IMPROVING RELIABILITY AND POWER RESERVE THROUGH DIGITAL MODERNIZATION OF SUBSTATIONS IN URBAN DISTRIBUTION ELECTRICAL NETWORKS

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Abstract

This thesis examines the issues of improving power supply reliability, forming a power reserve and reducing operational risks through the digital modernization of high-voltage substations in urban distribution electrical networks. The study analyzes the role of 110/35/10 kV substations in urban power supply systems, the technical condition of existing switching devices and relay protection facilities, short-circuit current withstand capability, the degree of transformer capacity utilization and redundancy requirements under prospective load growth conditions. Using the Sagban 110/35/10 kV substation as an example, the technical importance of replacing obsolete oil circuit breakers with modern vacuum and SF6 switching devices, introducing complete switchgear on the 10 kV side, applying microprocessor-based relay protection and automation systems, and reorganizing the auxiliary power supply system is substantiated. The analysis shows that substation modernization is not merely a process of equipment replacement, but a comprehensive engineering solution that ensures the preparedness of the electrical network for future load growth, improves reliability and expands the ability to manage emergency operating conditions.

Keywords digital substation, modernization, power supply reliability, power reserve, microprocessor-based relay protection, vacuum circuit breaker, short-circuit current, urban electrical network, N–1 criterion.

Introduction

In urban power supply systems, substations are the main technical link in the

process of receiving, transforming and distributing electrical energy to consumers. In particular, 110/35/10 kV substations perform the function of connecting high-voltage networks with medium-voltage distribution networks. Their reliable and stable operation directly affects the continuity of power supply to industrial facilities, public utility consumers, social infrastructure and the population.

In recent years, the growth of electrical loads in urban areas, the development of new residential districts, service facilities, small industrial enterprises and transport infrastructure have sharply increased the requirements imposed on existing substations. Under such conditions, substations designed and commissioned in previous decades cannot always fully meet modern requirements for reliability, safety, automation and power reserve.

Modernization of substations in the traditional sense is not limited to replacing old equipment with new equipment. In a modern approach, this process includes improving the electrical scheme, selecting equipment resistant to short-circuit currents, introducing microprocessor-based relay protection and automation systems, providing the auxiliary power supply system with reliable sources, digitalizing operational control and approaching the N–1 reliability criterion.

From this point of view, the modernization of urban substations such as the Sagban 110/35/10 kV substation is not only the solution of a local technical problem, but also a strategically important engineering task aimed at ensuring the stability of urban distribution networks, their ability to accommodate future loads and the safety of power supply.

The purpose of this thesis is to substantiate the scientific and technical significance of improving power supply reliability, forming a power reserve and reducing operational risks through the digital modernization of substations in urban distribution electrical networks.

Research Methodology

The study evaluates the process of modernizing urban substations on the basis of a comprehensive systems approach. The main attention is focused on the existing technical condition of the substation, its electrical scheme, the service life of switching devices, resistance to short-circuit currents, the functional capabilities of relay protection and automation systems, and the provision of power reserve under conditions of prospective load growth.

The methodological approach includes the following stages: analysis of the existing electrical scheme and equipment condition of the substation; assessment of electrical load growth and prospective power demand; calculation of short-circuit currents; verification of equipment in terms of thermal and electrodynamic stability; justification of the need to replace oil switching devices with modern vacuum or SF6 apparatus; and analysis of the effect of introducing microprocessor-based relay protection and automation systems on reliability.

The evaluation of short-circuit currents is one of the main criteria for the correct selection of substation equipment. In the general case, the three-phase short-circuit current is estimated using the following relationship:

$$I_k = U / (\sqrt{3} \cdot Z\Sigma) \quad (1)$$

where: I_k is the short-circuit current, kA; U is the calculated voltage, kV; ZΣ is the total equivalent impedance up to the short-circuit point.

When assessing the loading level of a substation, the transformer loading coefficient is also of great importance:

$$K_{load} = Sactual / Srated \quad (2)$$

where: Kload is the transformer loading coefficient; Sactual is the actual or calculated load, MVA; Srated is the rated power of the transformer, MVA. These expressions serve to evaluate the technical compatibility of equipment, the reserve level and the possibility of stable operation under prospective load conditions during the modernization process.

Main Part

The reliability of substations in urban distribution electrical networks is determined by several factors. These include the redundancy capability of the electrical scheme, the capacity of power transformers, the service life of switching devices, the selectivity of relay protection, the stability of the auxiliary power supply system and the degree of automation of operational control.

The Sagban 110/35/10 kV substation is an important node in the urban power supply system. It receives electrical energy from the 110 kV high-voltage network and distributes it to consumers of different categories through 35 kV and 10 kV networks. The long-term operation of this substation leads to physical and moral ageing of some equipment, an increase in maintenance costs and a rise in operational risks.

The first important direction of modernization is the replacement of obsolete switching devices. Although oil circuit breakers were widely used in their time, today they have a number of disadvantages: the presence of a large amount of oil, high fire and explosion risk, complexity of maintenance, limited switching life and environmental risk in emergency conditions. Therefore, replacing them with vacuum or SF6 circuit breakers is an important condition for improving substation safety and reliability.

Vacuum circuit breakers are characterized by high switching life, fast operation, low fire risk and low maintenance requirements. They are especially effective at voltage levels of 10–35 kV. SF6 switching devices, in turn, are distinguished by high dielectric strength, compactness and stable switching characteristics in high-voltage installations.

The second direction of modernization is the reorganization of the 10 kV side of the substation on the basis of complete switchgear. Modern KRU or KRUN-type switchgear units have a high level of factory readiness, compactness, ease of maintenance, a high level of safety and the ability to integrate with microprocessor-

based protection devices. Such a solution enables rapid detection of emergency conditions in 10 kV networks, local disconnection of the damaged feeder and continued operation of healthy feeders.

The third important direction is the introduction of microprocessor-based relay protection and automation systems. Although traditional protection devices based on electromechanical relays have served reliably for many years, from the viewpoint of modern requirements their functional capabilities are limited. Microprocessor-based terminals can simultaneously perform protection, automation, measurement, event recording, diagnostics and communication functions.

The introduction of such devices makes it possible to disconnect faults quickly and selectively, record emergency processes and analyze them afterwards, create opportunities for remote monitoring and diagnostics, reduce the influence of the human factor, select relay protection settings more accurately and flexibly, and effectively organize automatic reclosing and automatic reserve switching systems.

The fourth direction of modernization is the formation of a power reserve. Under conditions of continuously increasing electrical loads in urban areas, substation transformers must be able to cover not only the current load but also the demand of future years. In this regard, the N–1 criterion is of particular importance. According to this criterion, even if one main element of the substation fails or is taken out for maintenance, the majority of consumers should not be left without power supply.

In the case of the Sagban substation, the two-transformer scheme is considered appropriate from the standpoint of ensuring a power reserve. If the transformers are correctly selected and the scheme is sufficiently sectionalized, load redistribution becomes possible in emergency or maintenance conditions. This significantly increases the reliability of power supply for consumers of the first and second reliability categories.

The fifth direction is the modernization of the auxiliary power supply system. The auxiliary needs of a substation are the energy source required for the operation of relay protection, automation, signalling, communication, lighting, heating and control circuits. If the auxiliary power supply system is unreliable, the ability to control and protect the substation in emergency conditions becomes limited. Therefore, transferring auxiliary transformers to an appropriate voltage level, organizing reserve sources and supplying operational circuits with battery banks and rectifier devices are of great importance.

Thus, digital modernization of a substation includes a set of interrelated technical solutions: renewal of switching devices, reorganization of 10 kV distribution equipment, introduction of microprocessor-based relay protection and automation, provision of power reserve, improvement of the reliability of the auxiliary power supply system and enhancement of operational safety.

Results and Discussion

The analysis carried out using the Sagban 110/35/10 kV substation as an example shows the need for an integrated approach to the modernization of urban substations. Replacing only one item of equipment or only increasing transformer capacity is not sufficient. To achieve a stable result, the electrical scheme, switching devices, relay protection, auxiliary power supply system and operational control must be considered as a single system.

The main directions of modernization and the expected technical results are summarized below.

Table 1. Main directions of digital substation modernization and expected results

Modernization direction	Existing problem	Proposed solution	Expected result

Switching devices	Oil circuit breakers, high maintenance requirements	Vacuum and SF6 circuit breakers	Safety and switching reliability increase
10 kV switchgear	Old cells, limited diagnostics	Modern KRU/KRUN cells	Feeder selectivity and maintenance convenience increase
Relay protection and automation	Electromechanical relays, limited functionality	Microprocessor-based terminals	Speed, selectivity and fault analysis improve
Power reserve	Limited reserve under load growth conditions	Two-transformer scheme and N–1 approach	Ability to accommodate prospective loads increases
Auxiliary power supply system	Limited reliability of operational circuits	Reserved auxiliary supply and battery-backed power	Control stability in emergency mode increases
Operational safety	Fire risk and maintenance risk	Modern devices and digital monitoring	Personnel safety and operational stability increase

The table shows that digital modernization affects all main functional areas of the substation. In particular, the combined use of microprocessor-based protection devices and modern switching apparatus makes it possible to quickly detect emergency processes in the electrical network, locally disconnect the damaged part and keep healthy sections in operation.

From the reliability viewpoint, the most important result of modernization is the increase in the redundancy capability of the substation. This not only reduces the number of accidents, but also makes it possible to limit their impact area when an

accident occurs. As a result, power supply interruptions for consumers decrease, while the technical stability of the network increases.

From the energy efficiency viewpoint, modern transformers, low-loss switching devices, correctly selected equipment and an optimal electrical scheme contribute to reducing technical losses in the substation. In addition, operating equipment under normal loading conditions reduces heating, preserves insulation life and decreases repair costs.

Therefore, the modernization of substations such as Sagban should be regarded not as a technical measure at the level of a single facility, but as an investment-engineering solution that ensures the long-term stability and energy security of the urban power supply system.

Conclusion

Digital modernization of substations in urban distribution electrical networks is one of the important directions for improving power supply reliability, forming a power reserve and reducing operational risks. The analysis carried out using the Sagban 110/35/10 kV substation as an example shows that, in order to adapt existing substations to modern requirements, it is necessary not merely to replace individual items of equipment, but to comprehensively improve the electrical scheme, switching devices, relay protection, auxiliary power supply system and power reserve.

Replacing oil circuit breakers with vacuum and SF6 apparatus, introducing modern KRUN cells on the 10 kV side, using microprocessor-based relay protection and automation, reorganizing the auxiliary power supply system and approaching the N–1 reliability criterion significantly increase the operational stability of the substation.

The results of the study show that substation modernization serves not only to improve power supply reliability, but also to ensure the readiness of urban electrical networks for prospective load growth, reduce emergency risks and use energy resources efficiently. In this respect, digital modernization can be assessed as a

direction of technical, economic and strategic importance in modern electric power engineering.

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