50	4.50	3.50	3.50
	Recording	11.53	2.97	0.85	3.08	0.99	2.54	0.80	2.30	5.42	4.20	1.01

TABLE IV. PERCENTAGE VOLTAGE THD

Industry	Site No.	Percentage Voltage THD			
		Limit	Phase A	Phase B	Phase C
Petrol Pump	1	8.00	6.25	6.37	6.14
Commercial Hubs	1	8.00	1.97	1.27	1.85
	2	8.00	1.89	1.84	1.84
	3	8.00	2.50	2.76	2.43
	4	8.00	1.63	1.58	1.58
	5	8.00	2.13	2.00	1.83
Food Processing Industry	1	8.00	1.98	1.96	2.54
	2	8.00	2.08	2.09	2.31
	3	8.00	1.19	1.32	1.34
	4	8.00	3.35	3.50	3.56
	5	8.00	4.63	4.43	4.76
	6	8.00	4.42	4.58	4.65
Plastic Moulding & Packaging Industry	1	8.00	4.74	4.91	4.42
	2	8.00	1.68	3.33	2.95
	3	8.00	5.00	5.14	4.59
	4	8.00	3.44	3.38	3.84
	5	8.00	5.64	5.66	5.42

Table V. shows a number of occurrences of instantaneous, momentary and temporary events. For example, value two mentioned in Table V. for site 1 of petrol pump indicates two events out of the total number of events flagged by the power quality analyser are instantaneous sags.

Figure III. shows the industry-wise comparison of events concerning the Information Technology Industry Council (ITIC) curve [6]. Table V. shows the occurrence of overvoltage along with swell in three categories instantaneous, momentary and temporary, mainly in food processing, petrol pump and plastic moulding & packaging industry. The high number of swell events in mentioned industries is because they have a fixed power bank installed at their premise for power factor correction. Therefore during light load conditions, temporary swell or overvoltage is observed.

Since the load fluctuation for commercial hubs is significantly less, no major number of swells are observed at these industrial sites.

From Figure III. few occurrences of voltage swell and overvoltage are observed to be present above the limit of the ITIC curve.

TABLE V. NUMBER OF VOLTAGE VARIATION EVENTS OCCURRENCE

Industry	Site No.	Short Duration variations						Long Duration Variations	
		Sag			Swell				
		I	M	T	I	M	T	Overvoltage	Undervoltage
Petrol Pump	1	2	1	0	1	1	22	125	0
Commercial hubs	1	2	0	0	0	0	1	1	0
	2	7	0	0	0	0	1	7	0
	3	5	0	0	0	0	0	0	0
	4	4	0	1	0	0	0	0	0
	5	4	0	0	0	0	0	0	1
Food Processing Industry	1	26	0	0	0	0	0	5	7
	2	2	0	0	0	1	0	20	2
	3	20	0	3	9	0	0	0	3
	4	1	0	2	6	2	28	28	3
	5	0	0	5	3	39	518	122	0
	6	0	0	0	0	0	0	0	0
Plastic Moulding & Packaging Industry	1	3	1	0	30	10	70	144	0
	2	3	0	0	0	0	1	22	0
	3	4	0	0	0	0	0	0	1
	4	9	0	0	11	12	22	59	0
	5	1	0	1	1	143	269	185	4
	6	0	0	1	5	16	74	20	2

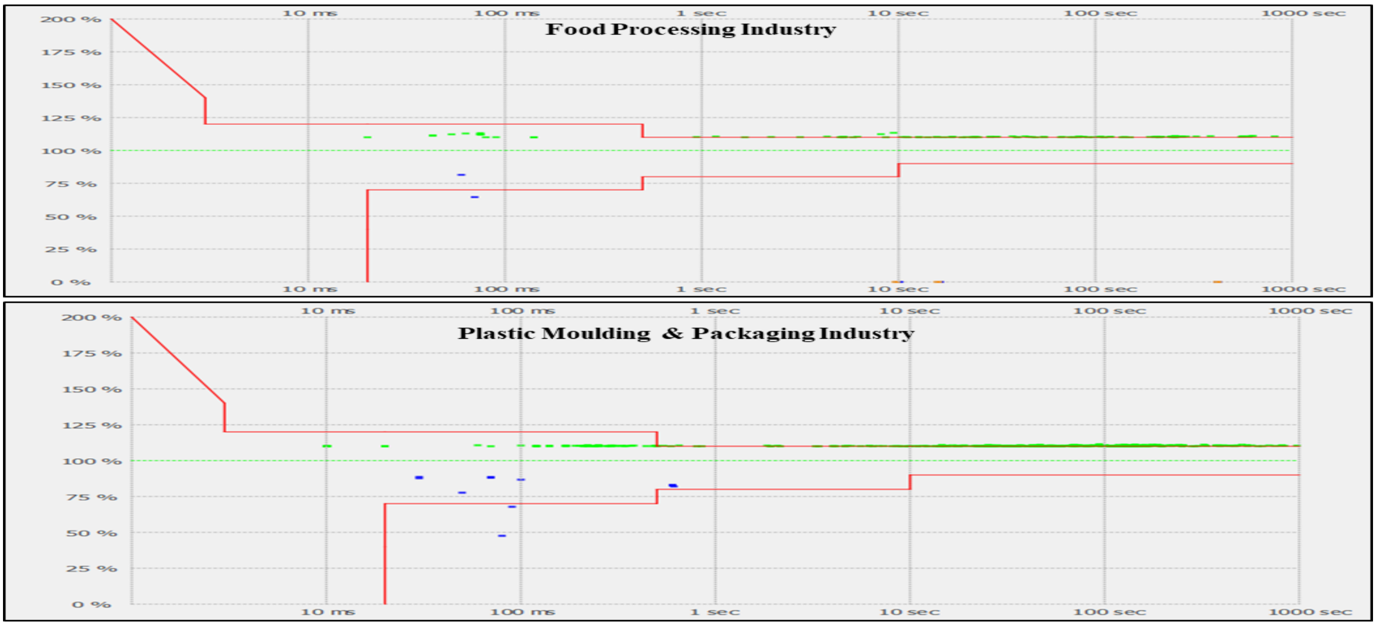

Fig. III. INDUSTRY WISE ITIC CURVE

III. INTRODUCTION

Extensive Power Quality data is recorded at multiple sites of five different category industries. The collected information is analyzed and compared with relevant power quality standards. The most common power quality disturbances observed are current harmonic distortion and voltage variation. Almost all industry sites have high values of current harmonic distortion. Some sites of commercial hubs, food processing industry, and all the Plastic moulding & packaging industry sites have crossed the TDD limits. However, Voltage harmonic limits are within limits for all sites. In Petrol pump site, the harmonic order found is 5th, 7th, 11th, 13th, i.e. 6n±1, which indicates the presence of six pulse variable frequency drive (VFD) at the site. In plastic moulding & packaging and food processing industries, odd-order harmonics exceeding IEEE 519-2014 standards are observed.

The second most common power quality disturbance is voltage variation. Though, the behavior of voltage events concerning the number of occurrence duration is different from one industry to another. However, mostly observed voltage variation is overvoltage and swell. The study has revealed the range of various power quality disturbances at various Low voltage connected industries. This information will be helpful for equipment manufactures to improve their design and act as an input to industries for taking reasonable efforts to enhance the quality of the power within their installation.

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An Integrated Approach on Transmission Planning Studies for Bulk RE Evacuation in Indian context

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***Abstract*— Climate change has been a major driving force for large scale adoption of Renewable Energy (RE) across the globe. India has also set an ambitious target for renewable energy capacity addition of 175 GW by 2022 and 450 GW (recently increased to 500 GW) by 2030. Resource rich locations for Solar and Wind energy are concentrated in a few pockets around the country. Hence, transmission becomes a critical element in Indian power system to enable transfer of renewable energy to major load centers. Transmission network planning studies play an important role in designing the network which is optimal both technically and economically. This paper discusses strategy for development of network models for transmission planning including aspects such as planning horizon and extent to which network is to be modelled. This paper also talks about the relevant sources of data for identification of planned generating plants, transmission lines and load forecasts to be included in network models. A holistic approach for substation and transmission expansion for proper evacuation of RE power to intended load centers is discussed. A comparative analysis between HVAC and Hybrid (HVAC + HVDC) transmission schemes has also been illustrated through a case study. The adequacy of transmission schemes has been evaluated using reliability, cost, and transmission infrastructure utilization as key metrics. While the basic planning is carried out in accordance with the CEA transmission planning criteria, this paper delves into practical experiences of authors and operational feedback from various stakeholders.**

Keywords— Transmission planning, Renewable Energy, Hybrid (HVAC + HVDC) transmission schemes, Power Systems

I. Introduction

Climate change has been a major driving force for large scale adoption of **R**enewable **E**nergy (RE). India has also set an ambitious target for renewable energy capacity addition of 175 GW by 2022 and 450 GW by 2030 [1], out of which 100 GW has been installed [2]. Resource rich locations for Solar and Wind energy are concentrated in a few pockets in the western and southern regions. Hence, transmission becomes a critical element in Indian power system to enable renewable energy to major load centers.

Transmission Planning study is an important aspect for reliable power evacuation from wind and solar power plant. The planning study is used to design analyze the suitability & sufficiency, including through short circuit, power flow and contingency analysis. Along with the typical active power planning, the reactive power needs of the network are also accounted for in short-term Transmission System Expansion Planning (TSEP) [3]. The consideration of key aspects like undervoltage and overvoltage phenomenon during peak and off-peak cases respectively is also essential in TSEP process.

"Power system planning is a process in which the aim is to decide on new as well as upgrading existing system elements, to adequately satisfy the loads for a foreseen future" [4]. These elements may pertain to expansion of Generation, Substations and Transmission lines. The augmentation of transmission system is generally planned to cater to the ever-growing power demand, generation capacity addition or to eliminate the network constraints like overloading, voltage stability, etc. to improve the reliability of the system [5]. Such augmentation comprises addition of new transmission lines and substations or upgrade/uprate of existing infrastructure.

This paper aims to present a stepwise approach for medium to long term Transmission Line Planning for large RE parks (say 20GW) at All India level. The biggest challenge to achieve this objective is the unavailability of a detailed network database for a future timeframe. This paper provides an integrated strategy for development of such network models and relevant sources of data in Indian context.

A holistic approach for transmission planning after development of network database in Indian context has been discussed. The adequacy of transmission schemes has been evaluated with cost and transmission infrastructure utilization as key metrics. With respect to this planning philosophy, a comparative study between High Voltage Alternating Current and Hybrid (HVAC + HVDC) transmission schemes has also been illustrated through a case study from RE evacuation perspective.

The rest of the paper is organized as follows. In Section II, the transmission planning guidelines is explained in detail. Section III covers descriptions of system used for transmission planning. In Section IV, the proposed methodology is demonstrated using a case study on HVAC and Hybrid Transmission scheme and results from the case study have been discussed. Section V concludes the paper with brief comparison between both the schemes.

II. Planning Guidelines/Methodology

In this section, the planning philosophy and methodology adopted for RE evacuation is introduced. It includes a stepwise discussion on data requirement, general assumptions, performance metric and criteria for simulation and studies. This approach has been implemented through a case study in subsequent section. The existing network database has been used to develop base model for a future timeframe (say FY-2025) [5].

A. Data requirement for network database

The following details are essential for proceeding with the development of the base model for generation evacuation planning.

a. Existing Power System Network

The existing power system data would be required for modelling of upcoming generation for which evacuation system is to be planned. For transmission planning at ISTS level, the network data should be modelled up to 220 kV (up to 132 kV for exceptional cases). For detailed study, network database should be modeled to 66/33kV. This data can be used to identify additional injection capacity in existing substation in the vicinity.

b. Load Forecasting

Growth in power demand is key indicator of economic progress of a country and hence, for a developing country like India, accurate load forecasting is of utmost importance. Load forecasting involves use of historical data to predict the future power requirements of a country/region/state. Demand projections are vital for formulating a generation expansion plan. **E**lectric **P**ower **S**urvey (EPS) report published by **C**entral **E**lectricity **A**uthority (CEA) covers year-wise electricity demand projection of all India. All India load growth is scaled to the concerned year using EPS report.

c. Generation Expansion

Generation expansion plans are driven by a country's demand projections. Hence, capacity addition through conventional and RE power plants are evaluated at frequent intervals for reliable power to all [6]. Generation expansion planning for a RE power plant is governed by the resource availability. Section 3(4) of Electricity Act, 2003 stipulates CEA to publish **N**ational **E**lectricity **P**lan (NEP) once in five years. This report consists of suggested areas/locations for capacity additions in generation and transmission and informs about the retirement year of thermal units. NEP Volume I (Generation) is considered for generation expansion details. CEA publishes schedule and construction status of new thermal units, which are also considered while modelling these generation. **M**inistry of **N**ew and **R**enewable **E**nergy (MNRE) and **S**olar **E**nergy **C**orporation of **I**ndia (SECI) publishes details about upcoming Renewable energy schemes.

d. Substation Expansion

Substation expansion is generally planned for pooling of RE. New Substations/switching stations/augmentation of existing substations are essential when power is to be transmitted over longer distances. NEP Volume II (Transmission) informs about the substation expansion requirement. This report only informs about the possibility of expansion. CEA publishes monthly and yearly update regarding construction status of expected substation.

e. Transmission Expansion

Transmission planning for RE power plant under consideration would entail identification of transmission technology (HVAC/HVDC/Hybrid) based on distance from load centers and determination of terminating and intermediate nodes in the network [7] [8]. NEP Volume II (Transmission) also gives information regarding new transmission lines required. This report only informs about the possibility of expansion. CEA publishes monthly and yearly update regarding construction status of all new transmission lines. CEA also consists of Regional Standing Committee Meetings (SCM), Empowered Committee Meetings on Transmission (ECT) and National Committee Meetings on Transmission (NCT) which approves new transmission lines requirement.

B. System Assumptions

The study assumptions considered for modelling of new generation, load growth, proposed transmission lines and related elements are given below.

Basic Assumptions

i. Existing network database has been considered for development of model
ii. Upcoming 765kV, 400kV and 220kV transmission lines have been modelled as per the data available
iii. In case of unavailability of information regarding generation injection level, it has been assumed to be injected at 400/765kV level

Generation:

Thermal Power Plants

i. Thermal generating units have been decommissioned as per NEP data.
ii. Thermal generating units have been backed down to their minimum technical limits i.e., 55% for the study.
iii. Generator parameters for upcoming generation have been considered as per the existing data of similar units.
iv. For maximum RE scenario, Thermal generating units have been backed down/shut down wherever required.

RE Power Plants

i. RE generators have been modelled in lumps (MW/GW range) and injected at pooling point.
ii. RE generating units have been modelled at 0.98 PF.
iii. For peak case Shunt reactors have been disconnected and shunt capacitor have been put into service wherever required.
iv. Rooftop PV generation quantum has also been considered and adjusted in load and generation values.

Transmission Lines

i. All 765 kV Transmission lines have been modelled with ACSR Hexa-Zebra unless otherwise specified in the data.
ii. Transmission line parameters have been calculated using EMTP software/conductor tool (developed in-house) for relevant conductors whose values not available in CEA Transmission line planning manual [4]
iii. Transformer parameters considered have been modelled using existing transformer of same rating.

Load

i. The load has been scaled up proportionately as per the existing load with projection from 19th EPS report [9] of CEA.

ii. A power factor of 0.95 has been considered for loads.

C. Performance Criteria

Transmission schemes planned shall be governed by state of system parameters during normal operating conditions and contingencies. The parameters include voltages, line and transformer loadings as well as angular separation between two adjacent buses. These parameters should be within their permissible limits during normal operation (N-0) and N-1 contingency scenario. In addition to the above, short circuit levels at new and existing buses determine the feasibility of additional injection/lines at an existing substation. For any newly planned substation, the maximum short circuit level at that bus should remain within 80% of the rated capacity, such that 20% margin caters to the future network expansion. Short-circuit levels at existing substations may exceed their design limits with continued network expansion. Hence, control measures such as bus splitting, installation of series reactors, etc. shall be adopted from time to time.

III. SYSTEM DESCRIPTION

The study was carried out with PSS/E software version 35.0. The validated network database for base timeframe has been considered for the study. The study inputs such as generation details, injection points, capacity and load growth were modelled as mentioned in Section II.

The planning study has been done in accordance with various load scenarios and generation dispatch conditions such as Solar Maximized Peak case and Solar Minimized off-peak case. The details of demand factor for load considerations and generation dispatch criteria has been mentioned in Section II (B). Post modelling of elements, power flow study was carried out to reach load-generation balance for a future timeframe. The outcomes of cases studied have been discussed in following sections. The step followed are identified in Figure 1.

Present paper discusses the outcome of short circuit analysis for all voltage levels. For short circuit level, standard rated breaking capacity of substation bus and transformer capacity has been considered from CEA transmission planning criteria guidelines. Reactive power compensation study has also been performed for different scenarios to validate the size and requirement of shunt capacitors, shunt reactors (bus reactors), static VAR compensators or other FACTS devices. The analysis has also carried out N-1 contingency for proposed lines as per the CEA transmission planning criteria guidelines.

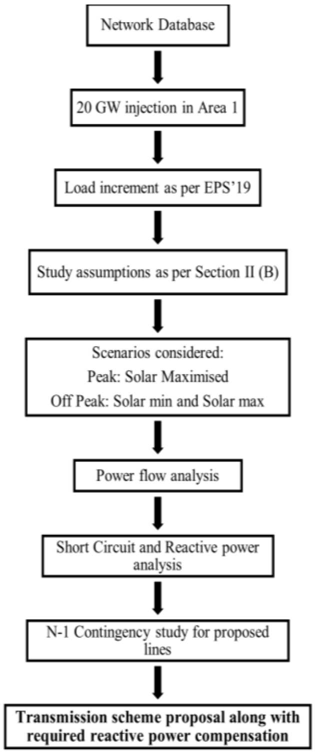

Figure 1: Transmission Planning Methodology

IV. CASE STUDY

A case study has been used to showcase the transmission planning philosophy and some practical experiences. In India, Wind and Solar energy resources are concentrated in pockets and power demand may not necessarily match the abundant potential of RE in the resource-rich states. Power may have to be exported out of the state as Renewable Purchase Obligation (RPO) requirement can be met through existing RE capacity. Thus, there is no real need to congest state's 400 and 220 kV transmission network with such bulk power. In that case, major load centers in adjacent states become the target for upcoming generation capacity.

To replicate the scenario for the study, a small fragment of the Indian power system is shown here. Zone 1 is considered as a resource-rich state (generation injection as shown in Table 1) and all the surplus RE power is exported to zones 2 and 3. The SLDs show major 400 kV, 765 kV and HVDC lines only while power is also exported through downstream 400 kV lines at various 765/400 kV substations.

The study incorporates two cases for power evacuation from RE parks, namely, HVAC transmission scheme and Hybrid (HVAC+HVDC) transmission scheme. A comparative analysis between both schemes has also been illustrated through this case study.

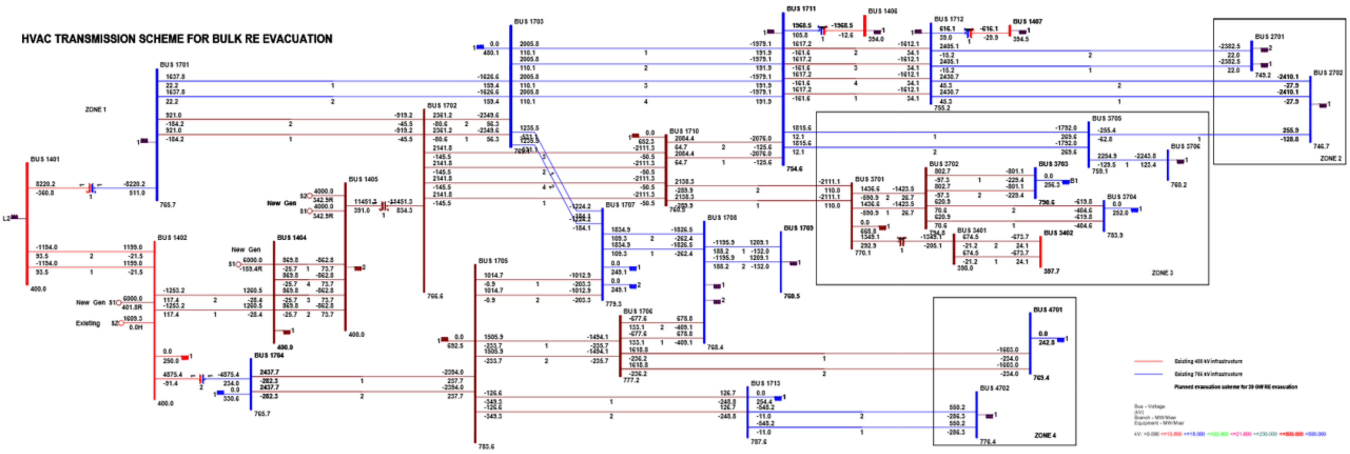

Figure 2: SLD showing HVAC transmission scheme for bulk RE evacuation

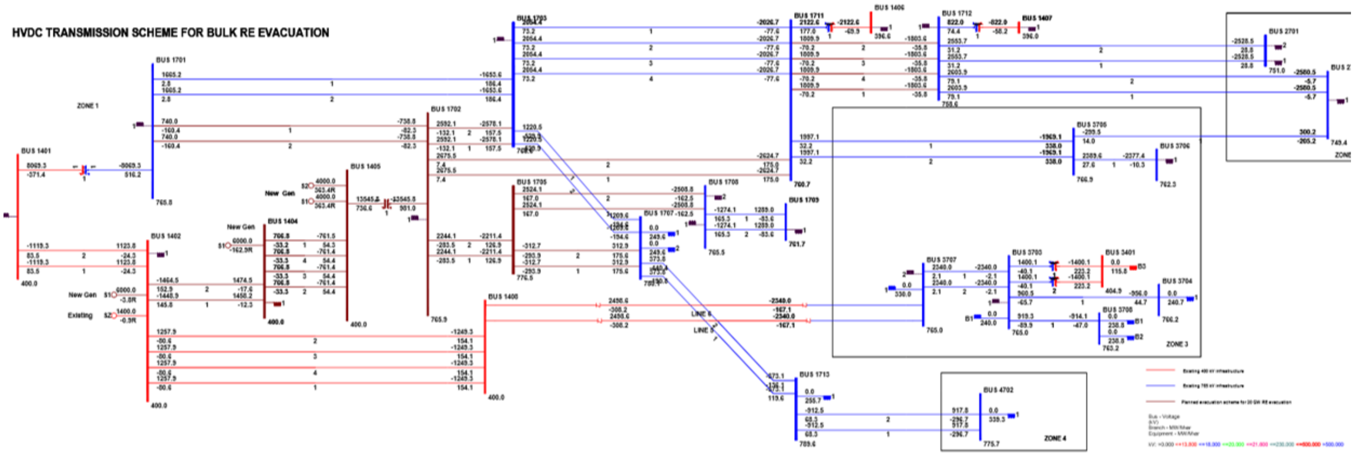

Figure 3: SLD showing Hybrid (HVAC+HVDC) transmission scheme for bulk RE evacuation

Table 1: Generation Injection data

Zone	Bus number	Generation Injection (MW)
Zone 1	Bus 1402	6000
	Bus 1404	6000
	Bus 1406	8000
Total		**20000**

A. Case 1: HVAC Transmission Scheme

In this scheme, power evacuation of 20 GW from Zone 1 using high capacity EHV 765 kV AC lines with a SIL of ~2100 MVA. Power evacuation is planned from three power pooling substations via two intermediate switching stations. These switching stations have been used to feed power either directly to load centers or to transfer power through existing underutilized infrastructure through Loop In Loop Out (LILO) arrangements. Such an arrangement allows for improved utilization of existing assets with minimal capital expenditure.

In this scheme, power is evacuated from Bus 1702 and Bus 1704 (765/400 kV power pooling stations) to two 765 kV switching stations (Bus 1710 and 1706). The generating stations are interconnected to accommodate any line outage. Line 1702 – 1710 is a 765kV 2 x D/C HVAC line and can evacuate around 9 GW of power to feed zones 2&3. Similarly, lines from Bus 1706 feeds power requirement of zones 1&4 as shown in Figure 2.

B. Case 2: Hybrid (HVAC+HVDC) Transmission Scheme

A hybrid (HVAC + HVDC) scheme was also studied to directly feed bulk power to a major load center as shown in Figure 3. An HVDC link of +/- 500 kV, 5000 MW, 2000 ckms between Bus 1403 and 3707 eliminates the requirement of two switching station as well as a 765 kV corridor of line length ~2800 ckms. Another important advantage in HVDC lines is the low RoW requirement in comparison to HVAC lines. This is being proposed keeping in mind that most of the AC infrastructure associated with RE generation will remain underutilized during off-peak (night) scenarios. A VSC based HVDC scheme offers a lot of other advantages in the form of controllability of both active and reactive power to improve the stability of the connected AC system. Reverse power transmission and black start capability make it a very suitable option for integration of intermittent RE sources.

C. Results and discussion

a) Power export to beneficiary zones: The transmission lines have been planned for Solar Maximized scenario and their adequacy and reactive power requirements have been verified from the off-peak case. The increased load demand can be easily met with the upcoming 20 GW of RE in zone 1 during the peak scenario. The power export from zone 1 to other zones for both the cases is shown in *Table 2*.

Table 2: Power export to beneficiary zones

From	To	Case I - HVAC	Case II -Hybrid (HVAC + HVDC)
Zone 1	Zone 2	9751	10392
	Zone 3	12404	12550
	Zone 4	3363	4523
Total		**25518**	**27465**

b) N-1 contingency study: The proposed lines were analysed for N-1 contingency and overloading of 765 and 400 kV lines were checked during such contingencies. All 765 kV and 400 kV lines were found to be loaded within their thermal limits and no voltage violation is observed.

c) Reactive power compensation study: A reactive power study was done for the proposed scheme using the peak and off-peak scenario. This scenario emulates the lightly loaded condition of the transmission lines associated with RE for the off-peak case. Most of the demand is met using Wind and Conventional generation. With Solar generation at zero, associated transmission lines are lightly loaded and draw reactive power in large amounts, leading to over-voltages at the buses. This scenario gives a clear picture of the reactive power support required at the buses and hence the size of reactors to be installed. Hence, adequacy of existing reactors and/or requirement of new reactors is assessed in this scenario. For the proposed scheme, the reactors proposed will suffice for lightly loaded condition. If required, one circuit of a long 765 kV line can be taken out of service for voltage regulation as and when line is not loaded beyond 400 MW. The reactors proposed at various substations have been shown in *Table 3*

Table 3: Bus reactor requirement at various buses

BUS NAME	Voltage (kV)	Reactors (MVAR)
Bus 1404	400	2 x 125
Bus 1405	400	2 x 125
Bus 1702	765	2 x 330
Bus 1402	400	2 x 125
Bus 1706	765	2 X 330
Bus 1708	765	2 X 330
Bus 1710	765	2 X 330
Bus 3401	400	2 x 125
Bus 3701	765	2 x 330
Bus 3702	765	2 x 330

d) Short circuit level study: Short Circuit studies were performed for identifying injections as well as post RE power injection. The study involves creating a symmetrical three phase fault at the concerned buses and fault contributions of adjacent buses are noted to identify the total short circuit current at that a particular bus. The study results were compared with standard design rating for 220 kV, 400 kV and 765 kV buses. Short circuit level of all 220kV, 400kV and 765kV buses were found to be within permissible limits as per transmission planning manual. Bus sectionalisation was proposed as a mitigation measure wherver SCL exceeded 90% of design limits.

V. Conclusion

From the analysis carried out for normal operating condition, it is noted that the planned and existing transmission network on 765kV and 400kV is adequate to meet the demand for future growth. Under N-1 contingency of 765kV lines, the network is adequate, however a few lines which over-loaded based on SIL are well within their thermal limits. Hence the planned transmission lines are adequate to evacuate 20 GW from Zone 1 to zones 2,3&4 as well as to the wider power system, using both trasnmission schemes. Capex estimates favour HVAC scheme as it would not exceed 70% the cost of Hybrid transmission scheme. However, Hybrid transmission scheme is far more advantageous that it outweighs the cost incurred. Firstly, Bulk power is injected into single nodes and the same is required to be evacuated to distant load centres. Hence, it is advantageous to put a dedicated long-distance HVDC link between power injections and load points, eliminating the need of multiple switching stations reducing the overall RoW requirement. It also improves system security in terms of angles or voltage stability as well as the reactive power requirement would be lesser with a HVDC interconnection. In addition to the above, since the generation is mostly from Solar parks, HVAC lines are bound to be underutilized during night hours, resulting in overvoltage issues due to underloading. Therefore, additional reactors would be required to control the overvoltage. However, this issue would not be there with HVDC links. Besides, reverse power flow capability of HVDC can be used to serve power requirement of zone 1 during unavailability of Solar generation. Hence, hybrid scheme favours the bulk integration of renewable energy with the above advantange over HVAC scheme irrespective of increase in capex.

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Implementation of Digital Substation Concept in Brown Field Project

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Abstract—**The World is facing a decarbonization challenge which can be managed effectively in part by digitizing the substations. In the power transmission and distribution world, digital substations make the substation more compact & cost effective, improves data availability, reliability, and the sustainability of the entire power supply.**

Understanding the need of digital substation, Larsen and Toubro (L&T) upgraded its existing conventional 33/0.415 kV and 11/0.415 kV Substations in Chennai Head Quarters (HQ) Campus with state-of-the-art Intelligent Electronic Devices (IEDs) with digital substation principles.

In this paper, we present the overall project architecture as well as the lessons learnt during the execution and commissioning of the project. L&T upgraded two substations not only to improve their monitoring & control capability in a more intelligent way, but also to observe and analyze the challenges faced while implementing the digital substation concept in brown field substations and prepare for future markets.

Keywords— digital substation, asset management, cloud integration, industrial internet of things (IIoT), merging unit (MU), bay control and protection unit (BCPU), remote terminal unit (RTU), intelligent electronic device (IED).

I. Introduction

In conventional substations circuit breakers (CB), voltage transformers (VT), current transformers (CT) and protective relays are connected together using copper cables. To establish conventional substations, more effort is required in installation and commissioning, more space is required, complex operation and maintenance involved, high capital cost redundant control and protection system is required. In contrary to conventional substation and development in digital technology and communication standards, conventional CTs and VTs are replaced with non-conventional instrument transformers (NCIT), CB statuses are wired to IEDs placed near to the primary equipments and copper cables are replaced with fiber optic (FO) cables to transfer the information from switchyard to control room. In digital substation concept, raw data are processed at yard level and transferred in digital form to station level, where data is further analysis and information are given in desired format.

One of the major challenges faced during implementation of conventional substation is land availability, which is supported by digital substations concept as this requires considerably less space. Digital Substation helps to reduce the copper cables which needs to be laid between yard and substation. It also supports the O&M personal in trouble shooting, maintenance, etc. The state of art substation ensures that future expansions are implemented without much complexity.

The paper is structured as follows. Section II of this paper describes the architecture of digital substation implement in the L&T Chennai HQ campus. Uniqueness of L&T's digital substation is listed in section III of this paper followed by the challenges faced during implementation of digital substation concept in brown field substation in section IV

II. L&T Digital Substation Architecture

This section will brief how the digital substation components are physically connected with each other in L&T's digital substation. Major components of digital substation are IEDs (MUs and BCPUs), ethernet switches, gateways, routers, firewall, operator workstations (OWS), engineering workstations (EWS), global positioning system (GPS), edge gateways. In L&T's digital substation conventional CTs & VTs and CB status and other status signals are wired through copper cables to MUs. MUs & BCPUs replace the existing protection devices in the panel. Two network busses were formed using ethernet switches one is process bus and another bus is called station bus. All the Merging units (MU) were connected to process bus network and all the Bay Control Protection Units (BCPU) were connected to both process bus and station bus network over parallel redundancy protocol (PRP).

In L&T's digital substation different makes of equipments are used. Like merging units and bay control protection units are from ABB, Siemens, GE, SEL and Nari. Ethernet switches are from Siemens and IS5. RTUs are from ABB and Siemens. This shows how the digital technology integrates different make equipments together.

Analogue values measured by CTs & VTs are sampled at the rate of 80 samples per power cycle by MUs [1] [5] [8] [10-11] which is transferred to BCPUs over IEC 61850-9-2 protocol. Status and control signals are connected to MUs which transfers the same through generic object oriented substation events (GOOSE) to BCPUs. [2-4] [6-7] [9]. The IEC 61850-9-2 standard replaced the communication through copper to fiber optic cables there by reduced the requirement of copper cable in the substation.

All the 415 V boards were integrated through remote terminal units (RTU). RTU is connected with station bus through IEC 61850 protocol. The RTU passes the status of 415 V boards and metering data to substation automation system. This information is used to monitor each feeders remotely by the operator in real time and take actions quickly.

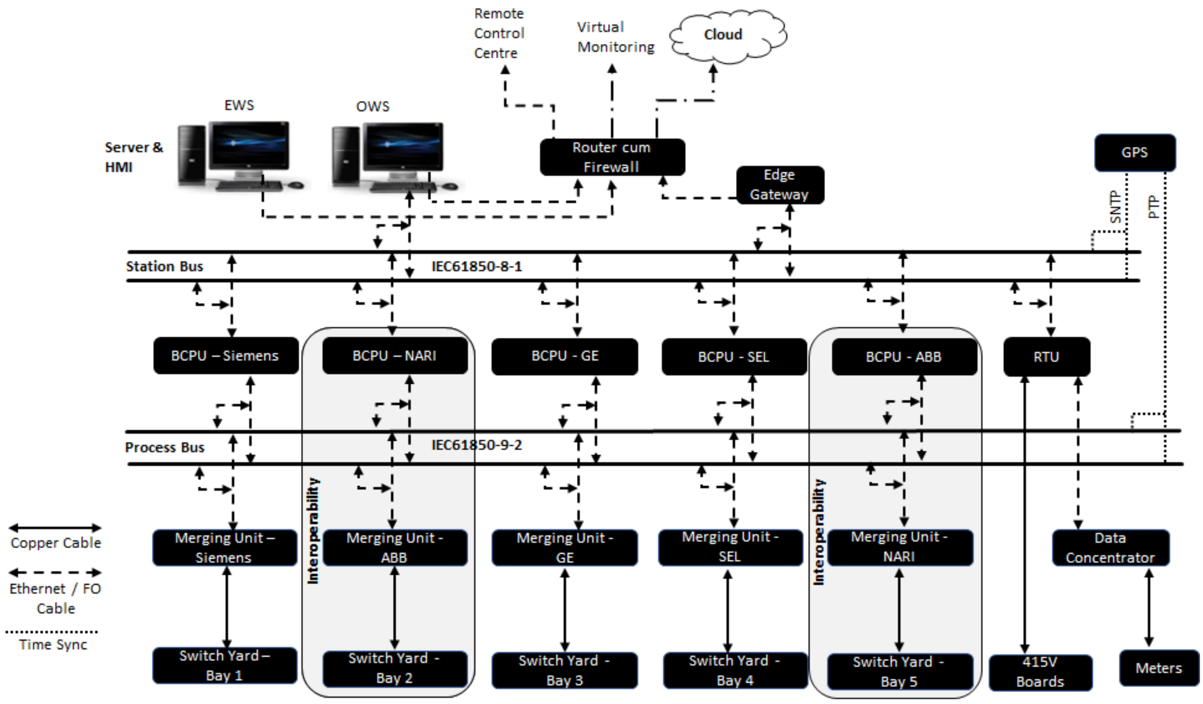

Fig. 1. Simplified L&T's digital substation architecture

One of the important requirements of digital substation is time synchronization which is very critical for sampling the analogue values. GPS unit syncs all the devices in station bus (bay level IEDs, RTU, Gateway, OWS and EWS) using simple network time protocol (SNTP). It syncs all the devices connected in process bus network like merging units Siemens, GE, NARI, SEL, analogue units, digital units and time synchronizing units of ABB, in Precision Time Protocol (PTP). IEDs (Intelligent Electronic Devices) connected with station bus will be time stamped on SNTP and IEDs connected with process bus will be time stamped on PTP. Physical GPS connected with station bus and process bus is named as master GPS. Failure of master GPS is managed with the help of master clock function available in one of the BCPUs/MUs in the network. Time sync alarm will be generated and displayed in operator workstation monitor (Human Machine Interface - HMI) whenever any IEDs loose the time sync pulse.

Network of digital substation has two main buses one is called process bus and another one is called process bus. To ensure the failure of network components does not affect the performance of the automation system, redundant busses were formed in both process bus and station bus. Each MUs are connected with process bus A and process bus B in redundant fashion. Each BCPUs are connected bus-A and bus-B of both process bus and station bus. All other station level equipments like servers, OWS, EWS, gateways, edge gateways are connected with station bus-A and bus-B in redundant fashion

Existing data concentrator was replaced with new data concentrator which as feature to communicate with two masters i.e., first master is existing L&T campus energy management center and second master is digital substation. The new data concentrator communicates with RTU through MODBUS TCP/IP protocol. Server cum operator workstation (OWS) does the functionality of data collection, storage and local display. Operator able to monitor the substation remotely in real time and take necessary action. He can generate the report and trends for analysis purpose. Engineering Workstation (EWS) is used for remote configuration of IEDs, gateway, router, substation HMI screens and network components. Gateway is provided to establish the communication with remote control center with is located in L&T Chennai HQ campus on IEC60870-5-104. Separate edge gateway is also provided to write the data on cloud over message queue telemetry transport (MQTT) / open platform communication unified architecture (OPC UA) publisher/subscriber (pub/sub) protocol.

III. Uniqueness of L&T's Digital Substation

A. *Five makes of IEDs integrated*

In few decades back implementation of substation automation is fully dependent on OEMs. Recent development in digital technology and international standards, integration of different OEMs is feasible. L&T went one step ahead and integrated five different OEMs like Siemens, GE, SEL, ABB and NARI Merging Units (MU) and Bay Control Protection Units (BCPU) which is very unique in the substation automation business.

B. *Interoperability between mering units and bay control protection units*

Latest standards talk about connecting different makes of IEDs to support users not to depend on one OEMs after installation of substation automation system. International standards on interoperability helps end users to have multiple options while designing the substation automation system. Interoperability also helps different OEMs IEDs talks each other seamlessly. In L&T's digital substation interoperability is implemented by integrating different make Merging Units (MU) with different make Bay Control Protection Unit (BCPU). In one of the feeder ABB make BCPU communicates with NARI make MU and the other feeder has NARI make BCPU which communicates with ABB make MU.

C. Different makes of RTUs integration

In addition to various makes of Merging Units and Bay control Protection Units, Remote Terminal Units (RTU) from Siemens and ABB were also used to integrate the 415 volt boards with the digital substation. RTUs not only used to transfer the status signals, it also used to control the feeder remotely from control room by operator who issues control.

D. Different makes of ethernet switches

Backbone of the digital substation is communication network. To avoid dependency and break the monopoly, two different makes of Ethernet Switches, one from Siemens and other one from IS5, were used in station bus and as well as in process bus which forms the redundant communication network.

E. Integrated with Cloud

Generally, substations are connected with central remote control center like state load dispatch center, national load dispatch center, etc., for remote monitoring & control of all the stations. In addition to connection with remote control center which is located inside L&T campus itself, L&T's digital substation is also integrated with cloud. The substation data is written on cloud with help of edge gateway through MQTT/OPC UA pub-sub protocol. This data is used for generation of reports on performance of the digital substation.

IV. CHALLENGES FACED

A. IEDs PRP function limitation in process bus

One of the bay control protection unit make is not having PRP function in process bus, due to which the bay control protection unit and merging units are communicating directly. Once new firmware released PRP function will be implemented.

B. Sample value failure error

"Sample value failure" error message popped up in one of the bay control protection unit and merging units combination when there was loss of time sync pulse and rebooting of IEDs occurred. This issue is resolved as below. Firstly, master GPS is configured as prime time synch device, master clock function of GE make BCPU is configured as secondary and ABB make time synch unit is configured as tertiary time synch device.

C. IEDs PTP time sync limitation

In one of the BCPU and MU time sync happens using PTP Power Profile (C37.238) instead of Power Utility Profile (IEC 61850-9-3), due to which the one set of IED is not in sync with other devices.

D. Existing data concentrator

Existing substation has approximately 30 numbers of multifunction meters with data concentrator which is connected with existing L&T Campus Energy Management Centre. To integrate the existing meters with Digital Substation Automation system, existing data concentrator had to be replaced with high end model with capability to communicate with multiple master. The data concentrator was supplied with single port with multi-master functionality which was still not communicating the existing L&T Campus Energy Management Centre and Digital Substation. This issue was resolved by replacing Data Concentrator with Dual Port.

E. Retrofit of HT (High Tension) Bays

One of the major challenges faced in implementing the digital substation is replacing the existing protection relay with Digital Substation components. Critical work to be carried out is to replace the existing front door of HT switchgear with the new door after office hour only. Limited time was available to carry out removal of existing wiring, components, existing doors, mounting of new doors, new components and existing equipments, re-wiring, testing and charging the bay. The challenge faced while retrofit the panels was well managed by having proper power back-up, Shutdown after office hour and follow all safety precautions.

Fig. 2. L&T's Digital Substation

V. FEATURES OF L&T'S DIGITAL SUBSTATION

A. Interoperability

Interoperability between various make IEDs is achieved through IEC 61850 Protocol. Thanks to the internal organization to frame the standard which helps user to have access to open system and to achieve integrated communication solution for substations. Interoperability reduces the complexity and ensures long term expandability.

B. Load Shedding

Loadshedding is achieved based on frequency and power. Load shedding logics were developed in RTUs. Four stages of configurable load shedding were implemented, i.e., 3 stages of frequency & utility load based and 1 stage of frequency & diesel generator (DG) load based logics were developed.

C. Network Management System

This helps to understand the traffic flow in the network by monitoring the data flow using SNMP (Simple Network Management Protocol). In this application all the ports of station bus and process bus switches were monitored continuously by measuring Port Speed and status of Ports. Central Processing Unit (CPU) of the network switches were monitored by measuring CPU usage, remperature, random access memory (RAM) capacity and available RAM. Power supply status of network switches is also monitored.

D. Cyber Security

IEC 62351 and NERC CIP 005 recommendations are followed in digital substation [12]. Substation secure zone (electronic security perimeter – ESP) is created by ensuring the single point communication to external zone through router cum firewall (electronic access point - EAP). Substation will have access to the external zone in secured manner to send and access the data through IEC-60870-5-104 for control center communication, MQTT Protocol for cloud communication and internet for virtual monitoring. Every external zones are communicated through designated ports, which will secure the network from unknown traffic and attacks.

Hardening features are implemented like disabling unused port, disabling or removing of unnecessary user accounts, services and programs, restricting changes to files system and operating system and password policies. Both hardware and software (windows operating system based) firewalls are implemented in the system. Other security feature like role based access control (RBAC) allows restricted access to the system, blacklisting through Antivirus and Whitelisting through app locker which is the feature of Windows operating system are also deployed for securing the L&T's digital substation.

E. Asset Management

The cloud data is used for performing the analysis on the assets used in the digital substation. In asset management performance of the asset is monitored based on the load pattern derived from the cloud data. Asset management system is useful in planning, maintenance and utilization of the asset in better way.

VI. Conclusion

Implementation of digital substation in brown field substation brings more benefit to users like maintaining the assets at less cost, better way of monitoring, supports in decision making, keeps track of the past data, optimizes the run cost by effective utilization of the assets, avoids OEM's dependency at equipment level, secured system operation, remote monitoring & control, space for future expansion.

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Implementation of Smart Pillar Box in LT Distribution System

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Abstract: **CESC LTD. being a profitable, consumer-oriented power distribution utility catering service to urban area of nearly 567sq km, it is our duty to meet the expectation of our esteemed consumers having a LT consumer database of 33.7 Lakhs approx. We intend to clinch this vision by achieving better efficiency in our LT distribution network operations. Our database indicates that there are some perennial problems faced by the utility while catering power distribution service in a metropolitan city like Kolkata. Some of these have been identified such as hazard of electrocution and electrical shocks to pedestrians as well as the employees in waterlogged streets, Pillar Box (PB) getting alive or occurrence of floated neutral and incidents of frequent fuse failure leading to consumer grievance and revenue loss. Moreover, long duration of interruption increases the SAIDI and in turn revenue loss which is detrimental for the company. This paper proposes various mitigation strategies for the aforesaid problems such as installation of water level indicator and PB alive/N-Float sensor which mitigates the incidents of electrocution and electrical shocks, while installation of HRC fuse fail indicators [both for *Distribution Transformer (DTR) and PB*] reduces consumer interruption time there by mitigating consumer grievance and revenue loss issues.**

Keywords: smart pillar box, remote monitoring, fuse failure, sensor, SAIDI, mitigating consumer grievance and revenue loss.

1. Introduction:

The LT poles, overhead conductors, underground cables (1.1Kv) and the distribution pillar boxes are the key assets of our LT Distribution network. Since the network in any urban city is very complex, the same complexity is evident in our LT distribution network catering supply to approximately 33.7 lakhs consumers. Thus, to reduce this complexity and there by achieving a better efficient network we went for the modification of pillar boxes and in the process making the pillar box a smart one. The solutions that are being aimed at not only mitigates the present problems but also helps in real-time monitoring of the network.

2. Symptom Pain:

I. **Submergence of Pillar Box in Waterlogged Area:** Our city, Kolkata faces the perennial problem of prolonged water logging at some of its low-lying areas. The level of accumulated water, when sufficient to reach the height at which cables are terminated on to the pillar boxes, creates a chance of electrocution, thus presenting a potential hazard for the general public at large.

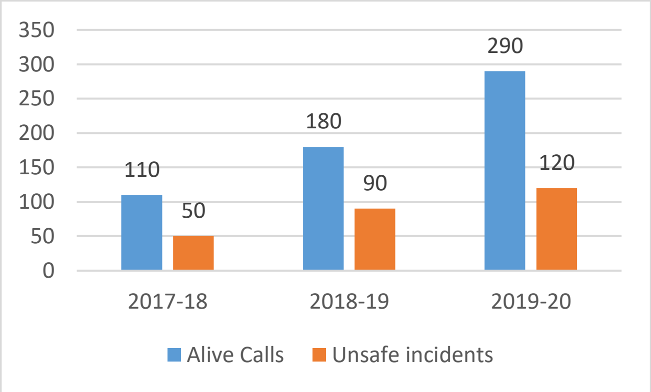
II. **Revenue Loss Due to Outages and Longer Time for Restoration of Those Outages:** From the historical data it has been found that **transformer LT HRC fuse failure and pillar box HRC fuse failure is two of the major reasons for power outages in our LT system**.

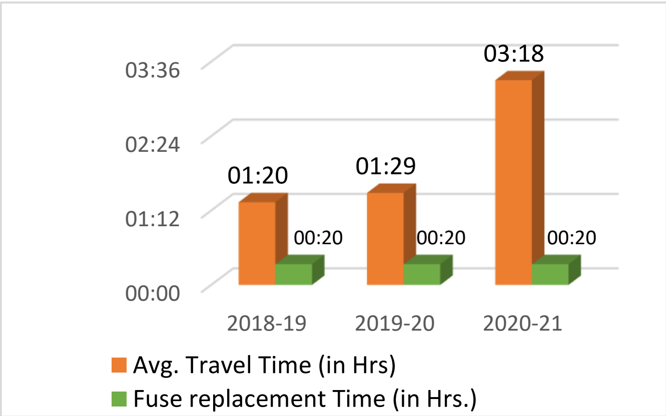
- **Delay In Restoration of Transformer LT HRC Fuse Failure:** In DTR LT HRC Fuse failure the restoration time increases due to multiple movement of the Depot Technician. First movement for identifying the probability of DTR LT HRC Fuse Failure. Next to restore the supply by changing the LT HRC Fuse.
  Thus, for restoration of a transformer LT HRC fuse call, it takes around 2 hours approximately.

  Delay In Restoration of Pillar Box HRC Fuse Failure: In case of pillar box fuse failure the depot technician follows the bottom-up approach for identifying the pillar box (where the fuse has blown) which increases the time of consumer interruption. Then they replace the fuse and restore the supply.

3. Problem Measurement:

- The increasing trend in number of PB alive calls and unsafe incidents is evident from the following graph, which implies the urgent need of incorporation of some preventive/proactive measures.



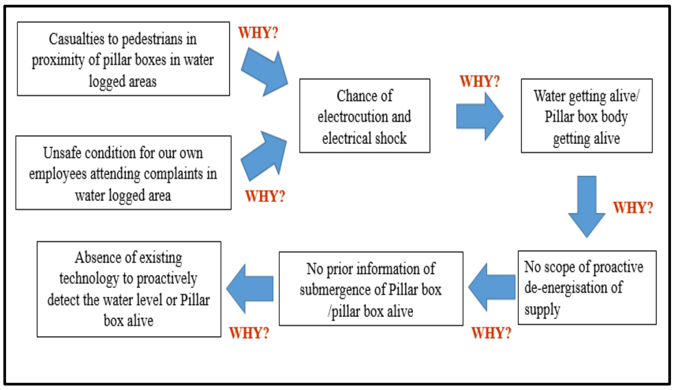


- The increase in ART of PB fuse calls due to time taken for pinpointing the fault is evident from the following graph.

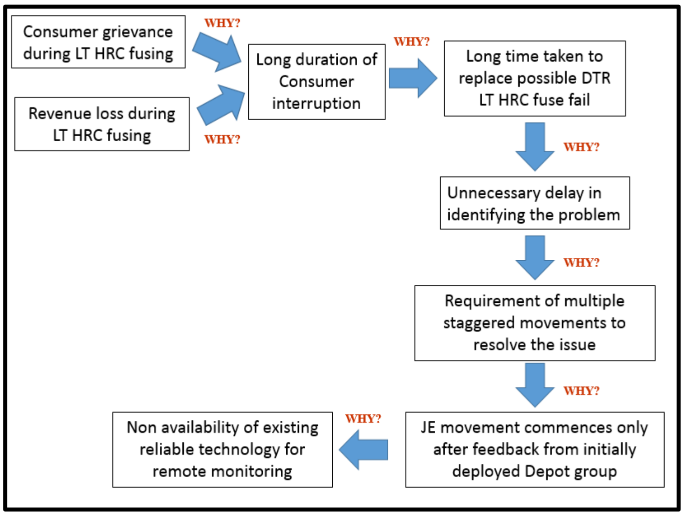
- During DTR LT HRC fusing it has been observed that over the previous years the ART has been continuously increasing mainly due to the staggered movement of our depot technician and foreman there by increasing the overall travelling time.

4. Root Cause Analysis:

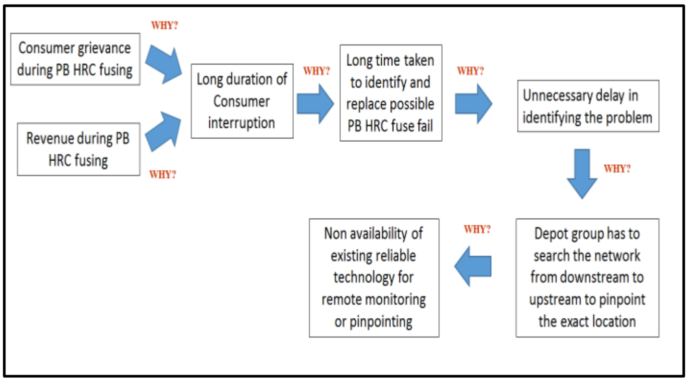
➢ **Submergence of Pillar Box in Waterlogged Area**



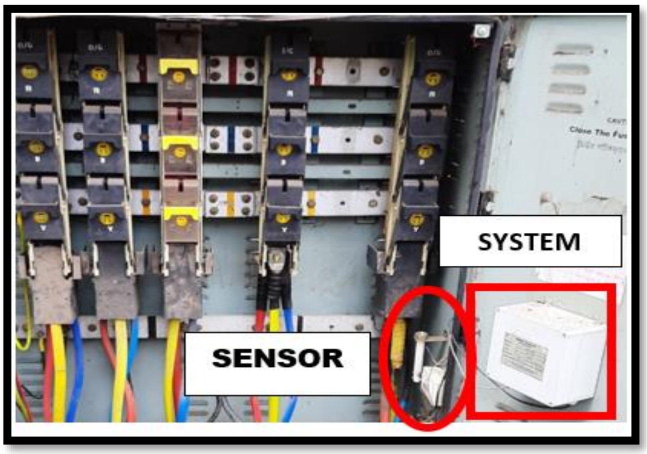
- **DTR LT HRC Fusing**



- **Pillar Box HRC Fuse Failures**



5. Finally Implemented Solution: Water Level Indicator



The scheme uses commercially available Level sensors (Containing Electronic Unit, a conductivity probe and SMS module and Battery) and GPRS based communication. The sensors detect the water level and triggers the generation of an emergency docket in the CRM system before the water level reached the danger zone. The docket is then allocated to the nearest Emergency Depot group to ensure prompt de-energisation of the pillar box. Once the water level subsides, the generation of another docket is triggered to ensure prompt resumption of normal service.

II: Finally Implemented Solution: <u>DTR LT HRC Fuse Failure Indicator inside Pillar Box::</u>

The device measures the voltage of the incomer cables (from DTRs) of the feeder pillar boxes available at all point of time. Whenever there is a missing of voltage presence in **one or two of the phases**, an SMS will be sent to selective recipients (Stakeholders) and a CRM system had already been developed (awaiting system launch) which will convert the SMS into a docket. So that we can proactively locate the possible DTR LT HRC fuse fail.

- Thus, the staggered travel time as well as the restoration time

was reduced to 30 mins instead of 90 mins.

DTR LT HRC Fuse indicator at BBD Bag D/S O/T No.-2

- The device will communicate with specially designed software through LTE mode of communication and will provide the LT HRC Fusing information.

III. Finally Implemented Solution : Installation of Pillar Box HRC fuse fail indicator device:

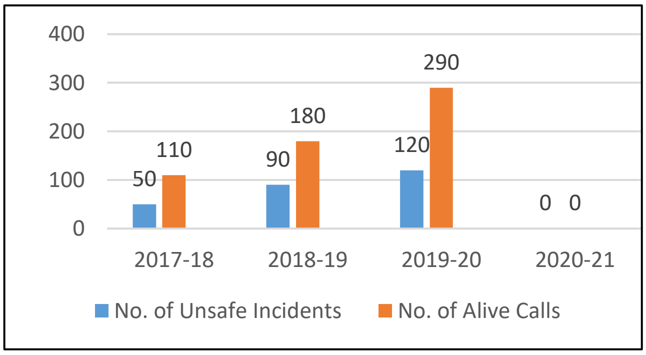
The device measures the voltage (at cable thimbles inside Pillar Box) and current (using ring CTs around the cable) available at all points of time. Whenever voltage/current presence is missing in **one or more phases**, an SMS will be sent to selective recipients (Stakeholders) and a CRM system had already been developed which will convert the SMS into a docket. So that we can proactively locate the possible Pillar box HRC fuse fail.
The device will communicate with specially designed software.

Added Advantages of this scheme:

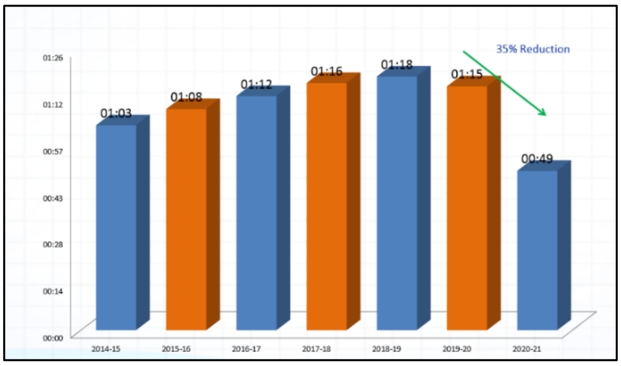
- ✓ Easy identification of cable fault location.
- ✓ Identification of overloading of cables a
- ✓ Proactive determination of high load centres

7. Tangible Gains:

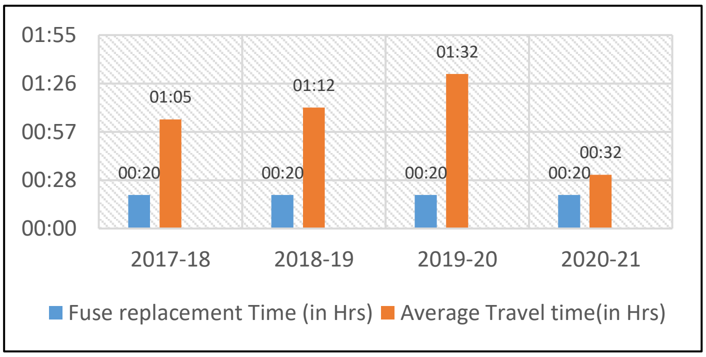
- After installing water level indicators in 400 Pillar boxes, **NO** alive calls of unsafe incidents were docketed for these pillar boxes. The following figure represents the number of alive calls and unsafe incidents for the specified 400 pillar boxes.



- With installation of PB fuse fail indicators, the ART (Average restoration time) of PB fuse calls has decreased by 35% from 01:15 Hrs in FY 2019-20 to 00:49 Hrs. in FY 2020-21 as reflected in the following graph. This data shows the efficacy of the method



- With installation of DTYR LT HRC fuse fail indicators, the ART (Average restoration time) has decreased by 47% as reflected in the following graph.



10. Conclusion:

This project conglomerates the different problem scenario of a LT Distribution network comprising the distribution pillar box. The team has made an effort to resolve the issues with smart cost-effective technologies available and used those sensors/devices to achieve substantial tangible and intangible benefits.

The smart devices utilised in a modern day CESC Pillar Box can easily categorised the Pillar Box into a Smart Pillar Box which is cost-effective, consumer friendly with installed safety devices.

Dynamic Notification Process for real-time updation of Consumer with Network using advanced integrated digital platforms

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***Abstract* — To envisage the Smart Grid vision, mapping consumers with electrical equipment is a prerequisite for a DISCOM to serve world-class operational and commercial services to its consumers. Hence, timely updation of consumers in the system holds greater significance because consumer updation task on an electrical network is a dynamic affair and not a static one. Incorrect consumer connectivity with network will lead to delay in identification of fault location, energy audit data mismatch and incorrect calculation of Reliability parameter. Tata Power-DDL with its 20 years of successful experience has tested and developed a dynamic process to update consumers at High Tension (HT) & Low Tension (LT) level through user-friendly digital channels. For updation of HT Network, segregation has been done in SAP application based on work profile for ease of Field Officials – data correction, updation of automated network and updation of non-automated network. Upon successful submission of request, Geographical Information System (GIS) creates a Common Interface Model (CIM) having xml (attributes of network) and gml (geographical latitude - longitude coordinates of network) file in GIS Application for introduction of changes done at site in Advanced Distribution Management System (ADMS). For instant updation of LT Network, LT Notification application has been developed and is integrated with Field Force Automation for Field official to takes Permit to Work (PTW) and updates network connectivity in ADMS. Dynamic mapping of consumers with network/equipment is a fundamental block for any Utility aspiring to become Smart for providing 100% transparency in service delivery to its consumers.**

Keywords —DISCOM, ADMS, FFA, GIS, SAP

I. Introduction

Tata Power Delhi Distribution Limited [Tata Power-DDL] is a joint venture between Tata Power and the Government of NCT of Delhi with the majority stake being held by Tata Power Company (51%). To ensure reliable power supply and to provide best in class service to its consumers, Tata Power–DDL has implemented several world-class technologies such as Advance Distribution Management system or ADMS which replaced the conventional SCADA-DMS-OMS system with features like integration with Geographical Information System (GIS) for accurate connectivity of consumers with electrical equipment through Notification System. For a DISCOM, an updated and synced electrical network in ADMS (SCADA+DMS+OMS) w.r.t Field plays a crucial part in maintaining Reliability and Consumer Satisfaction. The Network updation process in GIS starts from the time when a Field user raises a request to add/augment/remove/modify an equipment/network through SAP for HV and MV network and through LT Notification Portal and Field Force Application for LV network. Tata Power Delhi Distribution Limited has developed a robust Network Updation process and has ensured user compatibility and acceptability using digital technology adoption.

II. Importance of Network Updation for DISCOM

- *Safer Operation*

The major significance of Network Updation is to ensure Safety in work operations and switching tasks for Load back feeding. A synced network between ADMS and Field acts as a safety check before every operation is done at site through network connectivity verification. At the time of issuance of Permit To Work (PTW), Permit Issuer verifies Network State in ADMS with the details provided by Permit Requester at Field and takes necessary action after authenticating details.

- *Real-time Calculation of Reliability Parameter*

As per Regulatory guidelines, every Power Distribution company needs to maintain and store system-driven digital reliability data on parameters like SAIDI, SAIFI, and CMI, etc. In a digitally integrated system (ADMS+GIS+SAP+FFA), the actually affected consumer gets reflected in a given outage. It also helps in providing outage information to affected consumers via SMS and email with details of the Estimated Time of Restoration (ETR) and the real-time status of work being done at site.

- *Consumer back feeding*

In case of an outage, actual consumer connectivity with the network helps Control Room Operator to check loading on alternate sources for back feeding using Distributed Power Flow (DPF) Application and make back feeding provisions accordingly.

- *Asset Performance monitoring through Advance ADMS applications*

Advance applications like Automatic Power Restoration System (APRS), Distribution Power Flow (DPF), and etc. work on the simulated network. Hence, the synced network helps in faster restoration of the affected area as per the real-time scenario. Updated Network also helps in monitoring the performance of any asset connected at sites w.r.t electrical parameters like Current, Active Power, Reactive Power, and Voltage on real-time basis.

- *Accuracy in Prediction logic*

Outage Prediction at LV Voltage level works on two parameters i.e. call and network. Based on consumer connectivity with the electrical network, Advanced Distribution Management System (ADMS) makes prediction of the possible faulty tripped device after receiving 2-3 consumer complaints using consumer-network connectivity. It then sends Outage details to all affected consumers connected to that predicted device via SMS/email/Mobile App. Hence, the accuracy in predicting the correct affected device relies completely on actual consumers connected to it. This prediction logic helps DISCOM to identify faults/affected device within seconds of receiving initial 2-3 consumer complaints, hence reducing Mean time to Restore (MTTR) and it also further provides outage information proactively to other affected consumers. It also helps in an auto merging of calls with the respective outage if the consumer registers complaint forcefully thereby reducing the manual effort of the Field Engineer.

III. NETWORK UPDATION PROCESS

Network update in TPPDL is majorly classified into two categories i.e.

a) HT Network

b) LT Network

In general, the HT network updation process is further classified as per voltage level – 11kV, 33kV, and 66kV. For the LT network, the voltage level is classified as 415 V and below. In addition to it, the Patch Management process has been deployed to push updated network connectivity from GIS to ADMS.

- *HT Network Update Process*

For HT Network, Tata Power-DDL has deployed SAP Notification process to capture Network Change requests from Field Users. In this process, Field Engineer working in Zone/Project-related work creates a SAP notification, differentiated on the basis of Automated or Non-automated work type. Based on selected Notification Type, SAP Task and auto-intimation mail are triggered to respective departments for necessary information.

This notification then gets processed to the next level for feasibility check of the network getting updated. This work is done by Geographical Information System (GIS) department to check and compare the present network condition in the GIS application with proposed details given in the notification. If details submitted in System/Network Alteration are correct, then it further gets processed to Zone/Project field team for taking permission for creating and availing outage.

After finishing the work at the site, Zone/Project Team finally changes the status of notification to Complete (COMP).

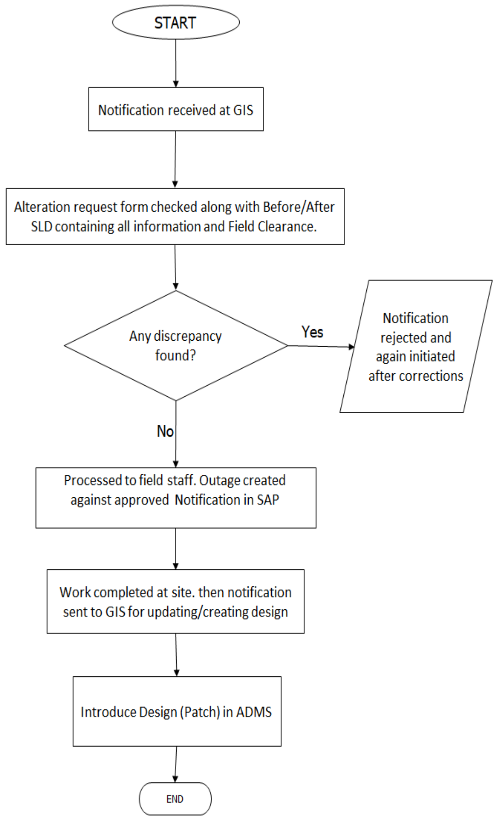

Fig. 1. Flow diagram of network update process

The GIS department then updates network change details on its application. From there, it gets updated in the GIS design map and at the same time, the updated network patch comes to the ADMS database system through Common Interface Model (CIM). CIM further contains 2 types of files - XML (Extensible Markup language) for equipment's details and GML (Geographical Markup Language) for geographical details of equipment that are getting added/removed/modified in the Field network. These 2 files then get converted into Data Manipulation Language (DML) file in the ADMS system as per given system compatibility. This network change data comes to ADMS as Patch.

- *LT Network Update Process*

Tata Power DDL has developed an in-house digitized process for LT network updation. Before implementation of this project, all request for LT Network Change was maintained in General Diary Register at each Zonal Office email, etc. LT change registers are maintained by field personnel who perform network changes on site. GIS updates the network information in the system based on these registers every month or bi-monthly. Occasionally, the GIS department was notified of changes to LT by mail.

LT network change process has been divided into 2 categories - Temporary and Permanent.

For Temporary change, notification request raised by Zonal Field Crew lands at PSC department bin for updation of details in ADMS to sync network as per site condition with the end of normalization of the network back to its previous state. Zonal Field crew also receives reminder mail and pop-ups on the application when the respective Notification request is about to expire.

For Permanent changes, notification request raised by Zonal Field Crew goes to the GIS Department bin for updating the network in the GIS portal. It then comes to ADMS through the same process as adopted in HT network update i.e. through CIM files and patches.

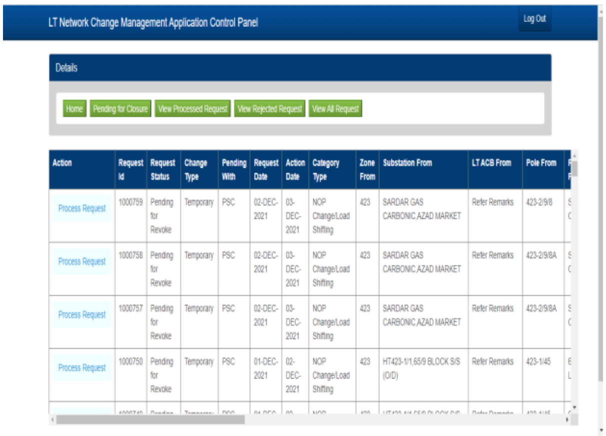

Fig. 2. LT Network Change Management Portal for LT change

- *Patch Process*

Patch deployment is done for respective network changes, both at HT and LT level. The Patch works on network override methodology wherein the old network patch gets replaced with a new patch for changes done at the site. Before introducing a patch in ADMS, the user has the option to check and compare the new details with the previous one. If the given changes are as per the notification request, then the patch is made ready and get introduced in ADMS. Otherwise, if it is not as per the notification request, then correction mail is sent to GIS for creating a correct design. Quality Check (QC) at this stage ensures the Network state in ADMS is maintained as per Field configuration.

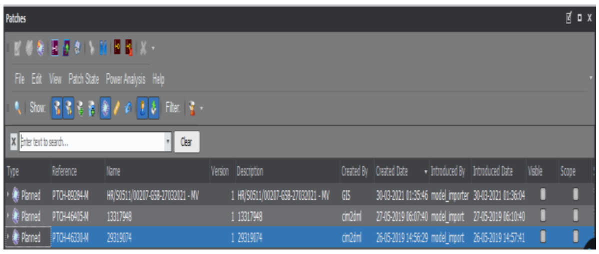

Fig. 3. Patch created for network update in ADMS

IV. Use of Smart Meter in Network Updation Process

Real-time network update plays a crucial role in enhancing consumer delight through the delivery of world-class service and calculation of correct reliability figures. The introduction of Smart meters in the system has significantly improved old Network mismatch cases.

Whenever an outage occurs in the distribution network, Smart Meter triggers an automatic call-in ADMS system which then directly informs field staff through FFA (Field Force Automation) about an outage.

This Smart Meter integration with ADMS also helps the Field crew to accurately identify the actual affected circuit, thus avoiding time spend patrolling for fault identification. It is also configured to send outage information to consumers, proactively, hence significantly reducing call landing at the Customer Care Centre.

V. Benefits of Network Updation

- *BENEFITS TO ORGANIZATION*

Tata Power DDL, being a benchmark Power Distribution Utility, has always developed and deployed emerging technologies to exceed the expectations of its stakeholders. Network Updation Notification Process is one such project.

If the connectivity of consumers with electrical equipment is mapped correctly, then it could be used for multiple important works like tracing consumers, finding the route of a network, faster consumer restoration, future Network planning based on a load growth trend, etc. All distribution utilities are moving towards a concept of a smart grid. Tata Power DDL is assisting 24 Power Distribution Utility in India in achieving their target to become Smart Utility.

TABLE I.

S No.	**Network Update benefit**		
		Before	***After***
1	Network and Equipment mapping accuracy	72.80%	99.84%
2	Network update cycle	10 days	3 days

Before the implementation of this process, Network and equipment mapping accuracy was 72.80% and now it is 99.84%. Also, the network update cycle time has reduced significantly from 10 days to 3 days.

- *BENEFITS TO CONSUMER*

Consumer satisfaction is the core of the innovation strategy for Tata Power DDL. This will give Tata Power DDL an upper hand when Consumer Portability will come into effect after Business Deregulation. In such a scenario, a stronger consumer offering will allow the organization to expand and increase market share. If a consumer is correctly mapped then they will get correct information about their estimated time of Restoration (ETR) of an electrical outage.

The network display window of FFA includes a GIS-enabled map of the network showing the location of the fault and allowing the crew to choose the route based on the proximity and severity of faults. Here, correct consumer connectivity ensures faster and quality delivery of services to its consumers.

V. Conclusion

Tata Power-DDL's innovative approach through the development and adoption of the latest technology has been a game-changer in building consumer trust and enhancing service delight. Implementation of integrated technology like Network Updation Notification Application will play a defining role in speeding up the coordination with other service utilities in a given area under Gati Shakti Mission for delivery of world-class service to citizens.

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Digitalisation of Power Transformer Monitoring System

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Abstract -- Power transformers are one of the most critical and valuable assets of a power system. Their efficient operation is necessary to supply uninterrupted and quality power to all the consumers reliably. Hence, they require integration of digital and smart grid technologies. Proper condition monitoring of the transformers will reduce the chance of sudden breakdown or failure and thus the effective service life of the transformer could be extended. This paper proposes the implementation of IoT based Remote Monitoring System with the following features :

i. It utilizes the existing resources from transformers and recommends installation of sensors for measurement of parameters previously unavailable

ii. The continuous measurement data are stored in a protected cloud storage system which can be accessed anytime

iii. Transformers, enabled with digital capabilities, allow remote monitoring and data analytics of its vital parameters in real time

This method of Digitalization is an attempt to upgrade the existing transformers to a smart one which, as an integral part of the smart grid will provide feedback about the power system network and the transformers themselves and in the process, enhance the reliability and enable higher utilization of grid assets and power network.

Keywords: Power transformers, remote monitoring, IoT, sensors, digitalization, data representation

I. INTRODUCTION

The country's power system is witnessing disruptive changes. The system is becoming extremely complex, with the integration of renewable sources and new demand loads. Moreover, ageing infrastructure and a greater focus on performance and safety targets are also posing challenges.

- ✓ Transformers are the centerpiece of electricity networks and hence, they immediately require integration of digital and smart grid technologies. Digitalization of transformers ensure efficient and cost effective power handling. Transformers, enabled with digital capabilities, allow remote monitoring and data analytics of its vital parameters in real time. This will enhance reliability and enable higher utilization of grid assets and power networks.
- ✓ The digitalization of asset management through IIoT (Industrial Internet of Things) helps organize the data for optimum utilization and management of assets. IIoT brings together industrial machines, advanced analytics and people. IIoT is the network of a multitude of connected devices that monitor, collect, exchange, analyse and deliver valuable new insights. These analytics-based insights are driving smarter, faster operational and business decisions for power generation companies.
- ✓ Internet-enabled condition monitoring systems can help analyse remotely collected real-time operational data of different transformers. **Machine learning** can be used to track transformer health and detect failures in advance and minimise repair downtime.

II. NEED FOR REMOTE MONITORING SYSTEM

With increasing demands and need for more power transformers, it may not be possible in near future, to completely monitor each and every transformer physically. So, we intend to go for remote monitoring system of power transformers. This system offers several advantages:

- ✓ Remote monitoring is comprehensive – every device can be monitored and supported remotely. Additionally, it can provide automatic updates and alarms.
- ✓ Remote monitoring collects system statistics over time. When viewing this data in monthly or quarterly reports, long-term trends can be identified, even before they reach levels that would trigger an alert.
- ✓ This system is more efficient than manned systems – it operates automatically without any failure due to unconsciousness.
- ✓ This system could be used for real time data monitoring of different types of loads.
- ✓ Remote monitoring system may be an economic and reliable method for preventive maintenance of the transformers.

III. STEPS IN IMPLEMENTATION

a. Selection & Measurement of parameters:-

The first step is to identify the parameters (physical and electrical), that affects the condition and health of an operating transformer and to measure them. Moreover, selection of parameters also depends on cost as the target is to implement a cost-effective system. The data for the parameters which are available from SCADA system, Control room or Online monitoring reports, are gathered without extensive measurement procedures.

Parameters (For power transformers)			
Already available		**To be measured using sensors**	
Parameter	**Source**	**Parameter**	**Sensor type**
Winding temperature	WTI repeater	Vibration level	Vibration sensor
Tap position	SCADA system	Conservator Oil level	VGA camera (Photo of MOG dial)
Voltage (LV & HV side)	SCADA system	Top tank temperature	Temperature sensor
Load (Amps)	SCADA system	Bottom tank temperature	Temperature sensor
Hydrogen level in oil	Online Hydrogen sensors (For few transformers)	Humidity inside breather	Humidity sensor
		Pressure inside breather	Pressure sensor
		OLTC motor current	Current transformer

Table-1: Measurement of parameters for Power Transformers

b. ***Transmission and representation of data:-***

The data of the parameters measured through sensors are transmitted over internet via a GSM/GPRS based module to a cloud storage known as **CIS (Cloud Integrated Storage)** application. The data already available from SCADA etc. are directly sent to the cloud storage. The data from cloud storage are then sent over internet to a server so as to reach the user end.

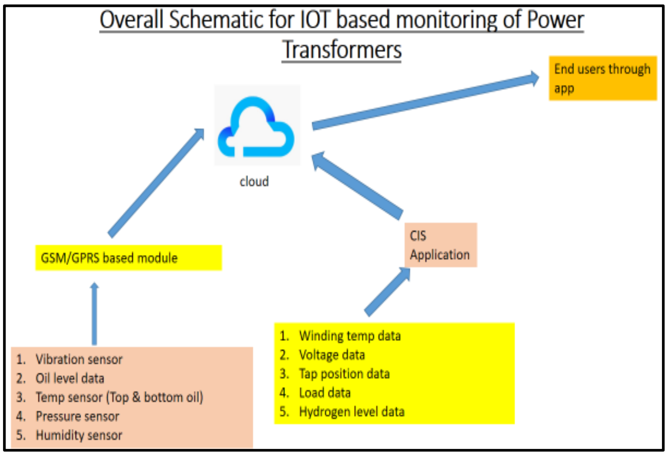

Figure-1: Schematic for IoT based monitoring system

IV. DATA COLLECTION & CODIFICATION

The data so collected has to be represented in a proper manner so as to represent the operating condition of the transformer. Data representation involves data-table, graphs, colour codes etc. to have a clear visual identification of operating conditions of the transformer.

The suggested codification of few of the parameters are given as test case:

Parameter	Colour code		Notification
Top oil temperature	**Temperature range(°C)**	**Colour code**	When temperature exceeds 70°C
	<= 60	Light green	
	60-70	Orange	
	>70	Red	

Table-2: Codification for Top oil Temperature (Power Transformer)

Parameter	Colour code			Notification
Voltage (HV & LV side)	**% increase from rated value**	**% decrease from rated value**	**Colour code**	When voltage increases beyond 9% from rated value Or, Voltage falls below 7% from rated value
	<= 7	<= 5	Light green	
	7 – 9	5 – 7	Orange	
	> 9	> 7	Red	

Table-3: Codification for Voltage level (Power Transformer)

V. DATA TRANSMISSION & STORAGE

The data of the parameters obtained either by measurement using sensors or from CESC SCADA system and online monitoring reports, are required to be transmitted to the end users.

The block diagram of the transmission and storage system undertaken is given as:

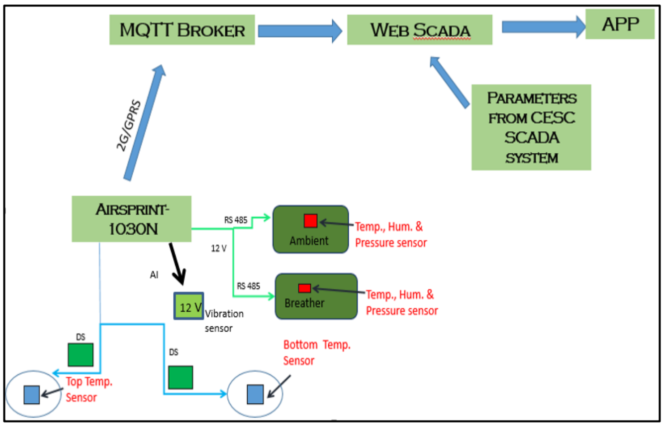

Figure-2: Data transmission and storage system for Power transformers

The steps involved in the system shown above are:

- ✓ **Sending sensor data to cloud**-
  The data measured using different sensors are sent to a gateway unit known as Airsprint-1030N which is a rugged GPRS based telemetry device cum gateway unit, meant for sending digital event/alarm, analog values and Modbus RTU device data to the cloud in secure encrypted lightweight MQTT protocol. It acts as a RTU (Remote Terminal Unit) which gathers data from the equipment and transfer them to the cloud.

- ✓ **Storing the data**-
  The data sent through the MQTT brokers, get saved in Web SCADA which is a cloud storage system with highly scalable storage space.

- ✓ **Representation of data**-
  The cloud storage system is protected. The users need to login using password to get access of the data. The data from the cloud may be brought into APP (Mobile application) through API (Application Program Interface). It's a technical development environment that enables access to another party's application or platform.
  The data may be represented in both tabular and graphical format as shown ::

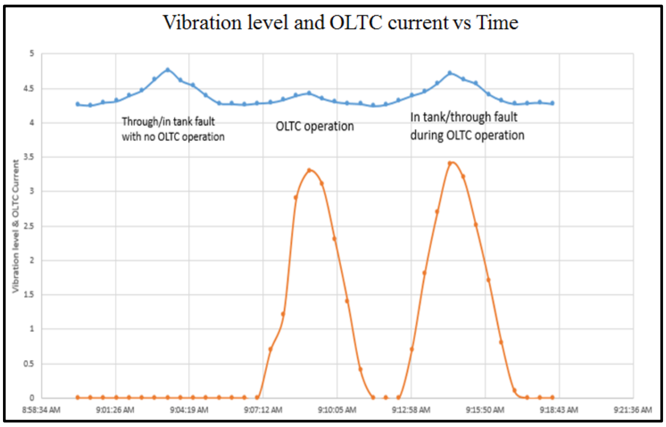

Figure-3: Sample Graph

VI. PATH FORWARD

In future, we may progress with further analysis of the data collected and avail much more benefits from them.

- Standard reference values may be set for each parameter at different times of the year which may be used for comparison.
- Abnormal values may be archived for further analysis and to find cause of discrepancies
- Improvement of performance and extension of life and reduction in maintenance cost

VII. CONCLUSION

In this paper, the method of implementation of Remote Monitoring of Transformers has been described. We have tried to produce a reliable, cost effective and beneficial IoT platform that would help any utility to monitor the huge number of Power Transformers at any time and from anywhere. The data stored in the cloud are of limited in nature. If required, the storage space can be extended as the cloud space is scalable.

IElectrix Project – Installation and commissioning of the Indian demonstration in Delhi

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Abstract

IElectrix is a response to the Horizon 2020 Call of the European Commission: "Integrated local energy systems", which experiments 1 demonstration in India and 4 demonstrations in Europe.
The Indian demonstration is set up in Delhi to explore innovative solutions allowing the implementation of "Local Energy Communities" using local PV and storage for self-consumption approach, and resiliency of the distribution of the electricity power.

The solutions that will be experimented in the Indian demonstration are based on innovative equipment and systems designed and manufactured in Europe. Therefore, after having shipped the configuration to Delhi, all the different equipment have been installed and the commissioning activities have started in the demonstration site, which is the St. Xavier Sr. Secondary School substation in Delhi.

Civil and engineering works have been carried out on site to allow the installation of the equipment that have been deployed within the project.

The proposed paper will provide a technical description of the installation and commissioning activities that have been carried out during the second half of 2021.

Keywords — Microgrid, Substation, Smart transformer, RTU, BESS

I. Introduction

The Shakti demonstration, located in Delhi, implements a microgrid solution being deployed in the St. Xavier secondary substation and its associated low voltage (LV) grid. The energy community is made of a large school with 3,000 students, a community center and several households and buildings, with 200 kVA power production provided by photovoltaic (PV) panels installed on the roofs of the school and neighbourhood building.

This is a normally connected microgrid with islanding capabilities. The microgrid embeds a Battery Energy Storage System (BESS) of 200 kVA located at the MV/LV substation.

The microgrid would also participate in a demand response program, involving therefore prosumers and consumers of the energy community. After a brief description of the architecture of the microgrid, the aim of this paper is to describe the activities related to the installation and commissioning of the global solution, highlighting all the new activities to be considered with the convergence of the automatization and electrification.

II. Microgrid Architecture

A. Distribution public electrical network

Shakti demonstration is a public electrical network serving to about 40 customers through 3 LV public lines (feeders), with also 3 PV fields, as represented in Fig. 1.

Connection to the medium voltage (MV) network is ensured thanks to a Ring-Main Unit (RMU) which manages the civil lines and ensures the MV/LV transformer protection.

To ensure the continuity of the power supply of the customers while the installation of the substation was on going, the LV lines were disconnected from the St. Xavier's secondary substation and connected to a nearby substation, thanks to network interconnection points.

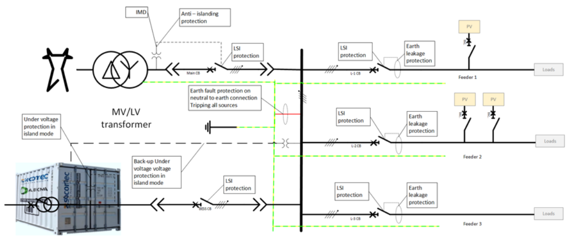

Fig. 1. Electrical scheme of SHAKTI demonstration

B. LV microgrid electrical scheme and protection principles

The new solution provided can work either on grid-connected or island mode, as specified in the on-going new edition 2 of microgrid standard: IEC 60364-8-2.

The connection of the reference conductor (neutral) to the earth is done downstream the main LV breaker. This configuration ensures the same earthing scheme whatever is the voltage source of the LV network.

The earthing scheme of the LV electrical network is TN–S, three phases, four wires. The power supply is distributed up to the customer premises with armored 4-wires cables.

The equipment and people protection are ensured by:

- **Intertrip** protection between MV breaker and LV main breaker.
- Overload and overcurrent protection of connected cables on breakers through Long, Short and Instantaneous (LSI) trip curve.
- Back-up protection is performed by an earth-fault protection on the link of the reference conductor (neutral) with the main earthing terminal of the LV ECC.
- In island mode, a protection is performed by an **under-voltage** protection on the BESS and the RTU.
- In island mode, when the main breaker is opened, the MV/LV transformer secondary is isolated up to the main LV breaker.
- The protection of cables against electrical shock is enhanced using earth leakage protection on the feeders.
- For insulation purposes, energy source breakers are withdrawable.

C. Hardware architecture

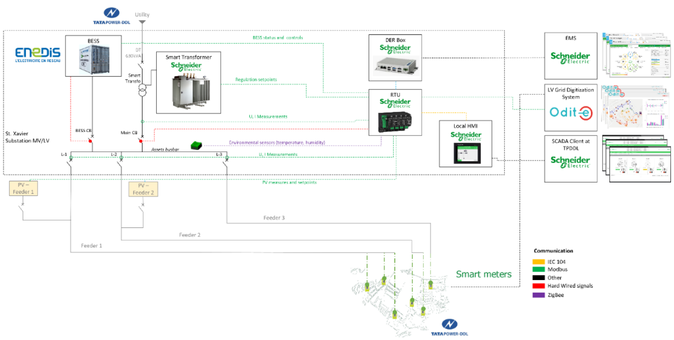

Fig. 2. Overview of Shakti demonstration architecture

Fig. 2 describes the architecture defined for the Shakti demonstrator. A brief description of its components are provided below [1]:

- **Energy Management System (EMS)**, to control the energy resources, composed by a cloud application and a controller on site.
- **LV Grid Digitization system**, to provide services adapted to the real conditions of the Energy Community.
- **Smart meters**, to provide individual measurements from the prosumers and consumers of the LV grid.
- **Supervisory Control And Data Acquisition System (SCADA)**, to visualize and control the different elements of the Shakti demo.

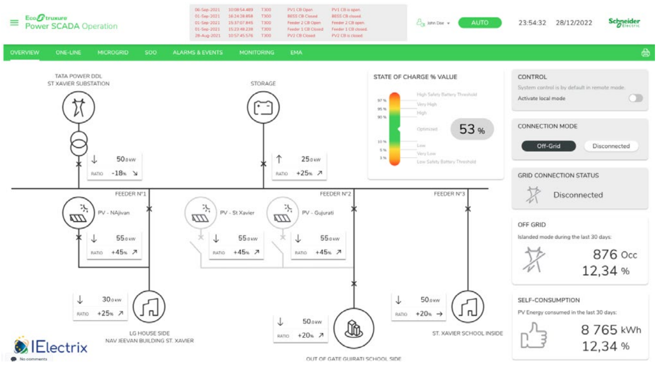

Fig. 3. Example of the SCADA view of the substation

- **Remote Terminal Unit (RTU)**, to monitor and control the LV grid and to interconnect all the elements involved in Shakti demonstrator.
- **Smart transformer**: A self-regulated 630 kVA MV/LV transformer, able to automatically adjust the LV voltage.

Fig. 4. View of the 630 kVA transformer at site.

- **BESS**: A battery system of 200 kVA will help improving network stability.

Fig. 5. View of the BESS container deployed at site.

- **Low Voltage Energy Control Center (LV ECC).** The LV ECC Switchboard is a power switchgear and control gear designed based on the architecture to be implemented.

Fig. 6. View of the LV ECC switchboard

III. INSTALLATION

A. Transport

1) Container crisis situation due to the pandemic:

The shipment of the electrical components happened during a period of global container shortage.

As the pandemic spread out from its Asian epicenter, countries implemented lockdowns, halting economic movements and production [2]. As Fig. 7 highlights, this shortage has significantly impacted World Container Index (WCI).

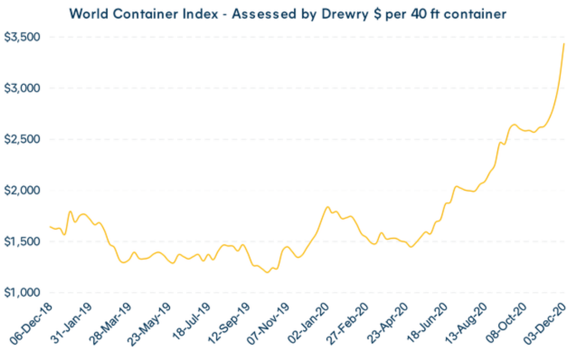

Fig. 7. World Container Index [2]

The Europe to India trade routes have been significantly impacted by this crisis. The equipment reached the demo site with a 2/3 months delay in delivery.

2) Maritime and inland transport of the components

In order to ensure that the equipment reached Delhi undamaged, specific packaging, compliant with the maritime and Indian inland transport conditions, were used.

Fig. 8. Package of the LV ECC

The battery modules were transported through a refrigerated container during the maritime shipment and a cooling truck in India.

Fig. 9. Transport of the components

B. Civil works

To ensure proper storage conditions for the electrical components, many construction works have been carried out at St Xavier's School in Civil Lines, Delhi.

1) Preparation of the site

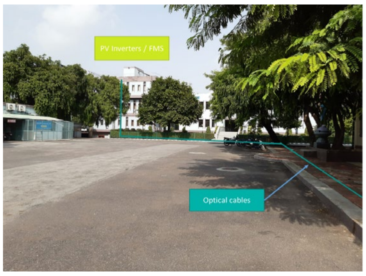

Fig. 10. Optical Fiber trench

Trenches have been built to install the optical fiber, which link the PV inverters on the school rooftop to the LV ECC switchboard.

2) Construction of the shed for the BESS

The Tata Power-DDL civil & engineering teams began by constructing a shed to install the BESS container, to protect it from direct sunrays.

A concrete base was built to protect from the flood and to ease the power and control cabling connections.

Fig. 11. Shed for the BESS

3) *LV ECC and transformer rooms*

The switchgear and transformer rooms were entirely renovated before the installation of the new equipment. The refurbishment work included the pouring of new concrete slabs, the consolidation of walls, the digging of trenches and the enlargement of the switchboard room door to allow the LV ECC panel to pass through.

Fig. 12. Tata Power-DDL St Xavier substation in Delhi

Then, all the components have been properly installed.

IV. COMMISSIONING

This section summarizes the main activities that have been performed during the commissioning phase.

A. *Control wiring*

Some of the control in the developed solution is done by control wiring. For safety purposes, or required by standards, or for time response delay requirements, a direct wiring is done between devices inside the LV ECC or between equipment inside the substation.

1) *Transformer*

The smart transformer is equipped with a digital relay (DMCR) and a pressure valve relief. The DMCR monitors transformer working conditions: oil temperature, tank pressure and level. It provides also safety dry contacts to switch off the MV breaker and power off the transformer, putting it on safety mode. These dry contacts are connected to the RMU of the substation. After the wiring was done, the transformer was powered on and verification was performed on it.

A motor-drive unit has been installed in the smart transformer that allows to adjust the operating position of on-load-tap-changers.

2) *LV ECC*

In case of an opening of the MV breaker, to avoid any power back up to the transformer from the BESS, it is necessary to ensure that the main breaker of the LV ECC is opened. This is done with a dry contact on the MV side, linked with the status of the MV breaker, in series with the power supply of the under voltage release coil (MN coil) of the LV main breaker. When the MV breaker is opened, the power supply of the MN coil is stopped, forcing the opening of the LV main breaker. When MN coil is deactivated, it is not possible to switch on the LV main breaker, either manually or remotely.

3) *BESS*

Regarding the developed application, the interoperability of the LV ECC and the BESS constitutes the main part. And a significant amount of control wiring is done between the two sets of equipment. All control wirings stand on dry contacts to share equipment status and drive carefully both equipment by the algorithm implemented on the RTU. Among the signals shared, there are the main LV voltages upstream the main LV breaker to help the BESS to perform the synchronization for the transition from islanded mode to grid connected mode. These signals are accompanied by the small breaker status protecting these voltage pickups.

All these control wirings were checked during the power on of the BESS and verification of the sequence of operation of the microgrid.

B. *Auxiliary power supply*

One service provided by this microgrid is its ability to provide power supply continuity of service even if a grid shut down is faced. Reaching this performance means to continue to power supply the edge control layer even if no voltage is present on the main terminals. This is done by using an auxiliary UPS (Uninterruptible Power Supply) in both LV ECC and BESS. Nominal connection of these UPSs is behind the main breaker of the equipment. The adopted strategy was then to bypass the main breaker to start the commissioning while the main voltage was not present. Once the auxiliary power supply was on, it was allowed to start with the commissioning.

C. IT communication

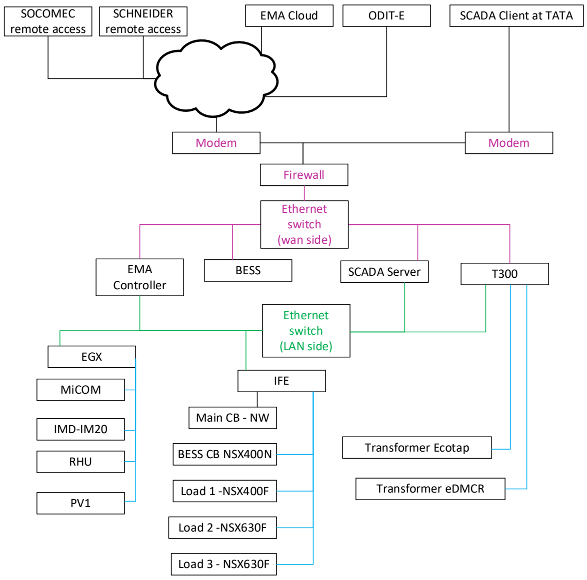

Fig. 13. Substation IT architecture

1) Edge control layer

On the bottom side all the LAN network is depicted (green and blue layers). Embedded in the LV ECC Switchboard, the edge control layer of the microgrid solution deployed on the Shakti demonstrator is composed of the EMS controller, the Easergy T300 RTU and a SCADA system. These elements are responsible of interfacing with other systems and of applying algorithms to properly control the microgrid.

The LAN is used either for the control of the breakers, either for the monitoring of all the digital devices, including all relays and the transformer. For example, while the anti-islanding relay or the earth fault relay are directly wired on the main LV breaker to avoid any time response in case of external trip required, or the transformer is directly wired on the RMU, with the LAN layer the internal variables of the digital devices provide highly detailed status of the microgrid through the SCADA application.

The RTU is the master of the LAN network and provides the information to the applications in the cloud. Easergy T300 RTU has been chosen to perform monitoring, PMS and transition (Sequences of Operation) functions to manage the microgrid.

During the commissioning, verification was done on the quality of the communication between the RTU and each connected device, checking that the communication is performed properly for the defined signals.

Even at the early stage of the commissioning, the communication capability offered by the microgrid solution has helped to diagnosis some issues in the behavior of the devices, and the data displayed by the HMI provided relevant information to identify the strategy to be applied. Two examples to illustrate the obtained benefits from digital devices. The first one is linked with a trip of the PV Box used to monitor the St Xavier PV field production.

The second is linked with some PV curtailment observation thanks to the remote energy measurement provided by the breaker inside the PV box, which is connected to the RTU of the microgrid.

Fig. 14. Schneider Electric EMS view

2) Analytic layer

The top side of Fig. 13 describes the analytic layer and, in this application, for the needs of each stakeholder, five external accesses are provided. Two are related with the remote access of the equipment to allow remote operation and support in case of issues or troubleshooting.

One external access concerns the link of the SCADA server with the SCADA client in the end user premises. The two last IT links are needed to ensure variables sharing with the two analytics algorithms, based on cloud applications, which optimize the microgrid usages according to the electrical status of the microgrid and forecast done, for example weather forecast.

One analytic application is responsible of the EMS uses cases, providing BESS commands in grid connected mode. The other analytic application is responsible of the voltage regulation and provides transformer tap changer position. The AVR (Automatic Voltage Regulation) algorithm is embedded in the RTU.

The objective of the commissioning for this layer is to configure both the modems and the firewall to ensure the communication of the substation with the public network, while ensuring all the cybersecurity aspects of the substation.

3) Cyber security

According to the Central Electricity Authority, the IElectrix demo has to be audited to ensure the respect of the Indian security standards. Globally the system must meet the IEC 62443 standard which is in line with all the electrical components and the IT products.

D. Sequence of operation

The sequence of Operation (SoO) and the transitions between grid-connected mode to islanded mode and reverse is managed by the RTU. Next figure shows a simplified schema of such a sequence of operation.

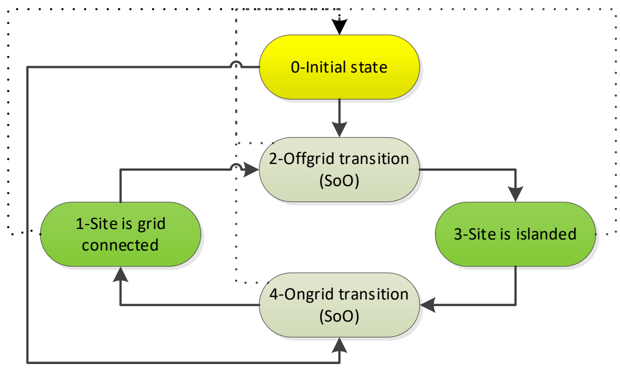

Fig. 15. Sequence of Operation of the microgrid

Once the transformer and the BESS had been powered on, a complete verification of the SoO was done. Firstly, it was performed by controlling the BESS manually, step by step, to make sure that the communication between the RTU and the BESS is working well and that the orders sent by the RTU are the right ones. Secondly, the strategy was to verify the full automatic mode, only playing with the external electrical conditions.

V. Conclusions

At the time this paper was written, the commissioning phase of IElectrix project in India had started with promising results. The remaining tasks for the commissioning are expected to be carried out during the beginning of 2022.

The presence of the European partners was an opportunity to present the operation of this state of the art technologies and to highlight their role on the energy transition. During two weeks, Tata Power-DDL, Schneider Electric and Enedis teams participated in the commissioning phase and progressed in the operation of the transformer and the LV ECC switchboard.

Acknowledgment

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This paper reflects only the authors' view and the Agency and the Commission are not responsible for any use that may be made of the information it contains.

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Accelerating wind power deployment in India through decentralised plants

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***Abstract*— India has installed 40 GW of wind capacity today, constituting ~5% of the total power generation. By 2030, this capacity is expected to reach 140 GW, implying an annual addition of 11 GW starting 2022. Today, 50% of wind capacity is concentrated in Tamil Nadu and Gujarat. These states house the best-resource sites in the country, and therefore, wind power projects (WPPs) located here realise low tariffs. As a result, these two states witnessed a ~10X growth in installed capacity between 2012 to 2021. However, the concentration of WPPs has also led to land and transmission-related stresses that contribute to slowing down the pace of deployment. To achieve the 2030 target of 140GW, India must direct its efforts to diversify deployment in other wind-rich states such as Maharashtra, Karnataka, Rajasthan, Andhra Pradesh, and Madhya Pradesh.**

One solution to diversify and accelerate wind deployment is decentralised WPPs across other windy states. Our study examines the proposition of utilising the existing spare capacity available at state transmission networks for WPPs of up to 50 MW. The paper introduces this concept, highlights the costs and benefits, and discusses elements of an enabling framework for the effective implementation of the proposed model.

Keywords*— *Wind energy, decentralised renewable energy, cost-benefit analysis, power tariffs

I. Introduction

At 40 GW, wind energy constitutes 10% of India's total electricity capacity [1]. A strong generation and manufacturing capacity base and complementary resource profiles with solar makes it a preferred technology to decarbonise India's electricity sector. However, wind capacity addition has been concentrated across two states, Tamil Nadu and Gujarat [2], which host the highest quality wind sites that can produce low tariff power. Further, most of the recent wind projects are being integrated with the central transmission network. The geographic concentration and bidding mechanism have further led to emerging stress on land resources and increased transmission and grid connectivity related challenges [3], thus impacting the ability to reach 140 GW of wind by 2030 [4]. Therefore, it is important to tap the enormous unutilised wind energy potential and underutilised state transmission networks in other windy states through a decentralised deployment approach, even if there is a slight increase in tariffs. The tariff increase can be offset by several benefits that this solution offers.

II. Proposed Model

This section describes the elements of the proposed model for deployment of decentralised WPPs in moderate wind states.

The model is designed to support WPPs ≤ 50 MW on land pockets identified near state transmission networks. Potential off-takers of power from these projects could include state distribution companies (discoms), public sector undertakings, and other obligated entities (Fig 1) in the host states.

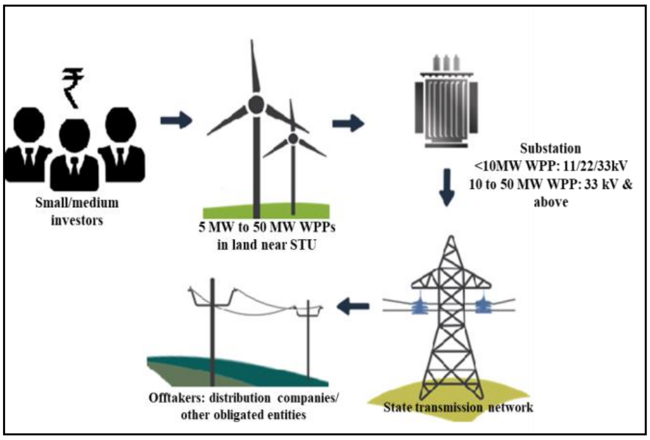

Fig. 1. Schematic for the decentralised WPP model

Maximum and minimum WPP size is proposed as 50 MW and 5 MW respectively, with 5 MW to be located at a single location to be techno-commercially feasible. WPPs of size up to 10 MW could be connected to 11/22/33 kV substations, whereas those beyond 10 MW could be connected to substations above 33 kV [5].

Original Equipment Manufacturers (OEMs), large, medium and small developers, and Micro, Small and Medium Enterprises (MSMEs) can be eligible to participate and set up these projects. Small and medium investors may be encouraged to invest in these projects. Only certified wind turbine models listed in the revised list of models and manufacturers (RLMM) may be allowed.

III. Cost-Benefit Analysis

We estimate the levelised cost of electricity (LCoE) at 14% return on equity (ROE) across wind zones[1]. Table 1 presents the expected average capacity utilisation factor (CUF) and LCoE from decentralised WPPs.

[1]Based on project cost of INR 9 crores/MW, operation and maintenance cost of INR 0.06 crores/MW, with a project internal rate of return at 11.8% and a payback of 11.2 years.

TABLE 1. ZONE-WISE LCoE ESTIMATES

Wind zones	Annual mean WPD (W/m^2)	Average wind speed (m/s)	Expected average CUF (%)	LCoE (INR/kWh)
Zone I	200-250	5.6 to 6.0	**22%**	**4.87**
Zone II	250-300	6.0 to 6.4	**25%**	**4.29**
Zone III	300-400	6.4 to 7.0	**30%**	**3.57**
Zone IV	400-450	7.0 to 8.0	**35%**	**3.06**
Zone V	>450	>8.0	**>40%**	**2.68**

We propose that zones I, II and III with moderate wind speeds across other states are where India can prioritise the deployment of decentralised WPPs. To offset the impact of slightly higher generation tariffs for these zones, we apply the concept of tariff indexation [6].

We conduct a case study to estimate the savings that the state discom can realise through 50 MW of decentralised WPPs at zone III sites of Maharashtra. We assessed four scenarios using the VGRS framework [7]. The scenarios consider intra-state procurement from the WPP without and with indexation in the wind tariff, and for interconnection at STU and discom level. We used the following parameters to estimate the savings:

1) *Approved average power purchase cost (APPC)[2] for 1st year, exclusive of RE [8]:* 4.19 INR/kWh

2) *Thermal APPC annual escalation rate [3] [8]:* 2.42%

3) *Landed wind PPA tariff:*

a) *Without indexation:* 5.13 INR/kWh

b) *With indexation:* 3.25 INR/kWh for 1st year with annual indexation of 5%

4) *CUF for zone III:* 30%

5) *Project lifetime:* 25 years

We compute the savings as a result of '*avoided costs*' of Maharashtra discom, i.e. *avoided generation capacity cost, avoided variable power purchase cost* and *avoided non-solar RPO penalty cost*. We find that the discom saves around **INR 279 crores to INR 336 crores** over the project lifetime.

We also evaluate additional economic and social benefits to the state in the form of lease rentals [9], land conversion charges[4][10], and employment creation [11]. The cost of grid balancing is estimated to be INR 19 crores to INR 21 crores [12]. These are summarised in Table 2.

TABLE 2. SOCIO-ECONOMIC COSTS AND BENEFITS FOR A 50 MW WPP IN MAHARASHTRA ZONE III

Cost	Estimate
Grid balancing	INR 19 – 21 crores per annum (expected to reduce with new dispatch and market mechanisms)
Benefits	
Lease rentals	INR 5 – 15 lakhs per annum
Land conversion charges, if applicable	~INR 68 lakhs
Discom savings	INR 279 - 336 crores over 25 years
Employment	30 jobs in construction and commission 25 jobs in operation and maintenance 8 jobs in business development and design

[2] Computed based on APPC for thermal stations for FY-23, excluding the transmission charges.

[3] Computed based on CAGR of total thermal power purchase cost for MSEDCL (as approved by Maharashtra Electricity Regulatory Commission, MERC) from FY21 to FY25

[4] Computed based on industry inputs. Land considered on footprint basis.

IV. Enabling Implementation Framework

For deployment of decentralised WPPs to be successful, certain challenges must be mitigated. There are no central guidelines for procuring power from WPPs less than 25MW (intra-state) and 50MW (inter-state) [13]. There are barriers associated with identifying spare capacities at STU, availability and acquisition of land in the vicinity of substations, permits and clearances for setting up infrastructure, and payment and financing related risks for small and medium-scale players. There is also a possibility of high tariff discovery in zones I, II, and III. These are likely to impact the uptake of the proposed model. However, a dedicated central scheme that mitigates these challenges can be developed in consultation with state-level stakeholders and regulators.

New and innovative bidding mechanisms or tariff determination methods can be co-developed to promote this model. Tariff indexation, demonstrated here, is one such mitigation measure. Further, bidding mechanisms may be designed to attract a high number of bidders, thus ensuring competition. These mechanisms should ensure sustainable price discovery to protect the interest of small and medium-scale investors and reduce the risk of underbidding and delays in project deployment. The procurement mechanisms must also encourage local economic benefits such as local jobs, domestic manufacturing and innovation in technology.

Planning and coordination amongst relevant agencies must ensure adequate load flow studies, development of land databases, preparation of wind resource maps, provision of single-stage permits and timely connectivity, and designing of power purchase agreements with payment security mechanism.

V. Conclusion

This paper proposes a novel approach to accelerating and diversifying wind power deployment in India. We also demonstrate the case for decentralised WPPs and estimate monetary savings for the states and the discoms. In addition to direct climate mitigation benefits, the model has several other value propositions. It encourages the market entry of small and medium-scale investors, developers and local manufacturers, paving the way for an 'Atmanirbhar Bharat' and ensuring green recovery in the post-covid era. It has the potential to optimally utilise transmission infrastructure, create local jobs, and enable a balanced and equitable energy transition. We recommend policymakers to develop a programme that enables Centre-State coordination necessary for the scale-up of the proposed model.

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Combustion Modification: Implementation Challenges & Impact on Boiler Performance wrt Indian Context

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This paper solely focuses on how to reduce NOx during combustion stage itself from 750 mg/Nm3 to 400 mg/Nm3 @ 6% O2 dry basis in existing boilers, which having tangential fired system, economically and with minimum impact on boiler efficiency and affecting other performances and steam parameters. For achieving above goal, Combustion modification will be required. In Combustion Modification aim is to provide equivalent latest state of art a low NOx firing system and additional over fire air (OFA) dampers will also to be provided. The Low NOx firing system uses state-of-the-art equipment. The NOx level is generally met by varying the Firing Zone Stoichiometry (FZS) and how and when the air is introduced to the fuel local to the burners. This lowers the firing temperature while maintaining fireball stability. The various arrangements used in the Firings Systems are designed to stage the combustion air in different amounts to achieve the lowest Furnace NOx possible. In some cases, there can be limitations in the amount of air staging possible and hence the lower furnace stoichiometry. These limitations are typically related to the fuel composition and boiler load. For example, fuels with a very low Heating Value or a very high Fuel Ratio may impose limitations on the minimum lower furnace stoichiometry that can be achieved. Similarly, at low loads sufficient air may not be available for staging and for over fired air dampers. This paper also indicates challenges faced for implementation of combustion modification. A case study with respect to Indian context comparing NOx reduction and impact on various parameters after combustion modification also covered in the paper.

I. Introduction

This NOx reduction is achieved by mainly two method i.e. primary method and secondary method. Combustion modification comes under primary method where NOx is reduced during combustion process and reduced in generation itself. In secondary method, NOx is reduced after generation of NOx. In India, most of the boilers installed before 31.12.2016 were designed for maximum NOx emission 260gm/GJ (750mg/NM3) as per world bank norm at that time. As per new norm combustion modification will be required to get maximum NOx emission 450 mg/NM3 level. NTPC envisaged around 50 boilers of 21000 MW for combustion modification. Combustion modification in around 26 boilers has already completed and implementation in balance units will be done during major overhaul of unit. In India, most of boilers are tangential fired (corner fired boiler). These Boilers are provided with coal nozzles and having common fire wall instead of individual coal burners. NOx reduction is achieved by the firing zone under sub-stoichiometric firing conditions by reducing Oxygen concentration in the active firing zone. This is accomplished by introducing a portion of the combustion air higher in the furnace through an over fire air (OFA) . Percentage of OFA shall be in the range of 20% to 25% total air and based on the coal quality and NOx turn down requirement. %CCOFA shall be 10% to 12% as per the original design condition. This OFA management system uses air flow measuring devices provided both sides of the Windbox to control to stoichiometry build-up and combustion process over the boiler operating envelope. This process of delayed combustion provides reduction in overall NOx with minimal impact on the unit performance. The OFA uses tilt in conjunction with the existing main Windbox tilts. All functional curves and set points are subject to field tuning based on actual unit operating characteristics. 20 % to 25% of the total combustion air will be introduced through the OFA registers, and the rest of the air shall be used for main Windbox as secondary air. The primary air required for transport of fuel from Mill to furnace shall be as existing. Nitrogen oxides, usually identified by the term NOx, arise from two sources in fossil fuel fired combustion systems. These are the nitrogen contained in the fuel and the nitrogen in the air for combustion of the fuel.

<u>Combustion Control – Low NOx system</u>

Steps Involved:

- Precise mixing of fuel and air is used to keep the flame temperature low and to dissipate heat quickly using low excess air.
- Control the mixing of fuel and air, in effect automating low-excess-air firing or staged combustion.

Combustion Control – Low NOx Concentric firing system (LNCFS)

Offset Auxiliary Air

Air is introduced between the coal nozzles. This air is injected through concentric auxiliary nozzle tips that are installed on the air nozzles in the main windbox. The angle of these nozzles can be adjusted both horizontally (yaw) and vertically (pitch). Nozzles are adjusted to direct the air toward the furnace walls to reduce fouling and to produce an oxidizing environment along the water walls. This minimizes the potential for corrosion and produces two concentric circular combustion regions. Most of the coal is contained in the fuel rich inner zone, which is surrounded by a fuel-lean outer zone that contains combustion air.

Flame-Attachment Nozzle Tips

This devolatilizes the coal as quickly as possible and releases the nitrogen in the fuel in an oxygen-poor region of the flame. This helps minimize NOx formation from the nitrogen in the fuel.

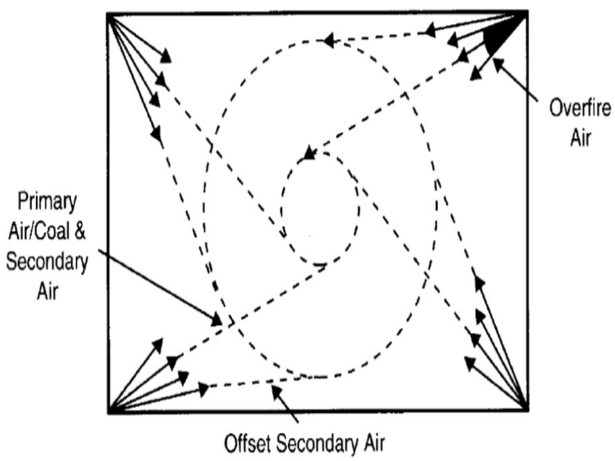


Fig.1: Nozzle tip orientation

Close-coupled Over-fire Air System (COFA)

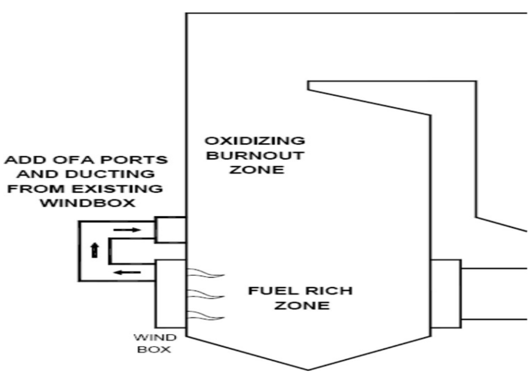


Fig.2: Close-coupled Over-fire Air System (COFA)

Over Fire Air System (OFA)

The overfired air (OFA) windboxes shall be of appropriate size with four (4) compartments. Note that the main windbox is approx. 800-850 mm wide. The OFA tips are designed for actuated vertical tilt and manually adjusted horizontal yaw of plus or minus fifteen degrees (±15 deg), allowing for field adjustment of the overfired air jets. Each OFA compartment damper will be controlled by its own damper drive. The OFA nozzle tips will be fabricated from 309 stainless steel. The OFA windboxes are located in the corners, directly above the main windboxes to minimize the potential formation of carbon monoxide (CO) emissions by covering as much of the furnace plan area as possible. To ensure proper secondary airflow velocities (in the range of 45 m/sec to 50 m/sec) for maximum flue gas mixing, all new nozzle tips are required for the main windbox.

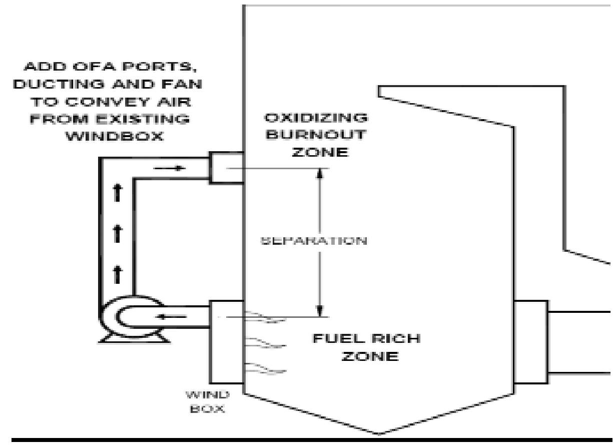


Fig.3: Over-fire Air System (OFA)

Parameters affecting NOx

Nitrogen oxides, usually identified by the term NOx, arise from two sources in fossil fuel fired combustion systems. These are the nitrogen contained in the fuel and the nitrogen in the air for combustion of the fuel. The fuel nitrogen NOx formation reactions are dependent upon the nitrogen level in the fuel and the stoichiometry of the combustion system. The NOx formation reactions occur less readily in reducing atmospheres, emphasizing the importance of reactant concentration, and mixing in the initial stages of the flame. The atmospheric nitrogen reactions are strongly temperature dependent and can be minimized by keeping the flame temperatures below 1500 deg C. Additionally, the amount of Nitrogen in Coal, Volatile matter determine the NOx produced, so even if the Combustion has been modified using Over fired air dampers, but there cannot be a fixed outlet NOx. It will vary depending on above parameters. Look at the figure below which shows typical NOX variation wrt type of coal and mill combination in operation:

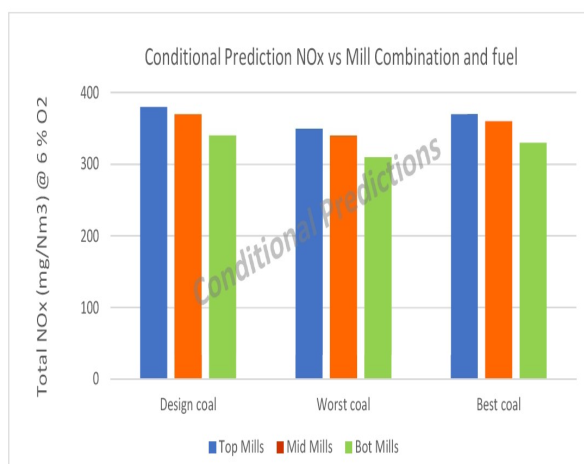


Fig 4: Conditional Prediction for NOx vs Mill Combination & fuel

COMBUSTION MODIFICATION – Details of various Suppliers

Generally, the Main Wind Box provides around 70% of the total Combustion Air (TCA) which is secondary air. This secondary air is distributed across the four corners through various secondary air and OFA nozzles in the wind box. The standard Over Fire Air nozzles (OFA, integral with wind box, known as CC-OFA) - situated above the Main WB top fuel elevation/top end air compartments, distributes 10-12% of the secondary air into the furnace through distinct layers or multiple zones. Over fire air is a portion of secondary air admitted to the furnace through (a) Close-Coupled Over fire Air (CC-OFA) nozzles located in the main wind box above the top coal elevation and (b) through additional over fire air nozzles located above the main wind boxes, at a higher elevation, in all the four corners.

BHEL DESIGN FEATURE:

- To modify the existing TT burner & wind box system in the boiler.
- A "Newly developed TT burner and wind box design" along with BOFA (Bypass Over Fire Air) system shall be introduced in the unit thru the proposed modifications.
- Around 30% of secondary air shall be distributed in the BOFA.
- Hot secondary air supply for BOFA system, shall be tapped from the hot secondary air duct connecting to the wind box.
- BOFA (Bottom) is placed at approx. 4-5 m above the top of wind box.

Arrangement of CCOFA and BOFA

CCOFA ports are integral part of wind box having two compartments. These compartments can be tilted vertically in synchronous with wind box. Horizontal sway (yaw) also provided.

BOFA port has four compartments located above the main wind box at certain height. These compartments can be tilted vertically in synchronous with wind box. Horizontal sway also provided.

Total combustion air (TCA) is distributed among main wind box, OFA and BOFA. Proportion of air and location of BOFA are optimized to achieve guaranteed NOx of 400 mg/Nm3 while firing specified coal.

Since heat fired is same as that of original design, heat absorption in the furnace shall be same as original and hence FEGT will not be appreciably changing from design predictions.

GE Design Features:

- Percentage of Separated over fired Air (SOFA) dampers shall be in the range of 20% to 25% total air and based on the coal quality and NOx turn down requirement.
- %CCOFA shall be 10% to 12% as per the original design condition.
- SOFA wind boxes shall have 4 compartments.
- SOFA tips are designed for +/- 30 deg of vertical tilt & manually adjusted horizontal yaw of +/- 15 deg.
- SOFA wind boxes are in the corners directly above the main wind box to minimize potential formation of CO by covering maximum of furnace plan area.
- SOFA (Bottom) is placed at approx. 4-5 m above the top of wind box.
- Coal compartments will remain at their current location.

L&T MHPS Design features

LMB will utilize the existing system / equipment as much as possible. In addition, LMB will install additional AirPort (AA-port) around 4-5 m above the existing wind box. LMB will modify / retrofit the wind box by modifying all wind box nozzle tips (coal, oil, and aux) for all four corners, using the existing coal burner body and oil gun. Necessary modification as required for boiler water wall and secondary air duct shall also be carried out.

Limitations in Combustion Modification in existing Boilers vs New Units

Combustion modification in existing boiler being planned to make it economical, make minimum changes and to complete combustion modification during major unit overhaul period (i.e., 45 days) and not to take additional shut down of unit to avoid disruption in power supply from the unit.

a. Furnace Size Restriction

Additional overfired dampers is provided around 4-5 m above wind box. In existing boiler, furnace height is fixed and hence it restricts number of additional overfired dampers and maximum one number of additional one number of over fired damper can be retrofitted above wind box. Approximate size of OFA is 2500 mm x 850 mm, there can be only one level of OFA dampers in the existing boilers. This restricts the reduction of NOx up to 400 mg/NM3.

However, two layers of OFA dampers are being provided in case of new units and NOx can be reduced up to 325 mg/Nm3. Hence, there is the limitation of NOx reduction for retrofitted units.

b. Mill Size Restriction

The new units are installed with a smaller mill with dynamic classifier which increases the fineness of mills thereby keeping in check the unburnt carbon.

However, for the retrofitted units, the unburnt Carbon increases by 0.8% and the OEM's face compliance issue to outlet NOx without affecting the unburnt. This acts as a major limitation for retrofitting in older units.

c. Mill PF Pipe Restriction

For existing units, the PF pipe sizes are already fixed which means the amount of minimum primary air is fixed to maintain minimum velocity in coal pipes to avoid settling of coal. This is resulting in lesser air, or no air being flown into OFA dampers (SOFA, BOFA, AA) which limits NOx control specially at lower loads. This situation is much worse at partial loads.

On the contrary, for new units the size of PF pipes can be reduced which will provide more air for OFA dampers thereby preventing air limitation for NOx control.

d. Fan and APH size Restriction

Distribution among the primary air and secondary air cannot be changed much in existing boilers due to PA fan, FD fan and APH size restrictions.

e. Water circulation ratio

Majority of existing boiler are supplied by BHEL, and water circulation ratio will be affected due to opening for additional OFA. So, it to be checked and opening of Additional OFA should be kept in such a way so that there should not much change in water circulation ratio.

Increase in Unburnt Carbon in existing Boilers wrt Indian Coal context

As explained above reasons of increase in unburnt Carbon after combustion modification in existing boiler due to various restrictions. However, wrt Indian Coal quality the following is also to be noted. Coal quality such as low VM content, high Ash content and low VMdaf (VM dry ash free) reduces the efficient combustion and increases UBC in the fly as well as bottom ash. Since Typical Indian coal has high Ash content > 35% which leading to high UBC loss post NOx abatement combustion modification. Mill fineness, air-fuel ratio, Coal and Air flow imbalance among all 4 corners are also important factors which play major role in increase in UBC. It was found that the high UBC content was a combined effect of poor coal grindability and low pulverized coal and air mixture velocity in the main burner zone. Larger Coal particle combustion and flow imbalance in the mill discharge pipes can lead to high UBC loss. This can be mitigated by installing the dynamic classifier and reducing the pulverized coal and air flow imbalance. Since, dynamic classifiers are not installed during these types of combustion modification retrofit jobs, leading to high UBC loss. Old boilers of Typical 500 MW were designed for certain UBC loss (heat loss basis) mostly supplied by BHEL (OEM). Hence, post combustion modification in these old subcritical boilers, UBC increases comparatively more with respect to new supercritical boilers.

A curve depicting change in UBC and NOx reduction wrt staggering air from overfired air dampers.

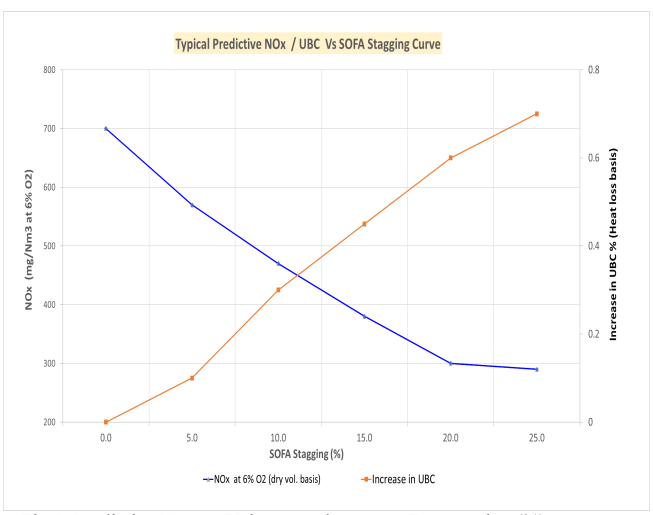


Fig 5: Predictive NOx & Unburnt Carbon vs SOFA Stagging (%)

<u>Implementation Challenges faced in Indian Context</u>

Combustion modification is required in all boilers which installed after 01.01.2004 to meet new environmental norms as a primary measure even if secondary measure is required or not.

Timeline for compliance is also defined by MoEF&CC. Further, it is preferable that combustion modification to be carried out by Boiler manufacturer to avoid any issue wrt Boiler performance. Boiler manufacturers are limited. Further, Combustion modification to be carried out during major overhaul of unit without taking any additional shutdown. Any mismatch in coordination and supply of material as per shut down plan will cause implementation delay. Combustion modification will delay by two years as major shut down taken in every two years.

For overfired dampers air, opening in all four-water wall either in corner or middle is required. Existing buck stay will obstruct the required opening so modification in buck stay will also be required. Steam/water circulation ratio also need to be checked after opening for additional over fired air dampers. Availability of detailed data of existing boiler is required for combustion modification and it is also a challenge when modification is being carried out by other OEM.

Operational Challenges

It is very difficult to maintain various parameters and performance at the level of pre modification. It has seen that it is difficult to maintain wind box DP set point as per pre modification with opening of aux air dampers and some cases it is required to closed fully even at full load.

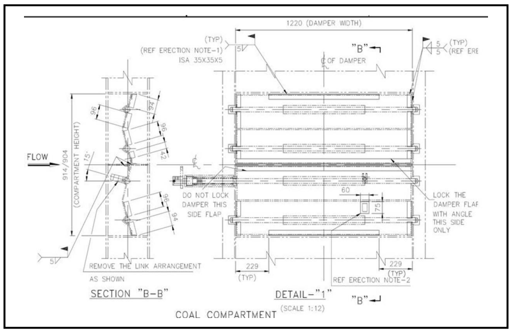
For Protecting Aux Dampers from closing fully, there is SOFA override protection. In the drawing, SOFA override protection is shown as 20%, this override protection is supposed to reduce SOFA demand as Aux damper command goes below 20%.

Even 10% override protection is leading to closing of SOFA dampers and increase in NOx value. On other hand reduction in over-ride protection value to 3% leading to closing of Aux dampers. There are high chances that full closing of aux. damper may damage aux. air comportment and aux air tips due to insufficient cooling.

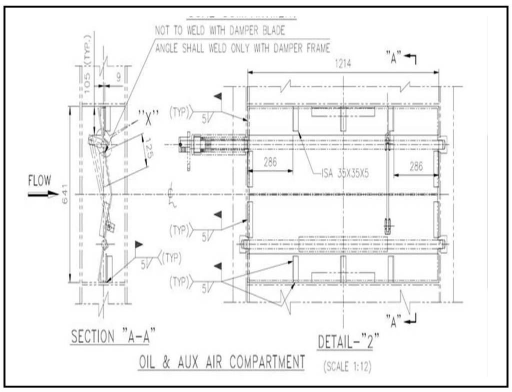
From the above, balancing between Wind box DP, Aux damper cooling and NOx is required, and which is challenging task.

To maintain NOx and Windbox to Furnace DP following changes in Damper compartment are being made:

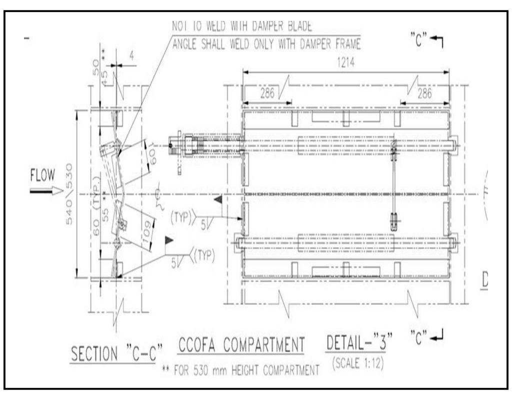
In coal compartment, 3 damper flaps are proposed to be locked, allowing 1 flap (existing drive flap) to operate with existing actuator. To avoid the overheating of other flaps, the cooling air through that flap will still go through as suggested in the modification. This is mainly done to get better control of Windbox to Furnace DP since air is being diverted from existing windbox to SOFA system.



For Oil and Aux. Intermediate Air – a 105 mm plate in back side of damper flaps in top & Bottom has been introduced. This gives the effective compartment height as 531mm. In this compartment flaps are **not locked**.



For CCOFA compartment -Like oil/aux air, placing a 50mm plate in back side of damper flap in top & bottom of compartment. Which gives the effective compartment height as 440/430mm. In this compartment also flaps are **not locked**.



In some of project, It was observed that SOFA dampers are found jammed and not closing fully (within 3 months of commissioning). In such a short duration, jamming of 10 nos. SOFA damper is a matter of concern and there are high chances that these dampers may jam again in future.

Performance Review Challenges

To review the performance of combustion modification, base line test before modification and PG test after modification is being done. However, it observed that due to coal characteristics changes, mill combination, excess air and other operating conditions at both cases cannot be maintained same. These will impact the performance and make difficult to evaluate the performance before and after combustion modification.

CASE STUDY FOR ANALYSING PERFORMANCE AFTER COMBUSTION MODIFICATION

A Case study wrt Indian Context on impact on Boiler Performance before and after combustion modification has been made. For this, detailed data were collected at different boiler loads before combustion modification named as baseline test and then data collected after combustion modification during PG test. The same was also demonstration/guarantee condition for combustion modification.

<u>Comparison between Baseline Results & PG Test results at one 500MW unit for Combustion Modification</u>

Baseline Test Report U#5

Description/ Load	**50% TMCR**	**TMCR**	**TMCR**	**50% TMCR**
	(250 MW)	**(490 MW)**	**(495 MW)**	**(250 MW)**
Date	28.01.19	30.01.19	30.01.2019	30.01.19
Mill combination	D-E-F-G	A to F	D to J	A-B-C-D
	(Top)	(Bottom)	(Top)	(Bottom)
UBC heat loss in BA in %	0.39	0.16	0.08	0.06
UBC heat loss in FA in %	0.71	0.36	0.36	0.24
Total UBC heat Loss in %	**1.10**	**0.52**	**0.44**	**0.30**
SH Spray in T/Hr	103..8	3.2	28.2	1.8
RH Spray in T/Hr	0.0	0.0	0.0	0.0

PG Test report –

Description	50% Top	100% Bottom	100% Top	50% Bot
UBC heat loss in BA in %	0.43	0.47	0.40	0.51
UBC heat loss in FA in %	0.38	0.45	0.39	0.50
Total UBC heat Loss in %	0.82	0.91	0.79	1.01
Increase in UBC loss in % from baseline	-0.28	0.39	0.35	0.71
SH Spray in T/Hr	87.2	11.6	47.9	22.9
Increase in SH spray in T/hr from Base line	-16.6	8.4	19.7	21.1
RH Spray in T/Hr	0.0	0.0	0.0	0.0
NOX in Mg/NM3	Below 400 mg/NM3 for all conditions			

Impact of Combustion Modification on Boiler Parameters: Conclusion

NOx Reduction

NOx generation during combustion has been reduced below 400 mg/NM3 after modification for loads 50% to 100% TMCR load and various mill combination.

Unburnt Carbon Loss (UBC)

Combustion Modification amounts to increase in unburnt carbon heat loss including bottom and fly ash for most of conditions to the tune of 0.4 to 071% at various load.

UBC heat loss basis in % shall decrease the boiler efficiency in equal extent. For example: If post combustion modification, UBC loss (heat loss basis) is increase by 0.7 %, then it will also decrease the boiler efficiency by 0.7%.

SH & RH Spray Variation

SH and RH spray variation amounts to nearly 10 T/hr and 5 T/hr respectively was kept limit after combustion modification. However, SH spray was increase up to 21.1 T/hr and RH spray was not increased but there was shortfall of around 20 deg in Hot RH temperature.

For a typical subcritical 500 MW unit, Increase in RH Spray by 5 tph will decrease the turbine heat rate by approx. 1.2 Kcal/KWhr.

In subcritical boiler, generally SH Spray flow tap-off location is BFP kicker stage outlet hence Increase in SH Spray by 10 tph will decrease the turbine heat rate by approx. 2.4 Kcal/KWhr. In case SH tap-off location after HPH heater then there will have no impact on heat rate due to increase in quantity of SH spray flow.

SH Spray quantity varies with the coal quality, excess air, burner tilt, furnace cleanliness etc.

Waterwall corrosion

Waterwall corrosion could not be known only after long operation of boiler after combustion modification.

Impact on other parameters

No noticeable change has been observed in other Boiler performance and parameters except HRH steam temperature. HRH steam temperature was lower than 20 deg C after combustion modification for all conditions except top mill and 100% TMCR condition.

Based on above, it can be concluded that there will be increase in unburnt carbon heat loss in the tune of 0.71%, increase in SH spray around 20 T/hr and reduction in HRH steam temperature of around 20 deg C after combustion modification. These losses are maximum at lower load and bottom mill combination and minimum at top mill condition.

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Envisioning Smart Utility through Field Force Automation

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***Abstract* — It has become imperative for Tata Power-DDL to develop and implement advanced technologies and create a benchmark for other Distribution Utilities to follow. One such technology developed is Field Force Automation (FFA) which empowers Filed Crews working at the site to have a real-time update of all interruptions and outages of their respective work area and further assisting them with load data to restore / back-feed supply swiftly. Integrations of Field Force Automation with Advanced Distribution Management System (ADMS), Smart Meters, Authorization Portal, Safety Portal, and Network Updation Notification Application have created a robust platform for Field crew to serve its consumers a world-class service. FFA gets real-time push of outage status through the Call grouping engine service of Advanced Distribution Management System by creating predictions based on consumer connectivity with the electrical equipment. Tata Power-DDL has installed approx. 2.5 lakhs Smart Meters in its area of operations. So prediction logic has been replaced by Smart Meter status and ping feature, developed exclusively in Field Force Automation for these 2.5 lakhs consumers, hence providing 100% accuracy and transparency to Field crew and end customers via Tata Power-DDL Mobile App. Interlocks have been provided in Field Force Automation login page through Authorization Portal so that employee authorized for specific profile gets auto-assigned work of that profile only. To capture Safety related issues at the site, Field Force Automation captures GIS coordinates and automatically forwards them to the respective Zonal bin for necessary action. For real-time syncing of the Network at site with Advanced Distribution Management System, Field Force Automation has been integrated with Network Updation Notification Portal to update consumer connectivity accurately. Hence the introduction of Field Force Automation in Tata Power-DDL has ensured efficiency in work productivity of Field Crew at the site and has transformed the service delivery to its consumers.**

Keywords* — *ADMS, DISCOM, FFA, GIS, SAP, ETR, NCC

I. INTRODUCTION

Tata Power Delhi Distribution Limited [Tata Power-DDL] is a joint venture between Tata Power and the Government of NCT of Delhi with the majority stake being held by Tata Power Company (51%). To ensure reliable power supply and to provide best in class service to its consumers, Tata Power–DDL has implemented several world-class technologies such as Advance Distribution Management system or ADMS which replaced the conventional SCADA-DMS-OMS system with features like real-time integration of Smart Meter Data / Distributed Generation integration and single data model from GIS, Integrated Geographical Information System (GIS) for instant services, Advanced Metering Infrastructure (AMI), Automated Demand Response (ADR), Smart Street Light Management system and Field Force Automation.

Field Force Automation (FFA) is the latest technology developed and implemented by Tata Power Delhi Distribution Limited that empowers the Field crew with all necessary data of their controlling area and work profile. The application of route optimization provides field staff comparatively faster routes to reach fault locations based on the GPS coordinates of crew member. This system is also integrated with ADMS, Meter data management system, Safety Portal, LT Notification Portal.

Fig. 1. Login Page of Tata Power DDL FFA Mobile App

II. SIGNIFICANCE OF FFA FOR UTILITY

- Real time dissemination of information to Field Official for swift action

FFA provides information directly to the field staff on the FFA device. Earlier, the Field crew used to get information from Telephone Operators about the list of interruptions and then they prioritize work based on complaints closest to them. But after implementation of FFA, route optimization and crew assignment is being done automatically based on the shortest route and allotment of work to the authorized crew after analyzing the average time taken to attend the previous complaint of similar category - No Current Complaint (NCC) or Streetlight.

- *Auto estimation of Fault's Estimated Time of Restoration (ETR)*

Based on the given fault type in a selected area, the FFA application calculates the Estimated Time of Restoration (ETR) using data analysis of the fault's previous restoration trend. This ETR is the sum total of Travel Time for a crew to reach the affected site and Repair Time to restore the power supply. This feature has brought transparency in the delivery of quality service to consumers.

TABLE 1

Parameter	Before	After
Real Time Tracking	×	✓
Raising Suraksha Issues	×	✓
Smart Meter Ping Facility	×	✓
Authorizations Interlock	×	✓
Network Updating from site	×	✓

III. END TO END INTEGRATION WITH VARIOUS IT-OT APPLICATIONS

- *Integration with Advanced Distribution Management System (ADMS)*

ADMS is an integration of Outage Management System (OMS), Distribution Management System (DMS) & Supervisory Control and Data Acquisition (SCADA) where GIS Data has been utilized to map consumer connectivity with the electrical network. ADMS is further integrated with SAP – CRM wherein complaints lodged by consumers during the initial minutes of an outage helps ADMS in predicting a faulty device using consumer connectivity data of GIS with the electrical devices. It then proactively sends an Outage update and ETR to all consumers connected to that respective predicted device. Outages information also gets forwarded parallelly to FFA via Simple Object Access Protocol (SOAP) service of ADMS for the field crew to take necessary action like outage acknowledgement, status update like Enroute, Arrived and, Work in Progress.

- *Integration with Smart Meters*

Installation of smart meters is another significant step for Tata power DDL to become a Smart Utility. Integration of Smart Meter data through its Head End System (HES) with FFA has greatly assisted Field Crew to know the real-time power supply status of respective Meter using Meter Ping feature. Hence, the Smart Meter will provide accurate interruption information and will further reduce Mean Time to Restore (MTTR) by pinpointing the faulty / interrupted device.

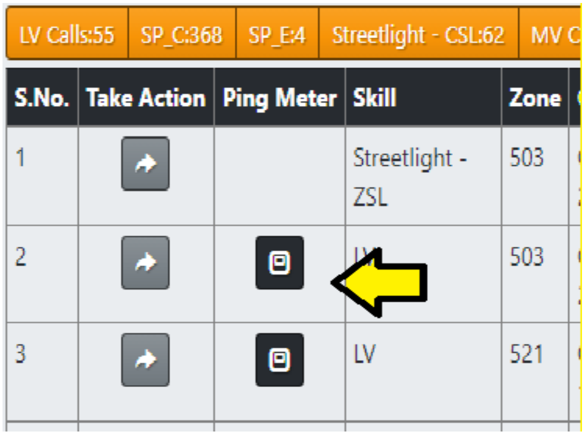


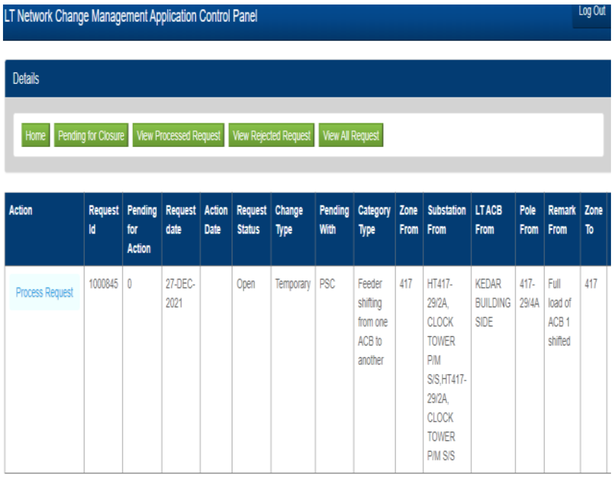
Fig. 2. Smart Meter Ping provision to confirm Outage

- *Integration with Authorization Portal*

It becomes important for Utility from a Safety point of view to restrict unauthorized access to its system applications which are being used for Network & Load Management. Tata Power DDL has restricted the rights exclusively to authorized personnel only based on their competency in assigned Work Profiles and level of operation (High Tension Voltage or Low Tension Voltage). This safety interlock feature has been achieved after the integration of the SAKSHAM Authorization Portal with FFA. Tata Power-DDL has developed an authorization application for its employees to train, assess and maintain competency records as per their work profile. This authorization application's database is integrated with Field Force Automation (FFA) for granting login rights to the authorized employee only. In case an authorized employee retires, resigns, gets suspended, or is transferred from Field Profile to another Department, then his/her authorization gets canceled automatically. This feature ensures safety compliance by granting access to trained and authorized personnel only working at the site.

- *Integration with LT Notification*

Tata Power DDL is the first Power Distribution Utility in India that has developed an integrated process for updating LT Network in GIS which then gets replicated in ADMS through patch management. Further integration of LT Notification Portal with FFA has given a platform to the Field crew to raise the request for updation of permanent and temporary changes done at sites. Before closing an outage in FFA, the Field crew can raise a request with just one click in Report Section if in case any LT change has occurred at the site. It then automatically moves for updation to GIS for updation of changes done by referring to the switching task of the respective Order.



Action	Request Id	Pending for Action	Request date	Action Date	Request Status	Change Type	Pending With	Category Type	Zone From	Substation From	LT ACB From	Pole From	Remark From	Zone To
Process Request	1000845	0	27-DEC-2021		Open	Temporary	PSC	Feeder shifting from one ACB to another	417	HT417-29/2A, CLOCK TOWER P/M S/S,HT417-29/2A, CLOCK TOWER P/M S/S	KEDAR BUILDING SIDE	417-29/4A	Full load of ACB 1 shifted	417

Fig. 3. LT Network Change request details on LT Notification Portal

IV. CHARACTERISTICS OF FFA

- *Dashboard view*

The most critical part for the field crews is to prioritize decisions based on pending field jobs. FFA has been enabled with the Dashboard feature so that the field crew gets a summary of the pending task immediately after login as it will help in better understanding of pending work and planning of tasks.

Fig. 4. Dashboard view of FFA Mobile App

- *Interlocking and Standardization in Report Section*

Outage Report Data is significant for a Power Utility as it provides actual information of interruptions, shutdowns maintenance activity, asset health performance and further provides a source for data analysis and Management Information System (MIS). To fill the report, FFA has a provision of an auto-fill report option based on fault type. It helps the Field crew working at the site to fill the report with ease. This feature has been developed meticulously by defining interlock logics and standardizing fault cause category-wise so that time and effort of the Field Crew should not get lost in data filling activity. Accurate and standard data captured helps Network & Maintenance Planning Group to analyze fault trend and make Network Optimization plan accordingly.

- *System Load Optimization during BCDMP*

To manage ADMS's system load effectively during Business Continuity & Disaster Management Plan (BCDMP), customer complaints getting lodged at SAP-CRM gets landed directly to FFA instead of ADMS. In this scenario, ADMS is only used for SCADA Operations purpose. During BCDMP, the Outage Management System (OMS) of the FFA application gets activated which receives the calls directly from SAP-CRM, bypassing ADMS. All reports and operational switching data of FFA get synced with ADMS after revoking of BCDMP feature of FFA. Hence, FFA helps in optimizing the ADMS performance during BCDMP by managing system load through the processing of call grouping engine at its end.

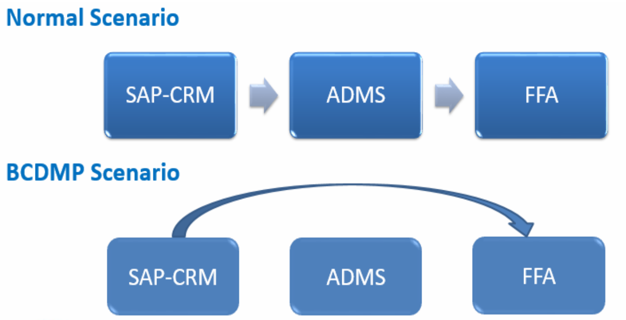


Fig. 5. ADMS-FFA architecture duing normal & BCDMP scenario

V. EVOLUTION FROM APPLICATION TO PLATFORM

- *Raise Safety, Ethics & Quality Issue*

Safety is one of the most important parameters for any utility to ensure at the site. Tata Power DDL, being a part of Tata Group, gives the highest priority to Safety, Ethics, and Quality. Hence, the company has created a culture of reporting Safety, Ethics & Quality issues observed by an employee (through FFA) or consumer (through the TPDDL Mobile Connect App). It gives flexibility to the user to report an incident immediately at the site, without memorizing or noting the case and then reporting it at the office. Issue reported then gets escalated to Safety / Ethics / Quality Assurance Team and respective Zonal Office for necessary action.

Fig. 6. Safety Reporting Feature in FFA Mobile App

- *Password Reset & FFA User Guide Feature*

To make the FFA application truly independent, password reset option has been provided to change/update login credentials through biometric authentication. If in case of any ambiguity in using FFA application functionality, the user has an option to refer to a manual or watch the tutorial video for each module of FFA (No Current Complaint, Streetlight Complaint, Shutdown Planning, Outage Reference, etc).

V. Benefits of FFA

FFA has redefined the work processes of all stakeholders linked with it. On one hand, it has optimized the resource management and on the other, it has delighted consumers by bringing transparency and accountability to services being offered to them. Some of the major benefits stakeholder wise are:

- *Benefits to Field Officials*

a. Real-Time information on Outage / Interruption

b. Best Route identification for the shortest distance to fault location: The network display window of FFA includes a GIS-enabled map of the network showing the location of the fault and allowing the crew to choose the route based on the proximity and severity of faults.

c. Crew optimization to assign jobs as per workload & location: Dispatcher modules runs the scheduler and assign the work to the available crew based on their location, workload, and previous performance in similar fault category, thus sharing work evenly through optimum utilization of manpower.

- *Benefits to Consumer*

Behind every idea and initiative, customer delight is the prime objective for Tata Power DDL. FFA is one such project that has enhanced consumer satisfaction.

a. Faster Outage Restoration: Smart Meter integration with FFA has resulted in locating actual fault location, hence replacing prediction model and reducing patrolling time.

b. Correct information on the Estimated Time of Restoration (ETR): Utilizing the GPS coordinates map and historical data of outages, the dispatcher module calculates the Estimated Time of Restoration by adding the time taken by the crew to reach the outage location with the time taken to rectify the similar fault as per the previous trend.

- *Benefits to Organization*

For Tata Power DDL to achieve its vision of becoming a smart distribution utility, it is very important to adopt new technologies that bring significant value to all stakeholders. FFA is one such technology that has brought the following benefits:

a. Additional Source of Revenue: Improvement of Reliability parameters (SAIDI, SAIFI) via FFA has increased revenue for the organization and has strengthened the brand value among its stakeholders. As a result of technology adoption, Tata Power DDL is the Industry leader and a benchmark for other utilities. It is also offering FFA as a solution to other State Utilities under the Business Development initiative.

b. Consumer Delight: Consumer satisfaction is the core of the innovation strategy for Tata Power DDL. This will give Tata Power DDL an upper hand when Consumer Portability will come into effect after Power Distribution Business Deregulation. In such a scenario, a stronger consumer offering will allow the organization to expand and increase its market share.

VI. Conclusion

Tata Power-DDL's innovative approach through the development and adoption of the latest technology has played a critical role in building and sustaining competitive advantage in the changing business scenario. Technology like Field Force Application has transformed the way Distribution Utility serve its consumer with world-class service.

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Augmented reality and other Digital Transformation and their applications in Power Transmission

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Abstract— Augmented Reality is a mixture of digital information and media, such as 3D models and videos, upon the physical world through smartphone, tablet, PC, or connected glasses. Virtual reality is another Technology which is Virtual reality (VR) technology can help the power industry to deliver workforce training and education in an immersive environment. Internet of Things (IOT) is a network that connects uniquely identifiable 'Things' to the Internet like the 'Things' have sensing/actuation and potential programmability capabilities. Artificial Intelligence having machine learning technologies and sophisticated algorithms that help machines and computers work smarter and more effectively than us mere mortals. In the long run, these emerging technologies like AR, VR, IOT, AI, robotics and others will bring higher productivity, reliability, availability, increased performance, and reduced operating costs

In this paper we will share the used cases of AI and IOT based voice operated device attached to safety helmet and used for remote assistance by two-way video calling, digital assistance by sharing drawings and filling voice operated forms, remotely controlling camera and for other requirements. In this paper will also discuss that how we can utilize AR, VR, IOT, AI robotics and other digital transformation in Power transmission division to improve overall performance of the system. In this paper areas which will be explored in Power transmission division are GIS Cable network, Live AR video conference at site, Cable jointing assistance, Cable fault testing assistance through AR device like Google Glass, Auto cable Drawing updating, Safeguarding of Cables from Damages as routes will be visible, Training to new Trainees, Supervisors, Contactors, Geofencing for safety, Accessing documents from site, Fast restoration of power supply, Inventory management etc.

I. Introduction

Generally, Power Transmission includes transfer of power from 220/110/33KV Receiving Stations to 33 KV/ 11KV Distribution Sub stations from where power is further distributed to consumers through 11/.415KV distribution transformers erected at different locations in consumer areas. Aera of Power transmission is having many operation, repair and maintenance activities which needs digital transformation for higher productivity, reliability, availability, increased performance, and reduced operating costs. In this paper we will share the used cases of AI and IOT based voice operated device attached to safety helmet and used for remote assistance by two-way video calling, digital assistance by sharing drawings and filling voice operated forms, remotely controlling camera and for other requirements. In this paper will also discuss that how we can utilize AR, VR, IOT, AI robotics and other digital transformation in Power transmission division to improve overall performance of the system. In this paper areas which will be explored in Power transmission division are GIS Cable network, Live AR video conference at site, Cable jointing assistance, Cable fault testing assistance through AR device like Google Glass, Auto cable Drawing updating, Safeguarding of Cables from Damages as routes will be visible, Training to new Trainees, Supervisors, Contactors, Geofencing for safety, Accessing documents from site, Fast restoration of power supply, Inventory management etc.

II. Augmented Reality

Image 1- Augmented Reality

If we talk about Augmented Reality than it is a mixture of digital information and media., such as 3D models and videos, upon the physical world through smartphone, tablet, PC, or connected glasses. AR can be defined as a live, direct or indirect view of a physical, real-world environment whose elements are augmented or overlaid by computer-generated sensory input such as sound, video, graphics or GPS data. AR may benefit utilities in improving business processes. It can speed power restoration and help address the challenge of an aging, retiring utility workforce by facilitating the preservation of institutional knowledge.

III. Virtual Reality-

Image 2 – Virtual Reality

Virtual Reality (VR) is a computer-generated environment with scenes and objects that appear to be real, making the user feel they are immersed in their surroundings. This environment is perceived through a device known as a Virtual Reality headset or helmet. Virtual reality (VR) technology can help the power industry to deliver workforce training and education in an immersive environment. VR headsets position the employee in a computer-simulated environment that imitates real-world conditions. Employees can now be trained effectively and efficiently on how to manage and respond to such situations.

IV. Internet of Things

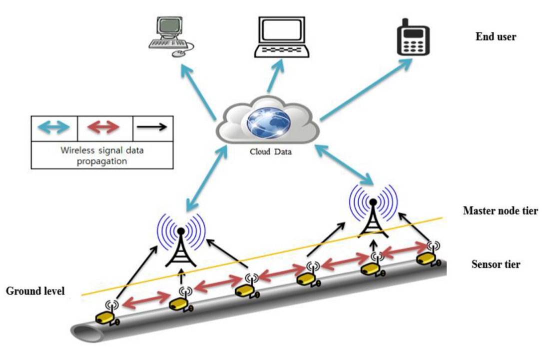

Image 3- Internet of Things (IOT)

An IoT is a network that connects uniquely identifiable 'Things' to the Internet. The 'Things' have sensing/actuation and potential programmability capabilities. Through the exploitation of unique identification and sensing, information about the 'Thing' can be collected and the state of the 'Thing' can be changed from anywhere, anytime, by anything. The concepts contained in the definition are described below:

A. . Uniquely Identifiable Things-

The "thing" refers to a physical object that is relevant from the perspective of a user of application. "Uniquely identifiable" refers to the assignment of a unique address on the internet to the "thing" so that it can send data to and receive data from other objects on the internet. The "thing" is therefore a node on the internet with an internet protocol (IP) address and uses it for communication.

B. Sensing and Actuation-

The sensors and or actuators are connected to the "thing" and perform the sensing and or actuation, which bring the smartness of the "thing."

C. Anywhere, Anytime-

Ubiquity is a major feature of an IoT system, indicating a network that is available anywhere and anytime. But in the context of IoT, the concept "anywhere" need not necessarily refer to "globally" and "anytime" to "always." The "anywhere" mainly refers to the concept of where it is needed and the "anytime" similarly refers to when it is needed.

V. Artificial Intelligence

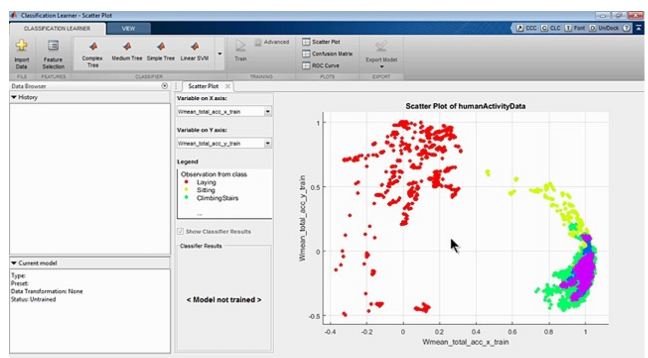

Image 4- Artificial Intelligence

Artificial intelligence (AI) is the ability of a computer or a robot controlled by a computer to do tasks that are usually done by humans because they require human intelligence and discernment. Despite its ubiquity and hype, not everyone understands what AI actually means. At the biggest-picture level, AI is simply the capacity of machines and computers to mimic human behavior. Underneath that big umbrella definition, though, are machine learning technologies and sophisticated algorithms that help machines and computers work smarter and more effectively than us mere mortals.

It's why AI's ability to identify trends and anomalies in huge data sets is such a potentially powerful tool for detecting diseases. What's even more exciting is that AI thrives on data: As the volume of data gets larger, AI's ability to translate that mountain of information into meaningful insights gets better.

The simple fact that utilities are now evaluating and testing AI to help transform their operations, customer relationships and business models is a testament to how mainstream it has become.

VI. Robotics

Rrobotics is design, construction, and use of machines (robots) to perform tasks done traditionally by human beings. Robots are widely used in such industries as automobile manufacture to perform simple repetitive tasks, and in industries where work must be performed in environments hazardous to humans. Many aspects of robotics involve artificial intelligence; robots may be equipped with the equivalent of human senses such as vision, touch, and the ability to sense temperature. Some are even capable of simple decision making, and current robotics research is geared toward devising robots with a degree of self-sufficiency that will permit mobility and decision-making in an unstructured environment. One of used case is shown in image 5 where robot is doing maintenance of OH Power line.

Image 5- Robot system for overhead distribution line maintenance (Courtesy of Manuel Ferre, Universidad Politécnica de Madrid) [1]

VII. AI, IOT Based helmet Device Used Case

We have done a pilot project with the One of voice operated device which is AI, IOT based and explored the areas in which this device can be used in Power Transmission activities. This device is mounted on safety helmet as shown in image 6 and 7. This device is having a micro screen targeting to one of the eye and this looks like tablet screen from the eye. This device is also having camera which can be controlled remotely. This device work on android platform in which application like teams , drive etc. can be downloaded and used . Below are the details

Image 6- Realwear device with helmet

Image 7- REALWEAR HMT-1 The original hands-free, head-mounted wearable solution for frontline work.[2]

This device provides the foundation for Connected Worker. This can be used in wet, dusty, hot, dangerous and loud industrial environments. A fully rugged head-mounted device, it optionally snaps into safety helmets or attaches to bump caps and can be used with safety glasses or corrective eyewear. The high-resolution micro display fits just below your line of sight and views like a 7” tablet. It’s an industrial dashboard, there when you need it and out of your way when you don’t. This works by completely hands-free voice control. That means no scrolling, swiping, or tapping - just simple voice commands. This can be used for remote mentor video calling, document navigation, guided workflow, mobile forms, and industrial IoT data visualization.

A. *Remote supervisoion of 110 /220 Cable Termination work at towers*

Image 8 - 110 KV Cable termination work at Tower

As shown in above image 8, 110 KV Cable termination work is in progress at Tower. It is very difficult for supervisors and engineers to sit at the scaffold of tower throughout the day and night along with jointers for supervising the termination work as there is load and safety constraint. Also sometimes there are situations where jointers needs help for quick guidance and Engineer needs to go to towers frequently which creates safety hazard. Other than serious issues, with the help of this device Engineer can handle general issues by seeing live video streaming using his laptop in his office.

Jointers wear this device with helmet and whatever they do everything goes live through the camera attached to this device to Engineers laptop. Engineer can guide the jointers anytime if they needed.

B. ***Inspection of 110 /220 Cable Terminations and Insulators***

Image 9 – Inspection of cable termination and Insulators at tower

As shown in image 9 in case of tripping Transmission team needs to check the cable termination and insulators at towers to confirm the failures. Generally field staff goes at top and he takes his call to confirm the failure while checking termination and insulators at tower and even it becomes very difficult for him to take photos at height as per Engineer's requirement. If field staff wear this device and as he looks anything and he moves his face, then camera also moves so whatever he inspect is visible to Engineer and he can remotely click the photo also. So, this help in accurate, easy and fast inspection of terminations and insulators at towers.

C. ***Inspection of Power Transformer Cable compartment etc, at eight***

Image 10- Routine maintenance of Power Transformer

During routine maintenance of power transformer filed staff checks and do maintenance of cable terminations ,bushings and other parts inside the cable compartments and at top of transformer. With the help of this device Engineer need not to go inside the cable compartment or at top to check the parts and he can guide the field staff from

D. ***Assistance in EHV/HV Cable testing , repair and saefguarding activites***

- In cable fault testing if site engineer find any problem in cable fault locating van then other engineer or expert can guide him to attend the same remotely with the help of this remote assisting device. This will save the time for testing the cable fault.
- In cable fault repair activities firstly Engineer has to identity the cable then he has to spike the cable and then jointing starts. In cities like Mumbai, Delhi etc. it takes much time to reach at substations and sites due to traffic. To avoid this time field staff with device can go at substations and can connect Audio frequency set to cable under the remote supervision of engineer. Now engineer will only need to go to site for identification and spiking so this will save his time.
- In cable safeguarding activities other utility require to shift or divert the cables for their excavation work . In that case engineer has to visit the site for planning and taking decisions. This takes huge time of engineer in travelling to different sites. A filed staff with device can be deputed for daily site visits and engineer may connect with him as he reaches at different sites. This can help for saving in time and better resource management.

E. ***Assistance in Remote operations of Switchgear and RMUS***

- Control Room Engineer can keep this device with him and if anytime he finds difficulty in operation of switchgear or RMU he can take help from other experts without wasting of time.

F. *Assistance in Switchgear maintenance activities*

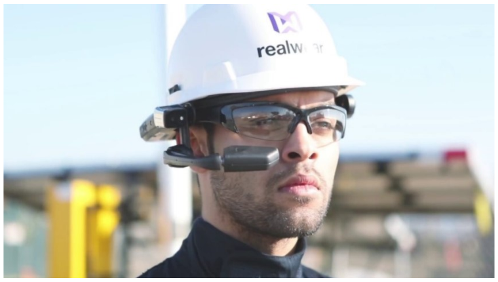

Image 7- Realwear Device with helmet

- For maintenance of control panel or breaker or any other complicated equipment where drawings and assistance is required this device can help in saving the time.

G. *Sharing of drawings , documents from cloud for mainteance and various other works*

- This device is having cloud based storage like one drive. So documents, drawings and images can be accessed by voice operating commands.
- This device have a screen in which drawing can be seen and further it can be zoom and move left right top or down as per need.
- Cable route drawing, switchgear ckt diagram, Images can be viewed or shared with this device.

H. *Filling forms in Mobile apps*

- This device allow to use power apps and other apps customized for voice operation. So maintenance forms can be filled and submitted by voice commands.

VIII. OTHER APPLICATIONS OF AR,VR,IOT,AI AND OTHER TECHNOLOGIES IN POWER TRANSMISSION

We have identified other activities in Transmission division in which AR,VR, IOT,AI and other digital technologies can be used. While AR, VR, IOT, AI are different technologies but we see that for improvement in any activity we need an application which has combination of AR, VR, IOT, AI and many other technologies. In below points we will discuss the areas of Transmission division in which combination of above technologies be used.

1. ***GIS Cable network-*** Currently GIS network is in 2 D and we can see this in computer or in mobile. In future this network can be seen in 3 D in VR (Virtual Reality) by superimposing on physical roads In AR (Augmented Reality).
2. **Live AR video conference at site-** Manager sitting in office can see the sites with superimposed images of cable network. He can take decisions about the work.
3. **Cable jointing assistance-** Supervisor sitting in office can see the cable jointing work in his mobile or laptop through camera device with site person . He can provide expert advice from office.
4. **Cable fault testing assistance through AR device like Google Glass-** Currently Cable fault testing is done by referring the physical of GIS drawings available in PC or mobile. Testing team has to find out the cable routes by seeing to physical copies of cable routes and it takes lots of time to confirm the cable route. With AR device team would be able to see the cable route network on physical roads along with depths and distances. Team would be able to see Superimposed 3 D model of cable roads on physical roads.
5. **Auto cable Drawing updating-** With the help of AR, IOT and AI devices cables images will be captured in 3 D and this will be automatically updated in 3 D system. Site person has to wear these devices and has to walk near to laid cables this will automatically analyse image , correct an update in 3 D format in the system.
6. **Safeguarding of Cables from Damages as routes will be visible-** External damage to cables during excavation is one of the bigger challenge. One of the reason of damages is unknow cable route under the grounds. As discussed in above points 3 D drawing of laid cables would be able in the system. Site supervisor will be wearing the AR device. He will give voice command and immediately 3 D drawing of cable routes would be visible on roads. JCB operator and site supervisor would be able to view the cable routes under the ground in real world. This will save the cables from damages.
7. **Training to new Trainees, Supervisors, Contactors-** As shown in image 8, Trainees can be trained with the help of AR, VR devices as these devices creates 3d images of actual object on which training is to be given.

Image 8- Training by AR and VR

8. **Geofencing for safety**-Field workers wear geofencing-enabled sensors that continuously track workers' location and health.

9. **Accessing documents from site**-Wearing Digital device site person can operate his PC or office computer and can access documents on voice command. This would help in repairing critical cables like EHV or critical equipment.

10. **Fast restoration of power supply**-As we have seen above with the help of digital devices we would be able to easily see the 3 D cable routes on roads this will help in reduction of time in testing of cable faults. Supervisor sitting in office or at other site can provide guidance during fault repair or during jointing. This will help in reduction in time of fault repair and will help in fast restoration of power supply.

11. **Inventory management-** In Electrical goods store augmented reality based glasses can help to find and arrange the goods quickly as all the racks and material would be mapped in the system.

Image 9- Inventory Management

ACKNOWLEDGMENT

Thus we have seen that AR, VR, IOT, AI , Robotics and other digital technologies can help in great way in various operation , repair, maintenance, inspection activities in Power transmission business. These digital transformations will help for higher productivity, reliability, availability, increased performance, and reduced operating costs. In this paper we shared the used cases of AI and IOT based voice operated device attached to safety helmet and used for remote assistance by two way video calling, digital assistance by sharing drawings and filling voice operated forms, remotely controlling camera and for other requirements. In this paper we also discussed that how we can utilize AR, VR, IOT, AI robotics and other digital transformation in Power transmission division to improve overall performance of the system. So this is very true that with the help of digital transformation in Power sector productivity, reliability, availability, performance will improve and operating cost will reduce

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Grid interactive affordable housing - a grid-management policy opportunity for distribution licensees in India

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***Abstract*—This paper provides a position statement for a grid interactive affordable housing programme called CELLULAR presently concluding its scoping phase. The study has so far balanced the technical, regulatory and financial aspects of socio-technical solutions that are practical and inexpensive. Later phases will deploy urban living labs which will site and test technology, decarbonization policy, regulatory sandboxes, urban land-use planning, human and social factors, financing innovations, and higher penetration of onsite RE. If successful, the programme would offer diverse benefits to affordable housing occupants, grid operators and builders. Observed efficacy of tested interventions will be pursued in a scale-up phase intending technical support for energy sector policy reform.**

***Keywords*—disruptive innovations, affordable housing, electricity distribution, demand side management, living lab**

I. Introduction

To date, very few Housing For All (PMAY-U policy) building developments have pursued Efficient Building (ENS building code) certification, and onsite renewables have very low uptake. India has pressing needs for reliable power supply as it has recently completed connecting all households for 1.4 billion people - but not yet for 24/7 supply and often only 300W [1]. India's electricity is heavily subsidised and so keeping electricity affordable is essential, but this constraint creates revenue challenges for electricity distribution companies (DISCOMs). Passive building design strategies, coupled with onsite renewable energy generation, demand-response/load management opportunities, and tariff design therefore have the potential for improving affordable housing while reducing energy costs and related GHG emissions. This potential has attracted researchers from two organisations and their donor to launch CELLULAR - Clean Energy Living Lab for Urban Low Carbon Affordable Residences. This paper is a position statement on the status of this new programme.

Implementing policies to best effect for the industry, DISCOMs, markets and building occupants is increasingly urgent as unchecked heating effects of global warming are anticipated to contribute to mortality of 10% of all deaths in India by 2100 [2] – we suggest that safe affordable housing should become critical disaster infrastructure. Rapid progress can only happen in a coordinated manner with clean energy provision relying on grid improvements and on-site solar and small wind generators – in turn provided by buildings and their occupants interacting with the grid – that is, grid interactive housing. There are also improvements in health, productivity, cost of living and other outcomes for more efficient buildings (for example: [3], [4]). Improving building performance and integrating with the grid could also hasten electrification and the conversion of cooking systems from propane and high particulate matter and CO biomass fires to electric stoves, a particularly serious health risk [1].

The importance of testing human factors means that innovators and governments alike can learn what will actually work and scale, rather than perpetuating the building-energy gap between as-designed and as-occupied energy use [5] [6]. Grid interactivity brings another layer to this situation as future DISCOMs will likely rely on cooperation from millions of occupants in heating events to prevent blackouts due to grid congestion. Space cooling in buildings (which constitutes around 33% of total electricity consumption in India) was ~135 TWh in 2017-18, and projections show that this will increase by a factor of four (to ~585 TWh) in the next two decades. Increasing use of air conditioners is already contributing to blackouts outside India (for example in Australia, [7]) where demand reduction bounties are being tested during high demand [8].

Household income and energy use have been found to be quite strongly correlated (for example in the UK [9]). At the same time, low-income Indian households are upwardly mobile: 8.5% of India's population moved up from the vulnerable category to middle class and 13.9% improved in status from poor to vulnerable up to the year 2010 [10]. Indians more generally have high expectations of upward mobility [11]. For those most vulnerable, 40% of energy distributed to informal settlements is lost with scheduled blackouts making refrigeration and other continuous energy uses impossible [12].

The study will have at least three phases. The present scoping phase runs to July 2022. Our methodology in the second phase from late 2022 is to deploy up to three sited *living labs* where we have convened supportive occupants, builders, and all levels of government. The study will seek dedicated funding for additionalities at all sites. At the time of writing these are initially in the states Gujarat, Karnataka and Maharashtra where we have engaged with the stakeholders already. A third phase of this work anticipates scale up of successful interventions to many other sites before 2030.

II. Living Lab Design

Living labs allow design interventions to be tested in situ so that adapted human social practices [13] can also be observed. Improvements in energy services and in grid interactivity will only be successful if they don't interrupt occupant's lives, do not require high energy literacy, have correct incentives operating, and can be seen to work in-situ. In India, there are few resources to deeply integrate improvements into households with little if any financial surplus, or time to learn and adapt. Such living lab research recognises that occupants:

- …are the experts on the products and services that will best meet their needs and preferences.
- …represent an under-tapped source of ideas and creativity.
- …involvement in shaping changes in their own lives extends the democratic space. [14]

From the side of DISCOMS, partners and educational institutions, labs:

- manage stakeholder cooperation
- lead to the pooling of complementary resources
- research the whole innovation process from conception to effective application in the real world
- encourage the sharing of innovations
- give end-users and communities more power in change processes and thereby deepen democracy
- make innovation more visible to those who need to help it along.[14]

The technologies in scope include:

- Changed demand: Buildings are entirely electrified to use grid energy; and, permanent energy-demand aware features that reduce energy demand via promoting energy efficiency (both for envelope and machines/devices).
- Connected and smart systems: Energy-demand technologies such as smart meters, building automation systems, sensors and others which support owners and occupants.
- Systems which rely on Distributed Energy Resources (DER) as a behind-the-meter solution such as onsite solar with batteries and vehicle to grid technologies potentially as despatchable generation and loads
- DISCOM facing controls: building infrastructure or appliances that send information such as smart meters or can actually be directly controlled such as header tank pumping.
- Systems which rely on cooperation and behaviour change of building occupants such as aligning solar generation with cooking, occupant energy curtailment advised by DISCOMs and so on.

Adjusting social practices such as introducing cooking on an induction stove during the solar day can see grid demand greatly reduced where there is onsite solar, and the typical evening demand peak reduced. CELLULAR will also explore the socialization of behavior change for which community-creation trials have been more successful (eg: [15]), long lasting and have demonstrated self-sustaining benefits (eg: EcoTeams [16]) and it will explore institutional design around sharing a limited resource [17].

Solutions under consideration:

- DISCOM-facilitated rooftop solar and small wind turbines (reproducing a BSES trial in Delhi [18]).
- Multifamily occupants sharing power from solar and small wind turbines via special metering (following AllumeEnergy.com)
- DISCOM-controlled HVAC and heat pumps for water heating (following from [19])
- 2-3-4wheeler charging and freight charging as a new social enterprise run by the building occupants through innovative business cases.
- Virtual power plant commons and socialisation of shared energy (from [20], [21]) along with DISCOM-messaging and demand reduction bounties (for example: [8]).

III. Conclusions and Future Work

The study covers at least four aspects of progressive energy use: the demand-side opportunities for resilience and affordability (energy reliability) and building efficiency (the building envelope); opportunities for energy utilities to coordinate with building occupants for energy efficiency (efficient devices and time-of-use); and, the potential for the formation of energy communities (groups of occupants who cooperate to make the best use of energy).

While India is not a large per-household user of energy and is largely not a cool climate country, the goal of building energy design is to cap or limit the growth in energy from quite a low base. The potential benefits to the users and grid operators via the bidirectional flow of electrons and value should be substantial as well as other health and wellbeing benefits for affordable housing occupants. The outcomes are intended to form technical support for further policy implementation in India.

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Unified Regulatory Management for Utilities in Smart City : Common Utility Alliance

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***Abstract*— This paper proposes a single management of utilities within a city for reducing losses and damage incurred to assets of utility. To access the impact of multiple utilities working disjointly, analysis of previous year external damages of Discom assets is shared along with its effect on reliability and consumer satisfaction. Further discussion on repetitive damages of assets such as roads, pipelines etc. due to works carried out by multiple agencies in Delhi is done. It is also shared how multiple agencies working on ground managed by multiple executives dire the consumer experience. In the end how a single governing body will help integrated utilities work together with integrity to make best for project decisions, manage risk and share gains and pains to deliver the best to consumers within city limits.**

Keywords*— Distribution Company (DISCOM), System Average Interruption duration Index (SAIDI), Consumer Satisfaction index (CSI), Smart meters, Geographical Information System (GIS), Public works department (PWD), Municipal corporation of Delhi (MCD), Delhi Jal Board (DJB), Indraprastha Gas Limited (IGL), System average interruption frequency index (SAIFI), Delhi State Industrial Development Corporation (DSIDC), Underground (UG), Irrigation & Flood Control (I&FC).

I. Introduction

Power distribution companies (Discoms) work towards providing a low cost power to consumers along with ensuring reliability and quality of power supply. Post-Independence India was fighting multiple battles under different sectors throughout the country. Same is not the scenario today. We are progressing from developing to developed nation, are now a power surplus country and forerunner in promoting renewable generation. Even though the Discoms financial viability and commercial discipline is still a challenge to be worked upon.

Some leading issues for distribution companies in India are (i) Gap between cost and revenue per unit (ii) AT&C Loss (iii) Delay in Retail Tariff Hike (iv) Increasing operational expenditure due to ageing/damage of assets (v) Revenue loss due to external factors such as pandemic. Further government policies to expand end distribution network such as (ex. Saubhagya) without cost restructuring and economic analysis further burdens utilities.

Multifarious Projects are launched each year under Smart City Initiative including water supply, electricity, sanitation, mobility, tourism etc. Execution of these schemes involves multiples agencies and hence isolated development plans, and lack of coordination leads to unwanted damages to involved or other assets, reduced project life and dissatisfaction among public. Successful Implementation, adoption and to sustain such developments require inclusion of multiple agencies and synchronized working. Real time dashboards are being created for each utility agency within city, GIS mapping of their services and equipment's is done, this data driven development approaches could be more utilized more effectively by providing a unified harmonized platform to the end consumers in the form of quality services.

Consumer service distribution among multiple agencies results into reduced ownership towards task and overlapping of services. Consequent to this is failure in rendering of site execution and delivery of quality service to consumers.

II. Annual External Damage of Power Discoms Assets

During development works carried out by utilities operating in city any lack of communication and coordination results into major damages to utility assets. 85% of 11000V High Tension network in Delhi is underground and hence such outspread laid out network is likely to be in domain of under any ongoing or proposed project. Be it road widening works being carried by Municipal Corporation, public works department or new optical network laying by broadband service providers these underground 11KV cables are vulnerable to damage.

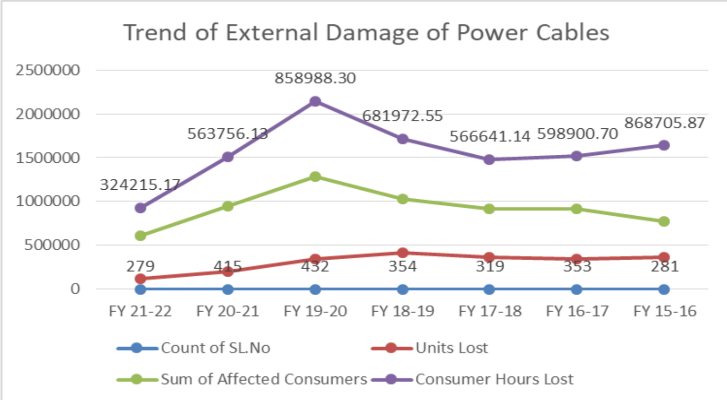

Figure 1: External 11KV Cable Damage trend of DISCOM

Details of Underground cable damages due to external agency works was captured in interruption report of DISCOM. When these events were analyzed, then trend of number of such events was nearly constant at 300-400 damages every year. Such events impact on utility performance was significant. Cable damages was within 80% of fault SAIDI Contributors and shared 6%-8% of total consumer hours lost each year.

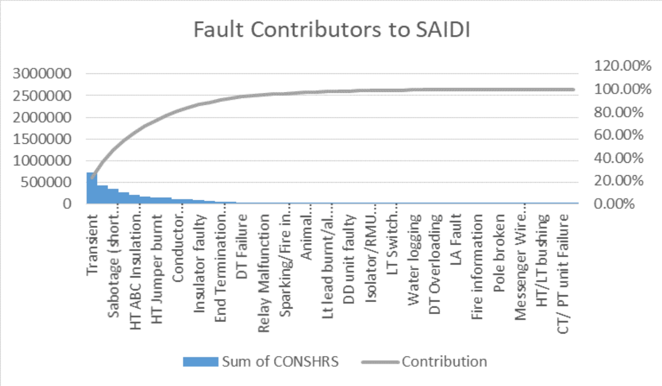

Figure 2: Fault Contributors in SAIDI

In terms of reliability indices and energy sales, impact on SAIDI was in increasing trend till COVID year as well as FY 20-21 and also same was trend in SAIFI. Energy sale loss was accounted around 3.5 lakh energy units each year due before COVID. There was 50% reduction in such events during COVID years due to limited development projects going on. Considering ABR of 6.5 Rs/KWH, annual unit sale loss to DISCOM amounts to approx. 27 lakhs annually.

III. Multiple Ownership a Stumbling Block in Consumer Service

Across the city multiple utility claim their territory/authority. Local Municipal Corporation, PWD, Industrial development body, Water department, Flood department, electricity boards etc. play their respective roles in running the lifelines of the city. Also based on landownership or road ownership, different services/functions responsibility such as street lightning, cleaning, repair & maintenance is assigned. Ambiguity in responsibility center and lack of skilled manpower leads to collapse in disbursement of duties which creates gremlins such as dark pavements, potholes, water logging, non-functional and unsafe utility systems etc.

Figure 3: I&FC Road Widening work and perilous electrical network

Currently three development projects (Pusta Road widening work in Burari, Cycle pavement work from Rithala to NSP by PWD and CC road construction by in Badli Industrial area) came under observation where major damage to power company network was done and execution of work under development plan had been completed without network restructuring of Distribution Company. This have two major impact, one is safety and reliability concerns due to current condition of network and other is damage to newly executed work (ex. Roads, drains, pavements etc.) which will occur due to revamping to be executed by power distribution company.

Figure 4: Dangerous electrical substation due to CC Road work in DSIDC area

Figure 5: UG Cable damage by PWD Works

During finalization of these development projects coordination with linked utilities was not done. Hence during work execution many hurdles came due to damage of electrical underground cables, water pipelines, filling around electrical substations etc. Many interruptions due to such works further deteriorated reliability of network made network more vulnerable to faults by decreasing its sturdiness. Also, in event of any minor fault condition or overloading now this sick network becomes more prone to fault. Electrical substations are widely located near load centers and hence any unsafe condition of them is a threat to human life, such uncoordinated plan between utilities raise safety concerns for residing consumers.

Also such damages are being done to other utility assets, after cost of repair/replacement is to be borne by concerned department which is again a burden to taxpayers. Moreover, by the time such cost is received for replacement, primary project gets into completion stage and post this work carried by victim utilities damages the newly constructed assets and hence a continuous damage-repair cycle begins. Further, in near future any new project in the same area of other utility if comes up, then this again becomes a pain for residing consumers due to repeated construction works.

Figure 6: Picture depicting condition of Karol Bagh Streets

In 2019, Delhi government completed Beautification work of Karol Bagh market and similarly next year same was done for Chandni Chowk. During work in Karol Bagh market the utility undertook only works related to streets and lightning and electrical, communication and water agencies were not coordinated during execution or planning. Later on due to breakdown or new project coming up of other agencies streets were again damaged and temporary repair was done. Series of such digging and repair & maintenance resulted into degrading beauty of market if observed as on date.

Figure 7: Water Logging after monsoon in DSIDC Area Delhi

Drainage systems alongside roads are designed for scheduled cleaning for proper disposal of water on roads and provide clear roads for vehicle movements. Similarly, streetlight is also needed to be maintained after any breakdown event and regular billing of energy usage is to be settled with Energy Company. Currently based on land/road ownership responsibility of drainage cleaning, payment of street light maintenance and energy usage, road maintenance is assigned. In Delhi, DSIDC areas land owning DSIDC claims no ownership on roads and road owning MCD convers land is owned by DSIDC hence rod ownership and maintenance pertains to DSIDC. This lack in clarity of ownership has created such a major nuisance for public. Every monsoon season due to lack of drainage cleaning heavy water logging in Industrial areas could be experienced. Also as payment of street light on roads is not being made by either party, dark roads can be seen all along the industrial area.

Figure 8: Dark Roads due to Non Functional Street Lights in DSIDC Area Delhi

Figure 9: Unsafe Street Light Boxes and Unsafe Street Light Installation Work during road widening work

Any utility has its own section for electrical works, civil works or horticulture. These trivial section workers are trained but not as skilled and experienced as primary utility workers. During I&FC work of road widening, street light poles and fittings were being installed by concerned department. For that two men climbed over hydra in a trolley without PPE and just went on installing this light fittings pole by pole.

Figure 10: Water logging in underpass due to non-functional motors

Similarly, due to distributed responsibility unsafe street light control panels, breakdown of drain motors due to lack of maintenance, non-functional traffic lights etc. can be seen very often across the city.

IV. INOVCATION OF UTILITIES UNDER ONE BANNER

Each utility working in city is guided by set of regulations set by an autonomous regulatory body. By laws they function and dispense their duties. As their regulator and management is self-governing coordination with other utilities and adherence to laws and systems of each other stalls. A single body to regulate, advise and govern this motley crew of utilities will simplify the execution of duties, bring down the lead time in project completion and resolution of complaints and improve services for consumers. Single body will improve cross organization coordination reducing time lost at approval desk and reduce corruption.

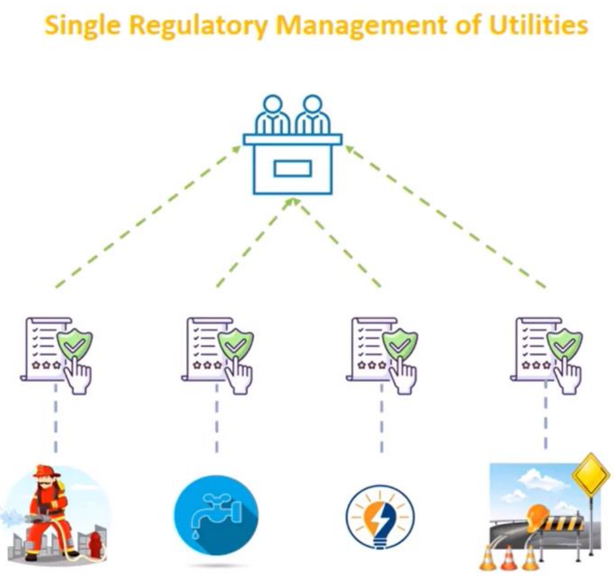

Figure 11: Depiction of Single Management & Regulatory control of utilities

A single body can channelize effective alliance between utilities to work together with integrity to make best for project decisions, manage risk and share gains and pains to deliver the best services to consumers. Further they can ensure sharing of ownership, adherence to common set guidelines and policies to guard interest of each utility for ensuring their sustainability and deliver rich consumer experience.

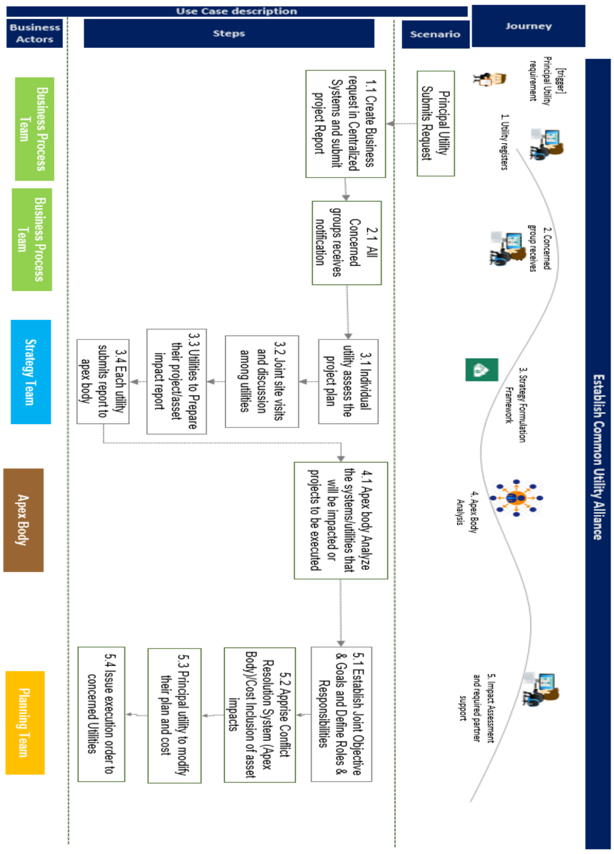

Figure 12: Common Utility Alliance - To be Procedure

Parallel to finalisation of development/improvement projects of a utility in particular area, apex body will conduct a coordination meeting with all agencies involved in particular area. This would ensure planning for shifting of assets pertaining to development project location. Also, in such meetings near future development plans in suggested location of all utilities will be discussed so that simultaneous execution can be ensured to avoid reiteration. Also such coordination meetings can be held monthly by apex body for ensuring smooth flow and approval of cross departmental request such as digging permissions etc.

A Skilled manpower can execute task efficiently and deliver quality results at same time to save time. Within a city if specific job is allocated to a particular group will definitely enhance standard of services delivered by eradicating ambiguities. For example, allocating all electrical related works such as streetlights, motors, traffic lights etc. to power Distribution Company will enhance ownership of work along with providing an additional source of revenue to discoms. Also as utility with primary job will be having all resources and training ensuring safety of field team and nullify safety concerns of consumers as well.

V. CONCLUSION

Distributed & unaccompanied function cause damages to public assets which either way could have been prevented. Also repetitive work at a particular site cause unnecessary inconvenience to residents. Formation of an Apex body for a Smart city and bringing all utilities and their regulator bound by their law and answerable to apex body will imbibe coordination and co-development culture along with eradicating disconcerting among residents. Aligning utilities together and ensuring they function with consideration of each other will definitely reduce cost of projects and bring down operational expenses

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Robotic Process Automation empowered Self functioning Utility Processes ecosystem

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I. INTRODUCTION

In RPA, Robotics means a configurable software, that sits on top of a company's existing IT infrastructure, pulling data, performing algorithms, and tasks. The "robot" is configured to complete the same process steps, follow the business rules, and use the same systems that a human does today. RPA makes the most significant impact on manual work processes, that are repetitive and recurring, and often have high human error rates. RPA needs a digitization strategy; prioritization of the right processes, governance approvals, and development, testing & deployment protocols. It needs an infrastructure to manage the new robotic workforce and support future RPA changes.

RPA software is an automation tool provided by "Automation Anywhere". Using this tool, we can automate business processes, workflows, reports & daily repetitive tasks. It works based on parameter configurations and enhanced logic.

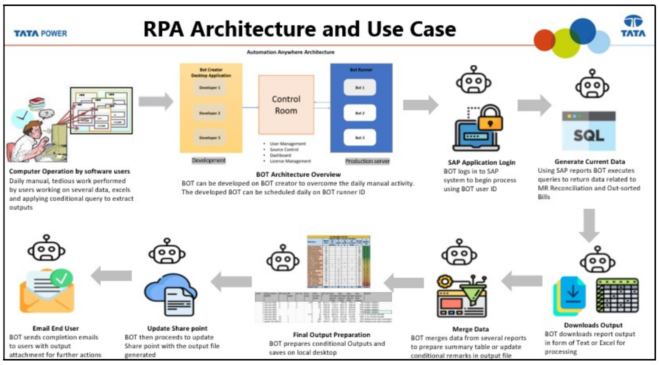
RPA Bot is a virtual robot, which mimics human actions by setting pre-defined rules & parameters and defining various tasks as per the process steps. RPA streamlines workflows, which makes organizations more profitable, flexible, and responsive. It also increases employee satisfaction, engagement, and productivity by removing mundane tasks from their workdays. We have implemented RPA automation tool for Billing & Meter Reading functions. We will be deploying RPA for various other process like Consumer life cycle monitoring, Tariff register compilation & analysis, Provisional v/s. Actual Billing, Storage space optimization, etc.

Objectives :

1. Improve digitalization index, Cycle time reduction, eliminate manual errors, improve workforce productivity
2. Cycle time for preparation of monthly MIS and for analysis of Implausible meter readings and out sorted bill documents to be reduced
3. Elimination of manual intervention and manual errors involved in current process.
4. Improve work force productivity by saving time involved in activities like downloading data and processing it for further analysis and decision making
5. Downloaded data, further analysis and reconciliation to be captured at central location which will be easily accessible to all stakeholders

Technology used: Automation Anywhere RPA tool to configure Bot and run bot at scheduled intervals. SAP server for execution of various reports and downloading report outputs. Microsoft Share point – Central storage of final Summary files

RPA Architecture



II. EASE OF USE

A. *Overview of RPA*

Robotic process automation is a technology that makes it easy to build & deploy, virtual robots that emulate humans' actions interacting with digital systems and software. Just like people, virtual robots can do things like understand what's on a screen, execute the right keystrokes, navigate systems, identify, and extract data, and perform a wide range of defined actions. Software robots can do it faster and more consistently than humans, without the need to get up and stretch or take a coffee break.

RPA is a form of business process automation that allows anyone to define a set of instructions, combination of automation, computer vision, and machine learning to automate repetitive, high-volume tasks that are rule-based and trigger-driven. RPA automates daily processes that once

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required human action. Following are the basic requirements for RPA: The process must be rule-based. It must be repeated at regular intervals or have a pre-defined trigger. Process must have defined input and output parameters and formats & the tasks must have sufficient volume to optimize the efficiency

B. *Improving workforce productivity*

Automation saves efforts & time which is spent for daily repetitive work. Employees can focus more on analytical and productive tasks. RPA Bot developed to automate BQC analysis & Meter data analysis process, has ensured 100% accuracy in analysis, saved time, enhanced morale of employees, increased billing efficiency, improved digitalization index. It does not require coding as it is a configuration tool to define sequential tasks to perform each process step.

III. Implementation Journey

Bill quality check is a critical process and needs to be executed with utmost commitment. With defined parameters & validations, the exceptional bills get out sorted considering current bill amount, connected load, contract maximum demand, number of days, variation percentage as compared to past history and various such parameters. Earlier, data for analysis was downloaded from various reports and analysis of these out sorted cases was carried out manually. Based on such analysis, the cases were released or reversed considering the above parameters and the outcome. Around 2.5 to 3 hours were spent on a daily basis to complete this activity. Ensuring accuracy was a challenge as it was person dependent and skill dependent.as huge volume of data was downloaded from various reports and collated in a single file, for further validations and analysis. These files remain on personal drives and are sent to other team members via email. This holds true for all such critical processes and hence the need for RPA has increased.

A. *Abbreviations and Acronyms*

RPA-Robotic process Automation.

BQC-Bill quality check

B. *Units*

NA

C. *Equations*

NA

D. *Implemented Use Cases*

1. Bill quality check : Bot has eradicated manual intervention and ensured 100% accuracy in analysis, validations, filters and calculations. It has saved around 2.5 TO 3 hours on a daily basis. It has improved employee engagement and productivity
2. Meter data Analysis for AMR enabled meters has helped to save around 2 hours on a daily basis as meter data is extracted and analyzed to ensure correctness of meter connection with respect to Current & Voltage parameters.
3. Meter reading reconciliation Bot has saved 3 hours on a daily basis as huge data is downloaded from various reports and collated in a single file for further analysis for tracking and optimizing meter reading and billing efficiency.
4. Master data reconciliation Bot executes 38 various reports to ensure data integrity and consistency in various master tables in the system which in turn ensures accurate billing to consumers and smooth execution of all customer processes. In case any discrepancy is found , auto email is triggered to respective team members to take corrective action. This automation has saved around 2 hours on a daily basis.
5. Manpower Deployment Matrix Bot analyzes data from various systems and ensures optimum utilization of resources at the site. The final output is stored on shared storage site for management reviews. This has saved around 3 hours on a daily basis.

All the above Bots store the final MIS files on a central folder which is accessible by respective team members only. Email notifications are also sent to respective teams along with attachments containing the required data.

Few other use cases that are being developed currently are mentioned below :

1. Consumer life cycle monitoring
2. Tariff Register compilation & analysis
3. Reading Quality checks
4. Storage space optimization

Benefits of RPA Use case Implementations:

1. Elimination of repetitive tasks, reduction in manual efforts resulting in Cost Saving
2. Significant Process improvements
3. Redeployment of resources to higher value functions
4. Improved Productivity
5. Improved Quality and performance
6. Improved Customer Service
7. Reduce human errors

IV. Authors and References

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Shivani Prakash

B. *References*

Automation Anywhere had arranged for demo session for business & D&IT team and discussions about various use cases were held. Use cases for implementation were identified and documented for further configurations.

RPA Use Cases

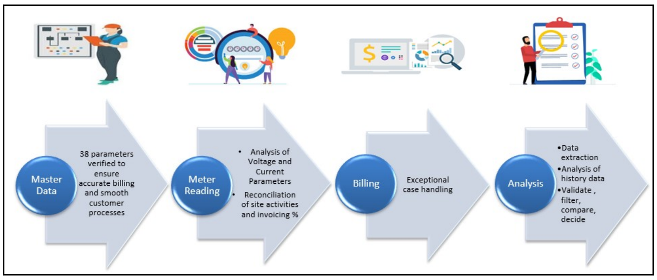

Fig. 1 : Illustration of high level use cases

Current BQC process cycle time

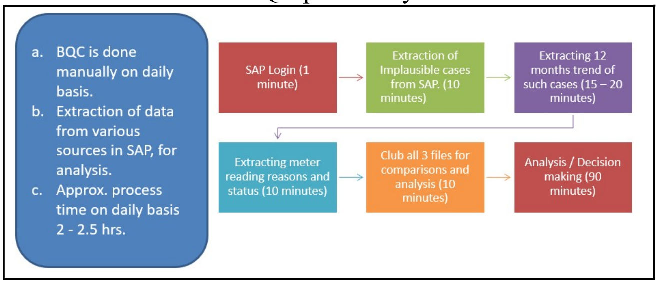

Fig. 2 : Illustration of current BQC process

BOT configurations in Automation Anywhere Tool

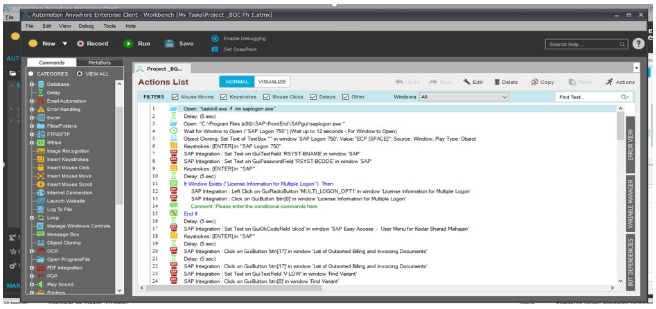

Fig. 3 : Illustration of BOT configurations

a) Fig. 1 llustrates the high level RPA use cases that have been implementedin our organisation Fig. 2 explains the various steps of BQC process that have been automated to save manhours and improve workforce productivity. Fig. 3 illustrates the Bot configuration using the Automation Anywhere tool.

ACKNOWLEDGMENT

We would like to thank Mr. Jayant Dabholkar and Mr. R M Kasarpatil for their support and guidance throughout the project implementation. Special thanks to Mr. Pratik Tated for supporting us in technical matters and guiding us throughout the project ensuring that best practices are adopted during the implementation.

CONCLUSION

RPA has accelerated Utility process steps. The adoption of RPA has offered opportunities for further automation and efficiency gains. However, it is critical to identify the scope, define the appropriate governance , support improvements and ensure integration with various systems within and outside our landscape, to ensure smooth implementation.

Introduction of Tower Mounted Substation

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Abstract— This paper highlights applications and advantages of building inhouse tower mounted substation in a Mumbai City where space is a major constraint. The customer substation installed in customer premises to provide the power supply to customer. Normally Substation comprises of HT Panel, Transformer and LT Panel. And to install these equipment's customer has to allot the space to utility in his premises. Considering the space constraint in metro city, the customer has very conservative approach and ask utility to reduce the footprint of substation, which is big challenge for utility to accommodate all equipment in small footprint.

To overcome aforementioned challenges, the TATA Power Mumbai has developed the new tower mounted substation, which is optimally sized and offer an overall space/footprint reduction of around 60% when compared to its conventional substation. The product is designed inhouse, keeping all electrical clearances intact, the regular distribution equipment can be fitted in this arrangement, no special equipment is required for this arrangement.

Keywords— Distribution, CSS- Consumer Substation, Tower Mounted, G+1 structure substation.

Introduction

Tata Power, a pioneer in providing reliable and uninterrupted power to Mumbai City, caters to the power supply requirement of large number of Residential, Commercial & Industrial customers. Tata Power being committed to lead adopter of latest technology has taken up the drive of modernising its Distribution network with introduction of new in-house tower mounted substation.

To provide the power supply to customer, the power utilities install the substation in customer premises. The substation comprises of equipment HT panel i.e., Ring Main Unit (RMU), Transformer, Low Tension Panel (LTP). These equipments needs to be installed with the proper clearances in the allotted space given by customer. This arrangement can be indoor/outdoor as per the site conditions wherein for installation conventional substation 8m * 5m (40 sqm) footprint is required.

A. *The problem*

Mumbai is vertically developing city, where space is very valuable asset. Hence the developers in Mumbai city have very conservative approach while allotting the substation space to utility. Considering the space constraint , developer asks utility to further reduce the footprint which is typically required for utility, which is a big challenge for utility to accommodate all equipment in such a small footprint. Optimization on equipment footprint and size was already reached in past and as such some new approach on arrangement of installing the equipment was required without compromising on electrical clearances as per statutory norms.

Mumbai is the only city where parallel licensing for different utilities is present, which brings the stiff competition between the utilities for customer acquisition. This enables developer to negotiate with utilities in order to reduce the footprint of CSS. Reduced footprint of proposed CSS is one of the key deciding factors for Customer while selecting utility. Thus it may result in loss of prospective customer due to challenge of space constraint.

B. *The approach*

Considering the overall scenario, change in design was the need of an hour. The Tata Power engineering team has worked for several options to reduce the footprint.

The use of package substation was immediate available alternative, but dependency on product design & maintenance of equipment, equipment replacements were putting complete dependency on particular OEM, which could be recurring cost.

Thus, out of various options vertical design was found as a golden middle. The CSS is designed ensuring all electrical clearance in place, ease for operations on equipment for day-to-day activities, ease for equipment replacement-transformer augmentation if required and most important aesthetics of overall design so as to align to customer's theme.

C. The arrangment

The design was planned in such a way that the RMU (HT Panel) and LTP (LT panel) were on ground level and structural arrangement was made above these panels for installing the transformer. A person can access the transformer by accessing the ladder to the structure. A person can move all sides to transformer for inspection or maintenance of transformer. Following are the key highlights about this project

The equipment design and arrangement were proposed on G +1 structure where some equipment will be on the ground level while the remaining equipment will be placed on the above of the equipment. (Ref: Fig 1, Fig 2)

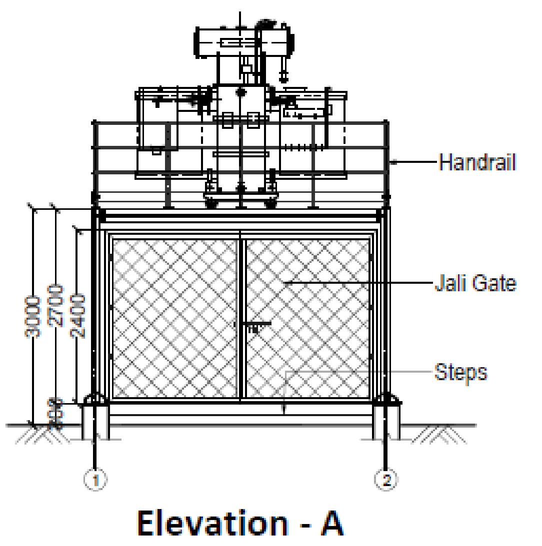

Fig-1

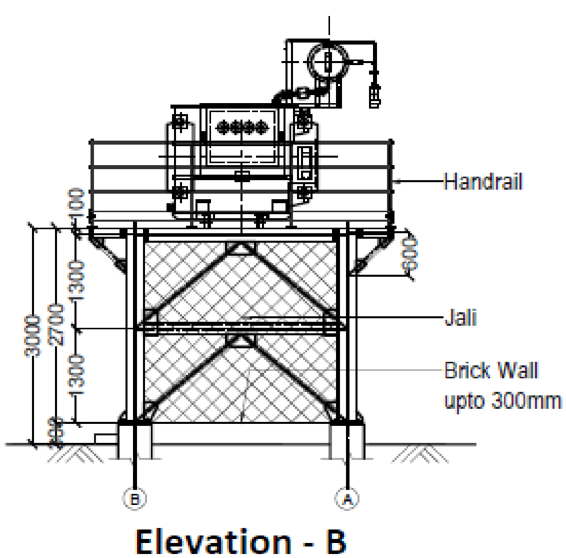

Fig-2

D. The Challenges & Remedies

Fitment of all electrical equipment's in such a compact space keeping all safety parameters intact was the biggest challenge. To overcome it, the structural study was done thoroughly for mounting the transformer on the steel made structure.

The footprint for new design was finalized as 4m*4m (16sqm). The RMU, LTP equipment's were kept on the ground level. The Transformer was kept on the structure made arrangement above this equipment. Additionally, a ladder arrangement was made to access the transformer above. This overall design setup was found helpful to accommodate all equipment's in given space.

Few vendors have approached with his G+1 compact design, the overall costing for the overall setup offered by vendors was 40% costlier than the conventional substation. Also, the offered product by vendor was not type tested as per the standards and hence such equipment could not be used for safety concern.

To overcome this, the engineering team gave a rethought about the design and decided to make the arrangement inhouse. The structural designing was carried out by civil experts of TATA POWER.

The design was newly introduced and hence the necessary statutory approvals were needed to be in place. The same was discussed with the electrical Inspector (Government Of Maharashtra) for necessary approvals and then the new design was moved ahead with the consent of the authority.

E. Risk & Remedies

Deferring the conventional approach of CSS design with new approach was slightly disruptive.. The tower mounted has G+1 structure where the transformer is mounted on more than working height. Hence while working on the transformer, the risk of falling was a safety concern.

The barricades were installed on all sides of transformer to avoid fall of man/material. The design also required capacity for load augmentation. To overcome the risk/challenge, the structure was strengthened enough to hold the weight of transformer more than the current rating.

F. The Dimensions

Typical Dimensions for Substations

- RMU – 1.2*0.8
- LTP – 1.8*0.8
- Transformer- 2.4*2.4
- Footprint at Ground Level – 4*4
- Height from Ground to first level – 3
- Height from First Level – 3 (Open to sky)

G. The Final Product

H. Benefits

- Footprint reduction of the substation enabling Customer delight and making Tata Power as a Utility of Choice
- Cost effective solutions upto 30% compared to other available solutions/approaches with innovative designs.
- No specialized equipment is required for this design resulting into minimum dependency on particular OEM
- No dependency on OEM for material or maintenance of product.
- Design can be modified as per the site conditions
- Flexible Design: Transformer augmentation is possible unlike any other product.

PLANNING TOWARDS ENHANCED GRID DISCIPLINE AND GRID RELIABILITY IN THE POWER SYSTEM OPERATIONS IN SOUTH ASIAN REGION

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Abstract— The significance of energy is very important for the socio-economic development of South Asian countries. It is essential to ensure access and availability of energy. In the pursuit of providing these requisites, the importance of sustainability of the grid in South Asian region has to be taken under consideration. With a view to operate the grid in a smooth and reliable manner, it is crucial that all the participants connected to the grid follow common principles. For instance, the grid code of every South Asian country has to be harmonious within the interconnected countries to ensure smooth power trade across the borders, the scheduling process and granularity of time blocks of scheduling should be the same, for integrated grid operation. Similarly, there needs to exist harmonious connectivity standards, so that there is protection and insulation coordination, to prevent insulation failures that can lead to unwanted tripping. In near future considering the penetration of intermittent nature of renewable energy sources and electric vehicles, there is necessity for secure, safe, reliable integrated grid operation through a sturdy regulatory framework. In the conclusion, certain regulatory measures or interventions will be needed to maintain grid discipline & grid reliability in order to get the unification of regional grid in South Asian region.

Keywords— electricity trade, regulatory interventions, mechanisms, grid discipline, grid reliability.

I. INTRODUCTION

The economic growth in South Asian countries (SAC) rose to 7.5 % from 6.2 % between the year 2013 & 2016 [1], that is expected to follow a strong growth trajectory up to 6.7 % in 2021 and owing to this growth, the energy demand is anticipated to increase in near future. Cross-Border Electricity Trade (CBET) in South Asian region has increased in last eight years. With the emergence of more transmission interconnections and projects in the pipeline, we expect that electricity trade will quadruple in the next decade to come. The policy framework with respect to CBET has also become strengthened in recent years and it has made conducive environment for power trade, especially among Bangladesh-Bhutan-India and Nepal (BBIN) region. It will eventually become a regionally integrated power system in South Asia. In CBET, the engagement of multi-disciplinary stakeholders like GENCOs, TRANSCOs and DISCOMs etc. possess challenge and threat to the power grid. The responsibility for maintaining and improving Grid discipline & Grid reliability is entrusted on entities that have overlapping and, very often, have inadequate administrative responsibilities. These entities range from central planning authorities, central & state regulatory bodies to regional and state load dispatch centers etc. In South Asian countries (SAC), multiple agencies have various business models to manage grid discipline & grid reliability. Some of the key challenges in maintaining the Grid Discipline & Reliability due to growth in CBET transactions are a) Dissimilar sets of regulations, guidelines and technical standards across countries involved in power trade across nations; b) Absence of relevant commercial mechanisms for deviating from norms; c) Difference in regulatory framework coupled with different stage of maturity in every South Asian country which impose miscellaneous level of problems for implementation of Grid Discipline & Reliability in interconnected grids.

This paper describes the regulatory interventions that will be required to improve Grid Discipline and Grid Reliability in the power system operations in South Asian region.

.

II. BACKGROUND

All the eight countries of South Asia i.e. Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka have a total land area of 5,135,481 sq. km. consisting a population of 1.79 billion. In terms of land area and population, Afghanistan, India and Pakistan dominate in the region. The island countries are Sri-Lanka & the Maldives. Bangladesh, India and Pakistan have coastal boundaries with Indian Ocean and the land-locked countries are Afghanistan, Bhutan and Nepal.

At present, the cross-border electricity trade, in South Asia, is taking place between Bangladesh, Bhutan, India and Nepal (BBIN). Across these countries, India is geographically placed at the centre amongst BBIN nations. It has interconnections with Bhutan and Nepal through AC link. Interconnections with Bangladesh is through HVDC back-to-back link. Looking at the quantum of cross border electricity trade in BBIN region as given in **Error! Reference source not found.**, it has increased to 18.74 billion units in 2021 from 9.38 billion units om 2015, a two-fold increase in the CBET transactions. [2]

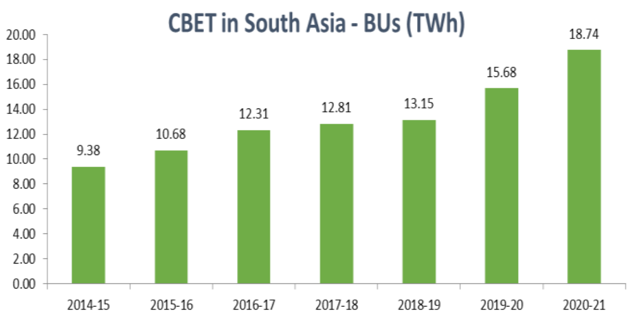

Figure 1: CBET in South Asia

Likewise, the total installed capacity in the region is 466214 MW in which approx. 85% of the capacity belongs to India. [3]

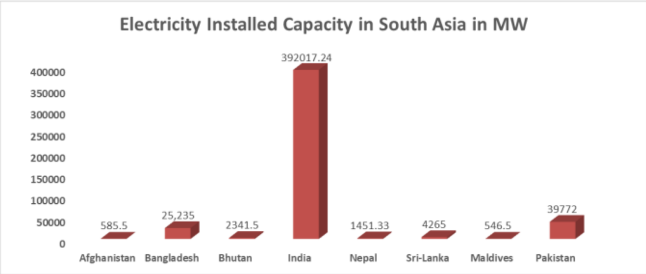

Figure 2: Installed Capacity in South Asia

The countries in the region also differs in the fuel mix. Nepal and Bhutan have rich hydropower resources. Bangladesh is a gas-based economy whereas India is dependent on coal and Maldives relies on oil-bases electricity generation. In terms of energy market development and sector reform, different countries are placed at multiple stages of market reforms. Countries like Bangladesh, India and Nepal have set up an Independent Transmission organization. It has been seen that only India has made departure from single-buyer model and is the only country that has retail competition in the sector.
These elements exhibit immense potential for cross-border energy trade in the region. In this direction, it is essential to work on frameworks/operation guidelines and identify key issues related to grid discipline & reliability in South Asian countries and accordingly devise the mechanisms to improve the same.

III. GRID DISCIPLINE AND GRID RELIABILITY

A. *Grid Discipline*

In a power system grid discipline refers to the adherence of operating rules, procedures, criteria and guidelines by generator, transmission & distribution companies with the objective to avoid grid failure that may arise due to withdrawal of more power than they are actually entitled to.

As CBET strengthens in South Asian region it will possess unique set of challenges in grid discipline. The trading of electricity across the boundaries requires robust technical compatibility and operational coordination. Difference in country-specific rules, standards and commercial mechanisms may impact grid stability, negatively in the form of tripping, voltage collapse etc.

B. *Grid Reliability*

Grid reliability can be described as the ability of the system to endure the instability, disturbance, uncontrolled events or unanticipated loss of system components and at the same time provide seamless supply of electricity by taking into account scheduled or unscheduled outages of system components. The ISO New England defines Grid Reliability as the ability to supply electricity when the consumer needs it and to withstand disturbances on the system.

Pertaining to growth of CBET, the participants from different countries shall follow similar rules & principles to ascertain reliability for planning and operating the interconnections.

IV. KEY INDICATORS THAT DEFINE GRID DISCIPLINE & GRID RELIABILITY

A. *Frequency Variation*

Frequency variation highlight load – generation balance in the grid at certain instance. The grid frequency is always kept within the specified range to ensure grid discipline and grid reliability.

B. *Voltage Variation*

Voltage violation may happen due to inadequate supply of reactive power, mismatched transformer taps and impedances, blown capacitor fuses, open-delta regulators, or open-delta transformers, overloaded/underloaded circuits, etc.

C. *Planning Reserve Margin*

It measures the amount of available generation capacity to meet the demand.

D. *Frequency Response*

It is a measure of an interconnection's ability to stabilize frequency immediately following sudden loss of generation or load.

E. *Partial or Complete Grid Disturbance*

It is the number & duration of outages in a power system

F. *Tripping per line and Tipping Duration per line*

It is regarded as an interruption in electricity supply. Tripping per line is the count of interruption over a period of time (daily / weekly/ monthly/ yearly) and tripping duration is the interval of time for how much duration an electric line is tripped.

G. *Angular Stability*

An unplanned or forced outage necessitates monitoring of PMU angle differences (Phasor Measurement Unit), a useful quantity, which is a means to measure angular stability.

H. *System Adequacy*

It can be referred as the ability of the system to supply the aggregate electrical demand and energy requirements of the end-use customers throughout.

I. *Total Harmonic Distortion*

It is the voltage & current harmonic distortion. It is used to measure power supply quality.

V. MEASURES TO ACHIEVE GRID DISCIPLINE & GRID RELIABILITY

A. *System Planning*

System Planning is a measure that primarily focuses on network design decisions, augmentation and capacity addition of generation resources, CBET growth, frequency variation limits, estimation & declaration of transmission capacities in advance, frequency variation limits & voltage variation limits..

B. System Construction & Safety

System Construction & Safety refers to provisions for the design, construction, operation and maintenance of power plants & transmission lines including safety requirements.

C. Grid Connection

Grid Connection refers to the development of connectivity & operational criteria to ensure that existing transmission system does not face adverse impacts due to increase in demand of electricity and addition of conventional & non-conventional generation capacities over the time.

D. System protection, testing and commissioning

System protection, testing and commissioning focuses on prevention of system damage, protection audit plans, special protection schemes and testing & commissioning guidelines so as to maintain stability in system and allow seamless transfer of power.

E. System operation

System operation is a key measure that has diverse functions such as ancillary service mechanisms, commercial mechanisms such as frequency-linked Unscheduled Interchange (UI) or Deviation Settlement Mechanism (DSM) for grid discipline and frequency control schemes, system restoration plans, system security measures, demand management and outage planning procedures etc. to match supply-demand while maintaining the reliability of the grid.

F. Scheduling and dispatch

Scheduling and dispatch refer to preparation & coordination of generating schedules in time blocks to meet the demand. Demand estimation, ramping rate, scheduling of cross border transactions are some of the aspects of scheduling & dispatch.

G. Information and communications technology

Information & communications technology is a measure that refers to communication facility necessary for communication & data exchange between users of the grid. It includes SCADA / EMS, WAMS / PMU for real-time operations.

H. Monitoring and compliance

Monitoring & compliance refers to implementation of rules, regulations, policies, guidelines etc. to maintain grid discipline & grid reliability. This measure can be achieved by demarcation of roles & responsibilities of concerned authorities, periodic reporting of performance parameters, third-party audits and Periodic monitoring of actual performance of grid operators and grid users against standards of performance.

An outlook on commercial mechanisms for grid discipline and frequency control is provided in Table 1 that signifies the need for such interventions required in the region.

Table 1: Outlook on Commercial Mechanisms

Country	Frequency-linked Unscheduled Interchange (UI) or Deviation Settlement Mechanism (DSM) for grid discipline and frequency control
Afghanistan	Information not available
Bangladesh	No commercial penalty/incentive mechanism for frequency management
Bhutan	
India	• As per clause 7 of Central Electricity Regulatory Commission (Deviation Settlement Mechanism and related matters) Regulations, 2014, frequency linked deviation settlement charges under-drawl and over-drawl of electricity governed by Central Electricity Regulatory Commission (Deviation Settlement Mechanism and related matters) Regulations (CERC DSM Regulations), 2014 and its five subsequent amendments. • As per clause 4 of Central Electricity Regulatory Commission (Deviation Settlement Mechanism and related matters) (Fourth Amendment) Regulations, 2018 frequency band is restricted from 49.85 Hz. to 50.05 Hz. • As per clause 2 and 3 of Central Electricity Regulatory Commission (Deviation Settlement Mechanism and related matters) (Fifth Amendment) Regulations, 2019, DSM penalties are linked to clearing prices in Day Ahead Market. [4] [5] [6]
Maldives	Presently Maldives does not have electricity transmission grid.
Nepal	No commercial penalty/ incentive mechanism for frequency management.
Pakistan	
Sri-Lanka	

VI. Gaps in Grid Duscipline & Grid Reliability in SAR

The chart below represents country-wise identified gaps with respect to sector framework & institutions, regulations, rules, codes and standards, and implementation and compliance of identified measures.

Key need gaps identified during the study	Afghanistan	Bangladesh	Bhutan	India	Nepal	Pakistan	Sri Lanka
System Planning							
Absence of standardized detailed manual on system planning	●	●	●	◐	●	◐	◐
System Construction and Safety							
Inadequate measures in system construction and safety.	●	●	●	◐	●	◐	
Grid Connection							
Absence of detailed procedure for grid connectivity.	●						
System protection, testing and commissioning							
Absence of standard system protections measures for ensuring grid discipline and grid reliability.	●					●	●
System Operations							
Absence of ancillary service market which is helpful in relieving congestion and minimising frequency fluctuations in the grid.	●	●	●		●	●	●
Absence of standardised operating procedure outlining operational planning, system security, demand management, outage management.	●			◐	◐		
Absence of imbalance settlement mechanism to handle real-time imbalance in the system.	●	●	●		●	●	●
Scheduling and Despatch							
Absence of detailed framework for CBET	●	●	●	◐	●	●	●
Absence of provisions to promote declaration discipline	●	●	●		●		●
Absence of provisions for compensating Gencos for forced under performance	●			●			
Information and communications Technology							
Need for adoption of advance operation technology and ICT infrastructure for reliable operations.	●		●		●	●	●
Cyber security standards for critical information infrastructure are absent.	●	●	●	◐	●	●	●
Monitoring and Compliance							
Inadequate provision to publish information related to power system in public domain.	●		●		●	●	●
Inadequate performance monitoring indicators	●	●	●		●	●	●

◐ **Partial Gap:** Steps are taken but scope for further strengthening and advancement ● **Gap:** Steps to be taken to overcome identified need gaps

Figure 3:Country-wise Identified Gaps

VII. Suggested Regulatory Interventions required for enhancing grid discipline and grid reliability in SA Region

A. Regulatory intervention for System Planning

A regional regulatory framework must set out a regional transmission planning criteria. At present there are no broadly recognized guidelines that determine the benchmark for transmission planning. A comprehensive transmission planning criteria shall include scope and philosophy for system planning, system reserve requirements, nominal voltage limits, scope for special protection systems, power quality limits (harmonics), system studies (load flow, short circuit etc.) and an assessment of system over a ten-year period. This will facilitate a consistency in system planning and an acceptable measure of adequacy and security. Thus, it will ensure an acceptable system performance.

B. Regulatory intervention for System Construction & Safety

A regional regulatory framework must specify standards related to system construction and safety for the interconnectors. It is recommended for South Asia Region Regulator to enforce a global-standards for system construction & safety like electrical safety standards defined by the Occupational Safety and Health Administration of the United States Department of Labour or the National Electrical Safety Code (NESC) by Institute of Electrical and Electronics Engineers IEEE

C. Regulatory intervention for Grid Connection

A regional regulatory framework shall chart out a procedure in detail for grid connection for different grid users. It is essential to homogenize the process for grid connectivity by describing test requirements for power system components like HVDC and FACTS devices, asynchronous generators and non-synchronous generators.

D. Regulatory intervention for System Operation

A regional regulatory framework shall publish procedure for operational planning, system security, demand management, determine key system performance indicators outage management and partial or complete grid disturbance and delineate grid incidence and disturbance like events. Similarly, regulatory interventions would be needed to build-up an ancillary service market in each South Asian country with the advent of increase in cross border electricity trade transactions in upcoming years. This can be commenced by acquiring ancillary services from the hydro power dominated nations like Bhutan, Nepal and Afghanistan under the surveillance of regional system operator. After substantial period of time, a market-based approach could be established. It can have a regulation for providing ancillary services that will entail participant's eligibility, establishment of a nodal agency, roles & responsibilities of participants, methodology for energy accounting and scope for financial settlement.

E. Regulatory intervention for Scheduling & Dispatch

A regional regulatory framework must incorporate penalty mechanism for maintaining grid discipline in context of interconnections. The penalty shall be levied on generating entities for misdeclaration and on distribution entities for inaccurate demand forecasting. A higher margin could be allowed in the meantime while beyond time the margin allowed for misdeclaration shall be gradually curtailed and penalty amount could be substantially increased to implement grid discipline in an interconnected grid. For better coordination of cross-border electricity trade, a framework shall be devised and implied in every South Asian country. It shall embrace nodal agencies & designated authorities for coordination of cross border power trade, a comprehensive procedure for scheduling & dispatch to help transactions, provisions pertaining to real time deviations, strategy for energy accounting & harmonize metering arrangements.

F. Regulatory intervention for Information & Communication Technology

South Asian countries must strive to undertake advanced technology including Information and Communication Technology and operational technologies. A regional regulatory framework shall stipulate the measures to safeguard critical information infrastructure and work on cyber security related aspects to determine critical information infrastructure. Initially, it is advisable that a regulator shall make guidelines for implementation of centralized monitoring system. Standardization of communication technicalities shall be done through technical standard document, which will represent minimum performance requirement. Similarly, protective measures to ensure cyber security must be outlined. The measures will relate to information protection/data storage, protection of communication systems, preparation of business continuity plans etc.

G. Regulatory intervention for Monitoring & Compliance

A regional regulatory framework shall roll-out terms for publishing the monitoring & compliance reports, system performance reports, third party audit reports and other prominent documents at regular intervals in public domain. To enable effective reporting of grid reliability, a uniform approach shall be defined to capture information related to grid performance indicators considering regional interconnection.

Presently, Joint Technical Teams (JTT) assess the dynamics for CBET and conducts feasibility studies, oversees functions of system planning, defines operating voltage. Their scope will be widened after rolling out the above suggested regulatory interventions in South Asian region.

VIII. WAY FORWARD

The electricity/energy regulator of each country in South Asia should adopt a three-pronged approach viz Short-term, Medium-term and Long-term approach. Considering that the maturity of the energy sector is still at nascent stage in few countries, the short-term approach could be to call for legislative measures that should be taken for creation of independent authorities/arms/entities. This shall also include developing the fundamentals such as Grid Codes, Grid Reliability Indicators, protection system philosophies etc. that will be necessary to set the stage for performing regulatory interventions. The medium-term approach would include conducting the technical & feasibility studies, publishing white-papers, model arrangements of measures which define grid stability & reliability. The long-term approach would consider implementation of market-based mechanism, conduct comprehensive consultations to finalize the regulations & related amendments and mandate regular reporting of the indicators in the public domain.

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Flexibility in Power System

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Abstract

Power systems are basically engineered and structured to effectively cater for uncertainty and variability in energy demand and generation availability. However, largescale Renewable and Distributed Energy resources, variable in nature in the power plant mix increases this aspect both in generation and demand and calls for investigation to ascertain flexibility in real time generation and net load.

Flexibility Planning leverages system and individual flexibility of various conventional and renewable resources including BESS, v2G, Prosumers, etc. and their availability and means to enhance ramping facility and improve system stability.

Indian power system operates as a decentralized system of scheduling & dispatching with a thin overlay of centralized systems applications and a small percentage of energy transacted through markets. Hence, Regulatory & Institutional frameworks and special Monitoring & Control tools maintain balance between the market-based solutions and mandatory requirements for achieving the desired ramping requirements. April 2020 Pan India Lights Off Event demonstrated flexibility of Indian power system and some vital take-offs. The comparative performance of power system of some other countries is also made.

The paper identifies factors contributing flexibility in the power system (Synchronous &/or non-synchronous), ramping rate and capacity factor of conventional and renewable resources, flexibility studies made in different countries including India, deployment of various platforms with AI, ML and Big Data analytics in Renewables for prediction and decision making under increasing uncertainties in future, etc.

Keywords—*Power System Flexibility, Power Plant mix, Platforms with AI, ML & large Data analytics for prediction & decision making, Regulatory & Institutional Frameworks overlay.*

I. Introduction

1.1. World Community at Nov 21, COP 26, agreed to ramp up their carbon-cutting commitments made at 2015 Paris Conference powering grid predominately with distributed renewables but watered down their pledge to phased-down instead of phased-out coal fired thermal plants by 2050 signaling the complicacy of future conglomerate of renewables & conventional generating plants, battery energy storage, rooftop solar, EVs, etc. and posed to the grid operators & Policy makers to fix system stability, flexibility, generation-load balance ensuring least cost. In nutshell, COP26 conveys that the energy sector is ripe for disruption and it has to go through profound change.

1.2 India in addition to enhancing its renewable capacity to 500GW by 2030and achieving Carbon Net Zero by 2070 at COP 26, India & Britain signed a solar power initiative: ‘One Sun-One World-One Grid’ that envisions an interconnected trans-national solar grid across 140 countries merging large wind and Mega solar farms thereby inhibiting setting up Cross Border Energy Market under common standard regulations to ensure affordable and clean energy for everyone.

1.3 POSOCO undertakes management and over-all operation of the power system and NLDC & RLDCs and SLDCs plan Generation and Load balancing in India. Seven independent REMCs- one for renewable energy rich State Gujarat, Rajasthan, MP, Maharashtra, Karnataka, AP and TN and one REMC each in North, West and South RLDC-controls operation of renewable resources and associated transmission lines and NLDC facilitates VRE integration along the Green Energy Corridors.

2. Flexibility & Flexibility Planning

2.1 Flexibility

Synchronous rotating machines with kinetic energy in power system contribute to system inertia. On the contrary, Inverter-Based -Resources (IBR), wind, BESS or HVDC not inherently provide an equivalent response and release stored energy immediately following an event. The challenges posed by reduced inertia are identified viz. those related directly to the loss of inertia and those attributed to more general reduction in synchronous generation (reduction in fault current and reactive power availability). As such different mitigation measures i.e., provision of additional inertia or Fast frequency response need to be evolved rather than simply seeking to develop a-like- for-like replacement for the lost synchronous generation.

2.2 Flexibility Planning

The methodology of flexible planning [1] envisions three steps viz.

Step 1: Assess current flexibility involving i) Production cost modeling and ii) Network studies

Step 2: Bridge gaps following least -cost approach involving i) unlock existing flexibility ii) Implement DSM scheme iii) Invest in new assets

Step 3: Assess future flexibility involving i) Optimizing VRE sitting using geospatial optimization, ii) Least cost capacity expansion to identify future assets and iii) Repeat Step1(Access of long -term plan identified on previous step)

Note: If gaps are identified in step1, go to Step 2, otherwise go to step 3

2.3 Flexibility Sources including Inverter-Based Resources (IBR)

2.3.1 Capabilities of Existing & Emerging technologies to provide inertia (Additional inertia as service thru synchronous condenser/ operating synchronous generation with low minimum stable generation / identifying and quantifying inertia provided by the demand side and frequency Fast response (BESS and Load (preferred), Wind, Solar, HVDC Inter-tie, and synchronous generation in some form where conditions allow (curtailment of solar). Furthermore, FFR services are variable from system to system based on their specific needs (response time, sustain time and recovery allowance).

2.3.2 Grid forming converters (Self-synchronization / Synthetic Inertia) of Mega Solar Plants [2]

These have capability to establish its voltage reference (magnitude and frequency) and self-connecting to grid provide both FFR and a form of virtual inertia (nearly instantaneous active power injections in response to demand/supply imbalance on the gird). The virtual inertia is preserved for this form of self-synchronized response and not the existing forms of FFR because of grid forming control of this nature may be able to mitigate Low Rate of Change of Frequency (RoCoF) related issues.

These FFR response can only impact the average RoCoF if it responds during the measurement window (500ms) and will not be able to limit the peak RoCoF.

Furthermore, grid forming control may need to be suspended during fault conditions due to current overload limitations on the converter and varied control architectures required to achieve grid forming control and primarily

Table1: **Impacts of VRE at Various Time Scales and relevant Flexibility Solutions [1]**

Cost	Time Scale	10s-1min	1min-10min-30min	10min-30min-1hr	30min-1hr-1day- more days
	System Operation	Regulation	Balancing	Load following	Unit Commitment
	VRE Impact	Frequency stability issues due to high Rate of Change of Frequency	Increased need for operating reserves	Increased net load ramps	Increased cycling, increased challenges to dispatch inflexible units
	Operational Flexibility	Pooling of Resources			
			Intra-day Mkt	Co-optimized hydro-thermal Unit Commitment	
			Improved VR Forecasting		
	Demand Side Flexibility	Demand Response			
	Sector Coupling		EVS		
				Power-to- Heat	
					Power- to- gas
	Supply Side Flexibility	Retrofitting Units, New Flexible Units			
		Synthetic Inertia	Down Regulation by VRE		
		Geographic dispersion of VRE			
	Electricity Storage	Flywheels (10s)	Batteries (1min to 30min)	Pumped Storage (30min to 1 day)	

grouped as droop-based control or virtual synchronous machine (VSM).

2.3.3 Inertia as an Ancillary Service [2]

Lack of inertia as an ancillary service in a system with high penetrations of inverter-based resources mean that these systems must enforce certain inertia requirements at the operational time scale. This may result in sub-optimal outcomes for both inertia levels and the energy market since in the absence of inertia product, system operators may lack tools for optimizing between start-up costs, minimum generation levels and inertia contribution of the resources. Table:1indicates Impacts of VRE at Various Time scale and relevant Flexibility Solutions [1].

3.Flexibility and Ramping Rates of Various Re-sources

3.1 Flexibility and Ramping Rates in India

Flexibility and Ramping Rates are mandated either by grid code provisions or procurement through markets or a combination of both. Unlike reactive power requirement, which is local and needs to be supplied by local resources, ramping requirement is system-wide but needs to be provided in a dispersed manner or it would lead to an adverse impact on tie-line flows.

[3] mentions thermal units run at 40-45%load, ramp rate was not found to be a challenge for system integration of renewable generation. Individual power plants, however, need to be capable of ramp rates of at least 1%/minute.

[4] indicates important Indian Regulations for Ramping Indian power system and some are listed below:

A number of pioneer agencies CEA (CEA Tech Standard for Const. of Elect. Plants & TLs), CERC (Indian Elect. Grid Code), POSOCO, etc. issue machined continuous rating (MCR) to support Renewable Variations and unit ramping rate @% / minute above % MCR and

supplementary control for increase / decrease taking AGC manufacturers limitation of all types coal fired gen. units. CEA Standard Technical Features for 660 /800MW sets recommend a technical minimum of 40% MCR.

The Regulation for ramping thermal generating Units wef 1st April 2020:
a) Rate of return on equity be reduced by 0.25% failing to achieve ramp @1% / minute;

b) An additional rate of return on equity of 0.25% be allowed for every incremental ramp @ 1% per minute achieved over and above the ramp rate of 1% per minute, subject to ceiling of additional @ 1 % on equity.

.These regulations require the National Load Dispatch Centre to assess the ramping capability of individual generators based on procedure laid down in [4]. NLDC, accordingly, already issued Guidelines to Individual Stn (POSOCO 2020).

3.2 Flexibility and Ramping Rates in Other Countries

[4] mentions regulations, control provisions, etc. as adopted in other countries.

Europe and UK, thru various categories of reserves held by Control Areas manage imbalance between load and generation, reserves sharing and a robust interconnection among the conglomerate provide the ways for fulfilling their ramping requirements. Over the years, the ancillary

services trending down and load & batteries are allowed to participate in the market.

In US market, ramp rates are included in the offers made by generators. Any system imbalance leading to area control

error / frequency deviation is generally compensated by dispatching regulation reserves

In some power systems viz Ireland & Northern Ireland, GB, ERCOT, South Australia, a minimum inertia constraint (additional synchronous generators, beyond what is needed for energy and reserves} is applied

S. No	Code	Country	Min. Inertia Levels Calculations Methodology	Frequency Containment Reserves	Fast Frequency Reserves	Other Mitigating Measures
1	ERCOT	USA	Yes	Yes	Yes	Yes
2	Hydro Quebec	Canada	Yes	Yes	Yes	Yes
3	Manitoba Hydro	Canada	Yes	No	Yes	Yes
4	Japanese TSO	Japan	No	No	Yes	No
5	AEMO	Australia	Yes	Yes	Yes	Yes
6	Amprion	Germany	Yes	yes	Yes	Yes
7	Statnett	Norway	Yes	Yes	Yes	No

Table2: Grid Code Policy in Various Countries [5]

Table:2[5] lists out some of the countries making provisions for definition, mini. Inertia levels calculations, frequency containment etc.

[6] Flexibility in Power System Performed by International Renewable Energy Agency (IRENA)

IRENA performed flexibility studies envisaging conventional generating units and VRE in Uruguay, Colombia, Panama, Thailand, Indonesia and Philippines deploying Flex tool initially calibrated with specific year data followed for specific future years with composite power system. [6] may be referred for further details of studies for each country.

4. Studies (Inertia-related) Performed on Indian Power System

4.1 Optimal Generation Capacity Mix for 2029-30 [7]

CEA [7], in a mid-term review of “March 2018: National Electricity Plan 2029-30, assessed likely installed capacity Year 21-22 and considered the same as input including Pumped hydro & battery energy storage and determined generation capacity mix by 2029-30 shown in Table3. The data given in Table4 was used to arrive at Table3

[7] also indicates that max VRE day absorption is around 85.32 % on 3rd July, 2029. Study on with minimum each load of coal platform 55% to 50%, 45% and 40%, the RE Curtailment 14.68 to 12.94%,11.84% and 10.56% respectively for same day.

Tab 3: Cap (MW) in 2029-30 & Mix Centages [7]

Fuel Type	Capacity (MW) in 2029-30	Percentage Mix (%)
Hydro *	60,977	7.46%
PSP	10,151	1.24%
Small Hydro	5,000	0.61%
Coal + Lignite	2,66,911	32.66%
Gas	25,080	3.07%
Nuclear	18,980	2.32%
Solar	2,80,155	34.28%
Wind	1,40,000	17.13%
Biomass	10,000	1.22%
Total	**8,17,254**	
Battery Energy Storage#	27,000MW/108,000MWh	

* including hydro imports of 5856 MW # Active Battery Storage.

Tab-4: Tech. Parameters Gen. Resources & Ramping Rate Year2029-30[7]

Technology	Type	Availability (%)	Ramping (%/min)	Min. Technical. (%)	Start -up time (hr)		
					Hot	Warm	Cold
Coal	Existing/Planned	75-87	1	55	2	5	10
	Candidate	88	1	55	2	5	10
Gas	Existing	90	5	40	1.5	2	3
Nuclear	Existing/Planned	68	Const. Load	-	-	-	-
	Candidate	68	-	-	-	-	-
Biomass	Existing/Planned	60	2	50	2	4	8
	Candidate	60	2	50	2	4	8
Hydro	Existing/Planned/ Candidate	As per actual month energy	100	-	-	-	-
Solar	Existing/Planned	As per available hourly generation profile	-	-	-	-	-
	Candidate		-	-	-	-	-
Wind	Existing/Planned		-	-	-	-	-
	Candidate		-	-	-	-	-
Pumped storage	Existing/Planned	As per the Project Report	50	-	-	-	-
	Candidate		50	-	-	-	-
Battery Energy Storage	Candidate	98	NA	-	-	-	-

4.2 Renewables Integration in India

IEA and NITI Aayog [8] inter-alia present findings and results of parallel in-depth analysis, including two newly detailed power sector production cost models 'the India Regional Power System Model' and 'the Gujarat State Power System Model' developed at the IEA to illustrate flexibility challenges specific to the Indian context 2030 based on Power System Transformation Workshops during

mentions share of solar & wind in ten Indian rich renewables states significantly higher than the national average of 8.2% as Karnataka (29%), Rajasthan (20%), TN

2018-2020 and virtual workshops in 2020 & 2021 at Delhi, Chennai, Pune, Kolkata, Mumbai and Gujarat. It also (18%) and Gujarat (14%).

Similarly, TERI & NREL [9] thru case studies of TN (8.4GW wind) in 2018 to be more severe than in Karnataka (5.2GW) and observed both States to experience seasonal flexibility problem, etc.

Regions and states constituents to deploy standardized open platform for flexibility Models /studies till transition completed.

4.3 Pan India Lights Off Event (9 PM 9 Minutes) on 5th April 2020- Flexibility Capability [10]

The Indian network flexibility was successfully demonstrated in Pan India Lights off operation all over the country and some vital take-offs are discussed as under:

Event 9PM 9min switching-off Residential lights [10] mentioned 'Underestimation Demand (Estimated 12-15GW & Actual 31GW)' highlighted need for modernization of methodology of demand forecast & its spatial demand composition and its accuracy; renewable generation resources forecast & rescheduling; loss of control center under COVID 19 situation; recognize flexibility attributes, measurement of flexibility, etc.

For Control Center reliability, rotation of tech. staff for site & equipment familiarization may be a practical a solution. Another advance solution [11] under research is to create a Virtual Twin and some achievements in virtual nuclear reactor, digitization of transformer, etc. have been made. Modernization of estimation methodology is welcome. Over estimation of lighting Load, be also attributed to public reaction to the switching off call.

5. TAKE-OFF

Power system, all over the world, are tending green thereby weakening the flexibility and instead use battery energy storage, EVs, Roof-top prosumers, gas, etc. in addition to hydro pumped storage for strengthening the system as also leveraging for performing Flexibility studies at Regional and State levels and ensure inter State transmission system for inter- transfer of power from rich renewable states.

Synchronous rotating machines with kinetic energy in power system contribute to system inertia. On the contrary, Inverter-Based -Resources (IBR), wind, BESS or HVDC not inherently provide an equivalent response and release stored energy immediately following an event. The challenges posed by reduced inertia related directly to the loss of inertia and more general reduction in synchronous generation (reduction in fault current and reactive power availability).

IEA and NITI Aayog deployed IEA power sector production cost models to illustrate flexibility challenges and solutions specific to the Indian context 2030 in the ‘India Regional Power System Model’ and ‘the Gujarat State Power System Model’. The study also mentioned solar and wind share in Karnataka (29%), Rajasthan (20%), TN (18%) and Gujarat (14%) significantly higher than the national average of 8.2% . Similarly, TERI & NREL thru case studies of TN (8.4GW wind) in 2018 more severe than in Karnataka (5.2GW) and observed both States to experience seasonal flexibility problem, etc.

Regions and respective Region States rich in renewables are proposed to deploy standardized open platform for flexibility Models /studies till system transition completed. Table 2 of [5] be also perused.

The Take offs from Pan India Lights Off Event 9PM 9minutes’ on Demand estimation (Estimated 12-15GW & Actual 31GW) and working of a Control Centre under COVID 19 situation, flexibility attributes & measurement, etc. need national review. For Control Center reliability, rotation of tech. staff for site and equipment familiarization may be a practical solution. Another advance solution [11] under research is to create a Virtual Twin and some achievements in virtual nuclear reactor, digitization of transformer, etc. have been made.

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Design and implementation of 'South Asia Energy Database and Expert System' for promoting excellence and enhancing trade in the regional grid

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Abstract - **South Asia (SA) is amongst the fastest growing regions in the world and the energy demand in South Asia is expected to be more than double by the year 2030, against 2018 levels. Such a high level of growth calls for expanding and improving the electricity services in the region for economic growth, as well as to meet the growing energy security concerns. Looking at the diverse energy resources as well as varied demand pattern, the enhancement of energy trade amongst the different countries in SA is extremely important to bring overall economy at the regional level and optimization in the use of resources in different countries. To make the best use of resources, the role of information and its timely use is extremely important. This can be achieved only with the help of digital technology, paperless and contactless operations for smooth and quick functioning and use of expert system for decision making. Under USAID's SARI/EI program, currently being implemented by IRADe, a digital energy database and knowledge resource platform has been developed, which provides all relevant data related to energy sector at the click of a mouse. The cloud based data platform, working on open source software and state of the art dual active-active data processors with data syncing and load balancing feature is also equipped with very powerful analytics and reporting tools, through which a lot of intelligence and insights are added to the decision making process, almost in real time. This platform is available on public domain in order to help and support all the utilities in South Asia. This paper deliberates in detail, the objective behind development of this utility, its design and architecture, the salient features of the expert system, deployment of smart tools and the advantages which would be derived from it by the different countries in South Asia, towards operation of the regional electricity grid, enhancement of the cross border energy trade, as well as integration of the renewable and sustainable sources of energy in the different parts of the regional grid.**

Keywords— database; expert system; cloud based platform; hydro potential; renewable energy; generation capacity; cross border trade; energy supply; electricity market prices and volumes; system configuration; analytics; reports; institutional; scalability; sustainability; *Portal e- address: southasiaenergydatabase.org*

I. Introduction

South Asia inhabits around 1.8 billion people, which is around 24% [1] of the world's total population and makes it the most populated region in the world. Against this, the cumulative nominal GDP of the region is estimated to be around 3.38 trillion US dollars [2], which accounts for only 4% of the world's estimated aggregate GDP. Further, if we compare the average per capita total primary energy supply of the countries in South Asia, it persists in the range of around 619 Kg [3] of oil equivalent, which is much lower than the world average of 1874 Kg of oil equivalent. Similarly, the per capita average electricity consumption in South Asia is also quite low, at an average value of 705 [4] units, against the global average of 3132 units. However, the silver lining is that the region is witnessing a vibrant growing economy and the year-to-year GDP growth of the region is far ahead than the corresponding values in the other regions across the globe. The region is bestowed with diverse sources of energy available in the different countries, combined with varied demand patterns and levels of electrification achieved. Such divergent conditions, not only provide the advantage of economic interchange and price advantage to the different countries, but also provides energy security and sustainability across the region. The region has around 350 GW [5] of hydro potential, and a major part of it is still not tapped. At the same time, a large quantum of Renewable Energy (RE) potential is available in India, in the form of wind and solar. Some other countries like Sri Lanka also have large potential of off-shore wind. By combining the untapped hydro with the abundant RE potential, i.e. solar and wind available in different countries, the issues of variability, intermittency and balancing the grid can be addressed and the region can be stimulated with green and sustainable form of energy, and reducing the carbon footprints.

However, in order to facilitate all this, cross border energy trade in the region needs to be enhanced for which a reliable and transparent information database covering the various aspects of the region's energy sector is extremely critical. It will be helpful in enabling the decision makers in the different countries to take their decisions based on facts and figures, sound economic and commercial principles, as well as to generate win-win conditions for each one of them. Presently if we look from the point of easy data availability and consistency in the region, there are gaps, and this attempt towards design and implementation of 'South Asia Energy Database and Expert System' is to fulfil this gap and promote excellence in the form of paperless and contactless operations and enhancing trade in the Regional Grid

II. Background

In the South Asia regional electricity grid, the four BBIN (Bangladesh, Bhutan, India and Nepal) countries in the region are strongly interconnected (Fig. – 1) and cross border transactions are continuously taking place across these countries. Further taking into consideration the power supply

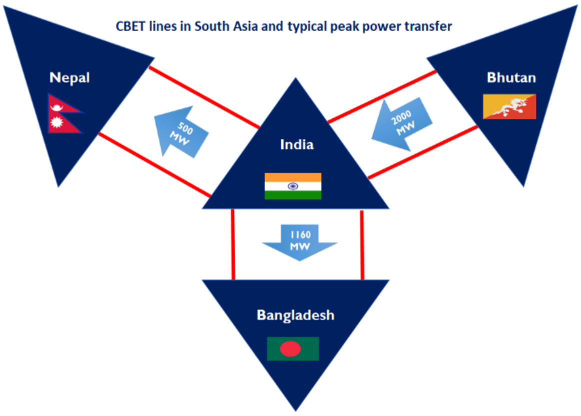

Fig. - 1, Cross Border Interconnections in BBIN Region

position of different BBIN countries as given under Table 1, it can be seen that there is a wide difference between per capita consumption figures of different countries, and thus a lot of opportunities exist to enhance the level of cross border flows. The diverse sources of energy, available in different BBIN [6] countries also point out the opportunities towards enhancing such cross border trades in energy. However, as elaborated in earlier paras, in order to facilitate the different countries to take a judicious decision in this regard, availability of a reliable and transparent data is essential. The data in addition to informing the utilities about the availability of surplus/deficit conditions, also needs to apprise them about the prevailing prices as well the trends of the historical/recently past prices.

TABLE-1. PER CAPITA CONSUMPTION OF BBIN COUNTRIES

Per Capita Electricity Consumption			
	(KWh)	(KWh)	(KWh)
Year / Country	2017	2018	2019
Bangladesh	431	458	489
Bhutan	3086	3264	3165
India	1122	1149	1181
Nepal	169	177	245

In order to design and develop such a database and expert system in a structured manner, an initiative has been taken under the SARI/EI [7] (South Asia Regional Initiative for Energy Integration) Program. USAID (United States Agency for International Development) initiated this program in the year 2000 to promote energy security in South Asia Region and is currently in its 4th phase, which is being implemented by IRADe [8] (Integrated Research and Action for Development). The program aims to promote Cross Border Energy Trade (CBET); sustainable development of regional hydro power potential and clean energy; coordination/harmonization of policy, legal and regulatory frameworks; advancement of transmission interconnection; regional energy integration/cooperation and creation of an energy market in the South Asia Region. Since the innovation in the form of database platform is needed to increase the regional energy cooperation by enhancing the volumes of cross border energy trade, it was considered to take up this innovative project under SARI/EI program in the form of design and implementation of 'South Asia Energy Database and Expert System'.

III. PROJECT DESIGN AND ARCHITECTURE

The Project is a web-based Knowledge Resource Database in the area of Energy Sector and it contains information and time series data pertaining to the energy sector of different countries from South Asia, including the details about socio-economic factors, power supply position, generation and transmission capacity details, quantum of electricity generated from different sources, details of all primary sources of energy like, coal, oil, gas, hydro, nuclear, renewable sources of energy, their potential, annual production and consumption, export/import and energy balance, electricity market details including the prices and volumes and details of cross border electricity trades.

Database - The Database has been designed with a modular structure having separate and clearly demarcated sections for country level as well as regional level data under different time domains. Further, the database has been segregated into different Data Sets (10 Nos.) in order to distinctly identify and capture the data of separate fields. These data sets, as already elaborated in the above para, have been identified to cover the type of information which is critical from the point of view of regional cooperation and cross border energy trade and a basic layout of these data sets is shown in Table 2. As

TABLE-2. PER CAPITA CONSUMPTION OF BBIN COUNTRIES

Country Overview
Socio-Economic >
Power Supply Position >
Cross Border Electricity Trade >
Electricity Generation >
Electricity Transmission >
Energy Supply >
Energy Consumption >
Commercial Data >
Electricity Market Prices >
Electricity Trade Volumes >

can be seen in the Table, the list clearly demarcates the data, based on the broad categories as listed above and selection of the Data Set from one category to another is almost instantaneous. Each data set is further divided into a number of Key Indicators and Sub-Indicators in order to find out the specific information, in a quick and focused manner. In order to substantiate this further, the layout of the Sub-Indicators – 'Power Plant Capacity (Fuel wise)' under the Key Indicator 'Generation Capacity' is shown in Table 3. If we look at the contents of Table 3, it is clear that the Generation Capacity of each source of energy can be found out and under the Sub-Indicator Composition it is possible to find out the relationship amongst the different sources of energy in terms of trends as well as in terms of percentages.

System Configuration - The Project is a web-based Knowledge Resource Database [9] and contains information and time series data pertaining to the energy sector of different countries from South Asia. The portal captures the

TABLE-3. LIST OF KEY INDICATORS AND SUB-INDICATORS

Cross Border Electricity Trade
Electricity Generation
Power Plants Capacity (Fuel Wise)
Total
Thermal
Nuclear
Hydro
RES
Composition
Power Plants Capacity (Sector Wise)
Power Plants Capacity (Region Wise)
Renewable Power Plants Capacity (Fuel wise)

configured information, available in the public domain at regular intervals using automatic web crawling and other state of the art data capturing techniques. A broad layout of the architecture of the Project is shown at Figure - 2. As can be seen in the Figure, the system configuration consists of dual servers in Active-Active mode with a load balancer [10] and any request sent to the website through load balancer will be sent to any Active server having the least load, for optimum utilization of the resources. The system is also built-in with the mobile app (both on IOS and Android) for displaying the Power/Energy data in the different forms.

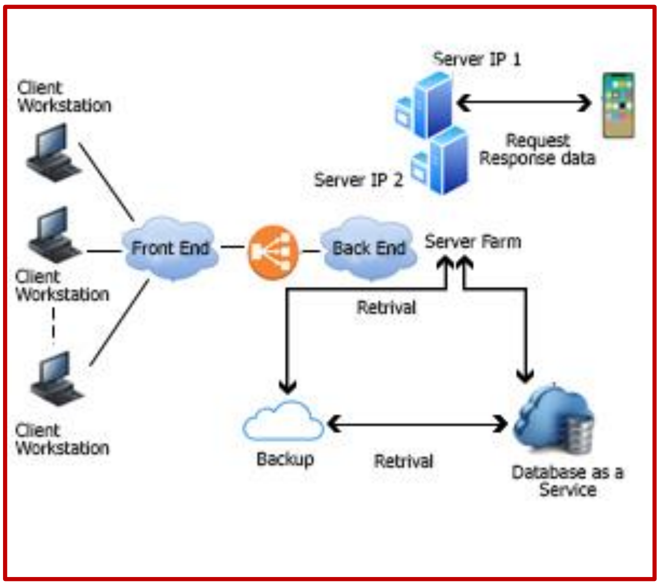

Fig. - 2, Architecture of the Database Portal & Expert System

Application and System Software – In line with the latest universal standards and norms, the complete solution has been developed on latest open source web development technology. This has helped in economizing in respect of the cost aspects and at the same time future development and expansion would also be seamless. The brief technological details in this respect are shown under Table 4.

TABLE-4. OVERVIEW OF APPLICATION & SYSTEM SOFTWARE

Sl No.	Description	Tools
SAED Portal		
1	Backend Coding Language	PHP 7.4
2	Database	Postgre SQL
3	Front End Technology	HTML 5, CSS 3, Angular JS 1.7, Ubuntu 18.04, Apche 2.4
Mobile App		
4	Operating System	Android 6 & above; iOS 6 & above
5	Database	SQLite 3.34.1
6	Coding Language	Hybrid App (React Native Java Script & HTML Tags

IV. FUNCTIONALITY AND FEATURES

The South Asia Energy Database and Expert System is a Cloud-based platform [11] having a detailed break-down of energy sector related data of different South Asian countries. The data for the platform is sourced from various energy utilities' websites, agencies, government and non-government entities' websites and other sources available in the public domain. As explained earlier, this data is further segregated in a number of categories based on usage and type. It is working on open source software with data syncing and load balancing features and equipped with powerful reporting and analytics tools. It is also equipped with policy, legal and institutional information related to the energy sector in the different countries in South Asia, as well as the details related to the regional transmission network interconnections, source wise and sector wise details concerning primary energy supply and consumption, regional electricity market and cross border energy trade details. Table -5 displays the salient features of the database portal:

TABLE-5. SALIENT FEATURES UNDER SA ENERGY DATABASE

Features of SA Energy Database

- Possesses time series data related to South Asian countries energy sector;
- Reduces data asymmetry and promotes data transparency;
- Presents the results in a configurable user friendly formats;
- Equipped with powerful reporting and analytics tools;
- Near real-time updated data in case of some critical parameters;
- Presents complete picture about primary energy resources and energy balance;
- Provides information about regional electricity market and cross border trade;
- Also equipped with policy, legal and institutional related information;
- Dashboard provides comparative analysis of KPIs of different countries in a single frame;
- Mobile application provides easy data access and portability;

Since the database is equipped with variety of data pertaining to the different countries in South Asia and has a versatile and state-of-the-art user interface to extract the specific data of choice, it is possible to display the desired data in different forms and customized reports and some of the case studies related to the use of the portal are substantiated below:

Fig. – 3, shows the specific values and a relative comparison of 'Electricity Consumption per Capita' and 'Population Growth' of all the eight South Asia Countries for a period of last 10 Years. The values pertaining to each country are shown in different color shades and in the e-platform there is a feature of auto-scale selection, with the help of which it is possible to show a wide range of data with a legible scale from the highest size to lowest size value.

Fig. - 3, Typical Trends from the Database Portal for SA Countries

Fig. – 4, shows the source wise details of the RE installed capacity in India both in terms of MW as well as relative percentages. As can be seen on the right top corner of the figure, there is a Pop-up window showing the year -2021. With the help of this Pop-up feature, it is possible to select the corresponding values for any other year also, just at the click of the mouse.

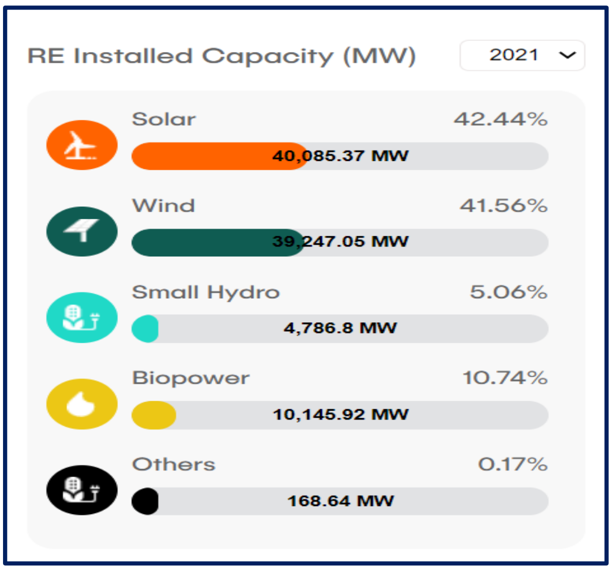

Fig. - 4, Details of Source wise RE Capacity in India from Portal

Fig. – 5, shows the details of the relative percentages of different sources of renewable energy (RE) installed capacity in India in a different format.

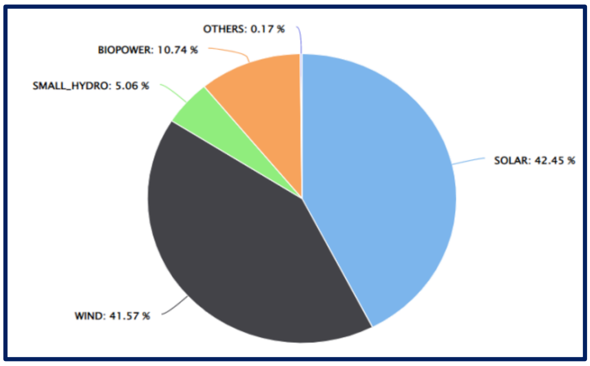

Fig. - 5, Comparitive Analysis of the different RE Sources in India

Fig. – 6, shows the details of the Final Energy Consumption in Bangladesh, and demonstrates the different energy sources in Bangladesh, in terms of kilo tons of oil equivalent (ktoe), during the year 2019.

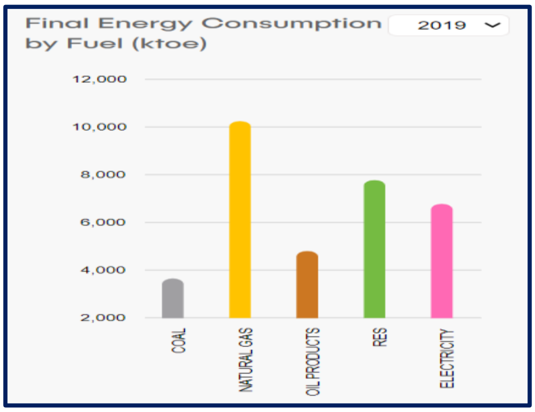

Fig. - 6, Source wise break up of Energy Consumption in BD

V. SMART TOOLS FOR THE EXPERT SYSTEM

As stated earlier, the database portal has been equipped with a number of smart tools, which help to categorize the portal in the category of a knowledge resource. Some of these tools are described below:

Data Analytics – Data Analytics [12] is a smart feature built-in the database portal, with the help of which it is possible to draw out certain inferences and get help in decision making by way of computations, based on the business logic already built-in the knowledge resource database portal. At present the parameters for which the analytics can be drawn out are Growth Analysis, Computation of plant load factor - capacity utilization factor (PLF-CUF), Information Analysis, Composition by Products, Country Comparative and Estimation of Projections. To elaborate some of these further, it is stated that under Growth Analysis, based on the past data in the portal, it is possible to find out the exact value of Simple Growth, Compound Annual Growth or Year to Year Growth of any given sub-indicator for any particular period in the past.

Fig. - 7, Analytics

Similarly, in case of Estimation of Projections, it is possible to find out future projection trend based on Linear, Compounded, or Exponential projection of any given sub-indicator, based on the past trend. This Analytics feature is a very powerful tool and makes the utility in the category of Smart Systems.

Reports (e-MIS) – Reports is another smart feature built-in in the database portal, with the help of which it is possible to configure the different categories of reports, primarily for the reference and review by the management. A very powerful and interactive menu based user interface has been developed for using this feature and based on the commands, prompted by the system and the past data, the desired reports can be taken out, in an almost instantaneous manner. While selecting the parameters and the time duration for generating the desired reports, there is a built-in facility to validate the data side by side, by looking at the temporary trends projected on the right side of the frame. There are a number of features incorporated in the design of this facility, as a result of which this specific tool is another smart tool available in the database portal and brings it in the category of expert system. This utility also enables publishing of an annual e-Databook comprising the energy data of the South Asia region and the individual countries for the year and smaller version of the reports can also be culled out, based on the parameters selected.

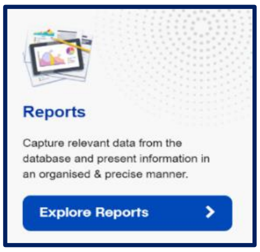

Fig. - 8, Reports (e-MIS)

Institutional – This is another smart tool provided in the database utility, to facilitate the selection and extraction of the desired document of any country in South Asia. To make this feature interactive and easy to operate, all the documents in the database relevant to the different fields in energy have been segregated in a structured manner, and a menu-driven user interface facilitates the selection of the desired document almost instantaneously and accurately. This saves a lot of time and efforts of the user to go through the infinite number of sites, in case any specific information/document in respect of any particular country is needed. Similar to the documents, the information about the different institutions has also been built-in in the database and the same is provided to the user on demand almost instantaneously.

VI. SYSTEM SAFETY AND SECURITY

As a fallback arrangement, a different location cloud based back up system has also been provided, as shown in Fig. -9

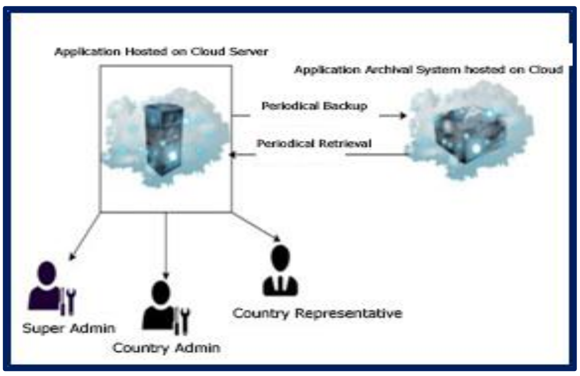

Fig. - 9, Cloud based Back-up to provide fall back system

which maintains a copy of the application and database with a quick and easy data retrieval facility. The periodical backup is done automatically by triggering the timer job at the fixed interval time and user gets the view of status of running backup service on the dashboard. In case of failure of the main system, the recovery will be done using the backend backup and recovery solution, which will help to manually recover the application, files and database. Since the whole application and database is a cloud based solution with built-in redundancy at every stage, its availability and accessibility is almost cent percent with assured access and use.

Security Audit - For safety and security of the information, there is a provision of security audit and examination by a cert-in empaneled security auditing organization [13] with respect to different vulnerability angles, including with respect to Cross-Site Scripting (XSS), Security Misconfiguration, Sensitive Data Exposure, Cross-Site Request Forgery (CSRF) and Invalidated Redirects and Forwards and many more. This security audit [14] process ensures the security of database, files and applications from unwanted hits and hacking.

VII. INNOVATION

This is the first-of-its-kind Knowledge Resource Database Portal and Expert System in the area of energy sector in South Asia which has been designed specifically to cater the requirements of different government organizations, utilities and other stakeholders. The Portal enables a quick and assured access to the knowledge based information, related to the stakeholders' different functions towards energy management and sustainability. Looking at the necessity to maximize the level of efficiency and economy in the different areas of energy production and consumption as well as to maximize the gains from the cross border trade of electricity and other sources of energy, like gas and petroleum products etc., the portal has been provided with the features of smart analytics and reports for helping and guiding the user, based on the specific needs. The portal is also equipped with a versatile and user-friendly interface to give the desired output in different shapes, tables and exhibits, for quick and smooth dissemination of the information and knowledge.

VIII. SCALABILTY AND SUSTAINABILTY

In the Project, by design, the whole data volume (thousands in number) has been arranged in a modular and well-structured manner and enhancing the number of Key Indicators/Sub-Indicators in any of the Data Set or even adding any new Data Sets is feasible, by some data customization efforts. At the same time modifying the logic, as used under different analytics and reporting (e-MIS) modules and/or adding any new module under analytics and reporting is also feasible, simply by indexing the related data fields from the database with the newly designed/added module. Hence modular and structured design of the current Project is a big advantage and the desired level of scalability can be achieved seamlessly, by rendering the required efforts.

As far as sustainability of the Project is concerned, as shown in Fig. - 10 on the next page, concerned officers in different countries in South Asia are being identified as nodal officers to get associated in operating the project effectively and for validation and authentication of the used data, pertaining to

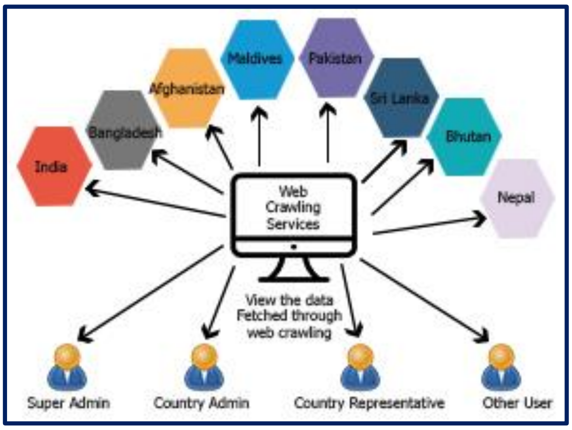

Fig. - 10 Country Representatives for Data validation and checks

their respective country as well as to make available any missing data. There are identified officers from each of the partner country, designated as Super Administrator, Country Administrator, and Country Representative and a clear-cut demarcation of the responsibilities amongst them has been worked out in order to get the requisite support towards day to day operation of the system as well as to maintain data consistency and accuracy. Further, USAID is committed to continue its support in terms of any financial and technical assistance required for running the project through its current program SARI/EI and subsequently through its newly launched regional program SAREP [15] (South Asia Regional Energy Partnership). Further to this, it is envisaged that in long run, the portal can also be taken over by a regional institution or forum to ensure free flow of information and promote transparency in the South Asia.

IX. IMPACT

The immediate benefits which it may render to the stakeholders in SA towards enhancing regional cooperation and trade are summarized below in the given Table – 6.

TABLE-6. DIRECT BENEFITS FROM SOUTH ASIA ENERGY DATABASE

Direct Benefits from Energy Database and Expert System to Stakeholders in SA

- Helping the countries in SA to enhance regional trade by using the information and time series data related to regional demand and resource diversity, available readily at a single source;
- Helping the utilities in expediting the decisions towards cross border trading of electricity, based on historical data and information related to market prices and volumes, across the region;
- Helpful to the government organizations in the matters of planning and decision making towards regional energy infrastructure, with the help of huge database available to them, across all the primary sources of energy, including oil and gas;
- Beneficial to utilities in SA, towards monitoring the performance of the operating projects/units, based on wide range of operational data, available to them, at the click of a mouse;
- Promoting the excellence in the operation of power system in the regional grid, with the help of built-in Analytics and Reports (e-MIS);

Since the project is an energy sector related web-based knowledge resource database and expert system, available in public domain, its scale/demand in terms of customer size is substantially large and shall ultimately be helpful in bringing down the cost of energy to the end consumer.

It shall also provide a very important source of information to the academicians, researchers and public at large, to carry out any study/research in the area of energy sector and to arrive at a decision based on logic and past data and suggest economical and efficient ways towards operation and managing of the system.

ACKNOWLEDGMENT

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Cooling Systems Design to combat ODP & GWP in LVDC paradigm

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Cooling System Design to combat ODP & GWP in LVDC

Abstract:

The need for revisiting the system design particularly cooling appliances is alarming from global perspective to combat ODP and GWP. Air conditioning and refrigeration systems (A/C-R) in general consume a considerable amount of energy to produce cooling effects in domestic and industrial applications such as ice-making industries, food industries, vaccine protection, and building and vehicle A/C applications. Vapor compression refrigeration cycles (VCRCs) are the most popular type of refrigeration systems in which different refrigerants, such as Chloro-Fluoro-Carbons (CFCs), Hydro ChloroFluoro Carbons (HCFCs), and Hydro Fluoro Carbons (HFCs) are used. However, these refrigerants cause significant ozone depletion and global warming. An ideal refrigerant should have favorable thermodynamic properties and should be noncorrosive, nontoxic, non-flammable, and environmentally benign. Therefore, development of green, sustainable refrigeration systems, which utilize environmentally friendly refrigerants, is of great importance.

As part of this project work, different types of adsorbers are studied and examined one activated carbon - methanol adsorption system. Structure of adsorber will be figured out, performance of adsorbent will be monitored. Efficacy of different adsorbers and adsorbents in data table are compared. Results obtained will be compared to check for the better performance of mass transfer and the performance of the whole system, and the project work basically comprises of engineering implementation for design consistency. This project intends to use thermo chemical transformations to obtain required cool temperatures in place of traditional compressors as we generally see in refrigerators and air conditioning systems. The final implementation of this conceptual design would lead to bring the cooling systems up to 3.5 KW capacity into IoT enabled LVDC paradigm.

Introduction: Traditional vapor thermo electric compression cooling systems consume more electrical power. And further, those systems are using chemically prepared refrigerants like chlorofluorocarbons (CFCs), hydro chlorofluorocarbons (HCFCs) etc., having high global warming (GWP) and also high Ozone layer Depletion Potentials [1]. Though Hydro fluorocarbons (HFCs), are currently being used in place of CFC and HCFC in cooling systems, they do not reduce the stratospheric ozone layer; but instead, they have high global warming potential (GWP). In order to address these problems, using solid-gas adsorption systems seems to be a better alternative in cooling system design in the aspect that they are good from environment point o view and can be powered by low-grade renewable heat sources, like solar energy, industrial automobile waste heat, etc. Thus, they have a large energy saving potential and can also be used in the rural areas where there is no electricity. In comparison with the existing absorption systems and vapor compression cooling systems, Another unique advantage of being the adsorption cooling systems is, the absence of moving parts in the freezer area and thereby less vibration, and low maintenance requirement which ensures simple control and easy operation. Simple construction to explain the concept here, the process of an adsorption cooling system comprises 2 steps. The first being the adsorption of a refrigerant gas into an adsorbent at low pressure and the Second being the subsequent desorption by heating the adsorbent which was heated acts as a thermo chemical compressor driven by low grade renewable heat [2].

Here, for example, a simple adsorption system shown which comprises two linked vessels, one of which contains the adsorbent and both the vessels contain the refrigerant as shown in Fig. 1.

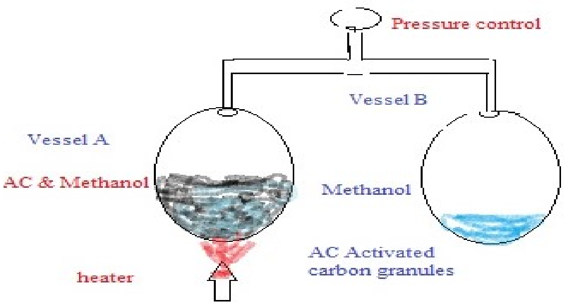


Fig 1 Adsorption cooling system Test Set up

Both the vessels in the beginning are at low pressure and temperature with more refrigerant concentration within adsorbent and only refrigerant gas in the other vessel (A). The adsorbent which basically acts like a generator is heated, to drive out the refrigerant and increases the system pressure. On the other hand, the desorbed refrigerant condenses to liquid in the other vessel and rejects the heat (B). At the end of the process, the adsorber cools back to room temperature and starts adsorbing the refrigerant.

Cooling system design concepts, parameters and related terminology:

Saturation temperature: It is also known as the boiling point. It is the temperature for a corresponding saturation pressure at which liquids boil into vapor.

As the liquid in the second vessel is depressurized, it boils and it absorbs the heat and produces the cooling effect. This study will present a review for adsorption cooling systems using methanol and activated carbon as adsorbents. It will focus on system description, system design, numerical and experimental analysis based on different driving temperatures, adsorption capacity, evaporation capacity, evaporation temperature and heat of adsorption. The functional system components are shown below in Fig 2.. The system operates in dual mode so as to achieve both functionalities like water heating and also as an ice maker.

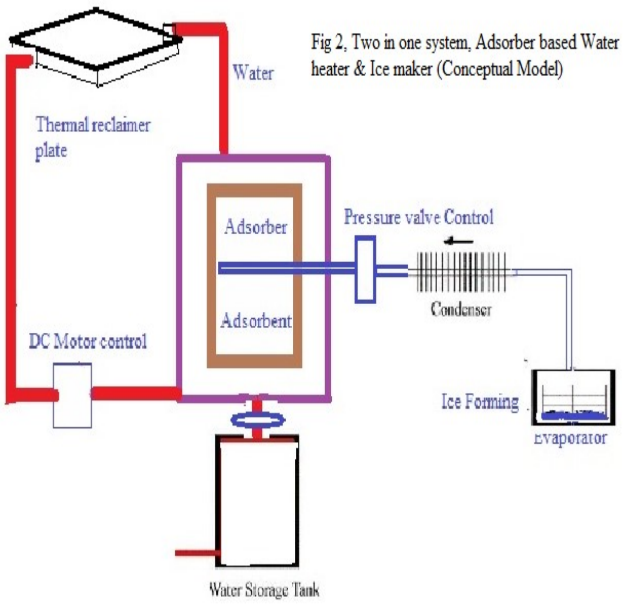


Fig2. Two in one system for heat & cold.

Saturated Steam and Super heated Steam: Saturated steam is the steam that is in direct contact with the water from which it was produced. Once methanol is heated to boiling point, it gets vaporized and turns into saturated steam. if all the moisture is removed, it gives dry steam and at the boiling it can exist as both liquid and vapor

Sub cooling and super heating in refrigeration: Sub cooling means cooled below its boiling point. Suppose if the boiling point of methanol is 64 deg Celsius, then cooling it to 54 deg is sub cooling. If the temperature of steam is 70 deg Celsius, then it is called 6 deg Celsius of super heating.

The main purpose of refrigeration is to remove heat from enclosed region, and for that purpose there are mainly four components [3].

Digital unit to control adsorption desorption thermal cycles presented here in Fig3.

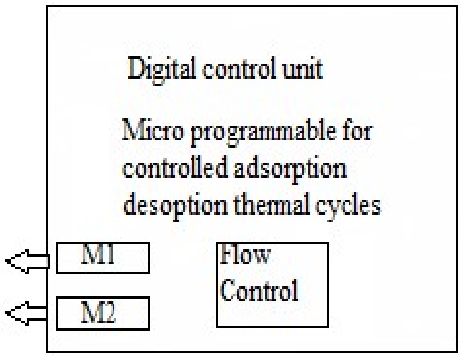


Fig3 Configurable Digital Control Unit.

This control unit helps in customizing the needs to change the thermal cycle according to application. This unit comprises solenoid valves, sensing devices and a programmable dedicated CPU to work in embedded computing environment. And also this computing power helps in remote monitoring making it IoT enabled for system health checks.

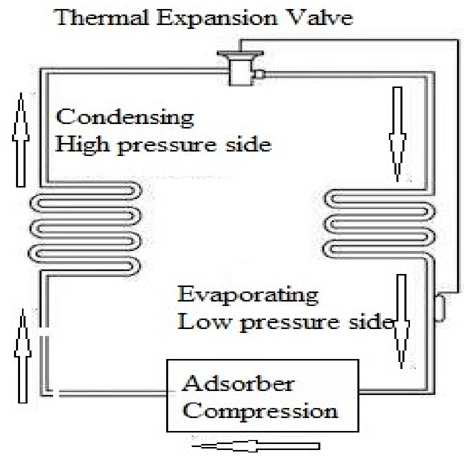


Fig4. Main modules in the system

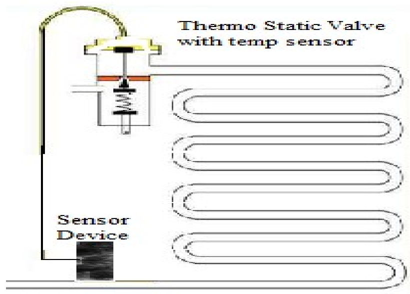


Fig5. Thermal expansion Valve (TEV)

The main system modules here are, Evaporator, Condenser, Adsorber & TEV. Purpose of the evaporator is to cool the enclosed space by absorbing the heat from the room and the refrigerant starts to boil. It might be fitted with a fan behind the evaporator for increasing the circulation. It works with Condenser, Adsorber & TEV. as shown in Fig4 & Fig5. Condenser is to liquefy the gaseous refrigerant and then to sub cool it. Here sub cooling means to maintain the temperature below boiling point. Adsorber raises the saturation temperature so that when it goes into the condenser, the heat is given off to the cooling water instead of absorbing heat from water and also it circulates the refrigerant.

Adsorber Design and the concept behind: The motivation here to design the adsorber based cooling systems is to make efficient use of energy losses or wasted energy in automobiles. And the same concept is being extended to develop other cooling systems by using renewable energy sources or energy re-claimer o thermal systems.

The traditional compression based refrigeration cycles (CRCs) in Automobile air cooling (A/C) systems usually can add up to 4-5 kilo Watt peak power load on internal combustion engines (ICE) of a vehicle. It is almost equivalent to the power used to drive a 1000-kg vehicle at 50 km/hour speed. Moreover, almost 65% of the total energy released in a combustion engine is consumed through the engine cooling system and exhaust gas in the form of waste heat.

In United States alone, yearly it expends nearly 40 billion liters of fuel like gasoline, diesel etc., for Air Conditioning of light duty vehicles. In a combustion vehicle, almost 70% of the total fuel energy is dissipated through the engine coolant and exhaust gas in the form of waste heat [4]. There are several heat-driven systems that can use the waste heat to generate cooling power and reduce the negative impacts of CRCs. The following is a brief overview of available systems.

Therefore, the need arises to make efficient use of that energy by way of reclaiming it and put it to use by designing new devices to replace the traditional compression based CRCs. The adsorption based cooling system (ACS) use adsorber beds in place of compressor and the excess heat of a combustion engine is utilized in adsorber beds to generate cooling power. There are different possible combinations of adsorbent material like e.g., zeolite, silica gel Acivated Carbon etc.,, and an adsorbates like e..g., water, ethanol, methanol etc.,. Most of these materials are non-toxic, non-corrosive, and GWP, ODP friendly (non threatening), and also price wise inexpensive. These systems are quiet and the controlling valves are only the moving parts. The initial designs of these adsorber beds mainly dependent on natural thermal cycles of solar radiation based heating and almost follow day and night cycles in natural course.

Commercialization and deployment of Adsorber based cooling system faces couple of challenges because of their size and weight that can lead to low specific cooling power (SCP) and low coefficient of performance (COP), but by implementing with proper engineering techniques in different applications they have the potential to significantly reduce power consumption and carbon footprint.

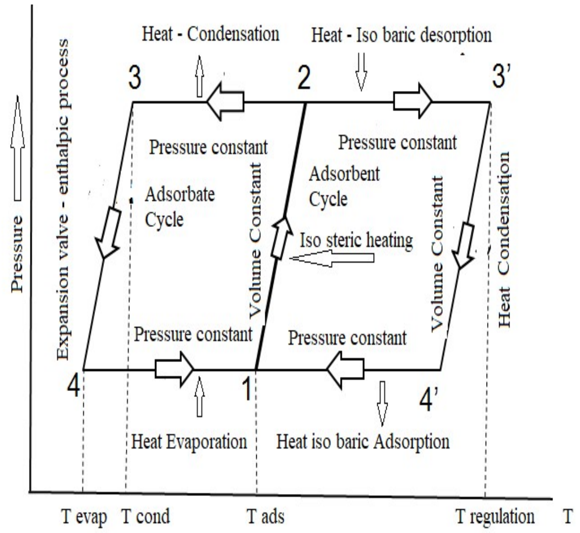
Tackling SCP and COP through design: The definition of SCP is being the ratio of evaporative cooling energy to the mass of dry adsorbent multiplied by the cycle time. Thereby, the SCP can be enhanced by increasing the evaporative cooling energy and/or decreasing the cycle time.

The low performance Adsorber based systems are mainly due to Low Thermal Conductivity of adsorbent particles (~ 0.1 to 0.4 W/m.K) [5] and the Low Mass Diffusivity of adsorbent-adsorbate pairs (~ 10-8 to 10-14 m2/s) [6]. Because of which, the heating and the cooling of adsorber beds are time consuming. As a result, the design and optimization of an adsorber bed is needed to improve the heat and mass transfer characteristics, and also low adsorber bed to adsorbent mass ratio (AAMR) which can effectively increase the CPP and COP of Cooling Systems.

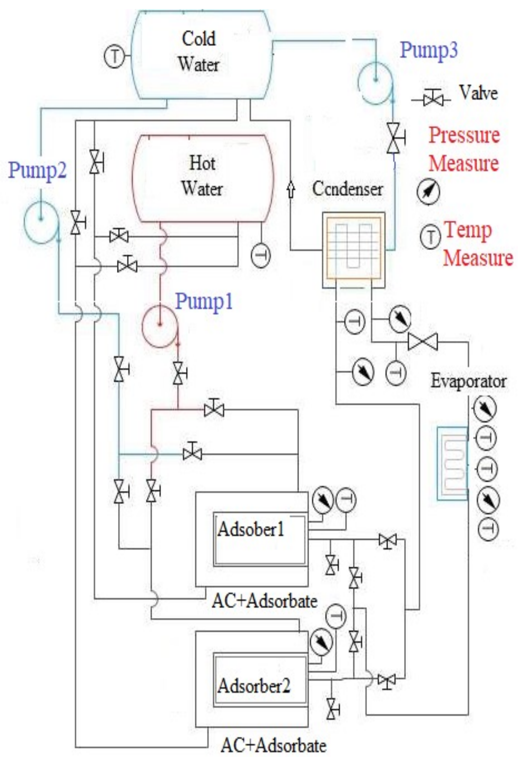
This Cooling System function based on two main steps: Heating-Desorption-Condensing and Cooling-adsorption-evaporating steps. According to these steps, Cooling System develops evaporative cooling effect. In order to develop uninterrupted cooling power, it requires to use more than one adsorber bed. Figure 2 depicts a typical two-adsorber bed Cooling System. The important modules of Cooling System comprises of anadsorber bed, a condenser, expansion valve (TEV), and an evaporator. A Cooling System is almost similar to a CRC, only with an exception that the adsorber bed replaces the Thermo electric compressor. Figure 2b shows the thermodynamic processes in a Cooling System which is further divided into two sub cycles: (i) an adsorbent cycle (on the right side), and (ii) an adsorbate cycle (on the left side). As shown in Figure 2b, the adsorbent cycle includes four steps: (1) isosteric heating (ih); process 1-2, (2) isobaric desorption (ibd); process 2-3', (3) isosteric cooling (ic); process 3'-4', and (4) isobaric adsorption (iba); process 4'-1. Isosteric processes occur at constant specific volume and isobaric processes occur at constant pressure. The adsorbate cycle shown in Figure 2b includes three steps: (1) isobaric condensation in the condenser; process 2-3, (2) isenthalpic process in the expansion valve; process 3-4, and (3) isobaric evaporation in the evaporator; process 4-1. Isenthalpic processes occur at constant enthalpy.

During step 1-2, the adsorbent-adsorbate pair absorbs the heat from an external heat source during an isosteric process. In this step, the pressure of the adsorber bed increases due to the adsorbate desorption from the adsorbent particles. This process is continued until the pressure of the adsorber bed reaches the pressure of the condenser and then the inlet valve to the condenser is opened. During step 2-3', the external heat source continuously heats the adsorber bed (ibd) in an isobaric desorption process, the adsorbate leaves the adsorber bed, and is condensed inside the condenser through an isobaric condensation process (step 2-3). The total heat transfer to the adsorber bed, during a desorption process is the sum of iso steric plus and iso baric desorption heat.

Upon reaching point 3', the maximum temperature of the system at the end of desorption time, the valve between the adsorber bed and the condenser is closed and during an isosteric cooling process (step 3'-4'), the temperature of the adsorbent is reduced by dissipating the condenser heat to a heat sink. In step 3-4, the adsorbate inside the condenser passes through the expansion valve and enters the evaporator. During step 4-1, the adsorbate absorbs the evaporation heat from the environment of interest and evaporates. At the same time, the valve between the evaporator and the adsorber bed is opened and the adsorbent adsorbs the vaporous adsorbate in an isobaric adsorption process (step 4'-1) and releases the heat of iso baric adsorption (iba). This process continues until reaching the end of adsorption time. The total heat removed from the adsorber bed, i.e total cooling, during an adsorption process is the sum of 'ic' and 'iba'. The cycle time is the sum of desorption and adsorption times. The waste heat of an engine or other energy reclaim can be utilized for desorption process. Waste heat- and solar-driven Cooling System for ice making and building A/C applications have been discussed at length in previous literatures [7]. Although many attempts carried out to improve the performance of CS, these systems are still bigger thus not practical for all A/C applications. So as a consequent, the main factors on the performance of the system, namely, adsorbent-adsorbate pair, adsorber bed design, and ACS design carefully studied.



System setup for measuring Performance:



Conclusion: The system proposed here comprises two beds and is it is fitted with temperature measuring LCD devices, pressure monitoring devices and solenoid valves to monitor the temperature and pressure and control the thermal cycles as per the requirement. For controlling the flow of working fluids, 12v or 24v DC motors may be used having precise DC motor control circuits which can be automated using micro programmable control unit. Experimentation is around achieving better specific cooling power and coefficient of performance values by controlling the thermal cycles and conductivity of adsorbents. More details can be shared during the technical presentation through slides.

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A study on smart solutions for water utilities in India

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***Abstract*— India has risen to become the world's fifth largest economy and with this comes growing population and in turn increased water consumption. Water scarcity is a critical issue in India mainly due to lack of Demand & Supply Management of water resources and inefficient Transmission & distribution system, without monitoring. These stressors require innovative solutions that ensure the sustainability usage of water. Implementation of technology would require huge investment, which is undermined as the water Utilities face financial crunches and lack of technology competencies. The average Non-revenue Water (NRW) in India is about 38%, which is way above global average range of 30%-35% as reported by World Bank. Though there have been developments in leak detection and network management, their adoption and implementation in India has been sluggish, primarily due to the limited revenues & lack of provision of in-depth monitoring of Transmission & Distribution losses.**

Keywords—Water, management, distribution, AMI, smart

I. Introduction

Globally, Water sector is ushering in Digital Transition by undertaking Digital Initiatives leveraging Digital Disruptions to upscale overall performance & manage perennial challenges of demand & supply. Smart Solutions for Water Utilities as latest technical upgradation will be boon for utilities & provide plethora of benefits to consumers & utilities. Water utilities needs a serious revamp to adopt technology enabled Digital, IT & Analytic solutions to become part of the solution of challenges of Water Utilities. Identifying end-to-end solution to digitize the transmission & distribution network, there is a need to build robust transmission and distribution water grids. This will help water utilities to realise the expected benefits such as reduced operational expenses, help increase customer outreach to remote areas, better planning of pipeline laying, pin-point drought areas and increase consumer satisfaction. As both the sectors are on the rise, an effective mutual unification is to be thought through that will help both the sectors to overcome its challenges and smoothen its roadmap.

II. Understanding the Challenges

India is mostly an agrarian nation. In this area, 70%[1] of the water is used for farming production. Water consumption is anticipated to increase by 50%[2] due to rapid urbanisation.

The water sector must respond to the supply/demand imbalance, through regulatory reform and infrastructure investment to secure drinking water supply and improve wastewater treatment.

Utilities have capital crunches and competing priorities and at the same time, customers have increasingly high demand of quality service, which is placing pressure on providers to focus on the customer experience. Customers are more digitally connected and increasingly price sensitive for water spending.

In addition many water utilities are still struggling with efforts to broaden the scope of AMI solutions, network and connectivity planning internally given that it is not a core focus business area of a utility as well as the high and intensive capex cost required to establish such connectivity. While investment in network and connectivity and the digital water grid is taking place, it has been primarily focused on addressing the concerns of today, rather than the step-change potential for future operations. The reasons for this include:

a. Need to self-fund digital grid projects
b. Aging Infrastructure -Most water infrastructure around India is in need of upgradation.
c. Retiring Workforce
d. Departmental silos preventing enterprise-wide view of digital water grid
e. Uncertainty about regulators, in terms of both their role and financial incentives
f. Difficulty making a business case for the digital water grid

III. Transformational Business Led Solution

Historically, AMI for water has been slower to adopt than electricity metering. The transformational journey of Water Utilities in India should be a business led solution focused on people, process, technology, governance and investigate innovative ways to attract the correct investment.

Fig. 1. Typical value chain for end -to-end AMI network for water utilities

The ultimate success of a smart network rests not only on the implementation, but on the management and data analysis so as to help the water Utilities to understand the real-time status and health of their networks, as well as inform on strategies for both demand and asset management. This can be envisioned by the concept of "shared services" between Water and Power Utilities by leveraging each other's infrastructure and identifying common consumer endpoints rather. A "Single Utility Corridor" for sharing digital assets with strong experience sharing and collaboration. These type of joint investments with part funding from both the utilities can lower down the ARR which will lead to commercially sustainability and less burdening on tariff for consumers. These solutions are envisaged as follows:

1. Power sector Utilities having existing GIS system for implementing smart metering system for which they have integrated with consumer indexing and updated GIS coordinates. This information exchange will benefit the Water Utilities to build efficient 'water grids' across the country by identifying potential consumers.

2. Common networks for last mile connectivity for smart metering for Power & Water Utilities can be utilizing the best of both worlds to engage in best practices of the value chain.The final and the most important member of the ecosystem- the Consumers. Consumer Satisfaction is the most vital function for any utility to focus on.

3. Building Unified CRM, Centralised Customer Call Centre for both Power and Water Utilities as both will have common set of consumers, so a mutual platform for bill processing, complaint registration, new connection requests, single service for payment mode, shared consumer database, awareness program etc. This will enhance consumer satisfaction as there will be 'One Stop Solution' for basic all services'.

4. Standardized IT workflows to reduce operation and maintenance costs. Customer on-boarding, customer base and outreach can be hugely increased by the help of customer billing data already available to Power Utilities. These can be ways for water utilities to comprehend customer engagement and study customer behaviour and predict usage patterns.

5. Unified and centralized billing system for all essential utility services including telecom, water, gas and power to have their single platform for billing. Consumers will pay their bills without any hassle in a user-friendly interface.

IV. Realization of Benefits

After In order to drive the benefits of smart, it has to be transformational, typically impacting 70-80%[3] of the traditional utility's operations. With AMI being one of the most data intensive activities of the new Digital Grid, the Smart Meter Operations Centres (SMOC) will be at the centre of this tsunami of new data.

The right business-led development of dashboards, visualizations and workflow management will be at the heart of helping make sense of this new world and in efficiently running operations, maintenance and issue management.

New capabilities and skills to gain insights through our advanced analytics and Business Intelligence (BI) platforms to optimise our process, protect and enhance revenue.

There is often the need for new skills and resources which is required in the organisation for the significant shift in the capability mix and potential short term impact to number of employees required.

Understanding how to use these advantages to improve the cashflow of the organisation is key to the benefits realisation process.

Benefits	Impact Delivered			
	Customer satisfaction	Revenue management	Reduced regulatory risk	Reduced cost
Remote location identification and extent of water main breaks				✓
Remote restoring service after an outage	✓			
Monitoring compliance with water restrictions, quality & conservation programs			✓	
Increasing theft detection			✓	✓
Reduction in O&M cost	✓	✓		✓
Reduced waste of water		✓		✓
Reduced leakage detection costs			✓	✓
Fewer pipe bursts	✓			✓
Backflow detection				✓
Remote controlled service lines/shut-off valves				✓
Lower energy costs due to adjustment in water pressure settings				✓
Improved forecasting of demand		✓		
Meter right sizing to capture all water usage	✓	✓	✓	✓

Fig. 2. Impact Vs Benefits across the value chain of water utilities

V. Governance Framework

Setting the right governance framework is important for a successful execution of the project, especially in India.

It must be established with the right people (structure), processes and technologies in order to enable us to gain insights from the field and make effective business decisions.

There is an impact on the traditional utilities processes and capabilities which requires the organisation to gear up such impacts.

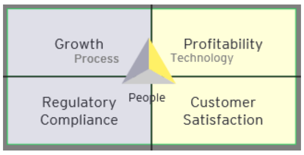

Fig. 3. PPT – Process, People, Technology

A. Process

- Establish the right business capabilities and align these to existing business operations
- Accelerate and refine the development of core processes and operating procedures
- Identify the right roles & responsibilities to deliver operations

B. People

- Provide insight & learning from other operational delivery and international project experience
- Establish focused and hands on training to ensure effective transition to to-be state
- Focus on the staffing of the command centre with skilled resources

C. Technology

- Establish a flexible and scalable technology platform. We recommend a platform on the cloud.
- Minimise complexity and cost to meet current requirements
- Focus the solution on enabling key business outcomes & services

VI. Way Forward

Water management may be made more sustainable with the use of smart water systems, which comes with challenges on privacy and security of data while sharing consumer data between services of any sector.

Ownership of assets, revenue sharing and payment terms for shared services might be another challenge in case of complexity of operations which would require strict regulatory approvals. Maintenance and differentiating SLA's and service quality for Water Utilities need to be monitored stringently.

Water Smart meters to be supported and made mandated to give BIS/IS standards as they follow European standards. These can be manufactured by Indian Manufacturers in less cost.

Contribute to smart-city target achievement for India. This idea will ensure complete growth of institutional and economic infrastructure by improving the quality of life for people with smarter outcomes.

Unification of a system architecture identifying stakeholders that is workable and feasible for smooth data exchanges must be thought through.

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Customer Complaints- A gift for the organization & a Key to increase the penetration of PNG in domestic house holds in India

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Abstract— "Smart City" has emerged as the dominant trend in the utility industry . Cities are seeking to create smarter infrastructure and improve the lives of the citizens they serve. City gas distribution project is in nascent state in major part of country. Government of India has aimed to reach contribution of Gas as 15% of total energy mix from current 6.3% and City gas distribution will play a major role. The key to profitability is driving operational efficiencies and improving customer service while helping customers become smarter about their usage.

The penetration of PNG in domestic segment has remained low and is a cause of concern for majority of CGD companies. Even though most organizations agree that they are customer centric, only a few are delivering experiences that aligns with the customer's expectation. The relevance of customer feedback is evidenced through organizations like trip adviser and Zomato which only exist because of the impact of customer reviews.

Smart organizations recognize the importance of customer feedback and consider receiving the customer complaints as an opportunity to solve the problem promptly and efficiently so as to impact loyalty.

Major reasons why CGD companies should actively seek customer complaints are

1. **They highlight key areas of improvement**
2. **Aid in understanding customer better.**
3. **Keeps the customers firmly as number one priority.**
4. **Prompt action shows you value their opinions**
5. **Complaints are fuel for new action**
6. **Drive leadership actions**
7. **Help create best customer experience**

Keywords—Customer, Complain, Feedback, Value, Business

I. INTRODUCTION

<u>Smart City and City Gas Distribution</u> "Smart City" has emerged as the dominant trend in the utility industry. Cities are seeking to create smarter infrastructure and improve the lives of the citizens they serve. The major objective of smart city is to optimize available resources to make a city for better place for living and provide a standard and quality life. The concept lies in how this technology is used rather than simply how much technology is available. The concept of smart city is much important in today world as 54% of the world's population live in cities and this is expected to rise to 66% by 2050, adding a further 2.5 billion people to the urban population over the next three decades. With this expected population growth there comes a need to manage environmental, social, and economic sustainability of resources.

City gas distribution project is in nascent state in major part of country. Government of India has aimed to reach contribution of Gas as 15% of total energy mix from current 6.3% and City gas distribution will play a major role. The key to profitability is driving operational efficiencies and improving customer service while helping customers become smarter about their usage.

City gas distribution plays a important role in expansion of smart city. It can be a tool for developing Smart Cities. Mitigation of the environmental issues like pollution, inappropriate consumption of natural resources and the waste of the resources, is one of the core values of the smart city mission. City gas distribution can play major role in controlling pollution as natural gas is not only reduce carbon emission, It can also utilize waste material to produce natural gas which can be further used in this industry.

The penetration of PNG in domestic segment has remained low and is a cause of concern for majority of CGD companies. Even though most organizations agree that they are customer centric, only a few are delivering experiences that aligns with the customer's expectation. The relevance of customer feedback is evidenced through organizations like trip adviser and Zomato which only exist because of the impact of customer reviews.

There may be many tools to expand business, but our focus will be customer, who not only adds value to organization but also assists business through their feedback. It is a normal formula that customer adds another customer if they are satisfied with service and expand our reach without any advertising.

They highlight key areas of improvement: A customer complaint highlights a problem, whether that's a problem with product, employees or internal processes, and by hearing these problems directly from your customers, you can investigate and improve to prevent further complaints in the future. Furthermore, research finds that customers' whose complaints are handled quickly can often turn into loyal customers and even brand advocates.

In fact, a study by Harvard Business Review found that customers who have a complaint handled in less than 5

minutes go on to spend more on future purchases. Simply put, a customer complaint can become very profitable when you can resolve their problem quickly.
In the CGD business specially in the new Geographical areas allotted in the 9th and 10th Bidding round, the population is largely in tier 2 and 3 cities. Customers prefer to walk in and discuss the issues. A sensitive approach towards customer care would lead to a good first impression with a potential to exponential increase in sales.. A prompt and sincere response would provide a feedback system which will result in the improvement of the process.

Customer complaints are a reminder to treat customer service as a profit center. Most large organizations hire cheap labor to answer the phone. They install recordings to sooth and mollify people who are put on hold for long durations. When the customer service is treated as a cost center, the above steps make sense. Any money spent on lowering the cost seems to raise profits. But customer service is actually a profit center because of the following reasons.

- The customer who calls or walks in with a complaint is fully engrossed. Unlike any other moment you spent with them, in this moment, they are paying attention and are on high alert. Everything that is done at this point, unlike all other marketing interactions done earlier, will go on a permanent record.
- Because your competitors have decided to treat this interactions as cost, there is a significant probability that you will overdeliver and customer will notice that.
- In the industrialized economy of our country, people love to tell stories about service. So, the word spreads about how you cared.
- It is demonstrated again and again that most valuable customers are the loyal ones. In the CGD business, while the marketing team is scouting for the new customers, the existing satisfied customers will bring repeat volumes by using both PNG and CNG and will also become brand ambassadors.

NO News is Not Good News. In today's Internet-driven world, customers have more power than ever. If customers have a positive customer experience, they will share this experience with friends, family and connections, which in turn can lead to new business. All at zero cost.
But what happens if you fail to provide a positive customer experience the answer is simple. **Your customers will complain**. According to research 13% of unhappy customers will share their complaint with 15 or more people. Furthermore, **only 1 in 25 unhappy customers complain directly to you.** And, customers that don't complain, they just stop doing business with you.

Using Social Listening Tools for improved customer care: Customer opinions have always had the potential to influence other people's attitudes towards a business. In the past, these opinions were communicated mostly by word of mouth.

But the internet has given customer opinions mass exposure. Millions of customers now post reviews of goods and services on websites, blogs and other social media. And millions of people read them. Research shows that positive online reviews increase the likelihood of customers using your business, while negative reviews reduce it.

Customer reviews are posted on:

- general review sites (e.g., Yelp, Product Review)
- specialized review sites (e.g., Zomato, TripAdvisor)
- retailers' websites (e.g., Amazon)
- personal blogs
- other social media (e.g., Twitter, Facebook).

Today's customer is going to talk about your business one way or another. They're going to chat, tweet, post, like, and share about you. They're going to reply, comment, frown, LOL, and GIF about you. You can't stop that from happening. That's the world we live in. But you can decide whether that discussion will be collaborative or corrosive. Many companies are already using social listening tools to monitor digital channels, understand public sentiment about their brands and products, and intervene in conversations to convert negative brand experiences into positive ones. Research shows that negative online reviews can reduce the likelihood of a customer using your business, particularly if there are no other reviews to provide balance. The best way to tackle negative reviews is to be proactive in managing them.

First response time is a critical indicator of success Response time is the period between when the customer asks a question and when the business provides its first response, either via human agent or automation. Reducing response times and replying to customers with relevant, helpful information is vital to providing a good customer experience. Traditionally, customer satisfaction has been regarded as the ultimate measure of efficient service. However, another critical indicator — one that's increased in value due to the stresses and sense of urgency around COVID-19 — is first response time. Faster response and case resolution is the new gold standard for both customers and businesses. When majority of customers say that valuing their time is the most important thing a company can do when providing customer service. and they expect instant service within five minutes of online contact; each contact center engagement can be make or break for future business with that customer. But while providing a poor contact center experience can negatively impact customer retention — and ultimately, revenue — the opposite is also true. A positive contact center experience that provides ease, comfort, and assurance can promote enduring customer goodwill.

Customer Complaint Checklist:

Solving customer complaints is a lot like putting out fires. It's reactive, and no matter how good your product or service is, it's impossible to please all your customers.

The following checklist will serve as a standard operating procedure for CGD companies to respond, resolve and keep your customer happy.

1. Acknowledge the complaint

2. Inform the customer that you are acting. If there is delay in resolution, kindly inform customer accordingly so that they get updated and feels unique that someone is caring about them.

3. Record and categorize the customer complaint and analyses reason for complaint. If same type is re-iterating again and again, initiate the process of corrective and preventative action.

4. Resolve the complaint according to company policy.

5. Follow up with the customer to make sure they are satisfied.

Customer complain and queries-City Gas Distribution

S.N	Type of queries	% of complaint/Queries
1	New Connection and Initial queries	23%
2	Invoicing issue-After Sales	14%
3	Interruption in Supply	8%
4	Alteration request-After Sales	39%
5	Other	16%

The percentage of complaint received against different type varies for different organization. The organizations who focus more on complaint type 2,3,4,5 and give excellent response , get more of type 1 queries through positive referrals ..

Conclusion

Customer Complaints and their feedback has always been a gift for the organization & a Key to increase the penetration of PNG in domestic households in India. The organization who focuses on customer satisfaction, not only excel in business but becomes a brand. Indraprastha Gas Limited, Adani Total Gas Limited apt examples who focus on customer and always searching for new tools that connect with people. There is a famous quote which states, "People done care how much you know until they know how much you care" and same is true for any business.

An IOT and Machine Learning Based Smart Water Supply System That Can Detect Supply Conditions Including Leakages in Underground Pipe

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Abstract: This paper proposes a sensor-based pipeline system along with machine learning based analysis system can detect some (if not most or all issues). It also provides capability to monitor the water supply including water supply pressure using sensors. The station is given the data from each sensor enabling the analysis using analysis system. The water department can make decisions to improve supply system and/or correct faults bases on the data.

Keywords: Water leakage, sensors, water pipe, pressure, flow rate

I. INTRODUCTION

Water pipelines are underground in almost all places. These pipes are re-laid occasionally, but they can corrode or develop cracks depending on their location and the area including soil composition. Leakage of water can not only result in water wastage but also can lead to cave-ins in the surface near the point of leakage. Therefore, it is imperative to monitor the pipes. However, it is also difficult to monitor the flow through the pipes for optimal performance as they are underground.

This paper proposes a monitoring system that combines IoT with Machine learning to aid the monitoring and detect faults in time.

II. THE SYSTEM

The water supply system consists of multiple pipes connected to one another starting from the pumping station to homes of end users. The water supply is monitored using monitoring system whose requirements are given below.

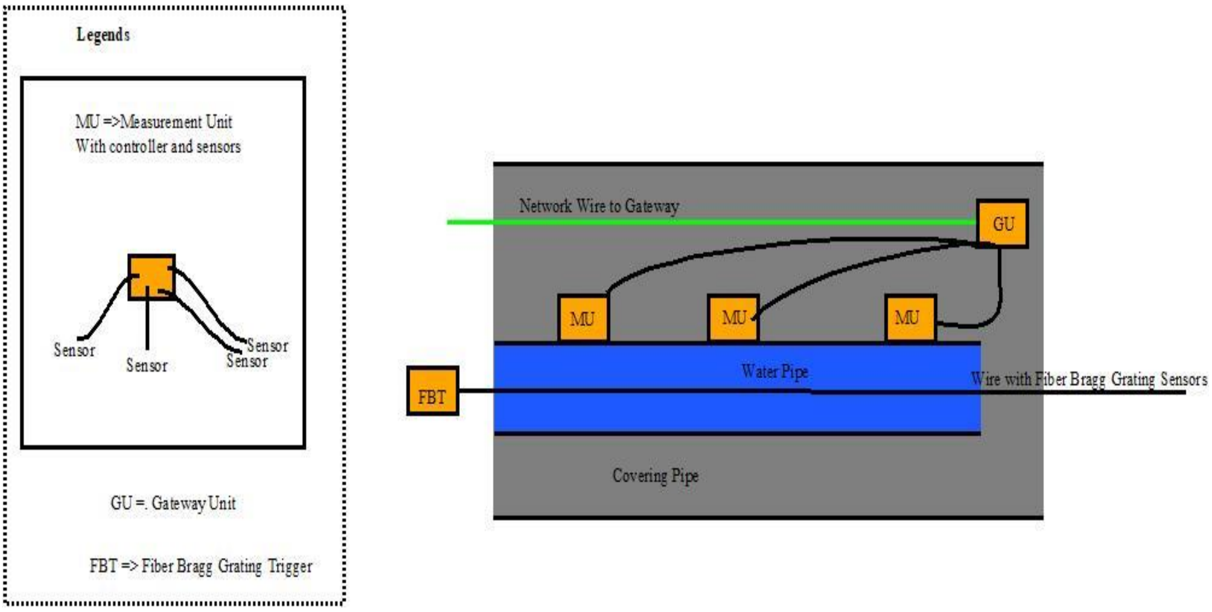

Figure 1: The Water Pipe Composition

A. *Ideal Pipeline Integrity Monitoring System Requirements*

The requirements of an ideal pipeline integrity monitoring system, as given in [2] are:

- Uninterrupted monitoring with no dead zone along the whole pipeline length
- Permanent and continuous 24/7 monitoring regardless of weather and pipeline conditions
- Ability to detect and locate any early signs of geohazards (or ground movements)
- Ability to detect and locate small leaks before they develop into large catastrophic leakages
- High sensitivity to guarantee fast response to any threat to the pipeline
- No false alarm

B. *The Proposed Pipe*

Only underground pipes are considered for the purposes of pipe. The proposed pipe structure and description is given in fig. 1.

Description of The Components

1. Water Pipe: They are used to carry water
2. Measurement units: They are used to monitor parameters and provide data to gateway for transmission for analytics and processing. The parameters measured are
   2.1. Flow rate
   2.2. Water pressure
   2.3. Pipe vibration
   2.4. Impurity
3. Gateway Units: The data is transmitted to stations using gateway unit. A gateway unit connects to measurement units to using Serial Peripheral Interface (SPI). Alternative wiring such as CAN or Modbus or Rs-485 may be considered. The gateway unit is connected to network to monitoring station using ethernet or wireless network.

III. THE WATER PIPE SYSTEM WORKING

A. *Working of the Pipe*

The pipes are laid out underground connected to each other. The layout of each pipe is given above.

The sensors within the measurement unit are inserted inside pipe and hermetically sealed. The vibration sensors are attached to surface of the pipe. Each sensor may be connected to one and only one measurement unit.

A measurement unit has one or more sensors attached to it. Each measurement unit has a unique id to differentiate from others. This helps to locate the measurement unit. Each measurement unit is calibrated before being placed in the pipe. It is recalibrated periodically to give accurate readings. The measurement period is configured in the system parameters. A gateway controller may also ask readings by sending request to measurement unit. This request initiates from the monitoring station. The monitoring station may also ask the measurement unit to identify itself by sending identification request.

If a sensor attached to a measurement unit sends no data, the measurement unit puts "No Data" <NDAT> for the missing sensor.

The gateway is connected to the monitoring station either using antenna that protrudes to the surface or using wiring or other connections as feasible. Each gateway is assigned a unique id that differentiates it from other gateways. It is configured with period of data reception from each measurement unit. If a measurement unit does not send data in this allowed period, the gateway sends <NDAT> for the concerned measurement unit. The station may request the gateway to identify a measurement unit or itself. If the request is for measurement unit, the request is forwarded to the concerned measurement unit. The gateway may also receive data request for obtaining data from a specified measurement unit. It sends this request to the concerned unit and gets the response. If the measurement unit does not respond within the allowed configured period, <NDAT> is sent to the station.

The gateway does no fault analysis for any data from any of the measurement units except inserting <NDAT> for missing data. It sends data to the water supply monitoring station

B. *The System at the Monitoring Station*

The system is given in fig. 2.

The monitoring unit has machine learning based monitoring system.

It has following parts

Initial Analysis System (IASys): This system is trained on expected data, data clustering and anomaly detection. The system is used because there are a lot of measurement units under supervision of a monitoring system. It takes in sensor data, puts in correct category, and checks if it is normal data or has an anomaly. This is forwarded to Display terminal, further analysis system and storage system.

Display Terminal: This displays the full system status as per incoming data. It consists of computer

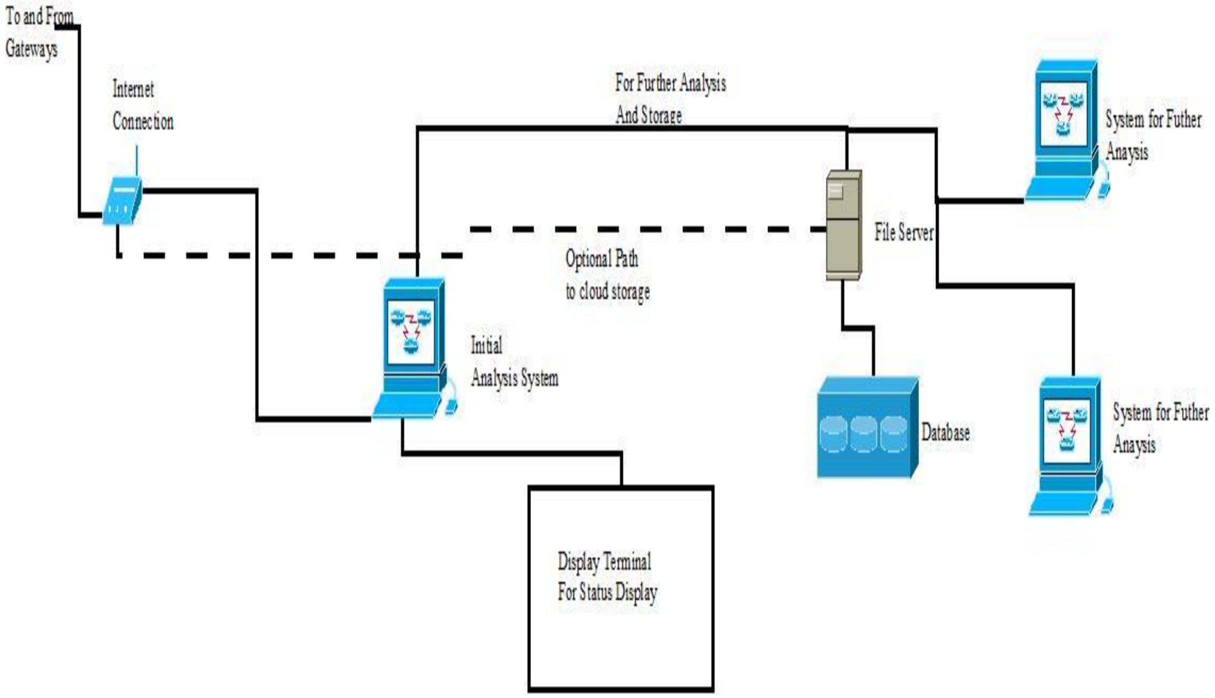

Figure 2: The Tracking System with Machine Learning

and display screen. It flashes the location of anomaly as per the incoming data.

Systems for further Analysis (SFA): There are multiple systems for further analysis. Each of them has personnel analysing the incoming data from the IASys. The personnel analyse the data and out of IASys and may take further action based upon analysis.

Storage System: The storage system consists of a file server and data storage to store all data. There is also an optional path for storage on the cloud or central storage.

The station managers may define the period for which data may be stored in the system as there is limitation on the storage capability.

C. What are the Sensors used?

The pipe may be fitted with one or more type of below sensors:

Vibration Sensors

These are MEMS sensors that are attached to pipes. Leakage is analysed by comparing the vibration of the normal water flow and the vibration when there is a leak in the pipe. The sensors are calibrated at installation time to measure the vibrations when

a. Water is flowing through the pipe and there is no leakage
b. Pipe is empty

If there is a leakage in pipe, the vibrations will change, and this change can be captured and analysed for leakage.

This method has been demonstrated in [3].

Fiber Bragg Grating Sensors

These are specialized sensors used to find out leakage points in a pipe. They depend on that fact that the loss of the medium transferred by leakage in the pipelines results in one or more of the following effects that can be detected: local cooling due to the Joule–Thomson effect, and soil temperature change due to differences in temperature between the soil and the liquids emitted because of leakage. Distributed optical fibre sensors (DOFS) measures the intrinsic backscattering, including Rayleigh, Brillouin, and Raman scattering, based on optical time domain reflectometry (OTDR) and optical frequency domain reflectometry (OFDR).

Distributed Strain and Temperature Sensing (DSTS) is a form of DOFS that is capable of detecting, locating, and monitoring ground movement and the bending and buckling effects of a pipe with three optical cables (strategically aligned 120° apart) installed parallel along a pipe's circumference

Their use is demonstrated in [2], [4] and [5].

Flow Rate sensors

These sensors measure the rate of water flowing through the pipe. The flow rate will decrease if there is a leakage. When there is a leakage in the pipe, impurities such as soil will mix with water and there will be deposits on the surface too. This will impede or change the flow rate. The measurement unit can detect this if sensors are places correctly.

These sensors use hall effect to measure the flow are through the pipe. An example of such sensor can be found in [6]

Impurity Sensors

These sensors measure the impurity of water. They are calibrated at installation. Corrosion or leakage will result in additional impurities being present in the water. The analysis the incoming data from sensors can be used to locate source of impurities. The sensor readings can point to approximate location where the impurity got added to water flowing through the pipe.

There may be multiple impurities and there are multiple sensors. One such is a pH sensor which is used to measure the pH of the water flowing through water. Dissolved oxygen sensors are another example such sensor. They measure the amount of dissolved oxygen in water flowing through the pipe.

IV. Advantages, Disadvantages and Scope of Future Work

The system is simple to work with. The presence of multiple types of sensors allows the water monitoring station to know the pipe leakage and can help in detecting the probable reason for leakage and source of leak. This will help the monitoring station prevent leakage or at least detect in time before the surface above it caves in.

There is a lot of data generated in the system. Machine learning helps in preliminary analysis which is expected to supplement the experts in analysis and detection. It can also aid experts in improving water supply and reduce wastage.

The measurement units and gateways rely on stable network connection which might not be easy to achieve in underground pipes. Protruding antennae may be used at regular intervals to allow over the surface communication. However, these antennae may need protection from breakage and pilferage.

The sensors need calibration and replacement/replenishment or battery change at regular intervals which means extra digging. Research is going on to increase battery life of sensors [7]. There are tricks available on internet (one example is [8]) to increase battery life. This may mitigate the need to dig up roads every now and then.

The measurement units can be damaged or short circuited by flowing water or leakage. They can be be hermetically sealed whenever possible to prevent damage.

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Solving Urban India's Water Crisis

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***Abstract*— As per NITI Aayog, 21 Indian cities, including Delhi and Bangalore, are on the verge of running out of ground water. 17.7% of the world population resides in India and 31.16% of that population resides in the urban cities. In India, problems faced by the water utilities ecosystem can be broadly classified into four different buckets. First, public water utilities are financially weak. Second, aging infrastructure assets with leakages and resource thefts. Third, low willingness to pay from consumers and fourth lack of technology intervention and data flow between the fragmented systems. This paper aims to mitigate the urban water crisis implementing solutions for asset management, water audit, billing & collection concerns, dynamic pricing and workforce management for consumer centric service approach. To realize the benefits and commercial viability of such technology interventions, the paper highlights a holistic cost benefit analysis for AMI projects capturing the socio-economic and the environmental factors. Finally, an integrated dashboard solution through shared resource mechanism leveraging from the electricity sector will help the utility monitor the flow of water through the entire value chain creating a harmonious water infrastructure and lower the total cost of ownership.**

Keywords—*GIS, AMI, Water Audits, Dynamic Pricing, Cost-Benefit Analysis, Workforce Management, Socio-Economic benefits, Environmental benefits, Integrated Dashboard.*

I. INTRODUCTION

It is recommended to consume 135 liters of water per capita per day in India (Ministry of Jal Shakti, 2020).But, high-income households tend to consume 250 liters per capita while many others have to do with 40 liters per head, forcing 600 million people in India to face high to extreme water stress. According to the UN, by 2050 India will add 416 million urban residents and about 100 million more at the front of a nationwide water crisis, has created concerns among utilities on supply of water. According to Central Water Commission (CWC) report, water levels in 91 major reservoirs in the country are at just 25% of capacity, 30% lower than last year, and 25% less than the average storage in a decade.

II. CHALLENGES FACED BY INDIAN UTILITIES

A. Financial Instability:

Non-revenue water is estimated to be around 38% which is above the global average of 30% to 35% reported by World Bank. Utilities also suffer financially because of poor billing practices, heavy subsidies and weak policies.

B. Aging Infrastructre

Aging infrastructure has led to water leakages and thefts, poor maintenance practices and lower service quality for the end consumers.

- *Water leakages* :- Assets like pipelines are usually underground and leakage detection isn't quick and effective, taking months for leakages to be discovered.
- *Resource Theft* :- Tampering of pipelines to tap water sources by the unauthorized users lead to contamination and low pressure situation for authorized users.

C. Low Customer Awareness

Water is not metered/billed at consumer level leading to low consumer awareness on utilization & wastage statistics, consumption pattern, financial implications, scarcity of the water supply. Change in consumer behavior and inclusive development can happen only with consumer awareness about sustainable personal water use and water quality threats.

D. Lack of Technology Interventions

Utilities have been far from using technology, rendering the entire ecosystem inefficient. Delayed technological interventions for a scarce commodity lead to laggard decision making, further exacerbating the dire situation in the country.

As part of Jal Jeevan Mission (JJM) (launched in 2020), more focus on technology interventions is being done to improve water infrastructure through "Technology Sub-Mission". It aims at providing every household with piped drinking water at an estimate of $38 billion over next five years.

III. INTEGRATED SOLUTION

An incremental /fragmented approach to revamp the water sector in India might not bring Indian utilities at par with global competition. Hence, a leapfrog approach, learning from integrated utility management in the western world, as well as the journey of electricity and gas utilities in India may be helpful. An integrated solution is required with holistic objective to manage the entire value chain using technology solutions and create an integrated enterprise infrastructure. Various components of such solution include Advanced Metering Infrastructure (AMI), Geographic Information System (GIS) based asset and leak management system etc.

A. Advanced Metering Infrastructure (AMI)

End-to-End AMI (from meters/ sensors to legacy systems) is capable of intelligent management of various related applications and carries out asset, consumer and event level analytics. This helps in operation and monitoring of assets, detection of anomalies, better workforce management, increased consumer engagement and better service quality.

AMI would result in optimization of operational expenditure, improvement in per capita revenue and willingness-to-pay, enablement of prepayment and remote connect/ disconnect functionalities, faster theft detection etc.

B. Geographic Information Systems (GIS) based Asset and Leak Management

Problems faced with current system of physical leakage identification include *non-existent and inaccurate data, resource intensive & time-consuming process, excessive water wastage etc.*

GIS based pipeline monitoring and surveillance system, compiles the geographic and technical features and detect leaks as small as 0.5l/min. This coupled with image processing techniques could prove as an efficient, cost-effective and reliable system for improved leakage detection while facilitating quick and precise damage analysis.

IV. COST BENEFIT ANALYSIS

Utilities are financially stressed and have limited funds for technology interventions, leading to fragmented digitization and sub-minimal returns. Hence, a proper cost benefit analysis for the deployment of integrated solution is critical.

AMI shares a major share in the cost of deploying an integrated solution. Component-wise share is provided in the diagram below. Smart meters may further get cheaper in an aggregated model of bulk procurement.[1]

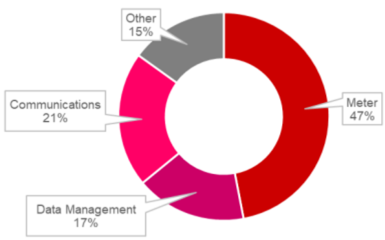


Fig. 1. Per meter cost breakup for AMI implementation

A. Cost Of Implementing an Integrated Project

Consider an area having average of 1Million customers with following monthly consumption

1. *25% customers > 500 units.*
2. *35% customers between 200 and 500 units.*
3. *40% customers < 200 units.*

Summary of deploying Smart water meter for 1 million customers:

Table 1. Total cost of Smart water meter for 10 years for 1 million customers

Items	**Total Cost (INR)**	**Remarks**
Cost of installing equipment at customer premises	4000 Million	One Time Cost
Cost of Neighborhood Area Network (NAN)	550 Million	
System Cost	140 Million	
Sub -Total (A)	**4,690 Million**	
O&M cost (including WAN communication for 10years(B)	2172.50 Million	Certain items for 10 years and few for 5 years
Total Cost for 10 years [(C) + (B)]	**6862.50 Million**	1000 Million
Overhead contingency and other unforeseen/contingency @ 10% of above, i.e.(D) = 10% of (C)	686.25 Million	1000 Million
Total Cost [(E) = (C) + (D)]	**7548.75 Million**	**2172.50 Million**

The total capex and opex (including fixed cost and cost of operation and maintenance for 10 years) for deploying Smart water meter for 1 Million customers is around is INR 7548.75 Million (INR 754.88 Crores) which turns out to **INR 7548.75 per customer for 10 years or INR 62.9 per customer/month.**

B. Direct Benefits to Utilities

Table 6. Benefits for deployment of AMI for 1 million customers

Benefits	**Value**	**Annual Benefits/Savings for 1 Million customers in INR**
Annual savings on meter reading cost against the traditional electricity meter (salary, allowances and travel cost of meter readers, stationery etc.) - (A)	INR 15 per customer/month considered **(15*12*1 Million)**	180 Million
Annual saving on data entry – (B)	INR 7.5 per meter read per bill **(7.5*12*1 Million)**	90 Million
Annual Savings from water theft/ water consumption not reported (taking INR 5 as average tariff. - (C)	Reduction in water theft due to Smart water considered as 5% (From 15% in case of normal water meter) **(5% 133.34 MU*12*5)**	400.02 Million
Annual savings due to faster detection of dead meter in the system (taking INR 5 as average Tariff) - (D)	No. of dead meters considered for 0.1% customers, time taken to detect dead meters as 30 days, monthly billed energy as 120 MU and billing efficiency as 90% **(133,333.34*12*5)**	8 Million
Annual savings due to reduction in peak demand cost through better estimation – (E)	20% reduction in current peak consumption during 4 hours of daily peak period; and energy input cost difference of INR 2/KWh considered **(=20% of [133.34 MU/30/24] *4* 2* 30 *12)**	106.67 Million
Total Annual Benefits (INR/year) = (A + B + C + D + E)		**784.69 Million**

Values are intentionally taken higher for incorporation the inflation over the lifetime of the smart water meter which is considered as 10 years

From the above calculation, **INR 784.69 Million** is the annual benefit of deploying Smart water meters for 1 Million customers.

Payback period = (Fixed cost + O&M cost for 3 years)/Total Benefit

= (4690 Million + 223.25 Million* 3)/784.69

= 6.83 Years

C. Other Synergy Benefits to Utilities

- *Water Audits:*

Such an integrated solution with metering provisions would facilitate real time water audits, reduce wastage and boost water conservation. Based on 200+ water audits conducted by CII[2], an estimated 160 billion liters of water has been saved annually with major benefits across the industrial sector as:

1. 15-20% savings using low-cost strategies (payback period 4-5months)
2. 30-40% savings using low-medium cost strategies (payback period 12-18 months)
3. 40-50% savings using wastewater recycling

- *Workforce Management:*

AMI data can be integrated with GIS and workforce management systems allow field personnel to address leakage issues with greater efficiency. Based on an analysis done by Panasonic and Intel[3], enabling workforce management in the utilities led to a 40% reduction in the total maintenance cost.

- *Dynamic Pricing:*

The current pricing mechanism of single (fixed) or two-part tariff (fixed + variable based on meter reading) involves cost of operations and infrastructure supporting them, ignoring social and marginal cost related to water consumption.

Using an AMI enabled integrated solution costs related to water availability, demand and scarcity can be charged to the consumer based on Time-of-Use.

- ***Water related savings***

Non-Revenue Water: Smart Water Meters could be very effective in curbing water loss and reducing NRW in India through leak detection, real-time data collection and monitoring, and machine-to-machine communications.

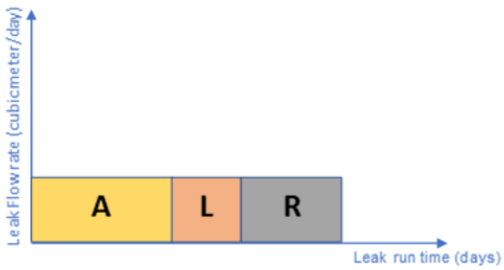
NRW=Water Pumped - Water Billed (1)

Resource Theft*:* 15% of total water consumption is stolen in India, prominent in region of unauthorized residences or slums, which can be curbed through such integrated solutions.

*Total cost= 2800ltrs (avg. HH consumption in India *(INR 20 per liter avg. cost of water distribution/1000) *x% population dependent of stolen water* (2)

The cost incurred by the government to send tankers to places which are deprived of water due to such thefts *= INR 1100/tanker * y (No. of tankers reqd.)* (3)

Water Leakage at consumer's end*:-* Household leaks unnoticed over time are serious issues for customers leading to higher monthly bill. The volume of water lost from an individual pipe burst does not only depend on the flow rate of the event but is also a function of run time.



A: Awareness time, L: Location time, R: Repair time

Fig. 2. Time take to solve the leakage

(A + L + R) [d] X Flow rate [cubic meter/day] = Water loss [cubic meter (4)

This is often overlooked. The leak run time consists of three components:

- *Awareness time: time until the utility becomes aware that there is a leak*
- *Location time: time spent to precisely locate the leak so that a repair job order can be issued*
- *Repair time: time between issuing of repair job order and completion of the repair.*

Smart water meter provides simple algorithms running over the 24 daily readings for each customer, can identify multiple hours of continuous nonzero use within a property - further segregated into minimum day flows and night flows.

This provides visibility of water leakage by providing daily water usage statistics and incentivizes the customers to rectify identified leaks through innovative and effective tariff structure.

Consumer savings*:* Smart water metering also adds beneficial customer impacts as it promotes innovative water retail tariffs, supporting more frequent and accurate billing, enhances customer engagement. For instance, in Bangalore, many apartment complexes claim that their **water consumption has gone down by one-third post AMI deployment[4]**

Calculating the water consumption before and after AMI implementation

Before AMI implementation

- Bangalore population - 84lacs.
- Average persons per household (HH)- 4.8
- Average water consumption - 100 liters
- No of Households = 84/5 = 16.8 lac HH

Table 7: Cost of water supply in Bangalore

Water consumption	Cost of water per liters
Up-to 8000 liters	Rs 7
8,001 to 25,000 liters	Rs11
25,001 to 50,000 liters	Rs 25
50,001 liters and above.	Rs 45

Considering in one apartment complex with 200 HH

- Average HH usage = 480 liters
- Per month consumption = 480 * 30 = 14,400 liters

Total Cost= **(7*8000+11*6400+25*0+45*0) = Rs 1,26,400**

After implementation of AMI: -

- Per month Consumption (1/3rd decrease) = 9,600 liters

Total cost = Rs 73,600

D. Socio-Economic and Environmental Benefit

Apart from the direct benefits, such deployment projects will also have repercussions leading to socio-economic and environmental benefits to consumers, utilities and society.

- *Employement Opportunities:* Digitalization of utilities would creates jobs for the skilled sector. People who are currently deployed in redundant jobs can also be upskilled by the utilities for better salaries as illustrated below.

a. Employees earnings before implementation of AMI

Employment Lost		
Job type	Costs of salary (Per person)	Total Per year
		S*HC*I
Installation of meters [One time cost]	800/-	
O&M of meters (Repairs)	150/-	
		S*HC*I*12
Meter Reading(per day)	176/-	

b. Employees earnings after implementation of AMI

Employment Created		
Job type	Cost of Salary (Per person)	Total Per year
Per Visit		S*HC
Installation of meters [One time cost]	1500/-	
O&M of meters (Repairs)	150/-	
Monthly (Utility Side)		S*12*I
Technical experts to maintain AMI infrastructures	25000/-	
Customer care executive	20000/-	

S- Salary, HC Households covered, N Number of Working days

Water Industries Carbon Footprint: Smart water meter can help to reduce the carbon footprints as illustrated below.

- AMI deployment leads to **reduction in usage** and thus **pumping of water** in turn leading to lower electricity consumption. Less water usage would also need **lower energy consumption in treatment plants**.
- Auto detection of leakage supported by less pumping of water would also reduce carbon footprints.
- AMI helps to identify non-potable water that could be reused which in turns helps to reduce energy required to pump sewerage.
- AMI enabled workforce management helps to reduce unnecessary vehicle travel decreasing fuel and transport requirements which could be significant in some regional areas.

E. Shared Resources Mechanism

Further the cost of the entire integrated system can be brought down by **Shared Resources Mechanism** Traditionally water and energy utilities have been viewed independent of each other and delivered to the consumers through separate entities. By using shared resources and leveraging the existing advanced infrastructure of the energy utilities, we would be able to address challenges in both, water and energy sector.

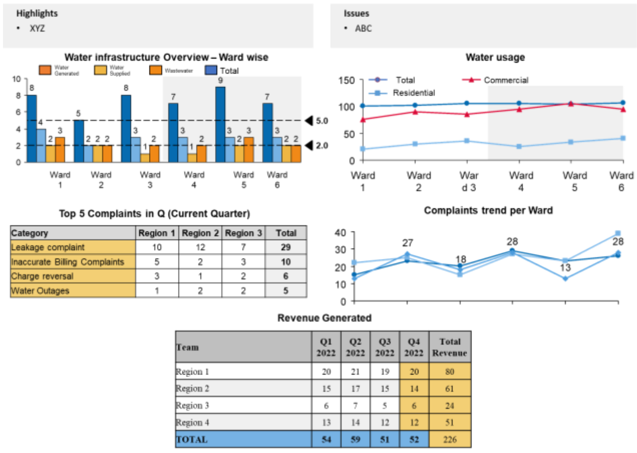
This would require a data platform to be developed for the operations of both the utilities to collect and protect data, improve data accessibility and interoperability, fills in the gaps and further leverage platform development for future planning and forecasting based on data analytics.

Such approach to capture benefits would tilt the business case in favor of implementation of such integrated solution with a lower payback period

V. Integrated Dashboard

An integrated dashboard would consolidate and enhance all existing performance management measures. It will provide a consolidated platform to Tracking a comprehensive list of KPIs that address all of the functions of the utilities sharing resources.

An integrated dashboard would ensure *effective tracking, transparent operations and aid decision making* by provide a steering view of functioning of all the related systems of the water & energy utilities value chain. Utilities will have to define their own inputs and output as well as thy can leverage the existing IT infrastructure for electricity consumers through shared resource mechanism.



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"AI Enabled Gas Management Solution"

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ABSTRACT

Over the last four years, oil, and gas companies' unprecedented focus on CAPEX and OPEX has enabled them to reduce their portfolio breakeven costs. Aging infrastructure, slower economic growth in developing countries, regulatory compliance is driving Gas Utilities to focus more on condition monitoring of pipeline infrastructure. Use of Digital technologies in a more strategically and holistically way can help the development programs of oil and gas companies to connect, consolidate, accelerate, and automate activities and decisions across the value chain.

According to International Energy Agency (IEA), Industrial consumers net demand is expected to increase by 40% with an expected growth of 34,500 kms by adding another 17,000 km.[5] gas pipeline and a $120bn Digital Transformation Opportunity globally.[1]

This paper proposes a data driven analytical solution based on Artificial Intelligence and Machine Learning technologies. It will help Gas Industry to rapid response to equipment failures by preventive maintenance, load and demand forecasting, workforce optimization and prevent hazardous situations by optimizing the operational performance and efficiency, enhancing security and safety to improve business growth and customer satisfaction.

Keywords— Oil & Gas, Digitization, Machine Learning, Artificial Intelligence.

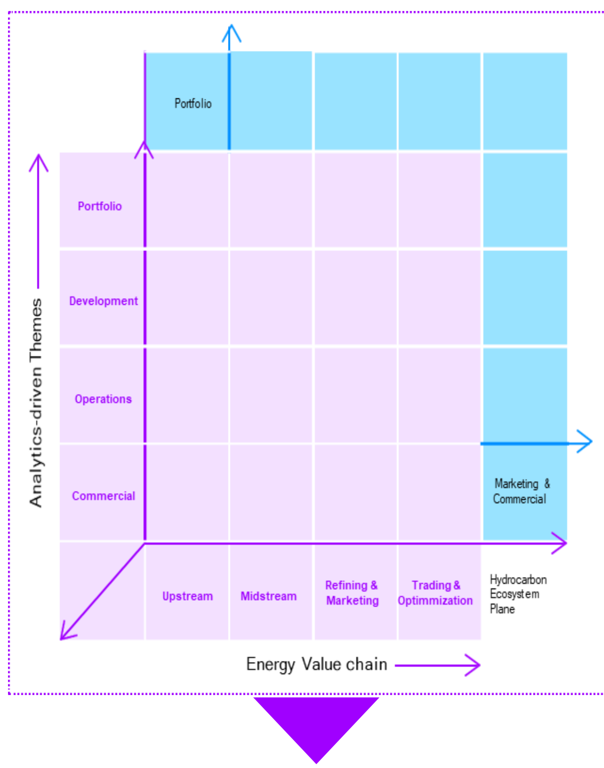
I. INTRODUCTION

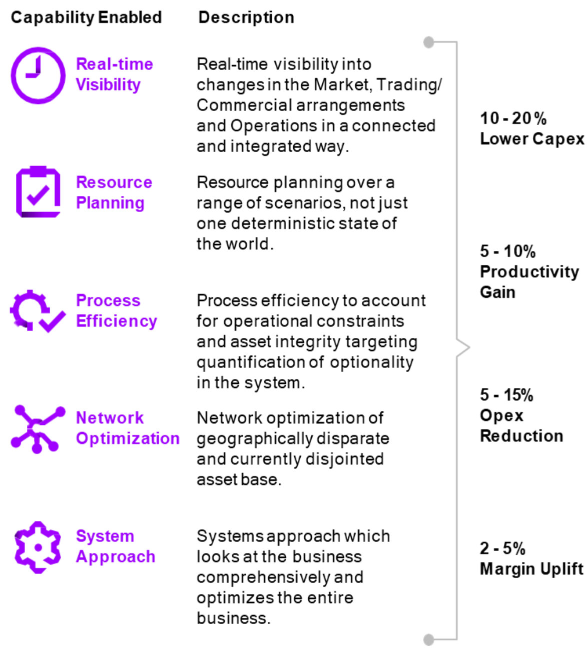
Analytics hold the key to future O&G success. The potential to unlock trapped value is significant across the value chain for three key reasons:

- The Industry collects large amount of data every second at different level, but only a small fraction of this information is been utilized for generating insights.[2]
- The industry has many disparate and disjointed databases that capture information concerning rock-properties, operations, maintenance, finance, and human resources. When connected, these granular data can enable prompt and reliable decision making.
- O&G players were among the first to use supercomputers, primarily to tackle very complex subsurface problems. Today, they are starting to generate tremendous value by connecting surface and commercial considerations with subsurface reservoir variables.[2]

Since the 2014 downturn, the O&G industry has struggled to lower supply costs and reduce the long cycle times. AI/ML has the potential to resolve these problems. The industry can reduce the cost of supply 30 to 50 percent and cut cycle times by multiple years when it employs advanced analytics decision making.

Figure 1 shows the key capabilities analytics that can enable untapped value potential.





Employing analytics and AI/ML, this new operating model will not only help in automating and digitally enhancing significant amounts of work, but it can also make these enhancements and activities more targeted and impactful.

II. CHALLENGES

Gas Pipeline Network needs to overcome bottlenecks such as real-time pipeline leakage detection and failure analysis, analysis of events occurring in the fields and highly conservative area. Failures and events risk in the field thus increases the fatality and injury rate. Scheduled maintenance work orders on affected pipelines are not monitored most of the times. These challenges are driving Gas Utilities to focus more on condition monitoring of Pipeline Infrastructure. The analysis and recommendations that AI can provide enable utilities to act promptly on specific, identified assets, rather than rely solely on periodic inspections across the entire system.

III. CURRENT TRENDS

A. "Moving to Cloud":

Most oil and gas companies are now moving to cloud-based platforms where they can host their business applications. IT is enabling infrastructure management, data interfacing with on-premises legacy systems and security management. With the business expecting ever greater control and self-service to be provided by applications using analytics and artificial intelligence, the trend is towards 100 percent cloudification of all new applications within a couple of years.[3]

B. Digitalizing of Physical Assets and Adoption of IoT Devices and Edge Computing:

"Digital twin" initiatives are driving the development of innovative new solutions for managing critical assets across upstream and downstream operations. Augmented/virtual reality technologies are playing a significant role alongside the APM tools and applications. Real-time asset and worker tracking solutions are becoming mainstream, as companies take worker safety and productivity more seriously. IT will play a growing role in managing the device connectivity, data processing and application workloads both on the edge IoT platforms and the cloud.

C. Increase Focus on Data and Data Technologies:

Today, business analytics and AI systems are scaling rapidly, with increasing availability of historical labeled data for model training and testing. Within a few years, assets will be deployed with self-diagnosing and healing capabilities. Asset maintenance decisions will be made by AI bots/operators with minimal to no human intervention. IT can play a major role in bringing new innovations around data discipline and administering the data foundation for all business intelligence (BI), analytics and AI applications.[3]

IV. PROPOSED SOLUTION

Digitalization not just enhances operational efficiencies; it also gives stakeholders new and powerful insights to radically improve decision making.

Fifty-seven percent of upstream oil and gas companies strongly agree that they need to innovate more quickly just to keep a competitive edge.[4] Faster decision-making leads to faster action. Similarly, faster processes allow the company and its systems to react quickly to changes, and scale production up or down, as needed.

Data Analytics and Artificial Intelligence underpin new models that deliver faster, more accurate results and identify opportunities for profitability or risk avoidance.

Following are some of the ways how we can achieve operational efficiencies using AI.

A. Monitoring & Control

Realtime Monitoring and Control of the gas network with fully integration of all the system can help the Utilities to track, monitor and control all the systems, to improve the operational efficiency.

Figure 2 – Monitoring & Controlling Important KPI’s

B. Advanced Asset Health Analytics of Field Devices. (Maintenance Analytics)

Analytical model to monitor health of all the field devices using advanced machine learning algorithms. Monitoring and analyzing of all the key KPI’s that can help in preventive maintenance, leak and failure detection to optimize the operational activities in O&G Industry.

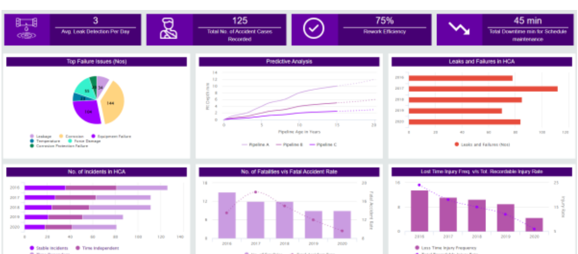


Figure 3 – Asset Health Analytics and Monitoring of key Field Devices.

C. Forecasting

Energy companies need to forecast natural gas demand to reserve pipe capacity and plan stocks effectively. Forecasting demand is a critical input to forecast gas price, which in turn drives the business decisions.

In this paper we proposed a Multi-Layer Perceptron (MLP) to forecast the demand of the gas supply. Factors such as temperature, calendar details such as holiday, weekend, weekdays etc were taken into consideration. Adaptive Moment Estimation Algorithm was used.

$$v_t' = \frac{v_t}{1-\beta_1^t}$$

$$s_t' = \frac{s_t}{1-\beta_2^t}$$

Where v is the first moment, it resembles momentum that records the past normalised gradient. And s is the second moment, which is the same as introduced in adaptive gradient descent & RMSprop.

The algorithm has shown promising accuracy that can be used or short term as well as long term forecasting of gas demand.

Figure 4 - Forecasting of gas Demand

D. Customer and Cost Analysis

A solution that can analyse the customer growth pattern, revenue forecasting, analysing customer gain/loss information, O&M actual to planned analysis to help the gas companies to be future ready with the blueprint.

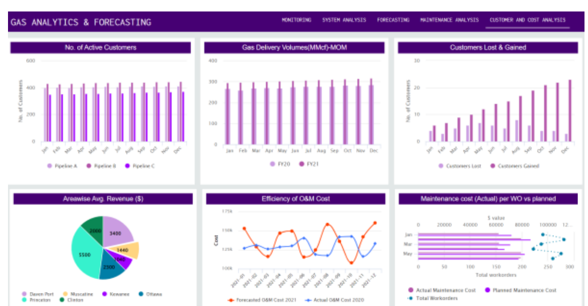


Figure 5 – Customer and Cost Analysis

V. CONCLUSION

More digitized asset management enabled by machine learning and AI alone can reduce an organization’s total costs by up to 20%, improve asset availability by 20% and extend the lives of machines by years. These savings can free up resources to invest in profit-seeking opportunities while also improving productivity and reducing downtime. Critically, they also can help advance sustainability goals.

As the tech trends described above play out for oil and gas companies, they will help to influence innovations in many areas of the business—with the relative timing and costs of these innovations varying widely.

VI. REFERENCE

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Webchat Integrated Chatbot (Tina).

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INTRODUCTION:-

Tata Power has deployed Webchat Integrated Chatbot TINA as an additional Digital touch point for its Mumbai Distribution consumers. This feature of "Live Chat with agent" along with automated chatbot services where user can get instant help through live chat option which gets activated after 3rd interaction. This is completely in house development with backend system integrated with CRM/SAP. This is also enhanced data security on Microsoft Azure platform. TINA chatbot was earlier hosted & managed by a third party platform of Yellow Messenger had limited features & there was lack of tracking and transparency of the services utilized.

EASE OF USE:-

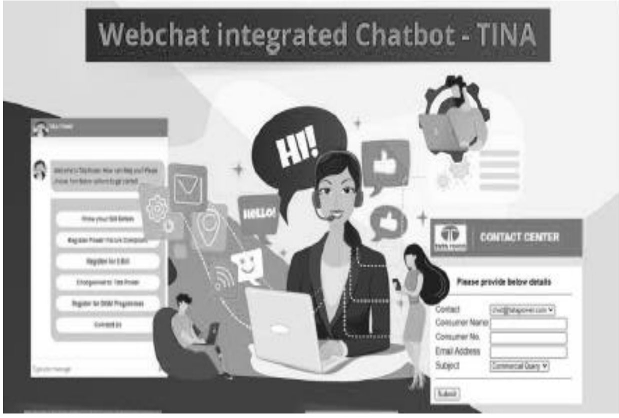
Webchat service is easy to use as this services gets activated post 3 interaction in case if consumer is not satisfied with the auto options provided in Chatbot TINA. This is an additional touch point for consumers. User can get instant help through live chat option.

In House Developed platform Chatbot was earlier hosted on third party platform of Yellow Messenger, now developed on our own platform, along with integration with SAP CRM BCM.

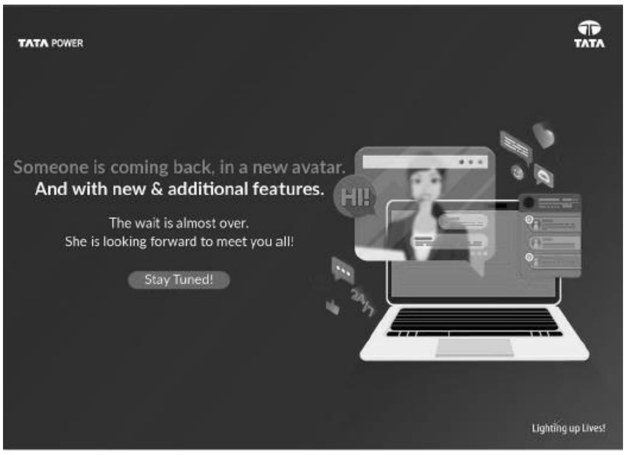
Another Digital Self-Service Touch Point with enhanced data security on Microsoft Azure platform to support our existing ones, for existing Consumers/ prospect consumers to get in touch with Tata Power

Chat Live with agent feature introduced user can get instant help through live chat option

A. This development has been done on Customer Portal. Earlier we had an option of Chatbot wherein the Webchat option not available. We only had certain queries which are auto answered by Bot. Further enhancing the consumer experience, webchat option had incorporated with Chatbot.



B. New digital touchpoint. For queries received on chatbot, identification for fetching details of consumer done on the basis of the Consumer no registered mobile no registered email address provided by user. This enhances customer experience self-service option available 24/7 on the Customer Portal. Real time based information is shared instantly with consumer, leading to customer satisfaction. Promotion across social media was done as mentioned below,



Webchat integrated with Chatbot facility has been made available for TPC Mumbai consumers. This is an additional option provided to consumer other than the already existing options available, which lead to increase the Consumer satisfaction.

Development of an in-house webchat integrated chatbot: with the additional feature of 'Chat live with agent' (which is activated at the 3rd interaction on the Chatbot). Auto-call logging is done in CRM for chatbot & live chat queries – basis the Consumer no./ registered mobile no./ registered email address provided by user. Self service options on chatbot instant live assistance available on webchat, enables multiple chats handled per agent (up to 5 nos.

KEY BENEFITS:-

Followings are the key benefits of the Product :-

Cost savings: - Due to in house developed platform
• Dependability on third party eliminated for AMC or adding of any new feature
• Consequent cost of transaction platform maintenance cost also eliminated
• Approximate cost savings of around 32 lakhs annually

Process improvement :- Self service options on chatbot instant live assistance on webchat
• Integration with SAP CRM application along with auto call logging help in tracking interaction
history, usage effectiveness of the chatbot feature
• Integration with SAP BCM application for feature of live chat with agent for user, enables multiple
chats handled per agent (up to 5 nos

Digitalization initiative: - New digital touch point
• For queries received on chatbot, identification for fetching details of consumer done on the basis of the
Consumer no registered mobile no registered email
address provided by user
• This enhances customer experience self service option available 24 7 on the Customer Portal
• Real time-based information is shared instantly with consumer, leading to customer satisfaction.

• YTD usage of the Chatbot with Webchat figures updated below:-

Type	YTD
Billing Details	7986
Change Over to Tata Power	639
Enquiry	240
Name Change	132
Register of E-Bill	95
Power Failure	94
SMS Registration	45
High Registration	24
NACH	22
Address Correction	22
Register for DSM Programmes	19
Permanent Disconnection - Query	5
Grand Total	9323

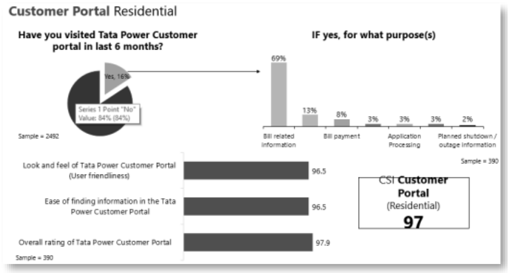
CUSTOMER SATISFACTION:-

Webchat Integrated Chatbot TINA placed **mainly on Customer Portal** also saw results increasing as compared to previous year & **customers rating us well in the Annual C-Sat.**

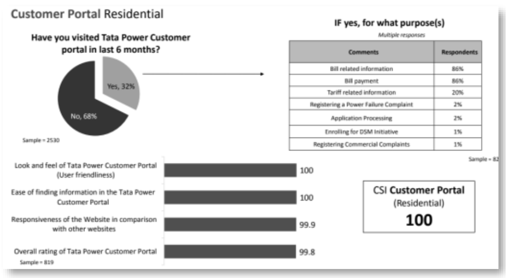
- **Ease of finding information** on Customer Portal **increased to 100% in FY-21** from **96.5% in FY-20**.
- Due to extensive promotion across Social Media and all Customer Touchpoints, **Customer reach for Bill Related Information** on Portal **increased to 86% in FY-22** from **69% in FY-21**.
- Overall Score for Customer Portal **increased to 100 in FY-22** from **97 in FY-21**.

Sample size also two-fold as compared to FY-21.

FY-20 Results



FY-21 Results



FIGURES & TABLES:-

This development has resulted significant cost saving as its In-house developed platform dependability on third party eliminated & Consequent high cost of transaction & platform maintenance cost also eliminated. Approximate cost savings of around 32 lakhs annually. Kindly refer the below mentioned table for the reference.

Cost savings due to in-house developed platform = Cost incurred earlier for earlier Yellow Messenger platform

Approx. Rs.32 lakhs per annum

COST INCURRED FOR EARLIER YELLOW MESSENGER PLATFORM	
Avg no. of transactions per month	90,000
Cost per transaction (in Rs.)	2
COST INCURRED PER MONTH (in Rs.)	1,35,000
ANNUAL COST INCURRED (in Rs.)	16,20,000
Annual platform maintenance cost (in Rs.)	15,80,000
ANNUAL TOTAL COST INCURRED FOR CHATBOT	**32,00,000**

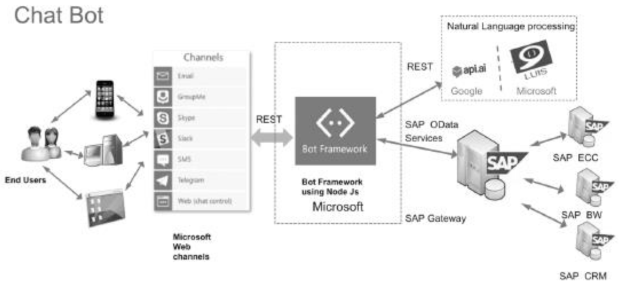
TECHNOLOGY USED & FRAMEWORK:-

* Before finalizing on which framework to be used for developing the new In House Chatbot for consumers, we explored the services of two biggest and best bot service providers viz IBM and Microsoft their respective services being IBM Watson and Microsoft Azure Bot.

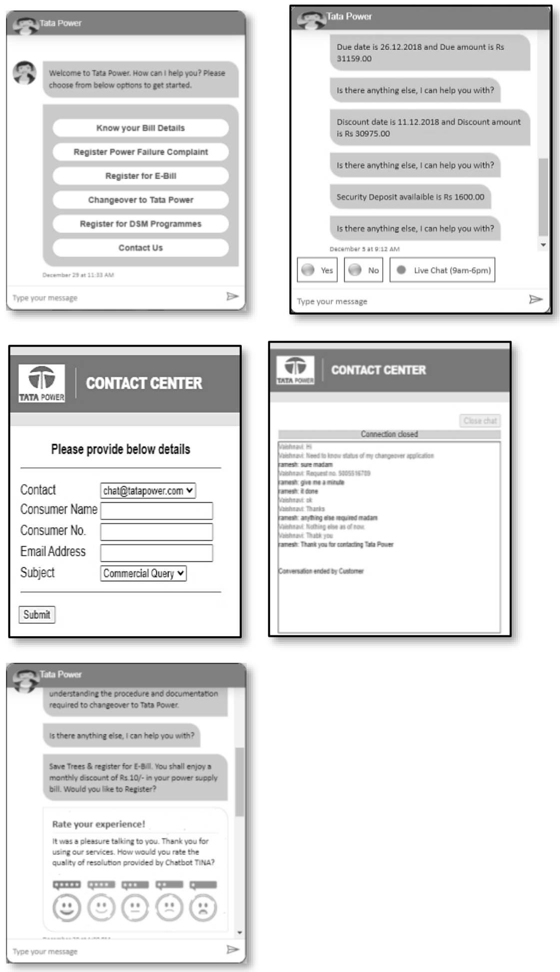
* We also found that the Azure Bot building interface is simple and straightforward and it is a code based platform where in our in house developers can code and modify to make custom bots with complex flows which also includes CRM based integration

* Microsoft Azure Bot also provides a simple Q&A maker which allows to build simple FAQ bot in addition to this LUIS (Language Understanding Intelligent Service) is another service which has multilingual capabilities.

* MS Azure Bot can be easily integrated with SAP ISU and CRM as well as with Skype, Slack, Office 365 mail and other popular services of Microsoft which are extensively used in our organization

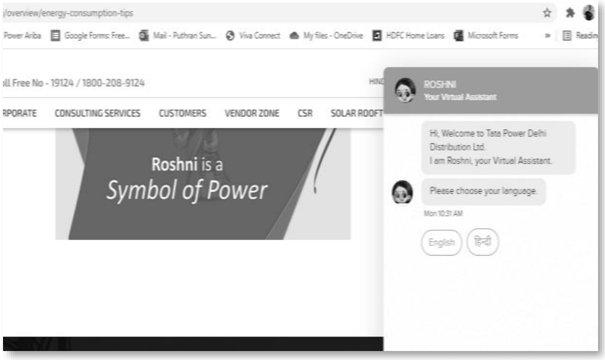


WEBCHAT INTEGRATED CHATBOT SCREENS:-

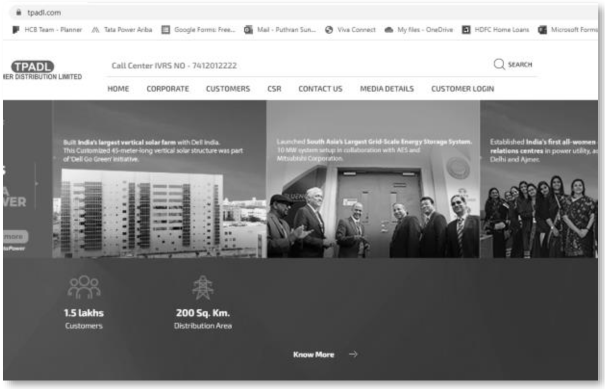


TECHNOLOGY ADOPTION:-

Study Conducted across Tata Power Group Companies to see the current use of Chatbot Technology & the technology adopted by the Tata Power Company Ltd can be used across all other Group Companies.



TPDDL Chatbot (Roshni) is currently powered by **3rd Party - Yellow Messenger & can be developed in-house.**



No Chatbot Deployed at Tata Power-Ajmer Distribution

No Chatbot Deployed at Tata Power-Odisha Distribution.

Understanding the Digital Consumers for better Service Delivery

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I. INTRODUCTION

The power distribution sector is the only link with retail consumers and the looming deregulation is pushing the sector to become increasingly competitive. As balance sheet pressure rise for cost as well as revenue, utilities are pursuing alternative strategies to improve the bottom line. One of the methods is customer experience transformation.

The threat of competition due to De-licensing, increased Cost to serve, absence of timely tariff revision, rapidly evolving consumer preferences have made Customer engagement more important now than ever. Consumers are now more connected to businesses through Digital mediums than before. They expect hyper customized experiences on-demand at the speed of now and are more vocal through Social Media. The Digital laggards are now forced to adopt Digital way of living for their basic day to day needs – starting from paying bills to reporting an outage.

An engaged Consumer will be less complaining, more likely to pay, less probable to churn and at the end will be the advocate of the brand. Apart from all these, the continued Pandemic has also accelerated the Digital adoption journey for the utilities as well as for the Consumers.

Utilities are hence forced to develop infrastructure to provide such services. This paper offers a guided framework for utilities to provide superior Customer engagements by deeply understanding their Digital Consumers.

II. EMERGING TRENDS

The various emerging behaviors, which is re-shaping the Customer Experience are:

*A. **Always Online***

Consumer expectations have increased many folds and they are increasingly expecting Utilities to be responsive with the speed of now. These have been shaped by service delivery from other day-to-day activities like Mobility, Food & Transport, grocery etc. They want to track, monitor and want to know the exact time of their service delivery- be it Meter reading or power restoration.

*B. **One-click services***

Earlier offline systems which were designed for compliance and not for speed and user experiences are undergoing an overhaul. Consumers are now spoilt with one-click delivery platforms be it from Amazon, Flipkart or the Myntras of today. Utility players are now adopting the principles and techniques from other industry behemoths to lead the Digital way of servicing. Digital-first approach is now a clear advantage and utilities are using them to reduce the complexity of their operations and turnaround time.

*C. **Promise of many***

Consumers do not want to spend much time in managing these low involvement jobs like managing their energy usage. They want plethora of choices to contact the utilites whenever and wherever they want. Utilities are building capabilities surrounding these and are providing seamless experiences across mediums.

III. UTILITY LIFECYCLE & MOMENTS OF TRUTH

Like all other Industries, in Power distribution sector also cost of average customer acquisition is higher than that of retention of Consumers. With deregulation, more choices will be there for the Consumers and also, they will become more demanding. This highlights the importance of ensuring that Consumers stays, thus Customer Stickiness is one of the key metrics. Customer service is one of the most primary factors to drive loyalty to a brand.

Utilities should aim at providing a seamless digital customer experience to its Consumers in a cost-effective manner, yielding maximum end user impact. A focus should be on providing a significant value to Consumers resolving their pain points. To offer truly customer centric services, Utilities should track key customer preferences such as channel of communication for various services. The different Customer stages of Customer lifecycle are:

A. Pre-enrolment – Consumers are in the deciding phase

B. Onboarding – Consumer decides to opt for the specific Utility players

C. Business as Usual – Day to day interactions between the utilities as well as Consumers for paying bills, meter reading, supply restoration etc.

D. Switching option – Consumer decides to opt for another player. (though not prevalent in India, however with upcoming de-regulation of the sector this will be a burning issue)

Consumers may contact utilities for various requirements , however there are four key moments that matter. Utilities need to understand those moments, capture them to turn those into a delightful experiences.

A. *New Connection*
B. *Bill payment*
C. *Outage / Supply Restoration*
D. *High Bill*

IV. CHANNEL WISE STRATEGY

Gone are those times, when Consumers used to visit a Utility office to report an Outage. Nowadays, utilities use plethora of channels to provide services to its Consumers. Nowadays, customers want to interact with their utility via multiple channels and want more control over how they are contacted back. Thus, utilities must offer omnichannel customer service delivery. The various Online channels utilized by Utilities:

A. Call Center

This is central communication platform for all Utilities, especially in India. For reporting an emergency like fire or an outage this is the most preferred medium. Consumers prefers to talk to an agent during such times as a voice call always garners more trust and also utility agents can be easily reached at any hour of the day.

B. Email

For Services other than emergency, Email is another channel for Consumers. However, this requires a degree of Digital Literacy. Services which do not require immediate response are mostly accessed via this channel.

C. Mobile App

Mobile App is a popular medium and is used for recurring services like Bill information, payment of Bills and also Outage registration. Services which do not require immediate response from the utilities are popular on this mobility medium.

D. ChatBot/WhatsApp Bot

These new age platforms are also gaining popularity amongst the Consumers for its zero-wait time and also 24X7 nature of service delivery. However, it has been observed that Services like Bill Information, payment receipt, payment confirmation, reporting of non-receipt of Bills are popular across these platforms. Non-essential services are mostly accessed through these platforms.

E. Social Media:

Social Media can be popularly termed as a platform where virality is high. Consumers reaching out through these platforms wants instantaneous response. Utilities are also leveraging these opportunity for providing better Consumer services. They are adopting to a comprehensive, curated as well as flexible strategy to respond to Consumers instantaneously. Utilities can also utilize these platforms in their benefit for :

a) Outage Notifications
b) Promotion and Branding – Promoting Electric vehicles
c) Building Awareness – Like monsoon safety campaigns
d) Emergency situation alert – Like Cyclone, Storms etc. notices dissemination

Along with Social media, Utilities should invest on Social Listening tools also. These advanced tools provide detailed views about Consumer sentiments across digital platforms.

With the induction of various channels, Utilities can craft their delivery strategy across platforms. One size does not fit all, hence specific channels should be utilized for precise set of Consumers. Like – Restoration related information could be sent to Consumers via WhatsApp Bot for a more personalized interaction. However, with these Omni channels , Utilities can longer operate in Silos. Seamless integration to provide a unified communication/ response is required. Hence, integration of all channels is critical.

V. CONSUMER SEGMENTS FOR INCREASING STICKINESS

'~20% of the Consumers provides for ~80% of revenue' this rule applies hugely for utilities. With the continuous cost pressure and to ensure profitable Consumers remains loyal, through increased stickiness, Utilities are analyzing consumers behaviors to understand who drives profitability. Utilities who have been focused on revenue per Consumers are now focusing on profitability per Consumers. Parameters like digital friendliness behaviors, payment default history, number of complaints, should be taken into account to derive the various segments and they should be merged with the profitability (Revenue - Average Billing units) to derive the profitable Consumer segments . The four prominent segments are:

A. **Highly Engaged** – Consumers who are willing to refer the utilities to their friends and business associates. Service delivery issues faced by this segment is minimal.
B. **Active Consumers** – Consumers who complains to utilities about any service delivery issues.
C. **Lapsed Consumers** – Consumers who repeatedly complains about issues and the most vocal
D. **Inactive Consumers** – This segment is no longer communicating with the Utility and will be the first to deflect to competitors

Based on profitability the service delivery should be designed.

Profitability	Segments	Remarks
High	Highly engaged	
	Active	
	Lapsed	High probability for switch
	Lost	
Medium/ Low	Highly engaged	
	Active	
	Lapsed	Probable for switch
	Lost	
Negative	Highly engaged	Value Eroded
	Active	
	Lapsed	
	Lost	

Service delivery for every segment should be designed keeping in mind the need of the segment. Turnaround time, delivery channel would be different for every segments. The breaking even or negative profitable Consumers should be handled through mass media channels or self-help channels like SMS, Mobile App etc. The turnaround time should be as per the regulatory guidelines.
The most profitable segments should be provided one-to-one communication and their service delivery issues should be addressed on priority.

VI. CONSUMER SEGMENTATION TO INCREASE ONLINE PAYMENTS

Meter to Cash cycle being a very critical process for all Utilities. Earlier Utilities used to operate multiple Cash Collection centres for collection of their monthly Consumption bills, with the advent of various digital channels these has undergone sea change. Consumers have

also changed , along with their online grocery shopping they are also preferring to pay their bills online. Convenience being the key parameter for such adoptions.
Based on the payer's payment behaviors Consumers can be segmented broadly into 4 categories:

TABLE: SEGMENTATION

Segment	Characteristics	Strategy to entice
Offline Loyal	Consumers who prefer Offline medium to pay their bills	Increase trust in the digital medium, provide trials to build trust in the process
Fence Fitters	Consumers who toggle between Online & Offline payment medium	Entice them with offers and harp on the benefits and saving potential of the Online mediums
Online Loyal	Consumers who prefer Online medium to pay their Bills	Convenience is the key for this segment. A well-designed smooth process flow will keep them loyal to the medium.

Utilities also need to invest sufficiently in the infrastructure so that issues like failed payments, loading error etc. does not occur. A smooth processes will go a long way in increasing the online payers. The strategy is to shift the Offline Loyal Consumers to Fence fitters and make them Online Loyal. Advanced analytics should be implemented to design the communication. Based on analytics, a payer's likelihood to pay a bill can be gauged and appropriate communication can be sent.

Communication should be sent keeping in mind Consumers preference to pay their bills along the various payment moments like:

- Nearing Due Date of the Bills
- Consumers prefers to pay their bills just after they have received their Bills
- Consumers pays their bills after the Due Date is over

Churn Analytics: This is an interesting concept adopted by Telecoms and can be adopted by Utilities. Consumers who pay their Bills Online and then switches to Offline mode can be identified through analytics and appropriate communication can be sent to ensure that they continue to pay their bills online.

VII. CONCLUSION

A well-designed Digital roadmap is the need of the hour as it will be the foundation on which Utilities will be able to quickly adapt to changing business dynamics. Creating a strategy with Customer at the core, will help the utilities to move ahead of the ever-changing customer demands and technology disruptions. It starts with understanding the Digital Consumers, their preferred channel of communication and with the continuous improvement on how Customers are digitally served and fulfilled at every touchpoint and across all channels.

[1] *https://www.cognizant.com/whitepapers/enhancing-the-utility-customer-experience-a-digital-framework-codex3164.pdf*

[2] https://www.bain.com/insights/digital-strategy-for-utilities/

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[4] https://ideas.repec.org/p/cam/camdae/1867.html

IMPACT OF DISTRIBUTED RENEWABLE GENERATION AND STORAGE ON TRANSMISSION AND DISTRIBUTION EQUIPMENT

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Abstract- Steadily rising peak power demand underscores the need to constantly upgrade and refurbish the network to avoid stress from future demand, which is expected to increase further with greater urbanization, population increase, rising incomes, and improving standards of living. Installation of Renewable energy generation and storage systems on Transmission and distribution equipments are expected to be the most helpful technological developments to meet the rising load requirement. In this paper, impact of distributed renewable generation on present network and required modification in network as well as system components are discussed.

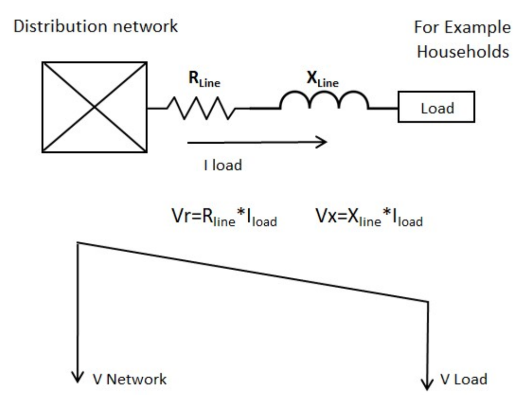
1. Introduction

Integration of distributed renewable energy generators and energy storage system is increasing rapidly. Their impact on existing power network, need for modification and up-gradation in present equipments, challenges and risks with smart and connected networks, electrical and protection changes with distributed energy resources and Impacts of distributed renewable energy generation sources & energy storage on equipment requirements are briefed herewith

2. Impact of Grid connected distributed generation sources on voltage profiles

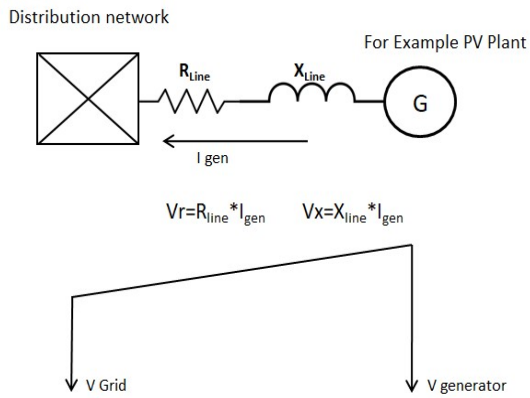
Solar Inverters are typical current sources. They do not regulate the voltage. PV system voltage is always synchronized with the utility voltage before their integration. Voltage drop characteristics along the Distribution line is as following:

A. General Case: Voltage decreases along the line from transformer to load



The voltage at the distribution transformer is set such that a sufficiently high voltage at the end of line is guaranteed even in case of high loading

B. Reverse power flow - Voltage increases along the line



With given transformer settings, strong reverse power flow may result in violation of voltage tolerance at the end of line, overvoltage may occur. Due to increase in voltage at PV plant terminals, insulation deterioration or breakdown may take place.

As load and generation are fluctuating there is no single design case for voltage profile. Therefore, there is need to broaden the voltage range presently allowed by the relevant standards.

C. Options to safeguard voltage tolerance for network users:

i. Network reinforcement –
To reduce the impedance values along the line and resulting voltage drop, larger cross sectional lines with additional number of lines shall be required. This option causes costs for distribution network owner.

ii. Curtailment of plant's maximum power production -
This causes limited yield losses. The yield losses depend on the annual profile of the solar irradiation. This oppression causes financial losses to the solar PV plant owner. This option does not really solve the problem. It just postpones it for later when more solar PV plants are commissioned.

3. Monitoring and control of distributed generation in low voltage distribution network

By now, capabilities for monitoring and control in distribution network are very limited. In the past, distribution network companies just facilitated power flows from generation at high voltage levels to end user at low voltages. Utilities ensure to provide power supply by appropriate planning and maintenance of assets. They provide power at acceptable voltage profiles by appropriate design and selection of transformer settings. Further they ensure safety of persons and equipments by appropriate protection. Utilities are responsible for correct invoicing and cost recovery by monthly metering and billing.

Generally, Utilities do not require online/high frequency acquisition of data and real time control. Hence respective infrastructure has not been implemented even after widely induction of IT. In fact, no other stakeholders had an interest in real time data within distribution networks or at the end user connections.

Monitoring and control capabilities will penetrate distribution network in the near future. Various players have their interests in adding monitoring and control capabilities to distribution networks.

4. Electrical safety and protection challenge with distributed generation sources:

Network sections of any transmission and distributions system are separated by protections. Grid connected distributed generation sources stands at higher voltage levels in the islanded conditions. Any unattended electrical island has to be avoided because of the associated risks. It may be dangerous for professional staff unaware of energisation. It may be harmful for equipment's because of violated power quality tolerances during islanding mode.

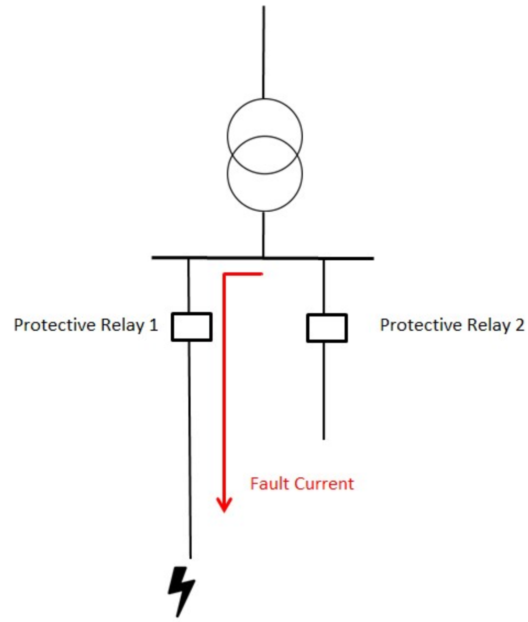
Therefore, any distributed generation has to include some anti-islanding detection. Most common detection mechanisms rely on violation of voltage tolerances, violation of frequency tolerances and observation of rate of change of frequency or vector shift.

Voltage and frequency will remain within the tolerances if there is a close and undisturbed balance of active and reactive power within the islands. This has been proven to be very unlikely.

Please refer following protection scenarios in a distribution network:

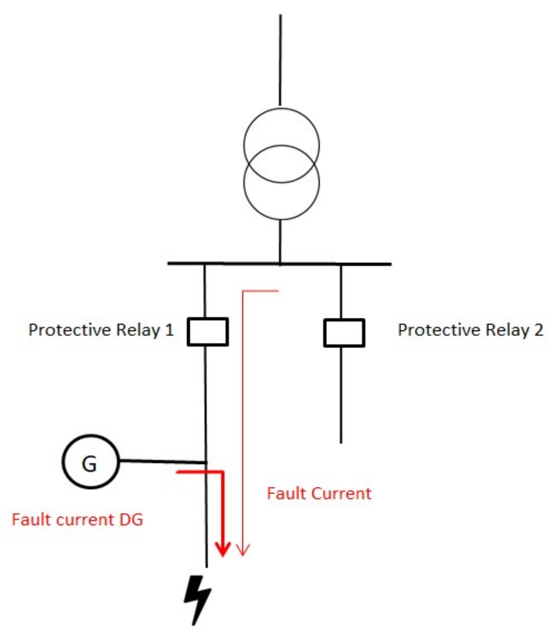
A. General philosophy of protection:

The fault current to the end of feeder correctly triggers protection relay 1.



B. Blinding of protection:

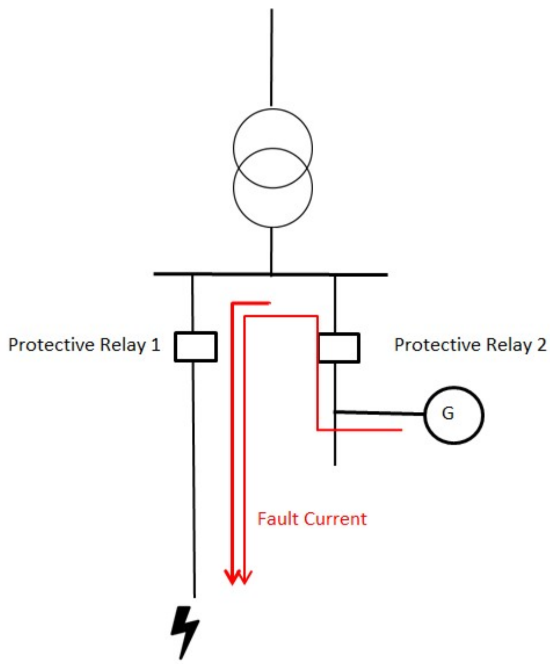
If the distributed generation unit (DG) contributes to the fault current. The current of protection relay 1 is reduced. The relay does not trigger and hence does not disconnect the fault.



C. Sympathetic tripping:

The distributed generation unit contributes to the fault current. The current triggers protection relay 2 despite there is no fault in this feeder. As a consequence, there is an unnecessary supply interruption at healthy feeder 2.

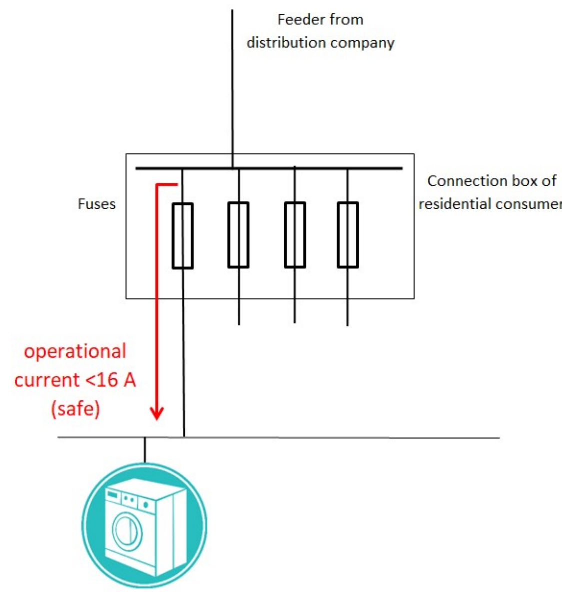
Such kind of sympathetic tripping like other protection issues, can be tackled by adequate coordination of protection schemes. This may include changes of settings outside the distributed generation units, deeper in the network.



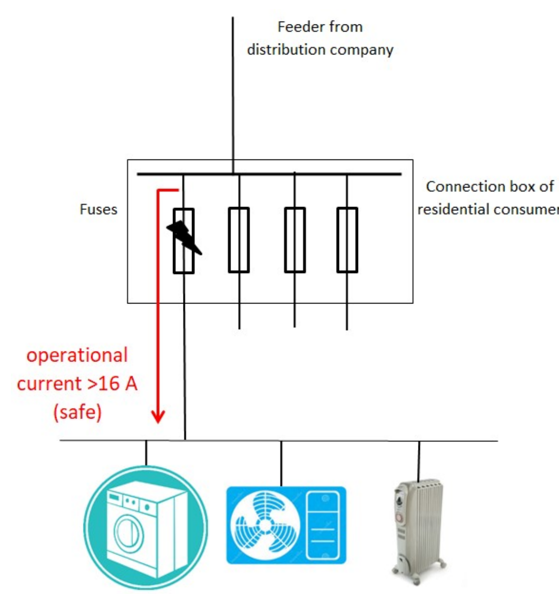
D. Challenges with Plug in distributed generation system:

It is always required to flow load current through protection devices only. Different cases of flow of current are as following:

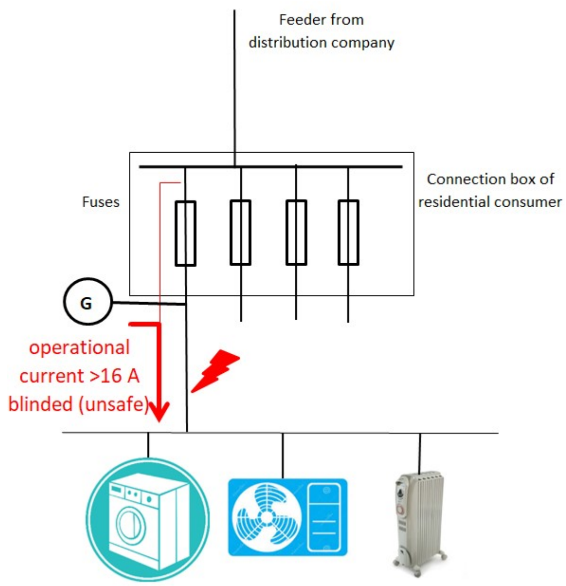
i. **Load current is under conductor current rating and passes through protection fuse –** Safe operation



ii. **Load current is above conductor current rating and passes through protection fuse –** Safe operation



iii. **Load current is above conductor current rating but part current is fed from distributed generation source** – Unsafe operation and example of blinding of protection



5. Impacts of battery energy storage system on Utilities:

Renewable energy sources are intermittent in nature. Unlike electro-mechanical power generators, in photovoltaic power generation plant, frequency dip take place immediately. It may lead to system instability. They do not have any stored kinetic energy therefore they have poor load variation response. Battery Energy Storage System (BESS) has emerged as a viable solution in today's scenario mainly to maintain reliability of power supply in case of demand – supply variation and to resolve the intermittency issues. Roles of battery energy storage systems for power distribution utilities and suitable technologies are discussed herewith:

A. Decongestion of the power distribution network:

In a power network, congestion may occur when transmission/distribution lines cannot be reinforced in time to meet increasing power demand. Battery energy storage systems installed at appropriate substation can relax the congestion. Load on associated various network components such as cables, switchgears, control panel, transformers etc may be reduced. Distribution utilities shall get the additional time to increase the network capability to meet load requirement in long run.

B. Maintaining load curve:

BESS can be used to store power during off-peak period and discharge during peak. If the gap between peak and off-peak demand is large, the case for storing electricity becomes even stronger. Using storage to decrease the gap between daytime and night-time peak to off peak load requirement leads to an improvement in operating efficiency and cost reduction.

C. Emergency power supply for protection and control equipment:

A reliable power supply for protection and control instrument is very important in electrical power distribution network. To meet the same, battery systems are always installed at various switchgear locations. BESS system may be integrated to existing battery systems for further improvement in reliability.

D. Economic benefits of deploying ESS in the distribution network: Despite the significant initial upfront investment, there are several economic benefits associated with deployment of ESS in the distribution network. Some of these benefits are listed below.

i. **Deferral of capital expenditure on:**

Diesel Generators- ESS can obviate the need for deploying diesel generators to meet peak demand. DGs are not only expensive but also contribute to greenhouse gas emissions.

Network upgrades- Large-scale batteries installed at appropriate substations may mitigate the congestion and thus help utilities to postpone or suspend the reinforcement of the network like investments in sub-stations, transformers, cables, protection, and other network elements.

Land- Reinforcement of the grid may require acquisition of additional land to accommodate an extra transformer/feeder. The cost of land can be quite substantial, especially in urban areas. BESS on the other hand doesn't require much space and can be installed in the already existing battery room of a substation.

ii. **Savings on account of:**

Avoidance of loss of revenue-

By greatly enhancing the reliability of the power supply, an ESS can help the utility to avoid revenue loss on account of non-provision of electricity to consumers that may be triggered by tripping of a transformer due to overloading of the network during times of peak demand.

Penalty for non-provision of power – ESS can also help utilities avoid paying penalties that they are liable to pay for failing to provide power.

iii. **Additional revenue from improved power reliability –**

It is also possible for utilities to realize additional revenues by demanding an additional charge for supply assurance on account of enhanced power reliability.

6. Conclusion:

Impact of Distributed Generation resources on existing distribution network as well as on consumer equipment is discussed in the paper. Protection Philosophy and recommended challenges with existing practices are highlighted. Impact of Battery energy storage and its benefits to the utilities are also briefed in this paper. Hope for the usefulness of the presented paper to the Power Engineering professional.

Survey and Impact analysis on Electric Utilities, by Energy saving, Monitoring and Management using IOT and Active Sensors.

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***Abstract*—This paper includes survey and analysis of the 10 countries focused on monitoring and reducing energy consumption. The programs design for the promotion of energy saving perspective and impact of educating the benefits of energy consumption,by promoting and benefiting consumers or Electric Utility with incentives and rebates. The energy management and efficient utilization program is controlled either by the government or by the electrical utility. Techniques and technology implemented using IOT(or IOE) and sensors for the smart sensor for the reduction of the energy consumption is discussed.**

***Index Terms*—energy consumption survey, CO2 emission,Policy framework,accounting energy saving, IOT ,Smart Sensors**

I. Introduction

In recent years, due to wastage of electrical energy, shortage of fossil fuels, there is an increase in dependency on energy saving for the residential/commercial/industrial customers. The optimum use of electrical energy utilization started playing vital part across the world. Production of energy requires lot of time and resources; on the other hand the energy consumption minimization is effective. For any developed country or developing country efficient energy utilization is the crucial parameter considering financial development, environmental impact and sustainable growth. Energy has been considered as an important factor for achieving sustainable development. The role of renewable energy consumption has been investigated as it plays a prominent role in carbon emission and carbon emission also influence renewable energy consumption. The demand for renewable energy usage has been increasing over the past few decades and is still increasing day by day. Increasing demand for energy can be the reason of increased in population, life style and improvements in competitiveness. The statistics indicates that the total energy consumption in the world have been increased which is based on fossil fuel resources. Increase in fossil fuels consumption results in increased carbon emission in atmosphere which affects environment such as the cause of global warming. Where it's been agreed that environmental degradation is mainly the reason of carbon emission. Considering the crucial parameter of the countries for the long term sustainable growth and reducing environmental impact it is required by the countries to design program, promote energy saving, incentives and rebate for energy efficiently utilization is promoted. Techniques involved are IOT, IOE, Home automation, Smart Metering, Building automation system, Wireless sensor communication.

Identify applicable funding agency here. If none, delete this.

II. Surveys and Analysis: Energy Consumption and Environment

A. Energy Consumption Survey:

As per the statistical data from www.enerdata.net fig.1. energy consumption of past 30 years from year 1990 to 2020 for the countries like, Australia, Canada, China, France, India, Italy, South Africa, United States, Europe, Brazil. Refer fig1, as per the plotted data it is observed increase in energy consumption in each consecutive year. Energy Consumption for the India, China, United States is relatively more than other countries mentioned. The total energy consumption is increasing every year. From the data,it can be predicted, with increase in development of electrical technology and dependency on automated systems, consumption of electrical energy would increase in future.

B. Major Reason for the increase in concern for reducing energy consumption:

- Fossil Fuel is depleting and their consumption is the largest contributor of the greenhouse gas[2].
- Global increase of the CO2 concentration due to burning of fossil fuel is a major drive of climate change [2].
- Reducing Energy related green house gas emissions.
- Energy Consumption reduction is one of the simplest and cost-effective tools to reduce energy consumption while contributing to greenhouse gas (GHG) reduction [2].

Energy is recognised as a driver of a country's economic growth, an essential commodity and an important tool for development. At present, global total energy production roughly comes 81 percentage from fossil fuels, 31.5 percentage,

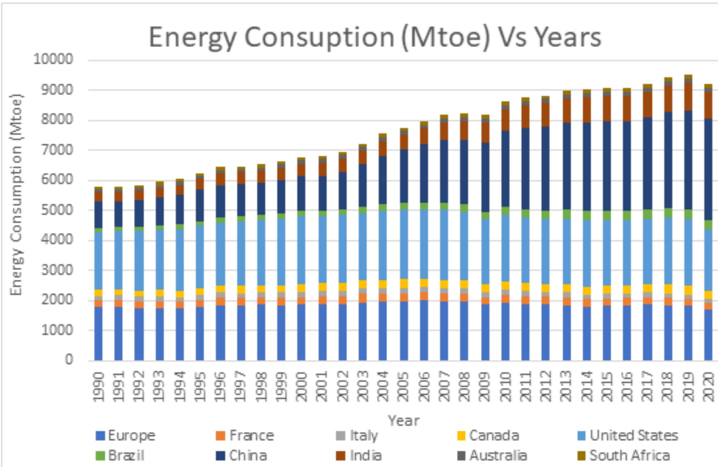

Fig. 1. Energy Consumption Survey(Mtoe-Million tonnes of Oil Equivalent)

coal—26.9 percentage and natural gas—22.8 percentage . Biofuels secured 9.3 percentage, nuclear energy—4.9 percentage and hydropower—2.5 percentage of global energy supply in 2018. By contrast, only 2.1 percentage of the world's primary energy comes from solar, wind, geothermal or biomass energy or other alternative energy sources[2].

III. Relation between Carbon Emission, Renewable Energy Consumption and Financial development:

Four hypotheses have been identified in relation to the causal relationship under study are as follows[2]:

- The growth hypothesis validates a unidirectional causality as between energy consumption and economic growth.
- The environmental protection hypothesis suggests a unidirectional causality between economic growth and energy consumption.
- The feedback hypothesis implies the existence of mutual interdependence of energy consumption and economic growth (bidirectional causality).
- 4. The neutrality hypothesis assumes no significant causality between economic growth and energy consumption.

Developing countries require large amounts of energy to meet industrial, urbanisation and transport needs but this comes at a cost of environmental degradation and results in increased carbon dioxide emissions [2].

According to the results, Fig.2. the influence of renewable energy consumption on carbon dioxide emissions is negative, while financial development has an increasing effect on carbon dioxide emissions. The study has also shown that both renewable energy consumption and CO2 emissions affect financial development in a positive and significant manner [3].

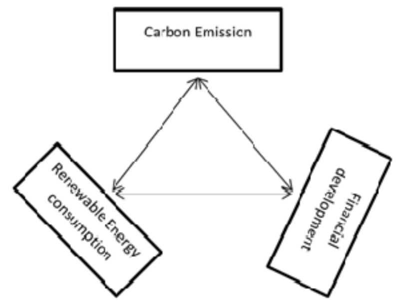

Fig. 2. Relation between Carbon Emission, Finanical Development and Renewable Energy Consumption)

IV. Policy frameworks and program designs:

A. *Policy frameworks:*

The typical policy frameworks in which incentive programs develop are either 1. direct government roll-outs with money raised through taxes or 2. mandatory savings goals (also referred as obligations) set for energy providers (also referred as utilities) to reduce their customers' energy use. Incentive programs have been principally implemented by governments to fuel long-run growth of domestic clean (Eg. Energy Star) product markets. By increasing production of efficient products that are at an early stage of development, incentive programs help technology (and thus the market) mature and spur private-sector investment. Implementation of incentive programs can also be motivated by the need to boost the economy at times of recession; governments deploy incentive programs to stimulate economic activity while also promoting clean technology development. Governments have also created regulatory frameworks that comply energy providers to deliver energy savings. Energy providers often then become the administrators of energy-efficiency programs. Utilities' direct link to energy consumers and access to valuable data on energy usage patterns are a significant advantage in designing effective programs. However, energy efficiency is not an obvious business for utilities to undertake, because when consumers save energy, utilities sell less of their product[4].

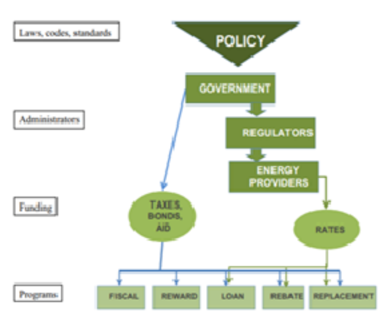

Fig. 3. Incentive program policy framework)

B. *Examples of Programs for Energy Saving:*

This section presents a variety of examples to illustrate how incentive programs have been implemented in different countries [4].

- **Downstream programs:** Downstream program either offer the incentives to the consumers or award point for the replacement of the inefficient product with efficient product. Downstream program implemented in the countries like France, Italy, UK, South Korea, Japan, Mexico. With the help of this program directly customers are benefited from government or local government by tax credits, tax deduction replacement, VAT reduction, Eco-points, financing on bill in the given countries [4]. **Consumer reward points** Two countries – Japan and South Korea – have implemented subsidies in the form of reward points to encourage consumers to select highly efficient technologies. This innovative approach aims to promote low-carbon lifestyles by encouraging consumer responsibility and awareness[4]. **Replacement programs**, also called early retirement and direct installation programs, replace inefficient residential appliances before the end of their useful lives with significantly more efficient appliances. This reduces electricity use by both encouraging the deployment of efficient appliances and ensuring that older, less efficient appliances are removed from the stock. These programs have the added advantage of minimizing the potential of a rebound effect in which a household would expand its appliance capacity by keeping and continuing to use the older less-efficient appliances in addition to the new one[4].
- **Midstream programs:** Midstream program offered incentives to HVAC distributors with the goal of promoting the sale of at least 7500 ton of central air conditioners that had a Seasonal Energy Efficiency Ratio (SEER) of greater than or equal to 14 (with a minimum eligibility of 13). Because of their relative modest per unit savings, midstream programs offer a good alternative to downstream program for consumer electronics. When compare to a retailer's profit margin on the product, incentives tend to be more significant for the retailers and distributors. Midstream program implemented by US (Texas) and US (California). California's utilities designed the Business and Consumer Electronics (BCE) Program in 2007. BCE provides midstream incentives to large retailers for the sale of high-efficiency consumer electronics, such as televisions and computer monitors [4].
- **Upstream programs:** Upstream program implemented in China, India, Sweden, United State and United State (California). Direct Manufacturers are benefitted with this program[4]. **Technology procurement** Sweden was one of the countries that pioneered upstream programs. In the early 1990s, the Swedish National Board for Industrial and Technical Development (also known as NUTEK) sponsored a technology procurement program in which a group of buyers and experts developed specifications for highly efficient ground-source heat pumps. The group specified high-quality heat pumps that were 30 percent more efficient and 30 percent less expensive than existing models on the market; China's upstream subsidy program began with a CFL promotion program in 2008. Suppliers received subsidies to provide a 30- percent discount on wholesale purchases and a 50-percent discount on retail sales. In 2009 and 2012, the government extended the program to air conditioners, TVs, refrigerators, washing machines, and water heaters. The program's main goal is to promote energy saving home appliances and stimulate the economy to offset the impact of the international economic crisis[4]. **Upstream fiscal instruments:** The U.S. government agency responsible for tax collection, the Internal Revenue Service, administered the program, whose goal was to transform the market by influencing manufacturers to produce increasingly energy-efficient appliances. **Subsidies** China's upstream subsidy program began with a CFL promotion program in 2008. Suppliers received subsidies to provide a 30- percent discount on wholesale purchases and a 50-percent discount on retail sales. In 2009 and 2012, the government extended the program to air conditioners, TVs, refrigerators, washing machines, and water heaters. The program's main goal is to promote energy saving home appliances and stimulate the economy to offset the impact of the international economic crisis[4].
- **Packages of programs:** Different types of incentive programs can be implemented simultaneously or consecutively. A combination of upstream, midstream, and downstream programs can be used to help a market grow and mature, addressing the barriers faced by different market players—manufacturers, distributors, retailers, and consumers. Sweden is an interesting example of a long-term, integrated approach to incentive programs that started with the technology procurement program described in technology procurement; that program was subsequently complemented with subsidies, favorable loans, training, and information campaigns[4].

V. COUNTRIES IMPLEMENTED ENERGY EFFICIENCY:

- United States: Utilities in the United States have the longest experience – more than three decades – in executing energy-efficiency programs. However, the scope and intensity of these programs vary significantly among states. Twenty-seven U.S. states have set efficiency goals for their electric energy providers, and 12 also have goals for natural gas providers
- In Europe, the UK was the first country to implement an obligation scheme in 1994, the Energy Companies Obligation (ECO). ECO has evolved and is now combined with another scheme called the Green Deal.Other European countries—Denmark, the Flemish region of Belgium, Italy, France, and recently, Poland—have also implemented energy-saving obligation schemes.

- In France and Italy, the efficiency targets are accompanied by trading markets where a unit of energy savings known as a "white certificate" can be either sold or purchased. Energy saved in any sector counts toward meeting an obligation. A new EU directive on energy efficiency requires that all EU Member States implement utility energy savings obligations equivalent to 1.5 percent of annual sales.
- Other examples of savings obligation schemes around the globe include those in some Australian states, Brazil, South Korea, South Africa, China, and India.
- Since 1998, the Brazilian power regulatory authority, ANEEL, has mandated that utilities invest at least 0.5 percent of their net revenues in energy-efficiency programs.
- Similarly, in South Korea, the Rational Energy Utilization Act covers investments rather than focusing on specific energy savings. The act requires that each energy utility establish an annual DSM investment plan with a total budget greater than the previous year's.
- In South Africa, the government set an initial energy-savings target of 4055 GW h (and 1037 MW) for the period 2011–2013. In China and India, utility efficiency programs are still in early stages of development. In November 2010, China adopted national energy-efficiency regulations that took effect on January 1, 2011 and require China's power grid companies to save the equivalent of at least 0.3 percent of their sales volume and 0.3 percent of maximum load compared with the previous year.
- In India, the Maharashtra Electricity Regulatory Commission (MERC) instituted a public-benefits type of electricity charge on utilities, with the funds to be used to finance renewable-energy and energy-efficiency programs in the state. In late 2005, MERC ordered utility companies in the state to use these resources to start CFL programs in Mumbai's residential sector and in the Nasik District.

As can be seen from these examples, governments around the world are developing policy frameworks to increase the role of energy efficiency in meeting new energy demand. These new regulations often lead to the development of incentive programs

VI. Funding sources for Energy Efficient Program

In most cases, government-sponsored incentive programs are funded through general government budgets financed by taxpayers. In the case of special stimulus packages, funding comes from exceptional funds, such as the American Recovery and Reinvestment Act of 2009 in the United States. Governments of developing countries or economies in transition can seek financial support from international financial institutions such as the World Bank, the Clean Technology Fund, and the Global Environmental Facility. For example, Mexico's Programa Nacional para la Sustitución de Equipos Electrodomésticos (PNSEE) is supported by loans from the World Bank and capital from the Global Environmental Fund (WB, 2010). India's Super-Efficient Equipment Program (SEEP) for electric fans will be supported by the Clean Technology Fund (CTF), which is administered by World Bank.In the United States, South Africa, South Korea, and Brazil, energy-efficiency programs are generally funded by a small levy or charge – a fraction of a cent per kilowatt-hour – on electricity sales. This levy goes into a common public fund that is used to recover the cost of implementing programs[4].

VII. Different Approach for Energy Efficiently utilization

A. Approach used to reduce energy consumption using smart sensor

1. Collection method with power saving. 2. Clustering algorithm 3. Leach 1.To minimize the energy usage, sleep time of the sensor is increased and wakeup period is decreased. Here wakeup time solely depends on duty cycle of the data collection device. During wakeup period sensor moves to active position and looks for slot contention which means it looks for any active data. If not found, it will move to sleep mode to save energy. By doing this energy can be saved also lifetime of the sensor can also be increased[5]. 2. Network with large number of sensor nodes is divided into clusters. Within each cluster one sensor node is chosen as cluster head and others are cluster member. Cluster members communicates with head and the head communicates with the base station. By doing this nodes involved will be decreased, so that energy dissipation will also be decreased[6]. 3. Self configuration protocol which organizes nodes by itself and forms cluster. It is used to adapt and rotate the cluster head which will be useful to distribute energy load among all nodes. It is same as clustering algorithm but it is self organizing protocol[6].

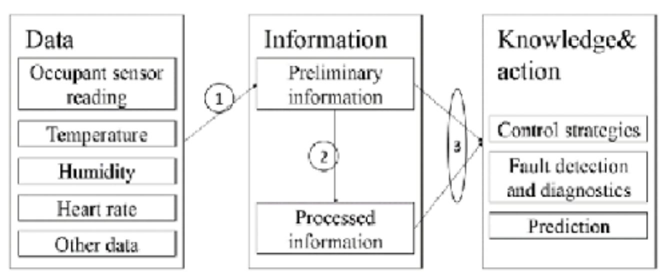

Fig. 4. Data Analysing Process)

B. Internet of Energy approach[7]

Internet of Energy (IOE) is a child of Internet of Things (IOT) and grandchild of cloud. IoT and the IoE are methods equipping different advanced energy sensors to create smart environments. IOE can drive down the energy utilization to very low levels. Goals with the use of IOE and IOT includes: Improving energy efficiency, increasing the permeability of renewable energies, diversifying and decentralizing energy mix and promoting industry competitiveness. [8]

Sensors for Smart Operations	Sensor Types
Occupancy sensors	Image based sensor, Passive infrared (PIR) sensor, radio-based sensor, Threshold and mechanical sensors, Chair sensors, Pressure Mats, Camera sensor, Photo sensor, Ultrasonic doppler, Microwave doppler, Ultrasonic ranging
Built environment measurements	CO2 sensor, Air Temperature sensor, Humidity sensor, Thermo-fluidic sensor, Sound sensor, Light sensor, Volatile organic compound sensor, Particulate Matter (PM) sensor, Air velocity sensor
Other sensors	Wearable sensor, IoT based sensor, Smart Phones, Heart Rate sensor, Fingerprint sensor, Mobile pupilometer, Skin Temperature Sensor

Fig. 5. List of the Sensors related to intelligent IOE operation

Energy Saving IoE approach, using sensors for Smart Buildings, Home, Grid and Monitoring [9]:

- **Smart Building:** Smart Building Design makes the buildings energy efficient with the optimum energy use and facility management. Connectivity for heating, ventilating, and air conditioning systems allows instant monitoring and control, resulting in significant energy cost savings. It can even wake up devices for maintenance work or turn off entire systems during holiday and vacation periods ,according to users demands. Potential energy savings could reach 35 percent [7]. The energy consumption of the building depends on occupancy of the building. Therefore, fine grain of occupancy information in the building is of utmost important for the energy efficiently use.
- **Smart Grids:** Implementation of smart grid results in annual gains of 3-6 percentage in grid efficiency. Smart Grids are highly automated and provide instantaneous adjustments as needed, building to building [7]. The microgrid technology is at present an inimitable opportunity to improve power quality, energy storage, integration of renewable energy sources, integration of facilities to home appliances, demand response, and services in intelligent buildings.
- **Smart Monitoring Meters:** A major component of Smart Grids is Smart Meters. They can help identify inefficiencies and reduce waste [7]. They also help match supply with demand. [6] The authors used GPRS, ZigBee, and energy meter in the development of the device and also used the high performance and low-cost microcontroller.

VIII. Conclusion

As per the analysed data, of 10 countries for the energy consumption and CO2 emission[2][1] it is observed that increase in the energy consumption in every year due to increase in the technology growth and development of the countries[2]. It is observed that relation between financial development, renewable energy and C02 emission its correlative effects varies as per the country is developed or developing[2][3]. Policy frameworks were introduced by the countries like ,Australia, Canada, China, France, India, Italy, South Africa, United States, Europe, Brazil with Incentive programs, often pay the up-front cost of efficient equipment and therefore require significant capitalization. There is no silver bullet for energy efficiency; policy must be developed on a case-by-case basis to respond to market barriers and must embrace local conditions.Successful programs address the barriers that hinder the penetration of highly efficient products at different stages of a product's market diffusion. These programs use a holistic market transformation strategy in which upstream, midstream, and downstream incentives are part of a package of interventions that speed the adoption of more-ambitious standards[4]. Wireless smart sensor provide wide range of applications with the extensive use in the market. Smart Sensor technology is evolving day by day with evolution of the requirement of the industries[5]. Providing efficiency without affecting the comfort and involving active element ensuring energy balance with the "Internet of things" + "Energy Management"[6][7]. IoE (Part of IoT) is capable to recognize temperature, light,sound, heat and proper humidity in environment, manage energy in smart environment, for the energy management and energy optimum utilization[5]. The Internet-of-Energy (IoE) provides sustainable development, monitoring for uptime and downtime, energy management, smart grid management for reducing downtime by incorporating a suitable sensor as per the requirement of the environmental and data acquisition[7].The sensors required for the data acquisition of the building or environment are divided into 3 types 1. Occupancy Sensors. 2.Environmental sensors. 3. Other sensors. Each sensors have its own added advantages as per the environment if used with best set of sensor combination occupancy based sensor network can save 70 percent of HVAC energy consumption and 40 percent of light energy consumption in building environment[8][9].

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Leap towards i4.0 – Digital Twin for Electrical Network

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Abstract*— To thrive in the rapidly transforming environment, power sector utilities need to keep themselves abreast with the evolving dynamics of the sector. Achieving this feat primarily requires the utilities to bridge the gaps between their traditionally isolated systems, drive interoperable exchange of data across their entire technological landscape, and ready themselves for a sustainable future by weaving their digital data together. Leveraging the 'digital twin' technology, TATA Power-DDL has implemented a digitalized model which is the full-scale accurate replica of the physical web of its electrical network gamut. The system, along with realistic speed and responsiveness, holds the capability of simulating nearly all practically possible and critical scenarios in the network, allows wide range of simulated faults to be placed in the network and captures the network reconfigurations carried out by the operator for power restoration. The model serves well to experiment safely while planning for any critical or unconventional operation, advancing the skillset of operators by reflecting on historic experiences and most significantly, it paves the path for the organization to avert unwelcomed brown-outs / black-outs.

Keywords—simulator, digital-twin, replica

I. Introduction

A full scale digitalized model, which accurately replicates the electrical network, has been developed and put in place by TATA Power-DDL. The model offers several operational learnings for system operator so as to enable swifter network reconfigurations during power outage and also averting mal-operations. It also acts as a test-bench for attempting unconventional operations for tackling unforeseen and unfavorable network conditions. With these few briefed and several un-briefed features, the model is putting the organization in control to relentlessly deliver uninterrupted and quality power to its customers.

II. Canvas of TATA Power-DDL Distribution Network

TATA Power-DDL, incorporated in 2002, operating in 510 square kilometres of area, covers the north and north-west portion of the national capital. It evacuates power through transmission circuits, running across hundreds of circuit kilometres, deployed by government run Transmission Company that is Delhi Transco Limited (DTL). Accordingly, TATA Power-DDL has put in place approximately 19,000 circuit kilometres of network with 10,000 megawatt of power evacuation capacity at combined 66kV / 33kV / 11kV voltage levels for the company to ultimately deliver the power to its approximately 1.8 million customers.

III. Why 'Digital Twin' for Electrical Network

With scaling up of trends like renewables, peer-to-peer energy trading, battery energy storage, electric vehicle penetration, etc. in the electrical network, the background data required for a utility to effectively run the network, has become more voluminous and complex than ever. Alongside, the expectations of customers has peaked and demand no less than uninterrupted and quality power. These individual opportunities cum challenges come together and pose greater challenges before a utility to keep itself few steps ahead of the trend. This requires readiness for unconventional / unforeseen scenarios, more skilled manpower, on-the-dot planning, etc. to name a few attributes. While the live system is too sensitive to attempt such endeavors, 'Digital Twin' serves the wholesome purpose, quite effectively and efficiently.

IV. Broad Structure and Components

Working in a simulated environment should not deprive the operator of sensation of a real-network. The deployed model achieves it by using the existing distribution management system in the form of a stand-alone development system with identical database and software to the production system as a component of the overall simulation framework. The model is broadly bifurcated into 'Network' and 'SCADA' verticals wherein the former catalogues the entire network topography and trails while the latter allows modelling of telemetry data reporting.

The 'Network' vertical is geared for real-time behavior by exploiting the radial nature of distribution network so that only the network that is affected by a change of status of a switchable device is re-evaluated for energization state.

Per contra, the 'SCADA' vertical allows forming of initialization data which is achieved by communication between the 'Network' and 'SCADA' verticals to report an initial set of values for all analogue points in the system. Once the energization state of all nodes and branches in the network gets determined, and all analogue values get set to initial values, the simulation enters a running state and starts responding to operators' actions, with appropriate feedback derived from changes of states or values of network nodes and branches.

V. Functional Requirements and Functionalities

For delivering realistic speed and responsiveness, the simulator maintains a memory resident model of the entire distribution network topology. The model is a branch and node representation of the network with branches representing cables or overhead conductors, and nodes representing bus bars, switches and other devices to which cables get connected. The model provides several functions like:

- placing of simulated faults on the network,
- variation in current on circuits as time evolves and as load is switched in the network,
- simulating customer calls for de-energized distribution transformers and critical information,
- allows recording and playback macro that allow multiple faults, calls and other events to be included in a macro for later execution.

The simulator, in aggregate, can model power system frequency dynamics, SCADA functionality, relays like overcurrent, overvoltage, under voltage and under frequency, load tap changers, load shedding in response to under frequency relay operation, transfer tripping schemes, multiple islands with individual frequencies, power system voltage collapse, synchronization of live islands, pick-up of dead segments, load changes, fault isolation and service restoration and ability to run what-if scenario for other associated applications.

VI. SCENARIO BUILDING, MODEL UTILIZATION AND SIMULATION MANAGEMENT

The simulator offers building of various scenarios with several dispatches, operations and events like operation of circuit breaker, breaker failure to operate, relay malfunction, local control malfunction including load tap changers and load shedding, limit violations of all types, permanent loss of equipment, loss of generation, single bus load change, area load change, loss of an interconnection line, occurrence of a fault, loss of a line of transformer, islanded operation, receipt of operational alarms, receiving trouble calls and dispatching field crew.

The simulator provides user interface including displays, control requests and all other user interface activities that are identical to the main system and all its features like:

- User can start, stop, pause and replay the training sequence at any time within a scenario with variable real-time speed,
- Initialize the training base case from any of the following sources,
- Scale the system load for different operating conditions,
- Store and recall scenarios and the associated initialization data.

VII. MAJOR BENEFITS GAINED / PERCEIVED

The model assists in keeping the operators and the system well skilled and configured to avert as much potential supply failures as possible. After all, the customer deserves nothing but the best and for that relentlessly improving operational efficiencies serves as a quintessential driver. The model helps increasing the efficiency and optimization of the processes, accuracy and consistency of the network, managing protection data, lays foundation for future digitalization use cases like asset performance management, adaptive relay settings, voltage and frequency ancillary services etc., to name a few.

VIII. SCALABILITY AND FUTURE POTENTIAL

With increase in penetration of trends like distributed energy resources, renewable power obligations, peer-to-peer energy trading and opening up of power sector for multi-dimensional competition, such ‘Digital Twins’ shall pave ways for a utility to secure the pole position by fetching valuable insights into their operational inefficiencies.

Feasibility of Green Hydrogen Production and Storage in the state of Tamil Nadu

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Abstract— India is moving towards a target of 500 GW non-fossil fuel capacity integration by the end of 2030. With the National Hydrogen Mission for India being launched by the Government of India, green hydrogen (hydrogen produced from renewable sources) along with initiatives such as solar-wind hybrid, off-shore wind, and repowering policy can provide a much-needed revival to the wind sector, along with establishing an immediate supply chain infrastructure to kickstart the hydrogen economy in India. In wind-rich states of India such as Tamil Nadu (TN) which currently holds 24.5percent of the country's wind energy power plant capacity (9.6 GW as of FY 21), and a wind power potential of over 68 GW, most of its wind energy is generated during the monsoon period (May-Sep). However, the grid is unable to absorb it fully due to low demand leading to underutilization of the power generated. By utilizing the excess wind power for green hydrogen production, Capacity Utilization Factor (CUF) of wind plants could improve. Hydrogen is suitable for seasonal storage, which can store the excess wind power generated in the peak season, playing a pivotal role in ancillary services.

Keeping these possible advantages of green hydrogen and the vast wind potential of TN in mind, this paper shares key findings from the techno-economic analysis for green hydrogen production and the storage potential for the 2030 and 2040 timeframe. The analysis is based on upcoming wind power initiatives, current wind capacity growth, and the expected cost trends of hydrogen technologies. TN could consider green hydrogen as a means to enhance the capacity factor of wind power.

Keywords— *Renewable Integration, Intermittency, Green Hydrogen, Seasonal Storage, Wind Energy*

Introduction

Government of India (GoI) set a national target of integrating 175 GW renewable (RE) capacity by 2022, which included 100 GW solar and 60 GW wind capacity [1] . For the longer term targets, 500 GW of non-fossil sources is planned to be added to the energy mix along with achieving 50 percent of the total energy needs from renewables by 2030 [2] . The 2030 target is expected to be driven predominantly by solar power, which accounts for over 280 GW of the planned target [3]. While solar power has certain advantages over wind power such as easier installation, better resource availability (in India), reduction in power generation cost over the recent years made solar power, the go-to RE option. With solar power unit cost seeing a drastic reduction in the past few years, wind power projects are losing their financial competitive advantage, despite the availability of a fully developed supply chain in India. The recently discovered wind energy tariff by Solar Energy Corporation of India (SECI) is around INR 2.4-2.7 /unit compared to that of solar, which reached a tariff under INR 2/unit [4]. This is in turn reflected in the installed capacity of solar power, which increased from 34.6 GW in the Financial Year (FY) of 2020 to 40 GW by FY of 2021, while wind power only saw a marginal increase in the capacity from 37.7 GW to 39.24 GW in the same period [5]. While increasing the renewable mix is a step in the right direction, it is imperative to consider all available renewable sources in India to achieve the ambitious goal set by the GoI.

Till FY 2017, wind power in India saw growth due to incentives and favourable policies such as accelerated depreciation and generation-based incentives. About 32.3 GW of the current wind capacity were installed prior to 2017. Post 2017, wind power capacity grew at a compound annual growth rate (CAGR) of less than 5percent. This slow pace has made it difficult for the wind sector to achieve the GoI's earlier target of 60 GW capacity by 2022. Apart from the financial competition, wind power is highly intermittent with the CUF reaching over 50 per cent during the monsoon period [6] (July-September) and ~10 per cent for rest of the year. Such high levels of intermittency make it difficult to integrate or to completely utilise the generated power. Tamil Nadu (TN), a state in the southern part of India, accounts for 24percent of India's wind capacity (9.6 GW out of 40 GW), leading the wind power sector of the nation. However, the challenges to evacuate wind power are becoming more pronounced. Several initiatives such as solar-wind hybrid policy, offshore wind targets and repowering have been suggested to support uninterrupted growth of the wind energy sector in India [1]. Due to technological advancements, new generation wind turbines can function at a high CUF even at less windy sites[10]. With complimentary policy support and the latest technological advancements, wind power can play a significant role in achieving the target India has set out for 2030.

With the global focus on reducing carbon footprints, many countries have started exploring alternative fuels with lower carbon intensity and related carbon capture technologies. Green Hydrogen has the potential to act as a clean fuel source where hydrogen is produced using RE through the process of electrolysis (a process of splitting water molecules into hydrogen and oxygen). Need of energy storage to offer grid flexibility will also be a priority with studies showing a need of at least 160 GWh of Storage by 2030, for accommodating the targeted RE capacity [11]. As the need for long duration storage will be essential in integrating the targeted RE power into the energy mix, hydrogen has the potential to act as a seasonal storage medium due to its minimal self-discharge loss. With the launch of the National Hydrogen Mission in India [12], this paper makes an effort to understand the role of green hydrogen in TN's power sector by assessing the feasibility of green hydrogen production from excess/spilled wind power generated (particularly during peak season) and its usage as an energy storage medium.

Current Wind Power Scenario: Tamil Nadu

The average wind evacuation occurs at an average rate of 15 percent CUF in Tamil Nadu. The CUF of wind power during the windy season (May – Sep) is around 30-32 percent, with peak CUF of 45 percent usually occurring in June or July. In the off-peak season, the monthly CUF varies from 6-8 percent. The monthly CUF values are depicted in Figure 1.

[1]National Wind-Solar Hybrid Policy [7], National Offshore Wind Policy [8] and Policy for Repowering of Wind Power [9]

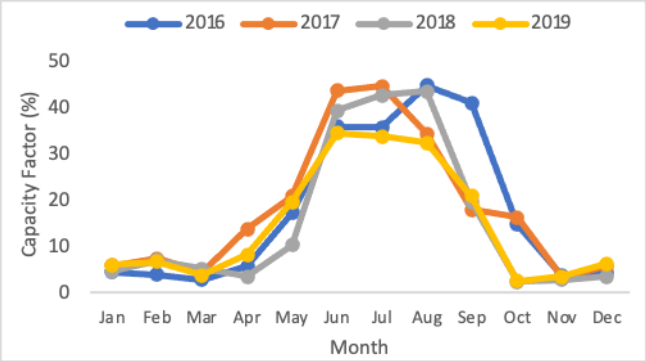

Fig 1: Monthly CUF based on TN wind power evacuation (2016-2019)

In TN, wind generation has seen a downward trend since FY 2017- from 9637 MU in 2017 to 8757 MU in 2020 [13], despite an increase in installed capacity (IC) from 7.6 GW to 8.5 GW during the same time period (Figure 2.)

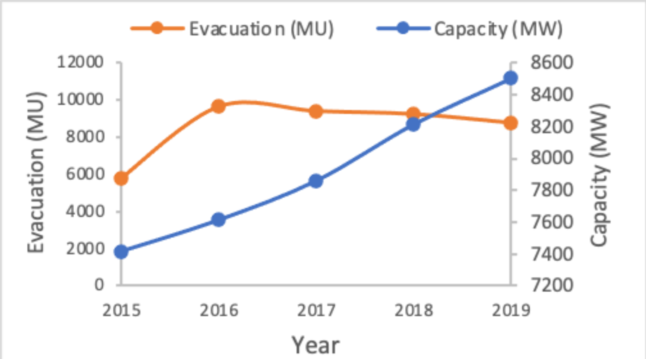

Fig 2: TN Annual Wind Power Evacuation vs Installed Capacity during Peak Season (May-Sep)

The primary reason is curtailment, particularly during the peak season. The backdown hours and instances during FY 2019 increased by more than 100 percent compared to the duration observed in 2018. State Load Dispatch Centre mentions grid stability and lack of accurate forecasts as the primary reasons for backing down of wind generation [13]. Since the percentage spillage data is not available in the public domain, based on our discussions with different stakeholders in the wind energy sector, curtailment ranges between 10 to 25 percent during the peak windy season.

Methodology

In this paper, authors have estimated green hydrogen production and storage potential using excess wind power spilled for the 2030 and 2040 timeframe. This is carried out by assuming installed wind power capacity based on state-specific wind energy targets and policies, and simulating annual wind energy generation. We assumed that the growth of wind power capacity will take place onshore, offshore and through repowering initiatives. Excess wind power is estimated by considering different power spillage scenarios based on available literature surveys and stakeholder consultations. This spillage is used to assess potential green hydrogen production and the size of storage capacity, while highlighting some important techno-economic parameters such as levelized cost of hydrogen production (LCOP), storage (LCOS) and production technology cost trend. Below are the considerations and assumptions for estimating wind generation capacity for TN for the period of 2030 and 2040.

On-shore Wind Power

- The past 10-year and 5-year CAGR have been considered for capacity estimation, which are 6.63 percent and 4.48 percent respectively [14].
- Current project in pipeline: ~ 1 GW capacity planned for TN by FY 2023[10].

Capacity addition till 2030 in TN is estimated by assuming 4 percent CAGR. Forfurther additions till 2040, 3 percent CAGR is taken based on the above-mentioned points and diversification of wind power installations in states like Rajasthan, Karnataka, etc.

Off-shore Wind Power

- Tamil Nadu and Gujarat have good off-shore wind potential. Ministry of New and Renewable Energy (MNRE), GoI estimated a 70 GW capacity potential across the shores of these 2 states [15].
- GoI announced a target of 30 GW offshore capacity by 2030 along with India's expected offshore capacity of 140 GW by 2050 [16].

Considering challenges such as long lead time, lack of financial model for facilitation, infrastructural constraints etc., 20 percent of the target set by GoI assumed for offshore capacity is a conservative estimate.

Wind Repowering

- MNRE announced wind repowering policy in 2015 [9] wherein wind turbines with capacity <1 MW and older than 15 years (operational life) are eligible for repowering. Based on this, Gujarat and Tamil Nadu launched their repowering policies.
- In the TN policy issued in February 2021 [17], queries such as power procurement rates for repowered projects and who will bear grid augmentation responsibilities were resolved. However, challenges with respect to land procurement, lack of incentives, and scope of re-powering are unclear.
- TN will benefit by repowering since most of the turbines have reached their lifetime, with nearly 2.4 GW capacity wind power eligible for repowering by FY 2022 [18].

Considering uncertainties in the wind repowering initiative, it is assumed that 50 percent of the capacity installed before 2005 (> 25 years old) and 25 percent of the turbines installed before 2010 (> 20 years) will be repowered. Repowering is limited to 2:1 capacity ratio for the scenario planning. The repowering matrix is provided in Table 1.

Table 1: Repowering Matrix table for 2030-2040 TN wind capacity scenario planning (Source: WRI Analysis)

Interval	% Capacity to be repowered (2030)	% Capacity to be repowered (2040)
< 2005	50	100
2005-10	25	50
2010-15	0	25
2015-20	0	0

Given the aforesaid assumptions, the total wind power capacity in TN is expected to reach 17.3 GW by 2030 and 31.6 GW by 2030 without wind repowering. If wind repowering materialises, it can add 1.6 GW and 3.8 GW to the 2030 and 2040 overall wind capacities as shown in Table 2.

Table 2: Wind power capacity addition for 2030/40 scenarios

Capacity addition since 2020 (GW)	2030	2040
On-shore	4.45	9.16
Off-shore	3.7	13.3
Repowering	1.6	3.83

Analysis I: Annual Excess Wind Power Generation in TN

With the assumptions considered for formulating the installed wind capacity in TN for 2030 and 2040 scenarios, an open-source online tool *Renewables.Ninja* [19] was used to simulate the generated wind power. The model takes in the location coordinates, wind power capacity, turbine model and hub height as inputs. Using MERRA 2 satellite data, wind power generation for the selected location is obtained with a 1-hour timestep as output. To understand the wind speed across all the wind-rich locations in TN, the cumulative wind capacity installation is split into different timeframes based on model specifications, as shown in Table 3. These are considered as inputs to obtain the desired simulated wind power generation output.

Table 3: Turbine Model Specifications considered for Simulation

Time frame	Turbine Model - 1	Turbine Model - 2
<2005	Rotor Diameter: 45 m Capacity: 600 kW	Rotor Diameter: 27 m Capacity: 225 kW
2005-10	Rotor Diameter: 60 m Capacity: 1000 kW	Rotor Diameter: 40 m Capacity: 500 kW
2010-15	Rotor Diameter: 80 m Capacity: 1500 kW	Rotor Diameter: 50 m Capacity: 750 kW
2015-20	Rotor Diameter: 120 m Capacity: 2000 kW	Rotor Diameter: 52 m Capacity: 850 kW

Location Coordinates: District-wise wind capacity share of TN is considered for the current (2020) wind generation simulation [14]. The district-wise share varied significantly between the time period before 2005 and after 2015. (as shown in Figure 3). In the recent years, the districts of Tirunelveli, Tirupur and Tuticorin have themajority of installed capacity while minor contributions have been made by the districts of Theni, Coimbatore, etc. Factors such as (a) preferred locations in recent installations, (b) new generation turbine models which can perform with better CUF in less windy sites, are considered while estimating future capacities (emphasising more capacity share for less windy locations in TN). The location coordinate for offshore wind power is taken as 8.5 ° N, 78.3 ° E along the Gulf of Mannar coastline [20].

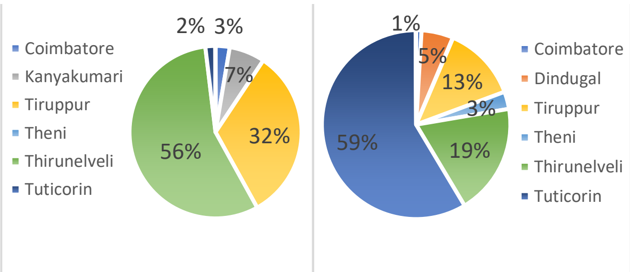

Figure 3: District-wise wind installation share of TN wind capacity
a) Installations before 2005 b) Installations between 2015-20

Turbine Models

- For the current base case scenario (2020) simulation, turbine specifications of the most common model was used [14], as given in Table 2
- For future onshore installations, a 100 m rotor diameter with a 2.1 MW capacity turbine model and for offshore installations, a 117 m rotor diameter with a 4 MW capacity turbine model [20] was assumed
- Other input assumptions such as the annual wind turbine degradation factor of 0.64 percent [21] and 2019 MERRA 2 wind data has been taken for all scenarios

With the above assumptions, wind power generation is simulated using the open-source application. To calculate excess wind power, TN-specific wind power spillage data was collected through stakeholder consultations, national and state-level grid integration studies [2] and available state-specific curtailment data [3]. It was estimated that the national RE power curtailment can vary from 5percent to 15 percent by 2030 based on demand variation, actual versus forecasted RE generation, etc. It was also shared by stakeholders that wind power's seasonal nature tends to result in heavier spillage during peak season compared to off peak season with an average spillage of 15 percent. Keeping these constraints in mind, three spillage scenarios are considered with **12%** annual spillage as base case with maximum spillage reaching 15 percent during peak season. In the optimistic scenario, the annual spillage is **6%** which is in line with the national level curtailment estimation [23], with the peak curtailment of 10 percent. Finally, in a pessimistic scenario **18%** spillage is considered with peak curtailment reaching 20 percent, which could be primarily attributed to insufficient evacuation infrastructure and low demand periods.

Analysis II: Hydrogen Production and Storage Potential utilising Excess Wind Power

In the current state of technological readiness, electrolysis is the only commercial option for green hydrogen production. Current electrolyser efficiency is around 55-65 percent . Alkaline electrolyser (AE) is currently the most mature technology. Proton exchange membrane (PEM) electrolyser is a fairly new technology in the market and is gaining momentum as the best option to handle RE power due to their ability to handle load fluctuations. Solid oxide (SO) electrolysis is another option, which has higher efficiency as compared to the existing technologies. Technical details of these technologies are given in Table 4 [27]–[29].

Table 4: Electrolyser Technology Overview

Technology	Advantage	Disadvantage	Technology Maturity
Alkaline	• Mature technology • Lower capex • Reliable stack lifetime	• Can't handle dynamic load • Huge system size	Mature
PEM	• Good dynamic load response • Small system size / kW	• High CAPEX • Complex system • High purity water requirement	Commercial
Solid Oxide	• High electrical efficiency • Low material cost	• Material degradation due to high temperature operation	Demo projects

Since our analysis focuses on using renewable power for electrolysis, PEM is a suitable option. Other electrolyser technologies can also be considered with the help of storage or buffer systems to help the electrolysis process with constant load throughout. Although AE is the most mature technology available with CAPEX under 400 USD/KW in China [30]**,** the inability of AE to handle fluctuating loads requires the aid of battery storage, making it unviable in the long run. Efficiency of these technologies is provided in Table 5 based on the current literature survey [4] . Based

[2] Annual wind power curtailment in TN [22], Maximum and minimum curtailment study of India [23] and TN specific curtailment analysis based on different RE pathways [24]

[3] Substation level generation loss in TN [13], Annual RE curtailment in TN [25] and off-peak wind power curtailment in TN [26]

[4] Electrolyser technology and CAPEX [27], [29], [31], Green hydrogen production and storage [28], [31], [32]

on the technology's efficiency, the hydrogen production and storage potential from the spilled wind power is calculated.

Table 5: Electrolyser Efficiency (%) taken for the considered timelines

Technology		Alkaline	PEM	Solid Oxide
Efficiency (percent)	2020	65	60	80
	2030	73	68	85
	2040	80	85	90

Levelized Cost of Green Hydrogen Production and Storage

This section deals with the green hydrogen production cost and levelized cost of storage, focusing on the seasonal storage aspect of hydrogen. CAPEX and other financial details/assumptions considered for LCOP/LCOS calculations based on state-specific orders and research studies [33], [34] are provided in Table 6.

Table 6: Financial considerations for levelized cost of hydrogen production and storage

	2020	2030	2040
Plant CAPEX (USD/kW)	700	550	400
Capacity Factor (%)	30	33	35
Interest (percent)	8	8	8
Interest Term (years)	10	10	10
Debt-Equity ratio	70:30	70:30	70:30
O&M (percent CAPEX)	2	1.5	1
O&M Escalation (percent)	5	5	5
Investment return (percent)	17.56	17.56	17.56
Hydrogen Technologies			
PEM Electrolyser (USD/kW)	1600	880	650
PEM Fuel Cell CAPEX (USD/kW)	1300	1000	900
Compressor CAPEX (USD/kW)	17	13	10
Storage (USD/kg H2)	500	330	220
O&M (percent CAPEX)	3	2.5	2
Interest rate	10	10	8

Assumptions taken for LCOP and LCOS calculation

- Electrolyser capacity is based on PEM's maximum operating capacity, constrained to utilize up to 90 percent of peak spilled power in the simulation run
- Hydrogen storage medium at 250 bar pressure is considered. PEM electrolyser and fuel cell are considered for the analysis.
- For LCOP: A temporary on-site storage space to hold one complete day worth of hydrogen generation is assumed.
- Loss of efficiency due to part load operation is neglected. With 6 hours discharge duration, battery cannot prove to be a perfect storage solution for wind plants which are seasonal in nature
- For LCOS: Storage duration of 3 weeks is assumed with storage to discharge duration ratios of 1 and 3. Seasonal storage roundtrip efficiency is linearly increased from 38 percent to 44 percent in the considered time-period expecting technological improvement in the coming year.

With these assumptions and considerations, levelized cost of hydrogen production and storage was carried out for the considered timelines as mentioned in the tables.

Key Findings

Wind Power Generation

With the present timeline of 9 GW installed capacity, the annual power generated is 14500 million units (MU) at 18 percent CUF. For the timeframes of 2030 and 2040, two separate cases are analyzed- Case I considers probable onshore and offshore installations and Case II considers the repowering potential. Since new turbines can generate more power in low wind locations and offshore wind turbines can perform over 40 percent CUF, the overall wind generation for2030 and 2040 sees a significant improvement reflected in ~30 percent and 60percent increase in CUF respectively, compared to the 2020 timeline.

Further, repowering contributes to sizeable addition, which will help the CUF reach 25 percent and 30percent by 2030 and 2040 respectively. Details of expected wind generation for the scenarios "with repowering" and "without repowering" are summarized in Table 7.

Table 7: Scenario-wise wind power capacity and simulated generation results

Timeline	Installed Capacity (GW)	Annual Generation (MU)	CUF (%)
Case 1: Without Repowering			
2020	9.1	14499.55	18.03
2030	17.33	36079.71	23.76
2040	31.64	79505.94	28.68
Case II: With repowering			
2020	Not Applicable		
2030	18.93	41512.96	25.03
2040	35.47	90976.88	29.28

Green Hydrogen Potential

Around 0.9 to 1.3 Lakh Metric Tons (LMT) of green hydrogen is estimated to be produced by 2030 and 2.2 to 3 LMT of green hydrogen by 2040 from spilled wind power based on considered spillage scenarios and electrolyser technologies (Figure 4). Green hydrogen production potential for all the spillage scenarios is provided in Table 8.

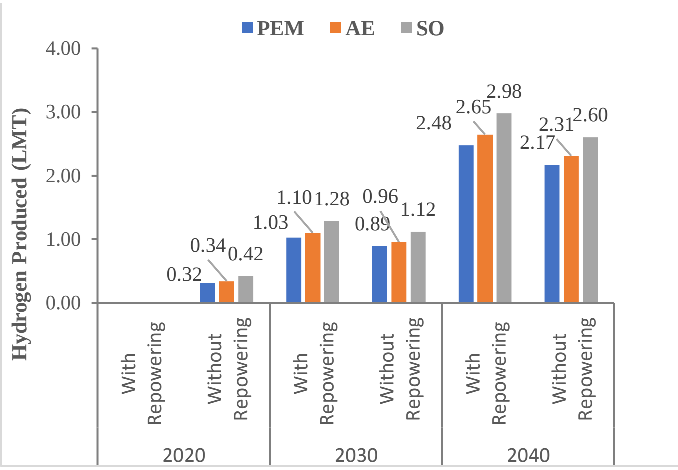

Figure 4: Green hydrogen production potential with different technologies for 2020, 2030 and 2040 (baseline spillage scenario)

By 2030, seasonal hydrogen storage can tap over 1700 million units (MU) and ~4500 MU by 2040 in base case spillage scenario. Even in the current timeline (2020), green hydrogen production potential in baseline spillage scenario is in the range of 0.3-0.4 LMT, which corresponds to 12-13 percent of Tamil Nadu's current hydrogen demand. The Draft National Hydrogen Mission policy, recommends 10 percent of green hydrogen for refineries and 5 percent for fertilizer sector with the green hydrogen share gradually reaching 25 percent and 20 percent respectively [35]. If the spillage of wind power at the state level can be effectively utilized, we can achieve this target with ease and help in revival of the wind sector.

Table 8: Green hydrogen production potential (LMT) from spilled wind power: Spillage scenarios for the year 2020, 2030 and 2040

Year		Spillage Scenario		
		Base case (12%)	**Optimistic (6%)**	**Pessimistic (18%)**
2020	Without Repowering	0.3-0.42	0.16-0.21	0.47-0.63
2030	Without Repowering	1.02-1.28	0.51-0.64	1.54-1.92
	With Repowering	0.89-1.12	0.44-0.56	1.34-1.67
2040	Without Repowering	2.48-2.97	1.24-1.48	3.72-4.46
	With Repowering	2.16-2.60	1.08-1.30	3.25-3.90

Green Hydrogen LCOP and LCOS

With the considered techno-economic parameters, average LCOE of wind power is INR 3.5/unit in base case scenario and reduces to INR 2.4 in 2030 and 1.5/unit by 2040. Given that green hydrogen technologies such as electrolysers and fuel cells are still at a nascent stage, estimated LCOE values for these scenarios are strictly meant for reference purposes.

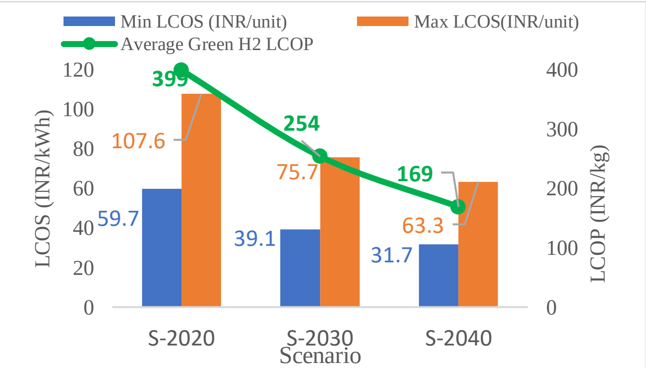

Figure 5: LCOP and LCOS of green hydrogen system for the considered timelines

The average cost of green hydrogen production (LCOP) is around INR 400 /kg hydrogen for the current timeline and is expected to reach 250 and 150 (INR/kg) by 2030 and 2040 respectively. The levelized cost of storage (LCOS) is expected to be around INR 60-100 /unit gradually reducing to INR 30/unit by 2040 as shown in figure 5. Factors contributing to this huge storage cost is due to low round-trip efficiency of the system (<40percent) and large storage area requirement.

Conclusion:

- This paper looks at feasibility of utilizing excess wind power for green hydrogen production in view of Tamil Nadu's wind power initiatives and policies.
- Based on different spillage scenarios, electrolyser capacity ranges between 400-1000 MW. This can reach over 2.5 GW by 2030 and 4.5 GW by 2040 for hydrogen storage.
- Green hydrogen production potential from wind power is about 0.35 LMT at present, which accounts for 13 percent of current hydrogen demand in TN. Based on the draft National Hydrogen Mission, this is more than the expected green hydrogen mandate planned by India. Green hydrogen potential of 1.1 LMT and 2.5 LMT is expected by 2030 and 2040 respectively.
- Hydrogen as seasonal storage will be able to tap 850-2500 MU by 2030 by utilizing excess wind power. By 2040, seasonal storage potential can reach over 2200-6500 MU, considering different spillage scenarios.

But there are some challenges to address for the effective utilization of spilled power for hydrogen production and storage such as,

- While RE wind generation tariff is expected to fall, landed cost of hydrogen (LCOH) production may vary when compared to the assessment provided in this paper. While the LCOH may be comparable for the onsite-hydrogen production, most of the hydrogen consumption will take place at refineries and ammonia production facilities. In that case, utilization of spilled RE power can be promoted.
- Clarity/Awareness on hydrogen system performance, water requirement for electrolysis and storage system is vital.
- LCOS of hydrogen storage with compressed gas vessel is not cost competitive due to huge storage requirement and low round trip efficiency of the system as compared to other seasonal systems such as pumped hydro, compressed air storage. The whole supply chain needed for the "hydrogen economy" needs to be more efficient and economically feasible.
- With current compressed hydrogen storage technology at ~200-250 bar, required storage space is around 0.15-0.16 m3/kg hydrogen when compared to the new type 4 storage technology, which needs 0.04-0.065 m3/kg hydrogen [36]. Type 4 storage vessel production costs are high due to the material requirements to withstand high pressure, and it needs massive production upscaling to match with the current storage technology [37].
- For seasonal storage option with discharge duration over a week [38], [39], hydrogen system with underground storage tends to be cheaper, Nevertheless, exploration of storage potential in rock and salt caverns, and hydrogen transportation through pipelines needs to be seriously considered for better utilization of hydrogen storage system. Further, a seasonal storage-specific pilot should be explored to study the competitive side of hydrogen storage.
- While forecasting is not 100percent accurate, RE generators (including repowered ones) can commit a certain the amount of capacity to utilities and use the remaining power for green hydrogen production and storage. With this kind of arrangement, distribution companies will also get reliable power and RE generators can maximize the plant utility factor.

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Digital Twin for Smart Grids: A Practical and Cost-Effective Technology for Resilient and Sustainable Power Distribution

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Abstract—**The power distribution sector in India continues to face challenges with high aggregate technical and commercial (AT&C) losses, aging networks, and low tariff rates. This is coupled with high costs for investment in technology and infrastructure upgrades. To meet future electricity demand and renewable targets, the distribution sector must be optimized for efficiency, resiliency, and profitability. Digitalization offers an opportunity to meet these challenges for both the Low Voltage (LV) and Medium Voltage (MV) grids.**

This paper presents the innovative Digital Twin Platform (DTP) where an existing distribution network is modelled digitally to replicate the physical and operational characteristics of utility assets. DTP is a state-of-the-art technology for visualization, active grid management, advanced analytics, and network prognostics. The paper shows how DTP helps distribution companies (DISCOMs) conduct impact analysis and grid behaviour predictions for integrating distributed Energy Resources (DERs). Advanced situational awareness of the grid helps DISCOMs dispatch DERs, thereby managing grid stability. Besides, it will be essential for technical validation of Local Energy Market by a DISCOM. DTP assists in dealing with increasing volatility by taking data driven decisions coupled with intelligent control to ensure service levels remain high. The DTP help reduce capital expenditure (CAPEX) as it allows achieving higher capacity on existing assets and defer infrastructure investments. DTP uses real-time data to simulate different use cases related to operation, expansion, cost optimization, and safety of the power system. Because it is an enterprise-cloud based solution, the DTP is future-proof with massive parallel processing, high-availability, data security, and scalability.

Keywords—digital twin, distribution grid management, grid control, grid planning, state estimation, real-time load flow, monitoring and control, DSO

I. INTRODUCTION

Electricity grids are increasingly being operated at their limits because of the expansion of both, utility scale and distributed renewable energy (RE) sources, leading to greater grid utilization. The relocation of electricity generation to regions with more demand pose a major challenge for the grid in its current state. To eliminate bottlenecks in the grid, distribution companies (DISCOMs) must intervene more and more frequently. Grid modernization is the need of the hour as they slowly become the backbone of the country's economy. With a steep increase expected for the number of electric vehicles (EV) on the roads, solar photovoltaic (PV) increasing on the roof of consumers, and demand for cooling increasing every year, it is important to strengthen the grid and optimize the grid assets for the energy security of India.

Having access to real-time information about the distribution network opens new opportunities for better integration of intermittent RE generation. Also, integrating added stresses to the network, like new residential and commercial connections, energy storage projects, variable resources can be easily assessed based on the feeder network parameters.

To support the further electrification of our society, grids are to be modernized, and many utilities are searching for cutting-edge technologies to deliver electricity more efficiently and reliably. Many are now looking towards smart grid technologies to help reduce costs, increase efficiency and reliability, and provide better grid transparency.

A smart grid encompasses the use of operational technology (OT) and information technology (IT), seamlessly communicating with each other, to monitor, analyse, and control an electrical grid. The power of digitalization especially at the low voltage (LV) distribution network helps electric utility improve situational awareness, increase RE integration, improve grid reliability, and reduce operational and capital expenditure. This is expected to be critical with gradual transformation of present day DISCOMs into Distribution System Operators (DSOs).

Under the guidance of the central government, Energy Efficiency Services Limited (EESL) has already installed one million smart meters across India by February 2020 [1] and is poised to eventually replace 25 crore conventional meters [2] under the Smart Meter National Programme. The data collected via smart meters, is essential, but alone does not constitute a smart grid. A crucial part of having a smart grid includes an intelligent IT enabled network monitoring system that keeps track of the vital parameters in the network, on a real-time basis.

Data collection and data analysis techniques helps utilities improve the flexibility and efficiency of the electric grid. Cloud computing, intelligent energy solutions and digital twin technology are becoming the backbone for the transformation of the smart grid and overcome the new challenges in the distribution grid.

II. Government of India Initiatives

Electricity is a concurrent subject under the Indian Constitution. The responsibility for distribution and supply of power to rural and urban consumers rests with both the centre (for Union Territories) and the state governments. The Ministry of Power (MoP) is India's top central government body regulating the electrical energy sector in India. The National Smart Grid Mission [3] was established in March 2015 by MoP to help accelerate the Smart Grid deployment in the country.

The distribution sector in India, in general, is struggling in terms of financial and operational sustainability. The outstanding dues of DISCOMs payable to generators/creditors as of February 2019 stood at an alarming level of 419 billion INR, as per data from 58 DISCOMs reported by 17 participating Generation Companies (GENCOs) [2].

The government of India aids the state through various centrally sponsored schemes, such as the Ujwal DISCOM Assurance Yojana (UDAY) scheme [4] and the Integrated Power Development Scheme (IPDS) [5], to help improve the financial and operational efficiency of the DISCOMs. The recent initiative includes the Revamped Distribution Sector Scheme (RDSS) [6] that supersedes the previous schemes, aims to help DISCOMs improve their operational efficiencies and financial sustainability by providing result-linked financial assistance to DISCOMs to strengthen supply infrastructure.

The objective is to strengthen the distribution networks in the urban areas. Some of the key parameters are reduction of aggregate technical and commercial (AT&C) losses to 12-15% by 2024-25, elimination of the average cost of supply (ACS)-average revenue realised (ARR) gap to zero by 2024-25 and developing institutional capabilities to improve quality and reliability of power supply to consumers. Infrastructure creation includes feeder separation, distribution transformers (DTs) metering, pre-paid smart metering, better consumer indexing through GIS mapping, and IT enablement of distribution sector.

III. Digital Twin – The Virtual Twinning of the Grid

The Government of Indian has one of the largest and most ambitious renewable capacity expansion programs in the world. In addition, it has embarked on a program to move to electromobility in the coming years. Since DISCOMs currently have limited insight into the real-time operations of the LV distribution network, the continued growth of RE feed in and EV charging will rapidly increase the need for new solutions to deal with the strain on the already stretched LV grid infrastructure.

A. What is a Digital Twin?

With the advent of smart grid, an innovative concept of "Digital Twin" or "grid twinning" is introduced. A digital twin is a virtual representation of a physical object while grid twinning is creating a digital image of the existing electrical grid on a digital platform. In this, modelling the grid assets along with capturing field data from intelligent electronic devices at various feeders, DTs, and nodes replicate the actual grid network on the platform, providing transparency via real-time depiction of load flow, energy consumption, and state of equipment.

With grid twinning, generally the grid replication is done on geographic information system (GIS) map which provides metadata which is especially useful to identify fault locations quickly and provide an overview regarding the physical length of the feeders, poles, and consumers from a particular substation. With GIS mapping, for example, it can be assessed to which closest DT a new consumer should be added without overloading the assets. Such advanced technology empowers DISCOMs to take quick and efficient decisions that they were earlier unequipped to take.

B. Need for a Digital Twin of Electrical Distribution Network

To ensure a secure and reliable supply of electricity in the future, the grid must be developed further, and operating costs be minimized. The basis for doing this is acquiring information about the existing capacity in the distribution grid. However, currently the corresponding data regarding the load or utilization of the medium/low voltage grids is very poor, especially for renewable energy as well as those of electric mobility connections that cause volatility.

Moreover, the distribution grids in India still have a minimal level of automation beyond the high-voltage domain, as this was not needed in the past due to the relatively limited dynamic and predictable operation of the grids. If a fault was reported, utility staff located the problem and rectified it on site.

Due to the rapid penetration of decentralized power generation plants and "new consumer groups" (e.g., electromobility), the dynamics of power flows in the distribution grids is increasing and cannot be controlled in the future by the conventional mode of operation of the grids without considerable investment in grid modernization. In order to maintain energy supply security and make better use of existing grid capacities, intelligent concepts and technologies for monitoring and controlling medium and low-voltage grids are required [7].

IV. Digital Twin Platform

The energy system is being driven by three megatrends: digitalization, decarbonization and decentralization. To stay on top of the challenges posed by these trends, the Digital Twin Platform (DTP) enables utilities to digitize, monitor, and control their low and medium voltage electricity grids. The DTP is a state-of-the-art technology that creates a real-time digital twin with high-performance parallel processing of various data sources and models load profiles to track distribution network operations in real-time and predict grid behaviour. This allows a real-time calculation and depiction of the distribution grid, which is not the focus of classic Supervisory Control and Data Acquisition (SCADA) systems due to the sheer volume and structure of the data in these domains.

The DTP makes grid capacity transparent, accelerates the detection of errors, reduces grid-related supply risks, and thus optimizes the costs of grid operation significantly. The solution integrates with GIS, asset management, smart meters, relays, meteorological and other third-party sources. The platform models the load profile of the grid assets and consumers, combines it with the data coming from the field from various sources, to continuously calculate and display the energy flow in the system in real-time. Because there, where no measured values are available today, DTP implicit intelligence simulates the real load behaviour. For this reason, thanks to continuous power flow estimation, the DTP offers the possibility of generating additional data about the distribution network status than possible based solely on measured data, as with classic SCADA systems.

The aim of the solution is to help increase visibility into the LV grid for power distribution companies. As the LV grid becomes the backbone of the economy with increasing penetration of *EV charging stations*, Solar PV and increased cooling load, modernization of grid is essential. Using this solution DISCOMs can increase operational efficiency and optimize CAPEX allocation.

A. Key Application Areas for DTP

1) Grid Transparency: From the information polled, a digital twin of the grid can be developed using a self-learning software. Based on calculations and simulations, grid operators can monitor load flows and electrical parameters throughout the grid, monitor the available capacity in the distribution grid and the current utilization, integrate RE and EV charging stations and automating processes in the day-to-day management of the grid. It provides large data set that can be exported and historized for carrying out system analysis.

2) *Grid Optimization:* Power flow calculations, asset optimization, comparison of load curves and energy consumption data and energy market participation are some of the capabilities of the platform that can help DISCOMs with grid optimization. This is of value when it comes to identifying constraints in the distribution grid especially for local congestion management in certain areas or ensuring quality of service to the customers.

3) *Energy Analysis:* The platform can perform historical data analysis to draw conclusions about the remaining life of transformers and distribution boxes, and feeder loss analysis. Comparison of load curves and energy consumption data is performed for early recognition of bottlenecks and failure prediction.

4) *Intellegient and automatic controls:* Based on the current state of the distribution network, the platform derives actions for optimized control of flexibilities to avoid grid bottlenecks, adjust DT tap changer for voltage level correction, feeder reconfiguration to avoid overload, detect and isolate feeder fault, and control of assets and flexibilities with operator forecasts.

5) *Efficient Planning:* The use of software-driven technology ensures significantly more speed and quality in grid expansion planning and precise state estimation. It is a valuable tool for system prognosis and precise load forecasts (short- and long-term) based on a hybrid of measurement data and intelligent algorithms.

6) *Generate scenarios:* The same platform allows a simulation tool which can carry out "what-if" scenario to help assess impact of onboarding new loads and consumers to the existing network. Creating and running a user-defined grid situation helps analyse the impact on the grid in a simulation environment and take instructive actions. Especially the onboarding proces of new prosumers, solar PV, EV charging stations, energy storage systems (ESS) can significantly be simplified and done in less time, as the impact on the grid can easily be derived from the platform and electrical parameters can be predicted. Thus, ensuring a reliable distribution system operation even with high variablility due to penetration of RE sources, or high volume of HVAC systems and EV charging stations.

7) *Easy integration with external systems:* The DTP can work on secondary sources of data like meteorological data, smart meter data or any other external systems to integrate and show on the dashboard. The heat maps function which is available shows the consumption patterns of a network or a region. This can also help predict energy demand in the network in the future. The platform can also pass on information to other third-party systems (e.g. ADMS/DERMS) which is preferred by the utility.

B. System Architecture and Interfaces

The modular structure of the DTP enables the implementation of various applications in the field of smart grids. The DTP is an enterprise-cloud based application which makes it a future-proof solution with massive parallel processing of big data, high-availability, data security, and scalability. The DTP supports seamless integration with various data sources, including existing SCADA system, GIS, smart meters, and other third-party applications through variety of communication channels and Application Programming Interface (API).

As shown in Fig. 1, the bottom layer describes the data source. Any infrastructure connected to a server within the customer network is communicating using various protocols. The data concentrator is a light-weight application that runs permanently and bundles various devices in the customer's network into a single data stream which is transmitted encrypted to DTP via virtual private network (VPN). The middle layer represents the backend and the core of the application. Data is stored in a scalable cloud storage. Information is exchanged between services through the service bus. Through the API, the partner applications can access both the static data and dynamic events in the system.

Data quality is a particular challenge in these projects. That's why a lot of effort was put into the development of highly specialized tools within the platform. Though data from the lower grid levels are digitized, parts of the grid area are still documented in paper form or that relevant information exists only in the experience of a few key people. Despite these gaps, due to the high degree of automation, one can provide a first working version in a relatively short time (few days) and fine-tuning could then take a few months.

The traditional SCADA systems typically scale with the number of data points. The information on the distribution grid is obtained by installing and polling measurement devices at all nodes in the network. For economic reasons, it is a limitation of SCADA systems, which is bound by the number of devices installed in the field and cannot expand to a sufficiently fine mesh. In contrast, the DTP solution focuses on the substation DTs and their feeders. The number of metering points increases the resolution of the state estimation method, but not the cost. This method scales with the number of substations and is therefore predestined for the gradual expansion of the system, especially with the inclusion of smart meter data [8].

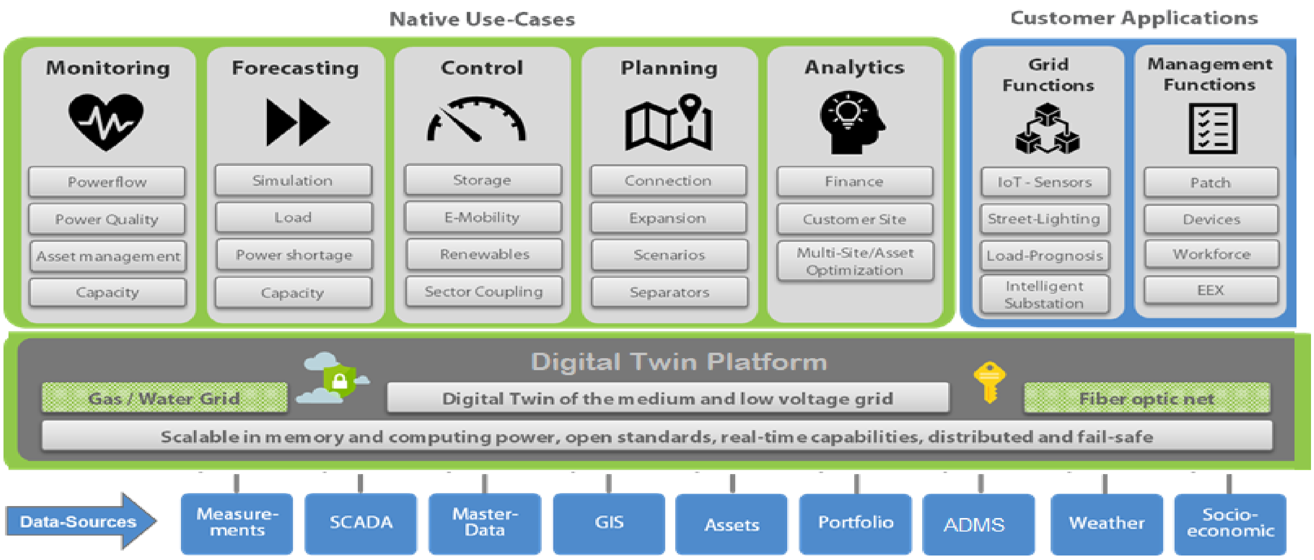

Fig. 1. DTP System Architecture

C. *Benefits of a Digital Twin Of Electrical Distribution Network*

By giving transparency and intelligence into the medium and lower voltage grids with DTP, DISCOMs get an operational grid management tool to assist in dealing with increasing volatility to ensure service levels remain high. The information and knowledge gained here can also form the basis for strategic grid planning.

The DTP allows the use of social-economic data to calculate different scenarios so that one can make valid and reliable investment decisions about how the grid coverage of a specific area would need to be in 1, 5, or 10 years. The focus is on the optimization of CAPEX and OPEX by utilizing savings and optimizing differences in the balancing group.

The use of DTP ensures efficiency improvements in many different places. However, some important advantages are not directly visible, but arise in the context of the functionalities and above all based on the generated high-resolution data. As a big data application, DTP is optimized for the massively parallelized processing of large volume of data.

Some of the concrete advantages for utilities from implementing digital twin for their MV and LV distribution network are as follows:

- Significant increase in efficiency through process digitalization and optimization.
- Improved understanding of the own grid by observing the grid state, controlling the load flow, and ensuring quality of service.
- Insights into the current behaviour to make optimum use of the grid capacity and reduce grid congestions.
- Improvement in reliability indices, including System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), Customer Average Interruption Duration Index (CAIDI), and Momentary Average Interruption Frequency Index (MAIFI), because of gathered network parameters and power quality data, leading to higher quality of service.
- Flexibility integration (automatic demand response and aggregated demand side flexibility) into their own infrastructure and thus usable for the grid processes of the network operator to avoid grid bottlenecks in short terms and avoid grid expansion requirements in long term.
- Optimization of CAPEX and OPEX in the power grid.
- Savings through optimized asset financing, management, and minimization of non-apportionable costs.
- Better handling of new complexities and network variabilities.
- Historize large volume of LV grid data for analytics.
- Future-proof solution, thanks to a flexible and scalable cloud-based platform with high availability and data security.

V. Digitial Twin Demonstration Project

BSES Rajdhani Power Limited (BRPL) is a progressive utility that supplies reliable power to an area spread approximately 700 square kilometres in the city of Delhi in North Central India. The utility serves over 2.7million customers with a customer density of 3100 per square kilometre. The utility has experienced high growth in the number of consumers served, increasing its number of DTs by 63% between 2003 and 2017. A pilot project was conducted at the distribution network of BRPL with the aim to build a sustainable LV network connectivity up to the last mile i.e., LV consumer through end-to-end process of networking and digitization.

The DTP project enables BRPL (within the respective grid area) to have visualization of their LV distribution network, efficiently allocate investments and being able to reliably do load forecasting, simulate scenarios, and voltage management for the said LV network. The solution will also help the utility to conduct impact analysis and grid behaviour predictions for RE, EV charging stations, and ESS integration at the LV network with live data from the field.

The scope of the project was decided for measurement and integration of all feeders outgoing from a particular DT. In total there are 34 consumers, 51 poles, and three roof top solar installations in the three-feeder network (Table 1). A high-resolution power quality meter with corresponding current and voltage modules was installed to measure currents and voltages for each feeder. The measured data is then polled into the DTP for display, calculations, and analysis. The data acquisition rate was set to 1 second interval, however, it can be altered as per the bandwidth available for the connection. A complete network virtual model is created in the DTP for real-time load flow analysis (Fig. 2). BRPL provided the historical monthly consumption of the consumers which was fed into the DTP model.

TABLE I. DETAILS OF LV FEEDERS CONNECTED TO THE DT

Feeder	*No. of Poles*	*No. of Customers*	*Sanctioned Load (kW)*	*Solar Installation (kW)*
Feeder 1	31	18	209	30
Feeder 2	17	15	282	72
Feeder 3	3	1	4	0
	51	**34**	**495**	**102**

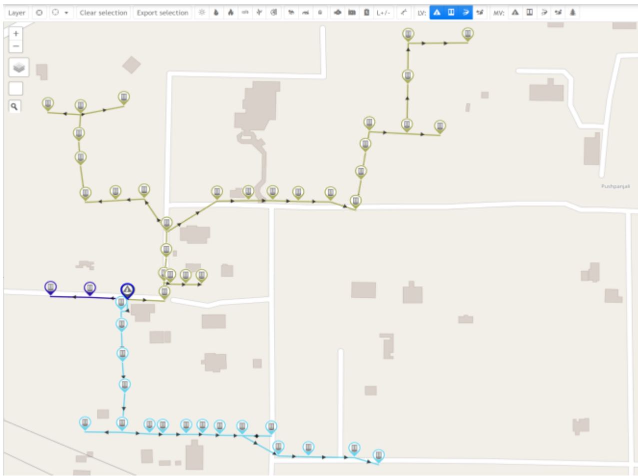

Fig. 2. GIS Mapped Birds Eye View of the Distribution Network

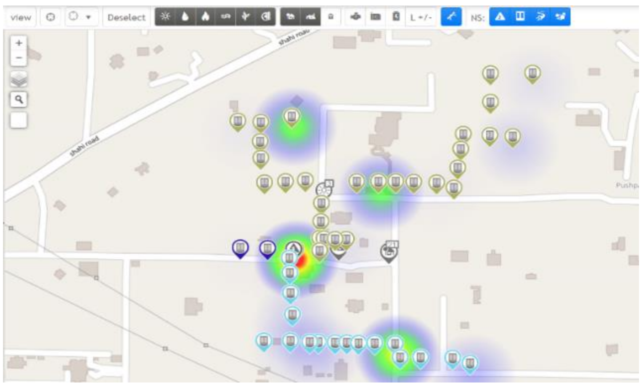

Fig. 3. Heat Map Showing Areas of High Consumption in the Network

The heat map (Fig. 3) shows the areas where maximum consumption is happening in the network. It makes it easy for the utility to understand and operate the distributed network. With a greater number of smart devices installed and integrated in the network, more live data is available that will further result in precise power flow estimations. Live or historical trends (Fig. 4) of the measurements can be analysed for root cause analysis of an event.

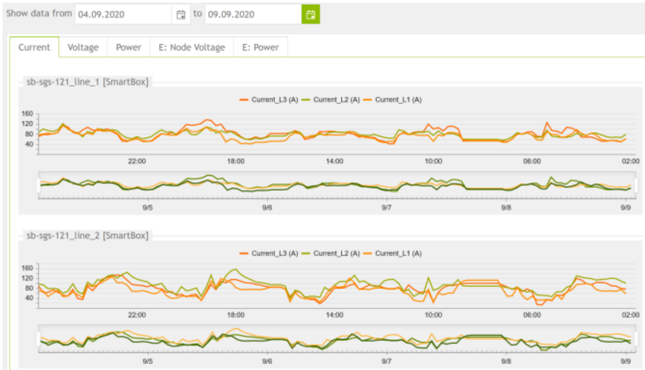

Fig. 4. Real-Time and Historical Treands for Analog Values

A. Analysis and Result

As for the demonstration project, the distribution network selected was limited to one DT with one meter integrated, limited data could be collected and analysed. The focus was to observe network operations in real-time, understand grid behaviour, and analyse power quality parameters. The consumption data is being monitored and captured by the meter at the DT and the individual consumers meters. Based on certain period of data gathering and analysis, some important findings from the project are highlighted below:

1) *Frequency of the network:* It was observed that for 80% of the time the frequency measured was below the nominal value of 50 Hz. The median frequency acquired was approximately 49.96 Hz (Fig. 5) that is within the operational band of the utility. However, any deviation from the operating range shall require control of the active power component for frequency regulation.

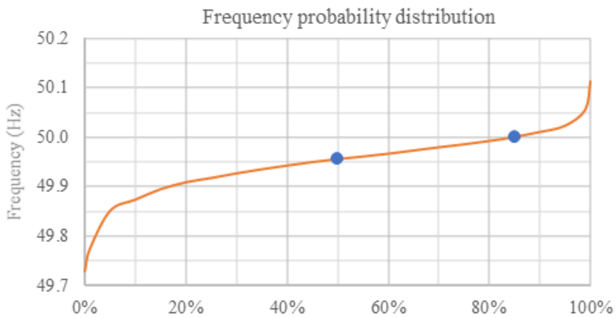

Fig. 5. Measured frequency deviation (August 2020; nominal and median value highlighted)

2) *Voltage of the network:* Voltage was clearly on the higher side of the bandwidth most of the time. The median voltage was calculated to be at 244V, which is 6% higher than the nominal value of 230V and at the upper limit of the specified acceptable range (Fig. 6). Roughly 10% of the time the voltage exceeded 250V, which may impact consumer appliances. On load DT tap changing is recommended to lower the voltage. It will also help to lower (dielectric) losses and have a positive effect on the aging behaviour of lines and equipment.

Voltage spikes were found several times a day, each day. The very high slew rate and the step size of approximately 12V (corresponds to 5% of nominal voltage) suggested a tap changing activity on a higher tension level as possible cause.

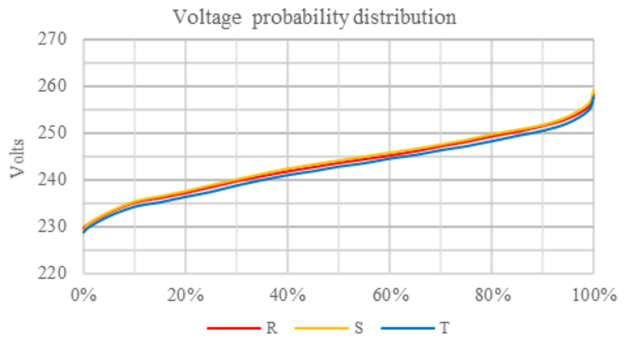

Fig. 6. Measured voltage deviation (August 2020; phasewise)

3) *Phase-wise Current of each feeder:* The current trends of the three feeders was observed (Fig. 4). Feeder 1 is well balanced with the current load equally distributed in the three phases. In Feeder 2, we see that the Y phase has higher current load compared to the R and B phase. The current trend of Feeder 2 also shows a dip during day which indicates that there is high solar injection into the grid. Feeder 3 has very low current values as there is only one consumer hence there is no need to check for loading effect on this feeder. Highest consumption typically occurs in the evening hours around 8 to 9 pm.

4) Solar PV Integration: There is a 30kWp solar PV in Feeder 1 and a 72kWp solar in Feeder 2. Power value trends showed that July and August were peak months when solar generation was at its high due to abundant sunlight. Day-wise plot of the power reveals that there is a huge swing in daily power trend for Feeder 2 while there are no swings visible in Feeder 1. The plot reflect that a huge Solar PV installation plays an important role in how the network behaves. During the day, power and current drawn from the DT is very negligible due to the injection of solar PV in Feeder 2. However, it rises in the evening as the injection from solar PV diminishes (duck curve as shown in Fig. 7).

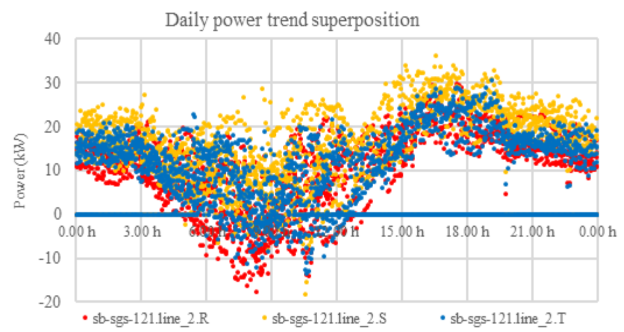

Fig. 7. Measured feeder power (*August 2020; feeder 2, phasewise, time in CET offset of +3:30 hours to IST*)

5) *Phase-wise Active Power & Reactive Power of each feeder:* High resolution load profiles can be established for the DT with respect to time-of-day, month, season etc. Based on the load patterns created, predictive maintenance can be scheduled and projections for equipment aging and replacement can be established.

6) *Harmonics in the network – Total Harmonics Distortion (THD):* It is observed that the network Y phase has more voltage THD compared to the R and B. Median values for voltage THD are around 2.5%. This seems a reasonable value which might be slightly optimized based on the voltage issue decribed above. The current harmonics observed in the feeders have to be compared to other DTs and feeders on the network for any conclusion.

VI. Conclusion

The latest developments towards increasing electrification of various sectors (such as transportation, heating, building) and the fluctuating feed-in from RE sources make knowledge of the load flows in the distribution network essential to ensure stable operation within given parameters. In this paper the concept of a digital twin for a distribution grid is discussed. It highlights the advantages of a Digital Twin Platform solution and how it can complement the existing systems (SCADA and ADMS) and extend their functional reach.

With the emphasis on transformation of a DISCOM to a DSO, the role of DTP becomes critical for real-time advanced situational awareness and DER despatch. The DTP not only allows grid transparency but also allows the automatic control of assets in the distribution system and sets the basis for the control of equipment on the end customer side (demand side management). With increasing complexity of managing the distribution network, it inevitably requires data driven automated grid operation.

The findings from a relatively small demonstration project show a clear added value of the DTP for grid management. Based on the analysed data, conclusions can be drawn for appropriate interventions and optimizations. To afford a grid-wide use, a solid database must be created. Prompt rollout of the solution to other parts of the distribution network will strengthen the system and lay the foundation for a stable, future-proof distribution grid.

Disclaimer

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Smart Grid Reliability Enhancement through FMECA and Quality Assurance Plan[1]

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Abstract—
*This paper covers a detailed Failure Modes, Effects and Criticality Analysis (FMECA) study of the Grid Substation Automation System. All the assets and technologies under scope of the automation department have been studied based on the past Device failure/ mal-operation reports and data. Using various QC tools, the root cause analysis of all the failure modes of assets have been identified, their criticality based on RPN (Occurrence*Severity * Detectability) and their CAPA approach followed. This study of FMECA has been done in two cycles following the PDCA approach. Firstly an exercise was conducted on the existing system identifying all failure mode, RPN of each mode and the approach followed to mitigate the same. After rigorous brainstorming sessions by the automation department, various innovative projects were identified to mitigate the gaps found from the FMECA study in the first cycle. These projects and approaches have been adopted and implemented. Further to check the impact of these improvement initiatives, a second cycle of the FMECA study has been done. As an outcome of the study Automation department has prepared a Quality Assurance Plan to ensure a robust mechanism of checks at various stages and maintenance approach for better automation asset optimization.*
This study is going the give an insight to Discoms, product companies, consultants, R&D units and Academics to understand the users' real field challenges and bring innovative solutions accordingly.

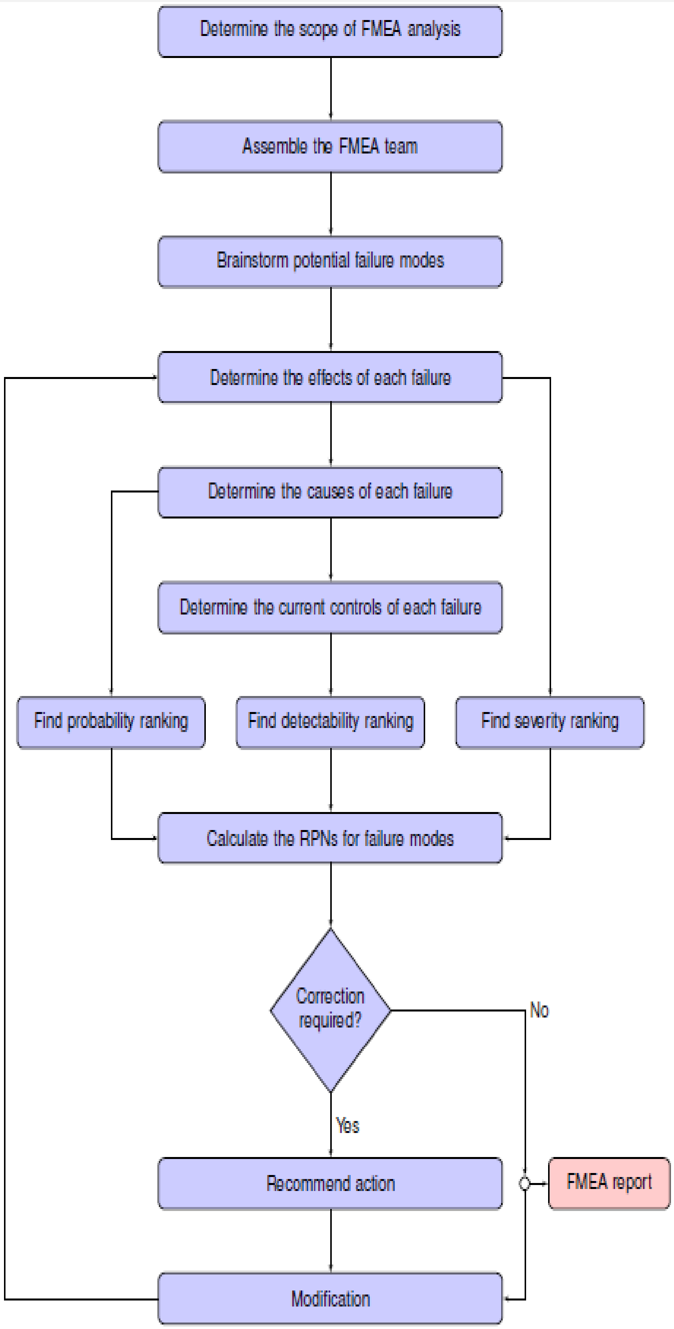
Keywords—FMECA, Smart Grid, OT Cyber Security, INMS-(Integrated Network Management System), Digital Substation, ADMS, PDCA, Grid Automation, FMEA, RPN, CAPA

I. INTRODUCTION

Efficient power infrastructure is a sine qua non for sustainable and economic growth of any nation. The power sector is undergoing enormous transformation. In the past few years we have seen a plethora of advancements in the Power distribution sector. Tata Power DDL, a Discom based in North and North West Delhi has adopted various technologies like SCADA, ADMS, IEC 61850 based relays, Digital Grid Substation, Advance Metering Infrastructure (AMI), RF Mesh, SAP, IP/MPLS based communication and OT Cyber security. All these technologies have increased reliability and reduced AT&C losses. But the iincorporation of these technologies has led to huge degree of complexity and challenges in management of the assets. So in order to optimally utilize these technologies and assets, a detailed reliability and risk assessment study is the need of the hour. This study is expected to make proper system planning, enhance the reliability of operation, and saving of O&M cost to Tata Power DDL.

II. APPROACH OF THE STUDY [2]

Steps followed to conduct the study



Steps followed [2]

- Step 1: Determine the scope of FMEA analysis in order to define boundaries and approaches that are to be considered during the analysis
- Step 2: Assemble the FMEA team in order to be cross-functional and multi-disciplined, forming a line-up of subject matter experts from a variety of disciplines with knowledge of the problem to be discussed
- Step 3: Understand the problem to be analyzed by dividing the system into subsystems and/or assemblies and use schematics and flowcharts to identify components and relations among components
- Step 4: Brainstorm failure modes that could affect the system quality and identify their causes and potential effects on the system
- Step 5: Determine Occurrence, Severity and Detectability for failure modes and calculate their RPN
- Step 6: Prioritize failure modes by ranking them in terms of the RPNs for preventive actions and recommend actions for the high-risk failure modes in order to eliminate them, increasing failure detectability and minimizing losses in the event a failure occurs;
- Step 7: Prepare FMEA report by summarizing the analysis results
- Step 8: Calculate the revised RPNs as failure modes are reduced or eliminated once the recommended actions have been taken to improve the system.

A. Analysis of the various anomaly reports

There are various reports which are being published by the automation department for measuring the performance of the assets. Various non-availability report of RTU, Ethernet Switch, OT Network Link, Bay, TMU, PU, LDR, TDR and Non Successful remote breaker operation through ADMS report have also been analysed for the preparation of this paper. For detailed analysis, last 2 year reports have been studied based on the availability of data.

B. Identification of the various failure modes of the Assets and CAPA

Various failure modes of the assets have been identified. For failure mode QC tools like Root cause analysis, Pareto, why-why, co-relation study, histogram and control charts has been used. Various failure reasons have been segregated into a common bin. Emphasis has been laid on Occurrence, Severity and Detectability of the issues. During the study, some gaps in Detectability of failure has been observed. Some projects have been identified and some implemented in this regards.

C. Calculation of Risk Priority Number(RPN)[2]

RPN has been defined as product of Occurance, Severity and Detectability. The scale for these parameters has been varied from 1-10.

Occurrence (O)		
Possible Rate of Occurrence	Criterion of Occurrence	Value
Once every 5 Years	Very Low	1
Once Every 3	Low	2
Once year		3
Once 6 month	Medium	4
Once every quarter	Average , Occassional Failure	5
One every bi-month		6
Once every month		7
Once Every fornight	High, Frequent Failure	8
One Every week		9
Every Day	Very High Failure	10

Severity (S)		
Duration of Service Interruption	Criterion of Severity	Value
> 8 Hours	Very Catastrophic	10
7 Hour	Catastrophic	9
6Hour	Very Serious	8
5 Hour	Serious	7
4 Hour	Medium	6
2 hour - 3 hour	Significant	5
1 hour -2 hour	Minor	4
30 min - 1 hour	Very Minor	3
5 min to 30 min	Small	2
Less than 5 Minutes	Very Small	1

Detectability (D)		
Level of Detectability	Criterion of Detectability	Value
Not Detectable	Impossible	10
Difficult to Detect	Very Difficult	9
	Very Late	8
Detecting Random (Unlikely)	Not Sure	7
	Occassional	6
Possible Detection	Low	5
	Late	4
Reliable Detection	Easy	3
	Immediate	2
Detection at all times	Immediate Corrective Actior	1

D. Defining the criticality using RPN and Strategy preparation[1]

Finally, based on the product of these parameters i.e. O*S*D RPN is calculated. Priority for the RPN has been assigned as per the matrix below:

Criticality Matrix		
Degree of Criticality	Value	Risk/Hazard
Minor	0-30	Acceptable
Medium	31-60	Tolerable
High	61-180	
Very High	181-252	Unacceptable
Critical	253-324	
Very Critical	>324	

E. Formulation of the robust Quaility Assurance Plan

Post completion of the study and application of the various projects to mitigate the gaps, a stringent Quality Assurance Plan has been prepared. Keeping an eye on all the failure modes of the assets and OSD parameters, a Quality Assurance Plan has been prepared. This included following precautionary measures right from the procurement stage, FAT checks, Post commissioning checks and checklist in the planned maintenance. For ensuring the quality during commissioning and maintenance, a checklist has been prepared and made mandatory to be filled by the field engineer before giving the final approval. This has proved to be a game changer as not only a lot of human error due lack of expertise or mistakes have been significantly reduced but also Standardization in configuration has been observed across the automation assets like RTU, Relays, Switches, Firewall etc.

F. PDCA approach

PDCA stands for:

P-Plan
D- Do
C- Check
A- Act.

This overall study has been done in accordance with the PDCA approach. DWM i.e. Daily work management has been planned based on the findings of this study. During the planning stage, all the standardization has been done like setting targets for availability of the assets, checklist preparation based on Quality Assurance Plan, etc. DO refer to carrying out all the activities based on the QAP, and Criticality study. CHECK refers to the regular check on the performance and reduction in the RPN, the check has been conducted after a gap of 6 months to check the efficacy of the applied approach as well as new initiatives/ Projects. After recheck still some gaps were identified and based on the inputs next step i.e. ACT has been defined. During the ACT stage, necessary changes in the standards and checklist were made. Some new projects were identified and various approaches have been changed for the desired objective.

III. DETAILED STUDY AND FINDINGS

FMECA Matrix:

Matrix format and RPN calculation:

This is a two dimensional matrix, the columns of which are in sequence as-

- Element
- Function
- Failure Mode
- Causes
- Detection
- RPN calculation (Occurrence*Severity*Detection)
- Maintenance Practices/CAPA.

1. **Column 1: Element**

   Devices covered in the Matrix are

   a. RTU

   b. Network Link/ Ethernet Link

   c. Breaker

   d. Relay/ IED,

   e. Ethernet Switch

   f. ADMS Server

But for reference, only RTU has been covered here.

2. **Column 2: Function**

   In this column, the function of every element has been mentioned.

3. **Column 3: Failure Mode**

   Based on the past 3 years or available data, all the failure modes have been identified and mentioned. For reference few of the failure modes of RTU and their cause have been mentioned.

Failure Mode	Cause
Communication Failure	LAN cable issue
	RJ 45 Degradation
	Address Mismatch
	Data error
	Card Failure/ Hardware issue
Operational Failure	Firmware corrupt
	Configuration issues
	Polling Error
	Database issue
	Card Failure
Power supply failure	Faulty power supply card
	DCDB issue
	Converter faulty
	Physical damage of Power cable
	AC DC mixing
	Connector damage
Toggling	Heavy RTU data loading
	LAN cable issue/
	T1, T2, T3, K, W mismatch
	Heavy ADMS Server Loading
Security Failure	Hacking for sensitive information
	Faulty information injection
	Unauthorised access

Similarly for the all other Devices, all kinds of failure modes have been identified and mentioned.

Column 4: Detection

In this column, the detection methodology of the various causes have been mentioned. For reference the Detection method of the above mentioned RTU failure modes has been tabulated.

Cause	Detection
LAN cable issue	ICMP connectivity /IP ping/ INMS
RJ 45 Degradation	ICMP connectivity /IP ping
Address Mismatch	1) Verification by the ADMS operator and field engineer
Data error	RTU Logs
Card Failure/ Hardware issue	LEDs on display, Error codes on RTUs, Logs of RTUs
Firmware corrupt	RTU logs/ Sys-logs
Configuration issues	Diagnostic logs
Polling Error(Part of configuration)	Checking in the configuration file of the RTU
Database issue	RTU Logs, Syslog
Card Failure	LED on display, Logs
Faulty power supply card	Field engineer inspection
DCDB issue	ADMS alarms, DCDB Report
Converter faulty	Inspection by site engineer
Physical damage of Power cable	Inspection by site engineer
AC DC mixing	No checking method
Connector damage	Inspection by site engineer
Heavy RTU data loading	Inspection of RTU Database
LAN cable issue/	Visual Inspection
T1, T2, T3, K, W mismatch	Configuration file RTU
Heavy ADMS Server Loading	ADMS Stick Report
Hacking for sensitive information	Firewall report and logs

RPN calculation:- The RPN calculation has been done by the multiplication of three parameters i.e. Occurrence, Severity, and Detectability. All these parameters are measured based on the Score from 1-10 obtained from the above mentioned matrix. The scores of these parameters has been multiplied in the last Column i.e. RPN This Score is calculated for each individual cause of failure. Post the score is calculated for all the causes, this matrix is rearranged

Cause	Detection	Criticality (RPN)				Maintenance Practices (CAPA)
		O	S	D	C	
LAN cable issue	ICMP connectivity /IP ping/ INMS	5	4	2	40	LAN cable Replacement /Tightening
RJ 45 Degradation	ICMP connectivity /IP ping	7	3	4	84	Re-crimping
Address Mismatch	1) Verification by the ADMS operator and field engineer	5	4	3	60	P2P testing
Data error	RTU Logs	5	4	3	60	Reconfiguration of the RTU Database
Card Failure/ Hardware issue	LEDs on display, Error codes on RTUs, Logs of RTUs	7	5	3	105	Card Replacement and Repair of the faulty card
Firmware corrupt	RTU logs/ Sys-logs	4	5	3	60	Installing latest Firmware
Configuration issues	Diagnostic logs	5	5	7	175	Reconfiguration
Polling Error(Part of configuration)	Checking in the configuration file of the RTU	6	5	6	180	Unchecking SOE in the RTU for Analog and checking for Digital
Database issue	RTU Logs, Syslog	6	5	6	180	Central Repository and Database change report
Card Failure	LED on display, Logs	5	5	6	150	Card Replacement and Repair of the faulty card
Faulty power supply card	Field engineer inspection	7	5	4	140	Card Replacement and Repair of the faulty card
DCDB issue	ADMS alarms, DCDB Report	4	8	1	32	Providing input to System for further actions.
Converter faulty	Inspection by site engineer	2	4	5	40	replacement of Converter
Physical damage of Power cable	Inspection by site engineer	2	3	3	18	Power Cable replacement
AC DC mixing	No checking method	4	4	9	144	No as such practice (By un-grounding the DC)
Connector damage	Inspection by site engineer	4	4	2	32	changing of Connector
Heavy RTU data loading	Inspection of RTU Database	7	6	4	168	Reconfiguration of the database
LAN cable issue	Visual Inspection	6	2	3	36	replacement of LAN cable
T1, T2, T3, K, W mismatch	Configuration file RTU	6	5	5	150	Database Up-gradation
Heavy ADMS Server Loading	ADMS Stick Report	6	3	1	18	redistribution of loading into servers and co-ordination with vendor
Hacking for sensitive information	Firewall report and logs	1	8	7	56	Firewall configuration based on the Information
Faulty information injection		2	8	7	112	Firewall configuration based on the Information
Unauthorised access		1	8	7	56	Physical and virtual access control using firewall.
Mal Operation		1	8	7	56	Firewall configuration based on the Information

based on the descending order with the maximum value of the RPN. Then the top 5 causes are taken into consideration in the first cycle. Post the calculation, a Brainstorming session was conducted with all the team members of the Automation department. The major causes were discussed and various innovative approaches were adopted as well as some external companies were invited to resolve the challenges. In meanwhile various projects were identified. These projects were implemented and as per PDCA approach, the Check was conducted again to find out the revised RPN. There was significant reduction in the RPN. After this stage, now the Next 5 ranked RPN causes were taken into account and action plan was prepared for them. Similarly our approach was continuous improvement and in the next cycle we are looking to focus on rest causes.

A. Gaps identified in the department process

During the Preparatory stage, all the existing IMS process, work Instructions for carrying various departmental functions, checklist for the various closure of maintenance activities as well as various other departmental reports were revisited. In contrast to FEMCA and QAP, various gaps were identified. So it is highly recommended to revise the departmental documents along with this preparation. During the first stage, these changes were incorporated in the process for a trial basis and after the check stage of PDCA cycle, the necessary changes were incorporated. The most significant outcome was the formulation of Annual Maintenance Plan for the whole GSAS as well as DA assets. This AMP is a predictive maintenance approach based on the condition monitoring of all the assets. It consist of detailed analysis of predictive parameters which are leading factors for any failure.

B. Various projects identifed based on FMECA study

- **RTU Database Refinement**:- Database refinement was found very effective way to ensure the standardisation in all the RTUs and IEDs. As Tata Power DDL is using various vendor's RTUs and IEDs and RTU replacement as well as new RTU integration is a usual process. Mostly these projects are done by different engineers. While doing this study it was observed that RTU failure are accounted significantly due to lack of Database uniformity. As a primary step, various best practices were listed and a checklist was prepared. All these changes were introduced in all the database in standardised manner. Now this checklist has been made mandatory to be filled for any database update or new RTU installation.

- **IOT based Asset Health Monitoring**: Failure of various assets can be predicted based on parameter data analysis. So based on the AI and ML application along with IOT, Asset health can be monitored. We are managing proactively life of various critical assets like PTRs, RTUs etc.

- **Remote IED/ RTU reboot system**: - It has been observed that one of the major failure modes of RTU is hanging issue. With Hard-boot of the system we were able to resolve a significant number of cases. Hence we have deployed IOT based Remote RTU hard-boot system at 3 critical grids. This has significantly reduced the downtime and hence ensured the availability of OT communication.

- **Earth Resistance Monitoring**: - A large number of IED failures have been observed on account of leakage current. So very high accuracy Earth Resistance Monitoring has been installed and the same has been integrated with ADMS.As soon as the value crosses a fixed limit, an alarm has been prepared to take the necessary action.

- **UPS installation at critical Grids**: - It has been observed that due to Power Supply issue Communication failure is frequent in DTL grids and some Tata Power DDL grids. So UPS has been installed at those grids which are very critical.

- **Ungrounded DC systems with preventive measures** (Insulation monitoring & fault location):- This project was outcome of the high RPN causes analysis. The power supply is guaranteed in the event of an single-pole short to ground (i.e. first earth fault). No fault current flows in the event of first earth fault which leads to personnel and equipment safety. No fault current flows in the event of first earth fault which minimize the chance of fire accidents which may happen due to the earth fault leakage currents. Early indication by using Insulation Monitoring Devices IMD (Isometer), helps in predictive maintenance

- **High Quality LAN cable Connector and LAN Cable**: - It has been observed the major cause of the frequent failure of the RTU and IED communication was related to LAN Cable. Just by re-crimping we were able to resolve around 50-60% of cases. So it was decided to replace the existing LAN cable and connector with high quality material at critical grids. A significant reduction in the failure cases were observed with this implementation.

- **Firewall Installation**:- One of the failure modes of the RTU and IED communication can be an external threat and intrusion in our network. RPN was significant although occurrence was very low but Severity and Detectability score was very high. Hence Firewall has been installed at all Grid Substations and an Analysis and Monitoring system has been installed at control centre where the operators are vigilant for 24*7 for any event.

- **Material Management using Mobile Application**:- It has been observed that severity of few cases of asset failure is very high due to non-availability of spare parts/ redundant system. So for the critical grids we have decided to prepare a redundant system for communication and keep material supply chain management system proper. This material management at Automation department level has been integrated with SAP and the Operation Variances Application.

- **Environmental impact study on Relay degradation**: - Environment/pollution has been one of the major contributors in the IED failure in few grids, mostly those located near some Industry, Sewage channel, cremation centres etc. So an environmental gases and pollutant study has been conducted and their impact on the failure of the IED has been studied.

- **Advanced training for OT Network Visibility**:- As we are aware that Grids are turning smart with complex IEDs, Firewalls and Switches, they bring with them the requirement of expertise to have better network visibility. Deeper understanding of network traffic monitoring, packets, switching, etc. are required at OT level. Hence training need has been identified and we are yet to schedule a training for the same.

- **Substitute ACE card for Modbus:-** Serial/ Modbus communication has its own challenges. Automation Department has observed one of major cause of communication failure is related to ACE cards. Failure of these cards are very frequent. Hence to establish Serial communication of different panels, we are yet to find a solution which could replace the ACE cards.

IV. CONCLUSION AND WAY FORWARD

This is a very significant and unique study in order to ensure the reliability of the Smart grid. As various complex systems like advanced protocol based IEDs, RTUs, complex Switches, Firewalls, ADMS, SCADA system, Renewable Integration, DERMS are coming into the grid, sturdiness and sustenance of the system assumes prime importance. This FMECA exercise, Asset Maintenance Plan (AMP), PDCA approach, Checklist based approach for standardisation and various projects implementation based on the outcome of this study has helped in significant reduction in failure cases of assets and improvement in availability of system. This Study can help various distribution utilities to gear up for future grid challenges. This study will be of great help to the solution providers to understand the challenges being faced by the utility and come up with innovative solutions. Industry in close coordination with Utilities and Academics could ease India's journey towards Smart Grid.

ACKNOWLEDGMENT

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ABBREBIATION

SCADA:- Supervisiory control and Data Acquision

ADMS:- Advanced Distribution Management System

AMP:- Asset Maintenance Plan

PDCA:- Plan Do Check Act

FMECA:- Failure Mode Effect and Criticality Analysis

IED:- Intelligent Electronic Devices

RTU:- Remote Terminal Unit

OT: Operation technology

PTR:- Power Transformer

QAP:- Quality Assurance Plan

FAT:- Factroy Assesment Plan

Smart LT Network Management: Use of Low-Cost RF Mesh WAN Based Feeder Pillar Monitoring System

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Abstract— This paper highlights applications and advantages of Low cost RF mush based feeder pillar monitoring in a Mumbai City. This paper highlights applications and advantages of using Radio frequency for parameters monitoring of Feeder Pillars and associated networks by incorporating a local Wireless Area Network - WAN. Radio Frequency of 865-867 Mhz is a free band in India and has a range of around 400-500 meters in clear line of sight. It can easily transmit small volume data over the mentioned range. The data can include current, voltage, fuse status & Digital inputs like door switch status, fire alarm switch etc.

Feeder pillars are usually installed at maximum distance of 500 meters apart from one another. Radio frequency mesh network once established, can make data flow across all feeder pillars and finally it can be brought to a central server via a Data concentrator unit - DCU. DCU is a GSM enabled device which collects all data received on RF and then transmit that over GSM to the central server

Introduction

Tata Power, a pioneer in providing reliable and uninterrupted power to Mumbai City, caters to the power supply requirement of large number of Residential, Commercial & Industrial customers. Tata Power being committed to lead adopter of latest technology has taken up the drive of modernising its Distribution network with introduction of new in-house tower mounted substation.

To provide the power supply to customer, the power utilities install feeder pillars across the network. These feeder Pillars are LV equipments acting as junctions to release LT power supply across the city. In Tata Power's Mumbai LT Network there are close to 8000 feeder pillars installed in the LT network ,

A. The problem

Feeder Pillars forms the junctions in LT network of a power distribution network. These Feeder Pillars are mostly not connected via any communication medium and no meters are installed on these Feeder Pillars. It becomes important ot know the consumption of these Feeder Pillars to release any new loads from the said Feeder Pillar. Presently the reading is taken using manual interventions. A technician manually takes the current and voltage reading to check for the instantaneous current values. This method has two drawbacks – It doesn't give peak demand value of the feeder pillar. Also it creates a protentional hazard incident from safety perspective where the technician comes in close contact to the love panel for taking the current/voltage readings.

B. The approach

Considering the overall scenario, change in design / alternative salutation was the need of an hour. The engineering team has worked for several options to overcome this problem

By in-corporation of a local Wireless Area Network – WAN, these feeder Pillars can get communicated to a central location. Radio Frequency of 865-867 Mhz is a free band in India and has a range of around 400-500 meters in clear line of sight. It can easily transmit small volume data over the mentioned range. The data can include current, voltage, fuse status & Digital inputs like door switch status, fire alarm switch etc. There are other communication mediums to achieve the same like GSM based NB technologies, but these technologies turns out to be comparatively costlier solutions when a large number of feeder pillars are considered.

C. The arrangment

During the detailed engineering of design, 8-way feeder pillar network was selected. Pilot trails were conducted on these units with RF modules connected at these units. CT sensers were installed on the busbars at one location only as shown in Figure B.

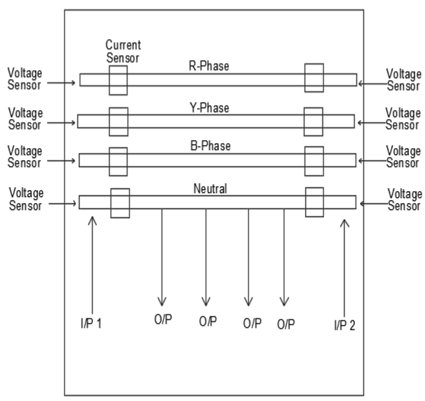

Figure A

The final design will incorporate use of CTs on both the sides of the Incoming cables. This is important to check the load in case of NOP point shifting as shown in Figure A above. Pilot trials results are shown in figure C

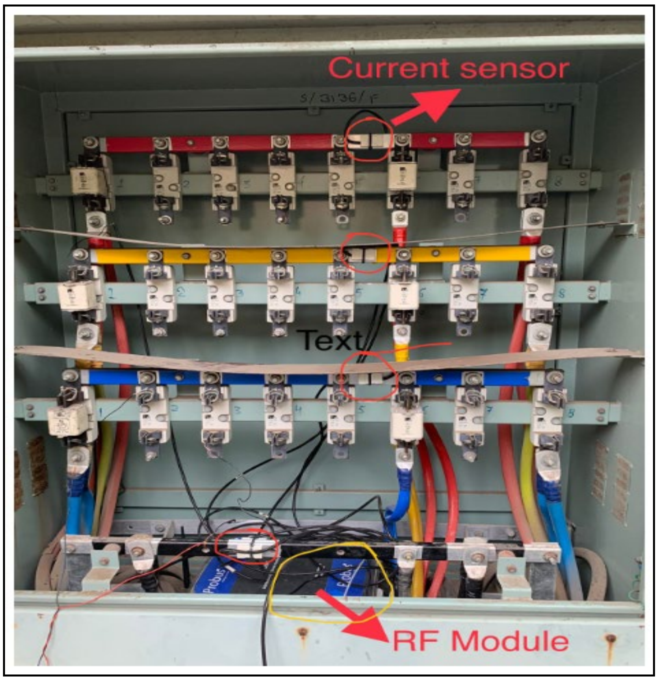

Figure B

Sr. No.	Ltacb-1				DI					
	R	Y	B	N	1	2	3	4	5	6(p
1	11	11	12	11	1	0	0	0	1	0
2	9	10	13	10	1	0	0	0	1	0
3	10	11	11	10	1	0	0	0	0	0
4	10	10	11	10	1	0	0	0	0	0
5	10	11	12	11	1	0	0	0	0	0
6	11	10	11	11	1	0	0	0	0	0
7	11	11	12	10	1	0	0	0	0	0
8	10	10	12	9	1	0	0	0	0	0
9	11	11	11	10	1	0	0	0	0	0
10	10	10	11	11	1	0	0	0	0	0
11	11	11	11	10	1	0	0	0	0	0
12	10	11	11	10	1	0	0	0	0	0
13	10	11	12	10	1	0	0	0	0	0

Figure C

D. The Challenges & Remedies

The design is newly introduced in Mumbai city and hence it is subjected to pilot trials first. There are challenges to this design in terms of loosing connectivity between the mesh network. Also if the radio frequency signal is weak due to heavy congestion, it will create hindrances in the network

E. Benefits

- Low-cost solution to have data connectivity of bulk Feeder Pillars at a central location
- Cost effective solutions with innovative designs. No recurring cost as compared to conventional GSM based solutions
- No specialized equipment is required for this design
- Design can be modified as per the site conditions
- Saves time in checking network feasibility and releasing load of new consumers
- Improves Safety by avoiding human intervention in taking readings

Beat Billing and Consumer Indexing for Smart Cities

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Abstract-Beat billing concept is used to enhance the energy meter billing quality. Beat billing system is a systematic attempt to eliminate the wastage of time in taking distributed consumer's meter reading. In beat billing system on one 11kv feeder 4 to 5 distribution transformer's consumers (1500 approx) combined and index in one beat and one meter reader assigned to get complete all consumers billing on assigned date as per billing schedule. This work describes the key elements in beat billing system of energy meter and compiles the efficient DT energy auditing to control distribution loss.

Keywords- *Beat Billing System (BBS), Distribution Transformer (DT), Consumer Survey App (CSA), Consumer Indexing (CI).*

Introduction

Deployment of Beat billing system is a systematic approach to reduce human effort and time in taking extensive distributed consumer's energy meter reading. In beat billing system at each distribution substation (33/11KV) approximately 8 to 12 number's of 11KV feeder's emanating and all 11kv feeder's sequentially distribution transformer's consumers data (1500 approx) combined in one beat and name one particular beat for one 11KV feeder. In similar way all feeders beat prepared and identified consumer's technical and commercial parameters indexed in one beat. At each beat one meter reader is appointed and his/her duty to provide each consumer's electricity bill every month on same date. Each beat meter reader also assigned a duty to use Consumer Survey App (CSA) to punch consumer's technical and commercial parameters for indexing in one beat. Overall beat billing idea is that assigned one meter reader to get completes all consumers of concern beat billing on assigned date as per beat schedule.

Objectives and Scope of work

Objectives: Objectives of Beat Billing plan is a day level route plan/sequence made for meter readers to take meter reading of a consumer at a pre-defined schedule. A beat plan defines whom to read and when to read the consumer's meter.

Scope of work: Beat will be formed in such a way that meter reading of consumers connected to the DT should be Completed in shortest possible time. Beat will be scheduled in such a way that the reading of each consumers should be done in uniform interval. All consumers of a DT shall be assigned to the single meter reader. As far as possible, meter read of a DT shall be completed on the same day or consecutive day. Meter reader shall read another DT only after completing the previous DT. Definitely Beat Billing System (BBS) and consumer indexing have a wide scope of work to improve our energy meter billing, collection and bills distribution system.

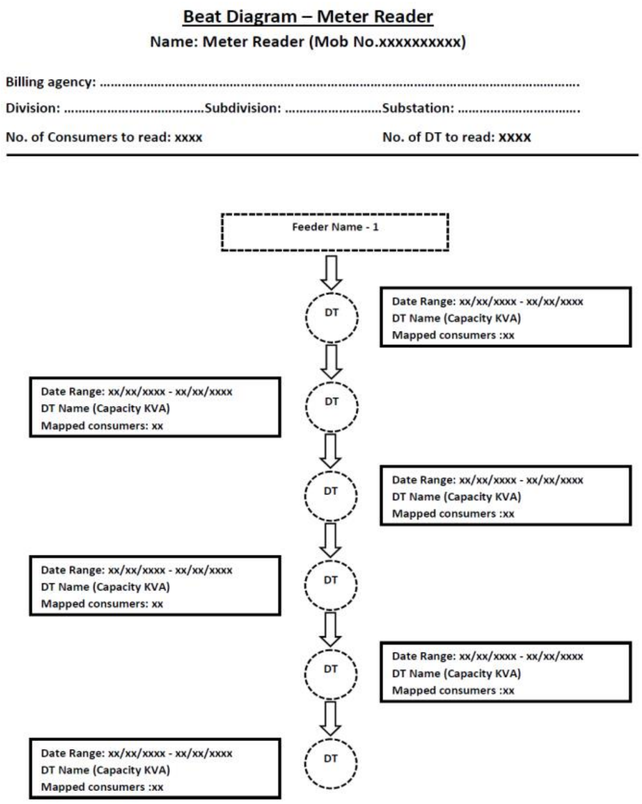

Figure1. BEAT MODEL (Beat Diagram)

BEAT MODEL

In beat model as per beat diagram meter reader start at first DT nearest to feeding end and prepare details like date range, DT name with capacity and number of mapped consumers. In similar way as per beat diagram all data collected by meter readers once during billing process. Beat Modeling is required to be done once in the beginning of billing cycle for number of beat estimations.

Significance of Beat Billing Model

Beat Billing Model helps in recording meter reading cycle of DT with their associated consumers as per beat scheduled. It also record meter reading of each DT's connected to a 11KV feeders for energy auditing. Beat billing model also eliminates problem of Non-uniform monthly billing cycle of consumers.

Beat Billing Model for Smart Cities

In this paper each 11KV feeder consider as one beat and each beat having 9DT's /10DT's/13DT's etc. Number of DT's in each beat covered 1500 consumers (approx).

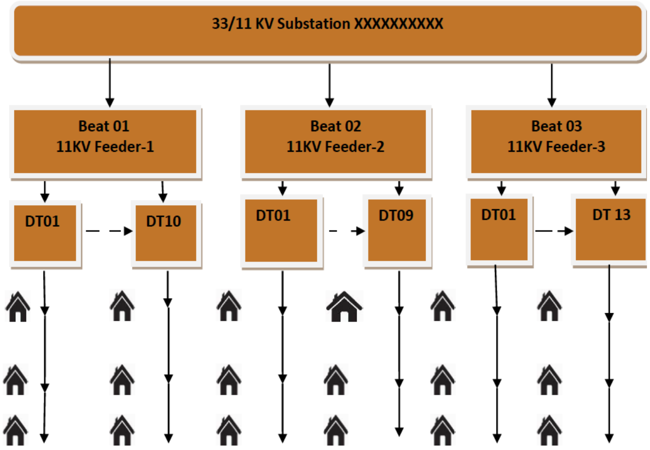

Figure 2. Beat Billing Model

Each meter reader has given a beat to fill various details in following format 1&2 available at each 33/11 KV distribution substations to update beats and energy auditing.

BEAT SCHEDULE OF METER READER (FORMAT - 1)

Name of Division :							
Name of Sub-Division :				Name of 33/11 kv S/s :			
Name of Meter Reader :				Mobile No. of Meter Reader :			
S. No.	Feeder Name	DT Name	DT Code	DT Capacity	Schedule date of reading	No. of Consumer	Remarks
1	2	3	4	5	6	7	8

Meter reader has to fill reading details in folowing format available at every substation

BEAT WISE DAILY BILLIG PROGRESS (FORMAT - 2)

Name of Division :												
Name of Sub-Division :							Name of 33/11 kv S/s :					
Name of Meter Reader :							Mobile No. of Meter Reader :					
1	2	3	4	5	6	7	8	9	10	11	12	13
S. No.	Billing Date	DT Name	DT Reading (Initial)	DT Reading (Final)	No. of Consumer (Target)	No. of Consumer (Progress)	Pending Billing for next day	DT Meter Status	DT Modem Status	Meter Reader (Signature)	Remarks by JE	JE (Signature)

Figure 3. Beat Schedule (FORMAT-1) & Daily Beat Billing Progress (FORMAT-2)

DT wise Consumer Indexing

The purpose of Indexing of the consumers is to identify and locate the entire consumers on geographical map, which are being fed from the Distribution Mains. There may be cases where electric connection exists but it does not exist in the utility's record. It may be a case of unauthorized connection or non-legderized connection. On the other hand, there may be cases where a connection exists in the utility's record, but it may not exist physically at site. Some time's connection might have been disconnected long back but the record may not have been updated. Using GIS, the LT lines coming out from Distribution Transformer and all service connections from the LT mains can be checked with reference to the consumers connected and accordingly the consumer database can be updated. Indexing of all the consumers in all categories so that the consumers can be segregated feeder-wise and DT-wise is necessary. The consumers are mapped using GIS technology and identified based on their unique electrical address, called Consumer Index Number (CIN).

Android Mobile Application based Consumer Indexing

Consumer indexing provides a platform to enable the utilities to generate verifiable and validated data of consumers of the utilities. Through door-to-door survey and with the help of the android mobile based CSA. It is possible to carry out consumer identification and collect data about consumers such as their paying capacity, connected load, consumer category, meter details and linkage to last pole or service pillar from the service connection taken out for consumer [1].

• Indexing is being done through GIS mobile application on the basis of QR Code which caters information of electrical network and location coordinates.

• Data gathered through mobile app is validated and then inserted to the billing software to finalize the tagging.

Figure 4. Data Validation via Consumer Survey App.

Procedure of consumer indexing

In DT wise consumer Indexing process through GPS and Mobile App. for different in formations such as 33/11 KV substations, 11KV feeders, DT identification etc details uploaded against asset mapping work done by hired vendors on Consumer Survey App. and same information forwarded for validation from Consumers Master Data. After Validation a unique 12 digit code generated with bar code and pasted/fixed on DT & Poles.

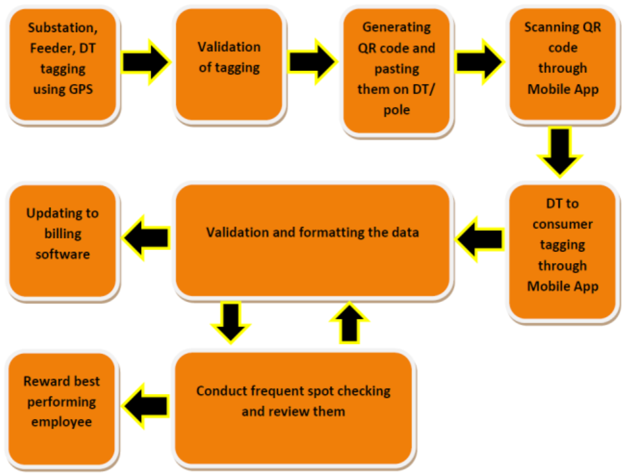

Figure 5. Consumer Indexing via GPS & Mobile App.

Now Meter Reader using CSA scanned DT/Pole code with available consumers and same information tagged /indexed in Consumers Master Data for updating in billing software. These indexed data used for checking, tracking and reviewing consumers activities.

CONCLUSION

Good quality of beat billing and consumer indexing (Appendix A) enhance design and process for consideration of better performance and customer management. An error-free identification of consumers and associated electrical connectivity enables proper tracking and updating of unauthorized and nonregistered connections.

APPENDIX A

ZONE	ZONE WISE BEAT PROGRESS					PROGRESS OF CONSUMERS INDEXING (DEC 2021)			
	Total No. of Divisions	Total No. of Feeders	Total No. of DT's	Total No. of Meter Readers Working	Total No. of Beats	Total No. of Consumers	Consumers Indexing done	Balance Consumers Indexing to be Done	% Indexing
1	1	2	3	4	5	6	7	8	9=7/6*100
AYODHYA	22	753	126961	1139	850	1748256	1680680	67576	96.13
BAREILLY	20	866	154287	985	1011	1629984	1493436	136548	91.62
DEVIPATAN	10	379	45192	590	648	1149278	1129671	19607	98.29
LESA CIS GOMTI	16	639	27248	335	318	722058	711212	10846	98.50
LESA TRANS GOMTI	10	444	6599	185	179	434181	434181	0	100.00
LUCKNOW	26	925	166634	1464	1602	2491901	2413039	78862	96.84
MVVNL DISCOM	104	4006	526921	4698	4608	8175658	7862219	313439	96.17

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Condition Monitoring of Surge Arresters Based on Third-Harmonic Analysis of Leakage Current

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Abstract— Metal-oxide surge arresters (MOSAs) are widely used to protect electrical equipment, including the functional components of power transmission and distribution systems, against lightning and switching transient overvoltage. Accordingly, an important aspect of maintaining the reliability of the entire power network consists in the regular monitoring of the condition of MOSAs to detect their possible failure in a timely manner the paper presents a low-cost system for monitoring the condition of metal-oxide surge arresters in service. The developed system integrates two methods currently used for evaluating the condition of surge arresters: analysis of leakage current and making categories voltage by current method. By measuring the total leakage current, 3rd harmonic current and capacitive current with various equipment. Perform detailed analysis and making the benchmark or threshold limits for leakage current flow through lightning arrester. The conducted tests confirmed the efficiency of leakage current analysis not only for detecting deterioration in the MOSA condition but also for differentiating its cause. Data obtained by testing provides useful to avoid future outages, predating life of equipment, the efficiency of the arrester operation, and the amount of energy absorbed by the MOSA. The paper describes the calculation, operational principles, and main technical specifications of the proposed system.

An effective and informative method for MOSA condition assessment during its operation is to regularly monitor changes in the resistive component and harmonic content of the leakage current. By this means, deterioration in the protective properties of a surge arrester arising due to degradation of the V–I characteristics of ZnO varistor blocks, humidification of the inner surface of the MOSA case due to its depressurization, or external soiling of the insulated casing of the surge arrester, can be identified . So making the certain standards while installing new MOSA and its life assessment.

Keywords— Metal Oxide Surge Arresters (MOSA), Health Monitoring, ZnO, 3rd Harmonic Current, Total Leakage Current, Lightning Arresters

I. INTRODUCTION

Lightning Arrester (LA)/surge arrester is a protective device used for limiting the effect of surge voltages on the equipment power distribution system. This arrester helps in discharging the surge current, thus protecting the system and equipment from dangerous over voltages and also disturbances. In Tata power-DDL mainly uses three types of LA like(a) silicon carbide “SiC” porcelain,(b) ZnO polymeric (oxide/metal oxide “ZnO”) and (c) ZnO silicon rubber (see in figure 1). These are manufactured mainly by Oblum ,ABB ,BHEL ,etc. lightning arrestors, age out during its period of services due to, (i) moisture ingress due to sealing problem.(ii) dust particles on external surface and ageing of Zink Oxide variations. (iii) cracks on porcelain surface internal.(iv) Partial discharges.

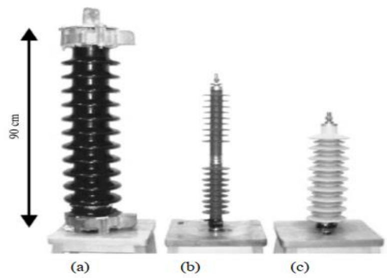

Fig.1 Types of lightning arrester

To avoid the failure of MOSA, it is necessary to monitor its health because if a lightning arrester fails, it explodes with porcelain splinters and apart from creating a short circuit, it also mechanically damages the other surrounding equipment like CTs, PTs, transformer bushing etc. Thus it creates a total disruption of power circuit. Methods for Monitoring of degradation of metal oxide surge arrester (MOSA).

- **Visual inspection** Locating external abnormalities on the arrester and gives practically no information about the internal of the arrester Surge counters
- **ThermoVision** Frequently used method. Detects the increased block temperature on the housing surface of the arrester.
- **Leakage current measurements** most used diagnostic method. For in-service testing, the method with indirect determination of the resistive leakage current with

compensation for harmonics in the voltage (THRC) is providing the best available information quality with respect to diagnostic efficiency.

II. MONITOR THE RESISTIVE LEAKAGE CURRENT OF LIGHTNING ARRESTERS

Normal service of a metal oxide surge arrester(MOSA) is carrying a continuous, but small leakage current, typically in the range of 0.1 -3 mA, see In figure 2. The leakage current is dominated by a capacitive current component whereas the resistive component may be in the range of 5 - 20% of the capacitive component. Or more information on proofreading, spelling and grammar.

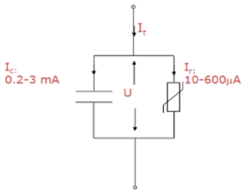

Fig. 2 Total leakage currentin LA

But with normal testing equipment fails to measure resistive current because see in figure 3, the total leakage current increases with only 4% when the resistive part is triple. This small change in it is difficult to read on the mA –meter.

Ic in the same size as It,*Ir* is nonlinear and depends on voltage level and temperature sinusoidal (fundamental component only): *I1c, I1r* and *I3r* Harmonics in the

Operating voltage U: *I1c, I1r, I3r, I3c I3r (and Ir)* is generated by the arrester itself and can be used as a diagnostic indicator[1].

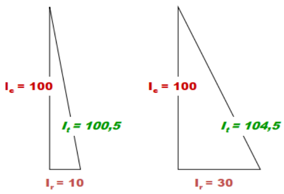

Fig. 3 *Ic vs Ir* graph

Typical Voltage – Current Characteristics the resistive current component typically 5-20% of the total leakage current under normal operating conditions.is a sensitive indicator of changes in the voltage current characteristic and it depend on the voltage and temperature[1].

- Metal Oxide Surge Arresters (MOSAs) are normally operated at a continuous voltage ranging 60% to 80% of the rated voltage. The nonlinear characteristic of ZnO (figure-4) blocks entails that even a large increase in the Resistive leakage current Ir is barely noticeable in the total leakage current. Thus the 3rd harmonic component if leakage current is measured health of LA[1].

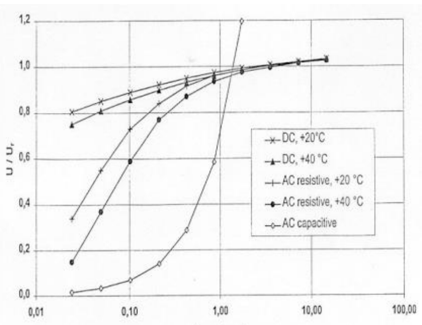

Fig. 4 Voltage – Current Characteristics

- Measurement of the resistive current component by the LA LCM is therefore the best way to obtain sensitive and reliable information about the arrester condition.
- One cycle of measurement of leakage current of lightening arrester should be completed prior to onset of monsoon.
- The lightening arresters with resistive leakage currents in between **350-500 µA** should be closely monitored and beyond **500 µA** should be replaced &jointly checked with manufacturer.

III. PRINCIPLE OF OPERATION

The nonlinear resistance of the ZnO blocks will introduce a 3rd harmonic resistive component in the leakage current when it is stressed by a sinusoidal voltage. This current component is the best indicator for detection of changes in the non-linear characteristics of the surge arrester over time.

If we ignore the harmonic content in the leakage current, we will not be able to know if an apparent increase in the resistive current is really due to the faulty arrester or if it is a false increase due to varying harmonic content over time. Thus it is necessary to take the effect of harmonics into account for diagnose of MOSAs. On-line test system for Residual Life Assessment of Metal Oxide Surge Arresters. The instrument measures and directly displays the values of Total Leakage Current and Third Harmonic Resistive Leakage Current. It provides system harmonic compensation as per IEC 60099-5-B2. It provides Corrected Resistive Leakage Current after applying correction factors for change in system voltage & temperature.

A. IEC 60099-5, clause 6.1.6.1.2:

"At given values of voltage and temperature, the resistive component of the leakage current is a sensitive indicator of changes in the voltage current characteristic of non-linear metal-oxide resistors. The resistive current can, therefore, be used as a tool for diagnostic indication of changes in the condition of metal-oxide arresters in service."[2]

i) Method B1: 3rd harmonic analysis of leakage current:

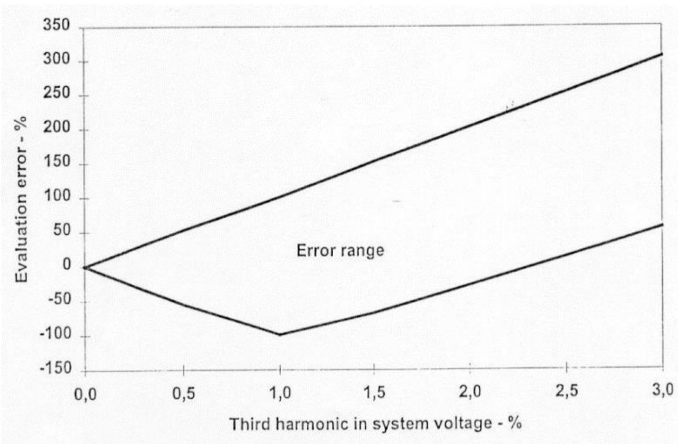

Fig. 5 typical %Error vs third harmonics voltage.

IEC 60099-5 says: Error range for third harmonic leakage current without compensation for different phase angles of system voltage third harmonics: *Includes various Voltage-*current characteristics of nonlinear metal-oxide resistors. 1% third harmonic in voltage May give ± 100% measurement error [2].

ii) Method B2: Harmonic analysis of leakage current using third harmonic with compensation:

3rd harmonic analysis chosen is used as a basis to obtain feasibility/reliability measurements in three-phase applications onsite. Presences of harmonics in the operating voltage generate harmonic capacitive leakage currents that is indirectly measured and compensated with system voltage and give compensated value. The key for compensation is application of field probe for indirect measurement of the 3rd harmonic capacitive leakage current generated by the operating voltage. The total and "true" resistive leakage current Ir is calculated from I3r and arrester data (incl. correction for temperature and voltage).

Weakness with Method B1: The presence of harmonics in the system voltage have been a great problem since these harmonics may interfere with the harmonics generated by the nonlinear resistance of the arrester. Favorable effect by Method B2: It introduces a field probe that allows a compensation for the harmonic currents generated by the harmonics in the voltage. This implies that the method shows low sensitivity to harmonics in the voltage.

Method B2: Measurement of resistive leakage current using 3rd harmonic analysis with compensation for harmonics in the system voltage.

iii) Method 2: Voltage Peak Method (IEC 60099-5-A1)

the method A1 of directly measuring resistive current involves using a reference signal which represents the voltage applied to the arrester. This signal can be used for measurement of resistive component in the leakage current at the instance of voltage peak. This means, the amplitude of current in the current signal, when reference voltage signal is at peak is the actual resistive leakage current. This method is suitable for factory or lab test.

B. Properties Of On-Site Leakage Current Measurements As Per Iec 60099-5:

In HV-DC test (at diagnostic efficiency) is effective but offline and complex.

Method B2: (using third harmonic) is ranked to be the best field method for evaluation of ageing and deterioration of MOSA.

C. Different Methods of IEC60099-5 with Its Effects.

MEASUREMENT OF TOTAL LEAKAGE CURRENT. : Poor sensitivity. Insufficient method.

DIRECT MEASUREMENT OF RESISTIVE LEAKAGE CURRENT: Attractive, but not usable on site.

METHOD B1: 3RD HARMONIC ANALYSIS OF THE LEAKAGE CURRENT: High sensitivity to harmonics in the voltage.

METHOD B2: 3RD ORDER HARMONIC ANALYSIS OF THE LEAKAGE**:** Ranked by IEC 60099-5 as most reliable on site Current with compensation.

Leakage current measurement method	Method No.	Sensitivity to			Diagnostic efficiency		Service experience	Ref. No.
		harmonics in the voltage	phase shift in measurement of voltage or current	surface currents	information quality	handling complexity		
Separate d.c. voltage source		n.a.	n.a.	high	high	high	limited	1
Service voltage or separate a.c. voltage source								
Measurement of total leakage current		low	low	mean	low	low	extensive	
Measurement of resistive leakage current								
- using voltage reference	A1	mean	high	high	mean	high	limited	2
- using capacitor compensation	A2	mean	high	high	mean	high	limited	3
- using synthetic compensation	A3	mean	high	high	mean	low	n.i.a.	4
- using capacitive current cancellation	A4	high	high	high	low	low	limited	5,6
Harmonic analysis of leakage current								
- using third harmonic	B1	high	low	low	mean	low	extensive	7
- using third harmonic with compensation	B2	low	low	low	high	mean	extensive	8,9
- using first order harmonic	B3	low	high	high	mean	high	limited	10
Measurement of power loss	C	low	high	high	mean	high	n.i.a.	11

NOTE - n.a. = not applicable; n.i.a. = no information available.

Fig. 6 Table of testing Methods in As per IEC 60099-5

IV. WORKING WITH LA LCM AND ITS BENEFITS

When voltage is applied to the arrester, due to non-linear voltage current characteristics of a metal-oxide used in arresters, harmonics are generated in the leakage current. In all the harmonics, the third order harmonics, which is predominant depends on resistive current of arrester. The magnitude of third order harmonics in the leakage current can be used as indicator of resistive current. The resistive component depends on applied voltage and temperature However as the system voltage itself may contain the harmonics which will significantly influence the measurement of third harmonics in leakage current. Hence it is very IR(corr): This field indicates the corrected value of the resistive current referenced to 70% rated voltage and 20deg.C.IR (TH): This field indicates the resistive current of the lightning arrester. This is the un- corrected value and must be corrected for voltage and temperature variations.

ITotal(mA): This field indicates the Peak values of the total leakage current in mA. The leakage current of the Arresters, Increased resistive current indicates a higher risk of breakdown of the Arresters.

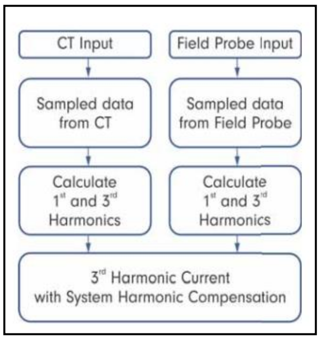

Fig. 7 shows flow chart for calculating 3rd harmonics in

Fig. 8 CT and voltage sensing device testing positions.

A. The LA LCM offers the following benefits.

- Confident knowledge to replace surge arresters in due time before an arrester failure occurs. The LCM is the most reliable system for diagnosis of metal oxide surge arresters (MOSA). Capability to prevent costly arrester failure and possible damages to other major equipment in the neighborhoods. An important achievement is an increased safety for the maintenance staff.
- No disturbance for the normal operation of the system. The condition of surge arresters is checked without any influence on the operation of the power system.
- Assured knowledge of the condition of the surge arresters. This experience is even more important as the age of the arrester increases. It is very satisfactory also to know whether the condition of the components in the supply system is “perfect”, or not.
- Systematic information about all measured surge arrester. It is included a comprehensive data base to give all necessary information like the status of each arrester, key data of each item, numbers of measurements, time for next measurement etc.
- The instrument should be used as a part of the regular maintenance program to increase the reliability of the supply.
- The LCM is a very reliable system for field measurements. The instrument is portable and gives fast results. The method for measurements is well accepted internationally. The LCM Is based on harmonic analysis of the leakage current using a principle called third harmonic with compensation. System for measurements of third harmonic resistive leakage current only, is considered very reliable.

V. RISK ASSESSMENT OF METAL OXIDE SURGE ARRESTERS

Based on the level and development of resistive leakage current *Ir* over time:

A. Confirming the lightning arrester counter healthiness and set max resistive leakage current to 500µA.
B. Trend analysis over time In general look for increasing trend Baseline reading when the arrester is new. If Ir increases by 300-400%, this confirms severe ageing
C. Compare to maximum recommended values from arrester manufacturers
D. Compare *Ir* for arresters of the same make and type: The three phases in a line or bay all arresters in the grid
E. Combination of step 1-3.
F. It and *Ir* are unrealistically high: Circulating currents? Check the insulated base and arrester grounding.
G. *Ir* higher than expected: Temporary heating? Consider to re-test in approx. 1 day to confirm measured value.
H. Confirmed high reading of *Ir* Monitor continuously or proceed with step 4.
I. Contact arrester manufacturer and consider replacement.

V1. TESTING STRATEGY OF METAL OXIDE SURGE ARRESTERS.

A. Classify all your MOSAs (name of substation, bay/line and phase, nameplate data (manufacturer, type designation, year/date of commissioning etc.), historical data/failure rates, importance etc.).

B. Establish threshold levels/maximum recommended levels for the resistive leakage current for each arrester type during the factory inspection or site commissioning.

C. Define action limits (good condition, satisfactory, retest/monitor continuously, replace).

D. Define measurement regularity (normal, frequent, monitor continuously, after special fault situations).

E. Define verification actions after replacement (laboratory test, dissection/inspection).

F. Evaluate measurements, action limits, regularity of measurements and verification tests to possibly improve the testing strategy.

VI. MEASUREMENTS AND ANALYSIS AT TPDDL GRID DURING 2021-2022

TABLE 1. The following bays are getting higher values during LA LCM test.

Grid	Bay	ϕ	IR (μA)	IR CORR (μA)	I TOTAL (μA)	REMARKS(On Monitoring (IR CORR)
RG-22	LINE BAY - 66KV	R	7	12	423	In this B phase LA need to test again since the ITotal shows less value.
		Y	32	59	30	
		B	280	324	128	
RG-5	LINE BAY 66KV	R	257	420	1348	R phase La need to clean the surface and remove the moisture content. value is >350μA.continues monitoring required
		Y	72	116	1293	
		B	59	95	1318	
A7	LINE BAY-66KV	R	16	27	951	In this B phase LA need to test again since the ITotal shows less value (not clarified).
		Y	12	20	941	
		B	926	941	987	
A7	PTR BAY-66KV	R	8578	13810	19999	Since the values are >500 μA need to replace the LA,to avoid tripping due to LA faulty. clean the surface and remove the moisture content for Y and B phase , ITotal is too
		Y	765	857	10654	
AIR	PTR BAY-33KV	R	12	10	777	Since the value is >500 μA in B phase need to replace the LA
		Y	10	20	709	
		B	7741	15490	19999	

CONCLUSION

This live checking of lightning arrester will helps to avoid shutdown on recommended testing method to monitor the leakage of current through the LA. For testing the equipment only required third harmonic leakage sensing devices like LCM, which helps to identify the total leakage and third harmonic leakage current. Ensure test results are should be less than 500μA in order to avoid unnecessary tripping due to failure of Lightning arrester. The obtained data on MOSA surge arrester allows control of the failure-free operation of the device by providing information on about intensity of leakage due Aging or other factor in the electrical equipment. This information makes it possible to identify those MOSAs subject to frequent or intense surge effects allowing their timely repair or replacement.

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Making of a digital rural consumer in Indian power utilities

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Abstract*— *Power utilities across India are taking various digital initiatives for their business processes and customer services. Whereas IT implementation in internal business processes have been a success for many utilities, the same cannot be said for customer service initiatives. The digital payment percentage covering all Indian utilities stands at less than 50%. The participation of rural consumers in IT driven customer service processes have been found to be very low. Consequently, majority of Indian consumers are unable to reap the benefits of the digital customer services being offered by the Indian utilities. The objective of this technical paper is to propose effective models for providing digital customer services to consumers of power utilities in India with special emphasis on rural consumers. The proposed models consist of implementation of symbol based user interfaces, feature phone based solutions, design of interfaces in local languages and incorporation of local cultural aspects in customer care solutions. The proposed models will also take into account Government of India's drive for rollout of prepaid smart metering across India and designing workflows for maximum utilization of this momentous digital initiative

Keywords—Digital Initiatives, Power Utility, Kiosk, Billing Application, Icon based user interface, Outage Management System, USSD

I. INTRODUCTION

The primary consumer centric digital initiatives taken by various Indian power distribution utilities are given below:

- Online viewing and payment of electricity bills and recharge of prepaid meters
- Sending different information like electricity bill amounts, payment information, outage information etc. via SMS and WhatsApp.
- Online application for CRM activities like new electricity connection, change requests etc.
- Online registration of complaints.
- Consumer portal via web as well as mobile app.

The success of the above initiatives is dependent upon:

- Literacy level and IT savviness of the end user
- Trust of the end users on the reliability of the digital services

Consequently, penetration of the above initiatives has not been satisfactory in rural areas across India.

II. ALTERNATE IMPLEMENTATION MODELS FOR RURAL AREAS (STRATEGIES)

Depending upon the type of the digital initiative, the following models are proposed for roll out in rural areas across the country:

- For online bill viewing/online bill payment/prepaid meter recharge/online electricity connection application/online change request/online complaint registration, Kiosks can be set up at village level/Gram Panchayat level. Icon based user interface may be used in the kiosks [1]. The icons should be representative of the corresponding functions. Minimum text (in local language) should be used in the User Interface of the kiosk.
- For online bill viewing/online complaint registration, USSD based solutions is proposed for feature phones.
- Utility mobile apps as well as consumer portals are proposed to be designed as multilingual with functional icon based user interface and minimum text.
- Public announcement systems at village level can be integrated with utility's outage management system for automated announcements related to impending outages.

III. TECHNICAL WORKPLAN

- **Kiosks**: The kiosk will run a GUI based application which will be integrated with the utility's billing and CRM engines. The kiosk will have the following icons for respective functionalities:
  - ➢ <u>Bill view</u>: On pressing this icon, option will be provided to the consumer to enter his/her registered mobile number. Automated audio support in local language will be provided during mobile number entry. The corresponding electricity bill amount will be fetched from the billing database and displayed in the screen. The same will be narrated by an automatic voice over in local language.
  - ➢ <u>Bill payment</u>: On pressing this icon, option will be provided to the consumer to enter his/her registered mobile number. Automated audio support in local language will be provided during mobile number entry.

    The payable amount against the mobile number will be fetched from billing database and displayed on the kiosk screen. The same will be narrated by an automatic voice over in local language.

    The consumer will then be prompted to continue. On continuation, he/she will be asked to provide his/her fingerprint at the scanner attached with the kiosk. The

Aadhar number of the consumer will be fetched from the billing database. The bio-metrics of the consumer as well as his Aadhar number will be provided as inputs to any Aadhar Enabled Payment System to complete the transaction. Successful transaction message as well as transaction number will be displayed in the Kiosk screen. The same will be narrated by an automatic voice over in local language. SMS/WhatsApp in local language containing the transaction information shall be sent to the consumer's mobile number.

- Prepaid Meter Recharge: On pressing this icon, option will be provided to the consumer to enter his/her registered mobile number. Automated audio support in local language will be provided during mobile number entry.

  The existing prepaid balance of the consumer will be displayed in the kiosk screen. The same will be narrated by an automatic voice over in local language.

  The consumer will then be presented with options having different recharge amounts. On choosing an option, the consumer will be prompted to continue. On continuation, he/she will be asked to provide his/her fingerprint at the scanner attached with the kiosk. The Aadhar number of the consumer will be fetched from the billing database. The bio-metrics of the consumer as well as his/her Aadhar number will be provided as inputs to any Aadhar Enabled Payment System to complete the transaction. Successful transaction message, transaction number as well as up to date prepaid balance will be displayed in the Kiosk screen. The same will be narrated by an automatic voice over in local language. SMS/WhatsApp in local language containing the transaction information and prepaid balance shall be sent to the consumer's mobile number.

- Apply for electricity connection: On pressing this icon, option will be provided to the consumer to enter his mobile number. OTP will be sent to the same mobile number which the consumer has to input at the kiosk screen. At every stage, automated audio support in local language will be provided. The subsequent activities related to new service connection shall be initiated from utility by connecting to the given mobile number.

- Apply for Change Request: On pressing this icon, the consumer will be presented with options for load change, meter change, consumer category change and tenancy change. Once the consumer presses the desired icon, option will be provided to the consumer to enter his mobile number. OTP will be sent to the same mobile number which the consumer has to input at the kiosk screen. At every stage, automated audio support in local language will be provided. The subsequent activities related to change request shall be initiated from utility by connecting to the given mobile number.

- Complaint registration: On pressing this icon, the consumer will be presented with options for No Power Complaint, Billing and Collection Related Complaint, Ethics Related Complaint, Power Theft Information and Any Other Complaint. Once the consumer presses the desired icon, option will be provided to the consumer to enter his mobile number. OTP will be sent to the same mobile number which the consumer has to input at the kiosk screen.

  After successful OTP verification, the consumer will be asked to narrate his complaint clearly (in local language) within a prescribed time (2-3 minutes). The recording will be sent to utility's servers.

  At every stage, automated audio support in local language will be provided. The subsequent activities related to complaint resolution shall be initiated from utility by listening to the recording and connecting to the given mobile number.

- **Feature Phone Solutions**: Unstructured Supplementary Service Data (USSD) based short codes can be used to implement feature phone based solutions for the following functionalities:
  - Distinct short code can be sent by a consumer from a registered mobile number to receive the billing details via SMS in local language.
  - Distinct short codes can be sent by a consumer from a registered mobile number to intimate the utility about the existence of a No Power Complaint, Billing and Collection Related Complaint, Ethics Related Complaint, Power Theft Information and Any Other Complaint. The concerned team of the utility will initiate subsequent action by contacting the consumer in his registered mobile number accordingly.

- **Revamp of utility mobile apps and consumer portals**: The following modifications are proposed for the mobile apps and consumer portals:
  - All mobile apps and consumer portals will be multi lingual.
  - The design of the portals and mobile apps will be icon based with minimum text.
  - Automated narration in regional language shall be incorporated to guide the user at every step of a transaction.

- **Outage messages through public PA system**: Utility's outage management system can be integrated with public announcement systems at village/gram panchayat levels. For any impending outage, this integration will facilitate announcement in local language by an automated voice over via the public announcement systems.

IV. APPLICATION PROGRAMMING INTERFACES (API)

In order to carry out the aforementioned workplan, the following APIs are proposed for data exchange between the billing application of the utility and the other relevant applications:

- API for Bill Value fetch from Billing System (API hosted at Billing Application end and called by kiosk application)
- API for Payable Amount fetch from Billing System (API hosted at Billing Application end and called by kiosk application)
- API for Prepaid Balance Amount fetch from Billing System (API hosted at Billing Application end and called by kiosk application)
- API for biometric data push from kiosk to billing application (API hosted by Billing Application and called by kiosk application)
- API for OTP validation (API hosted at Billing Application end and called by kiosk application)
- API for mobile number push during new electricity connection application (API hosted at Billing Application end and called by kiosk application)
- API for mobile number and change request option push during new change request application (API hosted at Billing Application end and called by kiosk application)
- API for mobile number, complaint type and complaint recording audio file push during complaint registration (API hosted at Billing Application end and called by kiosk application)
- API for fetching bill amount (API hosted at Billing Application and called by USSD application server)
- API for pushing complaint type and mobile number to utility's Billing Application (API hosted at Billing Application and called by USSD application server [2])
- API for pushing outage information to application controlling Public Announcement Systems (API hosted by application controlling Public Announcement Systems and called by utility's Outage Management System).

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Cyber War Prepardeness

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Abstract-Digital technologies are setting the pace of transformation for industries. While this is gearing up them for growth, companies must not overlook a major repercussion of this revolution – enhanced cyber security risk. India registered 1.16 million cyber security cases in 2020, which is 3 times more than in 2019 India. And the situation is not just alarming in India but across the world. While the trend was already on the rise, Covid-19 has accelerated it. In addition to that the increased adoption of interconnectedness of devices, new processes & procedures, and less-controlled work environments - have all led to an increase in vulnerabilities. This paper provides a broad knowledge of preventive methods for ensuring the cyber security in the CII through "Cyber War Preparedness" exercise. To defend against cyber-attacks, the organization must be able to understand the nature of cyber threats, their evolution, vectors and impact. In order to strengthen the cyber Security of the CII, it is imperative to identify the potential vulnerable points through red teaming exercise and decide a path of improvement and mitigating them through blue team exercise to establish a more efficient work environment for the operations of CII.
A red team/blue team exercise is a systematic approach for accessing cyber-security controls which involves simulated real-life cyber-attacks to gauge the strength of the organization's existing security capabilities and identify areas of improvement. The key advantage, is the continual improvement in the security posture of the CII by finding gaps and then filling those gaps with appropriate controls. This paper shall highlight on how red and blue team activity is planned and executed along with the associated challenges and benefits of the same.

I. INTRODUCTION

The field of cyber security is very intricate and extensive. It requires a lot of attention to protect the digital world. Private and public organizations, as well as individuals, have integrated information and communication technologies into their daily lives. Mobile telephony and other online services are gradually taking the lead in terms of means of communication and access to information.
With the increase in usage of the various online services and the ease of doing, the cyber-attacks on the CIIs are also becoming very prevalent. In recent years, we have been confronted with the rise of cyber-infractions that have an effect on varying sectors (Gas, Energy, Water, etc.) and their CII (SCADA, Communication Network, ERP, Call Center, etc.) as shown in Fig. 1. Unavailability of its CII may have a debilitating impact on the national economy, public health, security and safety of citizens. Various types of crimes are taking place over the internet be it phishing, espionage, dysfunction, fraud, destruction, or even terrorism. The key reasons of such attacks as shown in Fig. 2. Hence, it is becoming very challenging to ensure the availability, integrity, confidentiality of the CII and associated information being used, stored and transmitted. Cyberspace is now considered the fifth battlefield.

Target	Year	Root Cause
Florida Water Treatment Plant Hit with Cyber Attack	2021	Unpatched Software
Colonial Pipeline Hit by a Cyber-Attack	2021	Phishing Attack
Lupin Pharmaceutical	2020	Ransomware (Phishing Technique)
Ransomware Attack on India's Dr. Reddy's Pharmaceutical Company	2020	ransom-ware (Phishing Technique)
Norsk Hydro	2019	LockerGoga Ransomware

Fig 1: Cyber-attacks on various CII in recent years

In order to protect ourselves from the consequences and impacts of a cyber-attack, one must be cyber war prepared. Cyber War Preparedness is nothing but the process of ensuring that an organization has developed, verified, and validated its aptitude to protect against, prevent, mitigate, respond to, and recover from a potential cyber incident.

Cyber War Preparedness includes a range of activities which can be broadly classified into identification of threats and applicable scenarios, formation of red team to simulate various cyber-attacks like social engineering, penetrating the Network, Application and Infrastructure, Physical Security attacks and formation of blue team for handling the attacks and investigating the attacks. The results can be analyzed to determine how prepared an organization is to handle any type of cyber-attack.

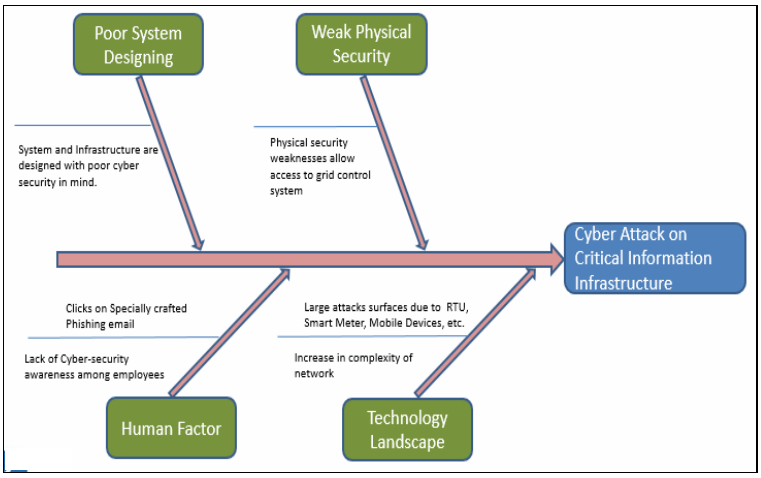

Fig 2: Cause & effect diagram of Cyber-attacks on various CII

II. CHALLENGES

Apart from the benefits of conducting Cyber War exercise, there are many challenges also associated with the initiative as shown in fig. 1. Few of the common challenges are:

1. **Getting right perspective:** Getting right perspective about the Cyber War preparedness exercise within the various stakeholders is a challenge. It is imperative to make participants understand that this is not a "pass or fail" test and the system is being exploited/ reviewed and not the individual.

2. **Coverage:** The internal simulated attackers may fail to identify and count all in-scope targets which may lead to not testing all the devices in the external perimeter. Including external service providers in the scope can be a good idea because it has been observed in previous global cyber-attacks like Solar Winds that service provider is also part of potential attack surface.

3. **Limited skillset**: Limited cyber expertise is a long-time challenge. It requires diverse skillsets like vulnerability assessment, penetration testing, social engineering, etc. to conduct effective exercise.

4. **Limited availability of resources:** Various tools are required for vulnerability assessment, attack simulation, etc. to strengthen cyber resilience. However, due to budget and size constraints, many organizations does not have the requisite tools which is an important challenge.

5. **Social engineering:** It has been observed in past cyber-attacks that there is always an element of human compromise and thus one cannot forego the importance of human behavior. Thus, compromising of human behavior intentionally or unintentionally can be envisaged challenge for Cyber War preparedness.

Fig 3: Challenges in Cyber War preparedness [6]

III. METHODOLOGY

Cyber War Preparedness identification of threats and applicable scenarios, formation of red team to simulate various cyber-attacks like social engineering, penetrating the Network, Application and Infrastructure, Physical Security attacks and formation of blue team for handling the attacks and investigating the attacks.

For an organization to be cyber war prepared, the employees in the organization have to be aware and up to date with the current cyber-attacks that are being carried out across the world. In order to isolate and act upon a threat, we first need to identify it.

Threats are basically of two types: Internal and External. [4]

1) Internal Threats-

Internal threats can come from dissatisfied employees of the company, but not limited to them. They may also be carried out by current or former subcontractors, business partners, who have or have had authorized access to an organization's network, system or data and who have deliberately used such access in a manner that has compromised the confidentiality, integrity or availability of computer systems .Historically, employees have been the greatest risk and the weakest link in an organization.

2) External Threats-

External threats are malicious attacks that come from outside, mainly from the environment in which the company operates or from any part of the world. Threat actors, hackers and attackers attempt to exploit security risks within the perimeter of your organization. These include threats to network, physical threats, piracy threats, software threats etc. All organizations with a digital presence are exposed to external threats from attackers. The most frightening attacks come from skilled and sophisticated external hackers. These attackers may find network vulnerabilities or socially manipulate insiders to bypass the network's external defenses. Attacks are generally aimed at damaging the image of their target, paralyzing or holding them to ransom. The attacker exploits the system's security weaknesses.

The cyber war preparedness will mainly consist of the following activities-

A. SOCIAL ENGINEERING CAMPAIGN

Social Engineering Campaign is a guidance for employees and employers to understand the threat of social engineering and what steps they can take to mitigate this. These Campaigns use deception to manipulate people into divulging confidential & personal information that may be used for fraudulent or malicious activities. Social Engineering Campaigns utilize a variety of methods such as phishing (spear phishing, whaling, pharming, etc.) and vishing. Phishing attacks attempt to obtain personal or sensitive information through electronic communications and have become very sophisticated. Google has registered 2,145,013 phishing sites as of Jan 17, 2021. This is up from 1,690,000 on Jan 19, 2020 (up 27% over 12 months).

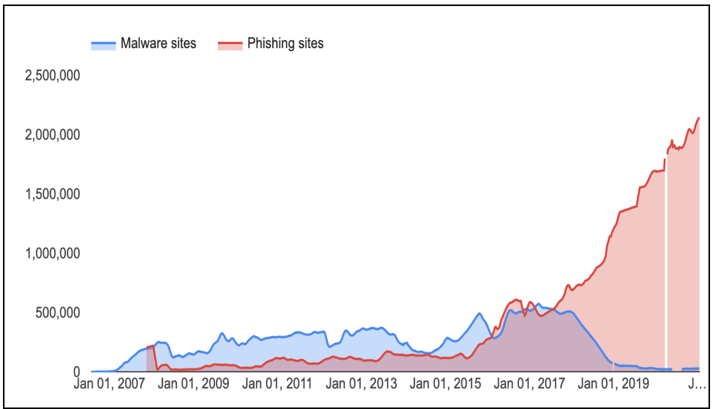

Fig 4: Trend of activities on CII deemed unsafe between January 2016 and January 2021 [7]

Why Should Social Engineering Campaigns Be Performed?

Human element is one of the most unpredictable factors, because humans are subject to manipulation, they often become a weakest link for an organization. Social Engineering campaigns provide an economical way to measure the effectiveness of the administrative controls and awareness programs that are in place to prevent unauthorized or accidental disclosure of data as a result of a social engineering attack. Performing routine social engineering campaigns also trains employees to spot these types of attempts and reinforces content provided through the security awareness training program.

B. RED TEAM FORMATION

A red team consists of security professionals who act as adversaries to overcome/bypass the cyber security controls. Red team engagement is an offensive attack simulation. Red teams often consist of ethical hackers who evaluate system security in an objective manner. They utilize all the available techniques to find weaknesses in people, processes, and technology to gain unauthorized access to assets. Red teams spend more time planning an attack then they do performing attacks. Red teams deploy a number of methods to gain access to a network. Likewise, prior to performing a penetration test, packet sniffers and protocol analyzers are used to scan the network and gather as much information about the system as possible. [1]

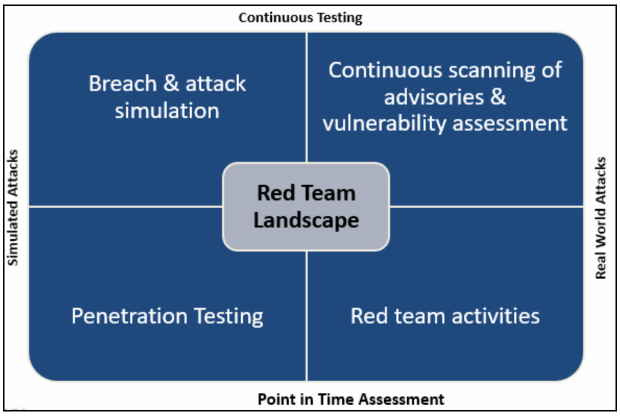

Fig 5: Red Team Landscape

The various types of information gathered by red team members includes the following:

- Uncovering operating systems in use (Windows, macOS, or Linux).
- Identifying the make and model of networking equipment (servers, firewalls, switches, routers, access points, computers, etc.).
- Understanding physical controls (doors, locks, cameras, security personnel).
- Learning what ports are open/closed on a firewall to allow/block specific traffic.
- Creating a map of the network to determine what hosts are running what services along with where traffic is being sent.

Red team activity is based on the following methodology-

1) **Reconnaissance-** It is focused on collecting as much information as possible about the target.

2) **Attack Planning-** Effective attack planning and pretexting involve preparation of the operation specific to the target taking into full account intel gathered from the reconnaissance stages.

3) **Exploitation- T**eam actively work to achieve the designated goal to "break-in" or compromise servers/apps/networks, bypass physical controls (i.e., gates, fences, locks, radar, motion detection, cameras), and exploit target staff through social engineering by face-to-face, email phishing, phone vishing, or SMS.

4) **Post Exploitation- T**he team aims to complete the mission and realize the agreed-upon objectives set by the client. Actions on objective happen through lateral

movement throughout the cyber environment as well as the physical facilities.

5) **Reporting-** Compiling the information gathered from all the phases of the engagement to provide a comprehensive report for the stakeholders that includes the information learned from OSINT/Reconnaissance, the initial plan developed in the Attack Planning and Pretexting phase, methods used and steps taken for Exploitation and Post Exploitation. The report will outline where the team was successful and where they were unsuccessful and will provide recommendations to improve the company's security posture.

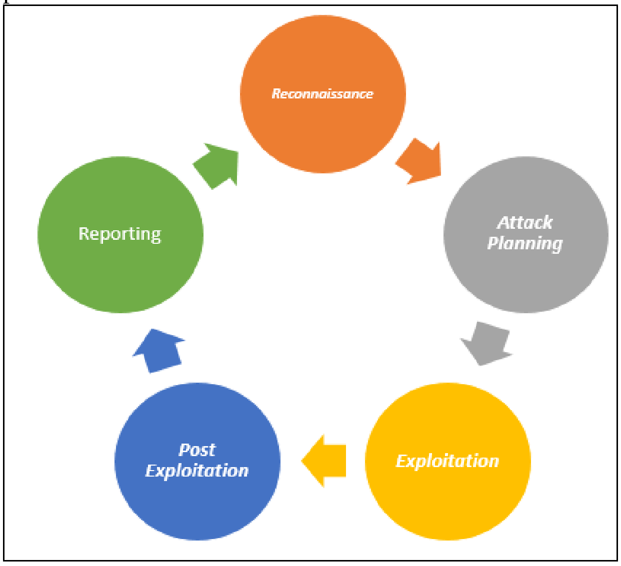

Fig 6: Red Team Methodology

Once the red team has a complete idea of the system, they need to develop a plan of action designed to target vulnerabilities specific to the information they have gathered above. After vulnerabilities are identified, a red team tries to exploit those weaknesses to gain access into your network. Once an attacker is in your system the typical course of action is to use privilege escalation techniques, whereby the attacker attempts to steal the credentials of an administrator who has greater/full access to the highest levels of critical information. It's important to note that red teams will use any means necessary, per the terms of engagement, to break into your system. Depending on the vulnerability they may deploy malware to infect hosts or even bypass physical security controls by cloning access cards.

Best Practices for Red Team:

- Plan in advance: It is imperative to plan the activities properly in advance. By planning in initial phases helps in assigning roles and deliver quality work.
- Choose tools carefully: Different tests can be performed in a variety of ways using different tools. Thus, tools should be carefully chosen taking consideration of the impact on the existing system.
- Quantitative benefits: To assess the effectiveness of any initiative, it is imperative to quantify the results.
- Controlled activity: While conducting the Red team exercise, one should understand their limits of penetration in the network. Red team member should be aware of the repercussions of their actions on the production system thus the activity should be conducted in a controlled manner instead of a destructive manner.

C. PHYSICAL SECURITY

Targeting physical security is one of the critical activities carried out by red team. The activity uncovers real-world vulnerabilities in the physical barriers and the systems that support them and which are meant to protect employees, sensitive information, and expensive hardware. Physical pen test specialists create simulated attacks that mimic the actions that criminals might take to gain unauthorized access to sensitive equipment, data centers, or sensitive information. Some of the tested barriers include doors and locks, fences, intrusion alarms, or even security guards and other employees. Social engineering techniques may be leveraged to convince well-intentioned employees to provide the building access that they should not have. They might even gain access to a meeting room and pick up credentials, access badges, or information left unattended.

PenTesters will carefully examine both the physical surroundings and internal environment to identify potential security vulnerabilities. Spotting of the weaknesses, that may exist in the established security controls, will also be done so that one can employ additional countermeasures.

D. BLUE TEAM FORMATION

A blue team consists of security professionals who have an inside out view of the organization. Their task is to protect the organization's critical assets against any kind of threat.
They are well aware of the business objectives and the organization's security strategy. Therefore, their task is to strengthen the castle walls so no intruder can compromise the defenses.

Blue teams have to establish security measures for the key assets of an organization. They start their defensive plan by identifying the critical assets, document the importance of these assets to the business and what impact the absence of these assets will have.
Blue teams then perform risk assessments by identifying threats against each asset and the weaknesses these threats can exploit. By evaluating the risks and prioritizing it, the blue team develops an action plan to implement controls that can lower the impact or likelihood of threats materializing against assets.

Senior management involvement is also crucial at this stage as only they can decide whether to accept a risk or implement mitigating controls against it. The selection of controls is often based on a cost-benefit analysis to ensure security controls deliver maximum value to the business.

The various types of activities carried out by blue team members includes the following:

- Performing DNS audits (domain name server) to prevent phishing attacks, avoid downtime from DNS record deletions.
- Conducting digital footprint analysis to track users' activity and identify any known signatures that might indicate a breach of security.
- Installing endpoint security software on external devices such as laptops and smartphones.
- Ensuring firewall access controls are properly configured and that antivirus software are kept up to date.
- Deploying IDS and IPS software as a detective and preventive security control.
- Implementing SIEM solutions to log and ingest network activity.
- Analyzing logs and memory to pick up unusual activity on the system, and identify and pinpoint an attack.
- Segregating networks and ensure they are configured correctly.
- Using vulnerability scanning software on a regular basis.
- Securing systems by using antivirus or anti-malware software.
- Embedding security in processes.

E. Formation of Vulnerability Response Team (VRT)

VRT is an experienced team to deliver vulnerability response which will determine your success in responding to an attack. It is important to continually evaluate and improve our vulnerability response practices. Proper response to the vulnerability is equally important as the identification of the vulnerability.

IV. BENEFITS

- **Identification of potential weaknesses**: Red team activities are able to identify gaps and potential weaknesses in organization's cyber resilience practices. [3]

- **Strengthening cyber resilience posture**: The prime objective of Red team test is to enhance organizational cyber resilience posture by developing realistic test scenarios and thus developing better threat intelligence.

- **Roadmap for cyber security practices**: Test results can act as a baseline measure for the management to develop roadmap for implementing cyber security practices. [5]

V. CONCLUSION

The methodology is prominence for the large and critical organizations. Cyber War preparedness is an effective way to enhance cyber resilience of the organization. It provides the systematic approach towards educating workforce and accessing the effectiveness of security controls. Red team and Blue team activities foster closer corporation among different groups. Companies will face new types of attacks, and it is essential to put in place the right foundation to protect organization by envisaging the cyber-attacks. [2]

VI. WAY FORWARD

Given that red team testing approaches are still evolving, it is important that authorities continue to assess the effectiveness of their controls and use the lessons learned from each test to improve the overall cyber resilience of the organization. Need to enhance cooperation with other relevant authorities and parties in order to enable effective implementation of the methodology.

VII. ABBREVIATIONS

DNS: Domain Name Server

IDS: Intrusion Detection System

IPS: Intrusion Prevention System

IT: Information Technology

OS: Operating System

OSINT: Open Source Intelligence

SIEM: Security Information and Event Management

SMS: Short Message Service

Tata Power-DDL: Tata Power Delhi Distribution Limited

VRT: Vulnerability Response Team

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Digitized grid OT Cyber Security and network behavior monitoring

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Abstract

A digitized grid is a fully automated electricity network, which monitors and controls all its physical environments of critical electrical infrastructure which being able to supply energy in an efficient and reliable way. As the power grid increasingly uses modern computational platforms, field devices, and communication networks, it gains access to new and higher-resolution data. New ways of measuring, analyzing, and communicating data support new capabilities for enhanced grid reliability, resiliency, and efficiency. These deployment of grid network devices generate a large amount of information exchanged over various types of communication networks. The implementation of these critical systems will require appropriate OT (Operational Technology) cyber-security measures and network analysis. The purpose of network traffic characterization is to explore unknown patterns in different types of network communications to help improve many aspects of the network a) stable is the communication based on different configurations b) different set of traffic pattern observe in different vendor equipment. c) Trends in the network traffic of same configuration in different grids d) Type of information gathered from the traffic (RTU, IED, Meters, Switch, Firewall, Gateways etc.) characterization to identify threat and vulnerability in grid network

Introduction

The technological shift took place with the introduction of “Intelligent Electronic Devices”. IEDs revolutionizes the conventional Grid substations monitoring and control These IEDs performs various complex functions like:-

- Advanced numerical, differential, distance Protection of Grid Electrical equipment’s and reporting of the same to master SCADA.
- Digitization of Electrical Processes.
- Centralized remote Monitoring & Controlling of Grid equipment’s & networks.
- Enhanced Transformers Monitoring and remote OLTC operations for voltage optimization.

The integration of cyber and physical systems is making major improvements in the capability to Monitor and operate the grid, as well as offering improved protection. But at the same time, it is also introducing new weaknesses. To reduce existing vulnerabilities and minimize the introduction of new ones, cyber and physical expertise must be integrated into all stages of the research develop-build-operate continuum. Additional integration is needed when existing systems are upgraded or repaired, not just when new technology is introduced. This is because such changes can introduce

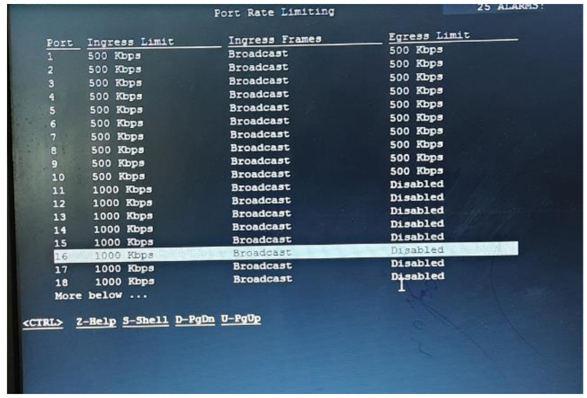
unrecognized vulnerabilities if both overall systems and components are not evaluated before changes are made.
Here we discusses methodologies involved to enhance cyber security for OT network i.e. Substation networks which consists of RTU, data concentrator, numerical relays and IED's.

Approach

Stable communication based on different configurations at switch and RTU.

The Utility grid is moving towards digitalization and monitoring of grid through a control center, hence grid communication and its stability are very important for monitoring and controlling of substation.

But it has been observed recently that frequent grid communication fail and disruption in utility network due to broadcast storm or it may be said as due to sudden change in network. But now it data traffic can be controlled in utility network by applying **port rate limit** at switch level. In utility grid manageable switch can be configured with limit on egress data traffic and egress data traffic. Controlling traffic in a network is like an art first need to investigate the reason of broadcast storm in the network and understanding the topology play important role. The network and data pattern can be collected through network monitoring tools then same can be utilized for network troubleshooting.



Port Rate Limiting

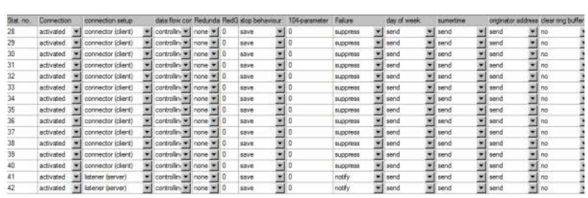
25 ALARMS!

Port	Ingress Limit	Ingress Frames	Egress Limit
1	500 Kbps	Broadcast	500 Kbps
2	500 Kbps	Broadcast	500 Kbps
3	500 Kbps	Broadcast	500 Kbps
4	500 Kbps	Broadcast	500 Kbps
5	500 Kbps	Broadcast	500 Kbps
6	500 Kbps	Broadcast	500 Kbps
7	500 Kbps	Broadcast	500 Kbps
8	500 Kbps	Broadcast	500 Kbps
9	500 Kbps	Broadcast	500 Kbps
10	500 Kbps	Broadcast	500 Kbps
11	1000 Kbps	Broadcast	Disabled
12	1000 Kbps	Broadcast	Disabled
13	1000 Kbps	Broadcast	Disabled
14	1000 Kbps	Broadcast	Disabled
15	1000 Kbps	Broadcast	Disabled
16	1000 Kbps	Broadcast	Disabled
17	1000 Kbps	Broadcast	Disabled
18	1000 Kbps	Broadcast	Disabled

More below ...

<CTRL> Z-Help S-Shell D-PgDn U-PgUp

Recently it has been observed in utility grid that all IEDs communicating on IEC-104 Protocol were auto rebooting after 5 mints due to some setting in RTU as shown in below figure. There is some option by default in RTU for monitoring failure of IEDs on IEC-104 protocol, if setting is notify RTU continuously send signal to updates the status of IEDs that causing slave device hang and choking in network occurred which also result in loss of communication. After setting modification to suppress the RTU and IEDs got stable but it took us time to understand the reason of getting reboot device periodically.so it is advised to look into some default setting of RTU or IEDs which need to modify as per our requirement otherwise it will contribute in failure of devices.



Stat. no.	Connection	connection setup	data flow cor	Redunda	RedG	stop behaviour	104-parameter	Failure	day of week	sumertime	originator address	clear rng buffer
28	activated	connector (client)	controllin	none	0	save	0	suppress	send	send	send	no
29	activated	connector (client)	controllin	none	0	save	0	suppress	send	send	send	no
30	activated	connector (client)	controllin	none	0	save	0	suppress	send	send	send	no
31	activated	connector (client)	controllin	none	0	save	0	suppress	send	send	send	no
32	activated	connector (client)	controllin	none	0	save	0	suppress	send	send	send	no
33	activated	connector (client)	controllin	none	0	save	0	suppress	send	send	send	no
34	activated	connector (client)	controllin	none	0	save	0	suppress	send	send	send	no
35	activated	connector (client)	controllin	none	0	save	0	suppress	send	send	send	no
36	activated	connector (client)	controllin	none	0	save	0	suppress	send	send	send	no
37	activated	connector (client)	controllin	none	0	save	0	suppress	send	send	send	no
38	activated	connector (client)	controllin	none	0	save	0	suppress	send	send	send	no
39	activated	connector (client)	controllin	none	0	save	0	suppress	send	send	send	no
40	activated	connector (client)	controllin	none	0	save	0	suppress	send	send	send	no
41	activated	listener (server)	controllin	none	0	save	0	notify	send	send	send	no
42	activated	listener (server)	controllin	none	0	save	0	notify	send	send	send	no

Different set of traffic pattern observe in different vendor equipment:

Now a days utility has different makes and module devices in its OT network, which traffic pattern is depends upon configuration and settings and based on these parameters impact can be seen in OT network.

I) GE Make

Ii) Siemens Make

Iii) ABB Make

IV) Schneider Make

V) Other OEM make

In various utilities OT system above makes devices are running, different makes has different configuration depends on purposes and limitation. Now a day most devices are on IEC-61850 protocols which use MMS or GOOSE protocols for communications based on requirement. GOOSE protocols broadcast data to all in networks, hence its increase traffic in the network. In MMS protocols server and client communication takes place which has limited data traffic pattern that can be captured from wire shark (network monitoring tools) and some snapshot of wire shark has been shown below for better understanding. For same time duration different devices has different data traffic captured. If data traffic increased more than limitation its communication also affected.

Details

File

Name:	C:\Users\mohamid.khan\Desktop\WIRESHARK DATA\before at rani bagh.pcapng
Length:	1498 kB
Hash (SHA256):	4b52bc33d88f81f2787f4dfa028ea506e14f63d2dc691a4f96c4250897a335c8
Hash (RIPEMD160):	30b8905c63da81ede933afb6d6533582025dd4ae
Hash (SHA1):	efbd29fa5a34d396ad7d28d9159240b08d9e450e
Format:	Wireshark/... - pcapng
Encapsulation:	Ethernet

Time

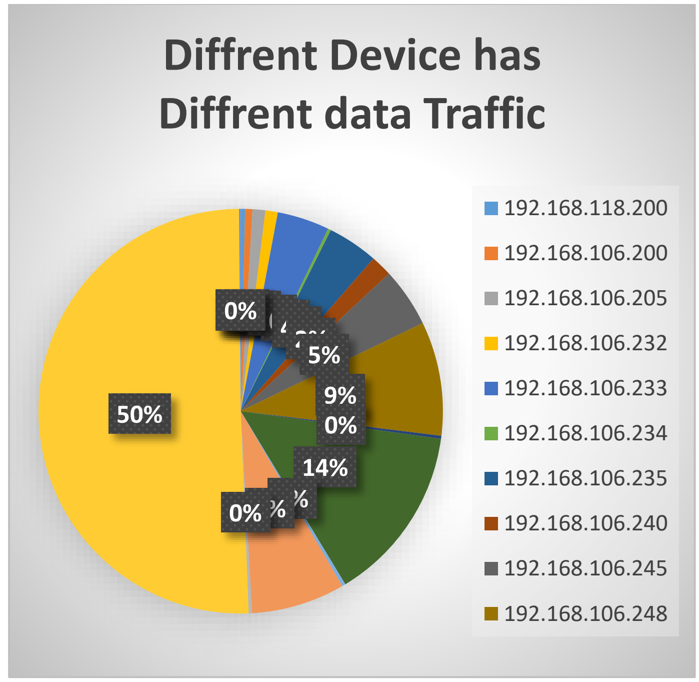
First packet:	2021-10-01 16:14:56
Last packet:	2021-10-01 16:17:05
Elapsed:	00:02:09

Capture

Hardware:	Intel(R) Core(TM) i5-5200U CPU @ 2.20GHz (with SSE4.2)
OS:	32-bit Windows 7 Service Pack 1, build 7601
Application:	Dumpcap (Wireshark) 3.0.1 (v3.0.1-0-gea351cd8)

Interfaces

Interface	Dropped packets	Capture filter
Local Area Connection	0 (0 %)	none



Different data pattern of RTU and IEDs						
Topic / Item	Count	Average	Rate (ms)	Percent	Burst rate	Burst start
192.168.118.200	63		0.0008	0.65%	0.04	21.363
192.168.106.200	106		0.0013	1.10%	0.04	30.131
192.168.106.205	185		0.0022	1.91%	0.06	82.406
192.168.106.232	179		0.0021	1.85%	0.06	2.517
192.168.106.233	754		0.009	7.80%	0.27	51.236
192.168.106.234	44		0.0005	0.45%	0.04	15.09
192.168.106.235	731		0.0087	7.56%	0.24	50.549
192.168.106.240	310		0.0037	3.21%	0.06	2.517
192.168.106.245	854		0.0102	8.83%	0.25	50.165
192.168.106.248	1649		0.0196	17.05%	0.22	1.837
192.168.106.249	43		0.0005	0.44%	0.04	8.889
192.168.106.250	2562		0.0305	26.49%	0.61	72.009
192.168.106.251	50		0.0006	0.52%	0.04	26.296
192.168.106.252	1354		0.0161	14.00%	0.16	8.281
192.168.106.253	48		0.0006	0.50%	0.04	27.584
192.168.106.254	9136		0.1088	94.47%	0.65	51.466
192.168.106.255	24		0.0003	0.25%	0.02	5.913

	A	B	C	D
169	164	ERROR	23:58.8	BUSCOUPLER-IED 18- Read DataSet Failed Error Code :27160 - see mms.log
170	243	ERROR	23:58.8	BUSCOUPLER-IED 18- IED Failed - Status set to Offline
171	1	INFO	23:58.7	RG2_CKT2-IED 9 Received response timeout on activity 0xb387a0e4 type 6 TXN 53 NetInfo :0xa661690
172	164	ERROR	23:58.7	RG2_CKT2-IED 9- Read DataSet Failed Error Code :27160 - see mms.log
173	243	ERROR	23:58.7	RG2_CKT2-IED 9- IED Failed - Status set to Offline
174	1	INFO	23:57.7	RG4_CKT1-IED 7 Received response timeout on activity 0xb3878884 type 6 TXN 53 NetInfo :0xa66045c
175	164	ERROR	23:57.7	RG4_CKT1-IED 7- Read DataSet Failed Error Code :27160 - see mms.log
176	243	ERROR	23:57.7	RG4_CKT1-IED 7- IED Failed - Status set to Offline
177	243	ERROR	23:57.6	RG2_CKT1-IED 8- IED Failed - Status set to Offline
178	1	INFO	23:57.6	RG2_CKT1-IED 8 Received response timeout on activity 0xb387826c type 6 TXN 53 NetInfo :0xa660800
179	164	ERROR	23:57.6	RG2_CKT1-IED 8- Read DataSet Failed Error Code :27160 - see mms.log
180	1	INFO	23:57.6	PTR1_BCPU-IED 1 Received response timeout on activity 0xb387763c type 6 TXN 53 NetInfo :0xa65fd14
181	164	ERROR	23:57.6	PTR1_BCPU-IED 1- Read DataSet Failed Error Code :27160 - see mms.log
182	243	ERROR	23:57.6	PTR1_BCPU-IED 1- IED Failed - Status set to Offline
183	1	INFO	23:57.4	PTR2_BCPU-IED 6 Received response timeout on activity 0xb3877024 type 6 TXN 53 NetInfo :0xa65e73c
184	164	ERROR	23:57.4	PTR2_BCPU-IED 6- Read DataSet Failed Error Code :27160 - see mms.log
185	243	ERROR	23:57.4	PTR2_BCPU-IED 6- IED Failed - Status set to Offline
186	1	INFO	23:57.3	NANGLOI_CKT2-IED 10 Received response timeout on activity 0xb3877c54 type 6 TXN 53 NetInfo :0xa6600b8
187	164	ERROR	23:57.3	NANGLOI_CKT2-IED 10- Read DataSet Failed Error Code :27160 - see mms.log
188	243	ERROR	23:57.3	NANGLOI_CKT2-IED 10- IED Failed - Status set to Offline

Above logs is taken for reference from RTU to shows that devices communication toggling due to network traffic is unstable.RTU not getting data from IEDs on time due to network congestion.

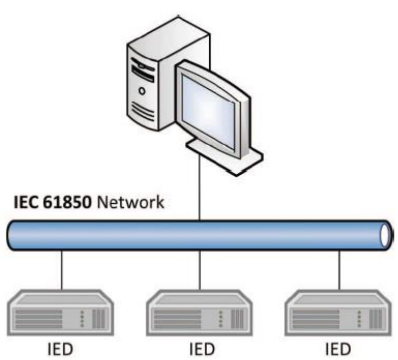
Type of information gathered from the traffic (RTU, IED, Meters, Switch, Firewall, Gateways etc.) characterization to identify threat and vulnerability in grid network:

There is some standard rule of protocol for communication between RTU and IEDs.But it has been observed that due to some bad setting unwanted transaction of data take place in network which hampered performance of RTU and IEDs.

For smooth communication between RTU and IEDs on IEC-61850 protocol we follow these configuration in RTU and it has made good improvement or smooth transaction in network.

RTU Database Refinement Checklist

S. No.	Task Description
1	IEC-61850 Analog RCB Integrity setting "20000ms". Trigger Options settings should be "Data Change - No, Data Update - No, Quality Change - Yes, Integrity - Yes"
2	Analog Values SOEs to be unchecked.
3	IEC-61850 devices GI to be configured as per performance requirement. Not less than 60 Seconds.
4	After completion of activity analog values updation to be randomly checked atleast for all Exchange Feeder Ckts
5	Cyclic Analog Transmission to be configured as 20 seconds.
6	IEC-61850 DI signals settings should be "Data Change - Yes, Data Update - No, Quality Change - Yes, Integrity - No".
7	Communication Fail signal for all devices to be mapped.
8	Time Synchronization of all IEDs
9	RTU splitting if required
10	No scrap files in RTU database



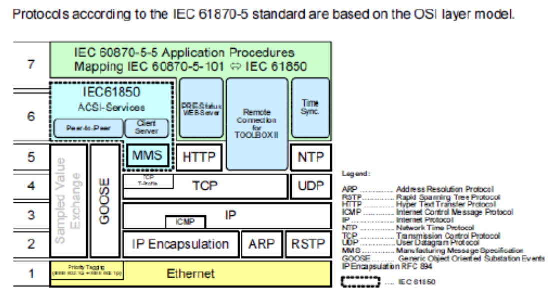
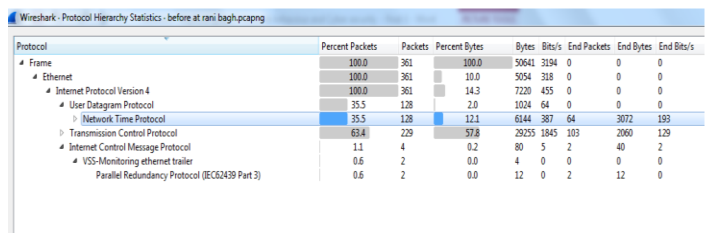
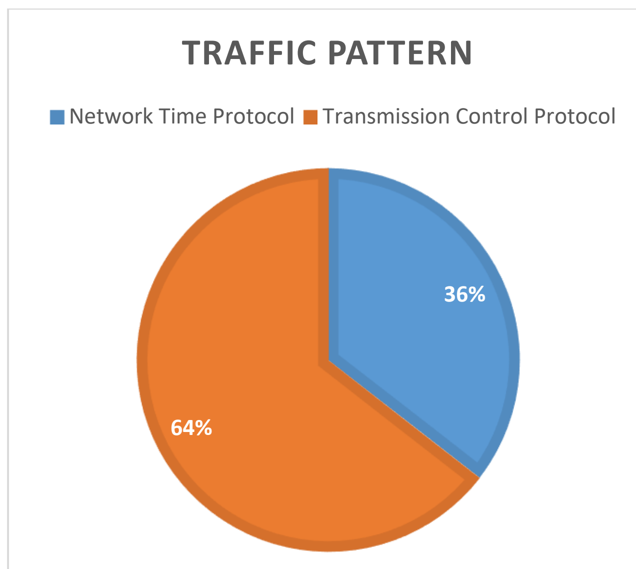


Fig: Communication in Ethernet network based on IEC 61850



Wireshark - Protocol Hierarchy Statistics - before at rani bagh.pcapng

Protocol	Percent Packets	Packets	Percent Bytes	Bytes	Bits/s	End Packets	End Bytes	End Bits/s
Frame	100.0	361	100.0	50641	3194	0	0	0
Ethernet	100.0	361	10.0	5054	318	0	0	0
Internet Protocol Version 4	100.0	361	14.3	7220	455	0	0	0
User Datagram Protocol	35.5	128	2.0	1024	64	0	0	0
Network Time Protocol	35.5	128	12.1	6144	387	64	3072	193
Transmission Control Protocol	63.4	229	57.8	29255	1845	103	2060	129
Internet Control Message Protocol	1.1	4	0.2	80	5	2	40	2
VSS-Monitoring ethernet trailer	0.6	2	0.0	4	0	0	0	0
Parallel Redundancy Protocol (IEC62439 Part 3)	0.6	2	0.0	12	0	2	12	0



SNTP Traffic in OT network:

Time synch is very important in SCADA communication for correct time stamping of events. There are various methods for time synch but most of devices in utility using SNTP protocol for time synch of device and all devices get synch with its master as per standard. Once devices synch with its master should not continuously send request for time synch. But it has been observed in utility network that due to wrong setting for SNTP parameter devices continuously sending request to its master for time synch which causing unnecessary data traffic in the network. Also due to fast polling from the server memory consumption increasing and when not getting data on each request hanging issue found in device and its getting faulty in some cases.with help of network monitoring tools which is openly available wire shark the reason of device failure is rectified and after right configuration issue is resolved.

Cyber security and finding Vurnablity in OT networks:

SCADA system play the most important roles in the remote monitoring system. The development of the communication system of the new substations like Digital substation Automation increases the nodes in a data communications network, which increases the number of possibilities to connect to the SCADA system. In designing the new substation, no one cares for cyber security. Due to various tools open in the market for exploitation of network anyone can easily hack the system so utility need to be very careful now a days.

The most common external threats that is encounter on a daily basis, are automated attacks through viruses, Trojans and software vulnerabilities on the victim workstation. Often, the main purpose of such attacks is to increase workstations botnet by another network. These risks are relatively easy to detect and disposal through the use of current software and virus definition subscription and spyware. It should however be borne in mind that many viruses can also lead to unstable operating system, and even loss of data integrity on an infected machine. Another type of external threats are coordinated direct attacks aimed at the acquisition or modification of the data on the victim machine. These attacks are usually performed using security vulnerabilities 0-day type like log4j, and the gaps caused by incorrect configuration. Due to not updated firmware of OT devices Vurnablity are available in network which easily can be exploite.They relate to greater extent machines available in public IP addresses, such as servers. From the perspective of technology, digital stations, a particular threat can be a combination of direct and automatic type of attack. An example of such a threat is a worm Stuxnet, discovered in 2009 in the Iranian nuclear power plants. This virus, after being infected machine tries to access and modify the software PLC SCADA system specific manufacturer. This is an example of both the automatic threat difficult to be detected by antivirus software because of the narrow specialization, while the risk of direct taking into account the known weaknesses affected system (in this case to leave the default password to configure PLC). Despite the fact, that the creation of such a worm requires a significant financial effort, should take into consideration this type of threat. The basic tool used to protect against attacks are:

The Firewall - software or hardware with dedicated software. It allows you to filter so that only pass comply with certain rules of network traffic. Most often associated with blocking access from the external network to the internal or local workstation. Another important, but often overlooked because of the cumbersome configuration function is to block outgoing traffic. It allows you to protect data before leaving a local area network / workstation.

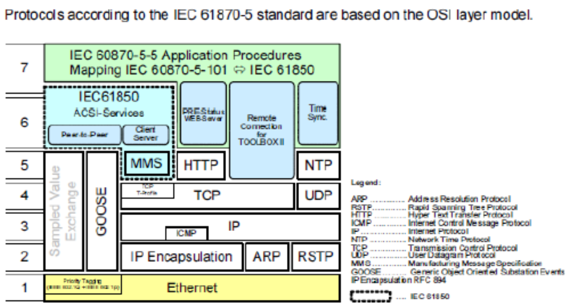


Fig-Digital communication in power Line network as OSI model concept

A very important Function is to monitor and record the most important events in the log. Correct firewall configuration possible to refute the known types of attacks software patches (called. patch) -Amendments made available by the software manufacturer or operating system. It is very important to maintain the system and programs possible date versions. Significant gaps due to the type 0-day, which are not known on a large scale. With time, however, access to knowledge on how to apply such a gap becomes simple, and the outdated version PC can easily become the victim of the attack.

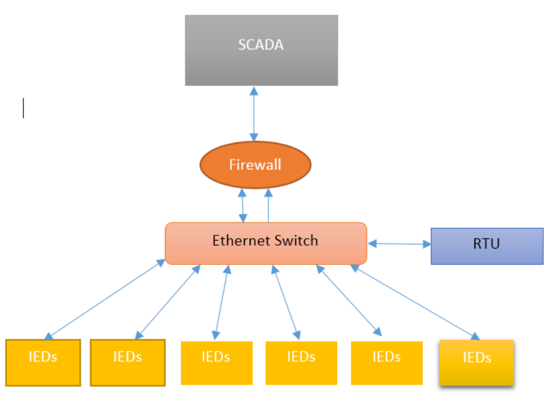
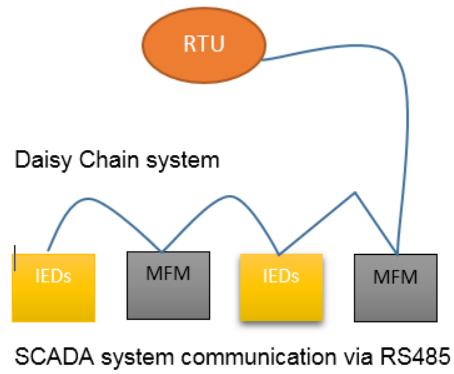


Fig: typical Grid communication



Some good Practices for Securing Our Network:

In order to secure the network, monitoring network traffic must be kept into account in policy. For this purpose, you can use event logs obtained from the previously described firewall. More complex and more filtered information is available through intrusion detection system (IDS), it provides alert or we can set alert for anomalies in the network.in starting days firewall observed the network behavior and the after implementation it makes base and other than base data it provides alert. Which greatly facilitates the observation of anomalies in network traffic. In the case of active network devices, ie. Network switches, you should use the solutions divisions, with trouble reporting software, eg. This facilitates diagnosis in case of incorrect operation of the network and significantly reduces the time to solve the problem. In order to verify proper operation in mechanisms should periodically perform penetration tests involving the simulation of attacks and system errors. In this way, you can get information whether all known methods of attacks are captured by network protection mechanisms.SNMP assumes the existence of two types of devices in a managed network: managing and managed. The device (computer) is the manager (called NMS - Network

Management Station) when it is running the appropriate program manager SNMP (SNMP manager). The device is managed if the program runs on an SNMP agent. Advantages and disadvantages. SNMP is currently the most popular protocol for managing networks

Its popularity is due to the following advantages:

• Relatively small additional load on the network generated by the protocol itself,

• a small amount of custom commands lowers the cost of devices supporting it,

• Low costs implementation to operation.

The main disadvantage of SNMP: inability to ensure the security of transmitted data (SNMP first and second version).

Firmware Update Details: one routine basis it is required to see if there is a new firmware version for the IEDs. After the security configuration in the IEDs, one should make a copy of the settings and store it in a safe place in case of a forced device settings reset.

Firewall Feature of Devices: an IEDs has an inbuilt firewall which should be activated and configured properly to allow authorized users to access a home network, it is advisable to create a black list for unauthorized websites, services etc. Also a firewall should be configured not to reply to ping requests to prevent exposing a home network to intruders, thus firewall should be used to control both incoming and outgoing traffic.

It's evident then that there's no simple solution to securing our critical infrastructure. The process is going to take a lot of time and effort, as well as some very careful planning. A combination of three strategies – policy and technologies designed for industrial security, best practices, and a focused effort – is effective in mitigating the risk of attacks on OT systems.

Conclusion/Benefits

It is the self-responsibility of Utility to develop skill set and analyse different set/pattern of network behaviour so that proper fine tuning in the network shall be done. Time to time OT firewall patches need to update to ensure the latest signatures.

Choosing the approach and standards generally depend on the Utility's understanding and acceptance for the implementation of cyber security at up to Grid level. The reward for the effort will be maximum protection against process disruption, safety incidents and business losses from modern cyber security threats.

Abbreviations

1. TPDDL: TATA Power Delhi Distribution Limited
2. OT: Operation Technology
3. SCADA: Supervisory Control and DATA Acquisition System
4. RTU: Remote Terminal Unit
5. OT: Operations Technology
6. IT: Information Technology
7. NCIIPC: National Critical Information Infrastructure Protection Centre
8. SNMP: Simple Network Management Protocol
9. SSL: Secure Socket Layer
10. ICS: Industrial Control System
11. OEM: Original Equipment Manufacturer
12. IED: Intelligent Electronic Device
13. IP/MPLS: Intelli Protection/ Multi Packet Label Switching
14. Syslog: System Logs
15. DPI: Deep Packet Inspection
16. IIoT: Industrial Internet of Things

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IEC-62443 Standards Understanding IEC 62443 | IEC

AI-Powered Customer Segmentation for Utilities: Congregation of Customers through their Holistic Profile

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***Abstract*—The demand for customer-centric sophisticated solutions has been rapidly increasing across the globe. With growing awareness, end-consumers expect impeccable service as well as accurate and personalized insights into the product they're consuming. Hence, it becomes imperative that the data-driven models are approached in a way that's easy to explain to individuals while simultaneously being algorithmically flawless.**

This paper explores techniques using AI to aggregate similar homes based on their demographics and derived attributes from smart meter data (non-intrusively). We deploy statistical techniques to understand user distribution and machine learning approaches that follow a top-down order to cluster similar homes. We use advanced feature engineering, classification, and unsupervised clustering algorithms to unlock this potential.

This customer-centric approach can be meaningfully used by utilities in multiple ways such as increasing smart meter adoption rates, load shaping, and demand-side management through efficient and personalized rate designs (time of use tariffs), educating customers about consumption patterns, and most importantly driving energy-efficient behavior for a greener planet.

Keywords—Customer Lifestyle and Engagement, Demand Side Management, Rate Plan Design, Artificial Intelligence and Machine Learning

I. Introduction

Utilities are striving towards implementing methods that would empower them to execute effective personalization and targeting programs to enhance customer experience [1, 2].

A consumer's energy usage behavior depends not only on socio-economic, geographical, and environmental factors but also their ever-evolving lifestyle patterns. Here, we describe a dynamic clustering approach that utilizes consumers' AMI data to derive consumer-level insights in the form of customer's lifestyle features, including their activities, interests, and demographics. These derived lifestyle features, home-level characteristics, and appliance-level details are used to similar group kinds of homes for multiple business use-cases-level through a segmentation process.

II. Challenges

Traditional methods such as mass survey and manual data collection are time-consuming, static and may not be statistically representative of the population. This leads to reliance on third-party data providers that do not offer a complete view of customer profile insights like lifestyle, outdoor timings, etc. In addition to the challenges faced in devising the complete profile of the consumer, the existing segmentation approaches built on top of such features might fail to serve utility use-cases.

Using AI models is an effective approach for segmentation that can derive appliance usage signatures and consumer behavior using smart meter energy data. These assists in creating a reliable, dynamic, scalable and hyper-personalized segmentation solution for the entire population.

III. Main Contents

This section explores the workings of this generalized framework in great depth. Using AMI consumption data, we build 360 degrees customer profiles on their lifestyle patterns, usage trends, etc. We then utilize these derived lifestyle features along with appliance level information to aggregate similar homes.

A. Advanced Metering Infrastructure(AMI) data

AMI enables two-way communication between electric utilities and households using smart meters. This allows utilities to record the energy demand of a house at specific intervals.

B. Customer Profiling

Each customer's energy data incorporates a wide variety of information associated with their daily energy behavior, and lifestyle. A crucial determinant of a customer's segment is the selection of attributes. We have demonstrated an approach to calculate an exhaustive set of non-intrusive energy data-driven customer features that covers required facets for the intent of segmentation.

- **Seasonal Energy Profile** - Variation in raw energy usage encompasses valuable details about a consumer's behavior, vacation patterns, and lifestyle choices. This paper employs k-means clustering to identify the seasonal demand curves of the user.

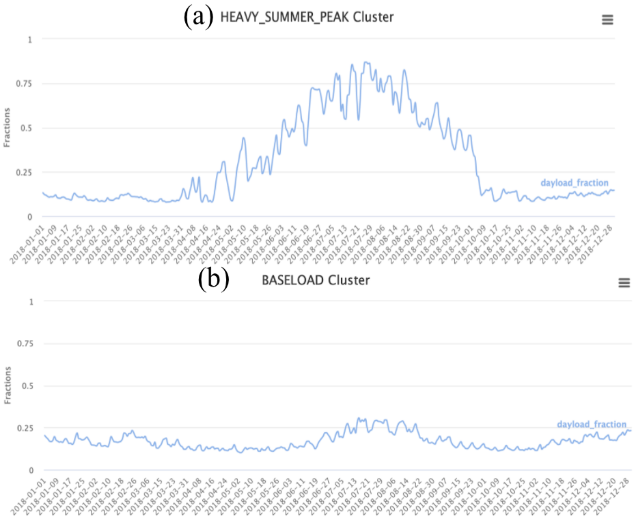

Fig 1. Demonstrates seasonal energy profile for two different homes. The homes belonging to category (a) consume heavily in summers, while the category (b) homes have similar consumption levels throughout the year. Segregation of similar kind will assist electric utilities to design personalized seasonal rate plans based on the lifestyle of their customers.

- **Daily energy profile** - Variations in daily consumption provide fine details on the consumer's usage preferences. A night owl person , with most of their consumption happening at night, will have a different lifestyle and potential for meeting a utility requirement compared with an early bird person.

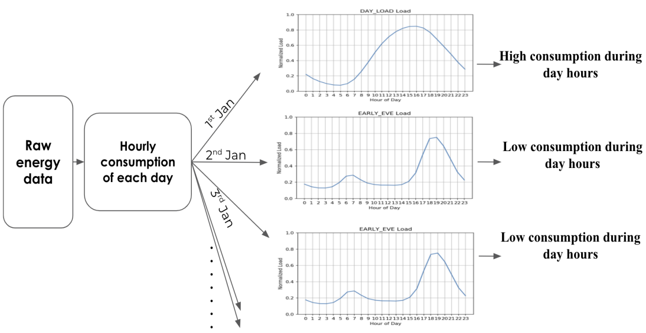

Fig 2. It demonstrates the tagging of daily load type for all the days of the year. On 1st Jan, the user was considered to be having peak demand during noon hours, while on other days, the demand peaked after 5pm. Segregation of days based on demand pattern enables electric utilities to design personalized TOU rate plans based on the lifestyle of their customers.

- **Occupancy profile** - Extending the analysis at the sampling rate level provides greater detail about the occupancy and inferences on time of day the user is likely to be present at home while maintaining customer privacy.

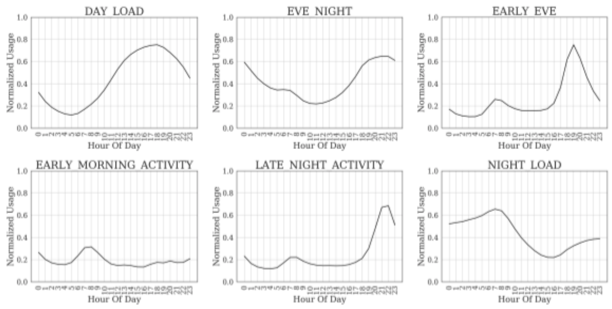

Fig 3. All dominant load profiles for users of Nevada region

- **Lifestyle profile** - Other than seasonal and behavioral signatures, raw energy data also carries lifestyle information including weekend habits, sleep hours, office-goers, etc.

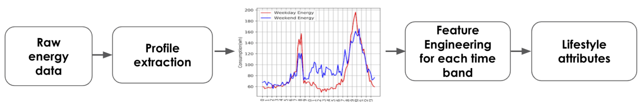

Fig4. Algorithmic flow of lifestyle profile calculation

Profile derived from Electricity usage

Seasonal Energy Profile

Consumption level : Low
Seasonal Pattern : High summer usage

Daily Energy Profile

Peak usage hours : 5pm to 8pm
Appliance usage in peak hours: HVAC
Reducible appliances : HVAC
Shiftable appliances : -

Occupancy Profile

Family type: Working adults
Office going hours : 8am to 5pm
Weekend occupancy : Stays at home on weekends

Lifestyle Profile

Lifestyle : Office goer
Active/Dormant profile : Dormant user
Wakeup time : 6:30 am
Sleep time : 11 pm

Fig 5. Profile derived using AMI electric usage data of the household

C. Customer Segmentation

We group users based on derived lifestyle-specific features as explained in section B. Out of all available customer characteristics, the segmentation framework intelligently decides on the choice and hierarchy of these derived features.

We employ unsupervised machine learning clustering techniques, probabilistic modeling, and statistical methods to extract required profile information and segment households. The algorithm is divided into multiple steps:

- **Feature extraction** - Users are perceived as 'similar' on many characteristics like Geographical proximity, Dwelling Type, Appliance Ownership, Lifestyle patterns, etc. The appliance-level features are devised from the state-of-the-art 'disaggregation' solution [4] that discerns consumption usage of appliances like electric vehicles, ACs, space heaters, etc.

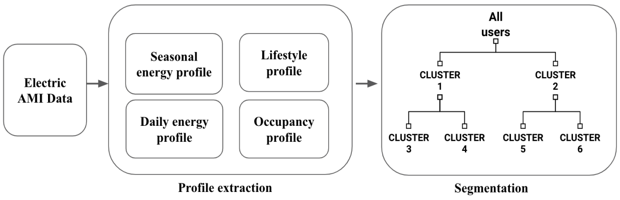

Fig 6. Two stages of solution architecture: Profiling and segmentation stage

- **Feature Pre-processing** - The derived features are dynamically bucketed into categories based on their frequency distribution.
- **Feature hierarchy** - Feature selection is a crucial step of the segmentation process. The order of attributes is driven by clustering objectives, attaining the most differentiated clusters, and sanity checks depending on the objective. For example, Figure 7 presents the segmentation process to compare household monthly energy consumption to fulfill a utility's objective.

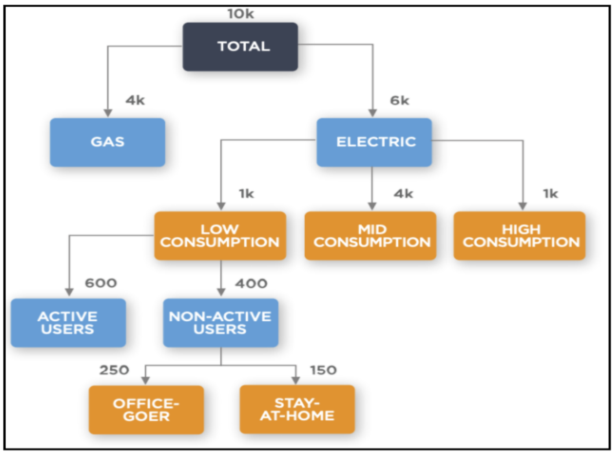

Fig 7. The image depicts a typical flow of segmentation of customers based on the features captured through customer profiling. This examples starts with 350k customers and get segmented into small homogenous groups with defined stopping criteria.

IV. Results and Discussion

A. Customer Profiling

We used smart meters data of 11k American residential consumers with AMI data of sampling rates of 15, 30, and 60 minutes.

User Classes	True Labels (316 Total)	Performance Acc.	Prec.	Rec.
Office-Goers	104	0.87	0.81	0.80
Stay-at-Home	212		0.90	0.91
Weekend Warriors	49	0.93	0.76	0.80
Non-Weekend Warriors	267		0.96	0.96

Table 1. Demonstrates the accuracy of customer lifestyle profile. (a) First section depicts the accuracy of distinguishing between office-goer vs stay-at-home customers. (b) Second section depicts the accuracy of distinguishing between weekend warriors (Stay at home on weekends) vs non-weekend warriors (Prefer to stay out on weekends)

B. Lifestyle analysis during COVID lockdown

We had investigated the change in consumers' daily usage behavior before and after COVID-19 lockdown. We observed that cluster fractions for day load had increased significantly in post-COVID period (Fig 8), as consumers started spending more time at home during daytime due to lockdown restrictions. Further, picked all the office goer users (derived using customer profiling) to analyze the change in usage behaviors compared to stay at home consumers. We saw a rise in day load for office goer consumers compared to stay at home consumers depicted in Fig 9. This clearly shows the difference in behavior due to people working from home.

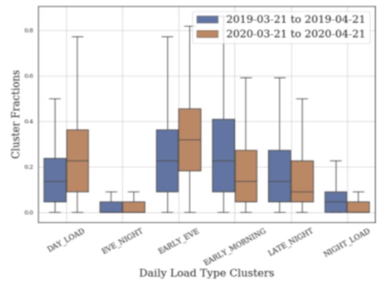

Fig 8. Change in day load distribution due to covid lockdown

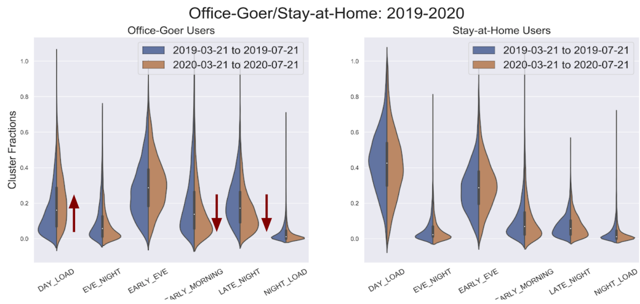

Fig 9. Change in behavior of Office goer and stay at home users

C. Similar Home Comparison

A user-set of size ~350k belonging to the South Carolina region is picked for the objective of comparing households with similar homes to identify inefficient users. The users are grouped based on appliance ownership, dwelling type, and lifestyle. The frequency distribution of consumption within each cluster represents a Gaussian distribution which indicates a real-world scenario where most users are concentrated around the mean with two extremities at both ends.

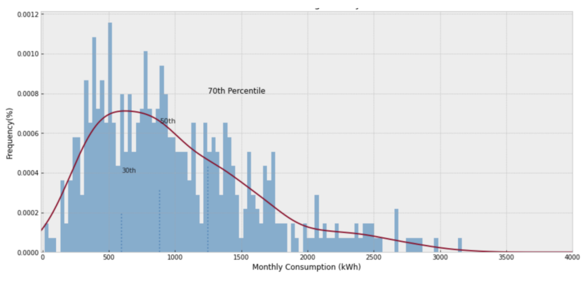

Fig 10. X-axis: Monthly consumption(kWh). Y-axis: user-frequency in percentages.

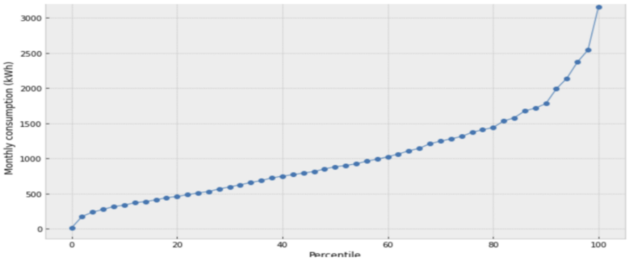

Fig 11. The graph indicates the trend of increase in user consumption within a cluster. Since the ultimate objective is to have two categories of users as efficient and inefficient, we should see two dents/spikes at the extremes to signify reasonable variation within a cluster. The users with higher consumption levels within their own cluster, are tagged as inefficient users.

V. USE CASES

This AI-driven segmentation framework is generalized to support many business use-cases.

A. Appliance Propensity

Customers' lifestyle parameters like occupation, and family type drive product purchase decisions like HVAC, solar panels, etc. Integrating these features for propensity modeling significantly increases the likelihood of a utility's success in the marketplace.

B. Rate plan design

The customer profiling solution provides details about a customer's consumption level, peak usage months, and peak usage hours which assist in clustering and developing relevant, personalized rate plans for individual segments of customers.

C. Demand Side Management

Customers are segmented based on their customer profile revealed inclination towards taking the necessary action. By focusing on the subset of customers who are most willing to take action to achieve the desired reduction in peak demand, utilities can realize improved DSM outcomes.

CONCLUSION

This paper introduces a two-step, AI-powered approach to produce more accurate and detailed customer profiles and then aggregate users based on the same. The proprietary algorithms can uncover hidden customer characteristics and utilize this intelligence to more accurately and effectively segregate consumers. We are also able to generalize the whole pipeline to accommodate multiple business objectives.

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Assessment on renewable versus coal-based energy generation: A case study of Indian power sector

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Abstract-

The operation schedule for microgrids has an important role in efficiently managing the electric power supply and demand. This work explores the ramifications of incoming changes brought by the increased penetration of variable renewable energy (VRE) into the grid and maximum utilization of RES upon conventional electricity sources. For this, the power system network will require additional flexibility capabilities like voltage stability index, total real and reactive power demand/losses, mismatch between generation and demand for smooth operation of the microgrids. In this study, we simulate the IEEE 33-bus radial distribution network (RDN) system and investigate the voltage stability index, total real and reactive power demand, total real and reactive power losses are verified through discussions on numerical results. Also this paper presents (a) an insight into the future power generation scenario including flexibilisation & ramp rate, (b) to find out the technical minimum load that thermal power plant would be required to run to maintain grid stability, (c) to suggest a proportionate energy mix of renewable power and conventional thermal generation at optimum cost and (d) to identify the procedures to be followed in Thermal Power Stations to make them capable of flexible operation. The method for optimum scheduling and cost involvement for flexible operation of thermal units in the Indian context has been elucidated in this paper.

Keywords— Energy mix, Flexible operation, Renewable energy sources (RES), Radial Distribution Network (RDN), Grid integration, security and Reliability.

I. Introduction

The power sector is at the cusp of significant transformation due to focus on smart cities, rapid urbanization, largest capacity addition of renewables in the world with the concept of 'One sun One earth One grid', hydrogen-based power & vehicles, rapid launching of electric vehicles (EVs), microgrids & consumers becoming generators, making it more complex than ever before. India has set an ambitious target of 175 GW of renewable energy (RE) capacity addition by 2022 to address energy needs and climate change. These priorities will result in a significant share of renewable energy power generation in India that has gained momentum. Integration of Renewable generation into the Indian electricity grid is a challenge and an opportunity that became a game-changer in the Indian electricity market. Increasing efficiencies in electricity with digitalization of the entire electricity value chain to turn it into an efficient & sustainable one as well as digitizing essential functions on priority within internal vertical operations processes & focusing on driving both revenue growth/operational efficiencies is need of hours. The Electricity is one of the key indicators for achieving socio-economic development of the country. After the enactment of the Electricity Act, 2003 the Indian power sector took huge strides in every electricity sector viz. Generation, Transmission and Distribution. Generation has been delicensed, which has given impetus to the generation capacity addition and the paradigm of the Indian power sector gained momentum in adding capacity addition of coal-based generation during the 11th and 12th plan. In recent times, the great momentum of renewable power into the grid, which is a more volatile residual load due to its fluctuating nature, leads to a great challenge in grid operation. The Electricity Act 2003, the transformation of the electricity sector and was a milestone in the reform journey. Since the distribution sector is the Achilles' heel of the power sector, it has become a big challenge to provide a healthy environment of the distribution segment to achieve 24 X 7 affordable power to all and better services to their customers. This is visible in the grid integration with the increasing deployment of clean renewables and the rising prevalence of grid-connected distributed generation. Due to the integration of large scale of variable Renewable Energy Sources (RES) into the grid, it is a big challenge to maintain secure and safe operation of the grid by a grid operator.

The total Installed Generation capacity as on 30.11.2021 is 3,92,017 MW. The maximum share is 59.9% from thermal, 11.9% from hydro, 1.7% from nuclear, and rest from renewable, which is 26.5%, respectively.

In the present context, Coal-fired power plants need to be more flexible in terms of possessing a resilience to frequent start-ups, operating the thermal units even less than their technical minimum limit, meeting significant and rapid load changes without compromising combustion parameters on one hand and grid discipline, on the other hand, to ensure stable, reliable and affordable power to all. Therefore, the systematic coordination of the operation of different types of generation plants is usually more complex to manage the electric power supply and demand efficiently. It is manifest that with an ambitious target of 175 GW of renewable energy (RE) capacity addition by 2022 to address energy needs and climate change, India promised a significant share of renewable energy power generation into the grid. The gained momentum of these renewable energies into the Indian electricity grid is a challenge and an opportunity that became a game-changer in the Indian electricity market. Since the future grid will be the integration of these sustainable sources into the conventional power system, Thermal power plants have to be flexible with the integration of RE into the grid, which becomes more complex for efficient management of supply and demand of power.

II. Sources of Operational Flexibility

Different sources of power system flexibility exist as is illustrated in Fig. 1.

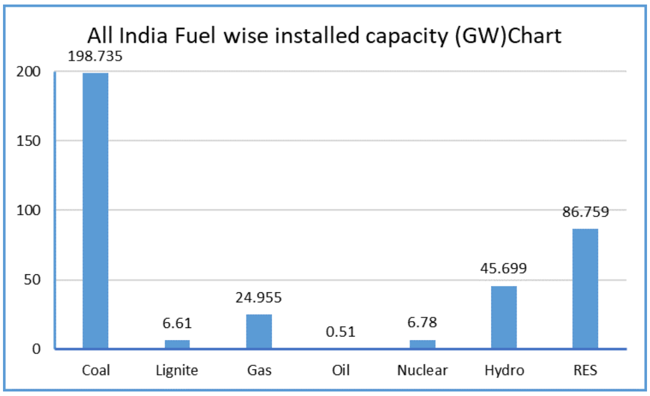


Fig.1 All India Fuel wise installed capacity (GW) as on 31.03.2020

Figure-1 portrays different elements related to the operational flexibility of the power system with secure, stable and reliable. In a real-time monitoring system, the dynamics of the power system right from generation (GENCOs), transmission (TRANSCOs) and distribution (DISCOMs) companies will rely on each other with an aim to ensure uninterrupted, affordable power to the consumers. In this context, Operational flexibility can be obtained on the generation-side in the form of dynamically fast responding conventional power plants with the latest automation, on the transmission side to know the current status of system network through digitization of load control centres/switchyards and on the demand-side by means of adapting the load demand curve to partially absorb fluctuating in case of large scale RES power in-feed.

In addition to this, RES power in-feed can also be curtailed or, in more general terms, modulated below its given time-variant maximum output level. Furthermore, stationary storage capacities, pumped hydro stations, mini/micro hydel units, storage battery systems as well as time-variant storage capacities etc., are well suited for providing operational flexibility. Additional flexibility can be obtained by importing/exporting power as and when basis on interconnecting grid zones, different distribution networking models, adopting proven forecasting models for load forecasting and power purchase is through very short term power purchase agreements is for the time being probably the most convenient and cheapest measure for increasing operational flexibility.

A) Combination of Operational Flexibility: For operation of any large power system network like India, with the availability of different types of generating units (type/fuel) it is very difficult to maintain study the power system analytics.

At present, all thermal units were advised to run at their technical minimum to maintain grid discipline and grid stability in order to promote the RES generation into the grid operation. Various study is going on to study the impact of the flexible operation of the thermal units, sudden ramp-up/ramp-down of the units, automatic generation control (AGC) of the thermal generating units to compare the needed operational flexibility for mitigating a disturbance event with the available flexibility that a given power system can offer.

B) India is undergoing an energy transition and has set targets for improving energy security, mitigating climate change and creating a sustainable future. While coal is currently the mainstay of power generation globally, it is also the biggest source of carbon emissions. In light of this, countries such as India are rapidly scaling up the deployment of renewable energy technologies while moving away from coal-based power and big concern about coal consumption, given India's commitments towards reducing pollution and greenhouse gas emissions.

Nonetheless, coal-based power still plays the key role of meeting the baseload power along with the added responsibility of maintaining grid balance in view of the increasing share of intermittent renewables.

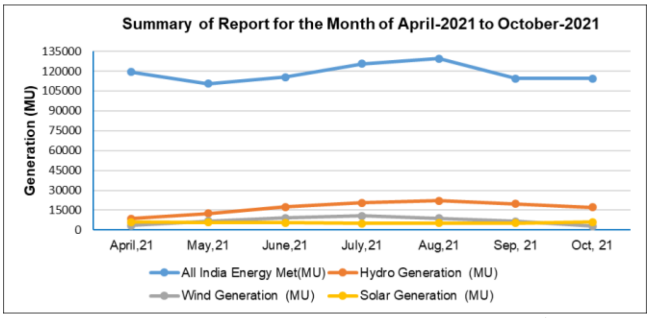


Fig.2 All India Energy met, Hydro, Wind & Solar generation from April 2021 to Oct 2021 in MU

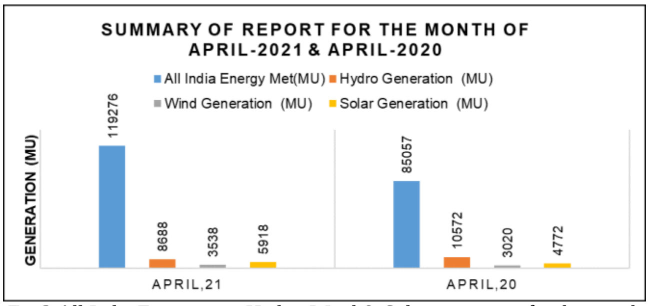


Fig.3 All India Energy met, Hydro, Wind & Solar generation for the month of April 2021 & 2020

Figure 3 reveals that the All India Eenergy met at National level decreased by 3.06% compared to March 2021 and increased by 40.23% compared to April, 2020. In hydro generation at National Level decreased by 1.41% as compared to March 2021 and decreased by 17.82% as compared to April 2020, wind generation it has been observed that there is an increase by 9.49% as compared to March 2021 and increased by 17.14 % as compared to April 2020 followed by Solar generation decreased by 2.93% as compared to March 2021 and increased by 24.02% as compared to April 2020.

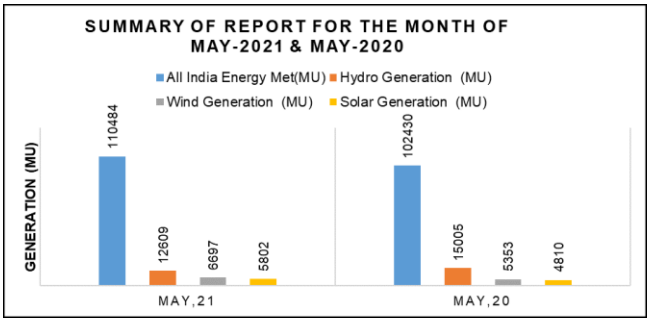


Fig.4 All India Energy met, Hydro, Wind & Solar generation for the month of May 2021 & May 2020

Figure 4 reveals that the All India Energy met at National level decreased by 7.37% compared to April 2021 and increased by 7.34% compared to May 2020. In hydro generation at National Level increased by 45.13% as compared to April 2021 and decreased by 15.97 % as compared to May 2020, wind generation it has been observed that there is an increase by 89.28% as compared to April 2021 and increased by 25.10 % as compared to May 2020 followed by Solar generation decreased by 1.96% as compared to April 2021 and increased by 20.61% as compared to May 2020.

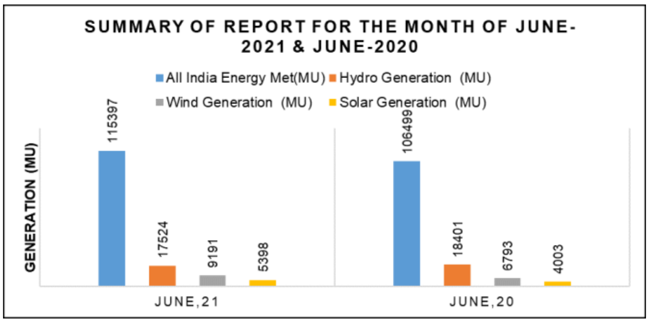


Fig.5 All India Energy met, Hydro, Wind & Solar generation for the month of June 2021 & June 2020

Figure 5 reveals that the All India Energy met at National level decreased by 4.45% as compared to May 2021 and increased by 8.36% as compared to June 2020. In hydro generation at National Level increased by 38.98% as compared to May 2021 and decreased by 4.76 % as compared to June 2020, wind generation it has been observed that there is an increase by 37.24% as compared to May 2021 and increased by 35.10 % as compared to JUNE 2020 followed by Solar generation decreased by 6.97% as compared to May 2021 and increased by 34.84% as compared to June 2020.

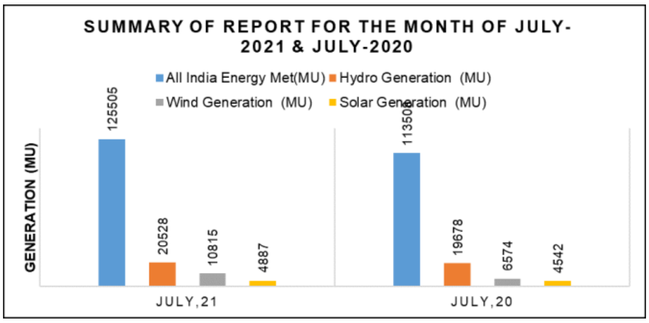


Fig.6 All India Energy met, Hydro, Wind & Solar generation for the month of July 2021 & July 2020

Figure 6 reveals that the All India Energy met at National level increased by 8.76% compared to June 2021 and increased by 10.57% compared to July 2020. In hydro generation at National Level increased by 17.14% as compared to June 2021 and increased by 4.32 % as compared to July 2020, wind generation it has been observed that there is an increase by 17.67% as compared to June 2021 and increased by 64.52% as compared to July 2020 followed by Solar generation decreased by 9.47% as compared to June 2021and increased by 7.60% as compared to July 2020.

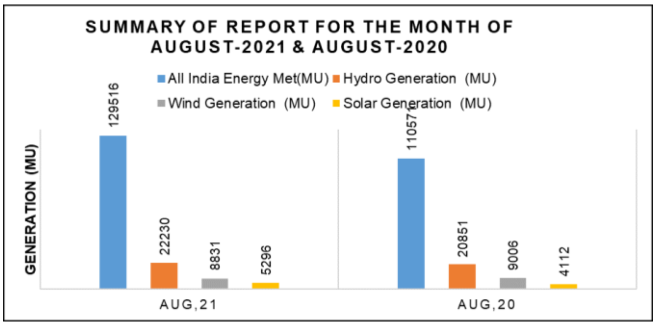


Fig.7 All India Energy met, Hydro, Wind & Solar generation for the month of Aug 2021 & Aug 2020

Figure 7 revels that the All India Eenergy met at National level increased by 3.20% as compared to July 2021 and increased by 17.13% as compared to August 2020. In hydro generation at National Level increased by 8.29% as compared to July 2021 and increased by 6.61% as compared to August 2020, wind generation it has been observed that there is an decrease by 18.35% as compared to July 2021 and decreased by 1.94% as compared to August 2020 followed by Solar generation increased by 8.37% as compared to July 2021and increased by 28.79% as compared to August 2020.

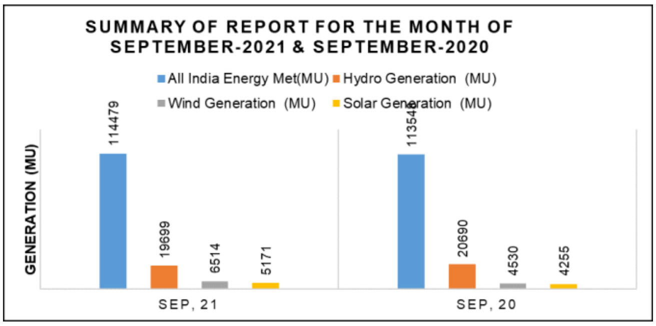


Fig.8 All India Energy met, Hydro, Wind & Solar generation for the month of Sep 2021 & Sep 2020

Figure 8 reveals that the All India Energy met at National level decreased by 11.61% compared to August 2021 and increased by 0.82% compared to September 2020. In hydro generation at National Level decreased by 11.38% as compared to August 2021 and decreased by 4.79% as compared to September 2020, wind generation it has been observed that there is a decrease by 26.24% as compared to August 2021 and increased by 43.78% as compared to September 2020 followed by Solar generation decreased by 2.36% as compared to August 2021and increased by 21.53% as compared to September 2020.

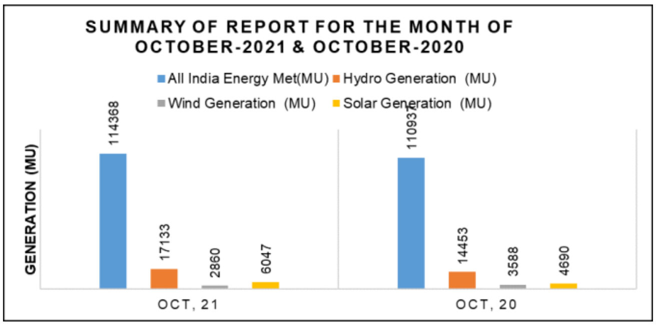


Fig.9 All India Energy met, Hydro, Wind & Solar generation for the month of Oct 2021 & Oct 2020

Figure 9 reveals that the All India Energy met at the National level decreased by 0.10% compared to September 2021 and increased by 3.09% compared to October 2020. In hydro generation at National Level decreased by 13.03% as compared to September 2021 and decreased by 18.54% as compared to October 2020, wind generation it has been observed that there is a decrease by 56.10% as compared to September 2021 and decreased by 20.30% as compared to October 2020 followed by Solar generation increased by 16.94% as compared to September 2021and increased by 28.93% as compared to October 2020.

As the penetration of variable renewable energy increases in the Indian grid, it is a big challenge for system operators to balance the variable renewable energy in real-time system operation. A special focus has been given to harnessing the flexibility attributes in generation and electricity markets so as to facilitate the integration of more renewable energy in the grid.

One part of the solution is the flexible generation by which power plants can ramp up and down quickly and efficiently and run at low output levels (i.e., deep turn-downs). It has been observed that wind and solar generation may accentuate the need for more flexibility and may lead to steeper ramps, deeper turn downs, and shorter peaks in system operations.

The details projected in the January 2019 report "Flexible Operation of Thermal Power Plant for Integration of renewable generation" regarding thermal ramping capacity in 2021- 2022 by Central Electricity Authority is as under:

(i) Thermal Generation on increasing trend; the peak of around 130 GW

(ii) Over the years, the thermal generation has also become flexible, with generation flexing down to 55% at present

(iii) At the all India level, around 35% of coal-fired generating units (438 Nos) have the Ramp – Up/Down capability of providing at least 1%/Min. and Majority of the coal-fired central generating stations are declaring a ramp of 0.5 % - 0.7 % MW/Min

(iv) 40 Central Generating Stations (CGS) coal-fired units provide a ramp up.

Distribution companies (DISCOMs) is the owner-operator who buys wholesale power either through the spot market or through direct contracts with GENCOs and supply power to the customers. In this deregulated electricity market regime, penetration of distributed generation (DG) in the distribution system becomes a challenging task to maximize its potential benefits for an operator. Since the location and size are the two influential properties of the distributed generations (DGs) behaviour in the system. As DGs are located near load centres and hence reduce the transmission losses and also it has been noticed that there is improvement in voltage profile as well as minimizing the real and reactive power losses of the existing network.

In this section, the forward-backwards sweep method will be applied at the IEEE 33 bus radial distribution network for load flow analysis, multiple distributed generation penetration for the voltage stability index, total real and reactive power demand, total real and reactive power losses is verified through discussions on numerical results.

The 12.66 kV, IEEE 33 bus radial distribution system containing 33 buses configured with 420KVA per unit with 0-85 pf is used to test two multiple DGs. The single line diagram of IEEE 33-bus RDN is as shown in fig 10.

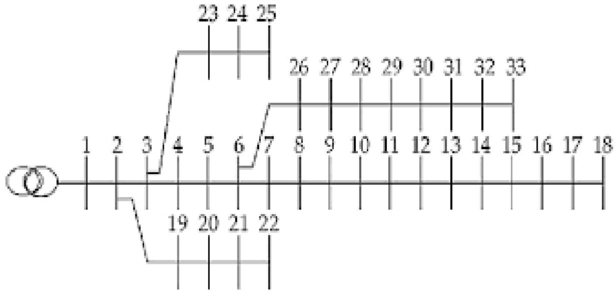


Fig.10: Single line diagram of IEEE 33-bus Radial Distribution System

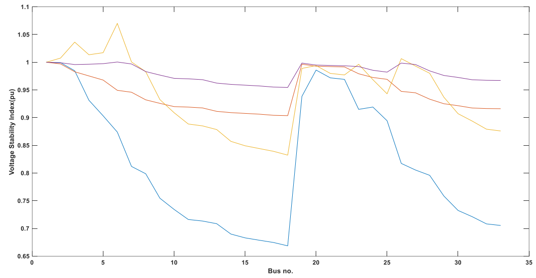


Fig.11: Voltage Stability Index (VSI) in pu of IEEE 33-bus Radial Distribution System

The results like minimum bus voltage with bus no, minimum stability index with bus no, total real power loss with the placement of dg_1 & dg_2 with bus no. are calculated and are tabulated as shown below in table 1.

Table 1: The system details

Total real demand (KW)	3715.0000	
Total reactive demand (KVAR)	2295	
minimum voltage and bus bus	0.9036	18
minimum voltage1 and bus bus1	0.9546	18
minimum stability index and bus bus	0.6686	18
minimum stability index1 and bus bus1	0.8323	18
Total dg_1 placement	3016.533	
Total dg_2 placement	685.656	
Total dg_2 placement	2564.07	
Total real power loss base case	0.503	
Total real power loss index with 1_dg placement case	0.178	6
Total index power loss with 2_dg placement case	0.134	30

III. FLEXIBILISATION OF COAL BASED GENERATING PLANTS – A CASE STUDY

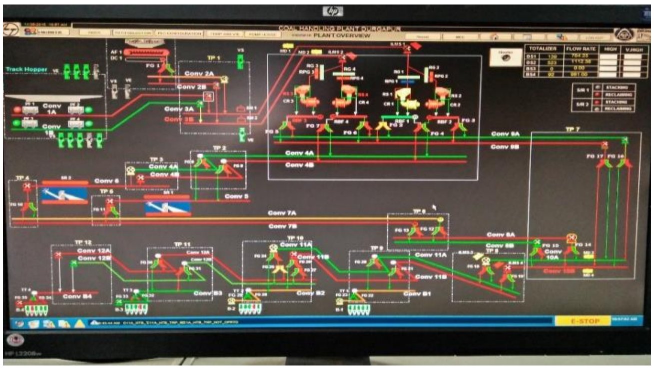
Objective of the study is to run thermal generating units at their technical minimum with optimum utilisation of coal and without sacrificing the combustion parameters to maintain virtuous support to grid in the era of integration of a large amount of Renewable energy sources into the grid. For this analysis, here we have considered a 1000MW (2 X 500 MW) thermal generating station.

Preamble: Durgapur Steel Thermal Power Station (DSTPS) is a greenfield project, near Andal in Paschim Bardhaman district of West Bengal, with an installed capacity of 2 X 500MW. There is a siding loop line of 14 Track KM (approx.) length with the provision of Track Hopper and Wagon Tippler for transportation of coal from mines to DSTPS. The design parameters of coal for both Unit#1 & #2 is 3300 Kcal/Kg, and Heat rate is 2291 Kcal/Kwh. For DSTPS, Coal is supplied by ECL, MCL and BCCL.

In the present scenario of coal availability in India, due to the low GCV of coal with a high percentage of ash, it is a big challenge to run the thermal units very efficiently, resulting in high generation cost. On the other hand, high-grade coal is more expensive. Reliable sustained generation with minimum cost, and optimum efficiency is the debate of the day. Therefore, the optimisation of coal blending to obtain higher plant efficiency and lower generation cost is very much essential. Since fuel cost is a major proportion of the total input cost, reducing it will really reduce the cost of the generation. There are so many ways to reduce generation cost of which blending different grades of available coal is an effective method. This has led us to focus on low- and high-grade coal blending, decreasing the generation cost and increasing plant efficiency. Hence, design, development and testing of new schemes at DSTPS for blending of coal was taken up.

Coal Handling Plant (CHP) of DSTPS: The coal handling plant (CHP) of DSTPS consists of two nos. of direct feeding (through Track hopper to Bunker & Wagon tippler to Bunker) and two nos. of reclaiming feeding through Stacker & Reclaimer-1 Stacker & Reclaimer-2. There are four nos. of stockpiles for stocking of coal. The total operation of CHP is totally PLC/SCADA based. After thorough study/analysis of existing available different systems with different combinations like Direct feeding from Track hopper to Bunker, Direct feeding from Wagon tippler to Bunker, Stacking from Track hopper to Stockpile, Stacking from Wagon tippler to Stockpile and Reclaiming from Stockpile to Bunker, the new schemes namely

a) Blending Path-1 [Track hopper –Wagon Tippler], (b) Blending Path-13 [Track hopper/Wagon Tippler - Reclaimer], (c) Blending Path-14 [Reclaimer (SR-1) – Reclaimer (SR-2)], (d) Blending Path-15 [Track hopper/Wagon Tippler to Reclaimer and Track hopper/Wagon Tippler to Stacker have been designed, tested and implemented. Now, the total coal handling system of DSTPS consists of 15 nos of the path.



(Fig.12. Real-Time Screenshot for the Path no-15)

With the implementation of the above schemes, any combination of coal handling facilities can be used for blending and different coal-handling scenarios applicable in coal stockyards and in bunker before firing into the boiler. Finally, the above schemes can be used for further experimentation and parametric analysis regarding possible improvements in the coal-handling procedure, plant efficiency, optimum coal utilisation, and reduction in energy charges.

Due to fast growth of renewables (solar /wind) the load pattern changed its paradigm, and for detailed analysis we have considered the total station generation of DSTPS following things mentioned in seriatim:

1. Total station generation on 4th November 2021 is 14.398MU and total coal consumption is 8459MT with a GCV of 4076 kcal/kg (ARB)
2. Total station generation on 8th November, 2021 is 22.222MU and total coal consumption is 14103MT with a GCV of 3591 kcal/kg (ARB)
3. Total station generation on 8th December, 2021 is 17.774MU and total coal consumption is 11309MT with a GCV of 3836 kcal/kg (ARB)
4. The receipt of coal from different coal linkages in the month of Nov'2021 (from 3rd November to 8th November 2021) has been considered for analysis.

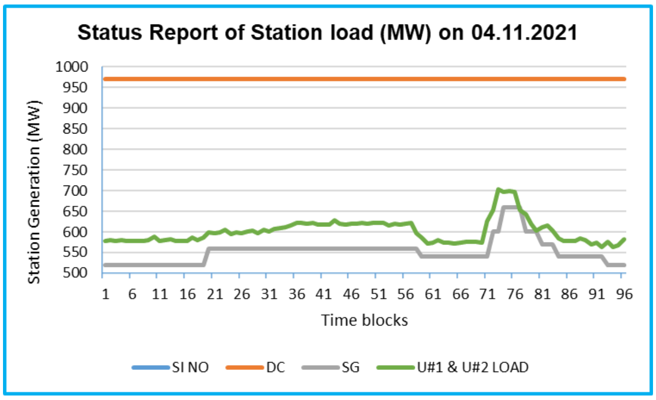


Fig.13 Station Load (MW) on 04/11/2021

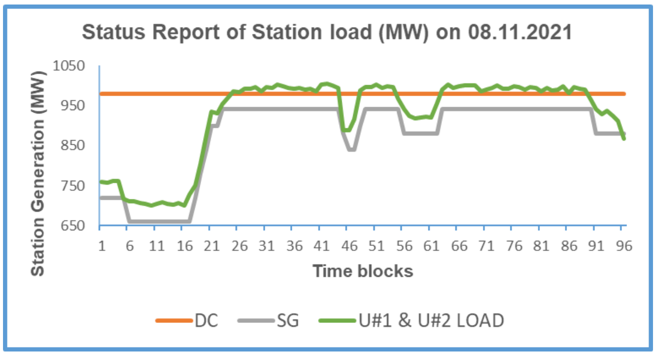


Fig.14 Station Load (MW) on 08/11/2021

From the above figures (13 to 15), it reveal that the maximum load achieved 703MW at 18:15hrs., and Minimum load 568MW at 23:30hrs., on 4th Nov'2021, the maximum load achieved 1005 MW at 10:30 hrs, and Minimum load 700 MW at 02:30 hrs on 8th Nov'2021 followed by maximum load achieved 991 MW at 19:45 hrs., and Minimum load 575 MW at 05:15 hrs on 8th Dec'2021. It is only possible through proper coal blending, ramp up/down rate the thermal units.

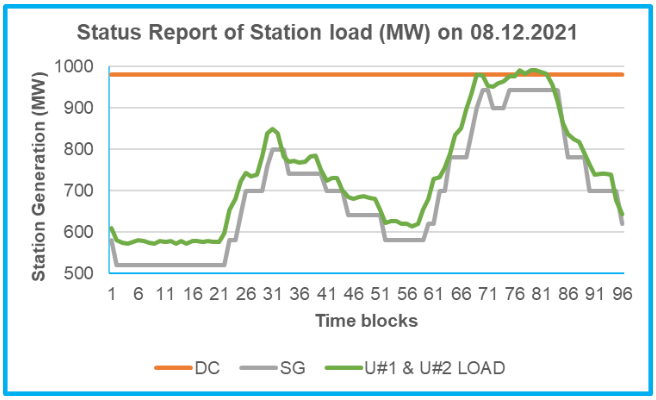


Fig.15 Station Load (MW) on 08/12/2021

The above example portrays that the thermal generation progressively to be reduced and maximizing the renewable generation so as to make the environment safer.

IV. CONCLUSION

In Section II the forward-backwards sweep method has been applied to test IEEE 33 bus radial distribution network for load flow analysis, multiple distributed generation penetration for the voltage stability index, total real and reactive power demand, total real and reactive power losses and are verified through discussions on numerical results. Similarly, in section III the case study of running a thermal power generating units at their technical minimum without sacrificing the combustion parameters with optimum utilization of coal by implementing different suitable coal blending schemes was examined. The work done in this paper has made strong approachability to face various challenges like flexibilisation of thermal generation i.e. operation of the thermal generation at their technical minimum (present it is 55%) and even less in coming future. Also, the paper portrays due to entering of RES in a large amount into the grid, operation of whole power system grid in a secure and stable manner.

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Life Extension and Health Monitoring of IED Power Pack units in grid substations

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***Abstract*— Protection Relays are essentially the brain of a power system network. Being a front-runner in the adoption of latest technologies in the utility space, TATA Power-DDL has successfully revamped its Protection and associated Communication Infrastructure by commissioning modern numerical relays having the capability to integrate on IEC 61850 communication protocol. The most significant advantage of these advanced Numerical Relays is that they assist in remote monitoring of several system parameters along with fault data thereby saving a lot of crucial time and assisting in early restoration. There are 210 number of Power Transformers in 82 Grid Substations spread across the Sub-Transmission network (66/11 kV or 33/11 kV) in the licensed area of TATA Power-DDL (North and North-West Delhi). A Transformer caters to the load through 11 kV Outgoing Feeders via the Incomers, each of whose Control Panels have dedicated Protection Relays or Intelligent Electronic Devices (IEDs). One of the crucial aspects of ensuring reliability of protection systems is that the Relays receive unhindered auxiliary power supply (Station DC) at all times to enable them to remain powered up and take effective trip decisions which would help in clearing a fault. Station DC Failure Events are a rare occurrence. Nonetheless, it is very essential to have a mechanism in place for safeguarding against any such disaster. After a careful techno-commercial analysis, Protection Group at TATA Power-DDL had decided to install an additional IED on only the 11 kV Incomer Panels. These IEDs and the associated trip circuit would be powered up through a Power-Pack which is an AC to DC Converter Unit working on PT supply. The watchdog of Power Pack based IED was given to the Station DC Powered Primary IED which would ensure the health monitoring of both the Power Pack as well as the associated relay.**

However, after taking the above scheme in service, a number of incidents were reported in which the dry type batteries of Power Packs started to die out in a short period of time much before the end of their anticipated lifecycle. The primary cause of such pre-mature failure was that the battery was always kept on float charging mode and rarely received an opportunity to discharge.

In order to prolong the life of the battery, it was decided to devise a system which would allow it to discharge at a predefined interval and let the supplementary IED remain powered up on the battery. As soon as the battery would completely discharge, the Power Pack would automatically start charging and remain in service as usual. The paper describes a novel system architecture which has been designed in-house to achieve the above objective. Logic has been developed in the associated IED for this purpose. Moreover, it has also been decided to extend the project by ensuring remote monitoring of the health of the Power Pack battery.

It is anticipated that the system would not only improve the life of around 200 numbers of Power Pack batteries by nearly 2-3 years, but also save crucial man hours spent on maintenance and battery replacement activities.

Keywords—Station DC, Health Monitoring, Power Pack, IED, Protection Unit, Relays, Incomers, Battery.

I. INTRODUCTION

Since its inception in 2002, TATA Power-DDL has been successful in creating benchmarks in the electrical utility industry. After the unbundling of the erstwhile State Electricity Board (Delhi Vidyut Board), the distribution license area of North and North-Western Delhi came under the purview of TATA Power-DDL. This license area comprises a total of 82 grid substations of 66/11 kV or 33/11 kV voltage level. Each grid substation has 2-4 Power Transformers of 16 MVA – 50 MVA capacity. The 11 kV power from transformer secondary is then further distributed from 11 kV outgoing feeder panels via the 11 kV incomers. A typical Single Line Diagram is illustrated in Fig.1

All the switching points in grid substations include circuit breakers, protection relays and associated circuitry. The protection relay instruct the breakers to trip and isolate a part of the circuit if it finds that certain conditions are satisfied. The relays and associated circuitry functions on the DC supply provided in the grid substation. The DC system is lifeline of the grid substation. The operation of the protection system of equipment is dependent on the proper functioning of DC system. In case of failure of DC supply, the protection system will not operate and it can lead to a major catastrophe like a fire accident.

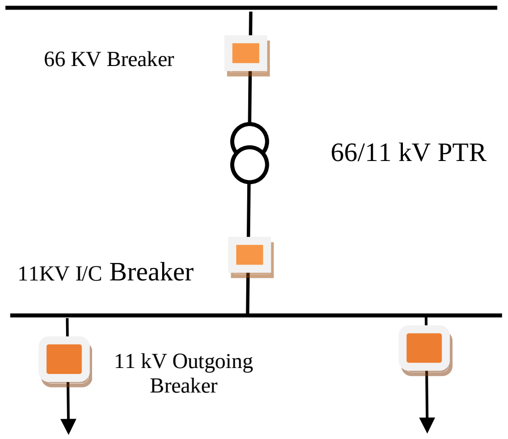

Fig.1- A representative SLD of a TATA Power-DDL grid substation

II. DC SYSTEM IN GRID SUBSTATION

DC supply is required for operation of protection relays, panel indicating lamps, dc motors, breaker trip coils and contactors etc. In normal condition, the DC is supplied by the charger. The input supply to charger is AC supply which is generally provided by a small local transformer installed in the grid. In case of failure of AC supply in grid, the DC is supplied by the battery bank. The major components include Battery Chargers- Float Charger, Boost Charger & Float cum Boost Charger, Battery Banks and DC Distribution Board (DCDB). Typical Layout of Grid DC system is shown in Fig. 2

- **Battery Chargers-** The charger output is used to supply the D.C loads, since, the characteristic of this output is non- drooping in nature and a constant voltage is made available over a period of time. The float charger contributes the load current at appropriate voltages. The charging current is generally kept at 2 to 5 percent of the capacity of the batteries depending on its age since commissioning. The function of a boost charger is to inject a high current into the set of the batteries that needs to be charged. The quantum of current to be injected is generally about 10 percent of the capacity of the battery

- **DC Distribution Board-** DC Supply is distributed within the substation through terminations on DCDB. Each battery bank associated with float charger and boost charger shall be connected to respective distribution board.

- **Battery Bank-** Battery stores energy in chemical form and converts chemical energy in to electrical energy. It constitute of Anode, Cathode and electrolyte. In Lead Acid batteries Anode is made up of PbO_2 (Lead dioxide), Cathode of Pb (Sponge Lead) which is the active material and Sulphuric Acid is used as electrolyte also a porous separator of insulating material is used in between anode and cathode. Lead batteries used in industries usually consists of two 6-volt batteries in series or a single 12-volt battery. These batteries are constructed of several cells connected in series each cell produces approximately 2.1-volts. Typical 12 volt battery has a rating of 125 Ah.

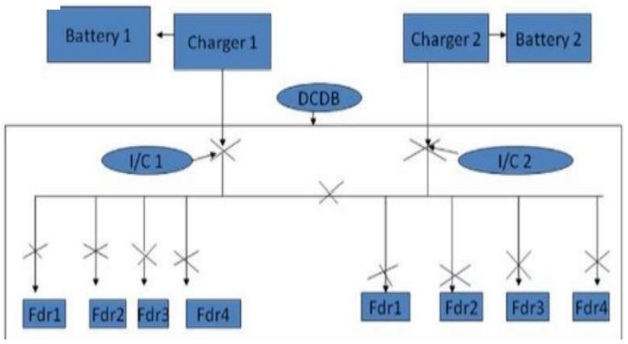

Fig.2 – Grid DC System with twin battery and charger

III. POWER PACK UNITS

Power Packs Units are a combination of AC to DC converters with batteries. The Power Packs in grid substations take 110V AC supply from secondary terminals of 11 kV PT and convert it to 48V or 220V DC output which can act as redundant DC supply for relays and other equipment.

In TATA Power-DDL, the Power Pack scheme was implemented in grid substations after carefully analyzing the requirements. It was decided to install these units only on the 11 kV Incomers to keep the costs as minimum as possible without compromising much on the safety aspect. Hence, another relay, (which is referred to as Protection Unit or PU hereafter), apart from station DC powered relay, was installed on 11 kV Incomers. These PUs and the circuits associated with them would be provided with the DC supply from Power Pack Units. A changeover logic was implemented which ensured that the PU automatically receives DC supply from Power Pack batteries if the grid DC gets switched off. The block diagram of Power Pack scheme is shown below in Fig.-3.

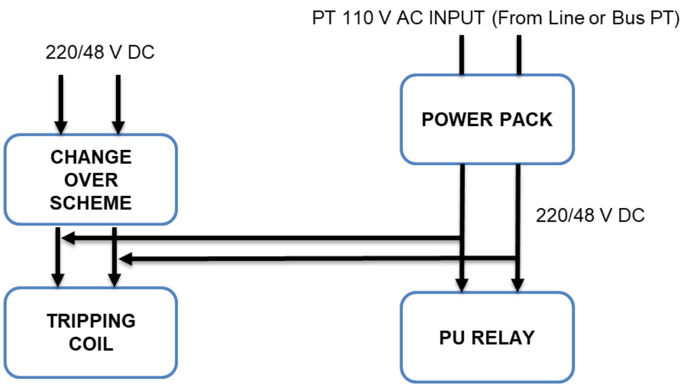

Fig.3- A block diagram of Power Pack Scheme

IV. LIFE OF POWER PACK BATTERY

Power Pack Units available in market generally have dry type rechargeable batteries. Depending upon the suitability of load and number of charging-discharging cycles, these can effectively work for around 3-4 years.

In TATA Power-DDL, Alan make Power Packs were commissioned when the scheme was taken in service (Image-1). A number of incidents were reported in which the dry type batteries of Power Packs started to die out in a short period of time much before the end of their anticipated lifecycle. The primary cause of such pre-mature failure was gradually found out. After a careful study, it was finally concluded that the pre-mature dying out of battery was primarily due to the fact that the battery was always kept on float charging mode and rarely received an opportunity to discharge. It is to be noted that whenever a battery is not used by discharging it, its life tends to decrease. Regular charging and discharging of battery for a required number of cycles for which battery is designed, ensures complete life usage of the battery. Keeping this fact in mind, it was decided to devise a system which would allow the battery to automatically discharge at a predefined interval and let the supplementary IED (PU) remain powered up on the battery. As soon as the battery would discharge, the Power Pack would automatically start charging and remain in service as usual. This system for automatic regular charging and discharging was developed in- house without involving any extra cost and using the least possible resources.

V. SOLUTION FOR LIFE EXTENSION OF POWER PACK BATTERY

GE F650 relays (Image-2) that have been installed as supplementary IEDs or PUs in grid substations can be suitably used to devise a logic based on which automatic charging and discharging of Power Pack can be achieved. It is to be noted that logic can be developed in any type of new generation Intelligent Electronic Devices (IEDs) but for the purpose of explanation in this paper, GE F650 relay has been used.

In the Relay, 2 spare binary inputs and 1 spare binary output contact is needed to be made available. Binary Inputs would be utilized for the following statuses:-

1. Power pack DC Healthy
2. Power pack on discharging mode

Binary Output of the PU relay would be used to cut off the PT supply coming on the Power Pack input

Based on the output contact of PU Relay, Power Pack's input PT supply would be cut off at some regular time period (which can be input in relay logic). Hence the Power Pack would be brought in discharging mode. Again, after some time, when the relay output contact would be closed as per logic, the power pack would again come under charging mode. The logic developed has been successfully integrated in the .pep file of the GE F650 relay. Fig. 4(a) and 4(b) shows the block diagram of logic.

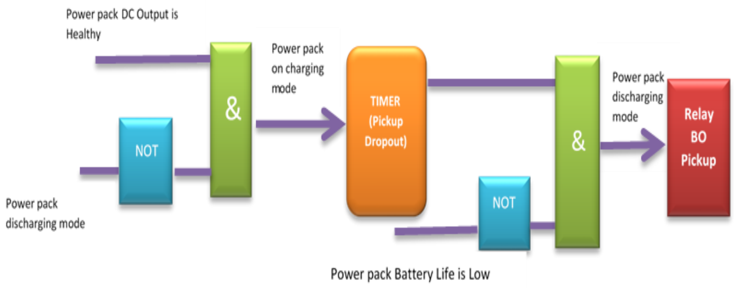

Fig.4 (a) – Logic for pickup of Relay Output Contact

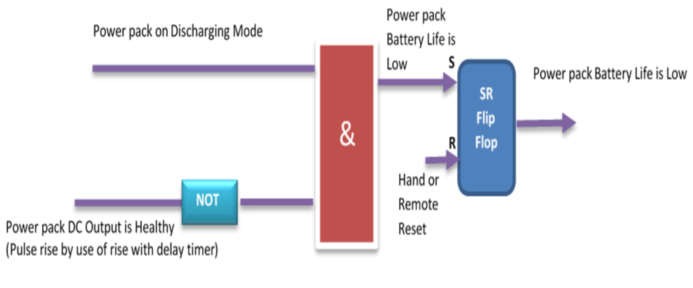

Fig.4 (b) – Low Battery life status

The status of Power Pack Battery Life Low Latched could be used to configure an LED in the GE F650 relay to give an indication to the field staff or remote team. This status is configured to be reset by any function key present on the relay.

The power pack would remain on discharging mode till the point when battery would no longer be able to maintain a particular output voltage. The time depends on the load as well as the Ampere-Hour rating of the battery. Alarms for Power Pack DC Healthy, Power Pack on Discharge mode and Power Pack Battery Low are provided in Relay front screen LED as well as on the Advanced Distribution Management System (Control Centre) for better monitoring. Fully charged Power Pack takes total 8 hours to fully discharge with only load of Protection Relay (around 150-300 mA). We are discharging it to 50% for 4 hours once in a week.

The complete system architecture has been developed as per the Fig. 5 shown below. The system is taken into service by using a GE F650 relay on which the explained logic is configured using 650 setup software. Moreover, a contactor or contact multiplier relay (CMR) is also installed which gets energized as soon as the PU relay output gets picked up depending in the fulfilment of the conditions.

The two NC contacts of the CMR through which PT input is given to the Power Pack change to open position and hence the PT input is cut-off from the Power Pack. At this time, the Power Pack goes into discharging mode.

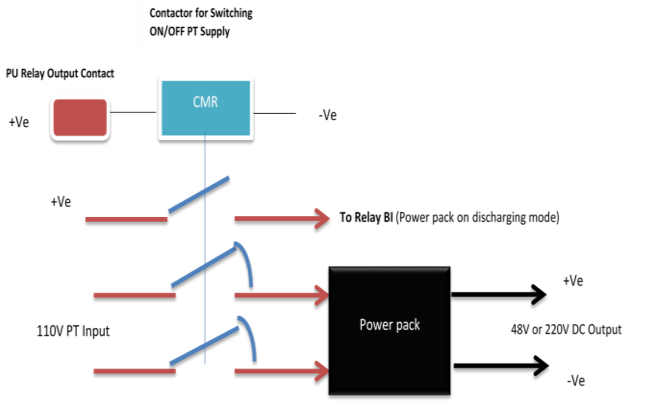

Fig. 5 – System architecture

Now, when the relay output contact is drop-off, the CMR is de-energized and the reverse process happens. Both the NC contacts are closed and Power Pack starts charging again.

Image-1 Alan make Power Pack Unit

Image-2 GE F650 Bay Controller (used as PU)

VI. CONCLUSION

The solution for extending the battery life of power pack units is developed without infusing any cost. The battery of Power Packs in the TATA Power-DDL grids had been found to be turned faulty within a time period of just 2-3 years. However, it is now anticipated that with the development of this system, life of around 200 numbers of Power Pack batteries would be increased by nearly **3-4 years**. Not only this, it will also save crucial man hours spent on maintenance and battery replacement activities. Further, the increase in life of batteries would mean that they would be phased out after a much longer duration which is also beneficial for the environment.

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Utility Secure Grid communication

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Abstract

A smart grid is a simple upgrade of a power grid, that delivers electricity from suppliers to consumers. Due to its heterogenous communication architecture, it has been a challenge to design a robust security mechanism across different layers of communication.

We foresee those utilities are in need to revisit the design of communication networks of smart grids and build a comprehensive solution for a robust, efficient, and secure information system. The current devices don't have enough processing power and storage to perform advanced encryption and authentication techniques communications in a smart grid system on over different channels with different devices.

Keywords - Secure Communication, Grid Security, Quantum Cryptography, Smart Grid

I. Introduction:

Conventional Electricity Grids offer affordable and reliable power to its consumers but are inherently complex in design encompassing several systems, devices, networks that are interconnected. The data of these power T&D systems is controlled in cyberspace. Grid communication is therefore required to strengthen grid performance. It enables large scale deployment while making efficient use of Distributed Renewable Energy (DER) Sources and aiding the sustainability of the electric grid by making use of real-time intelligence to enable automated protection, optimization, and control functions.

As of current market research, ~57% supply is interrupted, ~53% employee and customer safety are compromised and ~51% company's sensitive data is compromised to easy theft. The cyber-attacks market size of smart grid security is expected to grow till **$16.2 billion by 2026**.

Utilities are now gaining inclination towards grid security and secure communication. It has been estimated that during 2028 utilities will spend on an average of 5% of their total capex on grid related activities like IT & communication, SCADA, Smart grid technology, control sector and R&D initiatives. Figure 1 below shows the trend smart grids and utility applications together is a $100 billion opportunity in future.[1].

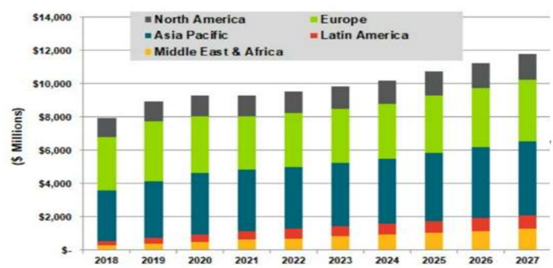

Fig 1: Total Smart Grid Communications Equipment and Services Revenue Region, World Markets: 2018-2027

II. Challenges:

Utilities companies, especially T&D operations, are facing an increasing physical threat to their infrastructure and to perform under critical events, like adverse weather, hence it is important for utilities to understand the likely impacts from these events to protect infrastructure, ensure effective functioning of critical systems and to be able to handle service disruptions. Also, with the focus on Renewables, Utilities are increasing commitment towards decarbonization.

A. **Grid Resiliency** – is one of them. Usage of smart grid can strengthen the resiliency of grid and hence save power loss.

B. **Supply Chain Security** – for Utilities to move one step closer to decarbonized clean energy future. Utilities urged to prioritize patching solar winds Orion and maximize telemetry collection.

C. **Grid Modernization and Security** – In addition to adding more renewable energy and smart meters, utilities are increasingly adopting OT Clouds as well as investing in cybersecurity to increase their cyber resilience. Also, today security tools aren't very well integrated, for instance, labour-intensive installation and maintenance. Hence, security breaches would become a greater concern as renewables infrastructure becomes more automated.

III. Proposed Solution:

By combining quantum-safe cryptography, AI/Edge and System-On-Chip architectural frameworks and algorithms, the plan is to secure grid assets and address real threats like cyber-attacks, denial of service, and authentication issues.

A quantum safe algorithm is used to write quantum programs used in securing the end-usage of electrical energy, usually after the meter has been consumed. Additionally, these programs can be reused across all IOT enabled devices, such as smart TVs and smart plugs, which rely on the home Wi-Fi network and are easily attacked.

A. Quantum Cryptography for Utilities:

Securing assets is an important aspect of T&D Utilities' business. Complex Quantum programs help address task as grid stability, reliability, predictive modelling, and grid safety.

For instance, Encoding and decoding information with quantum communication in physical systems could increase energy efficiency for input and output, eliminating energy losses and making renewable energy more achievable.
By applying quantum key cryptography, we can develop secure algorithms and programs to provide additional security of the grid assets.

B. Following are some of the features that proposed solution provides:

- Securing high performance and protecting critical Utilities data with moreover Cloud security.
- Service based model to build Utilities specific algorithms - Peer-to-Peer trading, Market exchange and compactible with IoT devices.
- Reusable Quantum Programs
- API base architecture for integration with Utilities applications ex- SAP, GIS, AMI, Smart Plugs and smart meters, etc.
- Dynamic Quantum Cryptography for securing Utilities IT-OT communication
- Identity and Access Management, Certificate Based, Device Level Authentication is protected.

C. How does AES-256 work:

In AES, the same secret key is used for both encryption and decryption. By using a key expansion method, it provides additional security since it generates a series of round keys using the initial key. AES-256 uses 14 rounds of modifications [2], each of which makes it harder to break encryption. Three AES varieties are listed in Table-1 based on key length, block size, number of rounds.

	Key Length (Nk words)	Block Size (Nb words)	Number of Rounds (Nr)
AES-128	4	4	10
AES-192	6	4	12
AES-256	8	4	14

Table 1: Key-block-Round Combinations

Figure-2 shows the pseudo code sample to create a Cipher [3].

```
Cipher(byte in[4*Nb], byte out[4*Nb], word w[Nb*(Nr+1)])
begin
   byte  state[4,Nb]

   state = in

   AddRoundKey(state, w[0, Nb-1])           // See Sec. 5.1.4

   for round = 1 step 1 to Nr-1
      SubBytes(state)                       // See Sec. 5.1.1
      ShiftRows(state)                      // See Sec. 5.1.2
      MixColumns(state)                     // See Sec. 5.1.3
      AddRoundKey(state, w[round*Nb, (round+1)*Nb-1])
   end for

   SubBytes(state)
   ShiftRows(state)
   AddRoundKey(state, w[Nr*Nb, (Nr+1)*Nb-1])

   out = state
end
```

Figure 2: Pseudo code sample for AES-256 Encryption

Based on current computing power, AES-256, with its 256-bit key length, it's practically unbreakable and has the largest bit size. Thus, it makes up the strongest encryption standard. Figure-3 shows the flow diagram of Quantum safe AES-256 Algorithm.

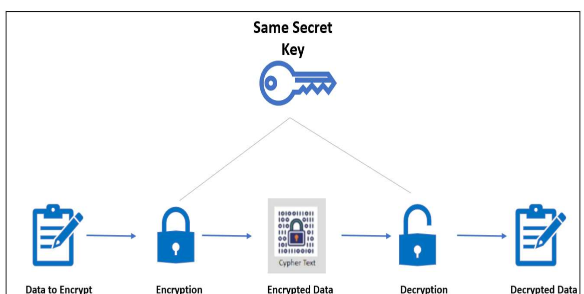

Figure 3: Flow Diagram of Quantum safe AES-256 algorithm

IV. Process:

An end-to-end process of encryption and decryption using quantum cryptography in a live Utility Platform is depicted in figure-4 below

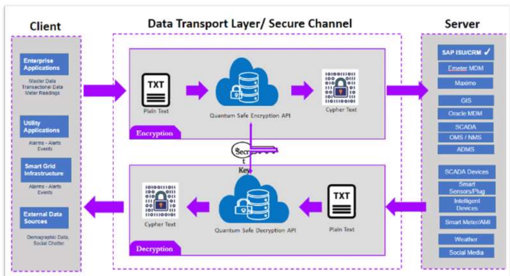

Figure 4: End-to End Implementation of Quantum Cryptography Program

Consider, a simple dashboard with an Enterprise Application where a customer manages and monitors his energy consumption. He clicks on bill history to view bill. In the backend it triggers a request to SAP system through OData service. Before sending the request, on client-side Customer ID will be encrypted using AES-256 quantum-safe algorithm. The encrypted text will be added to the request and sent to the server. SAP will decrypt the message using Quantum safe API, read the encrypted text and then uses the decrypted Customer ID to generate the output. Figure-5 illustrate the Quantum cryptography program implemented in application.

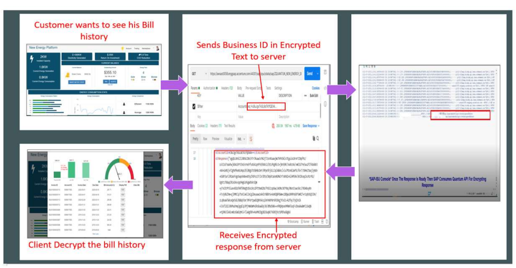

Figure 5: Illustration of application

Similarly, using Quantum safe encryption API, the output from SAP will be encrypted again. The encrypted response will be sent from Server to client. Using AES-256 algorithm client will decrypt the received output and the Bill data will be displayed in utility platform for that customer.

V. Conclusion:

Utilities need to reinvent themselves to increase operational efficiency, stability, and security. Secure grid communication is achievable using new technologies like Quantum, Edge, AI and more. Quantum AES-256 algorithms can be used in grid communication for a strong defence against cyber threats. Using Quantum, we can build a service-based models that can be used to protect Peer-to-Peer trading and Market exchange. The Quantum programs are reusable and can be easily deployed on IoT devices, ensuring safe messaging. Therefore, we foresee the need for Utilities to strategies, to build a strong physical structure preventing security threats and incidents in Grid Communication and, to modernize their communications networks.

VI. Benefits:

A. Reducing cyber-attack vulnerability by 25-40% to improve grid uptime
B. Cyber security incidents reduced by 50%
C. The global quantum cryptography market size is estimated at a CAGR of 19.1% by 2025.
D. Quantum cryptography offers a future-proof grid that enables secure energy trading and communication.

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VIII. Abbreviation:

AES - Advanced Encryption Standard

T&D – Transmission and Distribution.

Utilities Renewable Journey with Prosumer at the Center

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***Abstract* — Renewable is one of major game changers for the Utility Industry today. Convergence of the Industry boundaries, fusion of the energy and exponential technologies, adoption of the digital forces together with advent of disruptive innovation are creating an opportunity for the utilities to create new roles & responsibilities around the prosumers. Renewable is one of most preferred new roles for utilities as well as building block for many other emerging roles such as electrification of mobility, affinity services, grid management in transactive era, flexibility service providers etc.**

The paper will start with giving an outside-in and inside-out view of how various micro and macro trends are shaping the utilities journey towards renewable such as regulations, reduced technology cost, consumer empowerment, energy technology consumerization, new moment of truth for the customers etc.
Then it will outline how utilities are making this transformation towards renewable across 3 different horizons of achieving net zero, promoting new business models and having a sustainable ecosystem. The transformation framework between utilities and prosumers towards the renewable ecosystem– adoption, maturity and optimization will be also highlighted.
Subsequently the paper will bring global examples of the leading utilities renewable transformation journeys. Finally, the paper brings the importance of digital technologies like Internet of Things (IoT), Artificial Intelligence (AI), Digital Twin etc. towards building a distributed energy ecosystem (like solar and storage together) and emergence of collaborative business models with prosumers like Virtual Power Plants (VPP) which are a win-win scenario for both utilities and prosumers.

Keywords— (Prosumers, Sustainability, Virtual Power Plant, Distributed Energy Resource, Renewable ecosystem, new business model, carbon neutrality)

I. INTRODUCTION

Utilities renewable journey with prosumers at the center has created a plethora of new opportunities across the value chain of generation, transmission, distribution, retail and behind the meter services.

In the generation side, prosumer owned renewable's participation in the utilities Virtual Power Plant (VPP) program will meet the Gentailer demand of the new generation capacity and may defer investment in new generation. This will also help the utility to meet its sustainability agenda and reduce the greenhouse gas emission.

In the transmission & distribution side, the joint journey will reduce the cost of peak load management by avoiding the high cost of power purchase from the market during the critical peak time. Utilities can use the power from prosumers to manage the demand during the peak period. [1], [7]

In retail and behind the meter service, renewable is the foundation stone for the new business models of utilities where prosumers will be rewarded for their participation in the utilities renewable program like Bring Your Own Battery (BYOB). This will be a new source of the revenue for the utilities also where utilities can manage and operate the renewable installation of the customers.

II. GLOBAL CONTEXT

Renewable energy is the biggest focus area for the utility industry today along with the prosumer empowerment. Utilities today are looking for new roles and responsibilities while making a transition from the energy seller to the affinity service providers. Sustainability act as a key building block in this utility's transformation journey.

As part of Paris Accord related to climate change, limiting global warming to 1.5 degrees Celsius requires that global annual greenhouse-gas emissions be cut by 50% of current levels by 2030 and reduced to "net zero" by 2050.

Today's Utility is thinking to integrate circular economy principles into its business models; designing 100% of its products and processes using sustainability criteria including the principles of green chemistry; and reducing GHG emissions by 50% by 2030, including sourcing maximum percentage of its electricity from renewable energy.

Distributed and renewable energy is on an increasingly aggressive path for growth. Long-term contracts, priority access to the grid, and continuous installation of new renewable plants underpinned renewables growth despite lower electricity demand, supply chain challenges, and construction delays in many parts of the world.

Multiple utilities are setting 100% clean energy goals, creating new demand for workers to build solar panels and wind turbines. Planning for the inevitable coal-to-clean economic transition can create new economic opportunities in every corner of the country – and some forward-thinking policymakers are already heeding this lesson.

III. Macro and Micro Trends

We foresee there are multiple key macro & micro themes shaping the Net Zero journey for the Utilities –

- Sustainability Agenda from the Regulators – across the globe regulators are keeping multiple sustainability agenda/target for achieving the Net Zero. For example, the Reforming Energy Vision (REV) in US has agenda of reducing greenhouse gas emissions by 40% from 1990 levels along with setting up a 50% renewable energy portfolio for the generation of New York's state electricity by 2030. [1]
- Cost Competitiveness in next-generation clean energy technologies – for example, the levelized cost of electricity generation from onshore wind and solar projects has decreased significantly today, thanks to the technology advancements and reduce equipment costs. For an industry that has largely focused on solar and wind, private investment and pilot projects combined with Policy support could help expedite commercialization of emerging technologies such as green hydrogen, advanced batteries, and other forms of long-duration storage.
- Consumer Empowerment – The transition of the consumers to prosumer is also shaping the net zero journey as prosumer today is actively participating in the utilities VPP journey by own power generation and prompt response to demand requirements.
- Energy Consumerization – There is consumerization of the energy technologies among the prosumers such as adoption of roof top solar, electric vehicle or battery scale storages.
- Fusion of energy & exponential technologies – We also see there is fusion of the energy technologies with exponential technologies such as Internet of Things (IoT) for the digital twin of the renewable operation or blockchain for managing the EV infrastructure billing.
- Impact on the Return to Shareholder (RTS)– We also see some instances of the positive correlation between the RTS and the utilities Renewable Portfolio.
- Ecosystem approach with Prosumer – across the globe we observe utilities are adopting an ecosystem approach with prosumers for achieving the net zero. For examples, customers enrolled in the renewable target program will receive billing credits for surplus energy contributed to the grid and incentives for total energy generated from the renewables like solar.
- Circular Economy - transition to renewable energy and materials. A circular economy decouples economic activity from the consumption of finite resources. The circular economy is a systems solution framework that tackles global challenges like climate change, biodiversity loss, waste, and pollution. This is ensuring the accelerated establishment of renewables journeys through collaboration with related entities and partners with long-term planning to achieve global net-zero vision.
- Carbon Neutrality - latest technologies can provide zero-carbon electricity and longer-term seasonal electricity storage, ease grid congestion, stem renewable curtailment, boost reliability, and facilitate integration of solar and wind into the grid while supporting goals for 100% clean energy.[2]
- Technology trends - Ranging from physical technologies (wind turbines, photovoltaics, electric vehicles, battery storage, microgrids, and other distributed energy resources), to virtual technologies like artificial intelligence and big data, there is a holistic rise in technology. Such technologies are opening the door for new opportunities and business models that could change the energy and sustainability industry dramatically. [3], [4]

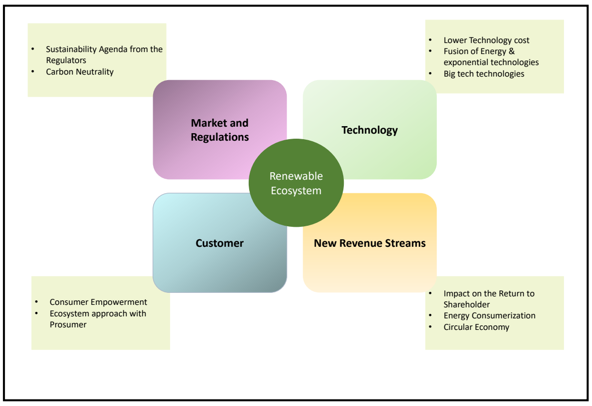

Fig. 1. *Micro and Macro Trends Shaping Utilities Renewable Journey*

IV. Transformation across Three Different Horizons and Key Benefits

We foresee utilities are making their sustainability journey across three different horizons.

- Horizon 1 – emphasizing on internal business processes to reduce the greenhouse gas emission. Some of the key examples are generation portfolio optimization, integration of renewables, energy consumption optimization and benchmarking to mention a few.
- Horizon 2 – building a new business model with prosumer at the center. Some of the key examples are e-mobility, demand side management, etc.
- Horizon 3 – establishing energy value ecosystem among utility, prosumer, and partner. Some of the key examples are virtual power plant (VPP), bring your own storage, etc.

Few examples towards this prosumer centric journey are-

In Australia, energy retailers are offering their end consumers, or prosumers, billing credits for the first couple of months of enrollments for harnessing the power of their solar batteries as part of the Utilities Virtual Power Plant (VPP) program.

In the US, utilities are establishing large-scale community solar programs such as 'Solar Together' - a subscription-based program allowing customers (commercial, industrial, and residential) to access solar-sourced power without the need of equipment.

The following diagrams highlights the utilities sustainability journey across the above 3 horizons.

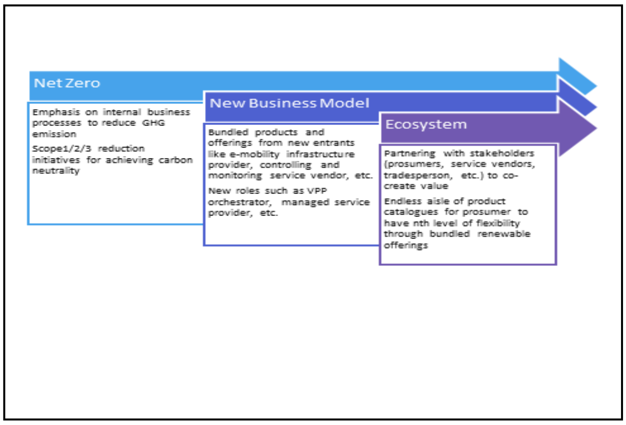

Fig. 2. *Utilies Journey Across 3 Horizons*

While utilities are making their sustainability journey across these 3 key horizons, some of the key benefits are-

- Increased stickiness to ensure customer delights – creates a 'moment of truth' for the renewable journey for the end prosumers. Consumers can also earn revenue by participating in the utilities VPP journey
- Renewable Integration- allow the utility to integrate the new energy sources with the old /traditional ones and create an optimized portfolio.
- New Source of Revenue – there can be several new sources of the revenue for the utilities such as operation & monitoring of the consumer renewable systems
- Peak Load Management- help utility to manage the peak load by utilizing the available energy from the prosumers
- Deferred Capital Investment- utilizing the prosumers power will also help utility defer the capital investment in generation
- Meeting the Sustainability Agenda – utility can achieve the sustainability agenda as defined by the regulator.

V. GLOBAL EXAMPLE OF LEADING UTILITIES RENEWABLE TRANSFORMATION JOURNEY

As part of sustainable journey, it is evident that all the utilities will try and expand services to ensure maximum access to energy irrespective of customer category, their demographics, usage patterns, financial conditions, etc. With the introduction of renewable energy, the utility and their partner companies are investigating new opportunities keeping an eye on the sustainability goals.

Utilities across the globe are making their sustainability journey at the intersection of environment, economy, and society.

In environment, the focus is on achieving the carbon neutrality and phasing out from the fossil fuel plant. For example, many utilities across the globe have a target of carbon neutrality by 2045/2050 and phasing out from the coal by 2025.

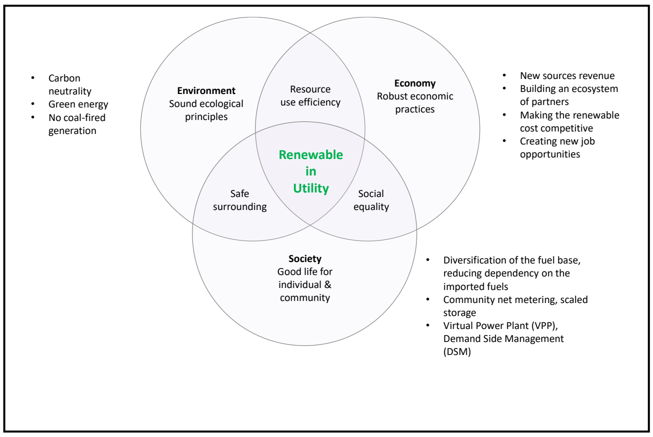

Fig. 3. *3 Key Themes of Sustanaibility*

In economy, the emphasis is on identifying the new sources of the revenue, making the renewable cost competitive and building an ecosystem of partners for new business models. For example, many utilities across the globe have a target of achieving x % of revenue from new energy sales and solutions.

In Society, the focus is on the consumer empowerment and diversification of the fuel base, thus reducing dependency on the imported fuels. For example, utilities are building multiple platforms like Virtual Power Plants (VPP), Bring Your own Battery (BYOB), community storage where prosumers can actively participate using its own generation.

We find following renewable initiatives by the global utilities in the intersection of environment, economy, and society across the globe.

- US – prosumer driven sustainable journey
- Europe – renewable as a key for grid flexibility management
- Australia – highest rooftop penetration in the world
- New Zealand – multi-product, multi-brand Gentailer with emphasis on renewable energy
- India – EV infrastructure extension [8]

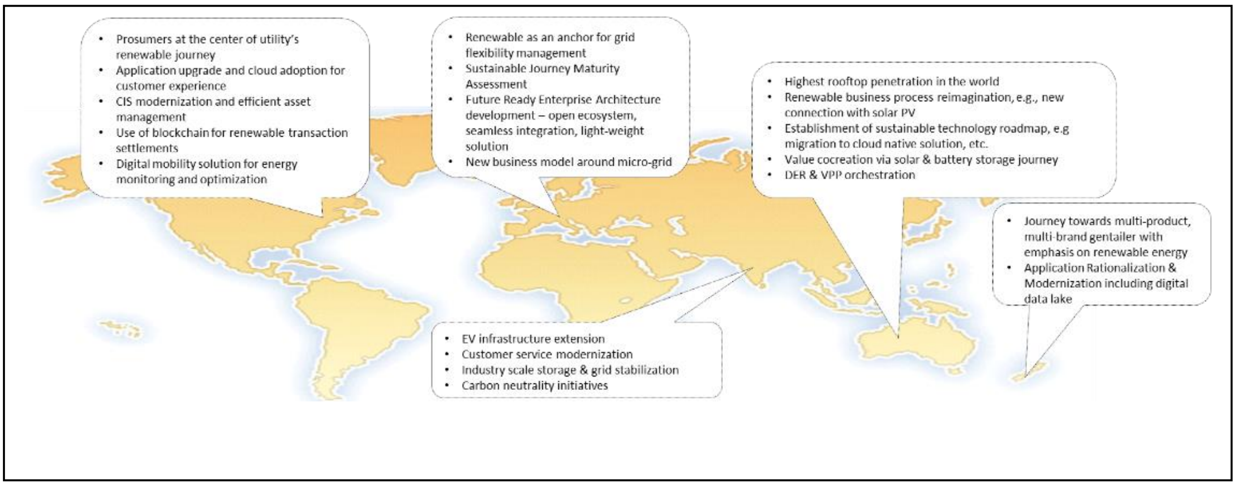

Fig. 4. *Renewable Initiatives in Utilities Across the Globe*

VI. DIGITAL TECHNOLOGUY FOR DISTRIBUTED ENERGY ECOSYSTEM

Rapid adoption of the renewables among the prosumers is making the utilities business model more latent and interconnected. Prosumers today are an integral part of the utilities renewables journey and play a very active role in defining the utilities renewable journey. The diagram below highlights how the business model is becoming a Mesh with multiple interconnected entities.

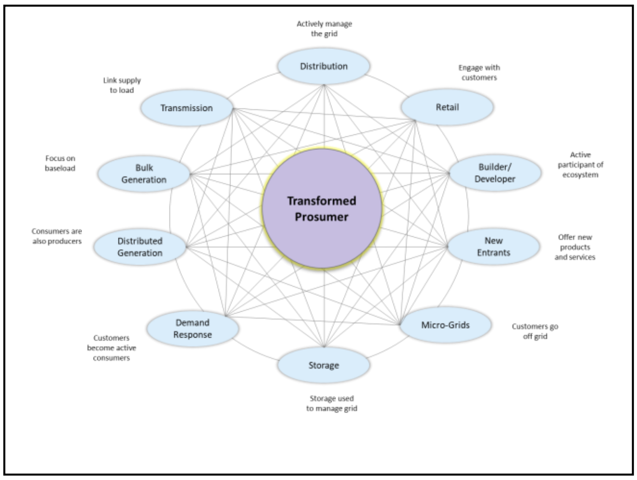

Fig. 5. *Interconnected Business Model with Prosumer at the Center*

This new business models also require multiple new need and business functionalities that utilities need to address to make the journey successful. For example, earlier the focus of the utility was reliability, affordability and efficiency, however the adoption of the renewable has added multiple new needs like flexibility, resiliency, and optimization. [4], [5], [6]

Digital technology plays a very important role to address the above new business needs. For example –

- Artificial Intelligence (AI) plays an important role across the utility value chain in addressing the business needs such as forecasting of the renewable, generation portfolio optimization, renewable bidding to the market, optimization of the renewable generation in the grid, pricing of renewable tariff to mention a few.
- Internet of Things (IoT) plays an important role in capturing the renewable asset conditions, remote operation, and monitoring of the assets, predicting the asset failures to mention a few.

However, the success lies in fusing the exponential technologies like - IoT, AI/ML, Cloud, Drone, 5G etc. with the energy technologies like - energy efficiency, distributed energy resources (DER), electric vehicles, storages to create exponential value for the customers. For example, it could be Energy efficiency with AI for Demand Side Management (DSM) program, or it could be DER with IoT for remote monitoring of renewable.

Efficient data capturing and storing is key to manage huge volume of data generated out of the renewable assets and VPP/DER orchestration. There are different sources from which structured/ unstructured data can be received, examples are – voice/speech, visual, manual, electronic records, radio frequency signals, etc. Some of this data may need to be ingested and processed real-time to get better insights. All types of data will need to be transformed and prepared for subsequent delivery and consumption.

Figure below shows an example of AI/ML based data-driven logical architecture which can enable several renewable use cases such as intelligent grid management, energy optimization, VPP/DER integration for demand side management, IoT for renewable assets and their predictive/prescriptive maintenance, etc.

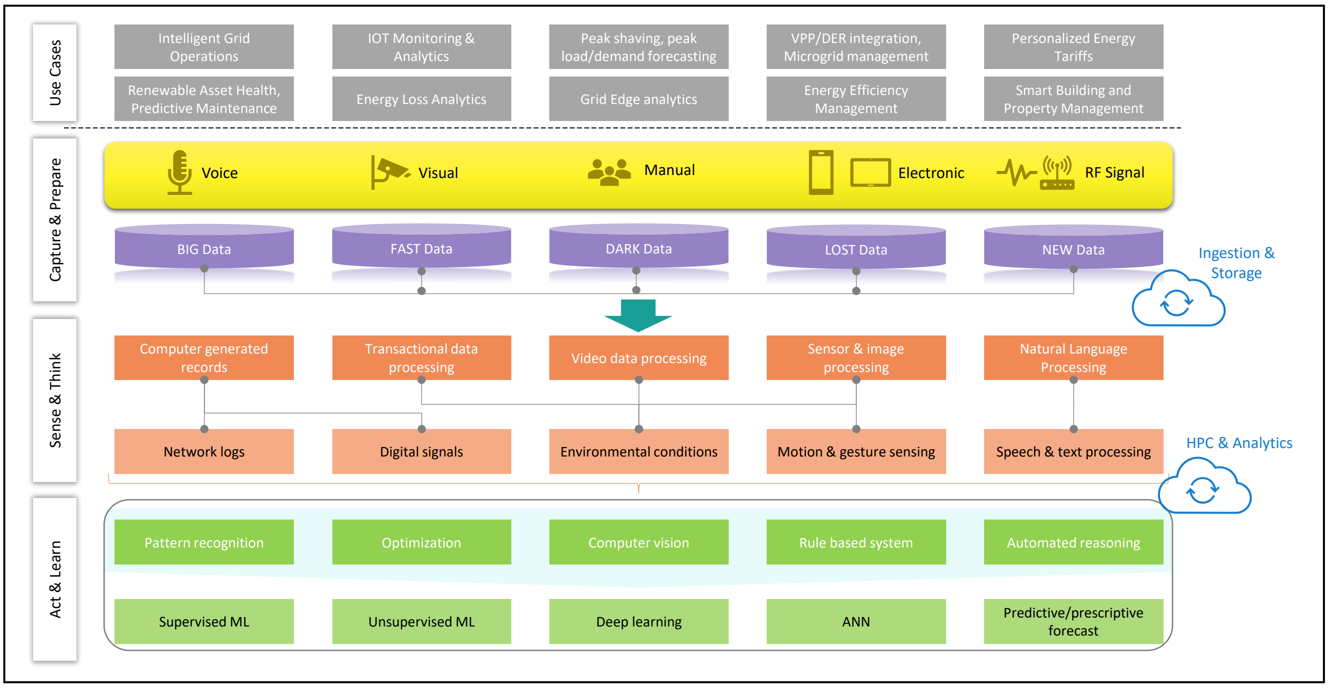

Fig. 6. *Technology Empowering Renewable Ecosystem*

Now-a days, cloud-based data ingestion, storage and high-performance computing are getting significant traction in this space. This enables the data warehouse to help generate analytical outcomes and support decision making to meet the business needs.

AI/ML powered learning and optimization will then bring-in more accuracy in forecasting (e.g., load vs generation profile forecasting), predictive schedules of renewable asset maintenance, to mention a few. The picture below depicts the holistic view on business imperatives that are supported and enabled by new-age technologies to generate exponential value for the prosumers.

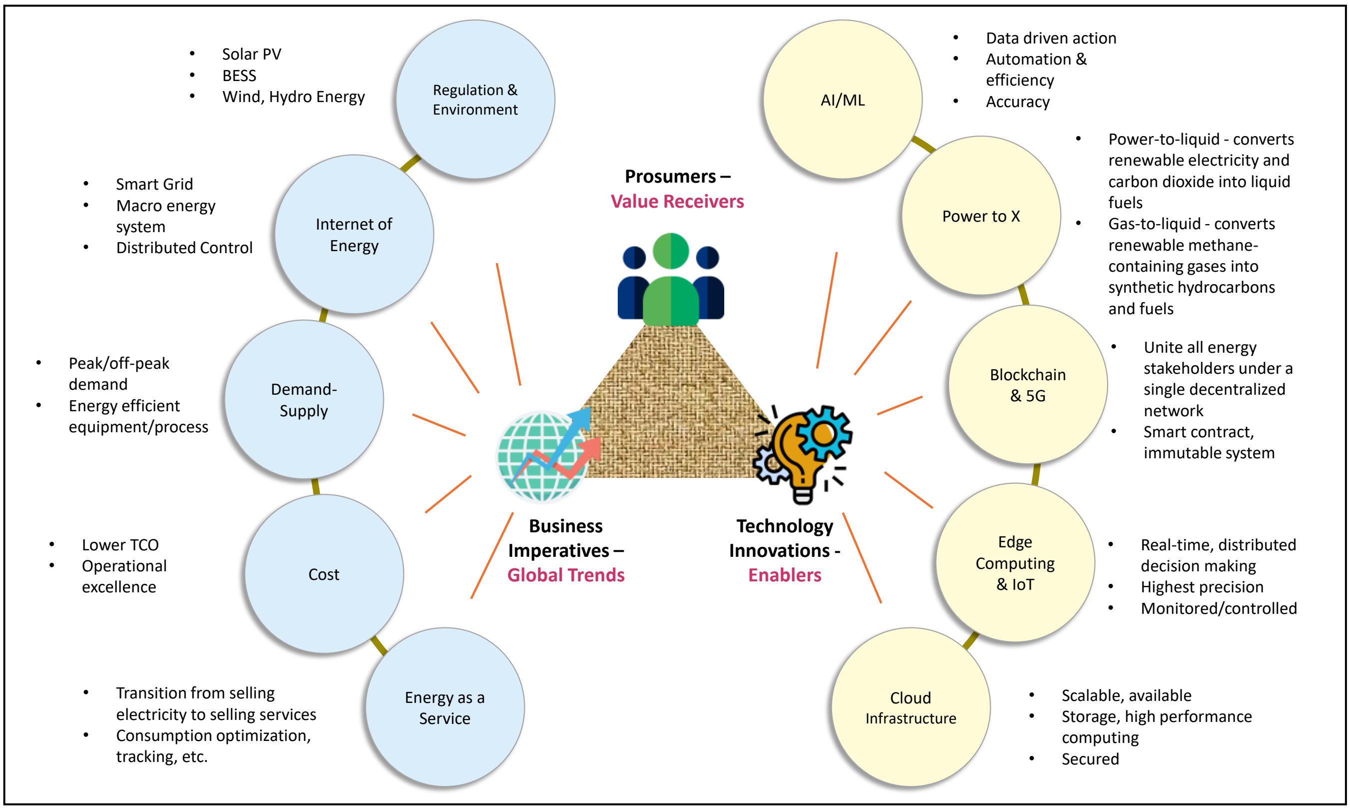

Fig. 7. *Business Imperatives vs Technology Enablement*

VII. CONCLUSION

Sustainability is the cornerstone for utilities' roadmap and future endeavor. Success of utilities sustainability journey depends on 4 key factors – Prosumer involvement, identification of the right ecosystem of the partners, investment from utility and technology enablement. Utility should proactively involve the prosumers in its renewable journey from the beginning. Prosumers can generate its own power and can contribute to the Utilities journey or can voluntarily pay in their electricity bill to contribute to utilities renewable vision.

Venturing with customers is a win-win situation, both for customers & utilities in terms of speed, risk, and capital. The success will also depend on identifying the right partner ecosystem – depending on the geographical location, customer behaviors, regulatory prevalence and other influencing parameters, utilities are poised to make partnership with entities within or beyond the industry vertical. Accordingly, utilities are shaping their roadmaps with judicial priorities on the capital investment planning. As the customer will have more choices, they will look for more innovative and attractive offerings which can make their life affordable and convenient.

Last but not the least, Technology will be the key enabler for this transformation journey – the advent of cutting-edge technology solution and their appropriate implementation will be important for the sustainable journey of utilities. Lowering the total cost of ownership and operational efficiency for the partner collaboration are main pillars of this approach. Leveraging the benefits of cloud is being harnessed along with the AI/ML capability to accelerate processes in decision making and optimization. Stakeholders are being empowered with relevant context to make informed decision at the right moment. We envisage further evolution of this renewable journey to establish a well architected balanced ecosystem along the way , as the interests grow for all the parties involved and they join hand-in-hand towards a more sustainable & collaborative business model.

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Short Term Load Forecasting for Dynamic Clusters using Deep Learning

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***Abstract*—Electrical load forecasting is critical for utility planning, with short term load forecasting (STLF) used in short term planning like sale and purchase of power and adjusting generation to match expected demand. Current STLF frameworks are limited to static clusters where the combined load can be physically measured through a device. The wide availability of Advanced Metering Infrastructure (AMI) data enables a bottom-up approach where clusters can be dynamic. In this paper, we propose a framework capable of performing STLF for dynamic clusters. Anonymised AMI data from Nevada, USA was used for the development and testing of the framework. This framework was also evaluated on the New York Independent System Operator (NYISO) load forecasting task for universal benchmarking.**

Keywords—load forecasting, deep learning

I. Introduction

Short term load forecasting (STLF) is used for demand-side management, sale and purchase of power, peak load reduction etc. The challenges faced in STLF conventionally have been the non-linear and complex nature of the predictions that have to be made [1]. These challenges have been further amplified with fast-growing adoption of EVs, home batteries, and renewable energy sources introducing uncertainty and variability in energy demand. They also segment consumers into groups primed for targeted grid management. Inaccurate STLF hampers grid management operations leading to increased operational costs and scenarios of significant surplus or shortage of energy.

Current STLF frameworks are limited to the levels where aggregate demand can be measured. Such frameworks overlook massive potential for a smart grid.

The STLF framework we propose, employs a bottom-up approach for cluster creation using Advanced Metering Infrastructure (AMI) data. Techniques used for STLF have evolved over time from smoothing and statistical models like ARIMA to using neural nets and machine learning. As a part of the proposed framework, we present a GRU cell-based encoder-decoder architecture for performing STLF for 1 to 14 days ahead at an hourly level.

II. Data Preparation

A. Datasets

Nevada Dataset: The dynamic clustering framework has been developed using consumer AMI data from Nevada.

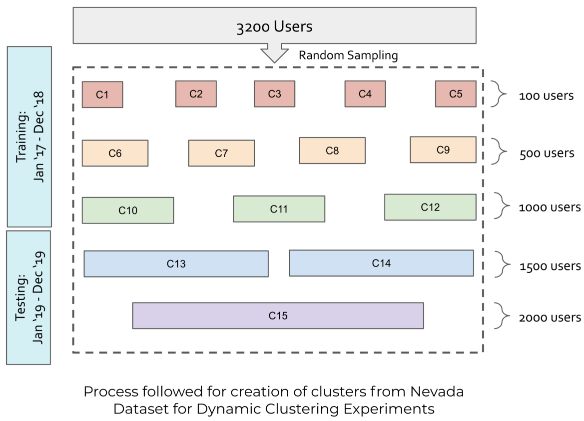

Figure 1. Nevada dataset preparation

NY-ISO Dataset: The model was also tested on NY-ISO data for benchmarking.

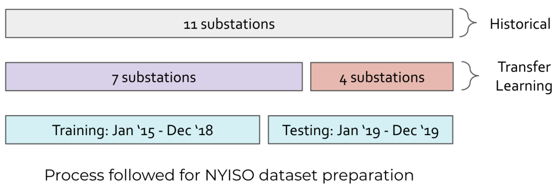

Figure 2. NY-ISO dataset preparation

Weather Dataset: Weather data was collected from weathersource.com [4] APIs.

B. Train and Test set creation

The features shown in Figure 3 were used to generate training and test examples. Each n-day ahead split had an n-day encoder sequence and an n-day decoder sequence. The Nevada set had ~6,400 training examples and ~3,200 test examples, and the NY-ISO set had ~1,400 training examples and ~300 test examples for each n-day ahead split.

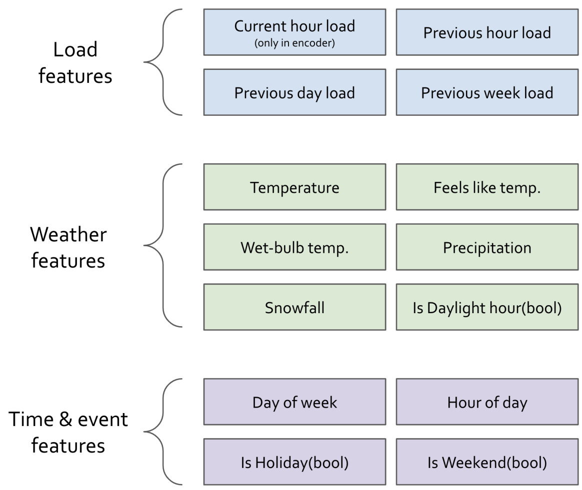

Figure 3. Hourly Feature Vector

III. METHODS

A. Framework

The dynamic STLF framework we propose is a sophisticated approach that takes any combination of consumers, selected by any criterion, as a cluster, and performs load forecasting. The clusters can be of any size needed. Once the cluster is defined, the framework can be used in three different ways depending on the amount of data available and time constraints.

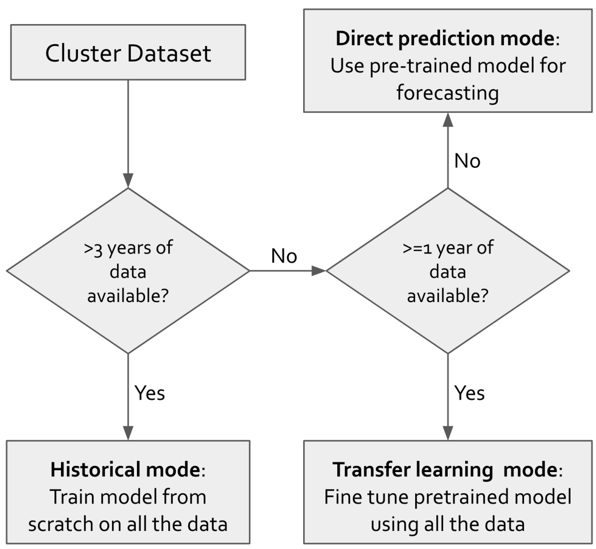

Figure 4. Training workflow

B. Architecture

In the last few years, the use of deep learning techniques for STLF has gained more extensive attention. We propose a Gated Recurrent Unit (GRU) cell-based encoder-decoder architecture for this task. The encoder-decoder architecture has been pivotal in sequence to sequence modeling tasks in particular with machine translation.

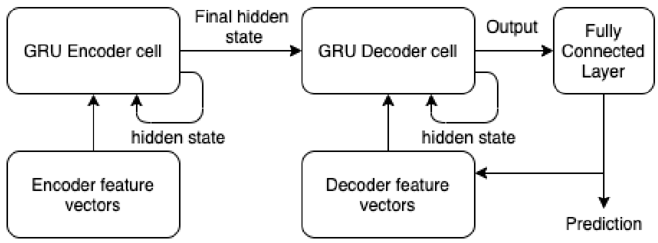

Figure 5. Encoder-decoder architecture

Architecture Description: For each hour in the encoder sequence, the GRU encoder cell is run recursively. The final hidden state is input to the decoder as the initial hidden state, which runs recursively on the decoder sequence. The hidden state from the decoder is passed through a fully connected layer to generate the forecast for that hour. This output is also used to populate the load features for further steps in the decoder sequence.

Training: Batch normalisation is used to ensure the generalisability of the model and avoid saturation. Training uses Adam optimizer and smooth L1 loss [2] defined as -

$$loss = \begin{cases} \frac{1}{2}(x-y)^2 & |x-y| < 1 \\ |x-y| - 0.5 & otherwise \end{cases}$$

It is less sensitive to outliers than mean squared error loss and can prevent exploding gradients.

Advantages of the architecture: The encoder-decoder architecture is very powerful and flexible. It is capable of learning highly complex non-linear patterns in the data. A single model can handle all n-day ahead predictions and allow transfer learning to suit any custom task.

The GRU cell-based architecture provides the benefit of being relatively faster to train than an LSTM cell while maintaining comparable accuracy.

IV. RESULTS AND DISCUSSION

The metric used to measure accuracy is Mean Absolute Percentage Error (MAPE). MAPE is calculated as the mean of the absolute percentage error for all predictions in the test set.

A. Nevada Dataset Evaluation

The Nevada dataset evaluation was done for clusters of different sizes to capture the forecast's accuracy with varying cluster size. This evaluation demonstrates the performance of the dynamic clustering framework. The errors are calculated for a 14-day ahead forecast. These results show lower errors once the cluster size is big enough. Some user level factors might not be captured in the model which get evened out in bigger clusters.

Cluster Size	Cluster Count	14-day ahead forecast MAPE		
		Avg	Min	Max
100	**5**	12.39	5.95	28.57
500	**4**	8.85	4.07	16.44
1000	**3**	8.77	4.23	16.32
1500	**2**	10.42	4.23	19.88
2000	**1**	9.95	3.94	19.01

Table 1. Results for Nevada dataset

B. NY-ISO Dataset Evaluation

The NY-ISO dataset was used to evaluate the different modes of running the framework. The historical mode was evaluated on aggregated data from all 11 substations. This evaluation also provides universal benchmarking on static cluster-based STLF. For the direct prediction and transfer learning mode, the base model was trained on data from 7 substations, and then the direct prediction or transfer learning was done using data from the remaining 4 substations. For each mode, the numbers have been reported for 1-day ahead and 14-day ahead forecast.

The results show that the framework works well with conventional STLF for static clusters. These results are also an improvement on the 1-day ahead forecast MAPE metrics reported by NY- ISO, which is around 3% [3].

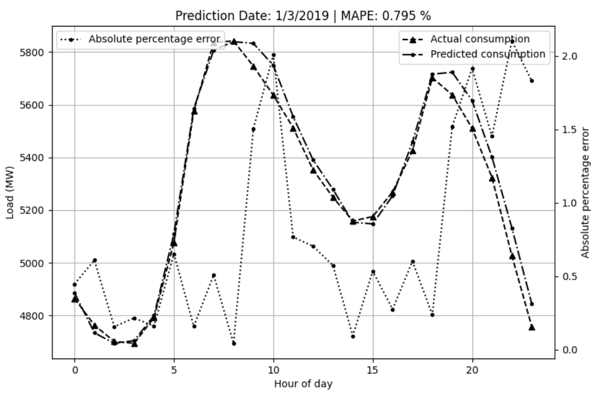

Figure 6a. 1-day ahead NY-ISO prediction sample

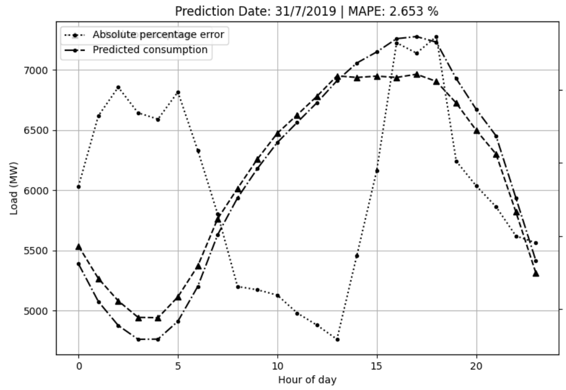

Figure 6b. 1-day ahead NY-ISO prediction sample

1-day ahead forecast MAPE			
Mode	**Avg**	**Min**	**Max**
Historical	2.502	0.528	18.728
Base Model	2.452	**0.423**	18.716
Direct_pred	2.873	0.65	17.482
Trf_Learning	**1.88**	0.501	**15.74**

Table 2. Results for NY-ISO dataset for 1-day ahead forecast

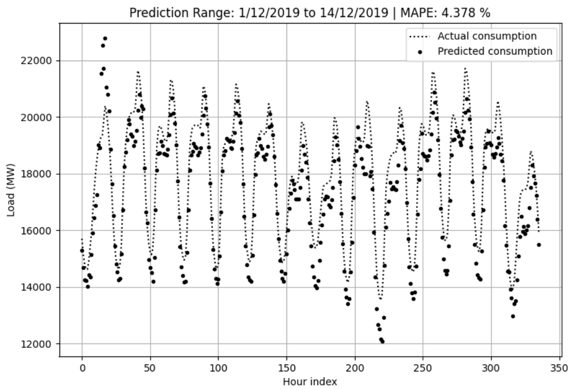

Figure 7a. 14-day ahead NY-ISO prediction sample

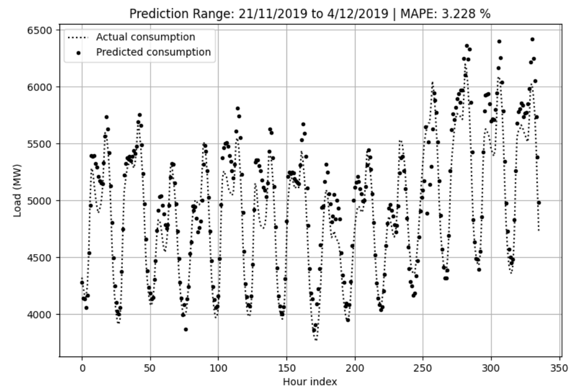

Figure 7b. 14-day ahead NY-ISO prediction sample

14-day ahead forecast MAPE			
Mode	**Avg**	**Min**	**Max**
Historical	4.632	2.467	10.235
Base Model	4.738	2.707	**8.317**
Direct_pred	5.035	3.241	8.659
Trf_Learning	**4.061**	**2.006**	8.98

Table 3. Results for NY-ISO dataset for 14-day ahead forecast

V. Conclusion

This proposed framework presents opportunities to take smart grid management to the next level by generating accurate forecasts for dynamic clusters. This capability can unlock decentralised dynamic pricing, more effective demand-side management and peak load reduction via targeted actions, and deep-dive analytics. The performance of the architecture on existing approaches for the conventional use case establishes the potential to use this for more accurate STLF, adding direct value to grid planning exercises. Overall the proposed framework encompasses a novel single point solution for accurate, scalable, and flexible STLF.

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Promising Business Models for EV Charging Stations

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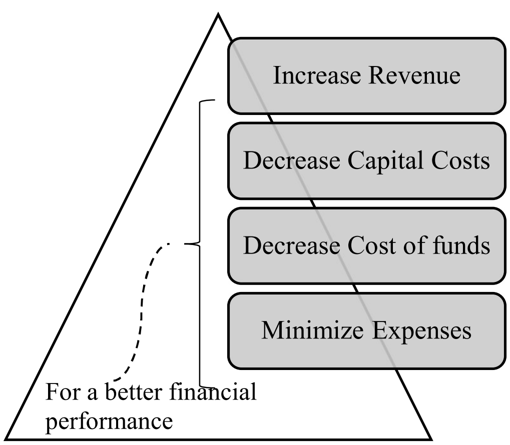
I. ABSTRACT

As EVs are becoming prevalent in the market, it is giving rise to new business models in vehicle energy. From commercial real estate developers to landlords of apartments or condos to entrepreneurs, many sectors are finding value in EV infrastructure. Here comes various business models to structure a profitable and sustainable charging station. Moreover, availability of charging facilities at public places is the key prerequisite for adoption and rollout of electric vehicles (EV). This Paper proposes various business models for creation of an enabling EVSE ecosystem for faster rollout of EVs.

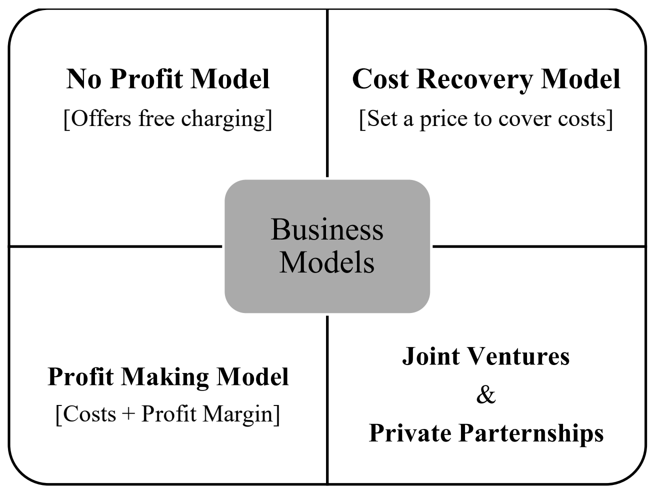
II. INTRODUCTION

Per Electricity Act 2003, resale of electricity requires electricity distribution license. Later Ministry of Power [MoP] has issued an order clarifying that EVSE's buying electricity from DISCOMs and selling to EVs is not considered as resale or trade of electricity. Now anyone can apply for new connections for EVSE and commence the business.[1] This order by MoP can help businesses, entrepreneurs, investors, utility companies and auto manufacturers to attract more customers and there by create a new revenue stream but in the present scenario, EVSE business is not viable for any entrepreneurs to invest.

III. WHAT CAN BE DONE?

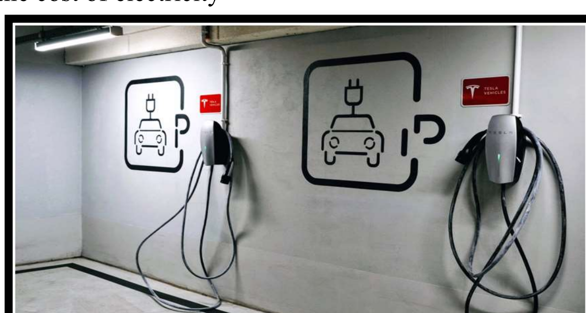


Now entrepreneurs and investors must build a strong and rigid business model that can attract capital, generate revenues greater than costs and get an appreciable return on capital.
Business models for an EV charging station can be broadly divided into four categories:



1. Offer free charging to attract drivers/ tourists/ customers. [No Profit Model]

This model can be implemented in restaurants especially those on highways (*Charging on the go*), office spaces, entertainment centers etc. It can help businesses to retain more EV customers and the revenue earned from these EV customers can offset the cost of electricity



EV charging facility in an office
Pic credit: https://www.greenbiz.com/

Offering free charging also shows the business commitment towards conservation and sustainability further helping in improving the brand recognition and gain positive publicity.

> *Consider the below findings from a recent study, which shows how customers really care about a company's commitment to sustainability:*
>
> a. *87% say a commitment to social or environmental issues gives a company a positive image.*
> b. *88% show increased loyalty to a company that cares about environmental and social issues.*
> c. *92% of millennial consumers say they're more likely to trust a company that supports social or environmental issues.* [2]

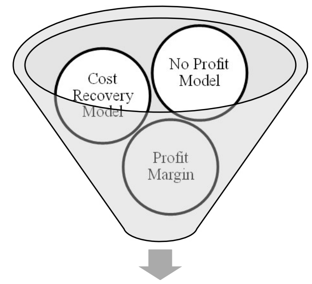
Out of the four models, this is the simplest one because you need not worry about billing the customers. Maintenance and charging costs can be placed under business expense. Revenue will come from increased traffic.

2. Set a price to cover the costs [Cost Recovery Model]

Unlike the above model, a fee is charged to use the charging points. The fee can comprise the operational costs and an additional margin to cover the hardware and installation costs. This model is more suitable for rapid chargers. If a driver is travelling a long distance, then due to the time constrain, the driver would prefer to pay and get access to fast chargers.

In general, more competitive prices will attract drives to the charging stations. And if a tariff is charged, then it's crucial to make the billing method easy to understand, access and use. Ex: getting contactless payments and mobile applications would help in the seamless operations and the charging stations.

3. Set a price that covers costs and profit margins [Profit Making Model]

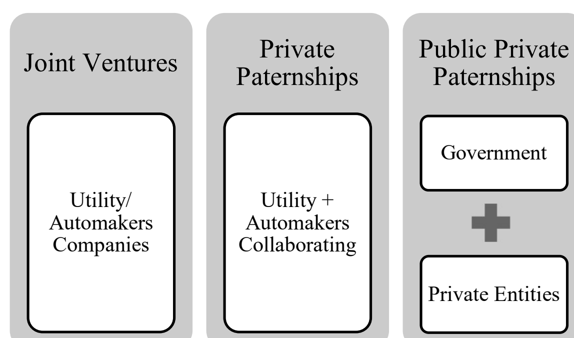


Profit Making Model

An extra fee is charged, when compared to the above model, to provide a profitable revenue stream. This can still attract and retain some EV customers. Customers who are willing to pay over the cost of electricity under some special circumstances such as when they have limited option or need to charge quickly. This is more suitable for fast/rapid chargers, roadside assistance, battery swapping and other emergency requirements.

On the flip side, this model can raise concerns over the damage to the reputation, if the business is unfairly exploiting the customers by setting high rates. Also, as the price increases it disincentivizes the customer to charge their vehicle.

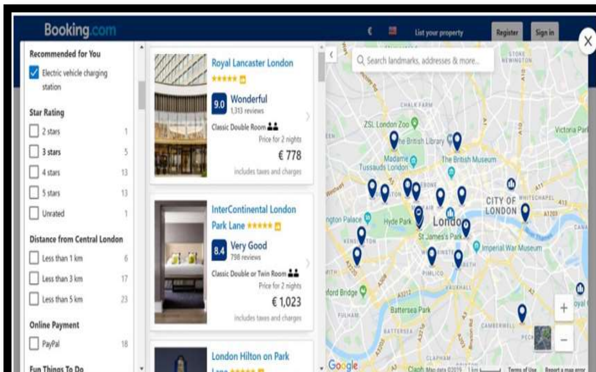
4. Joint investments or private partnerships



Through joint investments and private partnerships there is an opportunity to improve the financials, brand value, tourist revenue etc. Private Utilities and Automakers companies are venturing together to set an effective EV ecosystem across the country. This can create a positive brand image, promote "clean energy" marketing, and can also help automakers in selling more EVs. On the other hand, few other start-ups and companies are collaborating to develop an efficient EV charging infrastructure.

EV Charging point outside a restaurant
Pic Credit: https://rddmag.com/

It's worth noting that from now on charging points will become one of those things that a customer experiences when visiting any business place (hotel, movies, restaurants, library etc.)

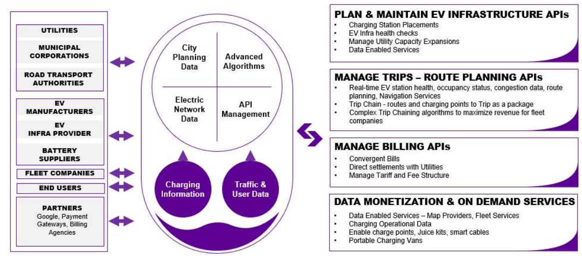


EV Charging Station Filter on Booking.com
Pic Credit: www.booking.com

Apart from simply providing a charging point at the business, one can enhance the customer experience further by integrating IT solutions in their business model to improve the look and feel, ease of use, control the pricing and enable seamless payments.

IV. PROPOSED IT SOLUTION

IT-OT and analytics backed solution, *Energize e-mobility*, can plan, simulate & monitor the electric vehicle process based on charging network conditions, manage charging, billing, settlement, manages trip chaining of fleet companies and enable charging infra services with OEMs.



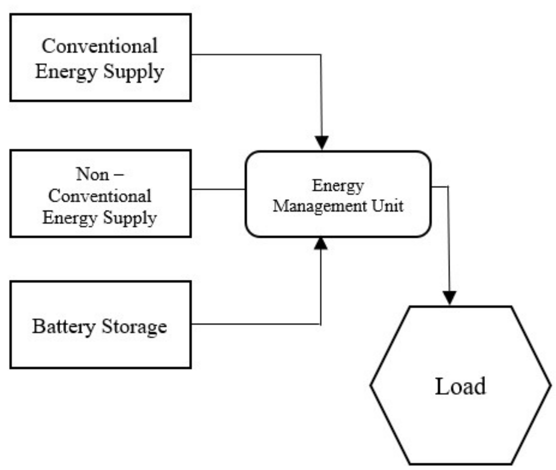
"Energize"

Such solutions can bring all relevant stakeholders on a single platform which includes B2C services for EV end users and B2B customers like, OEMs, Infra provides, Fleet Customers etc. and leveraging it:

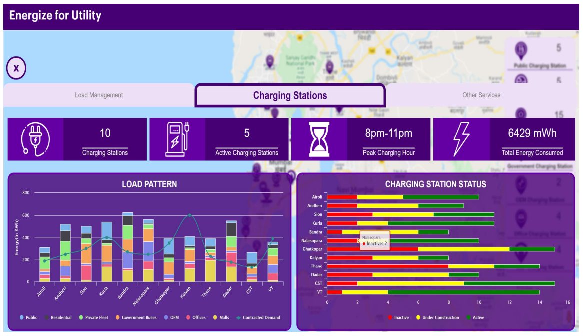
a. *Utilities* can manage load, monitor usage by the charging stations and provide other services such as non-utility services, third-party vendor support etc.

   Energize uses a load management algorithm, which implements Demand Side Management (DSM) Techniques such as peak clipping, load priority Techniques using Artificial Neural Network (ANN) to integrate both Conventional and Non-Conventional sources of energy. The current challenge is to manage/ estimate load and supply in the real time.

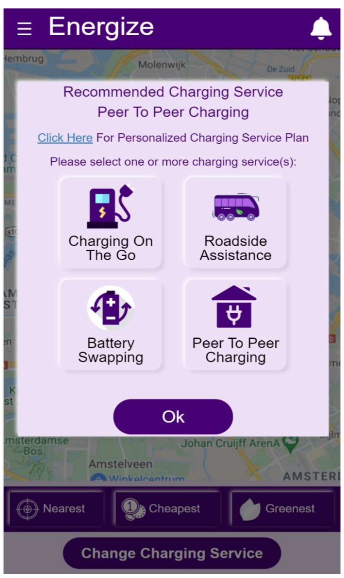
   An Energy Management Unit (EMU) can monitor energy consumption and control the loading with greater ease. It can effectively manage the loads by connecting Conventional, Non-Conventional and battery storage energy systems.



   Energize uses an ANN based prediction model, ANN is proven to be a potential methodology for modelling real-time (hourly and daily) energy consumption and load forecasting. [3]

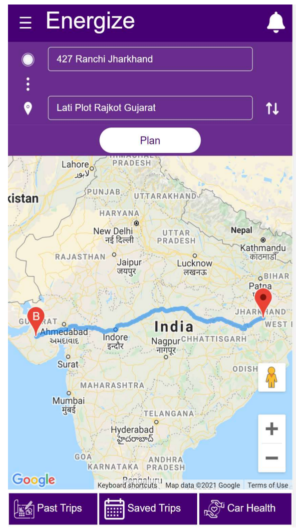


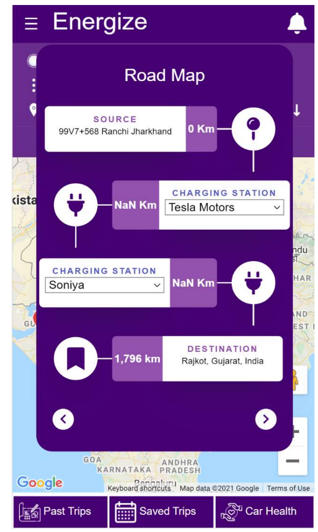
b. *Businesses* can improve customer experience as this can be a one stop solution to an EV end user by covering all probable services which includes various charging services (like, pre-booking a public charging point, renting out home charging point, battery swapping and charging on the go facilities), cumulative billing, information of dynamic tariffs, real time EV Health status and other services like EV rental, maintenance, insurance etc.



c. *Monitoring & Infrastructure planning*: Leveraging traffic data along the roads to create an automated solution that can find the best possible area/ location that need EV charging stations/ points along with monitoring the performance of different charging stations using data of occupancy rate, revenue generated and environment benefits.

Energize is backed algorithms such as spatial indices, which can arrange geometric data and can help in searching the data efficiently by not compromising on the performance. [4]





V. CONCLUSION

When considering a business model for an EV charging station, it's crucial to understand which model would be effective for the customers and the location where the charging station is situated as well as the costs incurred.

For such a young industry, flexibility and scalability would be critical. It's key to work with charging provider to understand the location and make tailored recommendations that would be most effective. When embedded with an IT solution, EV charging station and various other stakeholders can further boost their customer experience, revenues and enable a seamless charging experience.

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Analysis of distributed generation connected to distribution network

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***Abstract*— The traditional energy structure of our country has a serious issue of poor power quality challenges with the end consumers. With the energy problems increasing, seriousness on distributed generation is growing rapidly as a solution towards environmental protection, clean, reliable power supply, and flexible generations with wide range of applications against small investment. Distributed generation (DG) can be incorporated as a system improvement schemes on power distribution network having traditional feeders and substations. With the rapid development of renewable power such as wind, solar photovoltaic on the grid connected systems, DGs can play an important role with strategic significance for achieving better power quality. DGs has the advantages of adding capacities in modules, cleanliness, and reproducibility, which makes it more effective for the power systems. The capacity of DG can be few kilowatts to hundreds of megawatts. With abovementioned advantages such as modular design, better power quality/reliability, overall system improvement. So, it is very important to study the influence of adding DG on distribution network.**

Keywords*— *Distributed Generation, Wind power generation, Photovoltaic generation, Distribution Network Introduction

With the development of traditional energy sources and some drawbacks of the traditional generations, the distributed generation has attracted the worldwide attention for its environmental protection, efficiency and flexibility. As the distribution generation becomes more and more important, In the future electric system , distribution networks will evolve from current passive netw orks to active netw orks which will include a number of different types of distributed generation resources, such as fuel cells, reciprocating engines, distributed gas turbines and micro-turbines. There is often a lack of familiarity with DG technology, which has contributed to the perception of added risks and uncertainties, also to a lack of standard data, models, and analysis tools for evaluating DG or standard practices for incorporating DG into electric system planning and operations Nevertheless, DG offers potential benefits to electric system planning and operations. Using DG to meet local system needs can greatly reduce the congestion in the transmission networks and add up to improvements in overall electric system reliability. Also, DG can be used to decrease the vulnerability of the electric system to threats from terrorist attacks, and other forms of potentially catastrophic disruptions.

I. DISTRIBUTION GENERATION

DG can be defined as an electric-power-generating unit that is installed near the load center. By installing a DG near load centers, electric power transmission lines are bypassed thus bringing the generation closer to the load centers. A conventional electric supply system is a centralized system comprising generating units, transmission lines, and the distribution system. A conventional power system has poor reliability due to its complex configuration. A fault at one location can make the whole feeder trip, due to which all consumers connected at that feeder are affected. Therefore, with the help of modern technologies, power systems are changing, and new techniques are being implemented to make the current power systems more reliable. A DG uses on-site power generation, and before it is connected to an electric distribution network, it feeds the distribution system with information about the exact location, its type (either non- conventional or conventional), and, most importantly, the size of the DG which are all are important parameters to be considered.

Integration of distributed generation (DG) into the distribution systems offers many advantages and disadvantages to the distribution network. Increase in fault current and changes of power flow from unidirectional to bi-directional are the major two impacts of DG on the distribution networks, and these affect the existing protection of the distribution system relay, especially the over-current relays. Therefore, the impacts of DGs on the existing distribution system must be thoroughly investigated in order to ensure the stability and reliability of the system. The integration of DG into the distribution network has a great impact on the steady-state and transient behaviour of the network which depends on the DG capacity and penetration levels, type of generator, the method by which the generator is interfaced with the network and the location of the connected DG, just as in the case of capacitor and or phase measurement unit (PMU) placement. The steady state behaviour of the network describes the healthiness of distribution network before and after the integration of the DG. This is carried out by load flow analysis on the network, while the transient behaviour of the network has to do with the stability and the setting of the protection relay which is a major concern in this research work. Among all other challenges affecting the integration of DG into the distribution networks, protection issues are considered one of the major concerns because they are directly related to the system's safety and reliability.

DG has positive and negative impacts on the distribution networks. DG positive impacts are as follows, improved the voltage profile, improved power quality, and reduces the power losses in the distribution network; it eliminates the additional transmission and distribution capacity and improved reliability of the system among others. The negative impacts include lack of safety of the public and utility personnel, damage to the plant in the event of unsynchronized reclosure protection performance degradation, etc. The integration of DGs makes the distribution network no longer operate as a passive system but now operates as bidirectional power flow which may affect the network protection. This could lead to lack of relay coordination among the different protection schemes of the system. Therefore, the traditional protection schemes used in the distribution system need to be re-evaluated or reset with the integration of DG. However, before the protection issues are considered, it is very necessary to ascertain the healthiness of the existing distribution network with and without DG connection. Emphasizes here are on the power losses and voltage profile at each bus.

II. POTENTIAL BENEFITS OF DISTRIBUTION GENERATION

The interest in distributed generation in the past decades is induced by the potential benefits of distributed generation to the electricity system in technical and economic ways, at both the utility and customer sides. Research studies concluded that distributed generation technology can bring benefits far beyond the electricity network.

- DG can increase the electric system reliability. DG can improve the electric system reliability by both direct and indirect ways. In a direct way, DG can add to supply diversity and thus lead to the improvements in overall system adequacy. In an indirect way, DG has the potential to reduce outages caused by overloaded utility equipment's.

- DG can reduce peak power requirements (peak shaving). The national average load factor is about 55% . This means that electric system assets, on average, are used about half the time The installation and use of DG systems by customers. and/or by utilities can produce reductions in peak load requirements, and thus increase the load factor. This means D G can increase the average using efficiency of overall electric system assets. Since most investm ent decisions on new plants. or equipment's are based on the peak load requirements, reductions in peak load can displace or defer capital investments.

- DG can provide ancillary services like reactive provider, supplement reserve, etc. DG can be used to provide ancillary services, particularly those that are needed locally, such as reactive power, voltage support, but also those that contribute to the reliable operation of the entire system, such as back-up supplies and supplement reserves.

- DG can improve power quality. "Modern" DG systems are usually integrated with energy storage equipments, power electronics com ponents, and pow er conditioning equipments. These devices are very useful in addressing power quality problems. For example, they can protect sensitive equipments from voltage spikes or sags. They can also reduce the total harmonics distortion (THD) in electric system.

- DG can reduce the land use effects and rights-of-way. Energy generation transmission, and distribution have an obvious impact on land use. Under certain circumstances, DG can have positive land use benefits, including smaller land mass requirements, saving on acquisition costs, right-of-way, and land retention, and so on. A lot of DG systems are incorporated into buildings, in an engine room on a rooftop, or immediately adjacent, DG can reduce the CO_2 emissions and the pollutant emissions. "Modern" DG systems are using renewable resources or applying recycled energy technology. They can have significant impact on reducing the gas and pollutant emissions, and thus benefit the society on environmental protect and human health improvement.

- DG can provide the feasible solution to electrify the remote areas. DG technology can provide a feasible solution to electrify the remote areas by utilizing the local resources without great impact on the community. Those areas usually have too low population density to justify grid access or connection. DG technology is a far cheaper solution to supply power to those areas than grid extension. A number of micro-grids demonstration projects have been undertaken in the Greek islands.

- DG can reduce the vulnerability of the electric system to terrorism and provide infrastructure resilience. D G can improve electric system resilience through its reliance on large numbers of smaller and more geographically disperse power plants, rather than large central station power plants and bulk-power transmission facilities. During times of large-scale power disruption and outages, DG can continue to provide power to critical facilities.

III. IMPACTS ON VOLTAGE OF THE DISTRIBUTION NETWORK

The voltage level in a distribution network must be kept within a certain range, as some power system equipment and customer applications function only properly if the voltage is maintained within this range. The voltage range for normal operation In a distribution system voltage fluctuations occur when the load current flowing through the resistive and reactive impedances of the lines varies. The voltage variations in distribution networks without DG are caused by the variations of the active and reactive load in the distribution network over time. The fluctuations are generally larger towards the end of the line, due to the high impedance of distribution lines. Also, the voltage fluctuations are more expressed if the load is concentrated near the end of the (radial) system. Practically, for typical distribution lines the distance before the voltage drop exceeds the allowable fluctuation at rated current is only a few km. However, a line is normally not designed to operate at such loading levels. An in-depth analytical discussion of the impact of DG on the voltage profile in LV networks can be found as below

Traditionally, voltage control in distribution networks is performed in two ways:

- The control of the source voltage at the network substation by using tap changing transformers.

- The control of the reactive power throughout the system, by using shunt capacitors/shunt reactors [this is very seldom done in distribution networks], series capacitors, synchronous condenser or Static VAR Compensator (SVC).

DG can influence the voltage variations in two ways:

1. DG is operated in correlation with the local load requirements, meaning whenever the local load in the distribution network increases, the DG production increased as well and vice-versa. In this case, DG contributes to the

reduction of the variations between the maximum and minimum voltage levels, compared to the situation without DG. This mode of DG operation provides no challenges to the traditional voltage control approach.

2. DG power output is controlled independently of the local loading of the area. This control mode is implemented if DG operation follows price signals, which might or might not

correspond to the local load variations, or DG follows the availability of natural resources, like solar or wind power. In this case, DG might adversely affect the voltage control functionality of the network by increasing the variations between the maximum and minimum voltage level, compared to a situation without DG, since the minimum voltage level could remain (usually at a high load, no DG situation) but the maximum voltage level could increase, e.g. in low load situations with DG operating at maximum production and at a unity power factor.

As the distributed generations connected to the grid, the calculation of power flow will change. It's necessary to take different node types into consideration. Combustion engines and gas turbines and other traditional distributed power generally use the mode of synchronous generator. All synchronous generators and distributed generators connected to the grid by the voltage inverter can be processed into PV node. Photovoltaic system, some wind turbines, micro gas turbines and fuel cells are often connected to the grid by inverter. In this paper we chose the asynchronous wind turbines as the distribution generator to study the change of the voltage in the distribution network system. It can be simplified as a PQ node. Thus, the active and reactive power of the wind turbines are constant. The wind turbine runs at the rated output active power and reactive power and voltage runs in what mode should be analyzed according to the specific circumstance.

IV. IMPACT OF DISTRIBUTED GENRATION ON LOSSES

One of the major impacts of Distributed generation is on the losses in a feeder. Locating the DG units is an important criterion that has to be considered to be able to reach a better performance of the system with reduced losses, and this is used to reach an optimal performance of the network. Locating DG units to minimize losses is similar to locating capacitor banks to reduce losses; the major difference between both cases is that DG may contribute to both active and reactive power flow (P and Q) of the system while capacitor banks will only contribute to the reactive power flow (Q) of the system. Most generators in the system will operate at a power factor range between 0.85 lagging and unity, but the presence of inverters is able to provide a contribution to reactive power compensation (leading current).

The optimum location for placing the DG can be obtained with the aid of load flow analysis software that is able to investigate the location of DG to reduce the losses in the system. Considering feeders with high losses, adding a number of small capacity DGs. with a total output of 10–20% of the feeder demand will show a significant positive effect on losses and it will be reduced which is a great benefit to the system, but when deciding optimum DG location this is a theoretical decision as most of the DGs are owned by individuals, and the electric authorities or utilities do not have any influence on the locations at which the DG is required to be embedded. If the analysis shows that larger DG units are required other factors have to be considered in the study, such as feeder capacity due to the thermal capacity of overhead lines and underground cables because these elements of the network may not withstand the injected currents from the DG and will result in a poor or weak distribution system with a lot of weak points and the possibility of consequent undesirable consequences might take place.

V. IMPACT OF DISTRIBUTED GENRATION ON HARMONICS

DG can be a source of harmonics to the network; harmonics produced can be either from the generation unit itself (generator) or from the power electronics equipment such as inverters used to transfer the generated form of electricity (DC) to AC to be injected to the network. The old inverter technologies that were based on SCR produced high levels of harmonics, while the new inverter technology is based on IGBT's (Insulated Gate Bipolar Transistor) operating with the pulse width modulation technique in producing the generated "sine" wave. This new technology produces a cleaner output with less harmonics produced that should satisfy the IEEE 1547-2003 standards. Rotating machines such as synchronous generators are another source of harmonics; this depends on the design of the windings of the generator (pitch of the coils), non-linearity of the coil, grounding and other factors that may result in significant harmonics propagation The best or the most specified synchronous generators are that with a winding pitch of 2/3 as they are the least third harmonic producers when compared with other generators with different pitches, but on the other hand the 2/3 winding pitch generators may cause more harmonic currents to flow through it from other parallel connected sources due to its low impedance

VI. IMPACT OF DISTRIBUTED GENRATION ON SHORT CIRCUIT LEVELS OF THE NETWORK

Penetration of DG in a network has a direct impact on the short circuit levels of the network; it causes an increase in the fault currents when compared to the normal network conditions at which the substation is the only generating unit. This increase will be obtained even if the DG is of a small generating capacity. The contribution of DG to faults depends on some factors such as the generating capacity of the DG (size of the DG), the distance of the DG from the fault location and the type of DG. Consider a case at which one small DG is embedded in the system, the fault current will be increased at different fault locations and it can be generalized at any fault location in the entire network but the percentage increase in the fault current caused by the presence of one small DG might not be severe to the extent that causes an effect on the fuse-breaker protection scheme and it might not cause mis-coordination of the protection scheme and the fuse saving technique might still be maintained under this condition this will be discussed later in this chapter. If more than one small DG is embedded in the system, the sum of the current contribution of these DGs to fault could have a significant effect on the protection devices and may cause mis-coordination in protection scheme and the there will be no co-ordination between protective devices resulting in a failure of the protection scheme. Thus the fuse saving technique of laterals will be no more effective, consequently reliability and safety of the distribution network is affected in a negative behavior which is not acceptable.

Embedding one centralized DG in the system will have a quite significant effect on the increase of the level of short circuit currents in the system. The presence of DG on the system decreases the utility contribution to faults but on the other hand, the value of the fault current increases, this increase is due to the contribution of the DG to the fault. The percentage contribution of the DG to fault is varied according to the distance of the DG from the fault but in all conditions the fault current is increased. When placing a group of decentralized DGs distributed in different locations of the network with a total equal to that of the centralized DG mentioned previously, the fault current is still increased more than the normal condition, but it is less than the centralized DG case. The highest contributing DG to faults is the separately excited synchronous generator but during the first few cycles it is equated with the induction generator and self-excited synchronous generator, while after the first few cycles the separately excited synchronous generator is the most severe case. The least severe DG type is the inverter type, in some inverter types the fault contribution lasts for less than one cycle This shows that the type of DG and inverter used has a great effect on the severity of contribution to faults.

VII. ISLANDING DETECTION USING DISTRIBUTED GENRATION

The DG must be equipped with dual functionality such as islanding functionality and anti-islanding system based on site utility and site applications. It must be possible to activate and deactivate this anti-islanding protection on the site to allow cold start operation.

Anti-islanding mode: The DG must have anti-islanding protection according to standard IEC 62116 or an equivalent international standard. It must be possible to activate and deactivate this anti-islanding protection on the site to allow cold start operation.

Black start in islanding: The DG may have a black start islanding functionality to be able to supply the emergency needs of the power plant in the event of loss of the interconnected network. In this case, the DG must be able to control the voltage and frequency of the installation in islanding mode within acceptable ranges. The DG must have the necessary equipment and control in order to be able to operate in islanding mode.

During the past few decades, several islanding detection methods were introduced to protect the distribution systems with DG from the case of unintentional islanding. One of the direct and efficient methods is by monitoring the trip status of the main utility circuit breaker and as soon as the main circuit breaker trips, an immediate signal is sent to the circuit breaker at the interconnection between the DG and the utility system to trip the interconnection circuit breaker preventing the occurrence of islanding. Although this method seems to be easy and straight forward, its implementation is so difficult due the distribution of DGs in a large geographic range that will require special comprehensive monitoring techniques with dedicated systems.

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Regulatory Framework for Making India's Advanced Metering Infrastructure Secure

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***Abstract*— Advanced Metering Infrastructure (AMI), or smart electricity meters and related infrastructure, can enable solutions to operational challenges faced by an increasingly complex power grid. It can enable real-time demand and supply monitoring, pre-emptive network maintenance, dynamic tariffs and demand-side response. Smart meters, a core part of AMI, also hold the promise of improving efficiency in billing and revenue collection for power distribution companies and reducing their financial stress. The Government of India has advised states to convert 250 million domestic meters to smart prepaid meters, of which about 3.4 million had been rolled out by December 2021.**

AMI rollout at this scale and pace raises the exposure of the power system, classified as critical infrastructure, to cyber threats, due to its larger attack surface. In this paper, we analyse the current rollout and installation process for smart meters and AMI in India from a cybersecurity lens. Based on a review of secondary literature and drawing on international experience, we propose four steps to ensure a secure rollout and governance of AMI in India: i) identification and classification of relevant actors in the AMI supply chain, ii) setting a sector-specific compliance baseline for all actors, iii) efficient disclosure of vulnerabilities and breach events, and iv) efficiently allocating liability among actors. The paper attempts to map recommendations to existing institutions, going beyond abstract principles of efficient governance, to present a clear path forward for implementation and facilitate a holistic and informed discourse.

Keywords—Advanced Metering Infrastructure, AMI, smart meters, security, cybersecurity, regulation.

I. Introduction

Advanced Metering Infrastructure (AMI), or smart electricity meters and related infrastructure, can provide solutions to the emerging challenges of grid management. AMI can enable real-time demand and supply monitoring, network maintenance, dynamic tariffs, and demand-side response, besides helping power distribution companies (discoms) improve billing and revenue collection efficiency.

Fig.1 shows a basic schematic of AMI, which comprises a network of smart meters and other interactive devices that can transmit, store and analyse data. An increase in smart meters connected to the grid and resulting interface between digital and legacy systems such as distribution substations can increase the power system's cyber risk [1].

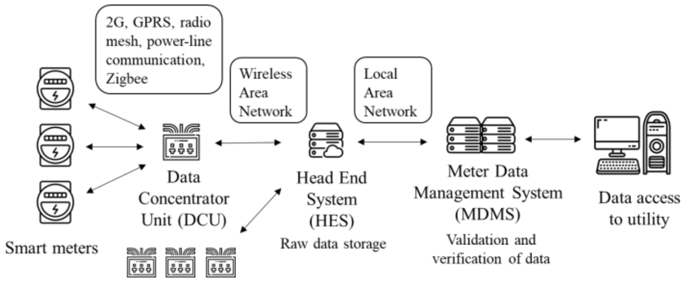

Fig. 1. Schematic of AMI
Source: Authors' illustration

II. Cyber vulnerabilities in AMI

AMI is as secure as its weakest link [2]. The value chain actor with the lowest incentives determines its security [3]. Hence, AMI requires a minimum set of technical and legal compliances for all actors. Enforcing such efficient decisions is complicated due to cybersecurity's nature as a public good with misaligned incentives of actors [4], [5].

Cyberattacks can occur at three levels of AMI architecture: component-level, communication protocol-level, and topology or architecture-level [6]. The system may be left vulnerable to these attacks because of: i) poor quality hardware and software components, ii) lack of adequate checks and balances at key nodes of decision-making or iii) gaps in transparency about system or component vulnerabilities. Fig. 2 shows the key pillars of cybersecurity and the threats posed due to these vulnerabilities [7].

Pillars	Threats
Confidentiality	• Unauthorised access to data
Integrity	• Unauthorised access to smart meter, DCU or HES
Availability	• Brief invisibility of any hardware in the chain hampering service provision
Accountability	• Gaps in logging/inspection mechanism crucial for ex-post investigation

Fig. 2. Pillars of cybersecurity and its threats
Source: Authors' illustration based on [7]

III. Gaps in current AMI rollout

In India, the responsibilities for AMI deployment and operation are distributed among various actors (Table 1).

Table 1 Responsibilities in the current smart meter rollout model in India

Actor	Responsibilities
Demand aggregator	• Procuring smart meters and DCUs • Testing smart meters for quality assurance
Component suppliers	• Manufacturing and supplying smart meters and DCU hardware components
AMI service provider (AMISP)	• Integrating smart meters with the upstream infrastructure • Setting up and operating HES and MDMS
Discom	• Paying for AMI through annual payments • Housing the MDMS in its premises • Procuring additional data analysis services

Source: Authors' analysis

The Central Electricity Authority (CEA) has prescribed guidelines on general functional requirements for securing AMI [8]. These guidelines are aimed at the "AMI implementing agency," but the definition of this entity is unclear. Further, the guidelines prescribe a basic level of security for AMI but fail to consider the geographical scale of AMI and the diversity of actors involved in manufacturing, deploying, and operating its various components. The absence of definitions precludes clear identification of responsibilities and liabilities. The guidelines also do not prescribe operating procedures for managing the aftermath of a security breach, including directions for disclosure of relevant information.

IV. Components of a regulatory framework

Based on a review of secondary literature, existing regulations and a AMI-related power outages [9], [10] we explore four critical aspects of the regulatory framework required to secure the AMI rollout.

A. *Identification and classification of actors*

The first step is to identify and classify actors within the value chain. For example, [11] classifies stakeholders in the cybersecurity domain into:

- **Users**: Entities deriving value from ICT software, hardware, and services, e.g., discoms, transmission utilities, power exchanges, etc.
- **Vendors**: Developers, manufacturers, and suppliers of software, hardware, and services.
- **Finders**: The community of individuals that identify and report vulnerabilities.
- **Coordinators**: Intermediaries between finders and vendors that ensure disclosure and mitigation, such as Computer Emergency Response Teams (CERTs).
- **Governments**: These can act as finders, vendors, and coordinators, as well as acquire or maintain vulnerabilities for national security purposes.
- **Media**: brings transparency by reporting on and disseminating vulnerabilities.
- **Adversarial actors**: may exploit vulnerabilities.

Embedding such classification in power sector regulations would help determine all actors' roles as per their respective capabilities.

B. *Actor-specific cybersecurity compliances*

The power system requires sector-specific baseline (minimum) and differentiated (actor-specific) compliances to security standards and certifications to avoid adverse selection and build trust in cyber services and products [12]. [13] provides a comprehensive list of compliances for the Indian power sector, while sector-specific CERTs circulate Cyber-Crisis Management Plans with concerned organizations [14]. However, compliances need to be mapped to each actor's capability [15], risk profile, and the potential impact on the system in case of failure.

The latest version of CEA's cybersecurity guidelines [14] sets baseline compliances for critical actors in the electricity value chain. However, they do not require actor-specific compliances considering their different capabilities and do not triage the actors based on their risk-impact profiles. For example, a component supplier may be required to follow information management practices but not as extensively as an AMISP. One reason for this may be the CEA's jurisdiction being limited to these entities. Hence, State Electricity Regulatory Commissions (SERCs) must enforce compliances via their regulatory jurisdiction over discoms, who are the eventual beneficiaries of AMI and procurers of AMISP's services.

C. *Transparency and information sharing*

Cyber resilience requires all actors to prepare for threats through a shared threat intelligence platform. Although the National Critical Information Infrastructure Protection Centre (NCIIPC) and CERT-India have created forms for reporting vulnerabilities and cyberattacks, a systematic mechanism for managing information on vulnerabilities, threats, and attacks is lacking [16].

Information Sharing & Analysis Centers (ISACs) for the power sector play a role in incident disclosure and handling [14], [17]. However, cyber threats are constantly evolving and are unrestricted by geography or sector. It is essential that ISACs in India collaborate with international information-sharing networks such as the Financial Services ISAC.

Further, a permanent institution, such as the existing CERT-Distribution housed at the CEA, or an analogous state-level institution, should be legally empowered to obtain information related to system-level attacks and ensure adequate disclosures and future response.

D. Locating liability

In the power grid, various actors in the value chain are heavily interdependent. Liability dumping can become a prevalent externality in such a scenario [18]. In the current model of AMI rollout, discoms only pay for the MDMS services and smart meters provided by AMISPs [19]. This model makes the allocation of liability difficult.

Liability due to vulnerability exploitation or technical glitches in automated systems should be defined in regulations at the sector level. Any such regulation should determine liabilities of vendors of hardware, software, and services so that liability cannot be escaped by placing vulnerable functions as a service on the cloud [20]. Regulators must follow the *principle of proportionality* to assign the two types of costs associated with vulnerabilities: patching costs (costs of identification and remediation of vulnerabilities) and damage costs (costs incurred due to exploitation of a vulnerability) [21]. Any firm that sells products having a large number of devices networked to it or devices that are going to connect to a single network in large numbers should have a larger liability [21].

V. Conclusion

The current cybersecurity regulatory framework for the AMI in India's power sector has gaps that need to be addressed (Fig.3). Sector-specific definitions, responsibilities, and liabilities must draw on the nation's general cybersecurity law and be enforced by entities with sector-specific jurisdiction. This would be essential to ensure a secure and consumer-centric roll out of AMI in India.

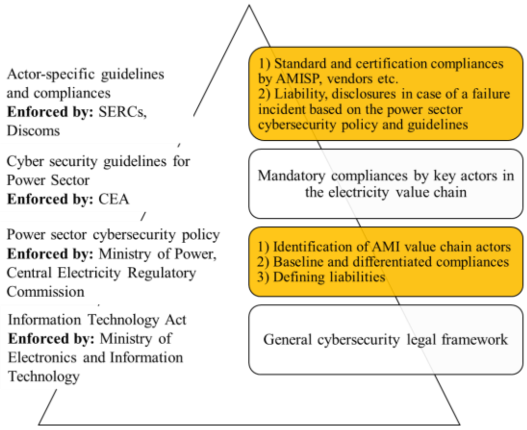

Fig. 3. Proposed cyber security regulatory framework
Source: Authors' illustration
Note: The highlight boxes show our proposals to fill existing gaps in the regulatory framework.

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Smart Grids as Anchor Infrastructure for Smart Cities & Smart Home Automation

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Abstract**—**In the ever changing world, 'Smartness' in every aspect of daily life is vital. As a responsible Electric Utility, we at TATA Power-DDL are always seeking and putting into practice, all smart and easy ways while involving our consumers; to conserve energy, utilize energy, consume energy, and in achieving smart ways of lowered energy bills. To achieve 'Smartness' in the complete value chain of Energy Generation till end consumer Energy Usage, SMART GRIDS form the heart of the business operation. Smart Grid, an integrated system of fully Automated, two-way communication, and Intelligent 'Electrical Value Chain components'; interconnected with each other through communication links to ensure Secure, Reliable, and Efficient – Production, Delivery and Consumption of Energy. To have smart cities, especially with the evolving IoT technology; Smart Grid plays a significant role. Smart Grids are inextricably linked to building up a smart city. As a part of complete value chain of energy, Smart Home Automation forms an integral component at Consumer home end. Instead of applying and practicing Smart ways of supplying the electricity, management of energy consumption at consumer end is also the need of the hour to achieve optimal balance between Supply and Demand of energy.

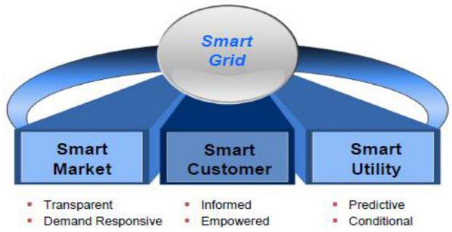
Keywords — AUTOMATION, CUSTOMER SERVICES, DIGITALIZATION, REMOTE MONITORING AND CONTROL, RELIABILITY IMPROVEMENT, SMART GRID NETWORK.

INTRODUCTION

Smart Grid, an integrated system of fully Automated, two-way communication, and Intelligent 'Electrical Value Chain components'; interconnected with each other through communication links to ensure Secure, Reliable, and Efficient – Production, Delivery and Consumption of Energy.

Smart City, a technologically modern urban area, build upon the concept of integrated information and communication technology (ICT), and various physical devices connected to the IoT (Internet of things) network to optimize the efficiency of city operations and services and connect to citizens. To have smart cities, especially with the evolving IoT technology, Smart Grid plays a significant role.

The popularity of and demand for Internet services technology has made our lives easier and hassle-free. These days, most house-hold products are internet of things (IoT) – enabled, thereby helping us control things from any corner of the room.

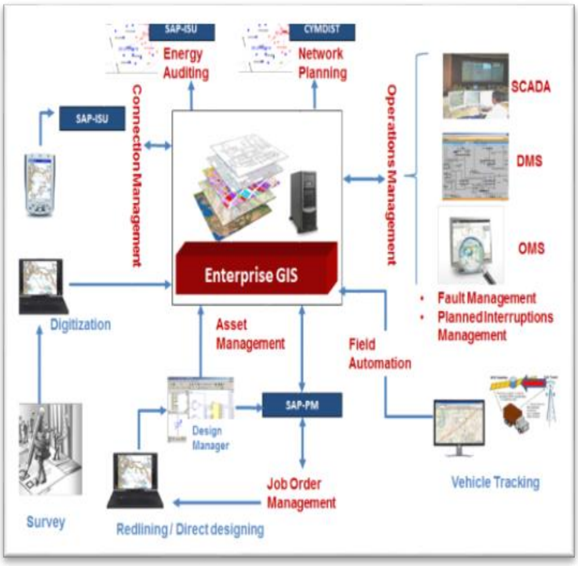


Smart Network Technologies

I. GIS(Geographical Information System)
II. GSAS(Grid Sub-station Automation System) & SCADA(Supervisory Control and Data Acquisition)
III. Unified Communication Network
IV. Advanced Distribution Management Systems(ADMS)
V. Automated Demand Response (ADR)
VI. AMI: Deployment of Smart Meter and associated technologies

GIS (Geographical Information System):

Is an information system for representation of on-field electrical infrastructure (viz. grid stations, substations, transformers, lines and cables etc.). TATA Power-DDL is one of the first utilities in India to implement an enterprise-wide GIS and was launched in 2007.GIS (Geographic Information System) is the heart of the overall information system landscape of TATA Power-DDL.



GSAS and SCADA

The old grid station and dilapidated relay panels had mechanical switches for control that limited the remote operation from a central location. Absence of coordination among different tripping devices added a delay in identifying the faulty section. All 33/66 kV control and relays in existing grids were replaced with electronic relays. This was needed to make relay panels communicable for proposed Supervisory Control and Data Acquisition (SCADA) system. This was possible through setting up grid substation automation (GSAS) panels.

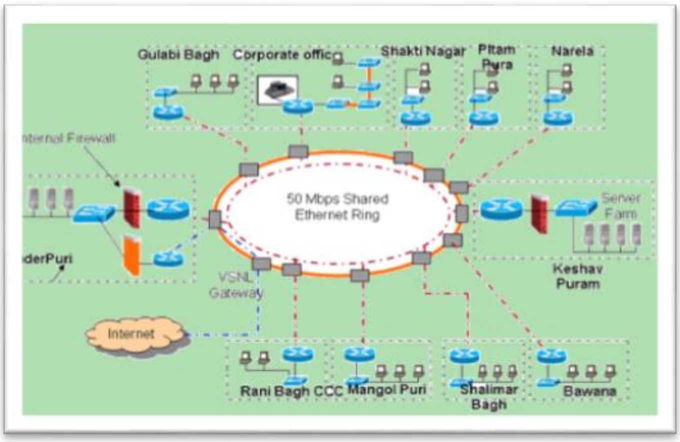
SCADA Control Center

Unified Communication Network

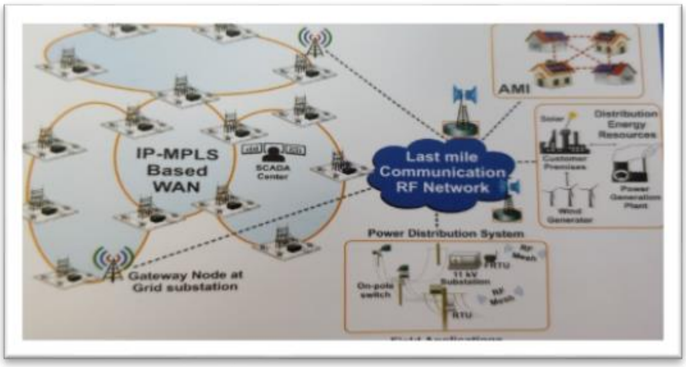
TATA Power-DDL established its Communication Network in FY 2004-05 across its area of operation to support:

a) Operational applications like SCADA/Tele-protection/GIS/OMS
b) Commercial and Billing Applications
c) Enterprise-wide Applications – SAP CRM/ SAP ERP, email etc.

TATA Power-DDL chose to deploy its own private network on already existing Tata Telecom laid fiber, which formed the backbone of communication network.

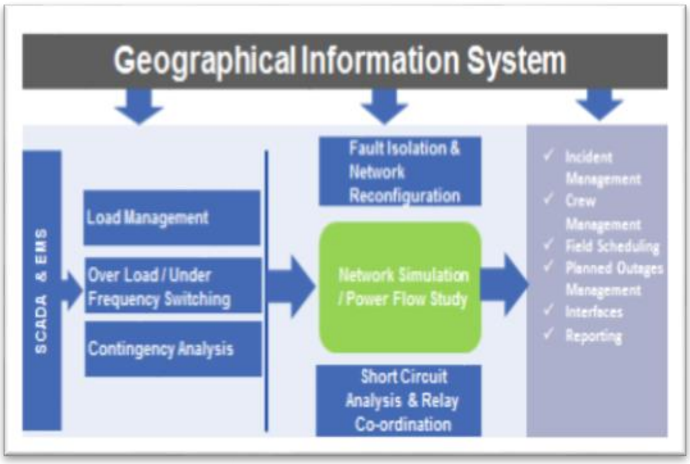


TATA Power-DDL's upgraded MPLS based Communication Network architecture is a IP/MPLS(multiprotocol label switching) network which is a packet-switched networking technology that supports Smart Grid applications like AMI, DER, EV charging stations, MWM, ADR and Integrated security solutions etc. Also there is provision of integrating RF network communication with mesh of IP-MPLS network.



Advanced Distribution Management System(ADMS):

ADMS is a unified platform for SCADA, EMS, DMS (Distribution Management System), and Outage Management System (OMS) functionality as a single modular solution. There is also integration with various systems like ERP, BO, FFA, MDMS, ADR etc. ADMS features automated fault location, isolation, and service restoration (FLISR), peak demand management, and volt/volt-ampere reactive (volt/VAR) optimization etc. SCADA/ADMS collects field data on IEC 60870-5-104 from Data Concentrator Units (DCU)/ Remote Terminal Units (RTUs) and interface to existing system like GIS, Customer Care, SAP, material management and future technologies like Field Force Automation (FFA), ADR, and Asset Management Systems along with Load Dispatch Center of other Electric Utilities & State Load Dispatch Center of Delhi.



AUTOMATED DEMAND RESPONSE (ADR):

In the event of high demand, non-critical load vetted by consumer is made shut off through two-way communication to and from ADR control center and consumer meter via built-in modems in smart meters through GSM/GPRS network.

SMART HOME AND SMART APPLIANCES

A smart home is nothing but an amalgamation of enhanced services and top-notch technologies via a network to ensure a better way of living, which also offers ease and convenience to daily routines in the home. Wireless, Bluetooth, DSL, cable broadband and other technologies offer a home network for electronic devices to communicate with each other as well as to the Internet.

Due to procrastination, forgetfulness or other reasons, we often switch the lights or water pump on and forget to switch them off. Smart home devices help reduce electricity and water bills by turning these devices/ appliances off via mobile apps or smart switches even when we are asleep or occupied with other work.

SMART COOKING

Connecting and automating kitchen appliances can save time, money and energy. Today's smart kitchen gadgets connect to your home automation system for convenience and savings. You can command your coffee maker to be ready with a hot beverage when you wake up. Preheat your oven on the way home from work so it's ready for making dinner. Optimize your refrigerator and freezer temperatures to minimize energy use.

Smart sensors, powerful chimneys, smoke detectors and alarms can be added to the kitchen for safety purposes.

A 'smoke detector' keeps an eye on things and can send alerts about a problem at home to users anywhere in the networked world. It can check up for gas building from a leaky forgotten stove, and alerts the users via text message or automated call. This way users know something is wrong even when they are not at home to hear the alarm.

A heat sensor enables the chimney to start automatically when cooking starts. An LPG sensor switches on the chimney if there is any leakage in the kitchen and throws all the gas out of the kitchen. Remote control feature allows users to operate the chimney remotely if they are caught up with other tasks.

LED LIGHTS

LED vs. CFL bulbs differ in technology. Instead of heating a filament until it glows, LED lights produce light from semiconductors. LED lights use 85% less energy and last 25 times longer than traditional bulbs.

To put that number in perspective, by the time most homes have switched to LED technology in 2035, over 569 TWh will be saved every year.

SMART THERMOSTATS

Higher-end smart thermostats use machine learning to detect patterns at home and optimize how the heater or air conditioner runs, truly fine-tuning the climate control system to save energy. These devices record data one can use to determine the heating and air conditioning power usage patterns.

SMART SECURITY

A smart security system can be connected to a Wi-Fi network and thus the security devices can be monitored and controlled via apps on smartphones. Smart Security system may include communicable sensors which can be installed on doors, windows etc. One of the most important security system is the smart doorbell camera. The doorbell button is equipped with a diminutive camera sensor, which sends alerts to the phone/tablet when someone is at the door.

SMART PLUGS AND POWER STRIPS

Any lamp, stereo, or household appliance can be remotely controlled, voice activated and programmed. Smart plugs can be used to disconnect devices from power, putting an end to wasted energy when devices aren't in use.

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Asset Management in Indian Power Sector using Drones & Artificial Intelligence

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Abstract

An unmanned aerial vehicle (UAVs), also known as drone, are used for different application in the transmission sector. Drones as a tools that increase many benefited in transmission sector, improves safety, uses topographic measurements of large areas, with using principles of aerial photogrammetry is possible to create transmission line aerial surveying, saves costs and projects time etc. The use of unmanned aerial vehicle in the transmission Sector can brings many benefits to the user; creating real time aerial images from the transmission line towers, challenges & overviews reveal assets. The aim of this paper is to create a general overview of the use of Drone in the transmission Sector. The contribution also contains many types of UAVs used for construction of transmission line, Drone flying regulations, emergency line patrolling, inspection of Sub-station equipment, their advantages and also disadvantages

Keywords— *Unmanned aerial vehicle (UAVs), Right of way (ROW), Transmission Lines (TL), Bolts & Nuts(B&N), Double Circuits(D/C), Central Electricity Regulatory Commission (CERC), Geographic information system (GIS), Artificial intelligence, Machine learning.*

1.0 INTRODUCTION

New digital technology has helped, over the last decades, to enhance productivity, reduce cost of construction and overall project timelines. The introduction of drones to the transmission sector is recent, although their use in other areas of industry (e.g., Mining, Monitoring security, Science & Research, Military purposes, agriculture, public safety etc.) has been frequent. Digital tools and plant cannot replace people but they are required to increase quality work, safety factors, reduce costs, improve decisions, reduce time-consuming methods etc. Drones presently increased opportunities for achieving all these goals.

2. USAGE/POSSIBLE APPLICATION IN TRANSMISSION SECTOR

2.1 Routine line patrolling

Drones can be used for routine patrolling of the lines by taking high resolution photographs/ videos of tower components which can be used for identification of any defects/ anomaly.

Picture 1

Picture 2

2.2 Patrolling of line section in difficult/ unapproachable areas

Patrolling of transmission line sections falling under difficult/ unapproachable areas (i.e. Valley, Hilly, River crossing) / an area having ROW issues can also be carried out swiftly using Drones

Picture 3

Picture 4

Photographs taken from drone

2.3 Inspection of sub-station equipment

Drones mounted with Thermal sensor can help in detection of incipient faults in electric equipment/ components due to thermal issues. Early detection of such defects/ faults has helped POWERGRID in taking advance corrective action for rectification to ensure uninterrupted power supply

2.4 Damage assessment during disaster management

India has experienced many natural disasters such as high-speed wind storm, cyclones, floods, earthquakes, landslide, avalanches etc. in the past. These disasters damage, various critical infrastructures like road, rail, port, power transmission, distribution network and communication links.

During disaster, movement by road get restricted/ blocked due to falling of trees and debris on roads which in-turn affect damage assessment. Use of Drones shall be very helpful for assessing the extent of damages at early stage in such condition.

3. BENEFITS OF USING DRONES IN TRANSMISSION SECTOR

3.1 Through tower scanning

Drones can thoroughly scan all 4 sides of transmission line towers by hovering around the tower and can identify the defects like missing/ hanging tower members, loose/ missing nut bolts, missing joint plates, conditions of insulators, condition of jumper bolts etc. It also help in Transmission Line Tower Visual Inspection from both Sides and Top, acquiring images in High Quality on defects such as unhealthy conditions of Earth wires (Rusting/Strand break/unhealthy joints of tension clamps/unhealthy joints of mid span), Conductors (Rusting/Strand break/unhealthy joints of tension clamps/unhealthy joints of mid span), Jumpers (Loose B&N), any loose members, missing members, unhealthy conditions of B&N in towers, condition of insulator (surface), broken insulators etc.

Picture 5

Picture 6

Pictures taken from drone

3.2 Eliminates climbing the tower for inspection

Tower top patrolling of transmission lines using Drones can help in eliminating the need for tower climbing for close inspection of tower and its components. This is quite helpful in case of any exigency by reducing the fault identification time and also it ensures manpower safety

3.3 Thermal signature of joints

Thermal camera mounted drones can detect the hotspot at joints due to loose connections. Such defects cannot be detected using digital camera/ naked eye. Early detection of such defects in incipient stage can avert any untoward breakdown. It helps to find out the hotspots on all bolted joints (Jumper Joints), Mid Span Compression Joints for conductor and Dead-End Compression Joints using thermo-vision camera.

3.4 Asset Mapping and GIS Survey- Drones can be used for Asset Mapping and GIS Survey

3.5 Right of Way and Pre-feasibility Survey for Planning- It also helps in Right of Way and Pre-feasibility Survey for Planning

3.6 Structural Anomaly Detection- It plays very important role in Structural Anomaly Detection

3.7 Managing vegetation- Vegetation management of transmission line can be done with the help of Drone taken photograph

3.8 In July 2019, Drones were used at various locations of 220 kV D/C Samardong-Dikchupool transmission line in Eastern Region for paying out the pilot rope.

Drone can be categorized into 5 categories

i) Nano : weight<250 grams,

ii) Micro : up to 2 kg,

iii) Small : up to 25 kg,

iv) Medium: up to 150 kg,

v) Large: Greater than 150 kg

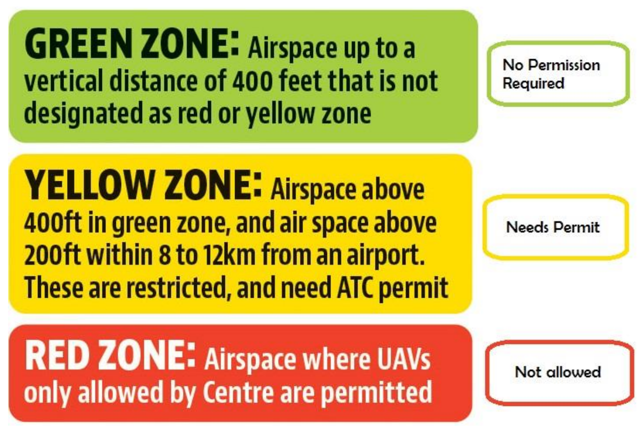
POWERGRID available Drones:

Total Drones: 35, Make: 33 nos of Dji Phantom 4 pro and 2 of Dji Phantom 3

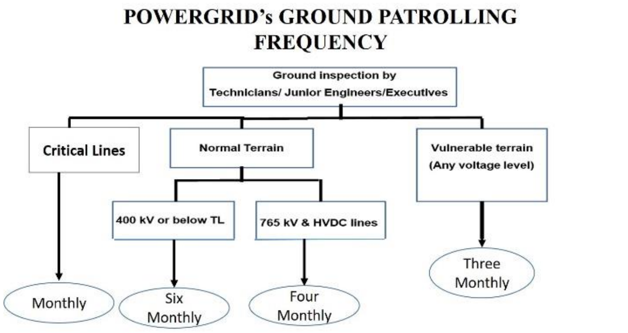
Type: Battery operated Quadcopter, Category: Micro, Weight: Dji Phantom 4 pro- 1.4 kg, Dji Phantom 3- 1.3 kg

4. DRONE FLYING REGULATIONS

As per Drone Guidelines 2021 (released on 25.08.2021) No permission is required for flying drones in Green zone(85% of country area) upto 400 feet or 120 metres



5. POWERGRID'S GROUND PATROLLING FREQUENCY



6. ADVANTAGES OF PATROLLING THROUGH DRONE OVER CONVENTIONAL PATROLLING

Following are the advantages of patrolling through Drone over conventional patrolling

Safety factors of patrolling increases.

Time saving-

By conventional method 5 to 6 Towers patrolling can be done in hilly terrain. However using Drone 10-15 tower patrolling can be done using Drone.

Cost saving-

Cost saving is the important factors in patrolling through Drone.

Man Power Saving- Manual intervention decreases. Therefore patrolling can be achieved with minimum no of Manpower.

Availability- Downtime of transmission line minimized. Hence it help to achieve higher availability of transmission system.

Early restoration of faulty transmission lines-It helps to early identify the defect, resulting early restoration of lines.

7. EMERGENCY PATROLLING OF LINE

Drones can help in eliminating the need for tower climbing for close inspection of tower and its components, in case of any tripping/ fault. Swift detection of fault/ abnormality would result in taking prompt action for restoration of line. This help us to maintain the availability as per the CERC guidelines.

Picture 7

Picture 8

Picture 9

8. APPLICATION OF DRONES FOR CONSTRUCTION

The usage of Drone for construction of transmission lines is important for safety, time and cost. The drone machinery develops the construction field with their vast benefits as compared to their traditional method for the transmission lines construction. Drone technology removes typical complex process divided into sub process of reattaching string and reduce the risk of injury for people involved.

This is to be noted that approximately 1.5 deaths every year from helicopter crews trying to perform same task but using drones and skill pilot, tasks are done with maximum cost effectiveness and with no risk of injury to manned helicopter.

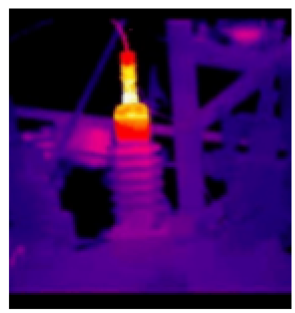
Impact of drone technology in construction of transmission line is very prominent and benefits decision making, easy operation, lower costs and increased safety as well. Indeed, drones are very much useful in pre-construction survey and investment monitoring in T&D construction. Monitoring locations using Drone which are critical or hazardous for workers can minimize safety risk and reduce additional expenditure to ground based monitoring teams being an aerial substitute.

The construction team use road transport and visual inspection is carried out with portable equipment. The construction of transmission line involves manpower, tools & Plant/Construction Machines movement across highways that is not easy in hilly and thick forest areas. Therefore, it is slow, time consuming and subjective, therefore actual ground conditions gets ignored. Sometimes team member must climb transmission line tower and complete the conductor pulling also in rain & bad weather. This results in slow progress of work hence Drone is very useful for the work

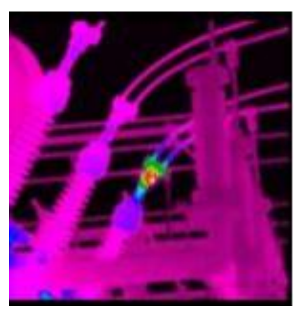
9. APPLICATION OF DRONES FOR SUBSTATION

Drones can be used for detailed inspection of substation equipment and components. Hotspot, physical condition of different substation components can be checked & necessary action can be taken at the earliest. It also helps in Gas Leak detection in difficult locations.

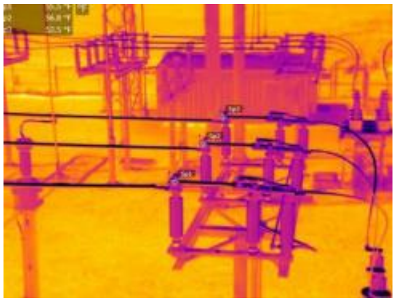
The end result is that the Substations can be inspected more frequently in greater details, the Inspectors are safe, the company saves time and cost, faults and damage to the infrastructure are more easily detected and consumers benefit from a continuous, uninterrupted flow of electricity.



Picture 10 – Thermal Auditing



Picture 11- Electrical fault detection



Picture 12 – Thermal imaging

10. APPLICATION OF DRONES FOR FINAL CHECKING OF LINES

After Transmission line is declared ready for commissioning, Drone patrolling helps to cross check proper fitting of Hardware & completeness and to check corridor clearance as well. This helps in fast identification of commissioning defects, resolution of defects & early charging of new transmission lines

11. RISKS ASSOCIATED WITH THE USE OF DRONES

The use of drones on a large scale entails a high risk. The main danger is the fall of a drone from a height, which may be due to:

1. Discharge of battery,
2. Damage due to weather conditions (Precipitation, low air temperature)
3. Hitting in an obstacle (High building, Tree, Power line).

These risks can be forecast; therefore the action must be taken to prevent their uprising. The battery status and other data, including temperature can be controlled remotely by the system. In case of abnormality in any of the parameters the alarm should pop-up. This will allow to take the action, such as emergency recall the drone to a Location

12. FUTURE PLAN

Large volume of Asset diagnostic data (Big Data) generated by Drones from scanning Power Transmission System needs careful study by Experts to develop Asset Maintenance Planning. Future plans are to implement Artificial Intelligence so that Big Data gathered after scanning by Drone are gainfully integrated with Asset Management System.

13. CONCLUSION

Drones have opened up new vistas in Asset Management & generated wealth of experience in POWERGRID Transmission System. Drones have been very useful in different geographic areas for Power Transmission tower inspection. Infrared cameras helps in detecting hot-spots, damaged components, Bus-bar damage, Insulator damage, Joint failures in very short time without risking the lives of Maintenance crew. Drone application has also proved usefulness in Transmission Line construction, final checking of transmission line just before charging/ commissioning. Drone scanning for emergency patrolling of lines is also very significant as it helps in early restoration and achieving higher availability of Transmission System. Drone imagery is being used for Condition based maintenance now and in future with AI can gainfully be used for Asset Residual Life assessment.

Drone usage is at an early stage in Indian Power Sector but has great future potential. As digital image recognition and digitization technology adopts Artificial Intelligence and Machine Learning gradually, further innovations shall open up a new era for the Power Sector

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https://digitalsky.dgca.gov.in

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Electric Vehicles as Virtual Power Plants

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***Abstract*— Globally, Electric Vehicles (EVs) market is growing exponentially, owing to various reforms across the world with respect to bridging the energy gap, energy security, climate change, technological and infrastructural advancements. It's quite evident that EVs will soon be in dominance Globally. India unveiled the 'National Electric Mobility Mission Plan 2020' in 2013, followed by Faster Adoption and Manufacturing of Hybrid and Electric vehicles (FAME) scheme, Go Electric Campaign, and various state schemes. Another upcoming revolution is of EVs being a Virtual Power Plant (VPP). A targeted study found that electric vehicle (EV) batteries used as a utility virtual power plant (VPP) could shift the entire residential peak load to night-time hours with only 10% EV market saturation. EV batteries are the source of the energy that can be injected in the grid, with VPP as a platform between the source and the grid, thus mimicking a power plant, and managing the grid services. The EV owners, though, can benefit hugely from this arrangement, there are challenges in the Indian context for EVs arrangement as VPP, viz., lack of charging infrastructure, grid infrastructure, costly batteries. But, with the recent development in the Indian distribution sector, and the focused initiatives, EVs role as VPP, along with the solar rooftops, is bound to happen soon than expected, in the acknowledged Vehicle to Grid (V2G) operations. Being energy banks, with less than 5% time utilization for transportation, EV Fleets can hugely benefit the energy sector by peak load management and stable grid operations.**

Keywords—EV, Electric Vehicles, Grid, Virtual Power Plant, Hybrid, Renewables, Energy

I. Introduction

The market of Electric Vehicles (EVs) is a growing industry, however the growth and the focus that it has been gathering in the world and in India as well is on all-time high, and will be on an exponential end ahead too. Reasons behind this rise are quite few, but very important and strategic. Owing to the number of reforms going around the world with respect to bridging the energy gap, energy security, climate change, technological and infrastructural advancements, EVs have gathered a major concentration from all governments and policy makers.

One of the major upcoming revolution is of EVs being a Virtual Power Plant (VPP). A VPP facilitates a more diversified and dynamic energy market by facilitating cleaner energy sources into our energy system for the asset owners. A VPP captures more value from Distributed Energy Resources (DERs) by enabling market participation thus bringing higher returns and encouraging investment into renewables. The VPP enhances grid stability with services to better match supply and demand allowing traditional utilities to better plan and optimize production efficiency. A VPP increases DER's returns thus encouraging more renewables installation leading to a cleaner and more sustainable energy supply ultimately benefiting the consumer.

II. Understanding the EV's role as VPP

The DER in this case are the EV batteries to be utilised as VPP. Clustered EV batteries are connected to grid through an online platform. This platform which centrally manages the electricity to be fed into the grid, also known as Vehicle to Grid (V2G). This set up not only can manage the peak demands when the renewable generation is at lower end, but it also serves as a great utilization of energy in the charged batteries of EVs not in use.

Almost 30GW of electric-vehicle virtual power plants will help balance renewables-rich grids when the renewable forces are not turning up [1]. A targeted study found that electric vehicle (EV) batteries used as a utility virtual power plant (VPP) could shift the entire residential peak load to night-time hours with only 10% EV market saturation [2]. EV batteries are the source of the energy that can be injected in the grid, with VPP as a platform between the source and the grid, thus mimicking a power plant, and managing the grid services.

III. Vehicle to Grid

Vehicle to Grid (V2G) process enables energy injection back to the power grid from the battery of an electric car. With V2G a battery can be charged and discharged based on different signals to balance variations in energy production and consumption.

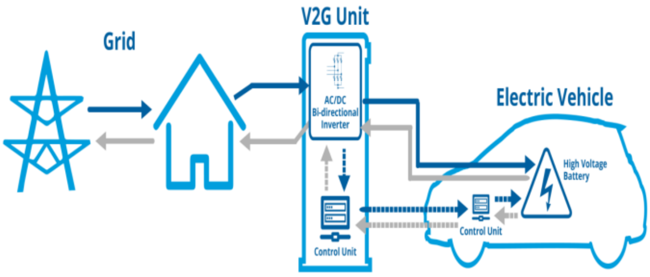

Figure 1: Schematics of V2G [3]

Since at any instance 95% of cars are parked, the EV batteries could be used to let electricity flow from the car to the electric distribution network and back. The potential earnings associated with V2G found that with proper regulatory support, vehicle owners could earn $454, $394, and $318 per year depending on whether their average daily drive was 32, 64, or 97 km respectively.[4]

When power consumption increases, it can overload the power grid in that area. A EV's ability to balance its electricity demand with V2G charging stations helps out the power grid on a larger scale. This will come in handy when the amount of renewable energy in the grid, produced with renewables, increases. The environmental circumstances sometimes cause grid congestion that prevent electricity from reaching its destination. Intelligently controlled EVs offer a solution to this problem and prevent the need for expensive grid infrastructure upgrades. Without V2G technology, energy has to be bought from reserve power plants, which increases electricity prices during peak hours. Without control, you need to accept this given price but with V2G you are master to optimize your costs and profits.

Benefits of V2G

- Peak load levelling
- Backup power
- Reduced total cost of ownership of fleets
- Car OEMs (manufacturers) are able to sell vehicles with added value
- Energy market parties can trade and optimize their balance
- Network operators can optimize investments & stabilize the grid

IV. Understanding the Challenges

Eventually the main purpose of EV remains to be transport and commute. Utilisation of EV batteries as a source of energy for transport as well as a power source for the grid is a big challenge when it comes to practical application, as the energy to be fed to the grid infrastructure needs to be secure in quantum to manage the demand and supply.

There are challenges in the Indian context for EVs arrangement as VPP, viz., lack of charging infrastructure, grid infrastructure, costly batteries. The environmental policies drove the technology disruption in electric vehicles.

Considering the Infrastructure constraints are dependent on multiple factors, the EV batteries manufacturing is turning the scenario for EVs' adaptation as VPP. The development in batteries and hydrogen fuel cells has accounted in the resurgence of Battery Electric Vehicles with DC fast charging, Plug-in Hybrid Electric Vehicle (PHEV), and Hybrid Electric Vehicles (HEV).

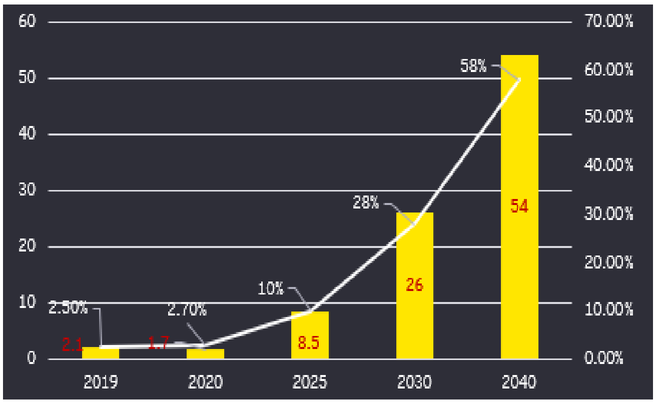

Figure2: Global Passenger EV Sales (in millions) / % EV Market Share [5]

V. EVs and the Indian Regulations

India unveiled the 'National Electric Mobility Mission Plan 2020' in 2013, followed by Go Electric Campaign, Faster Adoption and Manufacturing of Hybrid and Electric vehicles (FAME) scheme, and various state schemes. Apart from the government, e-commerce companies, car manufacturers, app-based transportation network companies and mobility solution providers are playing a major stake. It is very clear that EVs will be in dominance sooner than expected in the Indian automotive as well as energy market.

VI. Way Forward

Knowing where to play will require analysis of the future trajectory of DER and VPP market growth from technology, regulation, and customer perspectives.

But, with the recent development in the Indian distribution sector, and the focused initiatives, EVs role as VPP, along with the solar rooftops, is bound to happen soon than expected, in the acknowledged Vehicle to Grid (V2G) operations. Being energy banks, with less than 5% time utilization for transportation, EV Fleets can hugely benefit the energy sector by peak load management and stable grid operations.

EVs tend to become quite appealing as VPP as along with acting as DER, they can be utilized in maintaining the proper balance of the electricity grid at the lowest possible economic and environmental cost, if managed efficiently and effectively.

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