Asian Journal of Applied Science and Technology (AJAST)
(Peer Reviewed Quarterly International Journal) Volume 3, Issue 1, Pages 205-214, Jan-March 2019

Investigation on Communication Technologies and Networking Infrastructure for Smart Grid Applications

P.Murugeswari[1], S.Nagalakshmi[2], P.S. Sharan Shree[3]

[1]*Assistant Professor, Department of Electronics and Communication Engineering, Sethu Institute of Technology, Kariapatti, Tamil Nadu.*
[2]*Professor, Department of Electrical and Electronics Engineering, Sethu Institute of Technology, Kariapatti, Tamil Nadu.*
[3]*Assistant Professor, Department of Electronics and Communication Engineering, Sethu Institute of Technology, Kariapatti, Tamil Nadu.*

Article Received: 30 August 2018 Article Accepted: 25 December 2018 Article Published: 28 February 2019

ABSTRACT

The aging infrastructure of conventional power grids is ill-suited to encounter the future energy crisis. Moreover, global climate change and greenhouse gas emissions have become a recognized problem of international significance due to the traditional carbon fuel based power plants. To address these challenges, transition towards Smart Grid (SG) is necessary. SGs provide two way real time communication between consumers and utilities by integrating the Information and Communication Technologies (ICTs) into electrical power grid. As a main candidate of ICTs, both wired and wireless communications have obtained more and more attention due to their higher flexibility. There are many communication technologies available to render communications services to SGs. This paper first compile the information about the communication networking infrastructure. Then Presents the various wired and wireless communication technologies available for SG followed by an expounded discussion on communication requirements of each SG applications.

Keywords: Smart Grid, Information and Communication technologies (ICTs), Communication Network architecture.

1. INTRODUCTION

The conventional power grid requires a massive transformation due to its aging infrastructure. SGs are envisioned as future power grids to enrich the functionality of traditional power grids, to reduce the carbon dioxide emission and to meet the 21stcentury energy requirements [1]. The Information and Communication Technologies (ICTs) are the underpinning technologies for the successful operation of the SGs. ICTs provides two way real time communication between consumers and utilities using digital communication Technology. Hence, it is essential to integrate the ICTs into electrical power grid to increase the grid's reliability [2]. There are both wired communication technologies, e.g. Power Line Communication, Fiber Optic Communication and wireless communication technologies, e.g. IEEE 802.11 based wireless LAN, IEEE 802.16 based WiMAX, ZigBee based IEEE 802.15, ECHONET, OneNET, BACnet,6LOWPAN, Cellular Communications, Satellite Communications, Cognitive radio for various SGs applications [3].

Moreover, there are three communication networking infrastructure between utility and consumer such as Home Area Network (HAN),which provide access to in-home appliances within the consumer premises, Neighborhood Area Network(NAN), which interconnect multiple HANs through AMI and Wide Area Network (WAN) which connects the multiple NANs and serve as communication backbone[4][5].Among these communication and networking infrastructure, the choice of sophisticated and fast communication infrastructure is crucial to meet the basic functional requirements of SGs communication such as Quality of service (QoS) of data, high reliability, Bandwidth, high coverage, security and privacy.

CITE THIS ARTICLE: P.Murugeswari, S.Nagalakshmi, P.S.Sharan Shree, "Investigation on Communication Technologies and Networking Infrastructure for Smart Grid Applications", *Asian Journal of Applied science and Technology*, Volume 3, Issue 1, Pages 205-214.

There are different communication technologies has been identified for fulfill these communications requirements in SGs. The paper organized as follows, Section 2 provides three layered communication network architecture between utility and consumer, Section 3 compiles the information about various wired and wireless communication technologies and Section 4 presents the many SG applications and its communication Requirements.

2. SMART GRID COMMUNICATION NETWORK ARCHITECTURE

Smart Grid communication network architecture provides communication between consumers and utilities and fulfill the communication requirements. The SG communication network (SGCN) is divided into three segments based on the data rate and geographical area covered by the SGs such as Home Area Network (HAN), which provide access to in-home appliances within the consumer premises, Neighborhood Area Network (NAN), which interconnect multiple HANs through AMI and Wide Area Network (WAN) which connects the multiple NANs and serve as communication backbone. Therefore, each communication network requiring different communication technologies.

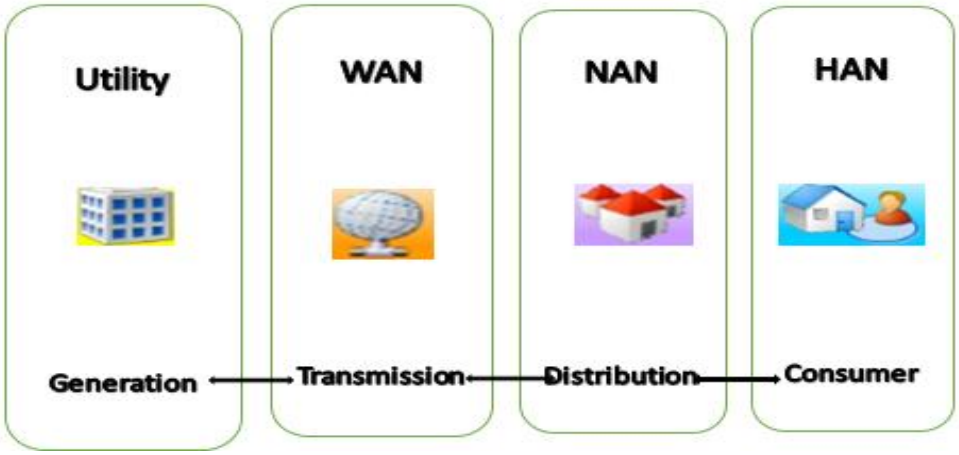

Fig 1. Communication Network Architecture

2.1 Home Area Network (HAN)

HAN is covering the consumer domain. It provides efficient energy management by connecting the home appliances within the premises, renewable energy resources, electric vehicles and wireless sensor networks with smart meters (SMs). Then all the on premise SMs are connected to the Advanced Metering Infrastructure (AMI) which provides the capability of monitoring and control of consumer's energy usage. The SMs and on premise appliances are communicated using ZigBee based IEEE802.15, ECHONET, OneNET, BACnet and 6LOWPAN. [9]. HANs covers nearly 100 to 200 meters and supports data rate from 10 to 100 kb/s [6].

2.2 Neighborhood Area Network (NAN)

NAN is covering the distribution domain and it interconnect multiple HANs through AMI. An AMI acts as a gateway between HAN and NAN to enable communication from home appliance to SMs and from SMs to the utility. The NAN segment communicates with third segment i.e. WAN using the communication technologies such

as IEEE 802.16 based WiMAX and IEEE 802.11 based wireless LAN, etc. [10]. NANs are Very vulnerable to privacy and security and it mainly supports Multi-Point-to-Point (MP2P) and Point-to-Multiple-Point (P2MP) traffic. NAN covers several square kilometers and supports data rate from 100 Kb/s to 10 Mb/s [7].

2.3 Wide Area Network (WAN)

WAN is covering the generation and distribution domain. WAN interconnects multiple NANs and serve as a communication backbone. WAN is suitable for supervisory control and data acquisition systems for monitoring and control of power plants, storage, and substations. The IEEE 802.16(WiMAX) and cellular technologies such as LTE, 3G, 4G, 5G, EDGE and GPRS are used for meeting the communication needs of the grid elements in WAN [8]. It covers thousands of kilometers and supports data rate from 10 to 100 Mb/s. The WAN needs to be built up of high bandwidth fiber optics-based telecommunication technologies such as SONET/SDH, WDM/DWDM, satellite or microwave technologies, among many others.

3. SMART GRID COMMUNICATION TECHNOLOGIES

Smart grid communication technologies provide two way real time communication between consumers and utilities. The SGs can use both wired and wireless communication technologies to communicate the information in real time. In this Section, various wired and wireless Communication Technologies deployed in the SG are investigated.

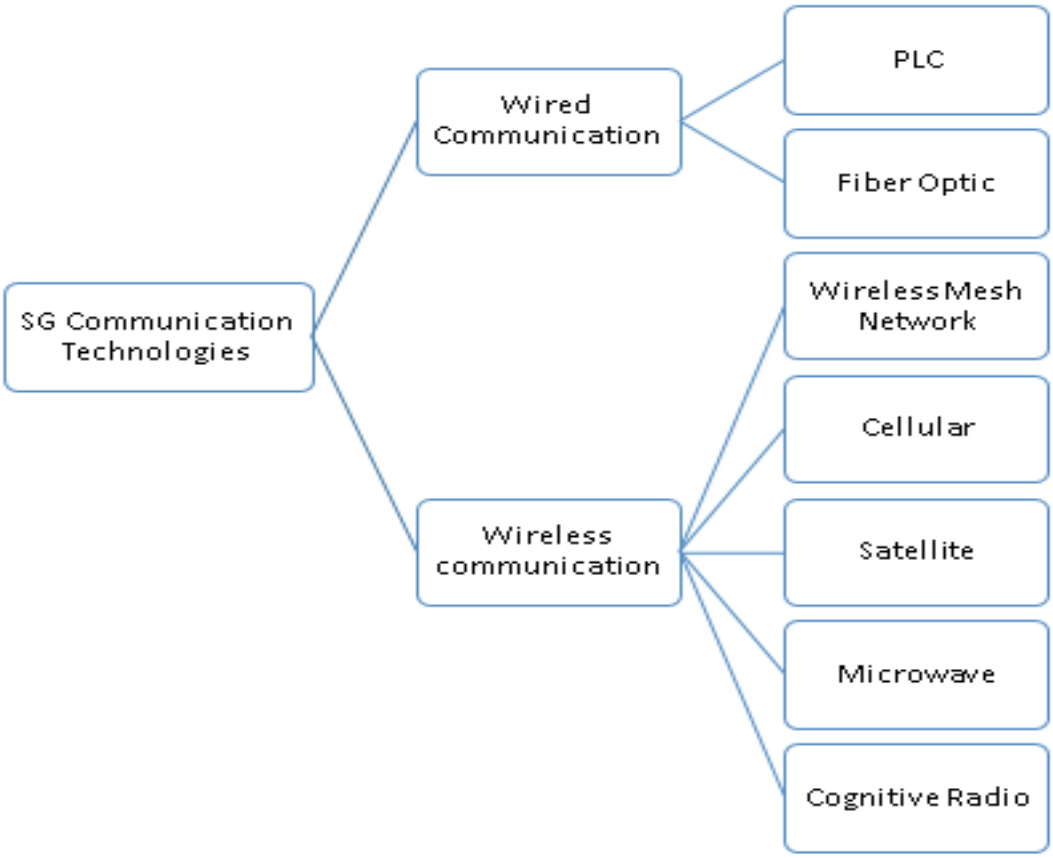

Fig 2. Smart Grid Communication Technologies

 Online ISSN: 2456-883X

A) WIRED COMMUNICATION TECHNOLOGIES

The advantages of Wired Communication are bandwidth, cost, reliability, security and maintenance. The following are the different wired communication technologies used in the SGs.

1) Power Line communication (PLC)

PLC is a technique of transmitting high speed data on the existing power distribution lines. The SG will be widely adapting PLC due to the uses of existing power distribution lines, low cost installations and reliability [9]. In SG, PLC is most suitable for applications like Substation Automation, AMI, Remote Monitoring, and Distribution Automation etc. but it is not suitable for HAN applications due to lack of standards and interoperability can be classified into Narrowband PLC and Broadband PLC. Narrowband PLC is well suited for smart metering infrastructure. Broadband PLC can provide the service of transferring data seamlessly from SG controllers to home networks and vice versa. In smart grid applications, the PLC is used in Neighborhood Area Network communication for connecting smart meters and Local Data Concentrator (LDC). The advantage of the PLC is already established, widespread infrastructure that reduces installation costs. The disadvantages are slower data rate, presence of higher harmonics in the power lines that interfere with communication signals, interruption on operation of switches, disconnectors in electrical system and limited frequency of communication.

2) Fiber Optic Communication (FOC)

FOC is one of the promising communication infrastructures that offer reliable data transmission. This technology is best suited for high voltage operating environment since it is highly immune towards radio frequency and other electromagnetic interferences. The major advantages of FOC are high bandwidth capacity, immunity characteristics and it provide strict Quality of Service (QoS). Although it is well-known that the installment cost of optical fibers may be expensive, sharing capability of FOC among various users can recover this cost in short time span. Fiber optic network is a cost-effective and reliable solution for high speed communication in future SG

B) WIRELESS COMMUNICATION TECHNOLOGIES

The Wireless Communication offers significant benefits over Wired Communication such as mobility, rapid deployment, scalability, flexibility, low installation cost and more suitable for remote applications [5]. The following are the different wireless communication technologies used in the SGs.

1) Wireless Mesh Network

WMN is a self-organized and self-configured multi-hop communication network. It is created through the connection of wireless access points installed at each SMs in customer premises. Each node in the mesh network could transmit the data from the SMs to the utility and receive control signals from utility and send back to the consumer. A mesh would provide an inexpensive, high speed network and extreme flexibility for the utility. A major benefit of wireless mesh networks is path diversity, which provides many routes to transfer the data in case one of the routers fails or its transmission path is temporarily blocked.

2) Cellular Communication

Cellular networks are well-established infrastructure and it is a good option for communication among smart meters, remote nodes and utility. The cellular networks allow the different components in the SG to communicate with each other using the communication technologies such as GSM, GPRS 2G, 2.5G, 3G, WiMAX and LTE [8] [10]. Moreover, they allow high data rate communications up to 100Mbps.The advantages of cellular networks are strong security control ability to ensure the safe transmission of data, low invested cost and operating expense, high rates of data transfer, larger coverage, and rapid installation. These prominent characters make cellular network the best option for smart grid communication technology. The major disadvantage is that cellular networks are shared with other users and are not fully dedicated to the smart grid communication.

3) Satellite Communication

Satellite communication widely used for remote monitoring and control of transmission and substation. Satellite communication is also known as space communication in which the signal is sent to the satellite through space, then the satellite amplifies the received signal and sent back to earth. The main advantages of satellite communication are quick implementation, extensive coverage and it provides 1Mbps of data rate. These prominent characters make the satellite communication to monitor the utilities remotely. The disadvantages are high cost, high transmission delay and severe weather affects reliability. However, it can be used as a backup. With the development of low cost and smaller earth station in Satellite networks can make it suitable to be used in SG environment [11].

4) Microwave Communication

Microwave is a technology that operates on licensed frequency band of 2-40GHz and provides the data rate up to 155Mbps [12]. Microwave communication uses antennas for transmitting of data for a longer distance coverage up to 60 kilometers. Digital Microwave accepts data from Ethernet or ATM port and transmits it to the other as microwave radio. It support point to point communication for smart grid applications. The advantages of Microwave radio are flexible, security, high channel capacity and susceptible to signal fading, The biggest disadvantage of microwave communication is the initial investment cost and implementing microwave communication systems is very challenging for utility engineers.

5) Cognitive Radio

Cognitive radio is the key wireless communication technology between consumers and utilities and it is used as secondary radios to handle high volumes of non-critical data and act as backup radios in emergency situations. In a smart grid, all consumers can communicate simultaneously with utilities, which requires a high-quality spectrum sensing scheme.CR is a key technology to improve spectrum utilization and to overcome the problem of spectrum scarcity in future wireless communication systems [13].Two sensing channels allocation strategies are introduced to the fast discovery of idle channels during the sensing time in each slot, in the first strategy, called the Random allocation strategy, the access point randomly selects licensed channels to sense in each slot. In the second strategy,

called the Keep-on allocation strategy, the access point first senses the idle channels detected in the former slot. Then, the access point randomly selects other channels to senesces provide high performance, high speed data transmission more security, scalability, robustness, reliability and sustainability to SGs.

4. SMART GRID APPLICATIONS AND COMMUNICATION REQUIREMENTS

The Smart Grid will employ a variety of communications and networking technologies to support many Smart Grid applications. The Fig 3 depicts the communications requirements of each of these application categories.

4.1 Advanced Metering Infrastructure

AMI is the backbone of SG. It enables two way communication between smart meters with an IP address deployed at consumer locations and utility. The goal of an AMI is to measure the energy consumption, transmit the information about energy consumption to utility in real time [14]. The benefits of AMI are, it allows the customers to make informed choices about energy usage based on the price at the time of use and helps the utility avoid estimated readings, provide accurate and timely bills, operate more efficiently and reliably, and offer significantly better consumer service. AMI is comprised of HAN, smart meters, communication infrastructure, data management systems to make real time communication between utility and consumers.

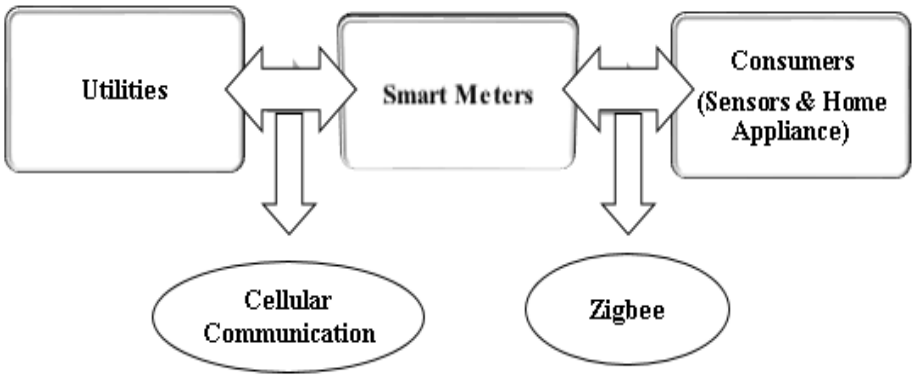

Fig 3. Advanced Metering Infrastructure

Smart meters deployed in the consumer premises collect real time data and transmit the collected data through commonly available communication infrastructure such as Broadband over Power Line (BPL), Power Line Communications (PLC), Fixed Radio Frequency (RF) networks, optical fiber and cellular network. The meter data are sent to the Meter Data Management System (MDMS) that manages data storage and analysis to provide the information in useful form to the utility. Then the data is sent to the consumers from the utility to make them more aware of their energy usage. The Communication technologies currently being used for AMI include 2.4 GHz Wi-Fi, the common 802.11 wireless networking protocol, ZigBee, which is based on the wireless IEEE 802.15.4 standard and Home Plug.

4.2 Demand Response

DR is one of the main Demand Side Management (DSM) activities. DSM encourage the consumers to minimize their energy consumption. DR encourage both consumer and utility to reduce the peak power and electricity cost. The main objective of DR is reducing the peak power, promoting clean and green energy [15]. DR programs can be applied to different consumers such as industrial consumers, commercial consumers and residential consumers to reduce the energy consumption and maximize the social welfare.

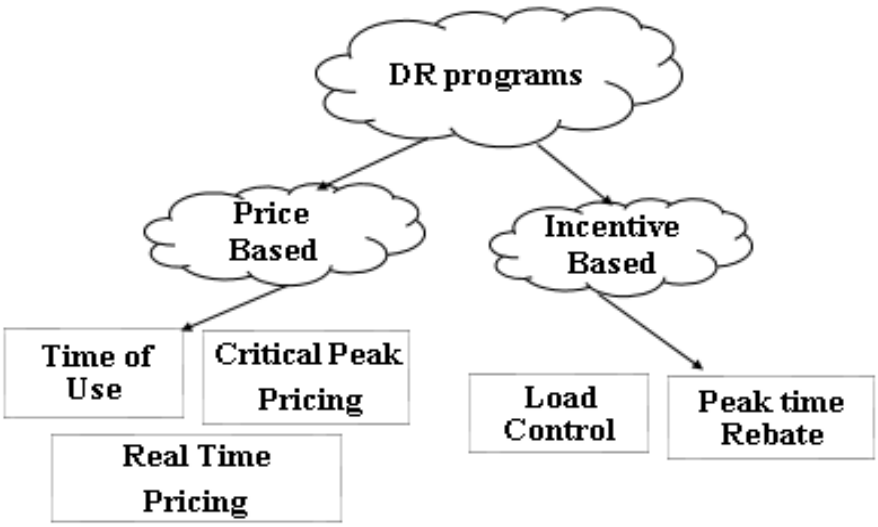

Fig 4. Demand response programs

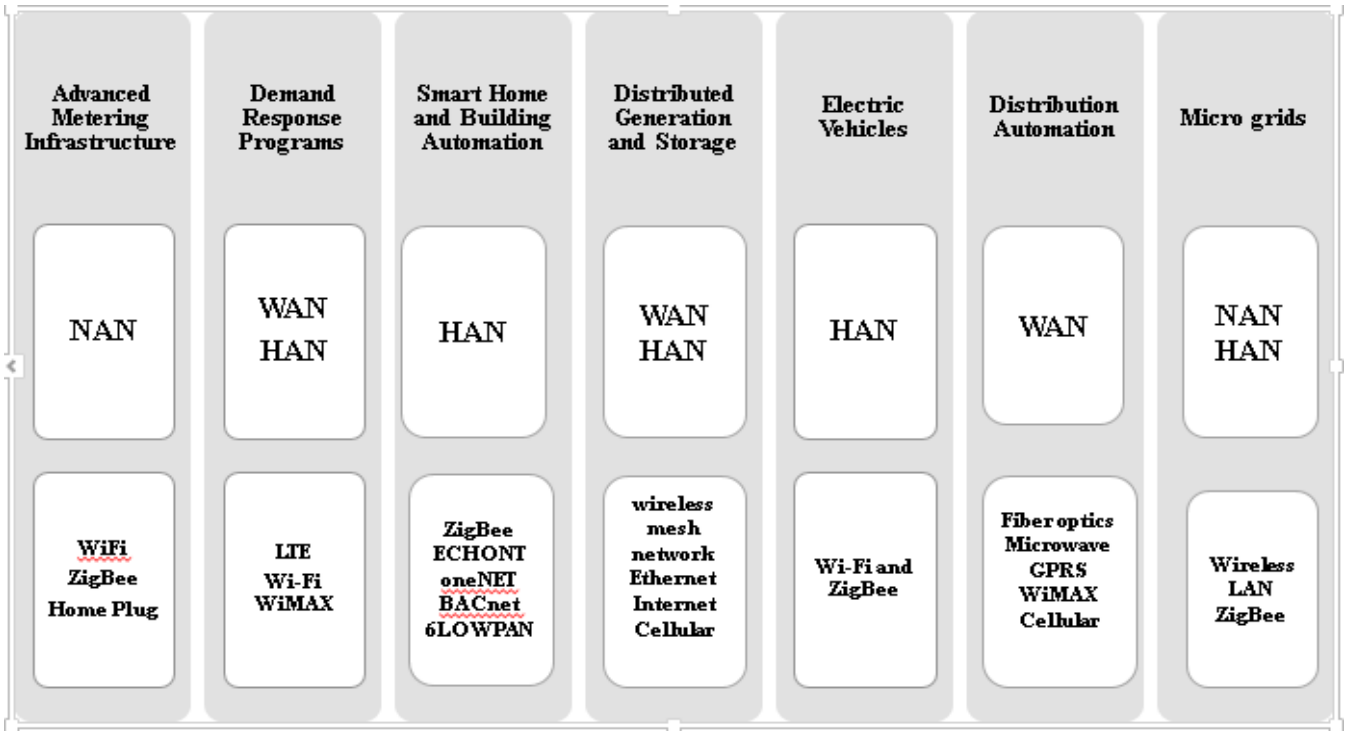

Fig 5. Smart Grid applications and communication requirements

Online ISSN: 2456-883X

DR programs based on price offers customers time varying prices that are defined based on the cost of electricity in different time periods. This prices are designed per the load level of the entire system. DR programs based on incentive offers fixed or time-varying incentives or penalties (payments) to customers that obeys or violates DR contracts during periods of system stress. DR program does not ensure same amount of benefit for all the participating players i.e. some may be incentivized whereas some can receive penalty. The employment of DR relies on the reliable, robust and secure communication system. The choice of efficient energy price structure is the main key factor to attract the users towards DR programs. The communication Technologies used for DR includes broadband, next-generation cellular such as LTE, Wi-Fi, or WiMAX.

4.3 Smart Home and Building Automation

Smart home and building automation systems automatically control the operation of customers' devices including lights, appliances, heaters, air conditioners, local generation facilities (such as solar panels), electric vehicles and storage devices in response to supply conditions such as electricity price. To manage the energy consumption devices, generation and storage devices on consumer premises, Home Energy Management System (HEMS) should be deployed [16]. HEMS remotely monitor and control the energy consumption of home devices, generation and storage devices to improve the energy efficiency. Communications among consumer devices are supported over a home area network such as ZigBee, ECHONET, oneNET, BACnet, 6LOWPAN etc.,

4.4 Distributed Generation and Storage

The Distributed generation system is an efficient and green alternative to the existing electric power generation resources. The DGs is necessary to meet the increasing demand of electricity. DG system provides electricity at a place near to the customer using different technologies such as solar panels and combined heat and power, solar photovoltaic panels. Small wind turbines. Natural-gas-fired fuel cells etc. The electricity power generated using these different technologies can be consumed locally and excess power is made available to the grid. So, the utility has economic benefits such as reduced costs of energy production, generation capacity, distribution and transmission capacity investment, reducing risk from uncertain fuel prices, green pricing benefits, etc. The advantages of DGs are provide minimum environmental impact, reduce maintenance investments. Improve the power quality and reliability.

The distributed storage system (DSs) is an important energy source in smart grid which store energy in various forms such as electrochemical, kinetic, pressure, potential, electromagnetic, chemical and thermal. The DSs such as batteries, super capacitors, compressed air, thermal energy, regenerated fuel cells, flywheels, hydrogen and pumped hydro are connected to the grid to store the energy. The DSs can store electric energy received from the grid during off period and deliver the stored energy to the grid during peak hours. The advantages of DSs are reducing peak load, improving electric stability and eliminating the quality disturbances. The communication Technologies used for distributed generation and storage includes wireless mesh network, Ethernet/Internet. [17] [18].

4.5 Electric Vehicles (EVs)

EVs is distributed storage systems, provided the charged batteries in the vehicle are used to supply power to the grid. The EVs can be charged using portable charger, wall box and charging station [19]. When EVs are plugged into the grid through power sockets at homes, the unused energy from the vehicle battery can be discharged into the grid during the peak hours. The advantages of EVs reducing GHG emissions and distribution system losses. The disadvantages of EVs are autonomy, cost of vehicle and charging station infrastructure, discharging process and battery lifetime. The communication Technologies used for EVs, Wi-Fi and ZigBee.

4.6 Distribution Automation (DA)

Distribution automation is the process by which the collection of data is automated and analyzed, and then controls executed by Utilities. If there is any fault identified in the grid, the information is transmitted to the data center through wide area network. Then the restoration is performed remotely. Intelligent communication devices are the backbone of the DA network. Today, both wired and wireless communication technologies such as fiber optics, microwave, GPRS, multiple radio formats, WiMAX, powerline carrier, etc. are used to send and receive information that is transmitted from substation to central control center [17][20].The automated service restoration involves the combination of monitoring the network, detecting an outage, and making switching commands that isolate the fault and allow restoration of service to as much of the grid as possible. DA optimizes a utility's operations and directly improves the reliability of its distribution power system.

4.7 Micro grids (MGs)

Micro grids are small electrical distribution systems with control capability, which means it can connect and disconnect from the traditional grid and operate autonomously [20]. Microgrids connect multiple customers to multiple distributed sources of generation and storage. They can generate power from both renewable and conventional sources located at or near the consumption sites, the advantages are installed quickly and easily, even in remote areas, lower the cost of electricity through self-generation and consumption. The communication Technologies used for MGs includes wireless LAN, ZigBee.

5. CONCLUSION

The smart grid has been perceived as development of traditional electric power system to meet the future energy crisis and to provide low carbon economy. The ICT plays vital role in SGs to meet out its requirements. This paper provides the compiled information about various wired and wireless communication technologies where the advantage and disadvantages of each communication technology were discussed. Then, the three layered communication architecture between consumer and utility were discussed. Finally, communication requirements of each SG application were discussed.

ACKNOWLEDGMENT

I wish to thank **Dr.S.Nagalakshmi, M.E Ph.D, Professor, Department of Electrical and Electronics Engineering, Sethu Institute of Technology**, for her encouragement and constant support throughout my work.

REFERENCES

1. Sandeep Kakran, Saurabh Chanana, "Smart operations of smart grids integrated with distributed generation: A review", Renewable and Sustainable Energy Reviews, pp.524–535, 2018.
2. M. Faheem , S.B.H. Shah , R.A. Butt , B. Raza , M. Anwar , M.W. Ashraf ,M.A. Ngai , and V.C. Gungor , "Smart grid communication and information technologies in the perspective of Industry 4.0: Opportunities and challenges", Computer Science Review ,pp.1–30,2018.
3. MichaelEmmanuel, Ramesh,Rayudu, "Communication technologies for smart grid applications: A survey", Journal of Network and Computer Applications,74, pp.133-148,2016
4. MuratKuzlu,ManisaPipattanasomporn,SaifurRahman," Communication network requirements for major smart grid applications in HAN, NAN and WAN", Computer Networks,67,pp. 74-88,2014.
5. Anzar Mahmood, NadeemJavaid, n and SohailRazzaq, "A review of wireless communications for smart grid" Renewable and Sustainable Energy Reviews, pp.248–260, 2015.
6. Haider,TarishHaider,Ong HangSee,WilfriedElmenreich," A review of residential demand response of smart grid", Renewable and Sustainable Energy Reviews,59,pp. 166-178,2016
7. Nazmus S.Nafi,KhandakarAhmed,Mark A.Gregory,ManojDatta," Software defined neighborhood area network for smart grid applications", Future Generation Computer Systems,79,pp. 500-513,2018
8. Charalampos Kalalas ,Linus Thrybom ,Jesus Alonso-Zarate," Cellular Communications for Smart Grid Neighborhood Area Networks: A Survey",IEEE access,4,pp.1469-1493,2016.
9. Ruofei Ma, Hsiao-Hwa Chen, Yu-Ren Huang, Weixiao Meng," Smart Grid Communication: Its Challenges and Opportunities", IEEE Transactions on Smart Grid, 2013.
10. Velin Kounev,Martin Lévesque,David Tipper,Teresa Gomes," Reliable Communication Networks for Smart Grid Transmission Systems", Journal of Network and Systems Management,24, pp 629–652,2016
11. Kazem Sohraby,Daniel Minoli,Benedict Occhiogross,Wei Wang," A Review of Wireless and Satellite-Based M2M/IoT Services in Support of Smart Grids", Mobile Networks and Applications,23, pp 881–895,2018
12. N.Shaukat,S.M.Ali,C.A.Mehmood,B.Khan,M.Jawad,U.Farid,Z.Ullah,S.M.Anwar,M.Majid,"A Survey on Consumer Empowerment,Communication Technologies and renewable generation penetration within Smart Grid", Renewable and Sustainable Energy Reviews,81,pp. 1453-1475,2018.
13. SherazAlam,M.FarhanSohail,SajjadA.Ghauri,I.M.Qureshi,NaveedAqdas, "Cognitive radio based Smart Grid Communication Network", Renewable and Sustainable Energy Reviews,72,pp. 535-548,2017
14. Yassin Kabalci N, "A survey on smart metering and smart grid communication" , Renewable and Sustainable Energy Reviews 57,pp.302–318,2016
15. Djabir Abdeldjalil Chekired, Lyes Khoukhi,and Hussein T. Mouftah, "Decentralized Cloud-SDN Architecture in Smart Grid: A Dynamic Pricing Model", IEEE Transactions on Industrial Informatics, Vol.14, Issue. 3, March 2018
16. Bin Zhou , WentaoLi , KaWingChan , YijiaCao , YonghongKuang , XiLiu a, Xiong Wang , "Smart home energy management systems:Concept,configurations, and scheduling strategies", renewable and Sustainable EnergyReviews61,pp.30–40,2016.
17. R.Bayindira,I.Colakb,G.Fullic,K.Demirtas,"Smart grid technologies and applications", Renewable and Sustainable Energy Reviews,66,pp. 499-516,2016
18. Nazmus S.Nafi,Khandakar Ahmed,Mark A.Gregory,ManojDatta," A survey of smart grid architectures, applications, benefits and standardization", Journal of Network and Computer Applications,76,pp. 23-36,2016
19. Yue Cao ; Ning Wang ; George Kamel ; Young-Jin Kim," An Electric Vehicle Charging Management Scheme Based on Publish/Subscribe Communication Framework", IEEE Systems Journal,11,pp. 1822–1835,2017
20. AhmetÖnen,S.M.Muyeen,Athanasios V.Vasilakos, İrfanAlan," Enhancing smart grid with micro grids: Challenges and opportunities", Renewable and Sustainable Energy Reviews,72,pp. 205-214,2017.