Technical Characteristics and Development Approaches of Smart Grids in New Energy Power Generation

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Abstract. Against the backdrop of global policies promoting energy conservation and emission reduction, the usage rate of traditional fossil fuels has been continuously declining. The world has begun to advocate the application of green energy, and the integration of smart grids with new energy generation methods has become an important direction. In this context, smart grids face challenges in the new energy generation field, such as volatility, instability, and low penetration rate, which further lead to issues like islanding effect, passive detection by monitoring systems, and geographical restrictions on energy sources. This paper proposes the use of a novel distribution system architecture to address these problems. By systematically reviewing relevant research literature at home and abroad, this paper focuses on exploring the grid-connection technical characteristics of China's smart grids and new energy generation, analyzes the robust optimization and distributed optimization solutions of new energy storage technologies (including physical storage, electrochemical storage, and emerging storage technologies) in new energy scheduling, aiming to solve the volatility and instability of solar and wind power generation. Advanced technologies and strategies are applied to ensure stable, efficient, and sustainable power supply. The above global power production issues are also applicable to the new energy generation grid-connection market. Therefore, a market-oriented distributed generation model is proposed. The core research of this paper focuses on new energy generation grid-connection technology and power generation technology fields. In the future, key technological research and development on grid-connection power generation combining smart grids and new energy generation will be carried out.

Keywords: Smart grid, new energy power generation, new energy storage, new energy dispatching, distributed generation.

1. Introduction

Under the global policies of reducing fossil fuel combustion, conserving energy, cutting emissions, and promoting green energy, China has continuously put forward sustainable development strategies for new energy. The development of new energy power generation is accelerating, and research into its application under smart grids is ongoing. Based on this, new energy power generation and smart grid power generation are being carried out. However, smart grid power generation faces issues such as mismatches on the generation side, consumption side, and information side, as well as challenges in dispatching and storage. The low proportion and instability of new energy generation lead to waste of new energy resources, making the research on energy storage for new energy power generation particularly meaningful. New energy storage power generation refers to various energy forms other than traditional energy. These forms all directly or indirectly come from the sun or thermal energy generated within the Earth [1]. The energy produced is stored and used when needed. On the basis of extensive existing research on new energy storage technologies such as wind power storage and photovoltaic storage, power generation is carried out, and distributed generation is utilized to develop an idealized power generation market system. How to integrate new energy power generation with the traditional generation mode of smart grids, and how to apply new energy storage and dispatching methods within the overall framework of smart grids—these are the technical characteristics and development paths of new energy power generation under Priority Research.

This paper elaborates on the existing problems of new energy power generation, analyzes them, and, within the framework of smart grids, explores the technical foundation, market effects, and development paths of new energy storage for power generation.

2. Theoretical Basis Analysis

2.1. Basic Modes and Technical Characteristics of New Energy Power Generation

The basic methods of new energy power generation, both in China and abroad, mainly include biomass power generation, solar power generation, wind power generation, geothermal power generation, tidal power generation, and fuel cell power generation. These six methods are currently the most authoritative and feasible approaches to power generation. Among them, wind and solar power generation are of the greatest reference value.

2.1.1. Solar and wind power generation

Solar power generation currently has two main methods: solar thermal power generation (CSP) and solar photovoltaic power generation (PV). The main shortcomings of solar power when combined with smart grids are intermittency and volatility [2]. To address these shortcomings, new energy storage technologies are used to store energy, thereby solving problems such as imbalance between supply and demand. At the same time, it has distributed characteristics, which can use small-scale power generation to realize power generation and distribution, and can realize a small-scale ideal market model in the power market.

Wind power generation is currently the largest and most promising power generation method because of its lowest cost and highest efficiency. China is rich in wind energy resources, and since 2015, China has ranked first in the world. For wind power generation, the efficiency and stability of new energy wind power will be affected by wind speed. Therefore, wind frequency regulation is needed to achieve power generation balance, and to balance the supply side and the user side. When wind power generation is combined with smart grid power generation, it is necessary to rely on energy storage systems to solve the problems of instability, fluctuation, and low proportion.

Both solar and wind power generation exhibit intermittency and volatility due to their susceptibility to extreme weather conditions. During the grid connection process, the island effect may occur. For example, if there is maintenance or damage at the grid connection port, but the power supply end still continues to supply power to the load, an independent power generation system will appear. In this process, because the monitoring system is passive detection, the monitoring system still fails to detect the continuous power transmission from the power supply end, which will cause damage to the load voltage and frequency, and in severe cases, danger and casualties may occur. A new type of power distribution system architecture should be adopted, using alternating current and direct current to cooperate in power generation. Direct current has the advantages of strong anti-interference ability and low loss for long-distance transmission, reducing environmental interference, while alternating current cooperates in power generation for distributed generation to form a network structure. At the same time, it is necessary to solve the passive detection method of the monitoring system so as to achieve full coverage and avoid the occurrence of the island effect.

2.1.2. Biomass and geothermal power generation

The main form of biomass power generation is to utilize the thermal energy absorbed by organisms, which is then converted into usable chemical energy within the organism. Its main forms of power generation include the following five types: direct combustion power generation, methanol power generation, municipal waste power generation, biomass gas power generation, and biogas power generation.

At present, China's geothermal power generation resources are vast, mainly concentrated in Tibet, Yunnan, and Xinjiang. The basic principle is to directly or indirectly convert the thermal energy contained within the Earth into electricity. The main difficulties currently lie in China's geographical limitations, low resource utilization rate, and high costs.

Both biomass power generation and geothermal power generation rely on Earth's resources to achieve new energy power generation. In the power generation process, there is a problem of uneven distribution of environmental resources. Through new energy dispatching technology, rational utilization and allocation of power resources can be realized. However, geographical limitations of the environment are unavoidable, and at present, transportation and processing can only be carried out manually. Therefore, it is proposed to use a new type of transportation system to address the problem of resource scarcity, realize resource sharing, and thereby achieve new energy power generation sharing

2.1.3. Tidal power generation

Tidal power generation converts marine energy into the electricity we need. It is currently the most authoritative form of offshore power generation available. At present, tidal power generation is mainly concentrated in several large-scale projects, such as Sihwa Lake in South Korea and the Severn Estuary in the United Kingdom. However, compared with wind and solar energy, the proportion of tidal energy in global renewable energy remains relatively small [3].

2.1.4. Fuel cell power generation

A fuel cell is a power generation device that efficiently converts the chemical energy stored in fuels and oxidants directly into electrical energy. It also has advantages such as diverse fuel options, clean exhaust, low noise, minimal environmental pollution, high reliability, and good maintainability. Fuel cells are regarded as one of the brand-new, high-efficiency, energy-saving, and environmentally friendly power generation methods in the 21st century [4].

Table 1. Comparison of Solar Power Generation and Wind Power Generation

Aspect	Solar Power	Wind Power
Energy Source	Sunlight (mainly daytime)	Wind (depends on speed and direction)
Stability	Highly intermittent, day-night difference, weather-dependent	Intermittent, unstable wind speed, but possible at night
Storage Need	High, to handle night and cloudy days	Medium, storage helps smooth fluctuations
Best Locations	Rooftops, urban areas, arid regions	Plains, coasts, high-wind areas

The comparison chart of the advantages of solar power generation and wind power generation is summarized in table 1. This table explains the general situation, sources, advantages, and disadvantages of the main new energy generation methods when combined with a smart grid.

2.2. Basic Overview of Smart Grids in New Energy Power Generation

Smart grids have become one of the most cutting-edge research topics worldwide, finding widespread application across various fields. They can ensure the continuous development of these sectors while enabling safe operations. Smart grids are extensively used in areas such as social service and security, companies and departments requiring safe and efficient operations, and energy-related sectors. Moreover, they bring significant social benefits, including improved operational efficiency, optimized dispatching processes, reduced energy consumption, and effective control of environmental pollution. These advantages are highly aligned with the long-term strategic goal of promoting sustainable development [5].

In new energy power generation, smart grids also play an important role. Taking wind power generation as an example, traditional methods rely on wind speed, which leads to instability and low penetration rates. The most critical issue is that when wind power is directly supplied to the user side, there may be insufficient generation or excessive supply, resulting in waste or resource shortages, which also require frequency regulation. With the continuous development of smart grids, the concept of wind-storage integration has been introduced, addressing the problems of low wind power penetration and mismatches between the user side and the supply side. Solar power generation faces similar challenges, and smart grids, through the use of energy storage systems, have effectively resolved them as well, which will not be elaborated here.

The integration of smart grids has optimized new energy power generation, achieved efficient utilization, and injected new vitality into the sector.

2.3. Main Technical Characteristics of Smart Grids in New Energy Power Generation

2.3.1. Physical energy storage

Physical energy storage technologies mainly include flywheel energy storage, compressed air energy storage, and pumped hydro storage. These technologies utilize their inherent kinetic energy for high-speed operation to achieve energy storage. For wind power generation, compressed air energy storage has the most responsive mechanism. Physical energy storage technologies have the advantages of fast response and simple operation, but they also have drawbacks such as large scale and system complexity. In wind power systems, flow batteries or flywheel energy storage technologies are used to buffer power fluctuations caused by changes in wind speed, ensuring stable operation of active power output within the range specified by dispatch commands [6].

2.3.2. Electrochemical energy storage

Electrochemical energy storage technologies mainly include widely used lithium-ion battery storage and sodium-sulfur battery storage. Lithium-ion batteries have high energy density (up to 250 W·h/kg), high cycle efficiency (over 90%), and long lifespan (usually more than 5,000 charge-discharge cycles), and are widely deployed in user-side energy storage and grid frequency regulation applications [6]. The advantages of this energy storage technology include high efficiency and strong energy capacity, but its disadvantages include short utilization time and limited safety.

2.3.3. Emerging energy storage

New energy storage technologies break away from the characteristics of traditional storage technologies and use chemical materials as the medium for energy storage. For energy sources such as solar and wind power, these technologies store energy and extend its usage time. The advantages of such new technologies include high energy utilization efficiency, high safety, and long lifespan. However, their disadvantages lie in the complexity of the chemical materials, which cannot be directly utilized and require cumbersome operational processes.

Comparison of the advantages and disadvantages of physical energy storage, electrochemical energy storage (chemical batteries), and emerging energy storage technologies in table 2.

Table 2. Comparison Chart of the Three Main Energy Storage Technologies

Aspect	Physical Energy Storage	Electrochemical Energy Storage	Emerging Energy Storage
Energy Source	Mechanical equipment	Chemical batteries	Natural energy
Disadvantages	Large scale, complex system	Short duration, low safety	Complex process
Advantages	Fast response, simple operation	High efficiency, strong energy	High utilization, high safety, long lifespan

New energy dispatching effectively addresses the direction of power distribution. As the core of the smart grid, new energy generation dispatching aims to ensure stable, efficient, and sustainable power supply by applying advanced technologies and strategies based on the characteristics of new energy and grid requirements [7]. New energy storage and new energy dispatching form a collaborative relationship centered around the principle of "supply-demand matching [8].

2.4. Market Practices and Applications of Smart Grids in New Energy Power Generation

From the perspective of China's current electricity market and the needs of development on the demand side, the continuous supply of electricity resources to the user side has led to a gradual depletion of resources on that side, accompanied by a shortage of electricity.

Through continuous innovation and development, during the pilot phase, the inter-provincial market has taken the lead, fully carrying out medium- and long-term and spot transactions between provinces, and taking the lead in realizing fully market-oriented operations. Eight pilot provinces with spot markets have been organized to establish intra-provincial medium- and long-term and spot transaction mechanisms. By 2020, China had gradually achieved the joint market-oriented operation of inter-provincial and intra-provincial markets, establishing an electricity market system with effective coordination between inter-provincial and intra-provincial transactions and orderly connection between medium- and long-term and spot transactions [5]. This pilot-based approach has been implemented to continuously enrich the electricity market system.

On the promotion side, pilot projects have served as models, and their successful cases have been continuously innovated and developed. Based on these developments and combined with China's national conditions, interconnection between provinces has been achieved, and on this basis, an interconnected system both domestically and internationally is being developed. Integration with the financial sector, agricultural sector, and other fields has been carried out to achieve mutual benefits.

Therefore, in response to the challenges faced by China's electricity market construction and future development trends, this chapter discusses important innovative research directions and key technologies for an electricity market theoretical mechanism with Chinese characteristics from multiple perspectives, including market form, development path, policy system, connection mechanism, risk prevention, cross-border transactions, and the current status and challenges of foreign electricity markets, aiming to provide a reference for China's future electricity market construction [5].

China's electricity system market and policy framework must be based on national conditions, always align with the socialist market economy system, and develop an electricity system operation mechanism on this foundation.

3. Specific Practical Cases

In recent years, the proportion of new energy in energy utilization has been steadily increasing, accounting for a large share of the market. Energy storage systems are continuously upgraded and applied on both the user and supply sides. Wind power and various other forms of new energy generation have already been implemented in real-world projects, while new energy storage and power generation technologies have also been widely applied in electric vehicles. However, the development and application of new technologies depend on the establishment of an effective electricity market mechanism. A well-designed market mechanism can provide impetus for the development and application of new technologies, driving them from research to practical use [5].

In wind power generation, structural instability and voltage fluctuations often occur. According to research by Yunnan Electric Power Technology, new energy wind power generation is subject to unavoidable factors. Changes in wind speed affect the node voltages of the power grid. The magnitude of voltage fluctuation depends on factors such as grid capacity, grid structure, wind turbine type, and wind farm capacity. Fluctuations in wind farm output power led to changes in node voltages across the grid—the closer to the wind farm connection point, the more significant the voltage fluctuation, with the largest fluctuation occurring at the connection point itself [9]. The formation of large wind dams is also influenced by unavoidable factors. Below are some survey data from Yunnan Electric Power Technology regarding large wind dams:

Gusts (rising speed of 5 m/s over 5 seconds) cause voltage fluctuations of 0.22% to −3.61% at the wind farm step-up transformer bus.

Gradual winds (maximum magnitude of 5 m/s over 5 seconds) cause voltage fluctuations of 0.51% to −10.8% at the bus.

Wind turbine startup and grid connection can cause voltage fluctuations of up to −16%.

Sudden wind turbine disconnection from the grid can cause voltage fluctuations of up to 4% [9].

An important aspect of balancing demand and supply that GES facilities can facilitate is "peak shaving," which allows plant operators to buy electricity cheaply at times of low demand, store it as gravitational potential energy, and then release it for use at peak times when its cost is higher. Gravitricity's demonstrator tower showed that the setup can reach its full power output in less than a second, said Franklin. “The peak speed of the falling mass in Edinburgh demonstrator was 0.62 mps [mps = meter per second],” he said. “The acceleration achieved took it to full power fast.” Such power plants, due to their good acceleration performance, can quickly reach full load operation, thereby being able to provide short-term frequency regulation services to a wider grid system. They can maintain optimal operating conditions whether power demand exceeds generation or generation exceeds power demand [10].

4. Conclusion

On this basis, we have studied some technical characteristics and development approaches for integrating new energy generation with smart grids, and discussed how new energy generation can use energy storage and dispatching technologies to address issues such as supply-demand imbalance, instability, low penetration, and fluctuations in smart grid power generation; first, we conducted research on new energy generation and proposed a new power distribution system architecture to solve the islanding effect during grid connection, which provides a research direction for combining smart grids with artificial intelligence to achieve active detection; we analyzed three key aspects of new energy storage systems and the methods of robust optimization and distributed optimization in new energy dispatching, and proposed that future research should combine energy storage systems with dispatching systems to form a new type of dispatchable energy storage; by combining smart grids with the key approaches for new energy generation grid connection, we analyzed distributed small-scale power generation models and proposed a research direction for an idealized market mechanism based on a distributed, wide-ranging network; Develop an optimized inverter scheme based on virtual synchronous machine technology, which simulates the rotational inertia of traditional synchronous machines through algorithms to alleviate the problem of grid inertia decline under high penetration of new energy sources. Construct a composite support system combining 'physical energy storage + virtual inertia' to address the challenges of new energy frequency fluctuations; research dedicated encryption communication protocols for power systems, promote standardization studies on interfaces between new energy generation equipment, energy storage systems and the grid, solve the problem of poor compatibility among different devices, and formulate unified safety testing standards for grid-connected distributed new energy; with the integration of smart grids and new energy generation, along with the continuous decline in fossil fuel combustion and policies promoting energy conservation and emission reduction, we can realize the vision of a clean, efficient, and intelligent future society.

References

[1] Ye Fei. Research on dispatching and optimal configuration technology of new energy power generation under the framework of smart grid. Zhangjiang science and technology review, 2024, (07): 102 - 104.

[2] Xing Yunmin, Zhang Wenjuan. Development of new energy and renewable energy power generation technology. Journal of Xihua university (natural science edition), 2007, (01): 50 - 52+102.

[3] Zheng Yansen, Su Huangsheng, Liang Yeying, et al. Development status and prospects of energy storage battery technology for wind power generation. Power capacitors and reactive power compensation, 2025, 46 (04): 1 - 12.

[4] Zhao Yan. History, current situation, and future development of tidal energy china municipal engineering north china design and research institute co, ltd, gas and heat magazine co, ltd. proceedings of the 2024 symposium on heating engineering construction and efficient operation (Part II). School of thermal engineering, Shandong Jianzhu University, 2024: 337 – 341.

[5] Zhang Xian, Shi Lianjun. Future research directions and key technologies of china’s power market. automation of electric power systems, 2020, 44 (16): 1 - 11.

[6] Lu Yong. Application of new energy power generation in power systems. Yunnan electric power technology, 2010, 38 (03): 91 - 95.

[7] Heyman, M, Awerbuch, S, & Lave, L. B. (2020). The integration of renewable energy sources into the power grid: challenges and opportunities. Proceedings of the IEEE, 108 (11), 1831 - 1845.

[8] A. G. Olabi, M. A. Abuelyaman, M. A. Al-Maadeedet, Compressed air energy storage systems: A review of technology, performance, and cost perspectives, journal of energy storage, vol. 58, p. 106348, 2023.

[9] D. C. Bhuiyan, A. K. M. A. Habib, and M. R. Islam, A comprehensive review on hybrid energy storage systems: Integration for renewable energy sources and future directions, IEEE Access, vol. 10, pp. 110057 - 110079, 2022.

[10] O'Neill S. Weights-based gravity energy storage looks to scale up. Engineering, 2022, 14 (07): 3 - 6.