REDUCING ENERGY LOSSES AND IMPROVING VOLTAGE STABILITY BASED ON OPTIMAL REACTIVE POWER COMPENSATION IN HIGH-VOLTAGE SUBSTATIONS

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Abstract

This thesis examines the issues of reducing electricity losses, stabilizing voltage regimes and improving the energy efficiency of the power supply system through optimal reactive power compensation in high-voltage substations. The study analyzes the effect of reactive power on current loading, active power losses, voltage drop and the operating mode of power transformers. Based on the example of the Fayzobod 220/110/10 kV substation, the technical significance of rationally distributed reactive power compensation at the 110 kV and 10 kV voltage levels is substantiated. The possibilities of increasing the power factor, reducing reactive power flows, decreasing transformer loading by apparent power and improving voltage quality through the use of static capacitor banks are considered. The analysis results show that reactive power compensation should be considered not only as a separate device, but also as an integrated technical solution for optimizing the energy operating mode of a substation.

Keywords: reactive power, compensation, high-voltage substation, static capacitor bank, energy losses, voltage stability, power factor, power supply, energy efficiency.

Introduction

Efficient use of energy resources, reduction of technological losses and improvement of power supply reliability in electric power systems are among the

important scientific and practical tasks of the present time. The stable operation of electrical networks depends not only on the volume of generated electricity, but also on the proper organization of regimes during its transmission, distribution and delivery to consumers.

High-voltage substations are the main nodes of an electric power system, through which large amounts of electricity are received, transformed and distributed to consumers at different voltage levels. In such substations, power transformers, autotransformers, busbars, switching devices and outgoing lines operate under high current loads. Therefore, rational management of active and reactive power flows is of great importance.

In electrical networks, active power is used to perform useful work. Reactive power is mainly required to create magnetic fields in transformers, asynchronous electric motors, pump units, ventilation equipment and other inductive loads. Although reactive power does not perform useful work, its excessive circulation through the network causes an increase in currents, growth of active power losses, voltage drop and overloading of electrical equipment in terms of apparent power.

From this point of view, reactive power compensation is one of the important technical directions for improving energy efficiency in high-voltage substations. However, this process should not be limited only to the installation of a compensating device. In optimal reactive power compensation, the capacity of the compensating device, its installation point, voltage level, load characteristics and the general operating regimes of the substation must be taken into account.

Research Methodology

The study used methods for assessing the influence of reactive power on the operating regimes of a high-voltage substation, analyzing changes in the power factor, comparing the efficiency of compensating devices and substantiating the use of SCB — static capacitor banks.

For a quantitative assessment of reactive power compensation, the required compensating power is determined by the following expression:

$$\mathbf{Q_k = P \cdot (tg\varphi_1 - tg\varphi_2)} \quad (1)$$

where: Q_k is the reactive power of the compensating device, MVAr; P is active power, MW; φ_1 and φ_2 are the phase shift angles before and after compensation.

When reactive power flows decrease, the current passing through the network decreases. This directly affects active power losses, because losses in network elements are expressed by the following relationship:

$$\mathbf{\Delta P = 3 \cdot I^2 \cdot R} \quad (2)$$

where: ΔP is active power loss; I is current; R is the active resistance of a line, busbar or transformer winding. This expression shows that a decrease in current reduces losses quadratically.

The methodological approach includes the following stages:

– analysis of the influence of reactive power on current loading and apparent power;

– assessment of the influence of reactive power flows on active power losses;

– consideration of possibilities for improving the network regime by increasing the power factor;

– comparison of options for placing compensating devices at 110 kV and 10 kV voltage levels;

– substantiation of the technical and economic advantages of static capacitor banks;

– assessment of the practical effect of compensation using the Fayzobod 220/110/10 kV substation as an example.

In the study, reactive power compensation was considered not only as a means of improving the power factor, but also as a technical solution for the integrated optimization of the energy operating mode of a substation.

Main Part

Excessive circulation of reactive power in electrical networks often causes an increase in energy losses. This situation is especially evident in large substations and urban power supply systems. This is because facilities of this type simultaneously operate loads of different character — industrial enterprises, pumping stations, ventilation systems, transport facilities, municipal and household consumers, and residential areas.

The Fayzobod 220/110/10 kV substation is one of the large energy nodes. It receives electricity from 220 kV and 110 kV networks and supplies it to consumers through 10 kV distribution networks. Power autotransformers and outgoing lines at the substation transmit large power flows. Therefore, reactive power flows have a significant impact on the energy efficiency of this substation.

Excessive reactive power flows increase the loading of power transformers and autotransformers by apparent power, increase current loading in lines and busbars, intensify active power losses and cause voltage instability. In addition, equipment heating increases, the insulation lifetime decreases and the network’s ability to transmit active power is reduced.

Since active power losses in electrical networks depend on the square of current, reducing reactive power in order to decrease current loading is of great importance. When the power factor is low, a larger current flows through the network to transmit the same active power. When the power factor improves, apparent power and current decrease, and as a result, losses in transformers and lines are reduced.

The essence of reactive power compensation is that part of the reactive power required by inductive loads is supplied not from the network, but through local compensating devices. In this case, static capacitor banks generate capacitive reactive power in the opposite direction to the inductive load. As a result, the reactive power

drawn from the network decreases, the power factor increases and the electrical network operates in a lighter mode.

Several factors are taken into account when selecting compensating devices. Although devices such as SVC and STATCOM provide fast and precise control, their cost is high and their operation is complex. Static capacitor banks, in contrast, are distinguished by simple design, high reliability, low operating costs and rapid economic effect. Therefore, for substations such as Fayzobod, where the load mainly changes slowly on a daily and seasonal basis, the use of SCB is considered appropriate.

Placing compensation at only one voltage level does not always provide the maximum effect. Centralized compensation on the 110 kV side reduces the reactive power passing through transformers and high-voltage networks. However, local reactive currents in 10 kV feeders may not be fully eliminated. Therefore, for large substations, combined compensation can be proposed as an optimal approach: the main compensation is placed on the 110 kV side, and additional compensation is placed near 10 kV feeders or consumer groups with the highest inductive load.

Using the Fayzobod 220/110/10 kV substation as an example, increasing the power factor from $\cos\varphi = 0.80$ to $\cos\varphi = 0.95$ can significantly improve the operating mode of the substation. In this case, the required compensation power is determined by calculation and a static capacitor bank is selected according to standard power ratings. This approach substantiates the idea of using static capacitor banks on the 110 kV side and, if necessary, applying additional compensation in 10 kV networks.

Results and Discussion

The research results show that reactive power compensation is an effective method for reducing energy losses and improving voltage stability in high-voltage substations. When compensating devices are used, the reactive power drawn from the network decreases, the power factor improves and loading by apparent power is reduced.

Under the conditions of the Fayzobod substation, increasing the power factor from 0.80 to 0.95 makes it possible to achieve the following technical effects:

Table 1. Expected technical effects as a result of optimal reactive power compensation

Indicator	Without compensation	After optimal compensation	Expected result
Power factor	$\cos\varphi \approx 0.80$	$\cos\varphi \approx 0.95$	The energy efficiency of the network increases
Reactive power flows	High	Decrease	Current loading decreases
Active power losses	Excessive	Reduced	Electricity is saved
Voltage regime	High probability of voltage drop	Stabilized	The quality of power supply improves
Autotransformer loading	High by apparent power	Reduced	Power reserve increases
Equipment operating mode	High influence on heating and insulation	Thermal load decreases	Reliability increases

The table shows that optimal reactive power compensation is not limited only to reducing electricity losses. It reduces the loading of transformers and lines, improves voltage quality, extends the service life of equipment and increases the operational stability of the substation.

At the same time, the correct placement of compensating devices is of particular importance. Centralized compensation on the 110 kV side provides a systemic effect for the high-voltage network and autotransformers. Additional compensation in 10 kV feeders brings the reactive power source closer to the consumer and further reduces

losses in distribution networks. Therefore, optimal compensation is not only the selection of a device, but also the process of scientifically substantiating its capacity, location and control mode.

From a technical and economic point of view, the use of SCB is highly effective. This is because these devices have a simple design, reliable operation and relatively low capital costs. The reduction of electricity losses as a result of reactive power compensation forms an economic effect. Therefore, such measures may occupy an important place in energy-saving programs.

Conclusion

Optimal reactive power compensation in high-voltage substations is an important technical solution for reducing energy losses, increasing the power factor and stabilizing voltage regimes. Excessive reactive power flows increase current loading in electrical networks, increase active power losses and negatively affect the operating condition of power equipment.

The analysis carried out using the Fayzobod 220/110/10 kV substation as an example shows that the use of static capacitor banks is an appropriate technical and economic solution for reactive power compensation. In particular, combining centralized compensation on the 110 kV side with local compensation in 10 kV networks makes it possible to comprehensively optimize substation operating regimes.

Thus, optimal reactive power compensation can be considered an important scientific and practical direction that ensures energy saving, improves voltage quality and increases the reliability of power supply in high-voltage substations.

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