Proceedings of the 3rd International Conference on Mechatronics and Smart Systems
DOI: 10.54254/2755-2721/117/2025.20146

Application Analysis of Wireless Communication Technology in China's Smart Grid

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Abstract: With the rapid advancement of China's economy and technological innovation, wireless communication technology has seen considerable development. Concurrently, global energy and environmental challenges have intensified, heightening the demand for efficient and sustainable energy management solutions. In response to evolving energy demands, China has introduced new standards for digital power grid construction, prioritizing the use of wireless communication technologies to improve energy efficiency and develop smarter grid systems. These technologies facilitate real-time data transmission, remote monitoring of equipment, and network interconnectivity, thereby improving operational efficiency and monitoring capabilities. This paper reviews recent applications of wireless communication technologies within smart grids, aiming to provide valuable insights for future developments based on existing literature and data. Wireless communication technology in smart grids mainly enhances the intelligence and efficiency of the grid by enabling real-time data transmission, remote device management, and optimized energy distribution. Technologies such as Wi-Fi, 5G, and LoRa facilitate key functions like smart meter monitoring, equipment status management, and demand response, driving the automation and intelligent development of power systems. Future research should focus on optimizing the integration of these technologies, strengthening network security, and leveraging big data and artificial intelligence to advance the intelligence of power systems, thereby addressing critical energy challenges and fostering sustainable development.

Keywords: Smart grid, Applied research, Power communication technology, Wireless communication technology

1. Introduction

With rapid social development in China, the conflict between resources and the environment has intensified. Simultaneously, the rapid advancement of wireless communication technology has led to its deeper integration across various industries, making it possible for traditional industries to transition towards informatization and digitalization[1]. Wireless communication technology relies on the transmission of signals through the air to achieve remote data transmission. Its core advantages lie in flexibility and extensive coverage, enabling communication without the need for physical connections. Wireless communication technology encompasses various forms, including satellite communication, cellular networks (e.g., GSM, GPRS, 5G), and other wireless technologies like Wi-

Fi and Bluetooth. Each offers long-distance, high-speed data transmission, making them especially suitable for remote, inaccessible areas[2]. Driven by the carbon neutrality goal, traditional fossil-fuel-based power generation methods need to be transformed into new energy sources like wind and solar power. By the end of June 2024, the national installed power generation capacity reached 3.07 billion kilowatts, with new energy installations accounting for 1.653 billion kilowatts (53.8%), surpassing coal-fired power generation for the first time[3]. In this process of transitioning power generation methods, the application of ultra-high-frequency wireless technology has enabled new substations to be more automated and easily deployable, enhancing flexibility in power management [4]. The continuous evolution of wireless communication necessitates that power sector professionals stay informed on emerging solutions to meet industry demands. Based on existing literature and data, this paper aims to analyze the application of wireless communication technologies such as 5G, ultra-high frequency communication, and LoRa in smart gird, exploring their potential in enhancing grid automation, reliability, and energy efficiency.

2. The definition of smart grid

A smart grid is a modernized power supply system that can monitor, protect, and automatically optimize the operation of its interconnected components. These "interconnected components" include both centralized and distributed generators, power transmission and distribution systems, industrial users, building automation systems, energy storage devices, end-users and their temperature control equipment, electric vehicles, and other electrical facilities[5].

Built on traditional grids, the smart grid integrates sensing, communication, computation, decision-making, and control, enabling a sophisticated flow of energy, information, and business processes. This improves the operational stability of the power system, maximizes equipment utilization, enhances safety and reliability, reduces energy consumption and emissions, improves power supply quality, and increases the efficiency of renewable energy utilization. The ultimate goal of the smart grid is to reduce energy consumption costs, improve the quality of electricity for residents, and lower the operating costs of the power grid, thus promoting national economic development[5].

New energy technologies such as solar and wind bring variability, posing stability challenges. Smart grids monitor and analyze the operational status and output of new energy generation devices in real time, enabling precise forecasting and scheduling of renewable energy generation. This not only ensures that the grid remains stable during fluctuations in renewable energy generation but also optimizes the integration and distribution of renewable energy, increasing its utilization. In addition to using energy storage technologies and demand-side management techniques to ensure the smooth integration and flexible dispatch of new energy generation, smart grids also support data transmission, monitoring, and management throughout the generation and transmission process through advanced wireless communication technologies[6].

3. The implementation of smart grid

3.1. Integration of 5G wireless communication technology with smart grids

China is at the forefront of 5G development, and its application in the power grid sector has already shown promising results. The application of 5G technology in smart grids is mainly reflected in areas such as real-time data collection and transmission, demand response and load management, equipment management and predictive maintenance, microgrid and distributed energy management, automated distribution and power dispatching, as well as drone inspections. As the economy and society evolve, the power grid faces growing complexity due to rising electricity consumption and the need for extensive coverage, requiring substantial investments in human resources and infrastructure. The integration of 5G technology with smart grids not only ensures the reliability of

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power supply and the implementation of distributed automation but also enhances the overall reliability of the grid. With its extensive coverage, 5G communication technology is especially effective for remote or hard-to-reach areas where laying wired networks is challenging, enabling large-scale grid connectivity that enhances the operational efficiency and automation of the smart grid[7].

5G technology can meet the large capacity and high bandwidth demands of power industry applications, especially in smart grid operations. For instance, drone inspections and video surveillance require real-time image transmission systems to ensure clear image quality and meet inspection requirements. This requires high bandwidth and low-latency communication network support. With 5G technology, these high-precision inspection tasks can be carried out smoothly, while providing reliable real-time data on the grid's operational status. Furthermore, 5G networks also support robots in performing tasks such as power line inspections, tower maintenance, and line construction surveying, further enhancing the intelligence and automation of grid operations and maintenance[8].

5G wireless technology also demonstrates unique advantages in disaster response and emergency management. Due to its strong anti-interference capability, 5G can maintain the stability of communication networks even in the case of disasters, ensuring the rapid recovery of the power grid [2].

3.2. Integration of ultra-high-frequency wireless communication technology with smart grids

Wireless communication technology achieves efficient information transmission and exchange by loading information onto electromagnetic wave signals at specific frequencies, allowing these signals to propagate freely through space. In the case where the distance between newly constructed substations and adjacent older substations is typically no more than a few dozen kilometers, wireless signals can encounter obstacles like buildings, trees, and other structures. To ensure reliable transmission around these obstructions, ultra-high-frequency (UHF) electromagnetic waves are used due to their ability to effectively diffract around such barriers, maintaining signal stability and quality. During the critical project acceptance and handover phase, ultra-high-frequency wireless data transmission systems quickly complete the deployment of simple wireless communication systems, temporarily replacing formal fiber-optic communication systems. This setup demonstrates the flexibility and cost-effectiveness of the technology. Before the fiber-optic channels are established, this system can rapidly create a stable and efficient wireless data channel for testing and verification by the automation scheduling system. This approach helps address the limited time for electrical automation commissioning and compensates for potential delays in fiber-optic construction, thereby ensuring the quality of the automation system and enabling timely substation commissioning[4].

3.3. Application of long range radio technology in the universal power iot terminal layer

LoRa technology integrates multiple advanced technologies, including spread spectrum, forward error correction coding, and digital signal processing, with the following key advantages:

- Wide Coverage and Low Power Consumption: LoRa provides long-range communication, low power usage, supports large-scale device connectivity, and offers good signal penetration, making it ideal for a wide range of IoT applications. It delivers stable communication in remote areas and complex environments and supports flexible, low-cost network deployment, making it widely applicable in smart cities, agriculture, and more. With its ultra-low power design, battery life exceeds 10 years, with a receive current of just 12 mA and standby current of 0.2 μA.
- High Precision Positioning: LoRa's distance and positioning are based on the transmission time of the signal rather than signal strength, ensuring higher accuracy. It operates on unlicensed, free

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frequency bands, which reduces costs for equipment and terminal nodes, and the fast-growing industry chain and commercial adoption further enhance its appeal.

- Adaptability to Large-Scale Monitoring Needs: As of 2022, China’s grid includes 880,000 km of 220 kV and above transmission lines, 5.1 billion kVA of transformer capacity, and 18.815 million kW of cross-regional transmission capacity, with 767.4 billion kWh of electricity transmitted across regions. In the future, under the ubiquitous power IoT strategy, large-scale monitoring of high-voltage transmission lines will be required, with terminal device demand potentially reaching hundreds of millions. LoRa’s low cost, wide coverage, and maturity make it an ideal choice for such applications.
- Ease of Maintenance: The low-power feature of LoRa ensures that devices can operate stably for extended periods, significantly reducing maintenance and repair requirements during their lifecycle.
- Transmission Rate Suitable for Scenario Needs: While LoRa’s transmission speed is lower than that of ZigBee, Wi-Fi, and Bluetooth, it is perfectly adequate for monitoring transmission lines, where small data packets such as temperature, current, time, and location are transmitted with a sampling cycle of minutes.
- Flexible Topology Support: LoRa’s link-layer protocol supports both "point-to-multipoint" and "multi-hop cascading" topologies, which are highly compatible with the structure of transmission line links. While LoRa technology is still in the early stages of application for transmission line monitoring, as the use of substation monitoring terminals, auxiliary systems, electricity usage collection devices, distribution automation terminals, distributed energy stations, and EV charging piles grows, the advantages of LoRa technology will continue to become more apparent[10].

The above analysis demonstrates the multifaceted applications of 5G, ultra-high-frequency (UHF) wireless communication, and LoRa technology in smart grids and the power Internet of Things (IoT). These emerging wireless communication technologies not only enhance the operational efficiency and reliability of smart grids but also drive the intelligent and digital transformation of the power industry. With continuous advancements in technology, broader application of these technologies will further support the comprehensive development of smart grids in the future.

4. Discussion

Wireless communication technology plays an indispensable role in the development of smart grids. Its widespread application is essential to the efficient operation of smart grids, with key features such as ultra-high speeds, ultra-low latency, massive connectivity, and high flexibility offering unique advantages in smart grid systems. However, significant challenges remain in its practical application.

Firstly, compared to foreign countries, China started later in applying power communication technology and faces many difficulties and bottlenecks in its actual use. Smart grids require higher standards for underlying technologies, which means that traditional processing methods need to be overcome. Conventional technologies are unable to fully meet the needs of smart grid development, especially concerning energy waste. According to the 2023 "Electric Ion Balance Table," China's total electricity supply capacity is 85.2 trillion megawatt-hours, while transmission and distribution losses amount to 3.256 trillion megawatt-hours[11]. Additionally, the development of smart grids faces the problem of a shortage of high-end, specialized talent. Frontline positions lack professionals with expertise in advanced communication technologies and intelligent power systems, hindering the progress of smart grid construction. Therefore, in building smart grids, it is essential to learn from successful international examples. For instance, in the U.S., large-scale deployment of smart meters and distributed energy management systems enables users to monitor their electricity consumption in real time and optimize load management, thus reducing peak power demand and improving energy efficiency. In Germany, the focus of the smart grid is on the integration of renewable energy and the application of energy storage technologies. Subsidy policies support the integration of distributed energy sources like wind and solar power, while investments in energy storage facilities help balance grid loads and ensure stable electricity supply. Similarly, in China, it is also necessary to adopt standardized management and optimization based on actual conditions and to learn from lessons in a timely manner to ensure the smooth implementation of projects and continuous improvement in grid construction quality.

To address the talent shortage, power companies need to increase efforts to recruit communication technology professionals and provide systematic vocational training for their employees. Strengthening collaboration between universities and enterprises, hosting high-impact campus promotion events, and providing more job opportunities for graduates will help attract more talented individuals into the fields of smart grids and power communications. Moreover, the development of smart grids should align with green energy and resource recycling, as preventing resource waste is a key premise for the sustainable development of smart grids. Promoting the widespread application of green energy and adopting sustainable development principles will ensure the long-term growth of smart grids.

5. Conclusion

In the development of smart grids, wireless communication technology plays an indispensable role. This paper explores the multi-layered applications of various wireless communication technologies, such as 5G, ultra-high-frequency (UHF) wireless communication, and LoRa, within smart grids. 5G technology, with its high speed, low latency, and wide coverage, facilitates real-time data collection and transmission in smart grids, supporting demand response, load management, and predictive maintenance of equipment. UHF wireless communication technology, known for its strong signal penetration and flexible deployment, is particularly suitable for commissioning power transmission and distribution equipment in newly built substations and complex environments, providing an economical and efficient wireless data channel for power systems. LoRa technology, with its ultra-low power consumption and long-distance transmission capabilities, is widely used for device connectivity and status monitoring in remote and dispersed areas, addressing the need for large-scale terminal device access in smart grids. These technologies significantly enhance the real-time monitoring, operational efficiency, and automation levels of power grids, laying a solid foundation for the comprehensive development and efficient operation of smart grids.

As a vital infrastructure supporting the stability and harmony of society, smart grids play an essential role in advancing national energy strategies. The integration of wireless communication technology into power communication networks not only improves the comprehensive information acquisition capabilities of smart grids but also provides great convenience for grid control personnel. Therefore, professionals in related fields should pay close attention to the organic integration of communication technology and smart grid technology to ensure the healthy and sustainable development of smart grids. However, the paper does not extensively address the future trend of technological integration, such as the deep application of big data and artificial intelligence in smart grids. The combination of these technologies with wireless communication will unlock more potential for the intelligent transformation of power grids. Future research should include specific application case studies, explore security mechanisms, and integrate emerging technologies to more comprehensively and systematically promote the continuous innovation and development of smart grids.

DOI: 10.54254/2755-2721/117/2025.20146

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