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Smart Grid Technologies and Indian Initiative: A Review

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Abstract

Worldwide, energy demand is continuously increasing consequence to rise in population, modernization, and industrialization. Climate change and rising in fossil fuel prices have forced the power sector to look into non-conventional energy sources such as wind, solar, and biomass. The power grids started integrating these renewable energy sources of generations into existing grids which in turn reduced the greenhouse gases and carbon footprint. The intermittent nature of Renewable Energy Sources (RES) generation systems and the bidirectional flow of energy pose anenormous challenge in the management and control of the traditional grid system. The Smart Grid offers an answer to the problems faced by today's electric grid system by integrating Information and Communication Technology (ICT), Sensing and Control, etc. This paper reviews the Smart Grid technologies, its general infrastructure, features, functionalities, and attributes. It also presents the research activities, difficulties, and issues relating to smart Grid and shows how these advancements have moulded the cutting edge power network and kept on developing and fortify its job in the better arrangement of energy demand and supply. Smart Grid activities in the Indian power sector have additionally been discussed.

Keywords: Smart Grid, Renewable Energy Resources, Distributed Energy Sources, Distributed Generation, Smart Meters.

I. INTRODUCTION

Numerous literature reviews have been published on "Smart Grid Technologies" in recent times. As innovations such as big data analytics, novel control strategies, demand-side management systems, Internet of Things(IoT) and cloud computing, smart metering, etc have been introduced in smart grids. Therefore a literature review is always needed to know the current progress in Smart Grid Technologies, and also to carry forward the research activities in the area.

Electrical power systems following a very long while of the moderate turn of events are encountering enormous changes because of a few components, for example, the necessity of huge scope for integration of sustainable power sources, ageing of power system infrastructure, power quality, energy efficiency, and reliability needs and expanding worries about vulnerability in the power system of entities in the open power business scenario. The smart grid is the advancement of the present electrical grid, using cutting edge technology to optimize the energy management and delivery of power. It empowers the power sector by creating the foundation necessary for new energy technologies, emission reductions, efficiency improvements, and electric transportation. The smart grid also encourages better energy management by providing real-time energy consumption data to customers.

In the coming years, one may notice drastic changes in the electricity generation and distribution scenario in most parts of the world. Renewable energy generation mainly Solar PV and wind on a large scale are integrated into the current power system. As these energy sources are intermittent and pose multiple issues viz. control and system management, which are needs to be addressed. The smart grid offers a better solution to the present crisis in the power system by adopting advanced cutting edge technologies like Information and communication, digital metering, energy management systems, etc. These movements are made possible by government exercises and utility calls to modernize the grid; everywhere throughout the world.

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This review study looks into smart grid technologies covering its definitions, infrastructure, functionalities, characteristics, and features. Paper also reviews the smart grid initiatives in India.

A. METHODOLOGY

The methodology of this paper is summed up underneath.

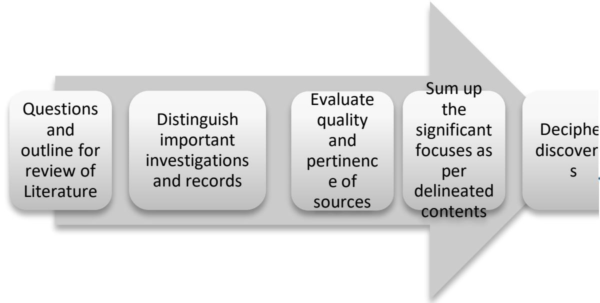

Fig.1 Flow Diagram of a Methodology for Review Study

The search for technical articles spanning years 2010–2020 on "Smart Grid Technologies" in ScienceDirect dated 04 June 2020, has yielded the following result: "31,675" journal articles and "3385" books. At the IEEEXplore Digital Library, "18,130" meeting distributions and "3714" journals, and "378" magazine articles were found. The large volume of literature contains less important and repetitive articles on the topic. Only relevant articles relevant to topics are being considered for review. The search for literature was carried out mostly on ScienceDirect and IEEE Xplorer.

B. SUBJECT MATTER AND EXPLORATION

This review on Smart Grid Technologies considered publications from 2010–2020 for the most part from ScienceDirect. The year-wise search results using keywords on the topic yielded "33739" outcomes and their year-wise break-up are shown in Fig. 1. Smart Grid innovations with an advanced search using the keyword on different technologies and their distribution are given in Fig.2. The search result shows a significant research activity on the topic.

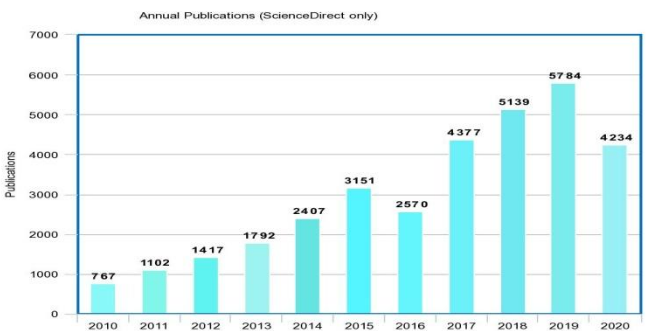

Fig.2 :Yearly publication distributions on Smart Grid innovations.

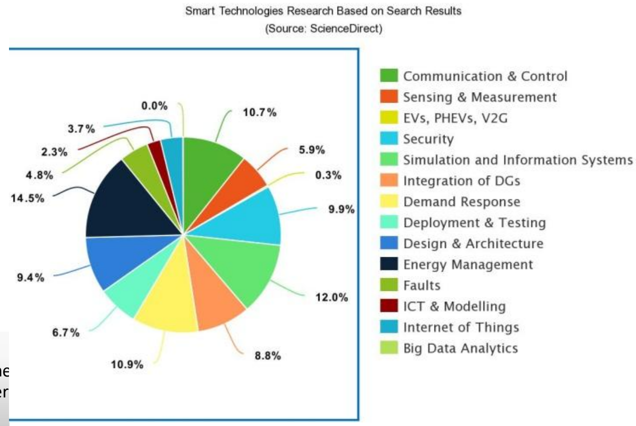

Fig.3: Smart Grid innovations search results

II. NATIONAL INITIATIVES

All over the world many countries deploying Smart Technologies to modernize the ageing grid infrastructure, minimize the effective cost of electrical energy and integration of renewable energy power generation. The development of new services and products by developing smart technologies will enhance the economic and commercial opportunities of a country [1].

A. China

The fast financial growth, and to minimize greenhouse gases, the state Grid Corporation of China (SGCC) has announced Smart Grid development plans. The SGCC defines the smart grid as "a solid and strong electric power framework, operating at Ultra High Voltage (UHV) systems; in light of the planned advancement of power grids at various voltage levels; reinforced by information and communication framework; portrayed as a computerized and interoperable power framework and the coordination of power, data, and business initiative"[2].

B. *The European Union*

The European Union's Smart Grids Technology Platform has issued a road map for Europe's electricity frameworks of the future. It states: "It is fundamental that Europe's power systems can incorporate all low carbon power conversion techniques just as to urge the demand side to have a functioning influence in the service sector. This must be furnished by updating and developing the systems productively and financially"[3].

C. The USA

The USA's Public Law defines the smart grid as "is promoting the up-gradation of the electrical grid systems to retain up a dependable and secure power system that can fulfill the future increase in power demand and accomplish expanded utilization of digital technology and control mechanisms; active

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management, and optimization of resources and control operations; integration and proliferation of distributed energy generation; uptake and adoption of demand-side resource management for better energy efficiency; implementation of smart grid innovations for data communication, real-time monitoring, metering and automation of distribution network; smart devices and consumer gadgets integration; adoption of modern power storage and peak shaving innovations; real-time data communications to users and provides control solutions; formulation of protocols and standards for interoperation and data communication" [4].

III. INTRODUCTION OF SMART GRID

A few years back, a little 'e' before something demonstrated that it was new and cheering - email, eCommerce, eHealth, eVoting, presently you read about smart - cell phones, smart cities, smart vehicles, and even smart water!. A smart grid is a system of electrical networks that carry power to consumers. The Smart Grid concept is a combination of various technologies that helps the power system to operate in a highly efficient and reliable manner. There is no unique definition for the smart grid.

TABLE I

SMART GRID DEFINITIONS

Agency	Definition of Smart Grid
The European Technology Platform	"A Smart grid is an electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers and those that do both in order to efficiently deliver sustainable, economic and secure electricity supplies" [5].
US Department of Energy	"A smart grid uses digital technology to improve reliability, security, and efficiency (both economic and energy) of the electric system from large generation, through the delivery systems to electricity consumers and a growing number of distributed generation and storage resources" [6].
IEA	"A smart grid is an electricity network that uses digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end-users. Smart grids co-ordinate the needs and capabilities of all generators, grid operators, end-users, and electricity market stakeholders to operate all parts of the system as efficiently as possible, minimizing costs and environmental impacts will maximizing system reliability, resilience, and stability" [6].

IV. THE MOTIVATION FOR SMART GRID

The main motivation for the development of a smart grid are[7]:

TABLE II. MOTIVATION FACTORS FOR SMART GRID DEVELOPMENT

Factors	Motivation
1. Infrastructure	In most parts of the world electricity infrastructure is becoming old and reaching its end of useful life. There is a need to renovate the power system with energy-efficient and reliable infrastructure.
2. Electricity demand	Increase in electricity demand due to the growing economies, industrialization, and rise in the population of the world.
3. Climate change	Public awareness about climate change and its extreme effect on the environment and food security, forcing the developed and developing countries to reduce greenhouse gasses by adopting renewable power generation, advance control, and management technologies in the power sector to improve efficiency and reliability.
4. Transmission & Distributi	As centralized power generations are located away from load centers, there are a significant transmission and distribution losses and

on losses	electricity theft is a great cause of concern to the utilities.
5. Power generation scenario	As the world is moving towards renewable and distributed generation in parallel with existing centralized power generation new challenges are emerging in operation and control.
6. Renewable power generation	The power system must possess more intelligence in order to integrate intermittent power generation systems viz Solar PV, Wind Energy Conversion Systems (WECS) with an existing grid system. This is possible with better power system monitoring and control mechanisms achieved through advanced information and communication system, energy storage technologies, digital metering systems, etc.
7. Smart buildings, Innovation of 8.EVs	As homes and building are started equipped with smart appliances a new energy consumption model are evolving. In the coming years the automobile industry is introducing a large number of Electric vehicles such as electric cars, buses, trucks, etc. need additional power generation and charging infrastructure.
9. The rise in fuel prices and environmental regulations	The limited availability of fossil fuels, increasing fuel prices, and environmental regulations forcing the power sector to look into alternate and renewable power generations.
10. The concept of the energy market	The decentralized and open energy market encouraging private players to invest in the power sector. A new model is evolving for the bulk transactions of electrical energy between power generation companies and industries.
11. Consumer's demand for transparency in power usage and billing.	There is a long pending demand from consumers for energy usage and billing. A new concept of "time of use energy tariff" is evolving for better operation and control for utility and as well as reduced bills for consumers due to the operating of their loads in less power peak period.

V. EARLY GRID INITIATIVES

Following the integration of Distributed Generations (DGs) such as solar PV and wind energy conversion system (WECS) at distribution level into the traditional grid system mostly causes voltage stability problems that put a limit on the extent of injection of DG power into the grid. The other effects of DG integration in power systems include a bidirectional flow of power, fault current issues, harmonics, and switching transients will impose burden and malfunctioning of existing protection schemes [8].

A. Distribution Network Active Management Scheme

Fig.4 shows a schematic representation of a typical Distributed Network (DN) along with Distributed Generation(DG). This scheme possesses a different set of attributes compared to passive DN. In a passive DN power flow is unidirectional, here it is bidirectional. The power demand and the amount of injected generation decide the direction of power flow and voltage levels in the network. To protect DN, the scheme must provide broader fault currents protection in DG by providing composite and coordinated settings. The active and reactive power flows are independent in DN. The switching actions of power electronics converters in DN, inject harmonics into the system and degrade the power quality. As per IEEE 519 standard, voltage distortion due to harmonics in the power system is limited to less than 5% total harmonic distortion (THD) up to 69kV and each harmonic is limited to 3% [9]. The Distribution Network Active Management Scheme (DMSC) also incorporates measurements of power system parameters and control. The action of control may be achieved by changing the DG output, changing tapping on the transformer, or by reactive power compensation. The penetration of DG at the distribution level changes the voltage profile and also alters fault current which intern affects protection systems. The active management scheme enhances the degree of DG penetration in-network by estimation and control of system voltage at various points [8].

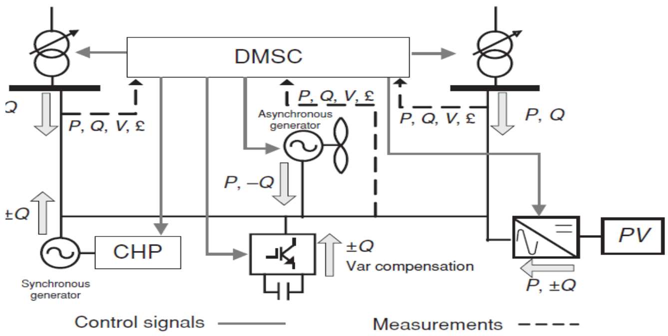

Fig.4 "Active Management Schematic of DN"[8]

B. Virtual Power Plants (VPP)

The power generation options are slowly shifting from centralized generation to decentralized and distributed generation, energy storage systems, and demand-side contributors. The DGs are integrated with the main grid, at the local community level. In the idea of DGs, all electricity consumers including household, business, and industrial are furnished with remunerations to generate power by introducing rooftop solar based PV or small scale wind or smaller scale hydel generators, and so on for their utilization and excess power will be offered to the grid and acquires income. In smart grid environment consumers are also contributing to power generation and so the new term is introduced in the place of consumers as “prosumers”. The provision of net energy meter at the “prosumers” premise provides two-way energy flow and a new tariff structure calculates net energy use and costs, after adjusting exported power to the grid. This is the crucial idea driving Virtual Power Plants (VPP). In the concept VPP the power generators assume the job of a power aggregator. The surplus generation from DGs and centralized power plants can be merged thus making adaptable power stockpile to be traded in the power market. The utilities can use VPPs to achieve balance in power demand and supply in the network and achieve low carbon ecosystems. The peak load, demand fluctuations can be managed by making use of VPPs using smart grid technologies vizAdvanced Metering Infrastructure (AMI), forecasting of load, etc. The VPPs will enhance the peak load management by quickly supplying stored energy to the system avoiding dependence on central power generation systems and this will enhance the dependability and efficiency of the grid framework in an increasingly affordable manner [10].

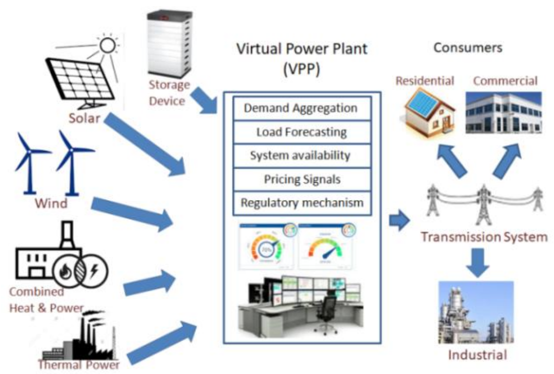

Fig. 5 The concept of VPP [10]

VI. PRINCIPAL SEGMENTS OF SMART GRID TECHNOLOGIES

The smart grids are an amalgamation of various advanced technologies and are shown in fig.6. This section will outline the most recent developments, key innovations, and present state of all these technologies.

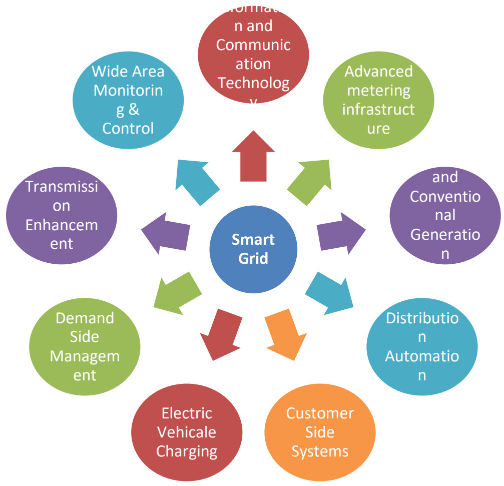

Fig. 6 : Smart grid technologies.

A. Information and Communication Technology (ICT)

This section reviews the most important developments in ICT in recent years, as well as the current challenges. The smart grid solely depends on the integration of modern wired and wireless vital communication technologies for its effective working. “The use of communication technologies ensures the reduction of energy consumption, optimal operation of the smart grid, and coordination between all smart grids’ components from generation to the end-users”[10]. Innovations in ICT have gained pace in recent years, especially in wireless communication technologies like cellular communication, ZigBee, Bluetooth, the wireless local area network (WLAN), WiMax, Power line communications, etc. The communication frame work for smart grid is shown in Fig. 7 .

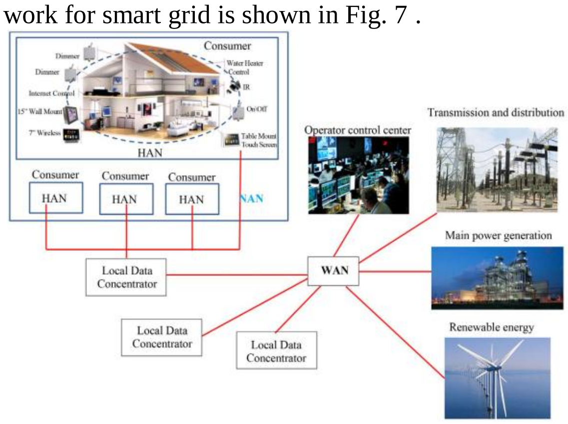

Fig. 7 Communication framework for Smart Grid[11]

“The smart grid communication framework can be established on three kinds of systems: Wide Area Networks (WANs), Neighbourhood Area Networks

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(NANs), Home Area Networks (HANs). Fig.6 shows the smart ICT infrastructure built on these three kinds of systems. The wireless communications technologies viz. wi-fi, ZigBee, WiMax, etc play a vital role in data acquisition and control applications of smart grids and table-3 shows a comparison of various wireless communication technologies" [11,12].

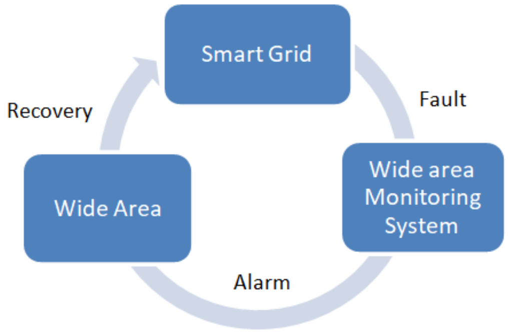

Fig 6 Typical WAMPAC System

- *Cyber-Security*

The other major concern in smart grids is the cybersecurity of ICT infrastructure which is prone to be hacked by cyber attackers and that will lead to disastrous and may cause huge economic loss to all the stakeholders. In recent times a lot of innovations are being undertaken by researchers to innovate a better solution for cyber-security for Information and Communication and other digital infrastructure of smart grids. To achieve an aggregate cyber-security, legal provision for objectives and requirements must be ensured[15]. The various levels of cyber-security objectives and requirements are shown in Table.

TABLE III

COMPARISON OF VARIOUS WIRELESS COMMUNICATION TECHNOLOGIES [11]

Variable	Wi-Fi	Thread	BLE	GSM	WiMAX	GPRS	PLC	ZigBee	Z-WAVE	DASH7	LoRaWAN
Year of Introduction	1997	2015	2010	1987	2001	1991	1922	1990	1999	2009	2012.
Technical Foundation	IEEE 802.11.1	IEEE 802.15.4	IEEE 802.15.1	IEEE 802.21	IEEE 802.16	IPv4 or IPv6	IEEE 1901	IEEE 802.15.4	ITU-T G.9959 (PHY and MAC)	ISO 18000-7	Open Standard
Frequency Band	2.4 GHz	2.4 GHz	2.4 GHz	890 - 915 MHz and 935 - 960 MHz	2.5GHz,3.5GHz, 5.8GHz	900-1800 Mhz	1-30 MHz	2.4 GHz, 868-915 MHz	800-900 MHz	433 MHz, 868 MHz and 915 MHz	433 MHz, 868 MHz, 915 MHz, 923 MHz
Nominal Range (0 dBm)	100 m	10 – 100 m	30 m	1-10 km	10-50 km	1-10 km	1-3 km	30-50 km	30-100 m	250m – 5km	2-7 km
Maximum Data Rate	54 Mbps	250 Kbps	1 Mbps	Up to 14.4 Kbps	1 Gbps (2011 update)	Up to 171.2 Kbps	2-3 Mbps	250 Kbps	9.6-100kbps	28-200 Kbps	27 kbps
Power Usage	Hi	Low	Low	Hi	Low	Hi	-	Low	Low	Low	Low
Applications	Data Transmi-ssion	Data Communicat ion	Data and Voice	internet, e-mail, data connectivity , remote monitoring, computer to computer communi-cation, security systems.	VoIP, VPLS, VoD, Vehicular Data and Voice, On line Gaming, Security and Surveillance Systems, Multimedia Communication, Sensor Networks, Telematics and Telemetry etc	WWW, FTP, Telnet, TCP/IP based applica-tions, Toll road system, UIC train control system, Weather info, road traffic info, news, fleet manage-ment, SMS	Control and Comma-nd, voice, Broad Band Over Power line, Home Net-working	Home Auto-mation, Smart Metering, Smart Grid monitoring	data comm-unication	WSN	IoT, Smart Metering, Data Communicat-ion etc

*VoD-Video on Demand, VPLS-Virtual Private LAN Services, VoIP- Wireless voice over IP, PAD-Packet Assembly/Disassembly.

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TABLE IV

CYBERSECURITY OBJECTIVES AND REQUIREMENTS

Cyber Security	
Objectives	Requirements
• Confidentiality • Integrity • Availability	• Authentication • Authorization • Accountability • Privacy • Dependability • Survivability • Safety Criticality

C. Advanced metering infrastructure

Advanced Metering Infrastructure (AMI) is the aggregate terminology used to depict the entire facilities including a smart meter to duplex communication framework to controlling devices and other applications being used to collect and communicate real-time energy usage data to utilities as well as consumers. The main aim of AMI is to access consumer meter reading remotely, fault identification, demand assessment, energy management and auditing, and partial disconnection of the load instead of complete load shedding during peak loads, etc. AMI is an integration of both hardware components and software, and it works collectively to measure energy usage, and other vital information, also communicates to both user and utilities[16].

The AMI includes[17]:

1. *Smart Meters* - Advanced meter gadgets having the ability to gather data about energy, water, and gas utilization at different spans and transmitting the information through the fixed channel of communication to utility, just as accepting data like price signals from utility and passing on it to buyers.
2. *Communication Network*-This enables two-way data communication between utilities and smart metering framework and vice-versa. These networks may be of wired or wireless channels for communication, which include Power Line Communication(PLC), Fibre Optics Communication, Radio Frequency communication, cellular, pagers, etc
3. *Meter Data Acquisition System*-Various software/hardware tools on the data control center and data concentrator units (DCU) are utilized for data acquisition from smart meters using various communication channels and convey it to the MDMS.
4. *Meter Data Management System (MDMS)* - Systems of Servers are used to collect, store, and analyze the smart meter data.

5. *Benefits of AMI*

There are various benefits of AMI are elaborated as[17]:

- An improved, and accurate meter reading and billing mechanism offer financial benefits to utilities.
- Eliminates visiting on-site for a meter reading.
- Enables energy theft detection.
- Improved power interruptions management.
- Customers will be benefitted from an efficient and accurate billing system, and also they can manage their energy usage, reduced power outages, and early detection of faults in smart meters.
- Improved resource and security threat management.

6. *Challenges*

Despite the above-mentioned advantages, deploying AMI poses the following challenges:[17]

- *Higher Capital Cost*- That includes the cost of AMI hardware, software, communication network, data analysis and management, installation, and support.
- *Integration*- AMI technologies are complex and suppose to integrate various other advanced technologies such as Information and Communication Technology (ICT), Geographical Information Systems (GIS), Supervisory Control and Data Acquisition (SCADA), Demand Side Management (DMS), Customer Information System (CIS), etc with utilities.
- *Standardization*-The AMI standards are required to be well defined for uniform hardware and software requirements, for interoperability options, and uniform operations across the platform, etc

D. Big Data Analytics in the Smart Grid

Research into big data analytics has gained pace in recent years, especially since the development of new artificial intelligence techniques allowing researchers to adopt these technologies in smart grids for data management. In the smart grid, electricity and information are both are in bidirectional. The integration of small scale decentralized generators viz. rooftop PV systems, wind farms, microgrids, deployment of advanced sensors, AMI technologies and incorporated with communication protocols, automated control, self-reconfiguration, and self-healing. The smart grid as compared to the traditional grid has 06 building blocks, viz. Network, Servers, Hardware, Software, Data, and User [18].

Owing to the huge amount of data generated in the smart grid, it is unworkable to handle the data with traditional analysis techniques to make real-time operations and control. The recent innovations in big data analytics can be effectively deployed in smart grids to handle huge amounts of data. The big data can be classified based on 5Vs (Volume, Velocity, Variety, Veracity, and Value). The 5Vs model is depicted in fig.8 [18].

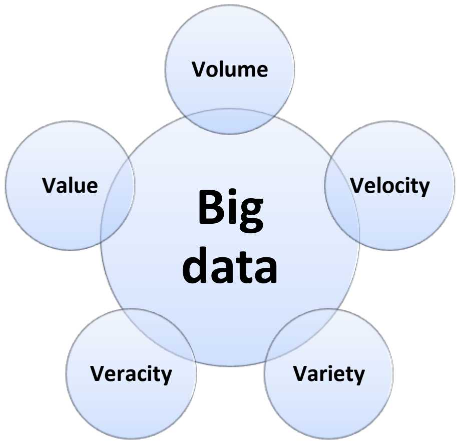

Fig.8 5Vs model of Big Data[18]

TABLE V.

CONFIGURATION SMART GRID DATA WITH 5Vs BIG DATA MODEL [18]

Prominent Attribute	5Vs Model	Smart Grid functionalities
Volume	Quantity of entities to be stored	Smart sensors, AMI generate a huge volume of data
Velocity	Data generation and accumulation	Real-time data collection for monitoring and control
Variety	Diversified sources form of data, multidisciplinary domain	Structured, semi-structured and unstructured data
Veracity	Dependability and data quality	Operational stability depends upon data quality and dependability
Value	Gathering useful information	Load forecasting and generation will derive value from gathered data in smart grid

E. Distributed Energy Sources and their integration

The electrical power system starting power generation, transmission, and power distribution prospered for many years with some degree of automation. The smart grid incorporates DERs into the generation system. "DERs are defined as small scale decentralized power storage and generation sites, typically 15MW or less per unit or site" [18]. Generally, DERs are owned, end consumers. The generated power from DERs is used to meet local demand and surplus power is disposed to a purchaser i.e. utility grid through the distribution network. There are various types of DERs, namely rooftop solar photovoltaic, small wind power generators, gas turbines, diesel engines, micro turbines, fuel cell stacks, batteries, flywheel energy storage systems (ESS), super capacitors banks, cogeneration systems, etc. DERs integration into the local distribution system causes number issues because of the bidirectional flow of power, which results in adding complications and possible malfunctioning of circuit breakers in the distribution grid. These challenges can be overcome by incorporating automation and control in the DERs integration system. The level of automation may be very complex to very simple, depending upon the type of equipment to be controlled. The DERs automation system is part of the IEEE standard 1547 reference to "Interconnection Systems"[19].

F. Demand Side Management

The customer's use of electricity may be differed, by making use of Demand-side management which encompasses the planning, execution, and monitoring of utility performance. It creates avenues and encourages consumers to use minimum power during a period of peak-demand or shift power usage during the period of off-peak time that results in flattening the load curve [20].

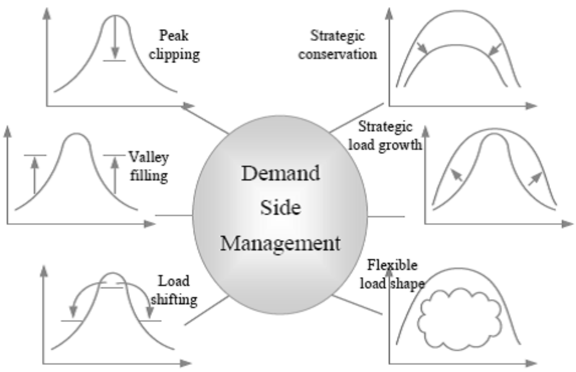

Fig.9: Demand-side management for load-shaping techniques"[21].

G. Transmission Enhancement

The electric power transmission line (mostly overhead) is used to transfer bulk power from a generating station to an electrical substation at high voltages. The transmission network is an interconnection of transmission lines, which facilitate the transfer of power high voltage levels.

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These transmission networks are susceptible to various faults due to various reasons, namely, lightning, falling tree branches, and decrease in insulation by the growth of trees underneath, failure of insulators, and breaking of conductors, etc.

Power production is dependent on various factors in deregulated generation systems such as weather conditions, load fluctuations, and other unseen factors. The power generation profile in transmission may change even during normal and steady-state situations. In the event of the occurrence of a fault such as tripping of line circuit breakers, generators, etc can result in a variation in power profile. If faults are unattended the system may be prone to transient state and tripping of protective relays, this may lead to a cumulative effect on the healthy part of the system and blackout the major part of the power system. The other reason for blackouts is excess loading of transmission lines, small-signal instability, and voltage fall due to the reduced reactive power in the system because of more inductive loads.

The factors discussed above highlight the problems faced by power systems in sustaining the economic and reliable operation of interconnected transmission networks. The above issues of the transmission line can effectively be resolved by the introduction of fast and dynamic control of active and reactive power by using power electronic Flexible AC Transmission System (FACTS) controllers [21,22]. The FACTS technology provides a great avenue for controlling the flow of power and improving the effective loading of transmission lines [23].

H. Electricity storage and Peak-Shaving and PHEVsTechnologies

The smart grid encompasses PHEVs, electrical energy storage, and thermal storage systems that will minimize peaks demand. Renewable energy systems are intermittent and therefore energy storage is essential in Smart Grids.[24] These storage units store excess energy during periods of high generation from renewable sources so that this stored energy can be expended during periods of increased demand [24]. EVs batteries when they are fully charged act like autonomous energy sources. The vehicle-to-grid (V2G) technology integrates vehicle batteries with the smart grid. When the electric vehicle is parked and linked to the grid, during peak hours they can deliver the stored energy from their batteries back to the grid [24]. Various research studies are underway in support of this import smart grid innovation.[24-31]

I. Application of Artificial Intelligence, IoT and Cloud Computing in Smart Grids

Research into Artificial Intelligence has gained pace in recent years, especially since the development of new techniques in computer engineering allowing us to solve complex problems. Artificial intelligence technology is used to develop intelligent machines and software in various engineering domains. Artificial intelligence (AI) techniques, namely expert artificial systems, neural networks techniques, fuzzy set theory, and have delivered technological advancement in power electronics and energy engineering. The smart grid can effectively utilize AI techniques in fault identification, fault resistant systems, load forecasting, generation forecasting in RESs, etc. The classic application cases of AI in these domains are the Automated design of Wind Energy Conversion Systems and its condition-based monitoring in the normal operating condition, the study of fault condition analysis in subsystems of Smart Grids, and simulator-based real-time monitoring and control of Smart Grids, etc [32,33].

Cloud computing is a computing concept that allocates computing resources employing virtualization technology. “Current load stability algorithms in the cloud center of attention on the unique systems or application requirements that lack scalable adaptivity. L Shen et al have proposed an Artificial Bee Colony (ABC) based optimization of load balance algorithm to enhance the typical load balance performance and attain better adaptivity in Smart Grids” [34].

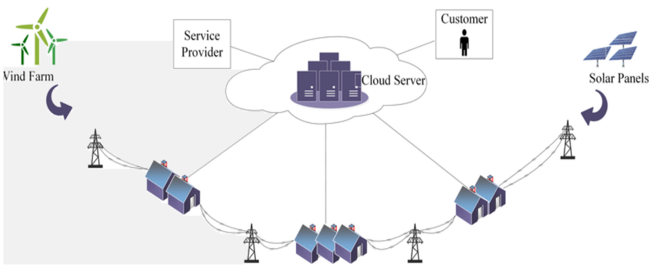

Fig.6 Cloud computing in Smart Grid [35]

Starting late, professionals are advancing endeavours to make the electrical power network progressively smart by adopting strategies for power transmission and distribution monitoring by the deployment of the Internet of Things (IoT) for the smart grid. IoT is a communication platform to help in data acquisition, analysis, and control of various applications using the internet. The applications include GPS, RFID, sensor data, etc. The targeted system can be intelligently monitored, tracked, positioned, and controlled by using IoT [36].A typical IoT system architecture for smart grid is shown in fig. 10 [37].

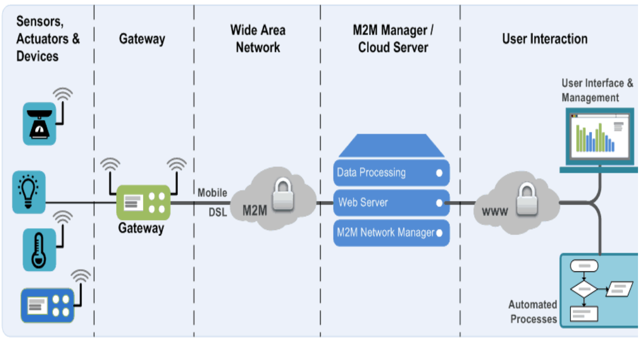

Fig.10 A Typical IoT System Architecture

VII. SMART GRID INITIATIVES IN INDIA

This section of the paper explores the possibilities for smart grids for India as the world moves from an out-of-date electric grid to a smart grid.

A. Indian Current Power Scenario

India's power sector is one of the principal diversified and third largest energy producers in the world. As per Central Electricity Authority (CEA), Govt of India, the total Installed Capacity of power generation is 370,348 MW as on 30 Apr 2020 and detailed breakup of power generation from specific sectors is given in fig-8[38].

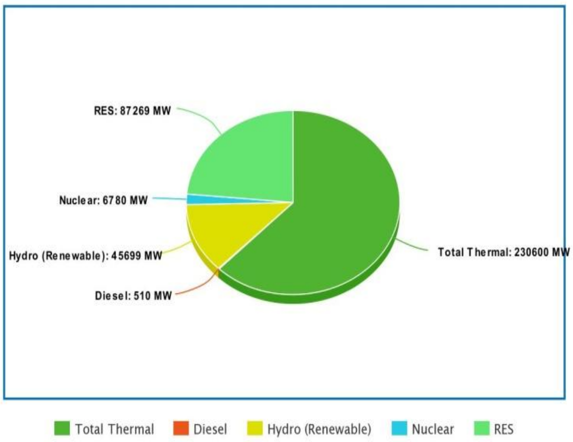

Fig.8 Installed capacity based on fuel used

Indian power generation is shifting from centralized power generation to decentralized distributed power generation mainly RESs. The Government of India by the year 2022, targeted to generate 175 Giga Watts (GW) using renewable energy. This is will be achieved by 100 GW from solar PV, 60 GW from wind energy conversion systems (WECS), 40GW from 'Roof Top Solar Generation Systems'. The contribution from thermal power plants (coal-based) is 229.40 GW (as of October 2019) and planned to add about 330-441 GW by 2040" [39].

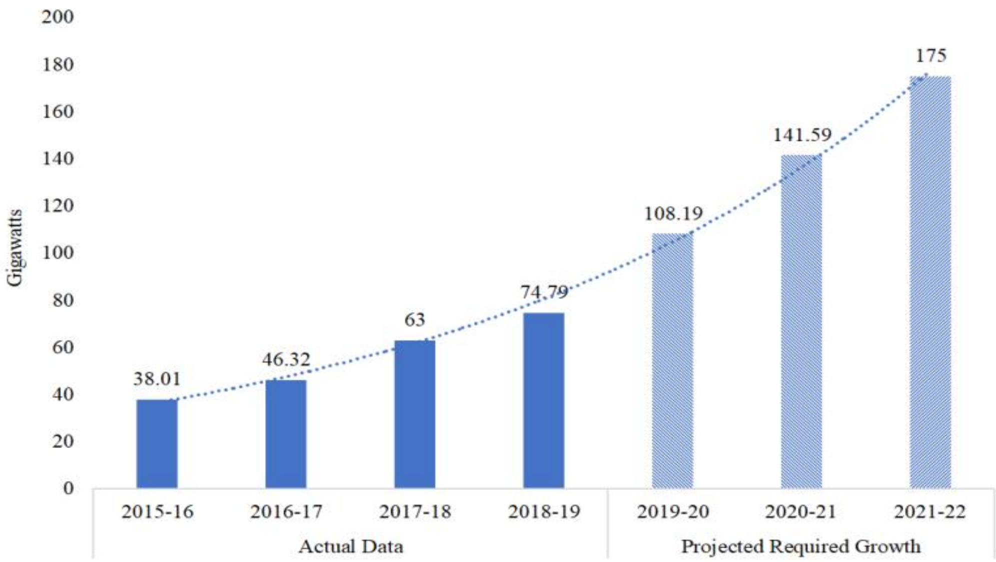

Fig.9 Progress needed for India to meet the 175 GW targets [39]

It has been assessed that India's energy demand should be two-fold by 2040. As per IEA without significant enhancement in energy efficiency in generation, transmission, and distribution level, India need's to add, the huge amount of power plants to fulfill the energy demand by various sectors.

By improving electricity efficiency in the energy sector, India would save $190 billion per year in electricity imports by 2040 and stagger electricity generation of 875 terawatt-hours per year. The growing older grid infrastructure, weak distribution system, massive-scale integration of DGs, bidirectional flow of currents pose operational and control challenges to existing grids.

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TABLE VI

BREAK UP OF RES ALL INDIA AS ON 30.04.2020

Small Hydro	Wind Power	Bio-Power		Solar Power	Total Capacity (MW)
		BM Power/Cogen.	Waste to Energy		
4683.16	37745.8	9880.31	147.78	34811.78	87268.74

B. Smart Grid Initiatives in India

The present-day power grid facing multiple challenges such as aging grid infrastructure, high amount of T&D losses, power theft, and integration of distributed generation systems, power quality issues, etc. Now it is the hour of need to develop an advanced grid system to mitigate the above challenges. The deployment of smart grids technologies in the existing power system will bring a new paradigm shift into its operation, control, and management. Also, these technologies will improve the efficiency, reliability, and economy of the power system. The theme smart grid vision for India is "Transform the Indian power sector into a secure, adaptive, sustainable and digitally-enabled ecosystem that provides reliable and quality energy for all with the active participation of stakeholders"[40]. The Govt of India has constituted the Indian Smart Grid Task Force (ISGF) in the year 2010 to undertake activities related to Smart Grid and also set up a road map for the development and implementation of Smart Grids in India. The present govt re-constituted ISGF and renamed it as National Smart Grid Mission (NSGM) in the year 2015. [42]

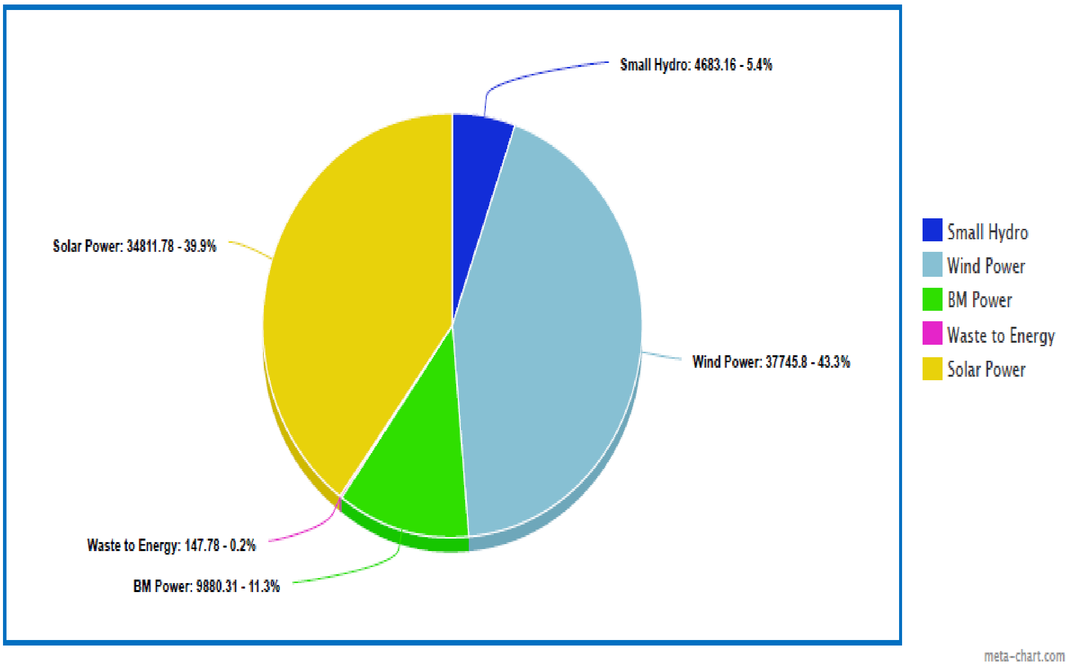

Fig.10 Break up of Renewable Energy System Power Generation all India as on 30.04.2020

The ISGF has constituted five Working Groups to take up the challenge related to Smart Grid activities. The role of these Working Groups (WG) are given in table-6 and to deal with the 'vital areas' ten more working groups have been constituted as shown table-7.

C. Smart Grid Pilot Projects in India

As a part of the smart grid initiative Govt of India has started deployment of Smart Grid projects on a pilot basis. The main functionalities of these projects are shown in fig.11 and smart grid projects functionalities and realization are given in Table-IX. The Smart grid pilot projects approved by GoI, and which are in initial phase of deployment are given in Table X and XI [42,43].

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TABLE VII

ISGF WORKING GROUPS FOR SMART GRID DEVELOPMENT [40]

WG	Activities
1	Trials/Pilot on new technologies
2	Loss reduction and theft, data gathering, and analysis
3	Power to rural areas and reliability & quality of power to urban areas
4	Dist Generation & renewable
5	Physical cybersecurity, Standards, and Spectrum

TABLE VIII

ISGF AREA WISE WORKING GROUPS FOR SMART GRID DEVELOPMENT [40]

WG	Activities
1	Advanced transmission
2	Advanced distribution
3	Communications for Smart Grid
4	Metering including Interoperability standards
5	Consumption & load control
6	Policy and regulations
7	Architecture & design incl. interoperability
8	Pilots and business models
9	Renewable and Microgrids
10	Cyber Security

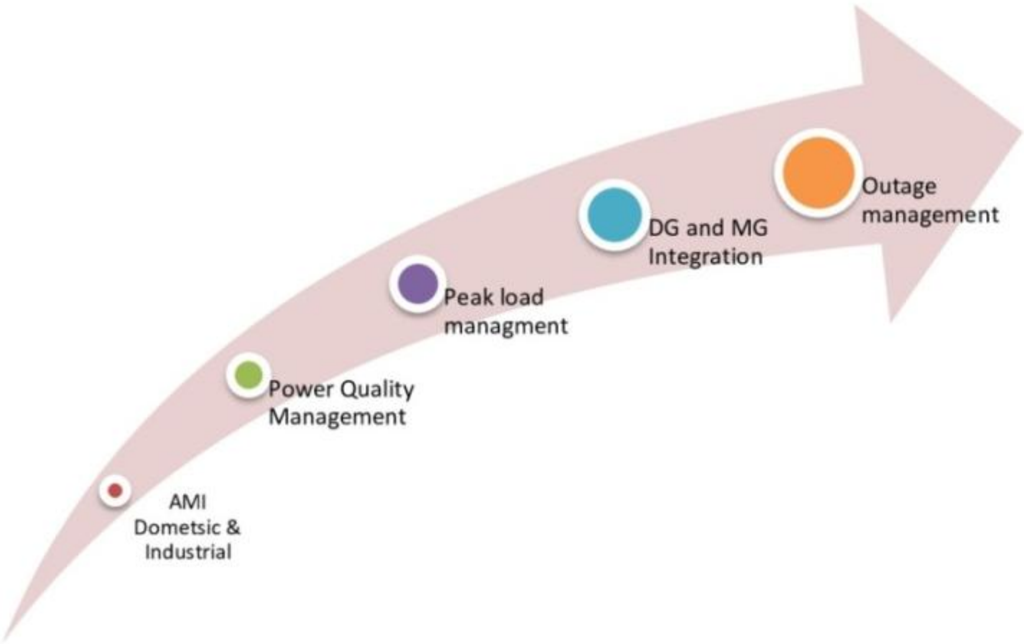

Fig.11 The main functionalities of Smart Grid Pilot Projects in India[44]

TABLE –IX

"INDIAN SMART GRID PILOT PROJECT FUNCTIONALITIES AND REALIZATION [44-47]

Smart Grid Function	Associated People	Process	Strategy
Advanced Metering Infrastructure (AMI) and Demand Response	End consumers; Utility personnel	Consumers shift their load as per incentives given as part of Time of Use (ToU) or Critical Peak Price (CPP) tariff for peak load management	ToU/CPP tariff policy; Rate recovery for AMI investment
AMI and Demand-side management	End consumers; Utility personnel	Utility manages the load thru HAN with a prior agreement with end consumer for PLM or frequency-based smart devices	Remote connect/ disconnect; ToU/CPP tariff policy; Rate recovery for AMI investment
Outage management via Signal Transmission Messaging Unit and AMI	Utility personnel	Utility dashboards to monitor load profiles and proactive actions to reduce outages and response time	Employee incentives based on outage-based Key Performance Indicators (KPIs)
Utility renewable energy integration via forecasting applications and AMI	Utility personnel	Wide Area Monitoring Systems, software applications and Demand Response for grid security	Time of use/Critical peak pricing tariff policy
Distributed renewable energy integration via AMI	Prosumers; Distribution Utility	Consumers participate in a generation through rooftop solar power or small windmills	Feed-in tariff and remote disconnection for grid security
Power quality management via Intelligent Electronic Devices (IEDs)	Utility	Dashboards for power quality	Employee incentives based on utility Key performance index dashboards; Penal tariff for injecting harmonics

LE X. GOVERNMENT OF INDIA APPROVED SMART GRID PILOT PROJECTS [44]

S. No.	Utility Name	Project Area	No of Consumers	Functionality
1	CESC, Mysore, Karnataka	VV Mohalla, Mysore	24532	• AMI Residential & Industrial • Power Quality Management • Peak Load Management, • MG/DG
2	TSSPDCL, Telangana	Jeedimetla Industrial Area	11904	• AMI Residential & Industrial, • Outage Management, • Peak Load Management, • Power Quality Management
3	APDCL, Assam	Guwahati Distribution Region	15000	• AMI Residential & Industrial, • Outage Management, • Peak Load Management, • Power Quality Management, • DG
4	UGVCL, Gujarat	Naroda of Sabarmati circle and Deesa of Palanpur circle	39422	• AMI Residential & Industrial • Outage Management
5	MSEDCL, Maharashtra	Baramati Town	25,629	
6	UHBVN, Haryana	Panipat City Sub-division	11,000	
7	TSECL, Tripura	Electrical Division No.1 of Agartala town	46071	• AMI Residential & Industrial, • Peak Load Management
8	HPSEB, Himachal Pradesh	KalaAmb	650	• AMI Industrial, • Outage Management, • Peak Load Management, • Power Quality Management
9	Puducherry (PED)	Division 1 of Puducherry	-	• AMI Residential, • AMI Industrial
10	JVVNL, Rajasthan	VKIA Jaipur	-	• AMI Residential & Industrial, • Peak Load Management
11	CSPDCL, Chhattisgarh	Sitara – Urla area of Raipur District	-	
12	PSPCL, Punjab	Industrial Division of City Circle Amritsar	-	• AMI Residential & Industrial • Peak Load Management • AMI Industrial
13	KSEB, Kerala	Selected Distribution Section offices spread over the geographical area of Kerala	-	
14	WBSEDCL, West Bengal	Siliguri Town in Darjeeling District	-	• AMI Residential & Industrial • Peak Load Management

TABLE XI. OTHER SMART GRID PILOT PROJECTS IN INDIA [44]

Utility Name	Functionality
Smart Grid Research Laboratory, CPRI, Bengaluru, India	• Smart Grid Research Laboratory comprising of Smart Grid Technology Centre (SGTC) and Interoperability Laboratory (Interop Lab).
AMI Project TATA Powers Mumbai	• AMI • Wireless technology from Cyan, • Metering data acquisition and systems interface by Neosilica • Meter Data Management System for billing and fault management by Tata's.
Smart Grid Pilot Project Bangalore Electricity Supply Company Limited (BESCOM)	• AMI • Peak Load Management and • Solar Rooftop PV Systems (RTPV).
Smart Grid projects, Odisha	• Underground and overground cables and gas-insulated sub-stations with full automation and control to withstand cyclone effects
Smart Grid Pilot Project Chhatrapur, Odisha	• A Smart Grid pilot project covering 5800+ consumers
Battery Energy Storage demonstration projects Power Grid Corporation of India Ltd (PGCIL)	• Demonstration projects of capacity envisaged is 500kW & 250 kWH on grid-connected battery energy storage technologies: – Lithium Iron Batteries, – Advanced Lead Acid Batteries, and – Flow Batteries or Sodium Sulphur Batteries.
Smart Grid Pilot Projects Calcutta Electric Supply Corporation Limited (CESC)	• SCADA/DMS/EMS enhancements, • Communications infrastructure for – AMI – Distribution Automation, – Smart metering – Enterprise Application Integration

10. Discussion:

The concept of Smart Grid was started in the year 1997 after that lot of innovations, breakthroughs, frameworks, gadgets, techniques, and procedures upgrade Smart Grids have surfaced, there is a vast potential for future exploration. To transform the traditional electric grid into Smart Grid requires additional layers such as automation, communication, and IT systems. This paper has reviewed major smart grid technologies and their development. The vast literature is available on smart grids in the form of articles, technical papers, journals, and books; it is a herculean task to cover all literature on the subject in a single paper. The review has found scope for further research in smart grid technologies. The main areas where the scope of further research may be undertaken include; advanced metering infrastructure, load forecasting, Outage Management Systems (OMS) and fault self-healing techniques, smart grid information security, automation of distribution networks, wide area, and monitoring control and techniques, EVs charging, DG integration and Power Quality, Transmission enhancement, etc.

Issues and challenges in Smart Grids**:** The smart grid is a complex infrastructure of a modern power system that encompasses advanced technologies like information and Communication, Internet of Things and Cloud computing, Energy Management systems, and Advanced Metering Infrastructure, etc. There is clear visibility in the research and developmental activities of smart grid technologies but there are huge issues and challenges embrace these technologies and full accomplishment is still very far.

11. Conclusions

This paper has reviewed innovations in smart grid technologies, issues, challenges, and solutions in the literature. In the literature it is found that the traditional grids were simple and built to serve consumers through a one-way channel from generation to consumption the system was prone to high losses power thefts and frequent power cuts, it also made it difficult for the grid to respond and cope with the evolving needs and lifestyle of consumers. Smart Grid technologies provide a solution to these challenges simply put a smart grid is an intelligent system that thinks about the consumer, it allows for a two-way interaction between the supplier and the consumer an enabling real-time exchange of electricity and information. The smart grid is a digitally controlled network of advanced metering communication controls and new technologies working together to make the grid more secure reliable efficient and cleaner. The full deployment of smart grid technologies to reap the benefits across the globe, needs local government initiatives, policies, standards, investments, innovations, finally interest of utilities, and consumer awareness.

REFERENCES

[1] J. Ekanayake, K. Liyanage, J. Wu, A. Yokoyama, and N. Jenkins, "Smart Grid: Technology and Applications". 2012.

[2] Sun, Q., Wu, J., Zhang, Y. et al. (2010) "Comparison of the development of Smart Grids in China and the United Kingdom". IEEE PES Conference on Innovative Smart Grid Technologies Europe, 11–13 October 2010, Gothenburg, Sweden.

[3] European Commission (2006) European "SmartGrids Technology Platform: Vision and Strategy for Europe's Electricity", http://ec.europa.eu/research/energy/pdf/ smartgrids_en.pdf

[4] Kaplan, S.M., Sissine, F., Abel, A. et al. (2009), "Smart Grid: Government Series:, The Capitol Net, Virginia.

[5] European Commission (2011) European "SmartGrids Technology Platform: Vision and Strategy for Europe's Electricity", http://ec.europa.eu/research/energy/pdf/ smartgrids_en.pdf .

[6] U.S. Department of Energy, "Smart Grid System Report", July 2009, http://www.oe.energy.gov/sites/prod/files/ oeprod/DocumentsandMedia/ SGSRMain_090707_lowres.pdf

[7] T. U. Daim et al., "Technology roadmapping," Technol. Roadmapping, pp. 1–783, 2018, doi: 10.1142/10859.

[8] A. Shafiu, et al., "Active management and protection of distribution networks with distributed generation," 2004 IEEE Power Eng. Soc. Gen. Meet., vol. 1, no. x, pp. 1098–1103, 2004, doi: 10.1109/pes.2004.1373011.

[9] IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems, "IEEE std 519-1992," Ieee, pp. 1–9, 1992, doi: 10.1109/PAPCON.2006.1673767.

[10] Pudjianto, et al., "Virtual power plant and system integration of distributed energy resources". Renewable Power Generation, 2007, IET, 1 (1), 10–16.

[11] D. Baimel, et al., "Smart Grid Communication Technologies," J. Power Energy Eng., vol. 04, no. 08, pp. 1–8, 2016, doi: 10.4236/jpee.2016.48001.

[12] V. C.Gungor, et al., "Smart Grid Technologies; Communication technologies and standard," Industrial Informatics, IEEE Transactions, vol. 7, pp. 529 - 539, 2011.

[13] A. Jindal et al., "Big Data Analytics in the Smart Grid," IEE Smart grid, 2017.

[14] N. Anandan, P. Sheeba, S. Sivanesan, S. Rama, and T. T. Bhuvaneswari, "Wide area monitoring system for an electrical grid," Energy Procedia, vol. 160, no. 2018, pp. 381–388, 2019, doi: 10.1016/j.egypro.2019.02.171.

[15] M. Z. Gunduz and R. Das, "Cyber-security on smart grid: Threats and potential solutions," Comput. Networks, vol. 169, p. 107094, 2020, doi: 10.1016/j.comnet.2019.107094.

[16] C. Selvam, et al., "Advanced metering infrastructure for smart grid applications," Int. Conf. Recent Trends Inf. Technol. ICRTIT 2012, pp. 145–150, 2012, doi: 10.1109/ICRTIT.2012.6206777.

[17] http://energy.gov/oe/technology-development/smart-grid

[18] R. Gore and M. Kande, "Analysis of Wide Area Monitoring System architectures," Proc. IEEE Int. Conf. Ind. Technol., vol. 2015-June, no. June, pp. 1269–1274, 2015, doi: 10.1109/ICIT.2015.7125272.

[19] P. Dove, A. Corporation, and I. A. Group, "Integrating Distributed Energy Resources into the Smart Grid," no. reference 1, 2010

[20] L. Gelazanskas and K. A. A. Gamage, "Demand side management in smart grid: A review and proposals for future direction," Sustain. Cities Soc., vol. 11, pp. 22–30, 2014, doi: 10.1016/j.scs.2013.11.001.

[21] K. R. Padiyar, "Facts Controllers in Power Transmission Distribution". 2007.

[22] I. O. Ozioko, et al., "Enhancement of Power System Transmission Using Static Synchronous Compensator (STATCOM)," 2019 IEEE PES/IAS PowerAfrica, Abuja, Nigeria, 2019, pp. 482-486, doi: 10.1109/PowerAfrica.2019.8928629.

[23] IEEE. Press, Narain G. Hingoranl, et al., "Understanding FACTS"IEEE Power Engineering Society, 2000.

[24] University of Delaware. "Car prototype generates electricity, and cash" science daily. Science daily n.d.⟨http://www.sciencedaily.com/releases/2007/12/ 071203133532.htm⟩

[25] Ferrari ML, et al., :Real-time tool for management of smart poly generation grids including thermal energy storage". Appl Energy 2014;130:670–8. http://dx.doi.org/10.1016/j.apenergy.2014.02.025.

[26] Pascual J, et al., "Implementation and control of a residential electro thermal microgrid based on renewable energies: a hybrid storage system and demand side management". Energies 2014;7:210–37. http://dx. doi.org/10.3390/en7010210.

[27] Koohi-Kamali S, et al., "Emergence of energy storage technologies as the solution for reliable

operation of smart power systems: a review". Renew Sustain Energy Rev 2013; 25:135–65. http: //dx.doi.org/10.1016/j.rser.2013.03.056.

[28] Biswas M, et al., "Towards implementation of smart grid: an updated review one lectrical energy storage systems" 2013, pp. 122–32.

[29] De Gennaro M, et al., "Customer-driven design of the recharge infrastructure and vehicle-to-grid in urban areas:a large-scale application for electric vehicles deployment". Energy 2015;82:294–311. http://dx.doi.org/ 10.1016/j.energy.2015.01.039.

[30] Schroeder A, Traber T. "The economics of fast charging infrastructure for electric vehicles". Energy Policy 2012; 43:136–44. http://dx.doi.org/10.1016/j. enpol.2011.12.041.

[31] Van Der KamM,Van Sark W. "Smart charging of electric vehicles with photo voltaic power and vehicle-to-grid technology in a microgrid; a case study". Appl Energy 2015;152:20–30. http://dx.doi.org/10.1016/j.apenergy.2015.04.0 92.

[32] B. K. Bose, "Artificial Intelligence Techniques in Smart Grid and Renewable Energy Systems - Some Example Applications," Proc. IEEE, vol. 105, no. 11, pp. 2262–2273, 2017, doi: 10.1109/JPROC.2017.2756596.

[33] J. T. C. Neto, et al., "Big Data Analytics of Smart Grids using Artificial Intelligence for the Outliers Correction at Demand Measurements," 2018 3rd International Symposium on Instrumentation Systems, Circuits and Transducers (INSCIT), Bento Goncalves, 2018, pp. 1-6, doi: 10.1109/INSCIT.2018.8546718.

[34] L. Shen, J. Li, et al., "Optimization of Artificial Bee Colony Algorithm Based Load Balancing in Smart Grid Cloud," 2019 IEEE Innovative Smart Grid Technologies - Asia (ISGT Asia), Chengdu, China, 2019, pp. 1131-1134, doi: 10.1109/ISGT-Asia.2019.8881232.

[35] IEA (2011), "Technology Roadmap - Smart Grids", IEA, Paris https://www.iea.org/reports/ technology- roadmap-smart-grids

[36] N. A. Hidayatullah, et al., "Power Transmission and Distribution Monitoring using Internet of Things (IoT) for Smart Grid," IOP Conf. Ser. Mater. Sci. Eng., vol. 384, no. 1, 2018, doi: 10.1088/1757-899X/384/1/012039.

[37] F. Y. Okay and S. Ozdemir, "A fog computing based smart grid model," 2016 Int. Symp. Networks, Comput. Commun. ISNCC 2016, no. March 2018, 2016, doi: 10.1109/ISNCC.2016.7746062

[38] "Power sector at glance ALL INDIA" (23 May 2020) https://powermin.nic.in/en/content/power-sector-glance-all-india

[39] KPMG, "Power Sector Overview: Georgia," no. December, 2016.

[40] I. S. Jha, S. Sen, and R. Kumar, "Smart grid development in India - A case study," 2014 18th Natl. Power Syst. Conf. NPSC 2014, no. March 2014, 2015, doi: 10.1109/NPSC.2014.7103866.

[41] "National Smart Grid Mission" , Ministry of Power , Govt . of India Status of NSGM Smart Grid Projects & Smart Grid Pilots , pp. 1–2, April 2020

[42] "The Smart Grid Vision for India's Power Sector"-A White Paper. PA Consulting Group; 2010 Mar. Available from: http://www. sari-energy.org/Page Files/what_We_Do/activities/smart_grid_ vision_for_india_power_sector_june_2010/White_Paper_on_the_ Smart_Grid_Vision_for_ India_final.pdf

[43] "Draft Smart Grid Roadmap for India". Available from: http://re.indiaenvironmentportal.org.in/ DraftSmart Grid Roadmapforindia.pdf

[44] A. Jain, "Smart Grid Pilot Projects in India – Applications and Experiences" Joint Director, Central Power Research Institute, India, IEEE PES, Power and Energy Society

[45] Manoj Gupta, Rajesh Kumar, Ram Awtar Gupta, "Neural Network Based Indexing and Recognition of Power Quality Disturbances" TELKOMNIKA, Vol.9, No.2, August 2011, pp. 227~236 ISSN: 1693-6930

[46] A. Raj, M. Gupta and S. Panda, "Design simulation and performance assessment of yield and loss forecasting for 100 KWp grid connected solar PV system," *2016 2nd International Conference on Next Generation Computing Technologies (NGCT)*, Dehradun, 2016, pp. 528-533, doi: 10.1109/NGCT.2016.7877472.

[47] Anita Pakharia, Manoj Gupta, "Dynamic Voltage Restorer For Compensation Of Voltage Sag And Swell: A Literature Review" International Journal of Advances in Engineering & Technology,. ©IJAET ISSN: 2231-1963, Vol. 4, Issue 1, pp. 347-355, July 2012