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Strategy and Practice of Power System Relay Protection under Extreme Weather Conditions

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Abstract: With the continuous expansion and increasing complexity of the power system, the protection requirements for the power system are also increasing. Although traditional relay protection systems can play a certain protective role, they have some limitations, such as the inability to comprehensively monitor the power system and the lack of accurate judgment. Developing and applying intelligent relay protection systems has become an important way to improve the safety and reliability of power systems. This article explored the relay protection strategies and practices for power systems under extreme weather conditions. Traditional relay protection systems have limitations in addressing the increasingly complex protection needs of power systems. Therefore, the development and application of intelligent relay protection systems have become a key way to improve the safety and reliability of power systems. This article verified the effectiveness of the knowledge base based relay protection fault handling process in improving the safety, stability, and fault handling efficiency of power systems through experimental results and discussions. The experimental results showed that under different fault conditions, the processing accuracy was generally high, and in the vast majority of cases, the accuracy exceeded 90%. For example, the accuracy of handling line short circuits and voltage anomalies was 95% and 96%, respectively.

1. Introduction

With the continuous expansion of the power system scale and the growth of electricity demand, the safety and reliability of the power system are increasingly valued. However, the power system faces many challenges under extreme weather conditions, such as storms, ice and snow disasters, high temperatures, etc. These extreme weather events may cause damage to power system equipment, line interruptions, and even system crashes, posing a huge threat to power supply reliability. The traditional power system relay protection system can provide protection for the power system to a certain extent, but it has many limitations, such as insufficient comprehensive monitoring ability for complex systems and weak accurate judgment ability. Therefore, the development and application of intelligent relay protection systems have become an important way to improve the safety and reliability of power systems.

This article aims to explore the relay protection strategies and practices in power systems under extreme weather conditions. Firstly, the introduction section introduces the extreme weather challenges faced by the power system and the limitations of traditional relay protection systems. Subsequently, in the relevant work section, a review of existing research results is conducted, and the latest strategies and practical experience for the protection of special power systems are discussed. Subsequently, the methods section provides a detailed introduction to the existing problems in the safety management of power relay protection, efficient and accurate fault detection methods, and a knowledge-based relay protection fault handling process. The effectiveness of the knowledge-based relay protection fault handling process in improving the safety and reliability of the power system is verified through experimental data in the results and discussion section. Finally, the conclusion section summarizes the main findings of the article and looks forward to the future development direction of relay protection technology in power systems.

2. Related Works

Experts have long conducted specialized research on relay protection strategies in power systems. Faazila Fathima S explored the technical prospects and challenges of microgrid protection strategies. Due to the particularity of DC (direct current) systems, traditional protection technologies cannot be directly applied. Therefore, more attention is needed. To address this challenge, Faazila Fathima S pointed out the emergence of innovative microgrid adaptive protection strategies, utilizing communication infrastructure to make the system more intelligent [1]. Traditional protection systems are not suitable for bidirectional power flow and multi-source systems. It is necessary to design protection schemes suitable for microgrids, including protection in grid connected and island mode. Alhadrawi Z summarized the challenges, effective strategies, and basic operating principles, and proposed future recommendations [2]. Hojjaty M proposed an intelligent protection scheme based on point-to-point communication of multi-agent systems, which solved the communication failures and network attacks faced by traditional protection systems. The simulation results showed that in active distribution networks, this scheme can effectively modify the working time of relays and achieve coordination between main protection and backup protection [3]. Wang Q proposed a relay protection method based on multi-level differential defense type distribution network feeder switch, which determined the position of feeder switch through greedy algorithm to improve energy utilization efficiency. The empirical results indicated that this method is effective in terms of safety, cost savings, fault diagnosis, and energy consumption, with a safety factor of 97% [4]. Yousaf M proposed a protection coordination strategy design based on dual-setting directional recloser (DSDR) to improve the reliability of distributed power generation devices in distribution networks (DNs). The verification results indicated that this strategy effectively reduced the number of interruptions for users and improved network reliability [5].

Wei X explored the relay protection issues of large-scale wind power integration into the global power grid, and analyzed the short-circuit current of wind turbines and the characteristics of collector line faults. He discussed the adaptability of high-voltage direct current protection and proposed suggestions for strengthening research on wind turbine fault characteristics, electromagnetic transient modeling, and new network protection principles [6]. Li F believed that in China, the research on relay protection models for dynamic simulation of power systems is still in its early stages, and there is insufficient understanding of the control laws of relay protection components, which affects the system's fault handling ability. Strengthening the power grid structure, improving the elasticity coefficient and reserve capacity allocation, and enhancing the regulation capacity of the main power grid connection lines are key to ensuring the safe operation of the power system [7]. Yuming H used particle swarm optimization and support vector machine algorithm to solve the problem of missing monitoring of substation relay protection equipment, improving operation and maintenance efficiency. Through comparison, it was found that the combination model can more accurately predict faults, and simulation results showed that the prediction accuracy for the three types of equipment reached at least 91% [8]. Andreev M conducted a detailed study on the processes of power systems and relay protection in different modes. He used real models, such as HRTSim software, combined with detailed mathematical models of relay protection, to effectively study the role of relay protection in integrated renewable energy power systems [9].

El-Sayed L M A proposed a power swing detection scheme for distance relays, which identified symmetric/asymmetric faults by estimating the rate of change of elliptical perimeter. This scheme can detect high impedance faults during single/multimode power swing and also has detection capability in asymmetric power swing. His test results on a dual zone four machine power system and a standard three machine nine bus system confirmed its effectiveness under conditions of power swing faults [10]. Reda A explored the optimization of overcurrent relay operation related to the coordination of distribution network protection. He combined theory with practice, observed optimization functions, constraint conditions, and relay parameters, proposed modification and improvement suggestions, and compared and elaborated on practical solutions [11]. Yang Z explored the relationship between apparent reactance and the positive sequence current angle of CIRES through sequence boundary conditions, and achieved a reasonable current angle by adjusting the current reference value of the controller to ensure that the distance relay correctly detects fault distance. Simulation analysis has verified the effectiveness of this scheme [12]. Zhiren L proposed a new protection strategy suitable for weak incoming distribution networks by separating differential permission signals and startup logic, which shortened the protection action time. He established a comprehensive synchronization scheme to improve the reliability of data synchronization. The effectiveness of this method was verified through real-time digital simulation [13].

Ataee-Kachoee A H optimized protection schemes for smart grids and microgrids, with particular attention to the performance of protection systems under different operating modes. He demonstrated significant advantages in reducing the protection scheme time by 31.78% and 21.62% respectively compared to existing methods in IEEE 38 bus and IEEE 14 bus testing systems [14]. Rostami A proposed a new method that combined direct indicators and AND logic of Z-relays to reliably detect mixed events and avoid false tripping during stable power swing. He verified the reliability of the scheme through simulation research [15]. The current bottlenecks in relay protection research are mainly reflected in the following aspects: the unique protection challenges in microgrids and smart grids have not been fully addressed, including bidirectional power flow, multi-source systems, and network communication issues; traditional protection technologies have limited applicability to DC systems and require more targeted innovative protection strategies; there are deficiencies in the dynamic simulation model and protection algorithm, which leads to insufficient understanding of the control laws of relay protection components and affects the system's fault handling ability; the monitoring and fault prediction technology for relay protection equipment has not yet reached the ideal level, and there are deficiencies and errors; there are still unresolved issues regarding the adaptability and protection performance of the new power system operation mode. Therefore, further in-depth exploration is needed in current research on relay protection to meet the rapid development and complexity needs of the power system.

3. Methods

3.1 Problems in Safety Management of Power Relay Protection Relay Protection System

(1) Equipment aging issues

As the service life of the equipment increases, its internal electronic components, mechanical parts, etc., can experience aging, wear, and other phenomena, causing a decrease in sensitivity, misoperation, or refusal to operate, thereby affecting its safe and stable operation. During use, relays are prone to aging due to long-term use and exposure to moisture, oxygen, and other factors. In addition, the design, manufacturing process, use, and maintenance methods of the relay itself have an impact on its failure rate. The aging of protective devices makes the protective actions insensitive or even ineffective, thereby affecting the safe operation of the power grid. For example, when a device malfunctions, due to slow aging protection action or failure to timely cut off the fault current, the protection fails to operate, causing the accident to expand [16].

(2) Issues with the device itself

Its main manifestations include button failure, plug-in damage, and abnormal display of the display screen. The main reasons for the above problems are: poor contact of the mechanical device after working for a period of time, damage to the wiring inside the device, and failure of the buttons. In addition, some equipment still has design and processing defects, gradually becoming apparent during service, such as inability to correctly identify faults, insensitivity to operation, etc., which may lead to relay protection misoperation or even failure, threatening the stability and safety of the power grid [17].

3.2 Efficient and Accurate Fault Detection

The efficient and accurate fault detection of relay protection systems is based on their ability to monitor and analyze the system in real-time. The relay protection system can detect faults in a timely manner by monitoring changes in parameters such as current and voltage, and comparing them with preset fault criteria. Relay protection systems provide better detection accuracy and agility than typical manual inspections or inspections, and they may discover problem locations fast and precisely, increasing the reliability of the entire power system. The relay protection system uses cutting-edge sensors and data acquisition technology to achieve precise and effective fault detection. These components can gather real-time data, such as the voltage and current of different power system nodes, and send it to a central processing unit for analysis. Relay protection systems can create fault models and increase the precision of fault detection by statistically analyzing past data. Furthermore, to accomplish higher-level fault detection and analysis, the relay protection system can be networked with other intelligent devices and systems [18-19].

3.3 Fault Handling Process for Relay Protection Based on Knowledge Base

In addition to the data-driven relay protection fault handling process, this article also provides a knowledge base based relay protection fault handling process. The process is shown in Figure 1.

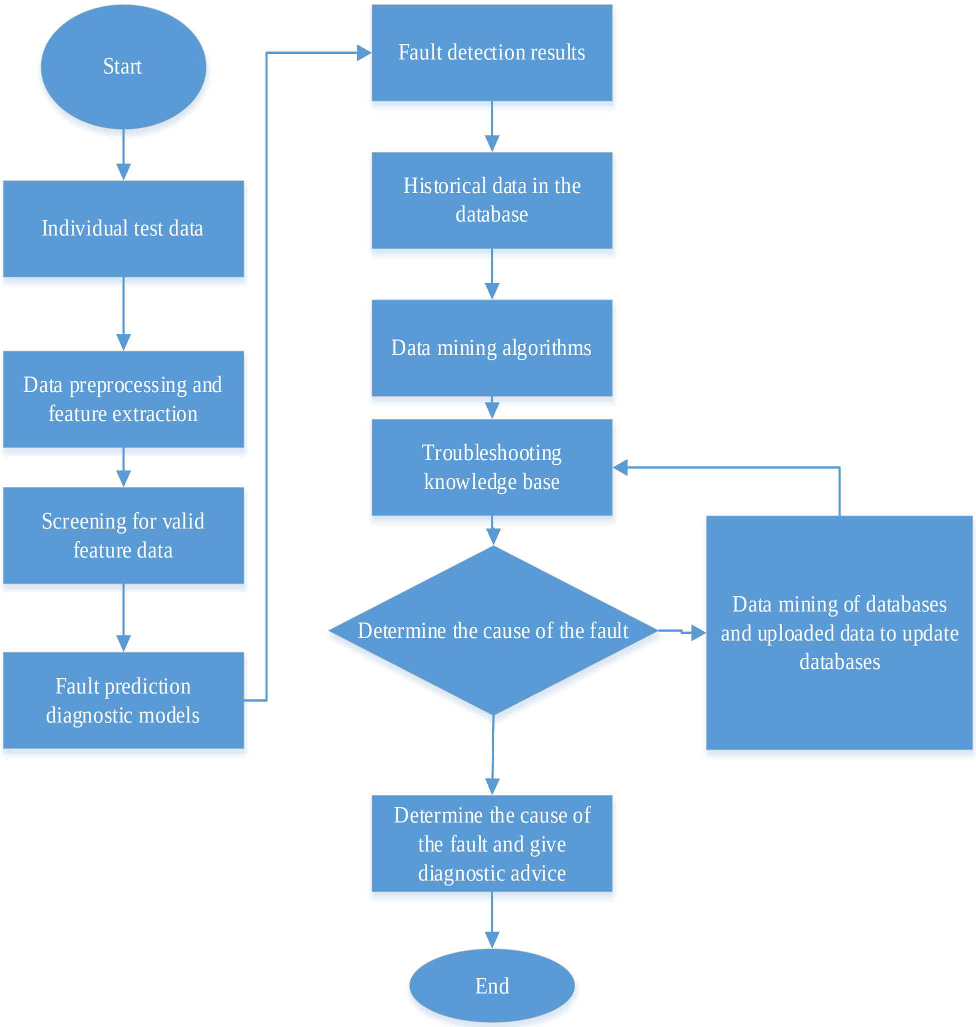

Figure 1: Fault handling process for relay protection based on knowledge base

Firstly, a knowledge base based relay protection fault handling process that includes information such as power system topology, equipment parameters, fault characteristics, and handling methods is established. These pieces of information can be collected and organized through expert knowledge and historical data. The knowledge base should include various types of faults and corresponding processing methods, as well as the possible causes and impacts of faults. At the beginning of the process, it is not only necessary to obtain various detection data in the power system, but also to process the original data through methods such as noise removal, data smoothing, and data sampling to make it more reliable and effective. By using feature extraction techniques, feature information related to faults is extracted from a large amount of data, such as abnormal fluctuations in current and abnormal deviations in voltage.

The knowledge base for relay protection fault diagnosis is the core part of the process, which contains a large amount of expert knowledge, experience, and rules. This knowledge base analyzes and summarizes historical and experimental data, and organizes the characteristics, causes, and treatment plans of various faults. When inputting the fault monitoring results into the knowledge base, possible causes of faults can be obtained through matching and inference based on pre-defined rules and matching algorithms in the knowledge base.

4. Results and Discussion

4.1 Experimental Preparation

During the implementation of the experiment, a simulated power system topology is used, and various types of faults and corresponding handling methods are set according to the experimental design. Before the experiment begins, the normal operation of the experimental equipment is ensured, and necessary calibration and inspection are carried out to ensure the accuracy and reliability of the experimental data.

4.2 Experimental Results

Table 1: Different experimental situations and handling methods

Experiment No.	Fault Type	Fault Location	Failure Level	Handling Method	Result
1	Line Short Circuit	Node A	High	Disconnect The Power Supply	Success
2	Overload	Node B	Medium	Adjust Current Limit	Success
3	Ground Fault	Node C	Low	Troubleshoot Ground Faults	Success
4	Abnormal Voltage	Node D	Medium	Adjust Voltage Stabiliser	Success

As can be seen in Table 1, for different fault types at different fault locations, the experiments are conducted with appropriate treatments, which are successful in the end, indicating the potential of the process in improving the security and stability of the power system.

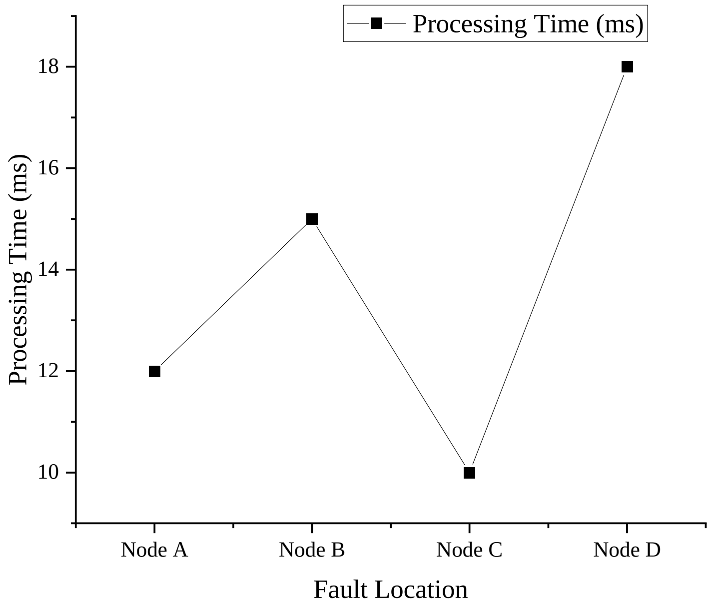

Figure 2: Processing speed

The processing speed of Figure 2 is one of the important indicators for evaluating the efficiency of the knowledge base-based relay protection fault handling process. From the experimental data table, it can be seen that the processing time varies slightly under different fault conditions, but overall it is within an acceptable range. For example, the processing time for line short circuits and ground faults is relatively short, at 12 milliseconds and 10 milliseconds, respectively, while the processing time for overload and voltage anomalies is slightly longer, at 15 milliseconds and 18 milliseconds, respectively. This indicates that the knowledge base-based relay protection fault handling process has a certain efficiency in processing speed and can respond to different types of faults in a timely manner.

Table 2: Accuracy of fault handling

Experiment No.	Fault Type	Fault Location	Processing Accuracy (%)
1	Line short circuit	Node A	95
2	Overload	Node B	90
3	Ground fault	Node C	92
4	Abnormal voltage	Node D	96

As can be seen from the data in Table 2, all fault types (line short circuit, overload, ground fault and abnormal voltage) are also handled with at least 90% accuracy. This indicates that the knowledge base-based relay protection fault handling process shows high accuracy in identifying and handling faults and can effectively improve the efficiency of fault handling.

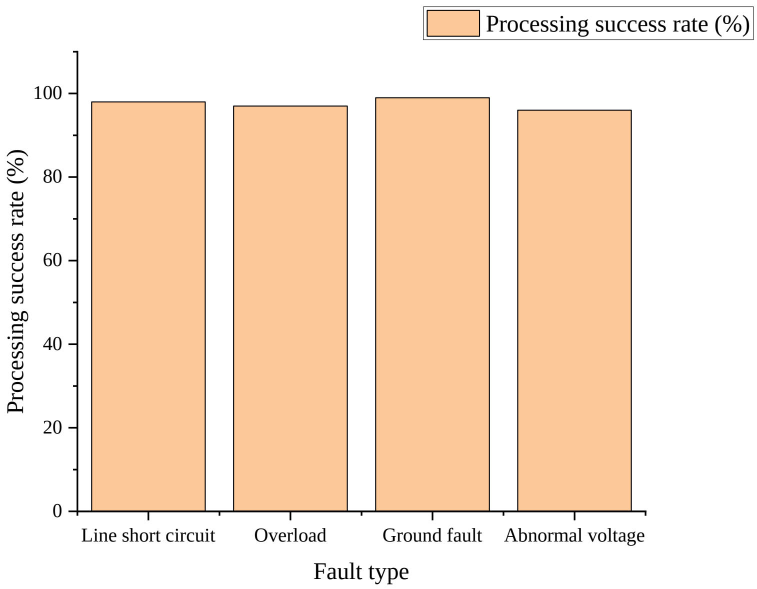

Figure 3: Success rates of handling different faults

From the data in Figure 3, it can be seen that the success rate of processing the impassable faults is likewise almost close to 100 per cent. This indicates that the knowledge base-based relay protection fault handling process has high reliability in practical application and can effectively cope with various fault situations in the power system.

5. Conclusions

Relay protection setting is a key link in ensuring the safe operation of the power grid. The conventional relay protection setting has been widely used in relay protection. However, with the increase of power grid scale and power grid scale, the conventional relay protection setting method can no longer meet the safety requirements of the power grid. Therefore, while ensuring the safety and stability of the power grid, it is necessary to further optimize and improve the relay protection setting method. In this context, this article aims to explore the relay protection strategies and practices of power systems under extreme weather conditions. Through literature review, existing research results are reviewed, and the limitations of traditional relay protection systems are analyzed. The latest strategies and practical experience for power system protection under extreme weather conditions are summarized. At the same time, the fault handling process of relay protection based on knowledge base is discussed, and its effectiveness in improving the safety and reliability of power systems is evaluated through experimental results.

References

[1] Faazila Fathima S, Premalatha L. Protection strategies for ac and dc microgrid–A review of protection methods adopted in recent decade[J]. IETE Journal of Research, 2023, 69(9): 6573-6589.

[2] Alhadrawi Z, Abdullah M N, Mokhlis H. Review of microgrid protection strategies: current status and future prospects [J]. TELKOMNIKA (Telecommunication Computing Electronics and Control), 2022, 20(1): 173-184.

[3] Hojjaty M, Fani B, Sadeghkhani I. Intelligent protection coordination restoration strategy for active distribution networks [J]. IET Generation, Transmission & Distribution, 2022, 16(3): 397-413.

[4] Wang Q. Feeder segment switch-based relay protection for a multilayer differential defense-oriented distribution network [J]. Soft Computing, 2022, 26(10): 4895-4904.

[5] Yousaf M, Jalilian A, Muttaqi K M, et al. An adaptive overcurrent protection scheme for dual-setting directional recloser and fuse coordination in unbalanced distribution networks with distributed generation[J]. IEEE Transactions on Industry Applications, 2022, 58(2): 1831-1842.

[6] Wei X, Yang J. Progress in research on relay protection of the power system with large-scale wind power access[J]. Journal of Electrotechnology, Electrical Engineering and Management, 2023, 6(3): 26-29.

[7] Li F, Zhuyuan L. A summary of relay protection-based simulation for Dynamic Performance and Reliability Assessment [J]. International Journal for Applied Information Management, 2023, 3(1): 11-23.

[8] Yuming H, Jiaohong L, Zhenguo M, et al. On combined PSO-SVM models in fault prediction of relay protection equipment [J]. Circuits, Systems, and Signal Processing, 2023, 42(2): 875-891.

[9] Andreev M, Bay Y, Malyuta B. Novel method for setting up the relay protection of power systems containing renewable energy sources and hydrogen energy storage systems[J]. International Journal of Hydrogen Energy, 2023, 48(76): 29425-29445.

[10] El-Sayed L M A, Ibrahim D K, Gilany M I. Enhancing distance relay performance using wide-area protection for detecting symmetrical/unsymmetrical faults during power swings[J]. Alexandria Engineering Journal, 2022, 61(9): 6869-6886.

[11] Reda A, Abdelgawad A F, Ibrahim M. Effect of non standard characteristics of overcurrent relay on protection coordination and maximizing overcurrent protection level in distribution network[J]. Alexandria Engineering Journal, 2022, 61(9): 6851-6867.

[12] Yang Z, Liao W, Zhang Q, et al. Fault coordination control for converter-interfaced sources compatible with distance protection during asymmetrical faults[J]. IEEE Transactions on Industrial Electronics, 2022, 70(7): 6941-6952.

[13] Zhiren L, Weilin T, Mingjun X, et al. Differential protection strategy for distribution network based on 5G communication[J]. IET Generation, Transmission & Distribution, 2023, 17(9): 2028-2037.

[14] Ataee-Kachoee A H, Hashemi-Dezaki H, Ketabi A. Optimal adaptive protection of smart grids using high-set relays and smart selection of relay tripping characteristics considering different network configurations and operation modes [J]. IET Generation, Transmission & Distribution, 2022, 16(24): 5084-5116.

[15] Rostami A, Rezaei N. A reliable and straightforward index to avoid nuisance trip of the conventional Z-based loss-of-field relay in synchronous generators[J]. IET Generation, Transmission & Distribution, 2022, 16(6): 1201-1211.

[16] Bakkar M, Bogarra S, Córcoles F, et al. Multi-layer smart fault protection for secure smart grids[J]. IEEE Transactions on Smart Grid, 2022, 14(4): 3125-3135.

[17] Tiwari R, Singh R K, Choudhary N K. Coordination of dual setting overcurrent relays in microgrid with optimally determined relay characteristics for dual operating modes[J]. Protection and Control of Modern Power Systems, 2022, 7(1): 1-18.

[18] Wang Z, Mu L, Fang C. Renewable microgrid protection strategy coordinating with current-based fault control[J]. Journal of Modern Power Systems and Clean Energy, 2022, 10(6): 1679-1689.

[19] Yousefi kia M, Saniei M, Seifossadat S G. A novel cyber-attack modelling and detection in overcurrent protection relays based on wavelet signature analysis[J]. IET Generation, Transmission & Distribution, 2023, 17(7): 1585-1600.