

Development Trends and Challenges of Energy Storage Technology in Coal-fired Power Plants

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Abstract: With the rapid development of new energy sources such as wind and solar power, the global energy structure is undergoing profound changes. The increasing penetration and scale of renewable energy bring unprecedented stability challenges to the traditional power grid systems. Against this backdrop, the development of energy storage technology in coal-fired power plants, as a conventional method of power generation, becomes particularly important. Energy storage technology provides a solution for coal-fired power plants, effectively balancing grid load, coping with fluctuations in renewable energy, enhancing the stability of the power system, and promoting sustainable energy development. By integrating energy storage systems, coal-fired power plants can better adapt to the rise of new energy sources and enhance their competitiveness. However, the development of energy storage technology in coal-fired power plants is not smooth sailing. In the future, with continuous technological innovation and industrial upgrading, energy storage technology in coal-fired power plants is expected to achieve higher performance indicators, lower costs, and more extensive application scenarios. Analyzed from different perspectives, energy storage technology will play an increasingly important role in coal-fired power plants, providing strong support to address the challenges in the context of new energy.

1. The Importance of Energy Storage Technology

With the transformation of the energy structure and the rapid development of renewable energy, energy storage technology is gradually becoming a key component of the modern energy system. The importance of energy storage technology is reflected in several aspects, as shown in Table 1. First, energy storage technology can solve the problem of the variability of renewable energy generation. The output of renewable energy is influenced by natural factors such as weather, resulting in instability. Energy storage technology can balance the fluctuations in renewable energy output by storing and releasing energy, ensuring the stable operation of the power system. Second, energy storage technology can improve the efficiency and reliability of the power system^[1]. In the power system, there are sometimes imbalances between power supply and demand, leading to energy waste and decreased system stability. Energy storage technology can store energy during low demand periods and release it during peak demand, effectively alleviating the contradiction between power supply and demand and improving the efficiency of the power system. Lastly, energy storage

technology also helps to achieve energy conservation and emission reduction. By storing excess energy and releasing it when needed, it reduces energy waste and pollutant emissions. Additionally, energy storage technology can be used in distributed energy management, smart microgrids, and other areas, improving energy utilization efficiency and the level of intelligent energy management. Energy storage technology has become an indispensable part of the modern energy system, and as technology continues to advance and application scenarios expand, it will play an even more important role in future energy transformation and sustainable development.

Table 1: The Importance of Energy Storage Technology

Importance	The Contribution of Energy Storage Technology
Resolving the Variability of Renewable Energy	By storing and releasing energy, it balances the output fluctuations of renewable energy, ensuring the stable operation of the power system.
Enhancing the Efficiency of Power Systems	Stores energy during periods of low demand and releases it during peak demand, alleviating the contradiction between electricity supply and demand, and improving operational efficiency.
Energy Conservation and Emission Reduction	Reduces energy waste and pollutant emissions, achieving the goal of energy conservation and emission reduction.
Distributed Energy Management	Used in distributed energy management and smart microgrids, enhancing energy utilization efficiency and the level of intelligent energy management.

2. Development Trends of Energy Storage Technology in Coal-fired Power Plants

2.1 Technological Innovation

With continuous advancements in science and technology, energy storage technology is also constantly innovating, providing more possibilities for the sustainable development of coal-fired power plants. In the future, coal-fired power plants will focus more on the research and application of energy storage technology, improving the performance indicators of energy storage systems through technological innovation to meet higher energy demands and environmental protection requirements. The innovation of energy storage technology will further increase energy density, a crucial metric for measuring the performance of energy storage systems. Increasing energy density can enhance the storage capacity and power supply ability of the systems^[2]. In the future, through the development and application of new materials and processes, the energy density of energy storage systems will be significantly enhanced, providing more reliable energy security for coal-fired power plants. The innovation of energy storage technology will extend the charge-discharge life, a key indicator of the reliability of energy storage systems. Long-life energy storage systems can reduce the frequency of replacements and maintenance, thus lowering operational costs. In the future, through improvements in battery materials and optimization of battery structures, the charge-discharge life of energy storage systems will be significantly extended, enhancing their stability and reliability. The innovation of energy storage technology will also improve efficiency. Efficiency is one of the important indicators of energy storage system performance. High-efficiency energy storage systems can complete the charging and discharging process faster, improving energy utilization efficiency. Through optimized control strategies and the use of advanced cooling technologies, the efficiency of energy storage systems will be significantly improved, providing more efficient services to coal-fired power plants.

2.2 Diversified Development

Currently, coal-fired power plants use a variety of energy storage technologies, including battery storage, supercapacitors, flywheel storage, compressed air energy storage, etc. Each of these technologies has its advantages and disadvantages and is suitable for different application scenarios and needs. In the future, with continuous scientific and technological progress, more types of energy storage technologies will be applied in coal-fired power plants. Different energy storage technologies are suitable for different scenarios and needs. Therefore, selecting the appropriate energy storage technology based on the characteristics and requirements of coal-fired power plants will be crucial. For coal-fired power plants, the choice of energy storage technology needs to consider several factors, including the performance indicators, cost, safety, and environmental impact of the technology. For example, battery storage technology has a high energy density and charge-discharge performance, suitable for scenarios requiring quick response; supercapacitors have high power density and rapid charge-discharge characteristics, suitable for scenarios requiring instantaneous high-power output; flywheel energy storage technology has the advantages of long life, high reliability, and low maintenance costs, suitable for scenarios requiring frequent provision of instantaneous high-power output; compressed air energy storage technology is suitable for large-scale energy storage applications. Therefore, in choosing the appropriate energy storage technology, it is necessary to consider various factors comprehensively and conduct in-depth technical and economic analysis and assessment. This requires thorough research and testing by the technical and management personnel of coal-fired power plants to ensure that the chosen energy storage technology can meet practical needs and bring the best economic and social benefits.

2.3 Intelligent Control

Due to the rapid development of technologies such as the Internet of Things (IoT) and cloud computing, the energy storage systems of coal-fired power plants will become more intelligent in the future. Intelligent energy storage systems will integrate IoT, cloud computing, and other technologies to achieve remote monitoring, intelligent scheduling, and optimized management of energy storage devices, improving the operational efficiency and reliability of the energy storage systems. First, intelligent energy storage systems will realize remote monitoring. Through IoT technology, energy storage devices can connect to remote monitoring centers, transmitting real-time data on device operation status and battery levels. This allows the monitoring center to timely understand the operating conditions of energy storage devices, perform remote diagnostics and maintenance, and reduce the frequency and cost of on-site maintenance. At the same time, remote monitoring also enables centralized management and scheduling of energy storage devices, improving their utilization rate and operational efficiency. Second, intelligent energy storage systems will achieve intelligent scheduling. Through cloud computing technology, big data analysis and mining of energy storage devices are conducted to understand the operating patterns and performance characteristics of the devices. Based on these data, the intelligent scheduling system can automatically adjust the charge-discharge plans of energy storage devices according to actual demands and operating conditions, optimizing energy configuration and scheduling, and improving the overall efficiency and reliability of the energy storage system. Third, intelligent energy storage systems will also achieve optimized management. Through cloud computing technology, deep analysis and processing of energy storage data can be conducted to extract valuable information and knowledge. Based on this information and knowledge, the optimized management system can improve the maintenance and upgrading of energy storage devices, enhancing their service life and operational efficiency.

3. Challenges of Energy Storage Technology in Coal-fired Power Plants

3.1 Technological Maturity

Although energy storage technology has made certain progress in the field of coal-fired power plants in recent years, some new energy storage technologies are still in the development stage, and their technological maturity needs to be further improved. For instance, the life and stability, efficiency, and other aspects of some new energy storage technologies still have deficiencies that require further research and improvement. The maturity issues of these technologies mainly manifest in their performance in practical applications. Since some new energy storage technologies are not yet fully mature, their application in coal-fired power plants may face many problems^[3]. For example, their storage life might be short, requiring frequent replacements and maintenance, increasing operational costs; their stability might also be insufficient, leading to unstable operation of the energy storage system, affecting the overall efficiency of the power plant. Additionally, the efficiency of some new energy storage technologies is also relatively low, leading to energy waste during the energy conversion and storage process, increasing operational costs. These issues not only affect the promotion and application of energy storage technology in coal-fired power plants but also limit their performance and development potential in practical applications. Therefore, to promote the widespread application of energy storage technology in coal-fired power plants, it is necessary to further increase research and improvement efforts, enhancing the life, stability, and efficiency of these new energy storage technologies. This requires the joint efforts of research institutions and the industry, through continuous innovation and improvement, to promote the continuous advancement of energy storage technology.

3.2 Cost and Economic Benefits

In the process of seeking energy structure optimization and reducing pollution emissions, energy storage technology is seen as an effective solution for coal-fired power plants. However, the cost of energy storage technology has always been a key factor restricting its large-scale application in coal-fired power plants. For large-scale energy storage projects, both investment and operational costs are quite high, directly increasing the economic burden of coal-fired power plants and causing many plants to hesitate. At the same time, the economic benefit assessment of energy storage technology is a complex and tricky issue. Due to the diverse application scenarios of energy storage technology, the forms of its economic benefits also vary, making it very difficult to accurately assess the economic benefits of energy storage technology in coal-fired power plants. Often, the investment return period of energy storage technology is long, and its short-term economic benefits are not obvious, further increasing the doubts and uncertainties of investors. Therefore, to promote the widespread application of energy storage technology in coal-fired power plants, it is necessary not only to reduce the cost of energy storage technology and improve its economy but also to establish a scientific and reasonable economic benefit assessment system to help investors better understand the long-term value of energy storage technology. Only in this way can the challenges of cost and economic benefit assessment be overcome, promoting the widespread application of energy storage technology in coal-fired power plants and making a greater contribution to energy structure optimization and sustainable development.

3.3 Standardization and Regulation

As a traditional energy industry, coal-fired power plants face dual pressures from energy structure transformation and environmental protection requirements. To achieve sustainable

development, many coal-fired power plants have begun to explore the application of energy storage technology to improve energy utilization efficiency and reduce pollution emissions. However, in the actual application of energy storage technology in coal-fired power plants, there are still some challenges. Specific challenges are shown in Table 2. First, the standardization and regulation of energy storage technology are insufficient. Due to the differences in working principles, materials, and equipment specifications of different energy storage technologies, the interfaces and protocols between various technologies are not unified. This brings difficulties to the integration and interoperability of energy storage systems, reducing the stability and reliability of the systems. To address this issue, it is necessary to develop and improve the standards of energy storage technology, unify interfaces and protocols, and enhance the compatibility and interoperability between different technologies^[4]. Second, the safety performance and application risks of energy storage technology need to be further standardized and clarified. Applying energy storage technology in coal-fired power plants involves high-risk factors such as high voltage and large current, making its safety performance particularly important. However, the safety performance and application risks of some energy storage technologies have not been fully studied and standardized, posing potential safety hazards in practical applications. Therefore, it is necessary to strengthen the research on the safety performance and risk assessment of energy storage technology, establish corresponding safety norms and standards, and ensure the safety and reliability of the technology^[5]. Third, the economy of energy storage technology is also one of the factors restricting its widespread application in coal-fired power plants. Although energy storage technology has the advantages of improving energy utilization efficiency and reducing pollution emissions, its investment and maintenance costs are high, increasing the operating costs of coal-fired power plants. In the future, it will be necessary to further reduce the cost of energy storage technology and improve its economy to promote its widespread application in coal-fired power plants.

Table 2: Challenges Faced by Energy Storage Technology in Coal-fired Power Plants

Challenges	Description
Insufficient Standardization and Regulation	The interfaces and protocols among different energy storage technologies are not unified, bringing difficulties to system integration and interoperability.
Safety Performance and Application Risks	Lack of sufficient research and standardization on the safety performance of energy storage technology, posing potential safety hazards.
Economic Viability	Higher investment and maintenance costs increase the operating costs of coal-fired power plants.

4. Conclusion

In the context of the rapid development of new energy, energy storage technology in coal-fired power plants, as a crucial means to enhance grid regulation capabilities and promote sustainable energy development, is gradually becoming a hot topic of research and focus of attention. With the global energy structure transformation, energy storage technology in coal-fired power plants will play an even more important role in the future. Facing challenges such as technological bottlenecks, cost pressures, and policy support, it is necessary to delve deep into the potential of energy storage technology, promoting its continuous innovation and progress. This involves not only breakthroughs in materials, processes, and equipment but also the integration and complementation of multiple energy storage technologies. However, the development of energy storage technology in coal-fired power plants is not an overnight process. It requires facing the challenges head-on,

continuously overcoming difficulties and obstacles, while maintaining confidence and expectations for future development. Through sustained efforts and innovation, it is believed that energy storage technology in coal-fired power plants will achieve greater breakthroughs and progress, making a positive contribution to the sustainable development of energy. This will not only help to address the challenges in the context of new energy but will also inject continuous momentum into the prosperity and progress of human society.

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