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Research on the Application of Automation Equipment in Distribution Network Fault Repair

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Abstract: As modern society increasingly relies on electricity supply, the reliability and efficiency of distribution network systems have become particularly important. Distribution network failures will not only cause serious economic losses but may also affect key public services and residents' daily lives. Therefore, quickly and effectively repairing distribution network faults is an important challenge for the power industry. The application of automation equipment has greatly improved the ability to repair distribution network faults. This technological development trend is of great significance to improving the reliability and safety of power grid operations. The article introduces the common problems of distribution network fault repair and the limitations of traditional methods and then discusses in detail the specific application of automation equipment in distribution network fault repair.

Keywords: distribution network failure; emergency repair; automation equipment; application

Introduction

In power system operation and maintenance, rapid diagnosis and treatment of distribution network faults are key to ensuring the safety and stability of the power supply. Distribution network faults are often caused by a variety of factors such as equipment aging, natural disasters, and human errors. Traditional manual diagnosis and repair methods are often time-consuming, costly, and risky. With the advancement of technology, automation equipment has begun to show its unique advantages in this field. These devices can not only quickly locate the source of faults and reduce power outage time, but also improve the safety of repair personnel and reduce maintenance costs.

1. Distribution Network Failures and Resulting Impacts

1.1. Line failure

Line faults are common problems in distribution networks, especially short-circuit faults and disconnection faults, which pose serious threats to the continuity and reliability of power supply. Short-circuit faults, such as single-phase to ground, two-phase, and three-phase short circuits, are usually caused by external factors such as animal contact, tree branch intrusion, or equipment aging. Such faults will cause a sudden increase in current and instantaneously generate a large amount of heat energy, which may cause damage to wires and related equipment. damage to the equipment. In addition, wire breakage faults, often caused by natural disasters such as storms or hail, not only interrupt the power supply but may also cause safety incidents such as fires or electric shocks due to exposed wire ends. The occurrence of these faults reduces the efficiency of the power grid, causing interruptions in power transmission, affecting the normal activities of residents and businesses, and in severe cases, causing widespread power outages. Since electricity is the infrastructure for the operation of modern society, line failures have far-reaching consequences, affecting the safe operation of the power grid and directly affecting economic activities and people's lives (Zhang et al., 2024).

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1.2. Equipment failure

Equipment failure is particularly critical in power distribution networks because it directly affects the stability and security of the power grid. Common equipment failures include transformer failure, switchgear failure, and protection equipment failure. These failures are mostly caused by equipment aging, improper maintenance, or external environmental factors. For example, if a transformer fails due to overload or aging of insulation materials, it will not only cause local power supply interruption but may also cause a fire in the power grid, further exacerbating losses. At the same time, when a fault occurs in a switching device such as a circuit breaker, it may not be able to cut off power when an abnormality occurs in the circuit, thereby preventing the fault from spreading to the entire power grid. In addition, the failure of protective equipment may cause the power grid to fail to respond correctly when subjected to external shocks such as lightning strikes, increasing the vulnerability of the system. This type of equipment failure not only increases the economic burden of power grid operations but also seriously affects the reliability of the power grid and the power supply to users. Especially in critical infrastructure and important commercial areas, equipment failure may lead to major social and economic consequences.

1.3. Grid overload

Grid overload is a common fault in distribution systems that usually occurs during periods of high demand when electricity consumption exceeds the grid's design load. In this case, equipment in the grid, such as transformers and transmission lines, can overheat because they carry too much current, resulting in reduced efficiency or damage to the equipment. Long-term power grid overload will accelerate the wear and tear of equipment, shorten its service life, and even cause power equipment failure or fire in severe cases. This will not only cause temporary power outages but may also affect the stable operation of the entire power distribution system. In addition, grid overload may also cause voltage drops, which may lead to abnormal operation of production equipment or data loss for industrial and commercial users who require stable voltage operation. In extreme cases, grid overload may trigger the protection system to cut off the power supply, leading to large-scale power outages, affecting the daily life and work of a large number of users, and causing widespread socioeconomic impact.

1.4. Ground fault

A ground fault is a kind of power fault that often occurs in distribution networks. It is usually caused by a part of the power system that should not be grounded accidentally contacting the ground or grounding body, resulting in abnormal flow of current. The occurrence of this kind of fault often causes voltage instability in the power grid, especially near the ground point. Voltage imbalance may occur, thus affecting power quality and the normal operation of equipment. Ground faults will not only increase the energy consumption of the power grid but may also cause overheating or even damage to power equipment, especially the impact on key equipment such as transformers and cables is serious (Jia & Ma, 2021). In some cases, ground faults may also cause electrical fires or electric shock accidents, endangering public safety. In addition, if ground faults are not detected and handled in time, they may cause faults to spread, increase the complexity and cost of repairs, and even cause large-scale power outages at the system level in severe cases.

2. Application Advantages of Automation Equipment in Distribution Network Fault Repair

2.1. Improve response speed and efficiency

In the emergency repair of distribution network faults, the use of automated equipment has greatly improved response speed and maintenance efficiency. For example, drones and robots can be quickly deployed to the scene of a fault. These devices are equipped with high-precision sensors and cameras to conduct aerial or ground reconnaissance in adverse weather conditions or inaccessible terrain. They can quickly scan and transmit back large amounts of data, providing engineers with detailed information about grid status and fault locations. In addition, these automated tools can conduct real-time data analysis at the early stage of a failure and quickly identify the root cause of the problem, allowing the repair team to directly intervene effectively without spending extra time on manual inspection and diagnosis. This rapid fault identification and handling not only significantly shortens the duration of power outages, but also improves the success rate of repair operations (Gao, 2020).

2.2. Enhance the safety of maintenance work

The application of automation equipment in distribution network fault repair greatly enhances the safety of maintenance work. Automated devices such as robots and drones can replace humans in performing dangerous tasks in high-risk environments. For example, when a power grid failure requires detection and repair in a high-voltage environment, the use of automated equipment can avoid direct manual contact, thereby significantly reducing the risk of electric shock or working at heights. Equipped with advanced sensors and actuators, these devices are capable of precise operation in unsafe conditions, such as stable operation in strong winds or heavy rains, ensuring that maintenance personnel can operate remotely from a safe control room. In addition, automated equipment can continuously monitor and diagnose faults, reducing safety incidents that may occur due to repeated entry into the fault area. In this way, automation equipment not only protects the health of power grid workers but also improves the safety standards of overall operations, making distribution network fault repair work safer and more efficient.

2.3. Improve the quality of emergency repairs

The application of automation equipment in emergency repair of distribution network faults has significantly improved the quality of emergency repair operations. Through advanced sensing technology and precise data analysis capabilities, these devices can provide more detailed and accurate fault diagnosis than traditional methods. For example, thermal imaging cameras mounted on drones can quickly identify hot spots in cables, while ground-based robots can perform close inspections and pinpoint faulty components. The application of these technologies ensures that problems are identified quickly and accurately, reducing duplication of work or delays in treatment due to misdiagnosis. When automated equipment performs emergency repair tasks, due to the accuracy of its programming, it can accurately perform complex repair operations, thereby improving the quality and success rate of repair work. They can operate stably in extreme or dangerous environments, ensuring that maintenance work can be completed efficiently and correctly under any circumstances (Shen & Peng, 2020). In addition, after the automation equipment completes the emergency repair task, it can also conduct subsequent testing and verification to ensure that the fault is completely repaired and the system returns to normal operation. This efficient and precise fault handling method not only improves the success rate of emergency repair tasks but also reduces the risk of potential future failures and extends the service life of the equipment.

2.4. Reduce operating costs

The introduction of automated equipment in distribution network fault repair can significantly reduce operating costs. The use of automated equipment such as drones, robots, and intelligent diagnostic systems reduces the need for large numbers of on-site technicians, especially when locating and repairing faults in remote or inaccessible areas. Through remote monitoring and automated control, faults can be quickly diagnosed and dealt with, thereby reducing unnecessary manual inspections and long on-site operations, which directly reduces labor costs and time costs. At the same time, automated equipment can improve the accuracy of emergency repairs and reduce re-emergency repairs caused by misdiagnosis or incomplete repairs. This not only saves material resources but also avoids additional maintenance costs. Precise fault handling reduces excessive wear and potential long-term damage to equipment, further extending the life of the infrastructure and thereby optimizing capital expenditures (Li & Wang, 2018). The use of automated equipment for fault repair can also help optimize resource allocation and improve the overall operating efficiency of the power grid. The automation of the system not only improves the speed of fault response but also makes the power supply more stable and reduces the economic losses caused by power outages. All these factors work together to significantly reduce the overall operating costs of the power system and bring long-term economic benefits to the power company.

3. Specific Application of Automation Equipment in Distribution Network Fault Repair

3.1. Application of drones

The application of drones in distribution network fault repair has become an important means to improve efficiency and safety. By carrying high-resolution cameras and infrared thermal imagers, drones can quickly conduct aerial inspections of vast areas, especially in areas with complex terrain or inaccessible areas, such as mountainous areas or power transmission lines near rivers. These devices capture detailed images from the air, helping operations teams quickly locate the source of a fault, such as a broken line caused by a natural disaster or a fallen tree touching a power line. In addition, infrared thermal imaging technology allows drones to conduct inspections at night or in low-visibility conditions, effectively identifying hot spots caused by electrical overloads or equipment failures. After large-scale disasters, such as storms or floods, drones can also quickly take to the sky to assess the extent of damage to power grid facilities and provide critical information to emergency repair teams to ensure that they can prioritize the most urgent or severe damage. Through real-time video streaming, technicians in the operation and maintenance center can remotely observe on-site conditions, make quick decisions, and guide the ground repair team to carry out precise repairs. Drones can also be used in conjunction with other automated equipment and systems, such as working in conjunction with ground robots to conduct more comprehensive power grid inspections and repairs (Liu, 2017). Through this joint operation of air and ground, the entire emergency repair process becomes more efficient and systematic, which greatly shortens the time for power grid recovery and also reduces the safety accidents that may occur due to direct contact of personnel with the high-voltage environment.

3.2. Application of robots

Robots play a vital role in troubleshooting distribution network failures, especially when handling tasks that may pose a high risk to humans. These robots are often equipped with a variety of sensors, including high-definition cameras and precision operating tools, allowing them to work effectively in a variety of environments. For example, in the maintenance of high-voltage lines or substations, robots can perform close operations without direct human contact, significantly reducing the risk of electrical accidents. In specific operations, the robot can automatically navigate to the fault point and perform tasks such as replacing damaged insulators, repairing broken wires, or clearing obstacles such as tree branches that have fallen on the power lines. The design of these robots often allows them to work in extreme weather conditions, such as strong winds, rain, snow, and other severe weather, maintaining efficient and stable operational performance. In further applications, some specially designed robots can also perform welding, cutting, and other complex repair work that require precise control. Through remote control, technicians can command the robot to operate from a safe location and monitor its execution in real-time to ensure the accuracy and efficiency of the work. In addition, robots can also be integrated with drones and other automated systems to build a multi-layered monitoring and maintenance network. For example, drones first conduct a large-scale rapid assessment from the air, and then robots conduct detailed inspections and actual repair work on the ground. This collaborative operation mode makes the repair work of the power grid more systematic and efficient.

3.3. Intelligent diagnostic system

The intelligent diagnosis system plays a core role in distribution network fault repair. It uses advanced data analysis and machine learning technology to optimize the fault detection and diagnosis process. Such systems can quickly and accurately analyze grid status and potential problems by integrating real-time data from all parts of the grid, including information gathered from sensors, smart metering devices, and weather forecast services. The working principle of these intelligent systems is based on a comprehensive analysis of historical data and real-time input and identifies abnormal behaviors in power grid operation through pattern recognition technology (Li, 2019). For example, the system can identify abnormal voltage fluctuations due to equipment aging or external factors, or detect a sudden increase in energy consumption in a specific area, which can be early signs of failure. The intelligent diagnostic system can automatically analyze this data, predict possible failure points, and issue alarms promptly. In actual operation, when the intelligent diagnostic system detects a potential fault, it will automatically trigger an alarm and send a detailed fault report to the maintenance team, including the specific location of the fault, possible causes, and recommended repair measures. The timely transmission of this information greatly improves the response speed and processing efficiency of the emergency repair team, allowing them to deploy emergency repair resources in a more targeted manner.

3.4. Automated power distribution system

The automated distribution system plays a vital role in the emergency repair of distribution network faults. It uses advanced information technology and automatic control technology to improve the reliability and self-healing capabilities of the power grid. This kind of system can realize real-time monitoring and management of the power grid by integrating fault detection, communication technology, and automatic control components, to quickly respond and automatically restore the power supply when a fault occurs. The automated power distribution system continuously collects data on the operating status of the power grid, such as voltage, current, frequency, and temperature, through intelligent sensors and terminals installed at key nodes of the power grid. These data are transmitted to the central processing system in real-time. By analyzing this information, the system can accurately locate the location and nature of the fault. When the system detects a fault, it can automatically isolate the fault area and quickly transfer power to unaffected areas by reconfiguring the switch status in the power grid to restore power supply outside the affected area, greatly reducing the impact of the fault. At the same time, the automated power distribution system can also optimize the operating efficiency of the power grid, predict power grid load changes through intelligent analysis, and automatically adjust the power grid's operating mode to ensure the optimization of power distribution. This intelligent adjustment not only improves energy usage efficiency but also effectively extends the service life of power grid equipment (Shen & Zheng, 2017).

3.5. Communication and data processing technology

Communication and data processing technologies play a vital role in distribution network fault repair. They provide powerful technical support for fast and accurate fault detection, diagnosis, and repair. These technologies ensure that the flow of information from the point of failure to the control center is fast and error-free through high-speed, reliable communication networks and efficient data processing capabilities. In practical applications, communication technologies such as 4G/5G networks, optical fiber communications, and satellite links enable various monitoring equipment and sensors to transmit data back to the control center in real-time even in remote or geographically complex areas. This real-time data flow allows the operation and maintenance center to obtain accurate fault information in the early stages of a fault, such as the specific location of the fault, its impact scope, and the possible cause of the fault. This is crucial for quickly initiating emergency measures and reducing losses. Data processing technology uses integrated software platforms and advanced algorithms to analyze and process the large amounts of data collected. These systems can use machine learning and artificial intelligence technologies to identify failure modes and trends from complex data sets, predict potential risk points, and provide a scientific decision-making basis for emergency repair work. For example, by analyzing past fault data and current operating conditions, the system can optimize the dispatch of emergency repair resources and improve the efficiency and success rate of emergency repair work.

Summary

To sum up, the application of automation equipment in distribution network fault repair marks a major shift in power system management towards high efficiency, high safety, and low-cost operation and maintenance. These technologies significantly improve the reliability and service quality of the power grid by optimizing fault response processes and improving operational accuracy. Drone and robotic technologies make fault diagnosis and processing faster and safer, while intelligent diagnostic systems and automated power distribution systems improve the predictability and efficiency of fault handling through precise data analysis and real-time monitoring. These advances not only improve the technical level of power grid operation and maintenance but also provide a solid guarantee for the continuity and reliability of power supply.

Conflict of Interest

The authors declare that they have no conflicts of interest to this work.

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