

Design and Application of High and Low Voltage Switchgear in Factory Power Supply and Distribution Systems

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Keywords: High and low voltage switchgear; Power supply system; Scheme design; Intelligentization; Operations and maintenance management

Abstract: High and low voltage switchgear is the core equipment in the power supply and distribution system of the factory, and the rationality of its scheme design directly affects the safety and reliability of power supply in the factory. This paper systematically analyzes the significance of high and low voltage switchgear scheme design in ensuring the safe and stable operation of the system, improving power quality and supply reliability, and promoting the intelligent and standardized upgrade of the system. The main influencing factors such as load characteristics and power supply level, short-circuit current and protection coordination requirements, installation environment conditions, and intelligent monitoring requirements are analyzed in detail in the design of switchgear schemes from four aspects: high-voltage switchgear selection design, low-voltage switchgear configuration design, intelligent integration improvement, and operation and maintenance management mechanism establishment. An optimized path for scheme design and application was proposed, with the aim of providing some reference for the design and management of related projects.

1. Introduction

With the increasing demand for electricity and the growing complexity of power distribution systems, high and low voltage switchgear, as the core equipment for power distribution and protection, is facing higher requirements for reliability, flexibility and intelligence. The power supply and distribution system of the factory is the infrastructure that ensures the normal operation of the factory. High and low voltage switchgear, as the core electrical equipment within it, undertakes important functions of receiving, distributing, controlling and protecting electrical energy, and the quality of its scheme design is directly related to the safety and economy of power supply and use in the factory. In recent years, with the continuous improvement of factory automation levels and the increasingly complex power load structure, higher requirements have been put forward for the selection accuracy of high and low voltage switchgear and the depth of system integration. In this context, systematically sorting out the key influencing factors and application paths of high and low voltage switchgear scheme design for factory power supply and distribution systems is of great practical significance in terms of improving the overall performance

of factory power supply and distribution systems.

2. The significance of the design and application of high and low voltage switchgear schemes

2.1 It helps to ensure the safe and stable operation of the power supply and distribution system in the factory

The scientific and rational design of high and low voltage switchgear schemes is a prerequisite^[1] for ensuring the safe and stable operation of the factory's power supply and distribution system. Switchgear is responsible for connecting and disconnecting power supply lines and removing faults. If the selection parameters of the switchgear do not conform to the actual operating conditions of the system, it is very likely to cause protection failure or misoperation in abnormal situations such as short circuit and overload, thereby causing power supply interruption or equipment damage. A scientific design scheme can make the rated voltage, rated current and short-circuit capacity of the switchgear match the system parameters, and the protection function can be effectively coordinated with the upper-level equipment, fundamentally reducing the risk of safety accidents in the power supply and distribution system and providing reliable power support for the continuous and stable production of the factory.

2.2 It helps to improve the power quality and supply reliability of the factory

Reasonable design of high and low voltage switchgear schemes plays a direct role in improving the power quality of the factory and enhancing the reliability of power supply. During the design stage of switchgear schemes, a thorough analysis of load characteristics and scientific arrangement of power supply zones can reduce the mutual influence between power supply circuits, suppress the adverse effects of harmonic pollution on the power grid, and thereby improve the power quality^[2] within the factory. At the same time, the reasonable setting of backup power automatic switching circuits and busbar tie switches can ensure that when a certain incoming line or a transformer fails, power switching can be achieved quickly, the power outage time can be minimized, the power supply reliability of important loads can be effectively improved, production losses caused by power outages can be reduced, and the continuity and stability of factory production can be guaranteed.

2.3 It helps to promote the intelligent and standardized upgrade of the power supply and distribution system in the factory

The scientific design of high and low voltage switchgear schemes is an important support for promoting the intelligent and standardized development of factory power supply and distribution systems. Simultaneous planning of intelligent measurement and control, communication and data acquisition functions during the design stage of switchgear can lay the hardware foundation for the subsequent establishment of an integrated monitoring platform for power supply and distribution, enabling real-time perception and remote control of the system's operating status. A unified specification of equipment interface standards in the scheme design stage can effectively solve the problem of interconnection and interoperability of equipment from different manufacturers and improve system integration^[3]. The design of standardized schemes can ensure that operation and maintenance personnel carry out standardized and unified operations for equipment inspection, maintenance, etc., reduce the complexity of operation and maintenance work, and thereby improve the refined management level and sustainable development capacity of the factory power supply and distribution system as a whole.

3. Main factors influencing the design of high and low voltage switchgear schemes

3.1 Constraints of factory load characteristics and power supply grades in the selection of switchgear

The types, scale and significance of factory power loads are the primary factors determining the design direction of high and low voltage switch cabinet schemes. The load composition varies among different factories. Large motors, electric furnaces, lifting equipment, etc. installed on heavy industrial production lines have large starting currents and frequent load changes. Therefore, higher requirements are placed on the rated current and breaking capacity of switchgear. The load in light industrial sites is relatively stable, and the main considerations are the accuracy of power distribution and anti-interference performance. At the level of power supply, there are certain technical limitations^[4] for switchgear voltage levels, circuit breaker types, and busbar cross-sections at each level. The differences in power supply reliability among primary, secondary and tertiary loads will determine the configuration of standby circuits, tie switches and automatic switching devices, so a comprehensive investigation of the plant load characteristics must be carried out and graded analysis must be conducted before the scheme design.

3.2 The impact of short-circuit current and protection coordination requirements at the cabinet parameter design level

The level of short-circuit current and the coordination requirements of the upper and lower level protection devices are the most critical technical constraints^[5] in the parameter design of high and low voltage switchgear. When a short-circuit fault occurs in the system, the inrush current will cause strong thermal and electrodynamic effects on the switchgear busbar, circuit breaker contacts and connecting busbars. If the rated short-time withstand current design value is insufficient, it will cause the cabinet to deform and even lead to serious accidents. Therefore, during the scheme design stage, the short-circuit current at each level of the busbar should be accurately calculated based on the system impedance parameters, and then the rated breaking capacity of the circuit breaker and the structural strength parameters of the cabinet should be selected based on this. At the same time, the protection devices at each level should meet the requirements of selective coordination, so that when a fault occurs, the first to act is the protection device closest to the fault point, thereby reducing the range of power outages.

3.3 Constraints of installation environmental conditions on the selection of switchgear structural types

The installation environment conditions of switchgear play a decisive role in the selection of structural type and protection grade, and affect the operational reliability and service life of the equipment. The indoor distribution room environment is relatively stable. The switchgear will mainly encounter conditions such as dust, humidity and temperature fluctuations. The appropriate protection level and insulation type should be selected according to the environmental parameters. In smelting and chemical sites with corrosive gases or conductive dust, the switchgear should be of the fully enclosed or gas-filled insulation type with a higher protection level. Prevent ingress of harmful media and resultant insulation degradation; for outdoor installation, account for ambient impacts including temperature, humidity, wind-blown sand, and solar radiation. In addition, there are specific requirements for the external dimensions and installation methods of the switchgear in the narrow installation space. During the scheme design stage, the overall planning should be combined with the on-site conditions to ensure the stable and reliable operation of the equipment in

the complex environment.

3.4 The impact of intelligent monitoring requirements on the integrated functional configuration of switchgear

With the deepening of intelligent construction of factory power supply and distribution systems, users' demands for the integrated intelligent monitoring function of switch cabinets are getting higher and higher, which has an important impact on the functional configuration and system integration design of switch cabinets. Traditional switchgear only has basic opening and closing operations and mechanical status indication functions, which cannot meet the requirements of modern factories for real-time collection of operation data, remote control and predictive maintenance. Driven by the demand for intelligence, the new type of switchgear should have intelligent measurement and control units, power quality monitoring modules, and various communication interfaces, as well as complete fault recording and event recording functions to provide data support for the retroactive analysis of operation and maintenance personnel.

4. Scheme design and application path for high and low voltage switchgear in Factory power supply and distribution systems

4.1 Scientifically carry out the selection and design of high-voltage switchgear to meet the requirements of the factory's main power supply system

4.1.1 Select the type and parameters of high-voltage switchgear reasonably based on the supply voltage level and short-circuit capacity

The selection of high-voltage switchgear should be constrained by the supply voltage level and short-circuit capacity. For 10kV and below distribution systems, the appropriate switchgear type should be selected from fixed, trolley, gas-insulated and other types based on environmental conditions and expansion requirements. Important parameters such as rated voltage and rated current should have a certain margin based on the results of short-circuit calculation, the breaking current of vacuum circuit breakers should meet the requirements of three-phase short-circuit, and the ratio and accuracy grade of transformers should be configured separately according to the requirements of metering and protection. The trolley type switchgear has been widely used in engineering practice because it can be operated and maintained live, and the gas-insulated type is suitable for limited conditions because of its small size and low maintenance. After the selection work is completed, a technical specification for the equipment should be compiled based on the actual engineering situation to ensure that the purchased equipment is highly consistent with the design scheme.

4.1.2 Optimize the main wiring scheme on the high-voltage side to ensure the reliability and flexibility of the main power supply circuit

For plants with Class 1 and Class 2 loads, it is advisable to use single busbar sectioning and rely on busbar tie circuit breakers to achieve rapid switching of dual power sources and shorten power outage time. In terms of optimizing the main wiring scheme, it is necessary to design the interlocking logic between incoming, busbar and outgoing line switches, use a combination of mechanical and electrical interlocking to prevent misoperation, and strictly set the protection values at all levels to ensure selective action in case of fault. In situations where high power supply reliability is required, a double busbar connection method can be adopted to ensure that each outgoing circuit has an independent power supply and can be powered by any section of the busbar.

After the main wiring scheme is determined, the relay protection setting calculation should be carried out immediately to ensure that the system can operate safely and stably in all operating modes.

4.2 Refine the configuration design of low-voltage switchgear to ensure the safe distribution of power circuits

4.2.1 Reasonably design the selection of circuit breaker parameters for low-voltage switchgear based on load classification and protection coordination requirements

The rated current is determined based on the calculated current, taking into account the temperature coefficient, and the rated breaking capacity is greater than the short-circuit current at the installation point. Frame-type or molded case circuit breakers are selected for the side close to the transformer, and miniature circuit breakers can be chosen for the terminal circuit. The upper and lower level circuit breakers should meet the requirements of selective fit, and the three-stage protection values should be reasonably set. For special loads such as motors and frequency converters, circuit breakers with special motor protection functions should be selected. After completing the circuit breaker selection, perform a step-by-step inspection of the stepped differential coordination to verify compliance with specified requirements, thereby avoiding malconfiguration-induced skip-level tripping and consequent expansion of power outage scope. In addition, the number of operations and service life of the circuit breaker should also be considered to ensure that the selected equipment can meet the requirements of continuous operation in the process production.

4.2.2 Standardize the layout of busbars and secondary circuits in low-voltage switch cabinets to ensure power distribution safety and maintenance convenience

The cross-sectional area of the main busbar should be determined based on the maximum load current and by a combination of dynamic and thermal stability checks. The busbar connection should be made by reliable crimping or bolt fastening to eliminate the risk of excessive contact resistance. The specifications, numbers and binding of secondary circuit conductors should be uniformly standardized. Different functional circuits should be physically isolated to avoid strong and weak electrical interference, ensure the normal operation of relay protection devices and facilitate future maintenance and inspection. Infrared temperature detection should be carried out regularly on busbars and connection points to detect and deal with abnormal temperature rise points in a timely manner. The drawings and data of the secondary circuit should be consistent with the actual situation on site, and should be updated and filed in a timely manner when the project changes to provide accurate and reliable basis for operation and maintenance personnel.

4.3 Strengthen the intelligent integration of high and low voltage switchgear to enhance the monitoring efficiency of the power supply and distribution system

4.3.1 Integrate intelligent measurement and control units and communication modules to achieve real-time monitoring of the operating status of switchgear

High-voltage switchgear should be equipped with multi-functional intelligent measurement and control devices to collect parameters such as voltage, current, power and power quality in all directions and transmit them to the monitoring system through standard communication interfaces. Smart meters or multifunctional modules should be installed on the low-voltage side to monitor the load of each circuit in detail. The communication network architecture should rationally plan the

bus or industrial Ethernet topology according to the system size, and the selected protocol should be compatible with the factory's existing automation system. Intelligent measurement and control devices should have the function of local storage, which can preserve important operational data in the event of communication interruption and ensure data integrity and traceability. Before the system is put into operation, all measurement and control units should be tested to ensure that the accuracy of data acquisition and the stability of communication transmission meet the requirements of actual operation.

4.3.2 Build an integrated monitoring platform for power supply and distribution to support remote management and fault diagnosis of high and low voltage systems

The monitoring platform should graphically display the main wiring diagram, operating parameters and alarm information in real time, so that on-duty personnel can quickly grasp the status of the system. For switchgear with remote operation conditions, the platform should support remote opening and closing, and set up permission classification and secondary confirmation. The platform should also have the functions of automatic analysis of fault recording waves and in-depth analysis of historical trends, gradually creating predictive maintenance models to shift operation and maintenance from passive to active. The construction of the platform should take into account the requirements of data security protection and use methods such as network isolation to ensure that external attacks do not affect the normal operation of the power supply and distribution system. As the number of operational data increases, the platform analysis model should be constantly updated and improved to enhance the accuracy and timeliness of fault prediction.

4.4 Improve the operation and maintenance management mechanism of switch cabinets to ensure the long-term stable operation of the power supply and distribution system

4.4.1 Establish a hierarchical preventive maintenance system to effectively reduce the risk of sudden equipment failures

Based on the manufacturer's technical documents and industry standards, formulate maintenance cycles and operation contents for high and low voltage switchgear respectively. For the high-voltage side, inspections focus primarily on circuit breaker contacts and insulation; for the low-voltage side, key tasks include infrared thermography and busbar bolt tightening checks. The maintenance system is carried out in three levels: annual overhaul, quarterly live inspection, and monthly visual inspection. Each level forms a standardized operation guidance card, effectively reducing the probability of sudden failures. After each maintenance operation, a maintenance record should be filled out immediately, and defects should be classified and dealt with according to urgency to ensure that hidden dangers are eliminated within the prescribed time. Maintenance personnel should also conduct regular skills training and emergency drills to improve their ability to quickly judge and handle various abnormal situations of the equipment.

4.4.2 Strengthen fault data recording and operation and maintenance analysis to promote the shift of maintenance mode to on-demand maintenance

A unified fault information registration system should be established, with detailed records made of the time, phenomenon, handling process and cause analysis of faults, to form a traceable equipment archive database. After systematic statistical analysis of historical data, big data and artificial intelligence algorithms are gradually adopted to build equipment health assessment models, so as to achieve the purpose of early warning of potential faults and promote the transformation of operation and maintenance management from planned regular maintenance to on-demand

maintenance based on the actual condition of the equipment. The results of the fault analysis should be formed into special reports on a regular basis and fed back to the equipment selection and system design stages to promote the continuous improvement and enhancement of engineering quality. The operation and maintenance management department should also establish a cross-professional collaboration mechanism to ensure that electrical, instrumentation, process and other specialties can cooperate with each other in fault handling and daily maintenance, so as to achieve the long-term stable operation effect of the power supply and distribution system. Combining four optimized paths, each path is hierarchically progressive and coordinated to form a complete system for the design and application of high and low voltage switchgear in the factory's power supply and distribution system, as shown in Figure 1.

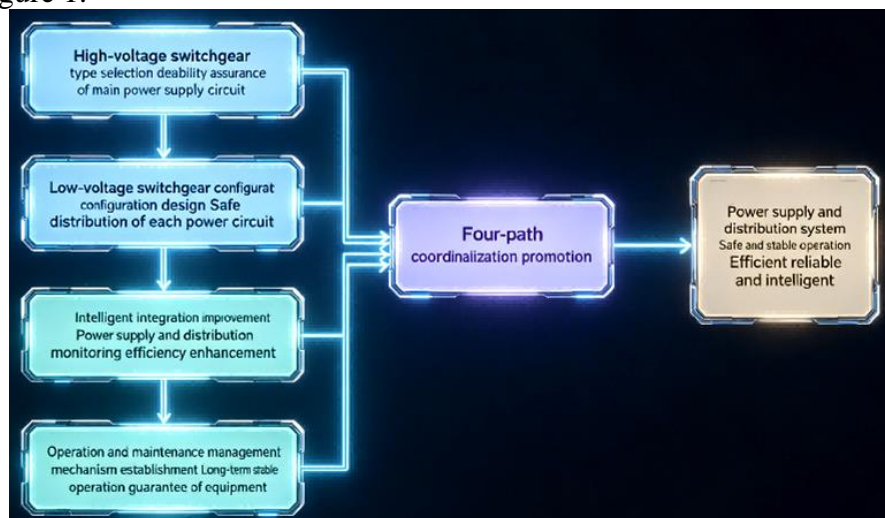


Figure 1 Framework of path design and application of high and low voltage switchgear schemes for factory power distribution system

5. Conclusion

The design and application of high and low voltage switchgear in factory power supply and distribution systems are fundamental to ensuring the safe, reliable and efficient operation of factory power systems. This is not only related to the continuous stability of factory production and the safety of personnel and equipment, but also requires engineers, technicians and managers to incorporate load characteristic analysis, protection parameter calculation, environmental condition assessment, intelligent function planning and other links into the entire process of scheme design in their actual work, to coordinate various technical decisions with systems thinking and prevent overall hidden dangers caused by partial negligence. Looking ahead, with the deepening of digital transformation in factories and the widespread use of new power technologies, high and low voltage switchgear will continue to develop towards higher integration, stronger intelligence and better reliability, bringing the management of power supply and distribution systems in factories into a more refined and efficient new stage.

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