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Power Management System for Minimizing Transmission Losses

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Abstract— **Globally, Indian power system is one of the largest with installed capacity of 372.693 Gigawatt and a complex transmission network which is an integration of Alternating Current and Direct Current transmission systems. With modernization and addition of new generating capacities to meet the growing demand, a robust transmission system can be instrumental in the growth of power sector and also significantly contribute to the country's economy. India's goal towards diversifying its energy source cannot be achieved until its transmission network develops capabilities such as distributed intelligence, demand response integration and effective coordination with generation. This research article emphasizes on the key power transmission challenges which can potentially hinder future economic growth of India. Advanced technologies that can be extremely useful in the augmentation of the transmission network are also discussed.**

Index Terms— Electricity, Power management, Power generation, Power transmission, Power transmission, Power transmission losses

I. INTRODUCTION

Power Sector plays a crucial rule in economic, industrial and social development of any country and availability of safe and reliable electric power is crucial to keep in pace with the proliferating demand of industrialization, economic and social lifestyle. Power Sector collectively represents the generation, transmission and distribution sectors. To enhance power supply in response to the growing demand, power network modernization and development is essential. Globally, India ranks at the fifth position for its size in energy economy with a combined revenue of $351,093 million. It ranks third in renewable energy investment and future plans according to a new study by British Business Energy.

India's power sector stands as one of the most diversified in the world and is undergoing a significant change targeting sustained economic growth. The country's installed capacity is 372.693 Gigawatt (GW) as on 31 August 2020 and has been successfully exporting electricity to Bangladesh and Nepal at cross borders. An undersea High Voltage Direct Current (HVDC) interconnection to Sri-Lanka has also been proposed. With enough availability of both conventional and non-conventional resources, power generation is less of a concern today.

However, with the surplus generation capacity, India lacks on reliable Transmission and Distribution (T&D) infrastructure. There are power shortages during peak hours, and remote areas lack access to reliable electricity supply. On an average, duration of power available is between 20-24 hours in cities and 18-20 hours in villages.

Power distribution sector in the country stands as the weakest link in the electricity supply chain owing to the fact that it has a direct impact on the sector's commercial viability, and ultimately on the consumers who pay for power services. Transmission capacity has been insufficient relative to the present generation capacities and load requirement.

Hence, targeting focus on addition of generation capacities to meet surging demand owing to the limited transfer capability and inefficiencies within the transmission sector can not only pose serious threats on shortage of natural resources on the long run but also hinder potential growth expectations.

By 2024, India's population is expected to surpass that of China's and is projected to reach 1.5 billion in 2030, according to a report published by the United Nations Department of Economic and Social Affairs. India's sustained economic growth is placing an enormous demand on its energy resources, energy systems and infrastructure. It becomes crucial for India to adapt to optimal strategies that would not only cater to the needs of nation's electricity demand but also adhere to the global crisis on greenhouse gas emission initiatives.

II. INDIAN POWER SECTOR

Electricity was introduced in India 10 years after it was introduced in London and 17 years after that in New York. Electricity was first demonstrated in India in 1879 through light bulbs in the streets of Calcutta (now Kolkata) by P.W. Fleury &Co. Kilbum & Co.(later Calcutta Electricity Supply Co.) electrified Harrison Road(later MG Road) in 1889 and is entitled to be the first street to have electric light bulbs in India. The total power generating capacity as of 1947 was 1362 Megawatt (MW) and per capita electricity consumption was mere 16.3 kilo Watt hour) kWh. It was only in 1948, that Electricity Supply Act was passed empowering the State Electricity Boards (SEBs) to step up the generation, transmission and distribution capacity in respective states and also being able to optimally utilize resources in their states.

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Electricity was primarily used much by the industrial sector while commercial and agriculture sector remained at the bottom of the chart. Electricity was not introduced in the rural section of the country, hence only the urban families reaped its benefits. In 1950, when the 5 year plan for economic development of the country was initiated, 5 regional grids were setup namely, Southern, Northern, North-Eastern, Western and Eastern regions. These were further connected to form the national grid.

The Electric Supply Act was amended in 1976 that lead to the establishments of National Thermal Power Corporation (NTPC), National Hydro-electric Power Corporation (NHPC) and eventually Nuclear Power Corporation of India Limited (NPCIL) was formed. These were the generating utilities that were responsible for operating the facilities for transmission to client SEBs. NPTC was set up for construction, operation and maintenance of grids between various states. One of the major steps was to connect the entire country into a single grid.

The Electricity Act, 2003 has been amended on two occasions by the Electricity (Amendment) Act, 2003 and the Electricity (Amendment) Act, 2007. The Act provides for National Electricity Policy, Rural Electrification, Open access in transmission, phased open access in distribution, mandatory State Regulatory Electricity Commission (SERC), license free generation and distribution, power trading, mandatory metering and stringent penalties for theft of electricity; with the aim to push the sector onto a trajectory of sound commercial growth and to enable the States and the Centre to move in harmony and coordination.

Today, India's power sector is one of the most diversified in the world. Sources of power generation range from conventional sources such as coal, lignite, natural gas, oil, hydro and nuclear power to viable non-conventional sources such as wind, solar, and agricultural and domestic waste. Electricity demand in the country has increased rapidly and is expected to rise further in the years to come

Indian power sector has been undergoing significant changes that have redefined the industry outlook. Sustained economic growth continues to drive electricity demand in India. The Government of India's focus on attaining 'Power for all' has accelerated capacity addition in the country. Total installed capacity of power stations in India stood at 368.68 Gigawatt (GW) as of January 2020. Electricity production reached 1,050.78 Billion Units in FY20 (up to January 2020).

Government initiatives such as Pradhan Mantri Sahaj Bijli Har Ghar Yojana- Saubhagya was launched with an aim to achieve universal household electrification by March 2019; Ujwal Discoms Assurance Yojana (UDAY) was launched to encourage operational and financial turnaround of State-owned Power Distribution Companies (DISCOMS) with an aim to reduce Aggregate Technical & Commercial (AT&C) losses to 15 per cent by FY19 and Government plans to establish renewable energy capacity of 500 GW by 2030 have had significant impact. However, in view of the growing population it is expected that the electricity demand could grow from 949 Terra Watt hour (TWh) in 2015 to between 2074 TWh and 2785 TWh by 2030. India's transmission and distribution loss is reported to be 20% which is twice more than the world's average. With the aim of reducing losses and improving the power distribution sector of state utilities, the Union Government has launched the Restructured Accelerated Power Development and Reforms Programme (R-APDRP). Going forward, an investment of Rs. 2.6 trillion is required in transmission alone to meet the future peak load, which is expected to reach 234 GW by 2021-22. Grid expansion will also be driven by the government's ambitious plan to scale up renewable energy to 175 GW by 2022. The landscape of power transmission in India is expected to change at a fast pace. The entire power sector in India and its ability to meet growing demand depends on a robust and sustainable transmission network.

III. POWER GENERATION

India has surplus generation capacity. It is the third largest producer of electricity across the world. Currently, 22 nuclear power reactors have a total install capacity of 6,780 MW; 117 coal-based power plants accounts for 200705 MW; Natural gas based power plants contributes near to 24,508.63 MW; the major grid connected diesel-based power plants is 993.53 MW and as of 31 March 2020, as per India's installed utility-scale, hydroelectric capacity was 46,000 MW, solar 37.627 GW and wind power was 37.669 GW.

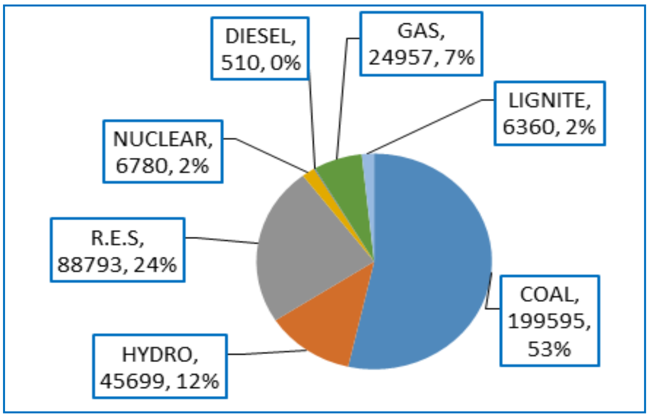

Fig. 1: Sources for electric power production

Of the total installed capacity, 62.2% is the total share of fossil fuels (coal, lignite, gas, and diesel); hydropower plants with a share of 12.3%; nuclear of 1.8% and other renewable energy sources of 23.7% (include Small Hydro Projects, Biomass Gasifier, Biomass Power, Urban & Industrial Waste Power, Solar and Wind Energy)

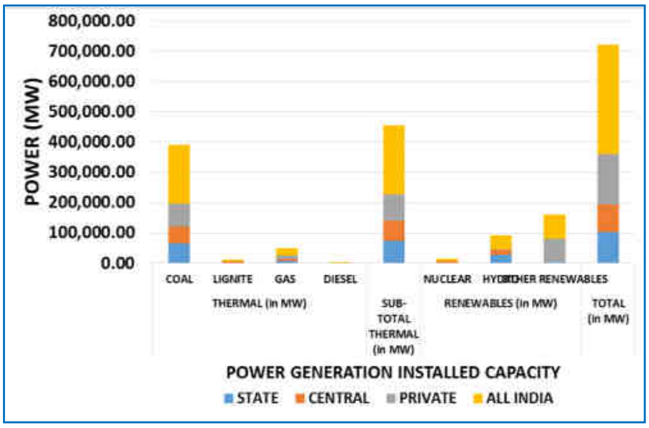

Fig. 2: Sector and type wise installed power capacity

Private sector holds 174,298 MW of installed capacity i.e. 46.9%. State Sector installed capacity is 103,652 MW which is 27.9% and Central Sector holds 94,027 MW which is 25.3%. India's focus on attaining 'Power for all' has accelerated capacity addition in the country .Wind energy is estimated to contribute 60 GW, followed by solar power at 100 GW by 2022 and 15GW from biomass and hydropower. The target for renewable energy has been increased to 175 GW by 2022.

IV. POWER CONSUMPTION

Per-capita Energy Consumption (PEC) during a year is computed as the ratio of the estimate of total energy consumption during the year to the mid-year population of that year. PEC increased from 19,669 Mega joules in 2011-12 to 24,453Mega joules in 2018-19, the annual increase in PEC for 2018-19 over 2017-18 was 3.67%.

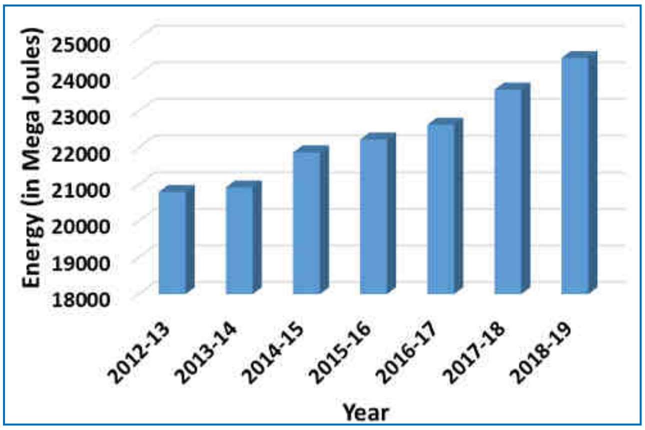

Fig. 3: Per capita consumption of electricity

According to International Energy Agency, India's PEC in 2017 stood at 1.12 MWh, as against China's 4.55 MWh and the US's 12.57 MWh.

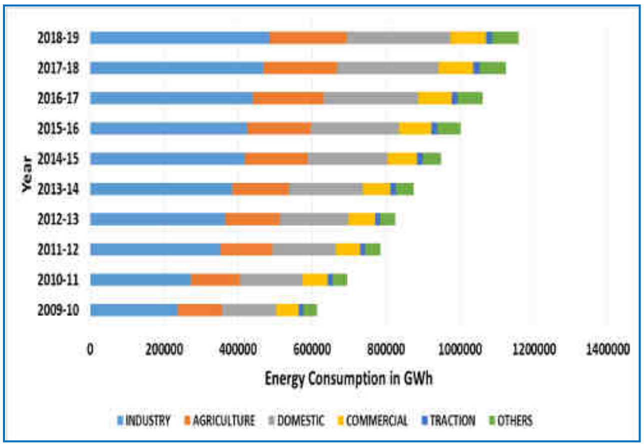

Fig.4: Category wise energy consumption

Fig 4 depicts the category wise consumers of energy in India. The industrial sector is the largest consumer of electricity, followed by agriculture which is highly volatile since it is predicated on a number of exogenous factors such as quality and duration of monsoon. Domestic sector is showing progress over the years as many household electrification need is realized under various government schemes.

Overall, the estimated electricity consumption of the year 2017-18 is 11, 58, 310 GWh. The percentage increase in electricity consumption from 2017-2018 (11, 23,427 GWh) to 2018-19 (11, 58,310 GWh.) is 3.11%. Of the total consumption of electricity in 2017-18 industry sector is accounted for the largest share (42.0%), followed by domestic (24.0%), agriculture (18.08%) and commercial sectors (8.4%)

V. GENERATION VERSUS CONSUMPTION

Consumption of electricity is known to follow economic activity, and India's sharper fall reflects its far more severe lockdown compared to many other countries. Apart from the fall in industrial consumption, the second factor that plays a role is the user mix. People in the US and Europe consume higher amounts of electricity compared to per capita electricity usage at home in India.

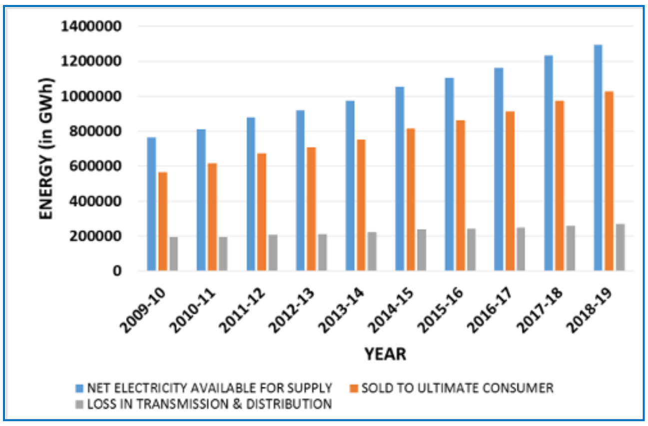

Fig 5 Net Electricity generated, distributed & transmission losses incurred

The PEC which was mere 16.3 kWh in 1947 increased to 1010 KWh in 2014 and the gross electricity consumption in 2018-19 was 1,181 kWh per capita. The PEC is low compared to most other countries despite India having a low electricity tariff. There has been a steady growth of PEC over the past years.

However, considering India's current 2020 population which is estimated at 1,380,004,385 people at mid-year according to United Nations data and is expected to rise and grow until mid-century, reaching an estimate of 1.68 billion in the 2050s; electricity demand is also expected to grow. Despite surplus generation capacity, there have been shortages to meet peak electricity demand.

Frequent power cuts leading to lack of access to reliable electricity supply is essentially due to the absence of a reliable T&D infrastructure. Though some loss is inevitable, in places with good technical efficiency and low theft, T&D losses generally range between 6% and 8%. India's T&D loss for the year 2018-19 is 20.77 % which is 269,165 GWh. Hence, there is an urgent need to revitalize our current T&D infrastructure before moving to the phase of accelerating generation with an objective of meeting higher demand in future.

VI. TRANSMISSION LOSSES

India's power transmission sector is mostly controlled by government – both the central and various state governments and institutions that work in the transmission sector. The individual state grids are interconnected to form the five regional grids covering the mainland India which are Northern, Eastern, Western, North Eastern and Southern Grids. The regional grids are further interconnected to form the National Grid. National Grid is the high voltage electricity transmission network that addresses the issue of availability to electricity supply anywhere in the country as the generation capacities are distributed unevenly in different regions.

The difference between net power generated and the total units of power actually distributed is known as T&D loss. This comprises both technical and commercial losses. Technical loss is due to energy dissipation in the electrical equipment which is inevitable. Commercial losses occur at the distribution side typically due to power theft by bypassing or tampering with the meter, or by bribing utility meter readers or billing agents leading to consumed energy's revenue not acquired or accounted for. Despite the global standing of third position in power generating capacity, the country's T&D losses which is 20.77% is very high where developed countries like the United States have T&D losses of approximately 6%. The following section describes the major factors impacting transmission losses.

Failure to upgrade technology: Not only there is less technological awareness among transmission utilities but also low investment in research and development. The sector focuses more on lowering costs than allowing the usage of new technology or construction methods. With the need to meet growing demands and optimally manage load and other technical inefficiencies there is an urgent need to upgrade technology of our power sector.

Table 1: Conventional conductor (ACSR) Vs. High performance conductor (HPC)

ITEMS	ACSR	HPC
TOWER COST	6.764	5.862
CONDUCTOR COST	12.626	37.203
ERECTION AND FOUNDATION	4.96	4.81
OTHER COSTS	8.718	8.267
TOTAL COST (100KM line)	33.06	56.142
TRANSFER CAPACITY	3400MW	6800MW
COST IN USD	972.38	828.229

ACSR- Aluminum Conductor Steel Reinforced
HPC – High performance conductor

It is observed that a High Performance Conductor (HPC) is comparatively advantageous over a conventional conductor (ACSR). Moreover, an advanced version of HPCs is the High Temperature Low Sag (HTLS) conductor that can operate at a much higher temperature range than the conventional ACSR conductor, and has low thermal expansion and sag. India's vast geographical area with its vulnerability to climate change impacts, HPC/ HTLS conductors can prove to be extremely beneficial in the making of a robust transmission network

Grid instability due to renewable energy: The share of renewable energy is expected to increase in India as the fossil fuel share declines. The technical challenges associated with it include power quality, power fluctuations, storage and protection issues and constraints to accommodate renewable energy system in existing transmission grid. All this is because of its variability nature. Renewable energy sources integration is essential to make optimal usage of energy sources available; however they cannot support the entire grid by themselves.

Low investment in power transmission: The investment of power transmission is low in comparison to power generation for adding new capacities. With the increase in demand, addition of transmission capacity should be a first priority of investment following the addition of power generation utilities to ensure safe evacuation and less wastage on losses.

Transmission congestion: Transmission congestion is a situation where the load on transmission network exceeds its available transfer capability. Congestion limits the capacity of the network and causes interruption in efficient power exchange. Due to recent surge in power generation, the transmission lines face serious transmission congestion arising from increasing demand and integration of renewable energy into the existing grids. Various energy exchange projects held without commissioning of the required number of transmission lines faced congestion in the existing network. Congestion and choking leads to power interruptions, outages and deficits that adds to large power losses.

Need for strategic planning: Transmission capacity's growth is insufficient in comparison to the generation capacities and the growing load requirement, and hence accounts for 20.77% losses procured. More than technical, there is a need for strategic intervention to address these issues, and to device action plan mechanism.

Poor performance of state utilities: The reason for this lies in the deteriorating finances of the state-owned power distribution companies. They are reeling under losses as they hardly ever pass on the cost of their operation to consumers. The Average Cost of Supply (ACS) of electricity is higher than the Average Revenue Rate (ARR) on it, making them financially unviable. Power distribution stands as a crucial and weakest link in the country's electricity supply chain owing to the fact that it has a direct impact on the sector's commercial viability, and ultimately on the consumers who pay for power services. They have high AT&C losses, that is, losses due to electricity theft and deficiencies in billing and revenue collection. A high AT&C means lower operational efficiency and higher cost of doing business.

VII. SUGGESTIONS

Energy supply market is undergoing deep transformation all across the world and with the ongoing economic crisis and shortage of natural resources, in comparison to the expectancy of growing demand of energy could be an alarming call for a more technologically advanced architecture of power system management. With special attention to distribution sector implementations of novel applications of smart grid technologies on power distribution systems that may include integration of distributed energy resources, plug-in electric vehicles, distribution automation, and distribution system optimization can significantly strengthen the distribution sector link. New and emerging technologies aim to address the challenges faced in the transmission and distribution network, such as space constraints, high downtime in case of a fault, time constraints, safety concerns and power supply to geographically remote locations.

Expanding HVDC: Long distance transmission losses can be reduced by using HVDC. Expanding Direct Current (DC) networks at distribution sector can also be beneficial which can also help in integrating Distributed Generation (DG) in future.

Digitalized substations: Advanced substation technology solutions aim at providing reliable, uninterrupted and quality power, while ensuring minimum equipment downtime. One of the key emerging substation technologies is digitalization. Digitalized substations leverage communications through Optical Fiber Cables (OFCs) that replace traditional copper connections. Digital substations are increasingly gaining traction in the country. A digital substation analyses performance data and provides recommendations on maintenance and repairs. It enables the identification of degradation in substation performance in real time, helping in predictive or reliability centered maintenance by capturing any anomaly in operations. This helps avoid unplanned outages and thereby lowers the risk of asset failure. There is also a reduction in material requirement owing to a reduced need for protection and control panels, making digital substations compact. Besides, these are faster to install as they use pre-tested process bus systems. Digital substations provide additional safety by eliminating open current circuits. Interoperable solutions and the use of OFCs instead of copper wires reduce the duration and cost of onsite work for refurbishment of secondary equipment. Digital substation, GIS substation, hybrid substation, modular substation, underground substation and mobile substation are few typical substation technologies emerging currently and embraced widely.

New conductor technology: A key trend in the transmission industry in recent years has been the adoption of new conductor technologies which are extremely beneficial for timely implementation of transmission projects to keep pace with upcoming generation projects. They also help in bringing down transmission losses and preventing power outages. HTLS conductors are aluminium wired conductors that have approximately the same diameter as that of ACSR conductors used, but are capable of operating at temperatures as high as 250 °C. HTLS conductors can carry almost double the current as that of ACSR conductors of the same size, while the maximum sag and maximum tension remain the same for both. These conductors help in augmenting the thermal rating of transmission lines. A major advantage of HTLS conductors is that they can be installed without any modification of the existing structures and foundations, which results in time and cost savings. Popular HTLS conductors are Thermal Resistant Aluminium Conductors Steel Reinforced (TACSR), Super Thermal Alloy conductor Invar Reinforced (STACIR), Aluminium Conductor Composite Core (ACCC), Aluminium Conductor Alloy Reinforced (ACAR), GAP and etc...

STACIR conductors: Reconductoring is emerging as an increasingly important industry need. The reconductoring of existing transmission lines helps in augmenting the quantum of power transmitted through them. To this end, project developers can install STACIR conductors.

GAP conductors: GAP conductors are another type of conductor that can be used for reconductoring. GAP conductors are manufactured from (super) thermal-resistant aluminium alloy wire and high strength steel core. They are extremely useful for reconductoring old transmission lines and can increase the capacity of existing lines by 50-100 per cent.

STACIR conductors are relatively costlier. Of all the new technology options, GAP conductors are the most economical and efficient option.

Smart distribution transformer (UK): The improvement of power factor, optimization of operating voltage, and balancing the load across Alternating Current (AC) phases could be an effective strategy to reduce losses. Smart distribution transformers can provide all the above functionality to improve the overall efficiency of distribution networks. The losses reduction potential of such technology is analyzed and assumed that the smart transformer can reduce the imbalance by 10%, improve power factor and also support voltage optimization. The results showed more than 13% losses reduction, 5% reduction from load imbalance and the remainder from improved power factor and voltage optimization.

Applying advanced and new technologies (South Korea): KEPCO has established and been operating Smart Grids. As for the distribution part, plans to complete the development of the Advanced Distribution Management System (ADMS) into which the existing Distribution Automation System (DAS) and Information and communication Technology (ICT) are converged, is the prime focus. Development of ADMS, active distribution networks in response to the spread of various distributed generations including Energy Storage System (ESS) is planned. The transmission & transformation part is expected to adopt an intelligent Supervisory Control and Data Acquisition (SCADA) system that can monitor, control and interpret power systems on a real-time basis. Moreover, there are plans to establish 150 IoT-based digital substations that can independently diagnose and operate power facilities. In addition, further strengthening of power supply reliability by detecting abnormal symptoms of power systems at an early stage and quickly restoring facility failures has been the prime focus.

K-SEMS is KEPCO's own smart energy management system to improve energy efficiency and reduce energy costs by monitoring, analyzing and controlling information on all energy including electric power, gas, heat, etc., consumed by customers on a real-time basis. K-SMES was introduced to 21 sites in 2017 and 25 sites in 2018 and are planning to install K-SMES to 2,000 sites including industrial complexes by 2026. The main role in leading and optimizing energy-use efficiency at the national level is achieved through this.

Distribution loss minimization (Oman): The key implementations include removal of low voltage network as high tension line was extended nearer to the consumer premises; implementation of Advanced Metering Infrastructure (AMI) system which is installation of smart meters for recording of real time data; implementation of automatic reading of meters to enable capturing consumption details and reducing the cost of the billing system. Proper Load Management which may include ability to turn on and off meters from data management center aiming to limit the load of consumers and also alarm management to notify any technical or tampering faults in the system.

VIII. CONCLUSION

Despite market restructuring and policy reforms, India continues to face problems in reliable power accessibility which lie mainly due to the insufficient transmission corridors and transmission congestion in the present network. This results in inefficient evacuating of power to meet the growing demand. India is vulnerable to climate change impacts and is exposed to growing water stress, storms, floods and other extreme weather events. Adaptation and resilience of the energy system to these extreme climate conditions should be a high priority.

Hence in the interest of growing energy demand, augmentation of transmission infrastructure specifically at intra-state level, must be accelerated to ensure that the government's renewable energy and 'Power for All' goals are met. The paper provides an insight to the key challenges in the transmission network up-gradation of the country and various trends and technologies in the power sectors were presented. It emphasizes on the need of a robust Transmission infrastructure.

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