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5G technology to help the development of smart grids: A review

Hongyi Liao

College of Electrical Engineering, Sichuan University, No. 24, South Section 1, First Ring Road, Chengdu, China, 610095

Hongyi_Liao_scu@163.com

Abstract. The continuous advancement of technology has led to an increase in electricity consumption by residential, industrial, commercial, and other users in all aspects, and the demand for electricity quality is also increasing. In such a context, the smart grid is regarded as a new generation of power systems. The smart grid uses advanced communication and information processing, remote automatic control, and other technologies to achieve precise control of fault removal, three-dimensional monitoring of the system and optimal dispatch of electrical energy; while ensuring that the reliability of the power supply can be maintained even when a variety of uncontrollable renewable energy sources and a large number of new electricity loads are connected. Smart upgrades require strong communication systems to support them, and the characteristics of 5G technology perfectly match the various needs of smart grids for wireless communication, which is why 5G is widely studied. This paper is a review of the use of 5G technology in smart grids. Firstly, an overview of wireless communication in smart grids is given, and then the three main scenarios for the use of 5G and various grid services are adapted. This is followed by a summary of the problems and under-researched areas in the use of 5G in smart grids. In the end, the current advanced solutions are summarised and analyzed, and it is determined that the most urgent issues to be addressed in the use of 5G in smart grids are the confidentiality of critical data, network anti-attack capability, and other security guarantees. There is also further value in the use of big data to calculate the optimization of energy dispatch solutions. In general, its development prospects are quite optimistic.

Keywords: 5G, Smart Grid, Power System, Network Slicing, Information Security, Energy Management

1. Introduction

The conventional grid is dominated by fossil fuels in terms of energy, which poses the risk of serious environmental pollution and a sharp reduction in non-renewable energy reserves. Clean energy sources, such as wind power and photovoltaic power, are more susceptible to uncontrollable weather changes and their direct connection to the traditional grid reduces the reliability of the supply. In addition, the traditional grid itself has low information utilization, a slow response time for some devices, a low assembly rate of smart devices, a high manpower cost, weak information sharing, and utilization. The transition to a smart grid is inevitable in order to make the grid more resilient to risks, while achieving multi-energy utilization, maximizing economic benefits, and improving customer experience.

The construction of smart grids requires the collection, transmission, and use of all kinds of information as a basis, so the development of smart grids is highly dependent on the development of communication technology. At the same time, as wired communication methods such as fiber optic cables have limitations in terms of long line laying, operation and maintenance costs, fast fault location and repair, and support for more intelligent devices, wireless communication devices will be increasingly used in smart grids due to their ease of deployment and flexibility.

Compared with the fourth generation of mobile communication technology (4G), the fifth generation of mobile communication technology (5G) has high reliability, low latency, a large number of accessible terminals and ultra-high bandwidth, which is reflected in the different degrees of improvement in the number, density, average rate, peak rate and latency of data transmission [1]. This makes 5G communication technology more in line with the performance requirements of smart grids for wireless communication networks, and theoretical analysis and attempts to use 5G in power grids have gradually accumulated in recent years.

The rest of the paper is structured in such a way that the second part of the article will first detail the various salient features of 5G technologies and their applicability in the context of smart grids. In the third part, we will summarize the various aspects of the current integration of 5G technologies and smart grids, and in the fourth part, we will collate and evaluate the state-of-the-art solutions to these problems. The article will conclude with a summary and an outlook for the future.

2. The salient features of 5G and the high overlap of smart grid services

The Third Generation Partnership Project (3GPP) has defined three main application scenarios for 5G, namely ultra Reliable Low Latency Communication (uRLLC), massive Machine Type Communication (mMTC), and enhanced Mobile Broadband (eMBB).

2.1. uRLLC

uRLLC involves two aspects, one is ultra-high reliability and the other is low latency. According to 3GPP, a 32-byte packet message has to be transmitted with a reliability of 99.999 and a delay of less than 1ms [2]. Low latency and high reliability are mainly geared towards control-type services, meeting the need for fast and correct responses when controlling equipment.

Scenarios in the power system where the need for low latency and high reliability is high are mainly in some key action devices such as millisecond load-cutting control and differential protection [3]. These protection methods are key measures to ensure the reliability of grid operation and have very strict requirements on the reliability and time delay of the signal transmission channels. Faults are a common phenomenon in power grids, and in order to avoid voltage and frequency anomalies leading to the progressive expansion of the fault, the fault point needs to be removed from the grid as soon as possible, which requires the action command signal to be communicated quickly within microseconds and without loss of signal under wireless transmission. Differential protection can selectively remove faults and shorten the time to remove faults, reducing the area of power loss, but with fiber optic networks it is not easy to re-adjust or expand the lines once the network architecture is complete [4], and wireless communication can provide more convenience if the rate and transmission distance are guaranteed.

In the future, under the concept of power distribution automation, the control connection will change from a star structure connection of the master station to the sub-station to a point-to-point distributed type of connection. The control and processing work of the master station will gradually sink to the distributed intelligent power distribution equipment. Terminals with 5G communication will enable bi-directional communication between devices and shorter distances when collecting data, enabling faster response to faults and a smaller and more accurate range when cutting loads. The 5G network slicing technology can also provide a wireless private network for the power system, ensuring that communication is free from interference and has high reliability and low latency, which is superior to the wireless communication technology already used in the past.

2.2. mMTC

mMTC is primarily oriented towards the Internet of Things (IoT) sector and is suitable for scenarios where a large number of devices need to be connected, with the number of accesses supported reaching one million within one square kilometer. To accommodate the dense access scenarios required by mMTC, 5G uses non-orthogonal multiple access technologies [5], which allocate a single wireless resource to multiple users for greater spectral efficiency.

The traditional power grid's ability to collect electricity consumption information is mainly a periodic one-off record of total electricity consumption within a certain area, which is gradually becoming obsolete compared to collecting big data on electricity consumption for accurate electricity forecasting and scientific electricity rate bargaining. In terms of monitoring power equipment and power quality, sensors and smart meters are mainly deployed in power plants and substations, with less monitoring of facilities on remote lines. The extensive use of wired communication to transfer data can lead to high costs and difficulties in laying lines, and communication between devices is temporarily unattainable.

The technology of massive device access can solve the quantitative limitations of sensors and smart meters in the grid, allowing the monitoring of equipment and power quality as well as the collection of electricity consumption information to be significantly expanded and the frequency of data collection to be increased to once per minute. A large amount of real-time data can be used to build a three-dimensional power operation model, with more intuitive electricity usage information, for accurate analysis and prediction of load changes, to realize refined power supply and demand balance and load demand response, and to support the implementation of power market mechanisms such as real-time tariffs and peak usage.

This type of service requires low latency and only needs to achieve data upload in seconds or quasi-real time, with many data packets in quantity but small in size.

2.3. eMBB

5G uses millimeter-wave communications and will have higher broadband compared to 4G. In densely populated areas, average data rates can be as high as 1Gbps, with peak rates reaching 10Gbps, a tenfold increase over 4G [6]. Ultra-higher broadband is mainly used for larger traffic demands such as ultra-high definition video and virtual reality (VR) technology.

Although many current power stations already have automated robots involved to assist with management, most of the work still needs to be done by humans. Manual maintenance increases the cost of operating the grid and poses safety risks such as electrocution and misuse. In addition, although fiber optic transmission of video images can already guarantee real-time, high-definition images, the fixed siting brought about by wired access makes video monitoring still very limited, unable to provide a full range of multi-angle images, and cannot monitor the operation of power equipment at close range. Some of the large-volume video files can only be used locally due to slow transmission rates, and are not easily passed to higher-level dispatch centers for shared monitoring.

With the support of 5G technology, video monitoring can be transformed from the original fixed cameras to inspection robots and drones. By setting a fixed trajectory for the inspection machines, not only can they monitor each power equipment in the power plant from multiple angles, at close range and in real-time, replacing manual inspections to reduce costs; they can also be used by employees to complete simple equipment fixes remotely from the monitoring center in the future when the robot arm technology is further developed. For example, in offshore wind power stations, if it is difficult for maintenance staff to go out to sea immediately due to wind and waves, wireless transmission of ultra-high definition video will provide more economic benefits in terms of fault finding and remote repair. Video can also replace paper or voice reporting, enabling centralized control centers to also quickly and accurately grasp the situation at lower levels of the power station.

Ultra HD surveillance video transmission has a very high demand for broadband, while the requirements for latency are not as stringent, and at the same time, the number of terminal accesses within a power plant is generally low.

Table 1. Indicators of communication network requirements for smart grid application scenarios [7]

<table>
<tr><th rowspan="2">Application scenario</th><th rowspan="2">Slice type</th><th colspan="5">Requirement indicators</th></tr>
<tr><th>Latency</th><th>Reliability</th><th>Number of accesses</th><th>Bandwidth</th><th>Data security</th></tr>
<tr><td>Precise load cutting</td><td rowspan="2">uRLLC</td><td rowspan="2">milliseconds</td><td rowspan="2">very high</td><td rowspan="2">medium</td><td rowspan="2">medium</td><td rowspan="2">high</td></tr>
<tr><td>Differential protection</td></tr>
<tr><td>Information gathering</td><td>mMTC</td><td>seconds</td><td>high</td><td>very high</td><td>medium</td><td>high</td></tr>
<tr><td>Video transmission</td><td>eMBB</td><td>seconds</td><td>high</td><td>medium</td><td>Very high</td><td>high</td></tr>
</table>

2.4. Network Slicing (NS)

From the above three scenarios, it can be seen that different control and information-gathering services in the smart grid have different requirements for wireless communication in terms of reliability, latency, throughput, and number of accesses. 5G provides 5G network slicing technology to meet the different network requirements of vertical industries, cutting the physical network into multiple virtual networks and defining different network configurations. This technology can also be used to tailor communication networks for different power services in the smart grid.

At a technical level, network slicing is implemented through Software Defined Networking (SDN) and Network Function Virtualisation (NFV). The core technology of SDN is the separation of the data forwarding plane from the control plane in traditional networks and the use of controllers to achieve centralized control of the network. NFVI provides the basic components for hardware to support the software, VNF is the software application that implements network functions such as IP configuration and forwarding services, and MANO is the unified framework for managing VNF and NFVI [6]. The three parts ultimately achieve the separation of hardware and software, facilitating the use of hardware to run the software for network functions.

SDN and NFV are two highly complementary technologies that share the same aim of separating software and hardware, enabling the use of a small amount of common hardware to support different functional software and compatible updates for new functional software in the future. SDN enables unified management of each function, while NFV enables flexible orchestration of services, thus enabling network slicing for different communication needs.

3. Risks and challenges

Although the excellent features of 5G are theoretically compatible with many business scenarios in smart grids, and the reality is that some power plants have already started to pilot the use of devices supporting 5G communications to meet certain wireless communication needs, some new challenges are gradually being identified in the practical application, as well as inspiring some ideas that can be further improved. The main research directions are currently: How will the security of important power information in communications be secured? How can large volumes of data be optimized in

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terms of collection and calculation? How will 5G improve the grid's ability to manage and optimize power dispatch? And how will network slicing be implemented for smart grids?

3.1. Information Security

With 5G technology, the smart grid will have the ability to collect and process a wide range of data, but this also increases the risk of data leakage. Although 5G technology can provide private network services through network slicing, wireless data transmission is still susceptible to malicious eavesdropping and theft. As the amount of data that can be processed exponentially overloads the central cloud, 5G provides edge computing to distribute large amounts of data closer to the user at the base station for distributed in-place processing. This approach also leads to information security risks: the deployment location of computing nodes is more accessible to attackers, and the increase in the number of risk points and the coexistence of differentiated risk points puts more pressure on security protection monitoring.

As in the previous analysis of the precision control class of business, some of the data is collected and calculated to ensure that it is done quickly and that the whole process is not easily retransmitted to the center. However, in addition to the data leakage issues mentioned above, the grid also needs to consider the risk of malicious attacks. Because the precise control device, in addition to transmitting data, also performs load-cutting actions according to the instructions, if a malicious attack triggers an abnormal mass blackout, there will be serious consequences, so the confidentiality of remote instructions under wireless communication is very important.

On the customer side, the abundance of electricity consumption data, while beneficial for building a three-dimensional electricity consumption model, also poses the problem of user privacy leakage.

3.2. Energy management

Due to the access to new energy sources such as wind power and photovoltaic power generation, excellent energy management becomes a key target for smart grids. The optimal scheduling of energy management needs to take into account the characteristics of unstable power generation by new energy sources on the generation side, to automatically execute energy storage when excess load demand is expected, and accurately determine the maximum benefit under the options of energy storage compensation, market power purchase, and controlled unit generation based on the information collected when there is a shortage of power generation.

On the customer side, how to handle and predict the electricity consumption of customers is the basis for strategies such as optimal dispatch of electricity, scientific tariff setting and staggered electricity consumption.

In addition, 5G communication equipment itself consumes a lot of energy, and the excessive cost is the main reason that prevents many power plants from choosing 5G equipment. How to reduce the resource cost of equipment operation is also a key point for promoting the widespread use of 5G technology in smart grids.

3.3. Implementation of network slicing

The application of network slicing in the smart grid is still in its initial stage, so there are difficulties in instantiating and coordinating multiple scenarios, i.e., how to dynamically adjust the resource allocation between slices for the specific communication needs of the smart grid at different times and different nodes, and how to allocate the sliced resources end-to-end.

The demand for spectrum resources for communication services continues to expand due to the continuous upgrading of communication technologies. The power system is a huge business complex, and the static allocation of network resources can hardly meet the needs of the smart grid, so it is important to study the maximization of the use of the limited spectrum resources in the network.

4. Advanced solutions

In this section, we present some of the relevant work that is already available.

Liyanage et al. analyse the privacy issues of SDN, NFV and other technologies due to shared environments, new interfaces and different perspectives on privacy by new participants, discussing Privacy-aware Routing Mechanisms by using SDN, Hybrid Cloud Approach, the Privacy by Design, Software Defined Privacy Approach, and many other solutions to protect privacy [8]. Although not the best solution, it gives the reader a more intuitive understanding of information security triggers and solution techniques. In addition, the authors emphasise the importance of involving multiple organisations such as governments, operators, and device vendors in privacy protection, in addition to good protection technologies.

Nyangaresi et al. propose an Artificial Neuro-Network-Fuzzy Logic (ANN-FL) based handover authentication protocol to improve the traditional 5G handover authentication protocols. protocol based on Artificial Neuro-Network-Fuzzy Logic (ANN-FL) [9]. They demonstrated through simulation that the protocol can reduce the number of handovers and handover delays in 5G networks by optimizing the target cell selection before handover. The protocol also encapsulates the practical session keys during switching to prevent malicious attacks such as eavesdropping. This common technology can also be used in smart grids, for example, in wind and photovoltaic power plants with multiple miniaturised base stations, where the inspection robot can switch between small areas to protect the images of some highly confidential equipment from being leaked and to ensure smooth video. If the user can observe the distribution of electricity in the home or workplace through the program, it also ensures secure and low latency reception of real-time data on the move.

M. A. Javed et al. focused on the resilience and protection of 5G communications against DoS and DDoS risks and analyzed traditional approaches such as Anti Malware Systems, Firewalls and new security services such as Security Operations Centre (SOC) and SDN merging, Dual-Homed Switching of Networks (DSN) and other new security services [10]. The centralised control brought about by SDN technology makes it more vulnerable to DoS and DDoS attacks, and an attack on a large number of wirelessly connected devices in the power system could have serious consequences. But DoS/DDoS attacks cannot be completely eradicated so far, so measures for wired and wireless multi-channel redundancy of important devices may have to be considered in power systems.

Valtanen et al. present the introduction of blockchain to 5G and smart grids, using the resource configuration framework and 4C typology for the study of proxies for 5G network slices and the internal distribution of electricity in a housing area. The study shows that the properties of blockchain and the value creation resource allocation process are a good match, demonstrating the feasibility of blockchain technology to optimise resource allocation [11]. The article provides ideas for future options for decentralised ecosystem governance in electricity business models, and further research is worthwhile in the direction of linking both grid-exclusive 5G network slicing agents and grid energy distribution through blockchain.

Tipantuña and Hesselbach apply network slicing techniques to improve the use of renewable energy by setting up a Demand-Response scheme in the energy consumption model with strategies such as prioritising the use of different energy types and scheduling workloads with time-shifting capabilities, and using Integer Linear Programming (ILP) to calculate the optimal results [12]. The article provides experiments to show that NFV and SDN technologies can meet the complex Information and Communication Technology (e.g. IoT) required for the energy management solutions in the paper. This experiment not only provides an excellent solution for increasing clean energy usage in complex grids, the proposed architecture is scalable for power consumption scenarios with more nodes, and it also demonstrates that 5G communication networks can support the collection of more data while effectively reducing computational resources to support optimisation of more complex grid models and improve the economic efficiency of smart grids.

X. xia et al. analyse the profitability model of network slicing for operators in smart grids. The study shows that the total annual cost of network slicing is lower than for fibre or eLTE networks, thanks to the sharing of the network. The return on investment is highest in uRLLC scenarios related to distribution automation [13]. Visual flowcharts are also provided for operators to create, manage and maintain multiple network slices in a unified manner for various business scenarios in the smart grid. These studies demonstrate the feasibility of designing dedicated network slices for smart grids with high return on investment prospects.

W. Li, Z. Wu and P. Zhang analyse network slicing isolation schemes for the grid in more detail, customising different isolation strategies in the access, transport and core networks, proposing for example that uRLLC and eMBB in the access network can share frequency bands, and then differentiate delay and reliability through different physical layer parameters, modulation coding schemes, etc., as a way to improve spectrum utilisation. The article also extends the planning scheme for network slice instantiation, proposing centralised management and monitoring of network slices, as well as the option of resource redundancy and master-standby switching for each slice to meet different needs [14].

5. Conclusion

In the article we detail the adaptability of 5G communication in smart grids, showing that there is a wide scope for 5G in smart grid construction from various perspectives such as load cutting, precise control services for differential protection, massive power data collection and ultra-high definition video monitoring support. We focus on the issues that still need to be solved in the areas of information security, energy management, and the development of exclusive network slicing after the power system has been technically supported by 5G communication, and analyse the progress of related work so far. We can see that the use of 5G in smart grids is still in the preliminary stage, and the security of data transmission and the improvement of network anti-attack capability are what need more attention and in-depth research, and the development of energy distribution and dedicated network slices has already yielded some results. In general, the prospects for the integration of 5G and smart grids are quite optimistic. This paper is more interested in providing an integrated analysis of 5G and smart grids, and therefore it does not specifically delve into a particular challenging direction. The article is limited in length, so only representative results have been selected for presentation and evaluation. The author will go further in the next section to investigate ways to improve the risk resistance and data confidentiality of wireless networks in smart grids.

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