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Application of Power Electronics Technology in New Energy Power Generation

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Abstract. The carbon peak and carbon neutrality dual-carbon target is an important development strategy for China. It promotes the transformation of the power system from coal-based traditional energy to new energy sources such as wind and solar power. This paper, through literature review, systematically explores the application of power electronics technology in wind power generation, photovoltaic power generation and other fields. The practical significance of new energy power generation is pointed out. The study further points out that power electronics technology in new energy generation faces challenges such as grid integration and accommodation and energy storage matching, insufficient compatibility of traditional power grid, and the need to improve the reliability of power generation. The research shows that the wide application of power electronics technology provides core support for the efficient utilization of new energy generation, helping to build a more flexible, clean, and stable new power system, and offers important technical support for achieving the carbon peak and carbon neutrality goal.

Keywords: power electronics technology, new energy generation, wind power generation, Photovoltaic power generation

1. Introduction

Advancing the carbon peaking and carbon neutrality strategy requires the power system to accelerate its shift from a traditional, coal-dominated structure to clean energy sources such as wind and solar [1]. However, the intermittent and fluctuating characteristics of new energy sources also pose a threat to the stability of the power grid. Through efficient energy conversion, regulation and control, power electronics technology can enable integration between new energy generation systems and power grid, and alleviate the problem of power grid fluctuation caused by unstable output of new energy generation [2]. The existing literature mainly focuses on the combination of individual technologies with new energy and lacks a comprehensive exploration of the development of power electronics technology in the new energy field.

Therefore, through a literature review, this paper systematically explores the typical applications of power electronics technology in new energy generation. The study also shows the future development direction of power electronics technology in the field of new energy. This study provides theoretical guidance for the development of power electronics technology in the field of new energy generation.

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2. Current situation and challenges of new energy power generation

2.1. Development status of new energy

Under the promotion of the national energy strategy, China's new energy construction has achieved remarkable results. According to data from the National Energy Administration, in 2025, China exceeded the "14th Five-Year Plan" non-fossil energy consumption target, thereby advancing the construction of a new energy system.

The proportion of new energy in the power system is increasing day by day, as reflected mainly in installed capacity and power generation. First, the installed capacity of new energy has reached a new high. The installed capacity of new energy power generation in China increased by 452 million kilowatts, accounting for 83% of the newly installed power capacity in China. By the end of the year, cumulative new capacity reached 2.34 billion kilowatts, accounting for about 60% of the total installed power capacity in China. Notably, the combined installed capacity of wind and solar power reached 1.84 TW, representing 47% of the country's total installed power capacity and surpassing thermal power capacity for the first time in history [3].

Second, power generation continues to grow. The annual power generation of renewable energy was 3.99 trillion kWh, with a year-on-year increase of 15%, accounting for 38% of the total power generation. The additional generation of 519.3 billion kWh fully met the year's growth in total societal electricity consumption. Amid coordinated development across all subsectors, hydropower, wind, and photovoltaic power maintained steady growth, while biomass and concentrated solar power (CSP) generation saw substantial year-on-year increases. Notably, newly installed CSP capacity surged by 203% [3].

2.2. Key challenges in new energy development

With the rapid increase of the proportion of installed capacity, the problems of new energy technology and application have gradually emerged. These mainly focus on grid integration and accommodation and power generation reliability.

2.2.1. Grid integration and accommodation

Grid integration and accommodation is one of the key bottlenecks restricting the large-scale development of new energy. In China, wind and solar resources are predominantly concentrated in the northwestern and northeastern regions. However, the major load centers are situated along the eastern coast, thus showing a reverse distribution. Due to the uneven distribution of source and load and the fact that the construction of trans-regional transmission channels fails to keep pace with the growth of installed capacity, there may be a situation in which electricity cannot be transmitted, leading to the phenomenon of wind and light abandonment.

The "Three-North" region (Northeast, North, and Northwest China), as the most concentrated and richest areas of wind and solar resources in China, its installed capacity of wind power and photovoltaic power accounts for more than 60% of the national total. However, its electricity load is only 30%, which further leads to a high rate of power and light curtailment [1]. Due to the limited local absorption capacity, the utilization rate of outgoing channels is insufficient. Therefore, it is imperative to further strengthen the coordination between trans-regional transmission capacity and local energy storage deployment.

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2.2.2. Insufficient power generation reliability

At present, wind and solar energy are the main new energy sources. Biomass energy and CSP have also been developed. However, natural energy is significantly affected by day and night, season and extreme weather, and has the characteristics of natural volatility and intermittence.

Specifically, photovoltaic power generation is limited by the day-night cycle and stops generating power completely at night. Wind power cannot generate electricity during calm periods (wind speed < 3 m/s). In Northwest China, the annual equivalent full-load hours of wind and solar power remain significantly lower than those of thermal power. Taking Gansu Province as a representative example, data from 2023 shows that the average utilization hours for wind power were 2,023 hours, and for photovoltaic power were 1,440 hours [4]. Meanwhile, extreme weather such as typhoons and sandstorms not only reduce power generation efficiency but may also damage equipment.

Consequently, mitigating power fluctuations and rationally storing surplus energy to cope with peak loads or emergencies constitute another major challenge in ensuring stable operation of the power system.

3. Key applications of power electronics in new energy

3.1. Power electronics technology in wind power generation

In recent years, as a highly promising and competitive new energy source, the proportion of wind energy in global electricity generation has continued to rise. Under this premise, the development and breakthrough of power electronics technology are also constantly promoting the progress of wind power generation and improving the stability of wind power generation.

3.1.1. Grid connection support

Power electronics technology is the key support to solve the problem of grid-connected wind power generation and improve the stability and operational quality of wind power access. In the grid-connected control of wind power systems, power electronics technology mainly ensures that the output voltage complies with grid-connected standards via converters and inverters. In order to solve the problem of harmonic distortion in the process of grid connection, the active filter function is introduced into the converter, which can reduce the harmonic distortion rate from 6.52% to 2.87%, thus meeting the grid connection standard. According to the experiment of an offshore wind farm, after the filter algorithm based on predictive control is introduced in the process of grid connection, its power quality index is significantly improved, and full power transmission is realized [5].

In addition, power electronics technology can be further used for troubleshooting. As the wind power system is exposed to the field environment for a long time, the natural environment leads to frequent failures such as voltage, overcurrent and short circuit during operation [6]. Power electronic protection devices can act immediately to disconnect the grid connection interface, thereby minimizing damage to both the power grid and the equipment.

3.1.2. Power generation reliability enhancement

Power electronics technology mainly solves the problem of insufficient reliability of wind power generation through two technical paths of stator-side converter control and high-voltage direct current transmission (HVDC) system. The stator-side converter can stabilize the variable AC generated by the wind turbine and convert it into DC, and then adjust it into AC in line with the grid

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rules through the inverter, effectively coping with the instability of power generation caused by wind speed fluctuations [7]. HVDC transmission is designed for long-distance power delivery. By converting AC to DC via power electronic converters and integrating energy storage systems such as lithium batteries or supercapacitors, HVDC technology smooths wind power output and enhances the stability and reliability of both grid connection and transmission.

3.2. Power electronics technology in photovoltaic power generation

Among various eco-friendly energy technologies, solar photovoltaic power generation stands out due to its shortest energy transmission path, highest conversion efficiency, abundant resource reserves, as well as clean and safe operational features [8]. A photovoltaic power generation system mainly utilizes the photovoltaic effect of semiconductor PN junctions and comprises solar panels, power electronic converters, energy storage devices, and loads. The application of power electronics technology permeates all aspects of photovoltaic power generation. Among the key components, the inverter plays a central role in improving system stability and conversion efficiency.

3.2.1. Grid connection support

To mitigate flicker and voltage fluctuations in grid-connected photovoltaic systems, inverters can adopt a full-bridge topology in combination with harmonic suppression techniques, thereby reducing harmonic content in the power grid. Du et al. applied high-efficiency multilevel inverters and MPPT dynamic tracking technology to a 100 MW photovoltaic power station. The experimental results show that the grid stability of the power station is improved by 80% through the ± 1% power fluctuation rate control (originally ± 5%) of the power electronic device [2]. Moreover, this technology can effectively alleviate the "power cliff" problem under extreme conditions such as low irradiance. For example, the efficiency of photovoltaic power generation under low light conditions in winter has increased from 87% to 94%, and the continuity of photovoltaic output has been improved—laying a foundation for the power generated by photovoltaic systems to match grid requirements [2].

3.2.2. Power generation reliability enhancement

Maximum Power Point Tracking (MPPT) serves as a core technology in photovoltaic power generation systems. Particularly under unstable irradiance conditions, MPPT technology ensures stable system output and grid security. Ye et al. found that adopting an interleaved Buck-Boost converter as the main circuit topology for the MPPT controller can reduce the input current ripple coefficient from 8% (prior to improvement) to approximately 2.3%, thereby effectively mitigating the impact of photovoltaic power fluctuations on the overall system and stabilizing the controller's conversion efficiency at 98.5% [9]. At the same time, in order to further ensure the reliability of system operation, the protection of inverter equipment can be strengthened. For example, in the topological optimization of power electronic inverters, a hybrid cooling scheme combining forced air cooling and liquid cooling can be employed to precisely regulate the junction temperature of IGBT modules. When the system is overheated, the output can be cut off in time to avoid the overall shutdown and improve the stability of the system [9].

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4. Significance and development prospects

4.1. Application significance

The results demonstrate that the application of power electronics technology facilitates efficient integration between new energy sources and the power grid, thereby significantly enhancing the operational stability of the grid. As a core enabling technology for safe and stable grid operation, power electronics achieves precise control over power conversion through devices such as inverters. This capability effectively addresses key challenges including harmonic distortion, voltage fluctuations, and insufficient supply reliability. Power electronics technology has greatly improved the energy conversion efficiency of new energy systems, thereby reducing the loss of traditional fossil energy and environmental pollution. In addition to these outstanding advantages, power electronics technology can further unlock the full potential of new energy systems, driving simultaneous improvements in both energy economics and ecological benefits, and thereby accelerating progress toward the carbon peaking and carbon neutrality goals.

4.2. Development prospects

4.2.1. Smart grid

The evolution toward a smart grid represents an important development trend for future power systems. Power electronics technology lays the foundation for the development of the smart grid and permeates the entire process of power generation, transmission, distribution and utilization. For example, Flexible AC Transmission System (FACTS) technology has attracted much attention due to its applications in harmonic suppression, voltage stability, power quality improvement, and efficient energy utilization [10]. With the application of wide bandgap semiconductor materials such as silicon carbide (SiC) and gallium nitride (GaN), new power devices perform better than traditional silicon-based devices under the conditions of high temperature, high frequency and high power density. This advancement further enhances the efficiency and reliability of power electronic equipment.

4.2.2. Energy storage technology

The combination of energy storage technology and power electronics technology is the key path to solve the problem of fluctuation and intermittency of new energy. Although the inverter and other power electronic devices can improve the power quality and enhance the stability of the grid, they can not solve the instability of the output when the power fluctuates intermittently. Energy storage systems can store surplus electrical energy and release it during peak consumption periods, thereby achieving peak shaving and valley filling. This functionality smooths power generation output, ensures supply continuity, and improves overall energy utilization efficiency. The synergy between energy storage and power electronics not only stabilizes power output but also enables the timely dispatch of stored energy through precise electronic control, thereby yielding substantial benefits for both system reliability and operational flexibility.

5. Conclusion

This paper systematically explores the application of power electronics technology in the field of new energy generation. The findings indicate that in wind power generation, power electronics

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technology can stabilize wind speed fluctuations and improve the stability of long-distance transmission through converter control and HVDC transmission technology. In photovoltaic power generation, the application of MPPT technology and multi-level inverter significantly reduces the current ripple and harmonic distortion, and improves the generation efficiency and grid-connected power quality.

However, there are still some limitations in this study. Only by combing the literature to carry out the analysis, there is a lack of real experimental data support, so the adaptability to different scenarios is insufficient. Future research can further combine empirical data to explore the reliability strategy of power electronics technology in extreme environments. It can also further explore the directions for the deep integration of power electronics technology with smart grids and energy storage technologies, as well as the potential for intelligent and integrated applications in the new energy field.

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