Research on Differentiated Grid Equipment Maintenance Strategy Considering Fault Consequences

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Abstract. The main substation equipment serves as the core hub of the power grid, and its reliability directly affects the safety of the power grid. The traditional periodic maintenance mode is likely to lead to "over-maintenance" or "under-maintenance", intensifying the pressure on equipment operation and maintenance. Aiming at the current situation of grid equipment maintenance, this paper proposes a differentiated maintenance strategy based on fault consequences. Firstly, it analyzes the existing problems in the current maintenance system, such as insufficient monitoring data, low data integration, limitations of the expert system, and the lack of reliability assessment standards. Then, it puts forward the implementation of differentiated maintenance through three stages: equipment fault consequence assessment, equipment status evaluation, and maintenance strategy formulation. Specifically, it includes constructing an equipment fault mode analysis model, determining the control level by combining health assessment and importance assessment, and formulating differentiated strategies covering condition monitoring, periodic maintenance, and corrective maintenance based on the principle of logic decision-making. This strategy effectively solves the problems of resource waste and reliability risks in the traditional maintenance mode by optimizing the maintenance cycle and project combination, and improves the lean management level of equipment. The application prospects show that this strategy can not only reduce operation and maintenance costs and improve equipment reliability, but also promote the management innovation of power grid enterprises and provide decision-making support for the construction of a modern equipment management system. The research results have important practical value for ensuring the safe and stable operation of the power grid and improving the economic benefits of enterprises.

Keywords: Grid Equipment; Maintenance Strategy; Differentiated Maintenance; Fault Consequences

1 Introduction

The main substation equipment is one of the most important power equipment in the power grid system. As a key power equipment playing a pivotal role, its reliability directly affects the safety of the power grid. With the continuous development of the grid framework, the capacity of the main equipment in the system is constantly in-

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creasing[1]. Equipment failures caused by potential safety hazards left in the stages of feasibility study and planning, production and manufacturing, installation and commissioning, operation and maintenance, etc., not only reduce the power transmission capacity of the power grid system, but may also lead to large-scale power outages in the power grid system, causing huge economic losses to power enterprises and society. Therefore, improving the reliability of the main equipment during operation is of great significance for the safety of the power grid. A piece of main equipment goes through stages such as feasibility study and planning, production and manufacturing, installation and commissioning, operation and maintenance, and decommissioning, among which the operation and maintenance stage is the most crucial. Among them, how to improve the level of differentiated maintenance of the main equipment and enhance equipment reliability is the top priority in equipment management work[2].

For a long time, the equipment maintenance of power enterprises has mainly adopted the periodic maintenance mode, which is likely to cause "over-maintenance" or "under-maintenance". The periodic maintenance mode occupies a large amount of human and material resources, resulting in great waste. More importantly, periodic maintenance will reduce the operation reliability of the main equipment. For example, the power outage maintenance of the main transformer is more frequent and takes a long time. In addition, new equipment defects may be formed during the maintenance process, reducing the operation reliability of the equipment[3]. With the continuous improvement of the power system, the increasingly strict supervision of power costs, the increasingly prominent risk of the equipment asset wall, the uneven quality of new and old equipment, and the prominent contradiction between the maintenance workload and the bearing capacity of maintenance personnel, the pressure on equipment operation and maintenance continues to increase. It is necessary to coordinate safety and development, comprehensively consider factors such as the importance of equipment, health status, risk level, and maintenance cost, conduct a structural evaluation of the fault consequences according to the operation status and test data of the main substation equipment, scientifically predict the fault types, establish a predictable maintenance mode, and propose differentiated maintenance strategies for different fault types to improve the efficiency and effectiveness of operation and maintenance on the premise of ensuring safety and reliability.

2 Current Situation, Problems and Future Trends of Grid Equipment Maintenance

2.1 Main Modes of Electrical Equipment Maintenance

By analyzing the development stages of the electrical equipment maintenance system, it can be known that the maintenance strategies of electrical equipment have gone through three stages: breakdown maintenance/post-fault maintenance, periodic maintenance, and condition-based maintenance. Breakdown maintenance/post-fault maintenance is to locate the fault location and fault components by analyzing the fault situation after the grid equipment fails, and then maintain, repair or replace the faulty

equipment. Its characteristic is that the maintenance is carried out only after the equipment failure occurs, which belongs to passive maintenance. Periodic maintenance, also known as planned maintenance, is to carry out maintenance on the equipment at a certain maintenance cycle according to the development law of the equipment failure rate summarized from operation experience, and it belongs to the category of preventive maintenance. The characteristic of periodic maintenance is that its maintenance cycle is based on time, and so far, it still occupies a dominant position in China's power system. Condition-based maintenance is a maintenance strategy that arranges maintenance when there is a possibility of equipment failure according to the information fed back by the equipment operation status monitoring system[4]. Condition-based maintenance is a decision-making process that integrates various status quantity information, and it depends on the development of modern sensing technology and online monitoring technology. It is an active predictive maintenance mode[5].

2.2 Current Situation and Problems of Grid Equipment Maintenance

Since 2008, power grid companies have been promoting the condition-based maintenance of grid equipment and have established a relatively complete standard system covering transmission and transformation equipment at and below 750 kV. By dynamically and periodically evaluating the equipment status and formulating maintenance strategies, the pertinence and purpose of equipment maintenance have been effectively improved, and the lean management level of equipment maintenance has been enhanced. However, there are still some outstanding problems to be solved urgently in the current condition-based maintenance work of the company, especially there is still a certain degree of inadaptability compared with the new situation and new requirements. Specifically, it includes: insufficient evaluation of equipment fault consequences, failure to comprehensively analyze and evaluate the equipment fault consequences; insufficient differentiated analysis, weak pertinence of maintenance standards and strategies, and the existence of over-maintenance and under-maintenance of equipment.

2.3 Challenges Faced by the Implementation of Differentiated Maintenance of Grid Equipment

First, there is insufficient status monitoring data of key equipment. Currently, the online monitoring systems for the operation status of key power equipment such as transmission lines and towers still have problems such as few monitoring points, single function, lack of systematicness and comprehensiveness, especially the lack of hierarchical and networked monitoring, which hinders the concentration and integration of equipment status information. At the same time, limited by business barriers and network access, it cannot support the large-scale application of reliability-centered maintenance technology. Specifically, it includes the following four points: ① The breadth and depth of power equipment collection points are insufficient, making it difficult to support the demand for massive data acquisition; ② The data collection frequency is not high enough, and the data volume cannot effectively reflect the real

status changes of the equipment; ③ The ubiquitous and real-time nature of the connection needs to be improved, making it difficult to support the synchronous concurrent transmission of massive data; ④ The edge computing function is lacking, unable to meet the business requirements of on-site processing and intelligent analysis.

Second, there is insufficient data integration and application. Although the informatization construction of equipment management is constantly advancing, problems such as information silos, insufficient mining of data value, insufficient informatization support means for front-line teams, and low efficiency still exist. It is urgent to strengthen the unified planning of information system construction, improve data sharing and analysis capabilities, and support the full online operation of grassroots businesses. There are both management reasons and relevant technical reasons. For example, the information on the whole life cycle of equipment in various professional platforms, including ECP, ERP, and PMS, has not yet formed a unified data standard and achieved interconnection. The traceability of equipment quality problems has not been realized, the data among various professional fields cannot be effectively integrated, and the application and development of data are still insufficient.

Third, there is a lack of knowledge in the expert system. The existing expert systems at home and abroad are still unable to automatically diagnose the faults of some key power equipment and still rely on experienced experts and on-site operation and maintenance personnel for judgment. Although the "Guidelines for the Condition Evaluation of Transmission and Transformation Equipment" has been issued to guide equipment condition monitoring and operation and maintenance, limited by differentiated conditions such as the geographical environment and operation conditions, the application of the reliability criteria of such equipment still has limitations in engineering practice, which also restricts the promotion and application of reliability-centered differentiated maintenance.

Fourth, there is a lack of reliability assessment standards for the transmission network and power generation system. Differentiated maintenance focuses on the impact of equipment failures on the system reliability. Therefore, it is particularly important to accurately assess the system reliability. Although relatively mature reliability assessment theories and methods for power generation systems, transmission networks, and distribution networks have been formed at home and abroad, currently in China, only the relevant regulatory standards for the reliability assessment of medium-voltage distribution networks have been issued, and there is a lack of guiding reliability assessment standards for transmission networks and power generation systems, which restricts the application of differentiated maintenance considering fault consequences in the maintenance of transmission network and power generation system equipment.

3 Implementation Steps of Differentiated Grid Equipment Maintenance Strategy Considering Fault Consequences

3.1 Conduct Equipment Fault Consequence Assessment

By comprehensively considering factors such as the importance of equipment classification and grading and the risk level, fully combining with the equipment operation historical data, analyzing the equipment fault modes, conducting a structural evaluation of the equipment fault consequences, and combining scientific and reasonable evaluation methods, formulate equipment fault judgment standards and clearly and effectively divide the fault types. Specific methods include: Professional technicians conduct analysis on the fault modes and fault impacts of specific equipment models, scientifically select the types of maintenance tasks (condition monitoring, periodic maintenance, corrective maintenance), determine the benchmark maintenance items, cycles, and requirements, etc.; according to the characteristics of the equipment itself, focus on analyzing the possible impacts on the equipment itself when the fault mode occurs, such as the assessment of routine fault status and sudden fault status.

3.2 Conduct Equipment Status Evaluation

First, conduct equipment health assessment. Comprehensively consider multi-dimensional operation information such as real-time video monitoring, online monitoring and live-line detection, and equipment fault risks, comprehensively and accurately assess the equipment health status, and divide the equipment health degree into four levels, such as normal, attention-needed, abnormal, and serious. Second, conduct equipment importance assessment. Evaluate aspects such as the value of the equipment itself and the impact on the power supply of important users, which respectively reflect risks, costs, and effectiveness. Take the highest level as the importance level of the equipment, and the equipment importance can be divided into four levels: "critical, important, concerned, and general". Third, clarify the equipment control level. According to the evaluation results of equipment health degree and importance, determine the equipment control level according to the equipment risk matrix.

3.3 Formulate Differentiated Equipment Maintenance Strategies

Determine which maintenance items are needed to control each fault mode and fault impact. Determine the maintenance items based on the equipment fault modes to ensure the integrity and necessity of the maintenance items.

First, conduct maintenance strategy decision-making logic analysis. Fully based on the reliability indicators of equipment and its components, importance, fault modes, and risk levels, for different situations corresponding to different fault types, fully combine with the maintenance logic decision-making principle centered on reliability. Through methods such as historical defect statistics and analysis, and modeling analysis, analyze the failure modes and failure times of equipment components, scientifically assess the cycle (probability) of component failures, and determine the mainte-

nance item cycle. For example, design the decision-making logic for the concealment, monitorability, and whether it is a key failure mode of the failure mode. Through the judgment logic, it is possible to analyze the maintenance types corresponding to the failure modes, such as condition-based maintenance, periodic maintenance, breakdown maintenance, and technical transformation, and give the recommended maintenance interval cycle.

Second, study the method of formulating maintenance strategies based on logic decision-making, and comprehensively consider safety, economy, and maintainability, and propose differentiated maintenance strategies for different fault types. Formulate maintenance strategies under different control levels, and clarify the specific operation and maintenance strategies, maintenance strategies, spare parts strategies, and technical transformation strategies for each piece of equipment.

4 Analysis of the Application Prospects of the Differentiated Grid Equipment Maintenance Strategy

The differentiated maintenance strategy considering fault consequences can provide strong support for establishing and improving the condition-based maintenance system centered on reliability and improving the quality and efficiency of equipment management, and provide decision-making support for the continuous improvement of equipment management in power grid enterprises, bringing multiple benefits to the development of the power grid.

4.1 Direct Application Value of Differentiated Grid Equipment Maintenance

First, conduct research on the evaluation technology of the fault consequences of the main substation equipment to support the establishment and improvement of the whole process quality management of equipment. By comprehensively considering factors such as the importance of equipment classification and grading and the risk level, combining with the equipment operation historical data, analyzing the equipment fault modes, formulating equipment fault judgment standards, and clearly and effectively dividing the fault types.

Second, formulate differentiated maintenance strategies to effectively guide on-site equipment maintenance and promote the improvement of the lean management level of equipment. Based on the reliability indicators of equipment and its components, importance, fault modes, and risk levels, for different situations corresponding to different fault types, study the method of formulating maintenance strategies based on logic decision-making, and comprehensively consider safety, economy, and maintainability, and propose differentiated maintenance strategies for different fault types to effectively solve the problems of over-maintenance and under-maintenance of equipment and continuously improve the lean management level of equipment.

Third, conduct application research on the differentiated equipment maintenance strategy to continuously promote the implementation of the strategy. Based on the

differentiated equipment maintenance strategy, select a certain type of main substation equipment, conduct application research on the differentiated equipment maintenance strategy, continuously improve the feasibility of the differentiated maintenance strategy, and promote its implementation.

4.2 Comprehensive Application Value of Differentiated Grid Equipment Maintenance

First, it is beneficial to improve the soft power of the company. By constructing the evaluation of the fault consequences of the main substation equipment and studying and formulating targeted differentiated maintenance strategies, it can dynamically adapt to the strategic requirements of the power grid company, improve equipment operation efficiency, be beneficial to improving the lean management level of equipment, enhance the reliability of grid equipment, improve the public's satisfaction with grid services, and establish the social image of the company optimizing the equipment management mode and improving the equipment management benefits.

Second, it provides a direction guide for equipment management practice. By formulating differentiated maintenance strategies considering equipment fault consequences and conducting application research, it is beneficial to guide each unit to continuously improve and optimize the on-site maintenance work process, beneficial to promoting the equipment management of power grid companies to keep pace with the times and innovate, seize the important opportunity period for innovation and efficiency improvement, and provide support for the optimization of the modern equipment management system of power grid companies.

5 Conclusion

The reliability of the main substation equipment is of great significance for the safety of the power grid. The disadvantages of the traditional periodic maintenance mode are becoming more and more prominent, and it is imperative to implement the differentiated maintenance strategy. Although there has been progress in the current condition-based maintenance of grid equipment, there are still problems such as insufficient evaluation of fault consequences and lack of differentiated analysis, and it also faces many challenges in terms of monitoring data, data integration, expert systems, and reliability assessment standards. The differentiated maintenance strategy considering fault consequences is implemented through conducting equipment fault consequence assessment, equipment status evaluation, and formulating differentiated maintenance strategies. This strategy can effectively solve the problems of over-maintenance and under-maintenance of equipment, improve the lean management level of equipment, and enhance the efficiency and effectiveness of operation and maintenance.

From the perspective of application prospects, it has direct application value, which can support the whole process quality management of equipment, guide on-site maintenance, and promote the implementation of the strategy; it also has comprehensive application value, which can improve the soft power of the company, establish a

good social image, and provide a direction guide for equipment management practice, promoting the innovation and development of equipment management in power grid companies, and having far-reaching significance for constructing a modern equipment management system and ensuring the safe and stable operation of the power grid.

References

1. Guo, J. Application of State Repair in Substation Equipment Management[J]. Electrical Engineering, 2012, (10):43-47.
2. Yu, ZZ. Research on Substation Equipment Temperature Monitoring Technology[J]. Applied Mechanics and Materials, 2014, (51):602-605.
3. Wang ZM. The Application of State Overhaul in Power System Plant Based on IOT[J]. Applied Mechanics and Materials, 2013, (389):1069-1074.
4. Rausand, M. Reliability Centered Maintenance[J]. Reliability Engineering &System Safety. 2008, 60(2):121-132.
5. Mokashi, A. J., Wang, J., Vermar, A. K. A study of reliability-centred maintenance in maritime operations[J]. Marine Policy, 2002,26(5): 325-335.

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