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New Paradigm of Risk Management Driven by Technological Innovation in the Field of Electric Power Engineering

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Abstract: In the field of electric power engineering, due to technological innovation, the evolution of smart grid technology and the access to new energy have changed the system structure, and the characteristics of risks have also evolved. Traditional risk assessment methods and organizational structures are facing challenges. Emerging technologies such as big data and digital twins are applied to risk management. The new paradigm requires the reconstruction of organizational structures and collaborative governance, and involves the construction of a standardized system and ethical norms.

Keywords: Electric power engineering; Risk management; Technological innovation

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1. Introduction

In the field of power engineering today, with the continuous innovation of technology, there are many new challenges and opportunities. The Guiding Opinions on Promoting the Development of Smart Grid issued by China in 2020 emphasized the importance of the development of the smart grid. The evolution of smart grid technology integrates various emerging technologies, such as 5G communication and digital twin technology, to promote its development towards intelligence and efficiency. At the same time, the large-scale integration of new energy sources such as photovoltaics and wind power has changed the structure of the power system, bringing about issues such as power balance and stability. In addition, traditional risk assessment models and organizational structures have limitations, and information security risks have become prominent. These have prompted a paradigm shift in risk management, including new assessment methods, organizational models, and standardized system construction, to adapt to the new changes in the field of power engineering.

2. Current status of technological innovation and development in power engineering

2.1. Characteristics of the evolution of smart grid technology

Smart grid technology presents various evolutionary characteristics in the field of power engineering. Its technological system is constantly iterating and integrating various emerging technologies. The application of 5G communication technology has brought high-speed and low-latency data transmission capabilities to the smart grid, making real-time monitoring and control of the power grid more precise and efficient. For example, in distributed energy access and power equipment status monitoring, 5G communication ensures the timely transmission and processing of data. Digital twin technology provides a virtual model for smart grids, enabling real-time mapping and interaction between physical grids and virtual models [1]. Through digital twins, power engineers can more accurately predict the operating status of the power grid, perform maintenance and optimization in advance, and improve the reliability and stability of the power grid. The application of these emerging technologies has driven the continuous development of smart grid technology, making it evolve towards a more intelligent and efficient direction.

2.2. The impact of new energy technology penetration

The large-scale integration of new energy technologies such as photovoltaics and wind power is profoundly changing the structure of the power system. New energy has characteristics such as intermittency, volatility, and randomness, which pose challenges to the power balance and stability of the power system. For example, photovoltaic power generation is affected by light intensity and weather conditions, while wind power is affected by changes in wind speed, making it difficult to stably control its output power. After large-scale integration, it may lead to problems such as frequency fluctuations and voltage instability in the power grid. At the same time, the distributed nature of new energy makes the control and management of power systems more complex, and traditional centralized control models are difficult to adapt to. In addition, the rapid development of new energy technologies has also put forward new technical requirements for the planning, operation, and protection of the power system, requiring continuous exploration and innovation to address these challenges [2].

3. Limitations analysis of traditional risk management models

3.1. Defects of traditional risk assessment methods

The traditional risk assessment model based on probability statistics has theoretical limitations in dealing with the uncertainty of new power systems. Traditional models often rely on historical data to determine the probability and degree of risk occurrence, but new power systems face many unprecedented complex situations, such as the intermittency and volatility of renewable energy, new risk factors brought about by electricity market reforms, etc. Historical data may not accurately reflect these new situations. Moreover, probability and statistical methods usually assume that risk factors are independent of each other, but in actual power systems, various risk factors may be interrelated and affect each other, and this complex correlation is difficult to accurately capture with traditional models. Therefore, traditional risk assessment methods face challenges in the risk management of new power systems, making it difficult to provide accurate and effective risk assessment results [3].

3.2. Management system adaptability crisis

The existing risk management organizational structure presents many institutional obstacles when facing the development trend of integrated power engineering technology and complex systems. Traditional architectures are often built on relatively stable and simple technological environments, making it difficult to adapt to the rapid changes brought about by new technologies. For example, in terms of technology integration, the integration of multiple technologies requires risk management personnel to have cross-domain knowledge and comprehensive evaluation capabilities, but the existing organizational structure's personnel configuration and training mechanisms may not be able to meet this demand [4]. Under the trend of system complexity, the transmission and correlation of risks have become more complex. Traditional risk identification and assessment methods may become ineffective, and there is a lack of corresponding adjustment mechanisms in organizational structures to update risk management processes and methods, resulting in lagging and inefficient risk management.

4. The evolution of risk characteristics driven by technological innovation

4.1. Construction of a new technology risk map

4.1.1. Information security risks of smart grid

In the era of technological innovation, the increasing complexity and interconnectivity of smart grids have exposed them to significant information security risks. Cyber-attacks on power automation systems are becoming more frequent and sophisticated, posing a severe threat to the stability and reliability of the power supply. These attacks can exploit vulnerabilities within the system to disrupt its normal operation, leading to data transmission errors, equipment malfunctions, and even widespread power outages. The cascading effects of such failures can propagate rapidly through the interconnected grid, amplifying the impact and potentially causing substantial economic and social losses. Given the critical role of smart grids in modern society, it is imperative to conduct in-depth research on the impact mechanisms of cyber-attacks and develop comprehensive strategies to construct an effective risk map. This will enable proactive identification and mitigation of information security risks, ensuring the robustness and resilience of smart grids against emerging threats [5].

4.1.2. Stability risks of new energy grid connection

The integration of a high proportion of renewable energy sources into the power system has introduced significant stability risks due to the unique characteristics of these energy sources. Renewable energy, such as wind and solar power, is inherently intermittent, volatile, and random. Wind power generation is highly dependent on fluctuating wind speeds, while photovoltaic power output is influenced by variations in sunlight intensity and weather conditions [6]. These uncertainties make it challenging to maintain a stable power balance within the grid, leading to potential power shortages or surpluses. Such imbalances can cause frequency fluctuations, which are detrimental to the overall stability of the power system. Additionally, the inverter control characteristics of renewable energy sources differ from those of traditional synchronous generators. In the event of grid faults, the response characteristics of these inverters may negatively impact voltage stability. This discrepancy further complicates the management of the power system, increasing operational risks and necessitating advanced control strategies and technologies to mitigate these challenges and ensure a reliable power supply.

4.2. Innovative path of risk assessment methods

4.2.1. Risk prediction driven by big data

In the context of technological innovation, the field of power engineering has witnessed a transformation in risk characteristics, which has driven the evolution of risk assessment methods. Big data technology has emerged as a powerful tool for risk prediction, offering a novel approach to address the complexities of modern power systems. By aggregating and analyzing vast amounts of heterogeneous data from multiple sources—such as equipment operation logs, meteorological information, and grid performance metrics—big data analytics can uncover hidden patterns and correlations that traditional methods might overlook. Leveraging advanced data mining techniques, a real-time risk warning model can be developed to identify potential risks with greater precision. This model is capable of pinpointing potential fault points and high-risk areas within the power system well in advance, thereby providing decision-makers with actionable insights to take timely and effective measures. As a result, the safety and reliability of the power system are significantly enhanced, and the risk management process is better aligned with the dynamic nature of technological advancements in the industry [6].

4.2.2. Artificial intelligence-assisted decision-making system

With technological innovation, the risk characteristics of power engineering have evolved, and traditional risk assessment methods are facing challenges. Artificial intelligence-assisted decision-making systems have emerged. This system can utilize deep reinforcement learning techniques to develop algorithms for generating risk response strategies. Deep reinforcement learning can learn optimal strategies through the interaction between intelligent agents and the environment, and is applied in the risk assessment of power engineering. It can dynamically generate response strategies based on different risk scenarios. Its advantage lies in its ability to handle complex risk relationships and a large number of uncertain factors, improving the accuracy of risk assessment and the scientificity of decision-making. For example, when facing the risk of power system failures, algorithms can quickly generate reasonable maintenance and recovery strategies based on real-time data and historical experience, providing strong guarantees for the stable operation of power engineering [7].

5. Implementation path of new paradigm of risk management

5.1. Organizational restructuring

5.1.1. Agile risk management organizational design

It is crucial to build a matrix-based risk management organizational model that adapts to rapid technological iteration in the field of power engineering driven by technological innovation [8]. This model should integrate personnel from different professional fields to form cross-functional teams to cope with complex and ever-changing risks. By clarifying the responsibilities and authorities of each team member, ensure the efficient operation of the risk management process. At the same time, establish a flexible communication mechanism to facilitate the rapid transmission of information between different levels and departments. This matrix organizational structure can fully utilize resources from all parties, improve the ability to identify and respond to risks, closely integrate risk management with technological development, and adapt to the constantly changing risk environment in the field of power engineering.

5.1.2. Cross-disciplinary collaborative governance mechanism

In the implementation path of the new paradigm of risk management, organizational restructuring and cross-disciplinary collaborative governance mechanisms are crucial. The organizational structure should adapt to the needs of multi-disciplinary integration in power engineering, break down traditional departmental barriers, and integrate relevant professional resources such as network security and power dispatch. By establishing a comprehensive coordination department or team, it is clear that each specialty should establish a risk prevention and control system that covers multiple specialties. Each profession needs to participate in the risk assessment, monitoring, and response process together to achieve risk information sharing. For example, the cybersecurity profession can provide timely information on network attack risks, and the power dispatch profession can adjust dispatch strategies accordingly to reduce the impact on the operation of the power system [9].

5.2. Technology integration application

5.2.1. Application of digital twin technology

The application of digital twin technology in the new paradigm of risk management is mainly reflected in the construction of a digital image of the power system to achieve risk simulation and deduction. By accurately digitizing the physical entities of the power engineering system, including equipment, lines, operating environments, and other aspects, a virtual digital twin is created that is highly consistent with the real system. By using this digital twin, various possible working conditions and risk scenarios can be simulated, such as equipment failures, natural disaster impacts, power load fluctuations, etc. Based on these simulations, it is possible to predict in advance the potential impacts of risks, including the extent of power supply disruptions, estimated repair times, and potential economic losses. At the same time, different risk response strategies can be tested in virtual environments to evaluate their effectiveness, providing a scientific basis and decision support for risk management in reality.

5.2.2. Blockchain certification technology

In the field of power engineering, developing a risk traceability management system based on distributed ledger technology is a key part of the technology integration application in the implementation path of the new paradigm of risk management. The blockchain certification technology provides strong support for it. This technology has the characteristics of immutability and traceability, and can accurately record data related to power engineering risks. By storing various risk information, such as equipment failure data and safety hazards during construction, on the blockchain, the authenticity and integrity of the data are ensured. This enables quick and accurate identification of the source of the problem during risk tracing, providing a reliable basis for risk assessment and decision-making. At the same time, the characteristics of distributed ledgers also ensure the security of data, preventing malicious tampering or loss of data, thereby effectively improving the efficiency and accuracy of risk management in power engineering.

5.3. Standardization system construction

5.3.1. Risk quantification assessment criteria

In the construction of a standardized system for risk management in the field of power engineering, risk quantification assessment standards are crucial. For the new power system, it is necessary to establish a scientific and reasonable risk level classification and evaluation index system. This requires comprehensive consideration of multiple aspects of the power system, such as the technical characteristics and potential risk factors of power generation, transmission, distribution, and other links. Equipment operation status, environmental impact, and personnel operation standards should all be included in the evaluation scope. By analyzing a large amount of historical data and actual cases, determine the weights and thresholds of each indicator in order to accurately measure the level of risk. At the same time, it is necessary to continuously update and improve the system to adapt to new risks and changes brought about by technological innovation, ensure the accuracy and effectiveness of risk assessment, and provide reliable guarantees for the stable operation of power engineering.

5.3.2. Framework for technical ethics standards

In the context of technological innovation in the field of power engineering, the construction of a standardized system for risk management and new paradigms requires a crucial framework of technical ethical norms. For the application of artificial intelligence algorithms in risk management, an ethical review system needs to be established. This system should cover the entire process of algorithm design, development, and application. In the design phase, it is important to ensure that the algorithm's goal setting complies with ethical principles and does not produce discriminatory results. During the development process, strictly monitor the use of data to avoid unfair or erroneous decisions caused by data abuse. During application, continuously evaluate the impact of algorithms on different stakeholders to safeguard their rights and interests. Through such an ethical review system, the application of artificial intelligence algorithms in risk management is standardized, promoting the healthy development of a new paradigm of risk management in the field of power engineering.

6. Conclusion

Under the background of technological innovation, the transformation of risk management paradigm in power engineering is of great significance. In terms of theoretical contribution, it provides new perspectives and methods for research in this field. In terms of practical value, it helps to enhance the ability of power engineering to cope with risks and ensure its safe and stable operation. In the future, ethical governance of intelligent technology and cross-border power network security will become key areas of concern. The ethical governance of intelligent technology is related to the rationality and sustainability of technology applications, while cross-border power network security involves the stability of cross-border power cooperation. It is necessary to establish a dynamic and evolving maturity model for risk management capabilities. This model can continuously adjust and optimize risk management strategies based on the development and risk changes of power engineering, thereby providing solid theoretical support for the safe and stable operation of new power systems.

Disclosure statement

The author declares no conflict of interest.

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