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Research on intelligent algorithm-based power system fault prediction and diagnosis technology

Yanhao Li, Xiaorong Sun, Luyao Tong, Bo Peng, Jinpeng Li

School of Computer and Artificial Intelligence, Beijing Technology and Business University, Beijing, 100048, China

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Abstract: Fault prediction and diagnosis technology in the power system is an important application field of intelligent algorithms. Intelligent algorithms play a key role in fault prediction and diagnosis technology in the power system, aiming to improve the accuracy and efficiency of fault detection. This article reviews the current development status of intelligent algorithms in fault prediction and diagnosis technology in the power system, summarizes several problems and corresponding countermeasures of several commonly used intelligent algorithms in fault diagnosis applications. Finally, the development trend of intelligent algorithms is discussed: by focusing on data quality and integrating multi-source data, optimizing the selection and parameter tuning of algorithms and models, as well as combining multiple algorithms and models, the effectiveness and accuracy of fault prediction and diagnosis in the power system can be improved, enhancing the stability and reliability of the power system.

1. Introduction

As the scale and complexity of the power system continue to increase, the importance of fault prediction and diagnosis technology in the field of power is becoming increasingly prominent. Traditional empirical and rule-based fault prediction methods can no longer meet the demand for the safe and stable operation of the power system, thus there is an urgent need for in-depth research and application of intelligent algorithm-based fault prediction and diagnosis technology in the power system. In recent years, with the rapid development of artificial intelligence, machine learning, and data mining, intelligent algorithm-based fault prediction and diagnosis technology has gradually become a research hotspot. By utilizing big data analysis and intelligent algorithm technology, potential faults in the power system can be predicted and diagnosed more accurately and efficiently, thus improving the reliability and safety of the power system. This paper aims to review the research progress of intelligent algorithm-based fault prediction and diagnosis technology in the power system. Through literature review analysis, it explores the application of different intelligent algorithms in fault prediction and diagnosis in the power system, evaluates their advantages and disadvantages, and proposes targeted improvement and optimization plans. At the same time, this paper will highlight the application of cutting-edge technologies such as deep learning, neural networks, and pattern recognition, and discuss their marginal contributions to fault prediction and diagnosis in the power system based on practical situations. Through this research, it is expected to provide strong theoretical support and technical guidance for the further development of fault prediction and diagnosis technology in the power system, promote the application and popularization of intelligent algorithms in the safe operation of the power system, and make contributions to the development and stability of the power industry.

2. The current development status of domestic and international research

Power system fault prediction is aimed at detecting potential fault states in advance and taking appropriate measures to avoid or minimize the impact of faults on power system operation. As shown in Figure 1, here are several common methods for power system fault prediction.

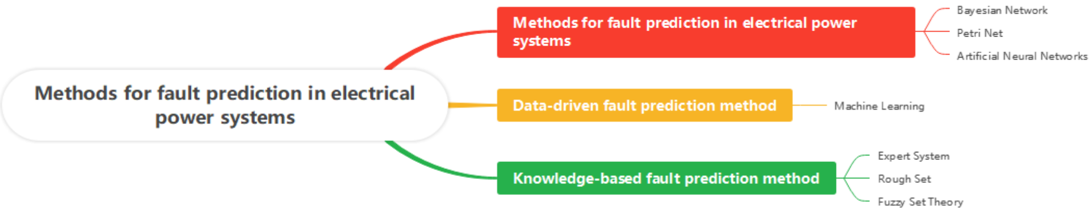

Figure 1: Several common methods for predicting power system faults

2.1 Fault Diagnosis of Power Systems Based on Expert Systems

The Expert System (ES) is an artificial intelligence computer program that applies a large amount of expert knowledge and reasoning methods to solve complex problems in specific domains. Currently, the expert system has been maturely applied to the prediction and diagnosis of faults in the power system. Its typical application is to represent the action logic of protection and circuit breakers, as well as the diagnostic experience of personnel, in the form of rules. Thus, it forms an expert system fault diagnosis knowledge base and, through forward reasoning, compares the obtained data with the data existing in the knowledge base to draw corresponding theories.

The expert system is characterized by its highly specialized and strong ability to solve specific problems. It has the ability to solve problems in professional fields through the orderly connection of databases, knowledge bases, and inference engines, combined with related professional domain knowledge. Literature [1] proposes an expert system based on a combination of Case-Based Reasoning (CBR) and Rule-Based Reasoning (RBR), which can continuously increase new cases to improve the system's ability to judge complex faults. Combining fuzzy theory with expert systems can effectively solve the poor fault tolerance of expert systems. Literature [2] proposes a combination of Petri nets and expert systems, integrating various types of fault features and consolidating multi-channel fault diagnosis information, making the diagnostic results more precise and reliable, and compensating for many shortcomings of traditional methods. It can quickly and accurately diagnose typical faults and provide feasible solutions.

2.2 Based on artificial neural network for electric power system fault diagnosis

Artificial Neural Networks (ANN) are complex computational models that mimic the way human brain neurons work and are widely used in the fields of machine learning and artificial intelligence. The most commonly used neural network is the BP network. The BP neural network is typically a three-layer network with varying numbers of neurons in each layer and enhanced connections between neurons, making it capable of strong application in areas such as multi-class pattern recognition and multidimensional curve fitting. Therefore, in the application of power system fault diagnosis, network with strong data processing capabilities such as BP neural network should be adopted.

A good artificial neural network model can effectively predict and capture faults. For example, using fault diagnosis techniques based on artificial neural networks, by collecting and processing data on the operation status of transformers and establishing a suitable artificial neural network model, faults can be captured in a timely manner, providing effective prediction and diagnostic support for ensuring the safe and efficient operation of the power system. Reference [3] used matrix and neural network algorithms to address the problem of fault location in the secondary systems of substations, outlined the interaction logic of the substation's secondary systems, and built a system state matrix and logic node description model based on logical nodes. The system state resolution formula is constructed based on the topological association of the substation's secondary systems. Using matrix and neural network algorithms, high-precision positioning of the substation's secondary systems is achieved, with good generality and fault tolerance, and it has value for large-scale application.

2.3 Fault Diagnosis of Power Systems Based on Bayesian Networks

A Bayesian Network (BN) is a graphical model that can be used for probabilistic inference modeling. It can effectively describe the conditional dependency relationships between variables, and is commonly used in fields such as data mining and machine learning. In fault diagnosis in power systems, a Bayesian network can be used to establish fault diagnosis models, effectively improving diagnostic accuracy and speed, and is suitable for the complexity and uncertainty of large-scale fault information. Currently, Bayesian networks are gradually applied in fault diagnosis of hydroelectric units, transformer faults diagnosis, and state estimation of overhead transmission lines, achieving good results. Ref. [4] established a distributed BN model under the conditions of complete and incomplete protection and circuit breaker action information, and then improved this model, preprocessing fault information for temporal consistency and completeness, and established a fault diagnosis BN model with temporal attributes. However, this method still has the following shortcomings: ① Acquiring knowledge is relatively difficult. ② How to achieve fault diagnosis under information fusion. ③ How to achieve automatic modeling under complex power grids. ④ There is still a distance from practical engineering.

2.4 Based on the Petri net for fault diagnosis in power systems.

Petri Net (PN) is a mathematical representation of discrete parallel systems. Based on Petri net, reference [5] establishes a comprehensive step-by-step model for fault diagnosis of power systems, and it builds perfect terminal models and lead-out line models based on the fault information system, through fault information search, suspicious fault components are identified to form a library of suspicious components. It sets up a step-by-step model and mathematical deduction method for diagnosing suspicious component faults, summarizes the principles of fault determination, and compares the credibility of the diagnostic results. This method has been tested in the actual fault diagnosis of the power grid, and the experiment shows that it has the advantages of rapid and accurate modeling and matrix operations, suitable for practical fault information systems in power grids. It is also capable of reflecting complex faults occurring in the power grid under multiple protection configurations and incorrect tripping of circuit breakers, making the diagnostic results more practical and suitable for real-time online fault diagnosis.

The advantage of applying Petri Net in fault diagnosis is that it can intuitively describe the behavior of the system, conduct reliability analysis and performance evaluation of the system, as well as model verification and simulation. According to reference [6], based on the characteristics of the power grid and the requirements of fault diagnosis, the hierarchical thinking, improved adaptive fuzzy Petri net, and fuzzy logic are combined to form a hybrid Petri net. It proposes an object-oriented hybrid Petri net method for fault diagnosis of the power grid, enhancing the accuracy of the diagnostic results. The fault tolerance of the microgrid fault diagnosis method based on the hybrid Petri net can give accurate diagnostic results in complex situations such as single fault, multiple faults, and information loss.

2.5 Machine Learning-Based Fault Diagnosis for Power Systems

Machine learning (ML) is a branch of artificial intelligence science that focuses on improving the performance of computer algorithms through empirical learning. Its core lies in allowing computer systems to learn from data without explicit programming, thus optimizing program performance standards. With the development of computational technology, machine learning systems have been fairly maturely applied to the prediction and diagnosis of faults in the power system. Reference [7] utilizes machine learning algorithms to classify power system faults, proposing fault type and distance estimation techniques based on support vector machines, enabling rapid, accurate, and thorough fault classification and localization assessment. It analyzes faults using transient data, thereby improving prediction accuracy and extending the lifespan of power lines.

However, this method also suffers from shortcomings: ① It is relatively difficult to handle missing data; ② It is prone to overfitting problems; ③ It overlooks the interrelationship of attributes in the dataset. Reference [8] proposes an efficient decision tree pruning algorithm. Based on the network security situational awareness model, it establishes a pruning decision tree situational awareness system architecture and analyzes network data flow. During the decision tree generation process, it uses enumeration and binary search algorithms to find the maximum depth of the decision tree, utilizes depth-first search algorithms to find the minimum number of splits and the maximum feature number of the nodes, and finally, combines these three optimal parameters to prune from top to bottom, effectively solving the overfitting problem of the machine learning system.

2.6 Fault diagnosis of power systems based on rough set theory

Rough Set (RS) theory is a mathematical tool for dealing with uncertain and imprecise problems. It does not require any prior information beyond the data set needed to solve the problem. By maintaining the classification ability unchanged, it derives decision or classification rules through knowledge reduction. It can effectively analyze and handle various incomplete data such as imprecise, inconsistent, and incomplete data, discovering hidden knowledge and revealing potential patterns. When a power system fails, a large amount of data signals are generated. In complex fault diagnosis modes such as incomplete signals, with the fault-tolerant capability of rough set theory, the data signals of protection and circuit breakers are first used as conditional attribute sets for fault classification. Various possible fault situations are considered, a decision table is established, and then the decision table is automatically and minimally searched for reduction to extract diagnostic rules, thus diagnosing the faults in the power system.

Reference [9] applied the decision table reduction method in rough set theory to the diagnosis and handling of power system faults, revealing the inherent redundancy in the data information. This provides a way to explore incomplete data information, where the loss or errors in certain information does not affect the diagnostic results. The use of rough set theory for fault diagnosis can effectively handle information incompleteness and redundancy. However, this method also has some areas that need improvement. Firstly, the acquisition of diagnostic rules in rough set methods depends on the training sample set of various fault situations under the conditional attribute set. Secondly, the diagnostic results will be affected when the lost or erroneous alarm information is a critical signal. Finally, in a complex and large power grid, the decision table will become larger, making reduction difficult and reducing the speed and accuracy of diagnosis.

2.7 Fault diagnosis of electric power systems based on fuzzy set theory

Fuzzy Set Theory (FT) is a method that fuzzifies classical set theory to describe imprecise and uncertain objects using the concept of fuzzy membership. It introduces linguistic variables and fuzzy logic for approximate reasoning, making it an intelligent technology with a complete inference system. A fuzzy system consists of fuzzy knowledge base, fuzzy inference engine, and human-machine interface. It can be considered as a combination of fuzzy set theory and expert systems, improving system fault tolerance. The fuzzy knowledge base uses linguistic variables to express expert experience, making it more in line with human expression habits. Due to factors such as misoperation of protection or circuit breakers, transmission channel interference errors, and deviation in protection actuation time, fault diagnosis in power distribution networks has a great deal of uncertainty. Fuzzy theory can simulate approximate reasoning processes of human thinking and is mainly used in situations where human experience plays an important role, with prominent advantages in fault tolerance. Therefore, fuzzy theory-based methods are more suitable for fault diagnosis problems. Fuzzy theory is rarely applied alone in power system fault diagnosis and is usually combined with other artificial intelligence algorithms.

Reference [10] addresses the significant uncertainty in power system fault diagnosis, combining fuzzy sets, fuzzy inference methods, and expert system engineering to diagnose faults. It also applies distributed problem-solving methods based on the characteristics of the distributed information in power systems. By using fuzzy extensional reasoning in fuzzy theory to establish a mathematical model and then optimizing it using optimization methods, fault diagnosis fault tolerance is effectively improved. However, the disadvantages of fuzzy theory are also evident: (1) complex maintenance of the rule base, (2) lack of self-learning ability, and (3) a lack of an effective solution to address a large amount of incomplete and uncertain information in power system fault diagnosis.

3. Challenges and Countermeasures for Intelligent Diagnosis of Power System Faults

With the continuous development of intelligent technology, intelligent fault diagnosis has become an important application field, bringing convenience to industry and daily life. However, intelligent fault diagnosis faces a series of problems in practical applications, such as data quality, model accuracy, and real-time performance. This article aims to explore and propose strategies to address these issues.

3.1 The problem with intelligent fault diagnosis.

(1) Data Quality

The results of intelligent fault diagnosis directly depend on the quality of the input data. However, the data in actual production environments are often interfered with by issues such as noise, missing, and abnormal data, leading to inaccurate or unreliable diagnostic results.

(2) Model Accuracy

The core of intelligent fault diagnosis is to build accurate fault diagnosis models. However, due to the complex and diverse nature of different types of fault characteristics, building accurate models is a challenging task. At the same time, over time and changes in the environment, the accuracy of the model may also decrease.

(3) Real-time Performance

In some scenarios, intelligent fault diagnosis requires real-time feedback and diagnosis to take timely measures for repairs. However, to achieve real-time performance, it is necessary to handle a large amount of data and computational tasks within a limited time, which places higher demands on algorithms and computational capabilities.

3.2 The solution to the problem

(1) Data Preprocessing

In order to improve the quality of data, methods such as noise reduction, filling missing values, and detecting outliers can be employed in data preprocessing. Through effective data cleansing and processing, the quality of input data can be enhanced, thereby improving the accuracy of fault diagnosis.

(2) Model Optimization

To address the issue of model accuracy, continuous optimization of model architecture and parameters, as well as the introduction of more features and data sources, can be utilized to improve the accuracy of the model. In addition, techniques such as transfer learning and incremental learning can be applied to iteratively update the model from historical data and prior knowledge, so as to adapt to different fault scenarios.

(3) Enhancing Real-time Performance

To improve the real-time performance of intelligent fault diagnosis, parallel computing and distributed computing can be employed to distribute the computing load across multiple computing nodes, thereby increasing processing speed. Additionally, caching techniques and data compression algorithms can be utilized to reduce time consumption in data transmission and storage. Furthermore, optimizing the implementation of algorithms and using high-performance computing hardware are also important measures to enhance real-time performance.

Intelligent fault diagnosis, as an important application of intelligent technology, faces many challenges such as data quality, model accuracy, and real-time performance. Through the research presented in this paper, we have proposed countermeasures to address these issues, including methods such as data preprocessing, model optimization, and enhancing real-time performance. We believe that through continuous research and exploration, the development of intelligent fault diagnosis will usher in a broader and brighter future.

4. The development trend of intelligent diagnosis in the power system.

1) The development of artificial intelligence technology promotes the iteration and upgrade of intelligent diagnosis technology.

Currently, with the continuous breakthroughs in artificial intelligence academic theory and cutting-edge technology, the integration of power system technology and knowledge is gradually deepening. In the field of intelligent diagnosis of power systems, due to the continuous generation of massive data by equipment and lines during uninterrupted operation, the application of artificial intelligence algorithms has become the main means of intelligent diagnosis due to the huge amount of computation required for data collection and analysis.

In recent years, artificial intelligence technologies represented by machine learning and deep learning have made continuous progress, continuously improving and developing algorithms, models, and architectures, promoting the iteration and upgrade of intelligent diagnosis technology in power systems. By applying more accurate information processing models and more efficient intelligent analysis algorithms, intelligent diagnosis technology deeply mines the value of data, constantly improving the economy and accuracy of power system and line diagnosis. Literature [11] also points out that introducing artificial intelligence technology into power system fault diagnosis is undoubtedly a major breakthrough, which can not only provide massive data for people but also make correct judgments on power system faults in the shortest possible time. Therefore, systematic research on power system fault diagnosis is particularly important.

2) The development of advanced communication technologies such as 5G improves diagnostic efficiency.

Data transmission technology is the basic means for power systems to achieve diagnosis, control, and management. Currently, power systems mainly use power dispatch data networks and other technologies for data and information transmission. With the continuous advancement of intelligent construction, power systems have higher requirements for the timeliness, stability, and economy of data transmission. 5G communication technology features high bandwidth, low latency, and stability, while NB-IoT and other Internet of Things communication technologies have the advantages of wide coverage, multiple access devices, and low power consumption. The comprehensive application of various communication technologies can meet the diverse data transmission needs in intelligent diagnosis scenarios, effectively improving the diagnostic efficiency of power system equipment and lines. A novel electrical equipment operating diagnosis system designed in reference [12] utilized 5G to develop a client for electrical equipment operating diagnosis, constructed an architecture for electrical equipment operating diagnosis, and designed functional modules for electrical equipment operating diagnosis, thereby achieving the diagnosis of electrical equipment operation. The test results of the designed system show a good response state and reliability.

3) The diversification and refinement of diagnostic targets promote the increase in the degree of industry segmentation.

The intelligent diagnosis technology of the power system conducts real-time diagnosis and evaluation of the operating conditions of equipment such as transformers, sensors, circuit breakers, as well as the temperature and humidity of the work environment, achieving “real-time perception of status, proactive hazard warning, and intelligent linkage of equipment.”

Due to the differences in perception technology and diagnostic algorithms applied to different diagnostic targets, the diversification and refinement of diagnostic targets have led to an increase in the segmentation degree of intelligent diagnosis technology. Literature [13] suggests that a diversified intelligent approach is adopted to meet the diagnostic needs of different equipment and circuits in the power grid system. Generally, multiple intelligent diagnosis technologies are comprehensively adopted in power grid systems, complementing each other and collectively forming an organic part of the intelligent diagnosis system of the power system.

5. Conclusion

Intelligent algorithms have significant advantages in fault prediction and diagnosis in power systems. Compared to traditional empirical and rule-based methods, intelligent algorithms can fully utilize big data analytics and machine learning techniques to effectively mine potential fault characteristics and enable accurate and efficient prediction and diagnosis in complex power systems. By optimizing algorithms and models, intelligent algorithms can improve the accuracy and reliability of fault diagnosis, thereby enhancing the reliability and safety of power systems.

Furthermore, this article highlights the application of cutting-edge technologies such as Bayesian networks, neural networks, and machine learning, and explores their marginal contributions to fault prediction and diagnosis in power systems. Bayesian networks can be used to establish fault diagnosis models, which can effectively improve diagnostic accuracy and speed, and are suitable for the complexity and uncertainty of large-scale fault information. The application of neural networks can simulate the learning ability of the human brain and improve the accuracy and reliability of fault prediction through continuous training and optimization. Machine learning, on the other hand, allows computer systems to learn from data without explicit programming, thereby optimizing the performance of programs. These cutting-edge technologies have high feasibility and potential in fault prediction and diagnosis in power systems.

The future development direction of intelligent algorithm-based fault prediction and diagnosis technology in power systems is multifaceted. Firstly, further research investment in intelligent algorithms is needed to continuously improve the accuracy and performance of algorithms and achieve better fault prediction and diagnosis effects. Secondly, efforts should be made to strengthen data collection and processing capabilities in power systems, establish sophisticated data analysis platforms, and provide more abundant and accurate data support for intelligent algorithms. In addition, cross-application with other fields is also an important development direction, drawing inspiration from intelligent algorithm technologies in other industries to bring new ideas and methods to fault prediction and diagnosis in power systems. With continuous technological evolution and improvement, it is believed that intelligent algorithms will play a greater role in fault prediction and diagnosis in power systems in the future, making greater contributions to the development and stability of the power industry.

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