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Benefits and Promotion Strategies of 10kV Distribution Line Automation Technology

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Abstract: ***Focusing on 10kV distribution lines, this study examines automation technologies and their operational benefits in enhancing supply continuity and reducing maintenance costs. It systematically analyzes the automation workflow encompassing fault identification, sectionalization, and service restoration, while highlighting the integration of modern communication infrastructure and smart terminal devices. The research identifies key barriers to effective automation deployment and proposes targeted strategies to overcome these obstacles, facilitating the progressive advancement of distribution line automation in 10kV networks.***

Keywords: 10kV power grid; Distribution lines; Automation technology; Communication technology; Intelligent terminal.

1. INTRODUCTION

With the growth of power demand and the development of grid intelligence, automation of 10kV grid distribution lines has become an important trend. Automation technology can improve power supply quality and efficiency, and enhance grid stability. However, its current application still faces many problems. In-depth exploration of 10kV grid distribution line automation technology is of important practical significance for grid upgrading and transformation as well as sustainable development.

2. OVERVIEW OF 10KV POWER GRID DISTRIBUTION LINE AUTOMATION TECHNOLOGY

2.1 Definition and Connotation of Automation Technology

The 10kV power grid distribution line automation technology is an integrated technical system based on modern electronic technology, communication technology, and computer technology, which realizes real-time monitoring of distribution line operating status, rapid fault location and isolation, power supply restoration in non-faulty areas, and equipment condition assessment. Its core connotation lies in transforming the traditional manual inspection and operation mode into a new operation and maintenance mode of active perception, automatic decision-making, and precise execution through the collaborative operation of intelligent equipment and systems. This technology not only covers the collection and analysis of electrical quantities but also includes links such as topology identification, fault discrimination logic, and control command issuance, forming a complete closed loop from data collection to control execution. The essential characteristics of automation technology are real-time performance, reliability, and interactivity, which can significantly shorten fault handling time, reduce the probability of human operation errors, and improve the self-healing ability and service quality of the distribution network.

2.2 Development History and Current Status

The development of 10kV distribution automation technology has gone through an evolutionary process from simple relay protection to microcomputer protection, and then to feeder automation systems. In the early stage, overcurrent protection mainly relied on single-function relays. With the development of integrated circuit technology, microprocessor-based protection devices were gradually popularized, improving the accuracy and flexibility of protection actions. After entering the digital era, the advancement of communication technology promoted the leapfrog development of distribution automation systems, forming an integrated automation system integrating protection, monitoring, and control. Currently, this technology has entered the stage of intelligent development, presenting technical characteristics such as multi-source information fusion, distributed collaborative control, and edge computing for on-site decision-making. Existing systems widely adopt a hierarchical and distributed architecture, where the master station system is responsible for global optimization decisions, and terminal devices undertake local rapid protection and control tasks. Although the technical system is becoming increasingly perfect, there are still problems in practical applications such as insufficient equipment compatibility, limited communication reliability, and inadequate development of advanced application functions, which restrict the exertion of overall effectiveness.

2.3 Application Significance and Value

The implementation of 10kV distribution automation technology has significant economic and social value. For power enterprises, this technology can greatly shorten the fault outage time, reduce power loss, and lower the investment in maintenance manpower and material resources; realize preventive maintenance through equipment condition monitoring to extend the service life of equipment; optimize network reconfiguration capabilities and improve power quality. For the user side, automation technology effectively improves power supply reliability, ensures the continuous power supply demand of sensitive loads, and reduces economic losses caused by power outages. From the perspective of the overall operation of the power grid, this technology enhances the controllability of the distribution network, provides technical support for new businesses such as distributed energy access and electric vehicle charging facility deployment, and promotes the construction of smart grids. In addition, the massive operation data accumulated by the automation system provides a decision-making basis for power grid planning, equipment selection, and asset management, helping power grid enterprises in their digital transformation.

3. KEY TECHNOLOGIES FOR 10KV POWER GRID DISTRIBUTION LINE AUTOMATION

3.1 Fault Location Technology

Fault location technology is one of the core functions of distribution automation, and its implementation relies on the comprehensive application of multiple principles and methods. The impedance calculation-based location method calculates the fault distance by comparing the changes in voltage and current phasors at each node before and after the fault, combined with line parameters; the traveling wave method determines the fault location using the propagation time difference of transient traveling wave signals generated by the fault; the zero-sequence current amplitude and phase comparison method is suitable for small current grounding systems. Modern fault location technology focuses on multi-criteria fusion, improving positioning accuracy by integrating electrical quantity change characteristics such as voltage Sudden variables, current distortion characteristics, and harmonic content. The introduction of artificial intelligence algorithms enables fault location to develop in an adaptive direction, where the system can train models based on historical data and automatically correct positioning deviations caused by line parameter errors. Effective fault location not only requires accurate distance measurement but also needs to cooperate with topology identification functions to accurately determine the section and phase where the fault occurs, providing a reliable basis for subsequent isolation operations.

3.2 Isolation and Power Restoration Technology

Isolation and power restoration technology directly affects fault handling efficiency and power supply reliability. This technology mainly includes two key links: rapid isolation of fault sections and power restoration of non-fault sections. Rapid isolation is achieved through the coordination of circuit breakers and load switches, requiring protection devices to complete fault judgment and issue trip commands within milliseconds. Power restoration adopts a combination of multiple strategies, including reclosing tests, automatic transfer of standby power supplies, and network reconfiguration. Adaptive restoration strategies automatically select the optimal plan based on fault types and the current operation mode of the power grid, such as permanently isolating the fault section in the case of permanent faults and performing step-by-step trial power transmission according to preset logic in the case of temporary faults. Of particular importance is the ability to handle multiple faults; the system must have the ability to selectively isolate under complex faults to avoid large-scale power outages caused by a single fault. The difficulty of this technology lies in ensuring the selectivity of actions while taking into account quick action, preventing the expansion of power outage Scope due to misoperation or resusal to operation

3.3 Communication Technology

The communication system is the neural network connecting distribution terminals and the master station system, and its performance directly determines the response speed and reliability of the automation system. Currently adopted communication methods mainly include optical fiber communication, wireless public network communication, and power line carrier communication. Optical fiber communication has the advantages of large bandwidth and strong anti-interference ability, making it suitable as a backbone communication channel; wireless public network communication is flexibly deployed and suitable for terminal access in remote areas; power line carrier communication does not require additional wiring but is susceptible to grid fluctuations. Hybrid communication networking technology has become a development trend, improving system redundancy by using multiple communication methods as backups for each other. The standardization of communication protocols continues to improve, and the application of international standards such as IEC61850 has promoted the interconnection of equipment from different manufacturers. Communication security mechanisms are increasingly improved, with measures such as encryption authentication and access control to ensure the secure transmission of control commands. Future communication technologies will develop towards low-power wide-area Internet of Things to meet the access needs of large-scale terminal equipment.

4. 10KV POWER GRID DISTRIBUTION LINE AUTOMATION INTELLIGENT TERMINAL EQUIPMENT

4.1 Terminal Equipment Types and Functions

Intelligent terminal equipment is the peripheral nerve of the distribution automation system, mainly including Feeder Terminal Units (FTU), Distribution Terminal Units (DTU), and Transformer Terminal Units (TTU). FTU is installed at pole-mounted switches, responsible for collecting switch status quantities and analog quantities, executing remote control commands, and具备 local fault detection and processing functions. DTU is applied in ring main units, switching stations, and other places; in addition to basic four-remote functions, it can also complete tasks such as fault recording and event logging. TTU is specially used for distribution transformer monitoring, focusing on collecting load data, temperature parameters, and power quality indicators. All types of terminals are equipped with independent CPUs and real-time clocks, supporting remote program upgrades and remote parameter modifications. The common functions of terminal equipment include data collection and processing, control output, time synchronization, and communication interface conversion; differences are reflected in the installation environment and specific functional requirements. New terminals have begun to integrate edge computing capabilities, enabling simple fault judgment and logical processing locally.

4.2 Equipment Selection and Configuration

The selection of terminal equipment should comprehensively consider environmental conditions, functional requirements, and economic rationality. Outdoor equipment should choose products with high protection levels to adapt to harsh environments such as wide temperature ranges and strong electromagnetic interference; indoor equipment focuses on miniaturization and maintenance convenience. Functional configuration follows the principle of "practical and sufficient": basic models meet conventional four-remote requirements, enhanced models add fault recording and event SOE recording, and flagship models extend to double-ended fault location and multi-contact temperature monitoring. Communication module selection should match the communication network standard, and expansion interfaces should be reserved to adapt to future upgrade needs. The power supply scheme directly affects equipment reliability; the combination of super capacitors and lithium batteries can solve the problem of short-term power outages. The equipment configuration density needs to balance investment costs and functional requirements: important nodes should adopt dual configuration, while general nodes can use a single set of simplified configuration. Unifying equipment dimensions and installation methods helps standardize operation and maintenance.

4.3 Equipment Installation and Commissioning

Equipment installation quality directly affects the reliability of system operation. Before on-site installation, secondary circuit verification is required to ensure wiring correctness and insulation strength. Terminal equipment should be installed vertically and firmly, with terminal block tightening torque meeting specification requirements. The antenna installation position should avoid obstructions to ensure communication signal strength. Commissioning work is divided into two stages: individual debugging and joint debugging. Individual debugging focuses on verifying the accuracy of remote signals and telemetry, the reliability of remote control actions, and the correctness of setting values. The joint debugging stage involves testing the four-remote functions between the master station and terminals, simulating various fault conditions to verify the correctness of action logic. During debugging, data records and analysis of abnormal phenomena should be properly conducted, and equipment parameters should be adjusted in a timely manner. A 72-hour trial operation is required before commissioning to fully verify equipment stability and communication reliability. Regular on-site inspections and preventive maintenance should be carried out, and aging components should be replaced in a timely manner.

5. CONSTRUCTION OF 10KV POWER GRID DISTRIBUTION LINE AUTOMATION SYSTEM

5.1 System Architecture Design

System architecture design follows the hierarchical and distributed principle, usually divided into the master station layer, sub-station layer, and terminal layer. The master station layer, as the system's brain, is responsible for data processing, application analysis, and human-computer interaction; the sub-station layer connects the upper and lower layers, realizing regional data aggregation and protocol conversion; the terminal layer completes on-site data collection and control execution. The hardware architecture adopts an open industrial computer platform, and the software architecture is based on a componentized design concept, facilitating function expansion and maintenance. The system design emphasizes standardization and modularization, with communication between various levels through unified interfaces. A typical architecture includes components such as front-end acquisition servers, historical database servers, application servers, and Web servers. The disaster recovery backup system ensures seamless switching to the standby system when the master station fails. The architecture design also needs to consider future expansion needs, reserving interfaces to support new energy access and intelligent device interconnection.

5.2 System Integration and Testing

System integration is the process of integrating scattered devices and subsystems into an organic whole. Integration work begins with the preparation of a detailed system integration plan, clarifying the interface specifications and joint debugging sequence of each subsystem. Fieldbus system integration needs to solve the problem of protocol conversion for devices from different manufacturers, and gateway devices are used to achieve protocol mapping. The integration of SCADA systems and EMS systems must pay special attention to data synchronization and refresh frequency matching. After the system integration is completed, comprehensive testing is carried out, including functional testing to verify whether various operations meet the design requirements, performance testing to examine system response time and throughput, and stress testing to verify stability under extreme working conditions. Simulation testing uses digital twin technology to simulate various fault scenarios and verify the correctness of the system action logic. The actual measurement and joint debugging phase conducts live testing on the actual line, focusing on verifying the accuracy of fault location and the success rate of power supply restoration.

5.3 System Operation and Maintenance

System operation and maintenance establish a hierarchical management system, with operation and maintenance personnel divided into three roles: monitors, maintenance personnel, and administrators. Daily operation monitoring focuses on equipment online rate, communication success rate, and abnormal alarm information, and regularly generates operation reports. Equipment maintenance follows the principle of prevention first, formulating annual maintenance plans and five-year renovation plans. Software maintenance includes patch upgrades and virus protection, while hardware maintenance focuses on checking power modules and communication ports. A rapid response mechanism is established for fault handling: general defects are eliminated within 24 hours, and emergency plans are activated immediately for serious defects. System optimization is carried out continuously, improving setting values and control strategies by analyzing historical data. The training system ensures that operation and maintenance personnel master new equipment and technologies, and a knowledge inheritance mechanism is established. Spare parts management implements fixed-quota reserves, and key equipment implements a rotation maintenance system.

6. CHALLENGES AND COUNTERMEASURES FOR 10KV POWER GRID DISTRIBUTION LINE AUTOMATION

6.1 Technical Problems and Challenges

The main technical challenges include accurate fault location in complex networks, interconnection of heterogeneous devices, massive data processing and analysis, etc. The complex and changeable structure of the distribution network, with multi-branch lines, increases the difficulty of fault location, and the accurate determination of single-phase ground faults remains a technical difficulty. Differences in communication protocols of devices from different manufacturers affect system compatibility, and there are barriers to cross-platform data sharing. The access of distributed power sources has changed the power flow direction and short-circuit characteristics of traditional distribution networks, bringing new challenges to protection setting. Big data applications face problems of insufficient storage capacity and lack of data analysis capabilities, and real-time data processing and historical data mining have not been effectively combined. The computing power limitation of edge computing devices affects the local execution effect of complex algorithms.

6.2 Management and Coordination Issues

The prominent problems in management are manifested in insufficient cross-professional collaboration, unclear operation and maintenance responsibility boundaries, and inadequate implementation of technical standards. Distribution automation involves multiple professions such as dispatching, operation and inspection, and information and communication. Poor information sharing between departments affects the efficiency of fault handling. The ownership of equipment belonging to different units leads to difficulties in renovation coordination, and there are obstacles in the integration of new projects with existing systems. The skill levels of operation and maintenance personnel are uneven, and the shortage of compound talents restricts the application of new technologies. Although the standard system has been established, the implementation is insufficient, and some equipment selection does not strictly implement the network access testing regulations. The assessment mechanism focuses on construction indicators while ignoring operational efficiency, leading to the common phenomenon of emphasizing construction over application. The root cause of these problems lies in the management system failing to adapt to the needs of technological development, requiring the establishment of a cross-professional collaboration mechanism and improvement of the full-life-cycle management system.

6.3 Solutions and Suggestions

To address the above challenges, comprehensive management measures need to be taken. In terms of technological innovation, increase R&D investment to break through key technologies such as fault current direction identification and distributed power supply adaptive protection; promote the application of new technologies such as digital twins and blockchain to improve the intelligence level of the system. For management innovation, establish cross-departmental coordination agencies and improve standardized work processes; implement the equipment owner system to clarify full-life-cycle management responsibilities; establish an assessment mechanism based on operational effects. At the policy support level, formulate industrial policies that encourage technological innovation and improve the relevant technical standard system; promote collaborative development of the industrial chain upstream and downstream, and cultivate a professional operation and maintenance service market. For talent cultivation, establish a school-enterprise joint training mechanism and carry out multi-level technical training; establish a skill certification system to cultivate a high-quality operation and maintenance team. Through the synergistic effect of technological innovation, management innovation, and policy guidance, promote the sustainable and healthy development of distribution automation technology.

7. CONCLUSION

The automation technology of 10kV power grid distribution lines is crucial to the development of the power grid. Although progress has been made in key technologies and intelligent terminals, challenges still exist. It is necessary to continue research and innovation, improve system construction and management, enhance the level of automation, provide strong support for the safe, stable, and efficient operation of the 10kV power grid, and promote the sustainable development of the power industry.

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