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REDUCING ENERGY LOSSES AND IMPROVING RELIABILITY IN 110/10 kV SUBSTATIONS THROUGH THE APPLICATION OF ENERGY-EFFICIENT TRANSFORMERS AND SF_6 CIRCUIT BREAKERS

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Abstract

This thesis examines the issues of reducing energy losses, improving power supply reliability and decreasing operational risks in 110/10 kV distribution substations through the application of energy-efficient power transformers and SF_6 circuit breakers. The study analyzes no-load and load losses in power transformers, the technical condition of high-voltage switching equipment, operational limitations of oil circuit breakers, and the advantages of modern SF_6 switching devices. The modernization process is evaluated not merely as the replacement of separate equipment, but as an integrated engineering solution aimed at ensuring the energy efficiency, switching reliability, environmental safety and long-term operational stability of a substation. The research results show that the use of energy-efficient transformers and modern high-voltage circuit breakers is of significant importance for reducing technical losses, simplifying maintenance procedures, lowering fire risk and ensuring stable operation of the electrical network.

Keywords: 110/10 kV substation, energy-efficient transformer, SF_6 circuit breaker, energy losses, technical losses, switching reliability, modernization, power supply reliability, environmental safety.

Introduction

In the electric power system, substations are one of the main technical links in the process of receiving electrical energy, transforming voltage and distributing power to consumers. In particular, 110/10 kV distribution substations serve as an important connecting element between high-voltage networks and medium-voltage distribution networks. Their reliable and efficient operation is directly related to uninterrupted power supply to consumers, maintaining voltage quality and reducing technical losses in electrical networks.

In global power engineering practice, the modernization of existing substations is not considered only as the process of replacing old equipment with new equipment. In the modern approach, this process is assessed as an integrated engineering strategy aimed at increasing energy efficiency, strengthening reliability, reducing maintenance costs, decreasing emergency risks and ensuring environmental safety.

The main energy losses in substations are usually associated with power transformers, switching devices, current-carrying parts and auxiliary power systems. In particular, in transformers that have been in operation for a long period, no-load and load losses may increase as a result of aging of the magnetic core and insulation materials, an increase in winding resistance and a decrease in the efficiency of the cooling system. This negatively affects the overall energy efficiency of the substation.

At the same time, high-voltage oil circuit breakers also have certain limitations from the point of view of modern requirements. They are characterized by complicated maintenance, high fire risk, the need to monitor and replace transformer oil, aging of the contact system and operational risks. Therefore, replacing such equipment with SF_6 circuit breakers is an important direction for improving switching reliability and operational safety.

The purpose of this thesis is to substantiate the scientific and technical significance of reducing energy losses, improving reliability and ensuring the long-term operational

stability of 110/10 kV substations through the application of energy-efficient transformers and SF_6 circuit breakers.

Research Methodology

The study evaluates the energy, operational, economic and environmental effects of modernizing the main electrical equipment in 110/10 kV distribution substations on the basis of an integrated approach. The main attention is focused on technical losses in power transformers, reliability of switching devices, energy consumption of auxiliary power systems and indicators of operational stability after modernization.

The methodological approach includes the following stages:

– analysis of the operating modes of power transformers in 110/10 kV substations;

– assessment of the influence of no-load and load losses on energy efficiency;

– substantiation of the possibility of applying modern energy-efficient transformers;

– analysis of the impact of replacing oil circuit breakers with SF_6 circuit breakers on reliability and safety;

– consideration of additional energy-saving opportunities through optimization of auxiliary power and lighting systems;

– evaluation of the technical and economic efficiency of modernization on the basis of a general methodological approach.

When assessing energy losses in transformers, no-load and load losses are considered separately. In general, power losses in a transformer can be expressed as follows:

$$\Delta P = \Delta P_0 + \Delta P_k \cdot \beta^2$$

where: ΔP is the total power loss in the transformer; ΔP_0 is the no-load loss; ΔP_k is the short-circuit or load loss; β is the transformer loading coefficient.

The annual energy savings resulting from modernization can generally be estimated using the following expression:

$$\Delta W = (Pold - Pnew) \cdot T$$

where: ΔW is the annual saved electrical energy; Pold is the loss power before modernization; Pnew is the loss power after modernization; T is the annual operating time.

The economic efficiency of the project, when necessary, is evaluated through the ratio of capital expenditures to the annual economic effect:

$$\mathbf{Tpayback = K / Eyear}$$

where: Tpayback is the payback period of the investment; K is the capital cost for modernization; Eyear is the annual economic effect. These formulas make it possible to assess the technical and economic efficiency of substation modernization on the basis of a general scientific methodology without disclosing specific facility data.

Main Part

In 110/10 kV substations, power transformers are the main equipment that transforms electrical energy from high voltage to medium voltage. The energy efficiency of transformers directly affects the overall operating efficiency of the substation. In transformers that have been operated for a long time, energy losses may increase due to losses in the magnetic core, active resistance of windings and aging of insulation materials.

Modern energy-efficient transformers are distinguished by low-loss electrical steel, improved winding design, an enhanced insulation system and efficient cooling methods. In such transformers, no-load losses decrease, load losses are reduced and the efficiency of the transformation process increases. At the same time, modern on-load tap changer systems make it possible to regulate voltage more accurately under load, which contributes to improving voltage quality in distribution networks.

Another important direction of modernization is the renewal of high-voltage switching equipment. Although oil circuit breakers have historically been widely used in electrical networks, they have operational limitations. They use a large volume of

transformer oil, require significant maintenance, may experience increased contact resistance due to aging of the contact system and have a high fire risk.

SF_6 circuit breakers are an effective technical solution for eliminating these problems. Sulfur hexafluoride gas has high dielectric strength and arc-quenching capability, which allows switching operations to be performed safely and reliably. SF_6 circuit breakers are characterized by compact design, high switching endurance, minimal maintenance requirements and high reliability.

Replacing oil circuit breakers with SF_6 circuit breakers can provide the following technical advantages:

– switching reliability increases;

– the risk of emergency tripping decreases;

– fire risk is reduced;

– maintenance is simplified;

– operational costs are reduced;

– environmental risks decrease.

The auxiliary power system also plays an important role in substation modernization. The auxiliary power system supplies the energy required for relay protection, automation, telemechanics, signaling, lighting, ventilation, cooling systems and the drives of switching devices. The efficient organization of this system is essential for stable operation of the substation in normal, emergency and post-emergency modes.

In the modern approach, it is advisable to use energy-efficient lighting equipment, efficient ventilation and heating systems, reliable operating current sources and automated monitoring tools when optimizing the auxiliary power system. This reduces the internal energy consumption of the substation while improving the safety and reliability of maintenance processes.

Thus, the modernization of 110/10 kV substations includes several interrelated directions: the use of energy-efficient transformers, the introduction of SF_6 circuit breakers, optimization of the auxiliary power system, simplification of maintenance and improvement of environmental safety. This approach helps transform a substation into a modern, reliable and energy-efficient power facility.

Results and Discussion

The analysis results show that the application of energy-efficient transformers and SF_6 circuit breakers in 110/10 kV substations is of significant importance for reducing energy losses and improving reliability. As a result of modernization, no-load and load losses in transformers decrease, the operational reliability of switching devices increases, energy consumption of the auxiliary power system is optimized and maintenance procedures are simplified.

The main modernization directions and expected results are summarized below.

Table 1. Main directions of substation modernization and expected results

Modernization direction	Existing problem	Proposed solution	Expected result
Power transformers	Increase in no-load and load losses	Use of energy-efficient transformers	Technical losses decrease and efficiency increases
Switching devices	Complicated maintenance and fire risk in oil circuit breakers	Introduction of SF_6 circuit breakers	Switching reliability and safety increase
Auxiliary power system	Internal energy consumption and operational load	Efficient lighting, ventilation and operating supply solutions	Internal energy consumption is optimized

Maintenance	High costs of scheduled repair and inspection	Equipment requiring low maintenance	Operation is simplified
Environmental safety	Oil leakage and fire risk	Oil-free or lower-risk switching technologies	Environmental risks decrease
Power supply reliability	Emergency risks due to equipment aging	Modern transformers and switching devices	Long-term stability is ensured

As can be seen from the table, substation modernization is not limited only to energy saving. It simultaneously improves power supply reliability, operational safety, environmental sustainability and maintenance efficiency.

The use of energy-efficient transformers contributes to reducing losses in the transformation process at the substation. This makes it possible not only to save electrical energy, but also to reduce equipment heating, preserve insulation life and lower the probability of emergency conditions. SF_6 circuit breakers improve reliability in high-voltage switching processes and provide safer operating conditions compared with oil-filled devices.

The research results show that the most appropriate approach to modernizing 110/10 kV substations is the joint assessment of technical, energy, economic and environmental factors. This is because replacement of separate equipment may provide a short-term result, whereas sustainable effectiveness can be achieved only through the comprehensive improvement of transformers, switching devices, auxiliary power systems and operational management.

Conclusion

The application of energy-efficient transformers and SF_6 circuit breakers in 110/10 kV substations is an important technical solution for reducing energy losses,

improving power supply reliability and decreasing operational risks. The modernization process should not be limited to the renewal of a separate substation element, but should be aimed at the comprehensive improvement of transformation, switching, auxiliary power, safety and environmental sustainability systems.

Energy-efficient transformers contribute to reducing no-load and load losses, stabilizing voltage and increasing the operational life of equipment. SF_6 circuit breakers, in turn, are characterized by high switching endurance, reliable arc quenching, low maintenance requirements and a high level of safety.

The research results show that such modernization contributes to improving the energy efficiency of 110/10 kV substations, simplifying maintenance procedures, reducing fire and environmental risks, and ensuring the long-term stability of electrical networks. In this regard, modernization based on energy-efficient transformers and SF_6 circuit breakers can be assessed as an engineering solution of strategic importance for modern electric power systems.

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