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Recent advancement in smart grid technology: Future prospects in the electrical power network

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ABSTRACT

With the advancement in technology, there is an immense increase in the demand of electrical energy that has not only become challenge for its production but also its distribution. So this rising demand is growing the complexities of power grids by increasing requirement for greater reliability, efficiency, security and environmental and energy sustainability concerns. These feature in a power grid towards smartness which eventually known as a today's concept of "Smart Grid". This is a conceptual technique in which all smart features are implemented in order to increase the distribution system of electricity efficient, more reliable and sustainable. In this article an overview of "Smart Grids" with its features and its different aspects on power distribution industry has been presented. It is also explained that how these technologies change and have more potential to evolve and strength the distribution system.

1. Introduction

Urbanization, living standards and advancement in technology has increase the demand of energy requirement. This made electricity consumption rises to levels that may no longer be manageable if left unattended. This is an alarming situation not only for providing sustainable energy but also preservation of environment worldwide. Almost 75–80% of total energy consumption is consumed in cities which is responsible for 80% greenhouse gas emission [1,2]. Traditional and centrally-controlled system for the distribution of electrical energy is being used for a long day. This is commonly name as power grid. Since the use of electricity, globally electric grids have similar structure, dynamics and principles even with the advancement of technology. These traditional power grids are focused on only some of the basic functions like generation, distribution and control of electricity [3]. The electricity grid in present form is unreliable, has high transmission losses, poor power quality, prone to brownouts and blackouts, supplying inadequate electricity, discouraging to integration of distributed energy sources. There is a lack of monitoring and real time control in the traditional non-smart systems, which creates a challenging opportunity for smart grids to act as a real-time solution. Countering these issues requires a complete overhauling of power delivery structure. Electrical benefits are not only the encouraging force for the introduction of 'smart grid' concept, but environmental aspects too. Efficient usage of energy and dependency on renewable resources will also help to reduce the carbon foot print of human.

Smart Grid technology has a way for a solution for better generation of electric power and an efficient way for transmission and distribution of this power. Due to its versatility it can be more easily installed and required less space as compared to traditional grids. Concept of Smart Grid design is aimed for grid observability, create controllability of assets, enhance performance and security of power system and specially the economic aspects of operations, maintenance and planning [4]. That's why it is also consider that smart grid technology can be used to micro-grid level which eventually connect to all other micro-grids to form a large network of Smart Grid. These smart grids have a huge potential and could be a solution of reliability of power transmission and distribution in developing countries which lack infrastructure. In US only 20% of the all carbon dioxide is been emitted by transportation while generation of electricity has 40% of the carbon dioxide emitting share

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in it. This is due to the high demand rise of electricity. Smart Grids are been considering as a key role to address this problem by distributing electric power in an efficient way and ultimately reduce greenhouse gasses and pollutants like NOx and SOx [5]. It will also help the customer to forecast its demand and the best economical utilization of energy.

Smart Grid research has a long history with the start of its first concept implementation in 1997. This article will discuss an overview of the Smart Grid, its features and functions which includes reliability, security, energy management, self-healing. It will also discuss that how smart grid is changing the concept of grid technology and how much potential to revolutionized in modern electrical power grid. Some implemented technologies related to smart grids and pilot projects in different countries of the world are also part of this article.

2. Smart grid concept

There is no specific start of Smart Grid. This concept was start evolving with the start of distribution system of electrical networks. By the time different requirements were needed like control, monitor, prices and services of transmission and distribution of electrical power. Normally, Smart Grid implementation is associated with the installation of smart meter. In 1970s and 80s they were used to send the information of consumer back to the grid [6]. But the most important and fundamental need which is still under consideration even with latest advancement is reliability and efficiency of energy transmission and distribution via electric power grid. But in the latest advancement research is undergo that grids and network systems should not limit to transmission and distribution but also play a vital role in generating clean and sustainable energy in order to reduce greenhouse gases and carbon foot print.

2.1. Definition

For the distribution of electrical power to consumer one need a network of electrical conductor which is known as *grid*. If this network is intelligent with automated control and monitor system than it might be known as *Smart Grid.* Technically, smart grid is a concept for the conventional grids with some latest and automated features which make them more reliable and sustainable. Conventional grids were use just to transmit and distribute the electric power but this modern concept of smart grid could communicate, store or even decide according to the situation. Therefore, according to Strategic Deployment Document for Europe's Electricity Networks of future, a Smart Grid is an intelligent network of electricity that integrate the actions of all the stakeholders that are generators, consumers and one who does both in order to supply electricity with efficiency, sustainability, economically and securely [7]. So Smart Grid is not a single technology that is to be implemented. Its vastness and dependency increases by its stakeholders as shown in Fig. 1.

It provides its stakeholder an opportunity to maximize the efficiency, reliability, economic performance and security of their electrical network. An overview of its architecture is shown in Fig. 2.

2.2. Design

To understand the design and concept of smart grid one has to understand its difference with the traditional power grid. This comparison was done by Yu et al. in 2012 [8]. This comparison is shown in Table 1.

The design of the smart grid is flexible with its use and related objectives. A conceptual model of smart grid was presented by National Institute of Standards and Technology (NIST) which describe planning, development requirement, stakeholders that interconnected and equipments that are required [9]. NIST classifies these stakeholders in seven domains for modeling as shown in Table 2.

2.3. Characteristics of smart grid

For the modernization of the electric grid, Energy Independence and Security Act 2007 (EISA) developed a platform [10]. Features and functionalities of Smart Grid have a promise to full fill these requirements set by EISA.

2.3.1. Reliability

Success of the grid system depends upon the customer need which is measured as reliability. This mean as flaw less and error less system with continuous supply of electric power. Smart Grid has a potential to detect any fault and allow the self-healing of the system [11]. Conventional grids have issues regarding interaction of renewable resources, micro grid and demand response. With increase the size and complexity of these grids with demand it makes more difficult to analyze its reliability. But these issues are very well addressed by Smart Grids [12]. For this, Smart Grids have capability to monitor and store all the data and estimate its service reliability. It may also possible to monitor remotely for hybrid generation and management of the grid which enhance its reliability [13]. Technologies like Dynamic Stochastic Optimal Power Flow (DSOPF) helps in estimating and optimizing the flow of power in Smart Grid [4]. Therefore, Smart Grids can have better reliability with the advancement in communication system [14].

2.3.2. Security

Security is one of the challenging issues for the Smart Grid evolution. With the increase of automation, remote monitoring and controlling of the grid make the grid more vulnerable by cyber assault. According to Electric Power Research Institute, cyber security of the system is one of the biggest issue of the Smart Grid [15]. Suleiman et al propose a way to identify the weaknesses of the smart grids that usually attackers exploit by using Smart Grid Systems Treats Analysis and by integration of Systems Security Threat Model [16]. Similarly in 2014, Ashok et al proposed an approach to address cyber-physical security issue of Wide-Area Monitoring and protection and control from a coordinated cyber-attack perspective which will eventually enhance the security [17]. For assessing the Smart Grid security, one needs a review for its methodology. There are different agencies and organizations like IEEE Power & Energy Society (PES), IEC Smart Grid Standardization, National Institute of Standards and Technology (NIST) are involve and help in standardization and regulation for the smart grid [18]. Some of the promising ongoing research in different domains of security for smart grids include: Privacy-preserving smart metering with multiple data consumers, Ortho code privacy mechanism in Smart Grid using ring communication architecture and Security Threat Model [19–21]. As security is to be consider one of the biggest barrier for implementation of Smart Grid technology, so ongoing these researches have promise to resolve this barrier.

2.3.3. Demand side management system

Smart grid provides the demand side or user to interact with the grid by using two ways communication ability. It provides a chance for the consumer to use the electric power in an economical way. It will not only help for increasing efficiency at demand side but also at distribution end. It helps grid to reduce demand and stress during peak period by reducing or shifting power requirement to alternatives. This gives some financial incentive to consumer which encourage them to do so. Currently, a lot of investment is being made in this sector of the smart grids including demand side

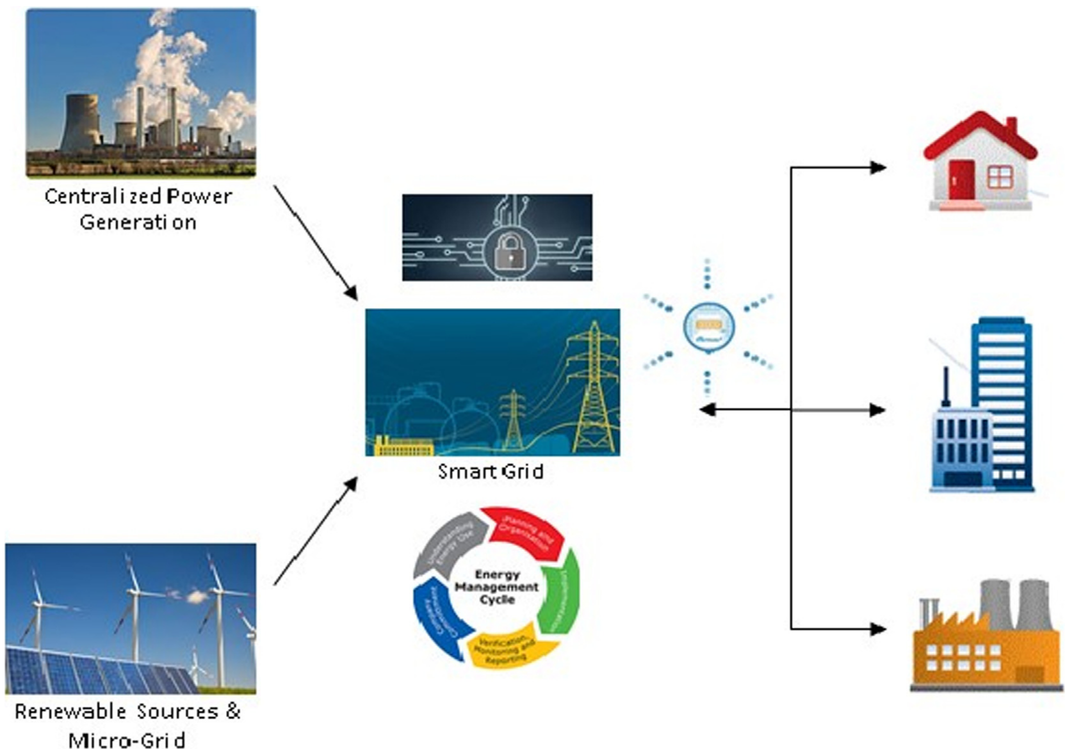

Fig. 1. Working concept of Smart Grid.

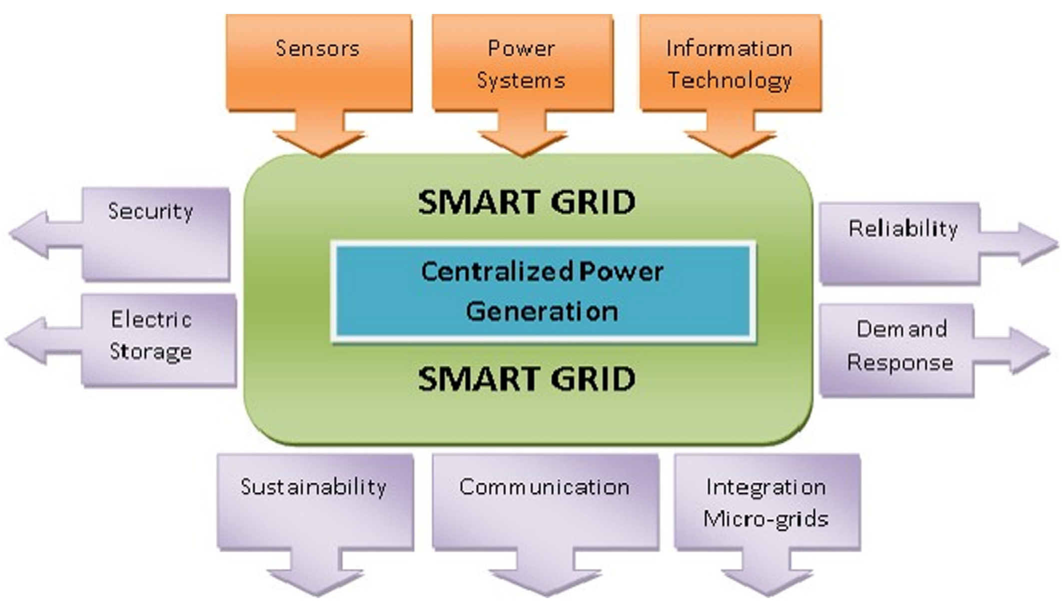

Fig. 2. Overview of Smart Grid architecture.

resources, load management systems and energy efficiency initiatives in order to address economical, reliability and economic perspectives [22]. Mostly demand side management systems focus only the communication between utility company and consumer. A new consumption scheduling technique is on the way to address the future grids in which each consumer can schedule their own consumption requirements. In this way it helps the distribution system to schedule itself accordingly to the requirement as peak loads for different consumers varies [23]. This also encourages the consumer to have financial incentives by scheduling their needs.

With the evolution of Smart Grid, this definition has also started revolution in the appliances and utilities to be "Smart" known as smart devices. These have ability to communicate with the grid which make house more autonomous and facilitate the user to use the electric power effectively and efficiently. These appliances shift demand of household electricity. Different networking protocols like 'ZigBee' provides a solution to have a wireless control of household appliances. These protocols have ability to communicate and coordinate with all the stakeholders involved in home energy management system hence providing the best optimal

Table 1
Difference between Smart and Conventional Grid.

Smart Grid	Conventional Grid
Two-way real-time communication	One-way communication
Distributed system of power generation	Centralized for power generation
Interconnected Network	Radial Network
A large number of sensors are involved	A small quantity of basic sensors are used
Digital Operation	Mechanical Operation
Automatic Control and Monitor	Manual Control and Monitor
Wide range of control	Limited control
Security and privacy concerns	No security or privacy concern

Table 2
Stakeholders of Smart Grid.

Stakeholder	Description
Customer	Electricity is consumed by consumer. It may be domestic, commercial or industrial
Operations	Operations related to power systems are performed. It comprises of regulatory authorities or management responsible for movement of electricity
Markets	Grid assets are used by stakeholders. Both operators and consumers are play role as market.
Generation	Electricity is generated. Generation companies in bulk quantity of electricity are involved as player.
Transmission	Electricity is transmitted. Companies or player responsible for transmission of generated electricity for distribution.
Distribution	Electricity is distributed to end consumer and monitored. They include distributor of electricity form and to customers.
Service Provider	Provide support services to all the stakeholders involved in generation, transmission and distribution of electric power.

solution to the user [24]. Therefore, smart grid is changing the trends of conventional household appliances to 'smart'.

2.3.4. Metering

Automation in distribution system is associated with the smart automatic meter. Metering provides a channel to enable two-way communication in Smart Grid concept between consumer and distributer. They not only help distributor for more accurate billing system but also help consumer to control their use of electrical energy. These meters are equipped with sensors for automation, power quality monitoring and power outage notifications. There are different drivers like price increase after electricity market deregulation, consumer dissatisfaction and monthly metering directives which encourages smart meters [25]. In traditional grid systems, SCADA was only used for communication purposes which provide a central control unit to monitor and control with second scan rate. But it's not much cost effective at different levels of electrical power distribution especially at utility end [26]. Advanced Metering Infrastructure (AMI) provides a real time solution that collects consumer data and provides a communication networks from grid to utility end. AMI provides opportunity to step forward for the modernization of the huge grids by combining consumer with the distribution system. It provides an opportunity for outage management, integration of electrical vehicles and smart devices, transformer and feeder monitoring and fault isolation [27]. Researchers have design a new system for the automation of distribution of power through a Substation Automation System (SAS). This system has ability to solve congestion through locally control actions with a minimum limitation of renewable energy resources [28].

2.3.5. Micro-grids and integration of renewable resources

Power generation from renewable resources likes, solar, wind, battery storage devices are bean of high consideration to full fill the increasing demand of electricity and reducing the greenhouse gasses. They even help to reduce the power stresses from grid during peak hours. Normally sites for these resources are far or in remote areas. Even sometimes it is not possible to have a complete functional grid to transmit or distribute electric power. Here micro-grids are used, which gather to form a big distribution network. So with this large number of micro-grids and sources will result in large amount of data to be handle. So researches like one by Penya et al. [29] have a solution for this problem by using an architecture that uses an intelligent system all over the grid to distribute the power effectively. This system will not be used as centralized but will handle individually by mean of individual intelligent nodes.

2.3.6. Self-Healing

For a robust Smart Grid, it should not limited diagnose the fault occur in the grid but could also be able to remove it for a constant supply of electricity. For a grid with a self-healing ability it uses real-time communication and digital components that are installed throughout the grid to monitor electrical characteristics of the grid. With this ability, grid is smart enough and capable to figure out the potential problem that may be caused naturally or by some human error. These intelligent systems react instantly to any such abnormalities and isolate the problem system before they snowball into a big problem and cause major blackout and automatically reroute the transmission of power for continuous services unless the error is removed. There are three main benefits of a smart grid with self-healing capability [30]: real-time monitoring and reaction, anticipation of problem, rapid isolation.

3. New technologies and research

A number of on-going research activities are being made for the advancement of the smart grid to make it more reliable and sustainable for the modern needs. These researches are focused on different technologies. It is difficult to cover all of these researches and advancement but this section includes some of the prominent and latest technologies and research activities associated with smart grid.

3.1. Energy management system

For a reliable grid, it's essential that all the components involve must be work together from generation to consumption. There are a lot of complex components involved in the grid. These components communicate and work together by mean of some computer software. So, planning and its implementation on grid are done by mean of interoperability. NIST initiated smart grid interoperability (SGIP) which was responsible to develop and maintain the standards for smart grids and all the components involve must communicate and operate efficiently. It was also liable to provide a platform for all the stakeholders of power grid including customer, markets, service provider, power system, generation, transmission and distribution network to work together to form a modern, reliable and efficient grid system [9]. For the understanding and implementation of energy management, both grids and consumer end must play their role. Technologies like advance metering infrastructure (AMI), communication network for grid and cyber security enables self-decision capabilities in grid which make energy management system more realistic for smart grid [31].

3.2. Internet of things (IoT)

Internets of things (IoT) take the internet to next step of evolution. It makes life easier, automate and handy by squeezing the whole world into one hand by computation and communication capabilities. With the advancement of smart grid and its components, a technology was needed to interact these components in an efficient, reliable and in more smart way. IoT has a promise to full fill all these characteristics taking smart grid into new era. But with this new technology, some serious security concern emerged which include impersonation, data tampering, overdoing, authorization, privacy issue and cyber-attack [32]. Researchers are doing study to deal with these issues. IoT base smart grid must have services like authentication, confidentiality, user's privacy and data integrity to avoid any security risk[32]. Connectivity that IoT provides to customer, enhance their experience and efficiency. It allows customer a flexible and easy interaction with the grid in order to reduce cost by diagnostics and neighborhood-wide meter reading capability [33]. In short, it makes smart grid smarter.

3.3. Smart grids with electric vehicles

As one of the biggest environmental issue is pollution due to vehicles. Use of electrical vehicles has the solution of this problem. There are several challenges for EVs to interact with the grid which include infrastructure, communication and control. Mostly it is seen that EVs are charged at home and even sometime charging take place at public or commercial Charging station [34]. Therefore, it is possible that it directly stresses the electric distribution network. But contrary it is possible that this EV charging can improve the quality of power and performance of grid if integration of EVs with the grid is well planned and follow the standards set for it [35].

As Smart Grids have advance technologies in the form of communication, smart meters and control. So it has a potential to offer electric vehicles not only as a load but can be used as a flexible energy source [36]. Smart meters play a vital role to address the challenges faced by the grid due to EV. As these meters have bidirectional communication ability and to monitor real time data so these smart meters can help in implementing a smart scheduling to optimize the available power in the grid [37]. An overview of this flow of communication and power was also describe by F. Mwasilu et al [38] in Fig. 3.

In vehicle to grid technology, one can predict the dynamics of power system. Charging is an essential part of vehicle to grid technology. A lot of research has been made in the area of this charging and discharging. A similar study was done in Portugal shows a good communication between charging of electric vehicle and solar energy [39]. In another study, Ota et al [40] proposed a way to consider charging request and battery condition for the next drive. There are very few cases of a weak grid that were reported while using V2G. Similarly renewable energy sources like solar and wind has a potential to overcome this weak grid scenario [38]. Understanding of dynamic behavior of the electric grid is essential to predict the reliability and effectiveness of the grid while operating with V2G.

3.4. Big data

Smart grid is full depended upon the data it receives. It is not just eyes of the grid but work as back bone for it. For a reliable and efficient working of a smart grid, a huge amount data is collected from power generation, transmission, transformation and power utilization [41]. All the decision made by the grid is depended upon it. It also plays a key role in the autonomous capabilities of the smart grid. There are numerous challenges for big data in smart grid technologies which include from storage to its visualization and security. Researchers have also focused on how to combine data into information and beneficial application. An overview of flow of data within components of the smart grid is shown in Fig. 4 [42].

A large amount of data gathered from different sensors, wireless transmission and communications is accumulated. All the data gather from generation to utilization is used by different algorithms to forecast and will also help full in recognizing the pattern of power utilization. This will ultimately useful for achieving a smart energy management system. Energy big data does not only include the data gather from meters but it has also a huge amount of data related to weather and environment. Characteristics of this data are incomplete without '4Vs' (volume, velocity, variety and value) and '3Es' (energy, exchange and empathy) [43]. Different algorithms and models were develop for the analysis of the big data but still there are some major issues related to big data like: IT infrastructure, Data Collection and governance, data processing and analysis, data integration and sharing and most importantly security and privacy which are to be address and are centrally focused by researchers [43].

4. Investment in smart grid

Different countries of the world have step forward in the era of smart grid and accept its reality. Many of them are working on smart grid pilot project or taking initiatives of this concept for testing and research in order to test feasibility before execution on full scale development and change. Government of different countries like Australia, United States, China, Britain, South Korea and Japan are already considering options like smart grid for reducing carbon emission and energy security. Some initiatives related to smart grid of different countries are following [44–46].

4.1. Australia

Australian government was interested in Smart Grid from 2009 when a call for proposal was given for smart grid, for which winner was announced in 2010. Government was interested to invest about $100 million initially. Government was more interested to raise awareness in customer about energy utilization and establishment of distributed demand as well as generation management system. Five different sites in New South Wales were selected for smart grid establishment and Energy Australia was selected for this purpose with collation of IBM, GE Energy and Grid Net. The idea was to build a WIMAX-based smart grid that has capabilities of automatic substation, able to accommodate electric vehicles and also supporting 50,000 smart meters' connections.

Another project was launch for testing network fault detection, isolation and restoration, power quality monitoring and automatic distribution of electric power via distribution management system. Australian government is also giving incentives for encouraging and investing in smart grid. Demand management, energy security and energy efficiency are the top priorities of Australian government.

4.2. Canada

Government of Canada made mandatory of installation of smart meters for business and households in Ontario by 2010 through legislation Energy Conservation Responsibility Act 2006. In the same year government also invested $32 million in a smart grid project for four years for research of problems associated of managing renewable energy. Federal government also took different initiatives like clean energy fund and eco-energy innovation initiative. Currently different pilot projects in province of Quebec and Ontario are going on. For the promotion and awareness campaign of Smart Grid, an association with the name Smart Grid Canada was formed which includes academia and all stakeholders involve. They were responsible to enable research and form different policies related to smart grid [44]. There are different

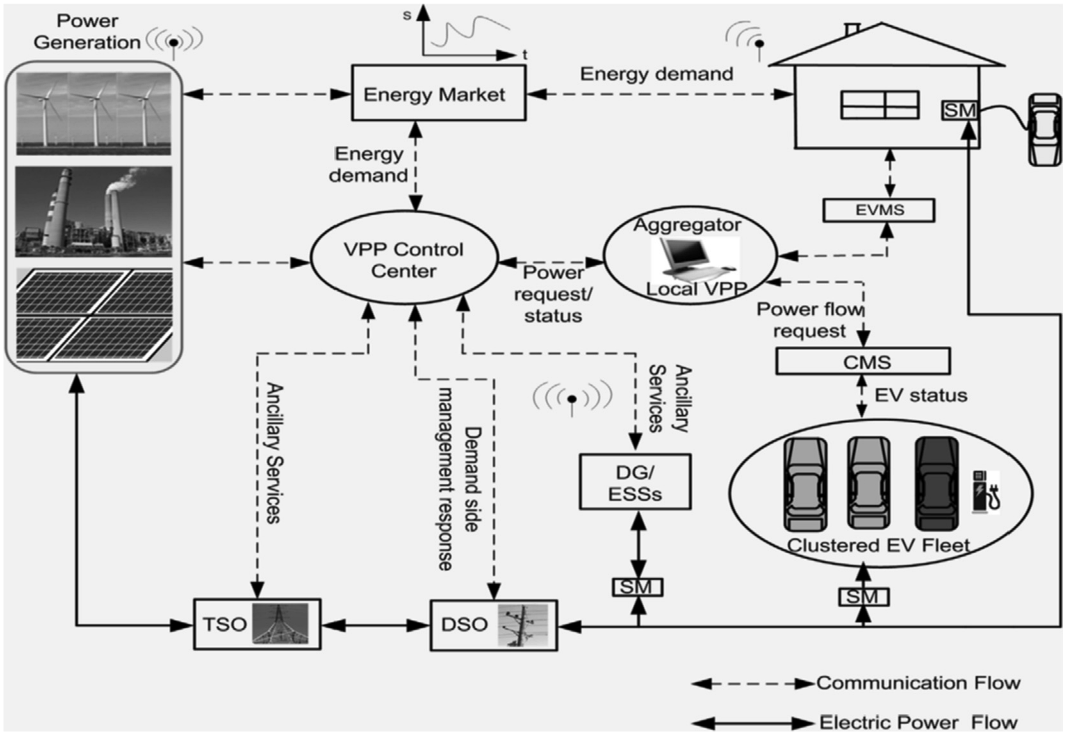

Fig. 3. Flow of communication and power in V2G.

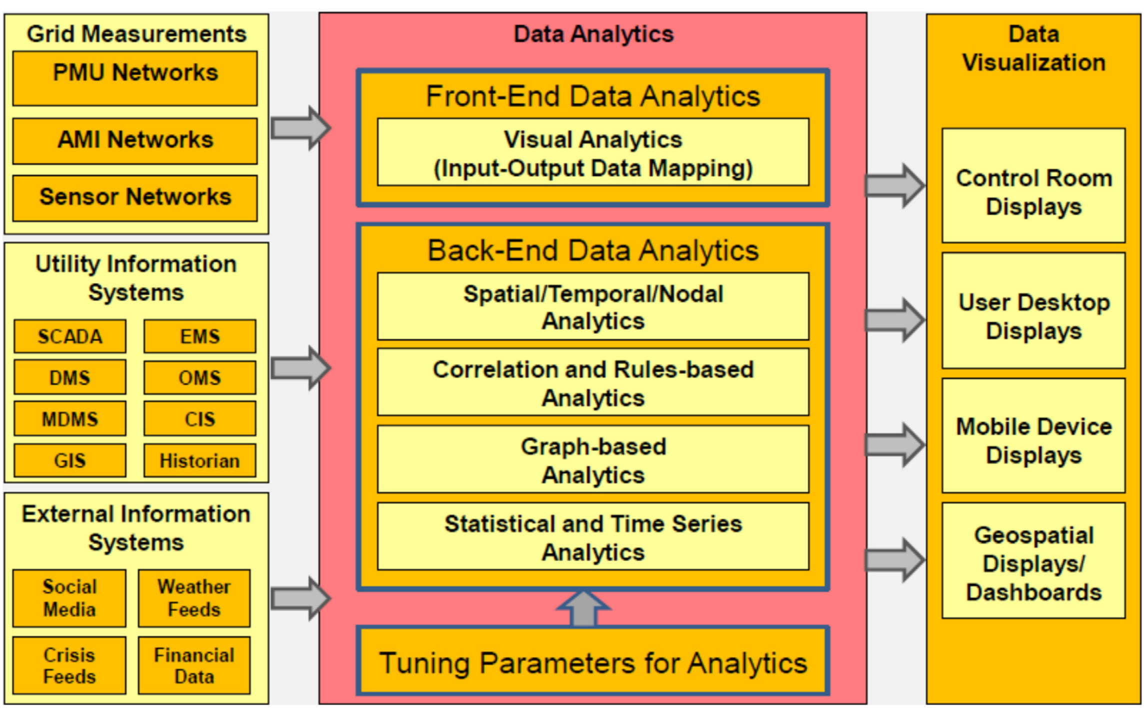

Fig. 4. Flow of data between components in Smart Grid.

entities like Natural Resource Canada, National Energy Board and National Smart Grid Technology and Standard task force which are being supported by government. National Smart Grid Technology and Standard task force was form for the development of all the aspects related to Smart Grid and also coordinate and involve provincial governments for the support and development of smart grid [47].

4.3. England

UK is one of the biggest producers of energy from photovoltaic. Low Carbon London institution integrated a number of technologies like photovoltaic, smart meters, electric vehicles and heat pump with the distribution system to reduce carbon emission. World's first cryogenic energy storage solution was implemented

Table 3
Ratio of GDP to Smart Grid cost for developing countries.

Nation	Population to be serviced	Initial Smart Grid Cost ($)	Nation's GDP	Ratio of GDP to Smart Grid cost
Afghanistan	8,686,000	3,136,862,040	19,331,000,000	6
Angola	11,022,000	3,980,485,080	102,627,000,000	25
Benin	4,782,000	1,726,971,480	8,291,000,000	4
Burkina Faso	5,406,000	1,952,322,840	10,678,000,000	5
Burundi	1,348,000	486,816,720	3,097,000,000	6
Cambodia	3,228,000	1,165,759,920	18,050,000,000	15
Central African Republic	1,962,000	708,556,680	1,584,000,000	2
Chad	3,154,000	1,139,035,560	10,889,000,000	9
Congo, Dem. Rep.	32,834,000	11,857,670,760	35,238,000,000	2
Congo, Rep.	3,021,000	1,091,003,940	8,553,000,000	7
Eritrea	1,000,000	361,140,000	2,600,000,000	7
Ethiopia	19,353,000	6,989,142,420	61,540,000,000	8
Gambia, The	1,187,000	428,673,180	939,000,000	2
Guinea	4,685,000	1,691,940,900	6,699,000,000	3
Haiti	6,282,000	2,268,681,480	8,765,000,000	3
Kenya	11,799,000	4,261,090,860	63,398,000,000	14
Lesotho	583,000	210,544,620	2,278,000,000	10
Liberia	2,238,000	808,231,320	2,053,000,000	2
Madagascar	8,508,000	3,072,579,120	9,739,000,000	3
Malawi	2,801,000	1,011,553,140	6,404,000,000	6
Mali	7,025,000	2,537,008,500	12,747,000,000	5
Mauritania	2,435,000	879,375,900	5,442,000,000	6
Mozambique	9,013,000	3,254,954,820	14,807,000,000	4
Namibia	1,147,000	414,227,580	11,492,000,000	27
Niger	3,728,000	1,346,329,920	7,714,000,000	5
Papua New Guinea	991,000	357,889,740	16,929,000,000	47
Rwanda	3,345,000	1,208,013,300	8,096,000,000	6
Sierra Leone	2,578,000	931,018,920	4,215,000,000	4
Solomon Islands	130,000	46,948,200	1,129,000,000	24
Somalia	4,266,000	1,540,623,240	5,925,000,000	3
South Sudan	2,320,000	837,844,800	9,015,000,000	10
Sudan	13,602,000	4,912,226,280	97,156,000,000	19
Swaziland	274,000	98,952,360	4,188,000,000	42
Tanzania	16,901,000	6,103,627,140	45,628,000,000	7
Timor-Leste	408,000	147,345,120	1,422,000,000	9
Togo	2,919,000	1,054,167,660	4,088,000,000	3
Tuvalu	6,000	2,166,840	33,000,000	15
Uganda	6,285,000	2,269,764,900	27,529,000,000	12
Vanuatu	69,000	24,918,660	742,000,000	29
Yemen, Rep.	9,286,000	3,353,546,040	37,734,000,000	11
Zambia	6,634,000	2,395,802,760	21,154,000,000	8
Zimbabwe	5,052,000	1,824,479,280	14,419,000,000	7

as a pilot project in Reading, UK. Similarly, in Ireland a successful trail of 9000 smart meters for homes and business was completed by Commission on Energy Regulation.

4.4. China

Chinese government is more focused on the policies related to conservation, encouraging diverse development, protecting environment and relying on domestic resources [48]. That is why development in Smart Grid is one of the priorities of Chinese policy which include increase renewable energy mix, improving energy efficiency and reducing carbon emission. Chinese agency National Development and Reform Commission (NDRC) is tasked for the research and development in smart grid technologies as its one of the priority in five year plan [49].

In 2011, China planned to build a Wide Area Monitoring System in a five-year plan and planned to implement phasor measurement units on all power generators above than 300 MW and substation above than 500 kV. China also announced a framework for smart grid in 2009 which was more transmission centric than other countries like US and Europe [50].

4.5. United States of America

US seem to be a promising region for the smart grid development since early 20th century. A federal policy was formed as Energy Independence and Security Act of 2007 which sets a funding of $100 million per year for five years from 2008 for developing and enhancing smart grid capabilities. According to this Act of 2007, National Institute of Standard and Technology will be responsible for looking after the development and modernization of grid and form a commission to access its benefits. It will also form standards to maintain the developments of smart grid. In 2009 a new act was formed as American Recovery and Reinvestment Act of 2009 which invested $11 billion for a smart grid pilot project. This was the result of the legislations and determination of US government that they demonstrated smart grid projects and related twenty-two utilities in five different states. A fully metering system with customer web portal and automatic notification features was developed by Houston's smart grid. Smart Texas also deploys a large number of smart meters for the automation of power distribution network.

4.6. Europe

In early 2005, European Union formed a European Technology Platform (ETP) for the development of smart grid technology. Its goal was to promote the vision 2020 of European electricity networks development. Portugal did a real time implementation of management and control system of smart grid in a pilot project [51]. Italy is playing a vital role in research and development of smart grid. Different pilot projects are on the way related to selec-

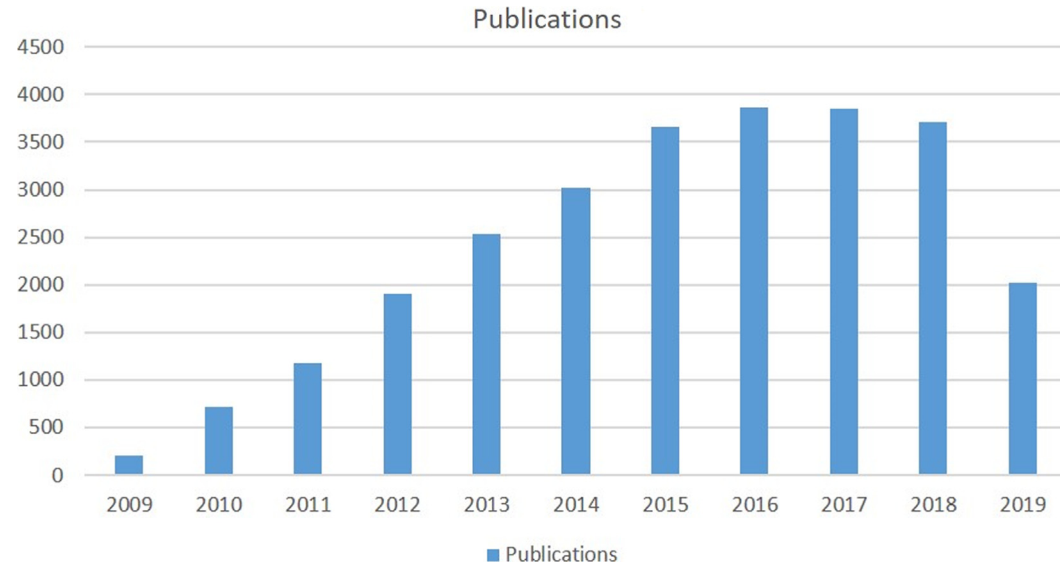

Fig. 5. Year wise publication of article on smart grid (data source science direct).

tion, assessment, regulation and instrumentation of smart distribution network [52,53]. University of Genoa is working on mathematical modeling of optimal operation for poly-generation micro-grid which is stepping stone towards advance large scale metering [54,55]. A cost benefit analysis for smart grid was done by Czech Republic [56].

5. Economical potential of smart grid in developing world

Cost is one of the biggest constraints in the development and implementation of the smart grid especially in developing world. A lot of financial resources are associated with the transmission and distribution system, metering and other related technologies. A complete financial feasibility report is essential before implementation. This financial feasibility must include nation's capacity to pay development cost for smart grid infrastructure. This is normally calculated per consumer that is to be served. Young [57] in 2017 apply different test and calculate ratio of nation's GDP to cost of development for smart grids in developing countries. Most of the financial data for this calculation was used form World Bank's report of 2015. The summary of these results are given in Table 3 [57].

6. Future research in smart grid

A lot of research is undergoing for the development of smart grids. Still a lot of potential is available for future research for different aspects in different areas of smart grid. This include in area of forecasting, power flow optimization, communication, micro-grid integration, demand and energy management system, conformance of standards for interoperability, scalability, economical factors, data encryption and most importantly automation of generation, transmission and distribution.

7. Conclusion

Advancement of the technologies and devices can change the utilization of energy in an economical and environmental friendly way. Evolution of Smart Grid concept has potential to meet all the future needs of utilization of energy in best possible manner by reducing carbon emission and integrate with more renewable energy mix. It can bring a considerable change in the conventional grid and consumer behavior towards utilization of energy by improving reliability, efficiency and quality of power delivery. Governmental policies are needed to facilitate smart grid implementation. This article pointed out the need of modernization of conventional grid and how researchers are implementing smart grid concept for electric power distribution networks. Still there is a lot of potential available for improving and implementation of this concept as it is just the start of the new era of modern grid. It is still difficult to predict that how far the research in smart grid is required to fully implement this concept but recent researches like smart meters, demand side management systems, self-healing and big data are source of encouragement in Smart grid technology.

8. Recent trends

Research and advancement on the smart grids have been seen tremendously increased in last decade. This is why smart grid technology has been shifted from virtual reality and concept to implementation phase. In last ten years 26,668 different research articles have been published on smart grids which shows a keen interest of researchers in this field. There was tremendous increase in the research in last five years (as shown in Fig. 5) in smart grid and soon this will be game changer in electrical power distribution with more flexibility and in efficient ways

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