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Energy efficiency improvement of 0.4 kV power supply systems in the far North districts

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Abstract. The article considers the method of energy efficiency improvement of 0.4 kV power supply systems for the enterprise located in the North of the Krasnoyarsk territory. The theoretical substantiation of the necessity of reactive power compensation is presented. The method for reducing reactive power in power supply networks through the use of devices compensating reactive power is proposed. The use of this method allowed reducing energy costs, as well as decreasing the level of reactive power in the network by 48.5% and 45% for the 1st and the 2nd inputs, respectively. Also, while using reactive power compensation devices for power supply networks, the following indicators can be achieved: the increase in the throughput capacity of electric networks, the reduction in active power losses and the rational electric energy use.

1. Introduction

According to the statistics, the main consumers of reactive power are alternating-current electric motors, mainly asynchronous electric motors, which account for about 70 % of the reactive power consumption, transformers consume about 20 % and various electrical machines and apparatus consume about 10 % [1].

Recently, the increase in the produced reactive power has been recorded, including domestic consumers. The reason for this is the increase in consumption of LED products, computer equipment, various household appliances, pumps and fans, etc.

For the normal operation of these loads, it is necessary to create a magnetic field, which in turn causes the appearance of reactive power in the system. Reactive power is the technical loss of electricity caused by electromagnetic processes in networks. At the same time it increases the load on the power supply and distribution system. The lack of it causes an increased heating of conductors and creates an excessive load on the network, resulting in the fact that an electricity source operates in the enhanced mode.

Reactive loads cause a decrease in voltage in power grids and lead to a deterioration in the power supply quality. In addition, power lines and transformer equipment are overloaded, resulting in increased capital costs for the construction and operation of power distribution stations [2]. This problem is particularly acute in the far North districts, where the construction or modernization of existing lines and facilities is rather problematic.

2. Materials and methods

The parameter for determining the active and reactive components of power, voltage and current is the cosine of the angle of the phase displacement (phase angle – $\cos\varphi$) between current and voltage. In electrical practice this parameter is called “power factor”.

$$cos\varphi = \sqrt{\frac{1}{1+\tan\varphi^2}}, \quad \tan\varphi = \sqrt{\frac{1}{\cos\varphi^2} - 1},$$

Since the electricity distribution system must be designed for full capacity, efforts are being made to improve its energy efficiency [3]. If capacitors of the appropriate size are installed parallel to the power consumer, the reactive current circulates between the capacitor and the consumer [4]. This means that this additional current does not flow through the rest of the distribution network. In this way, it is possible to achieve an optimal power factor close to one.

Reactive power Q_C, compensated by the capacitor is the difference between the inductive reactive power before the compensation Q1 and reactive power after compensation Q2

$$Q_C = Q1 - Q2$$

$$QC\ (VAR) = P\ (W) \cdot (tg\varphi1 - tg\varphi2)$$

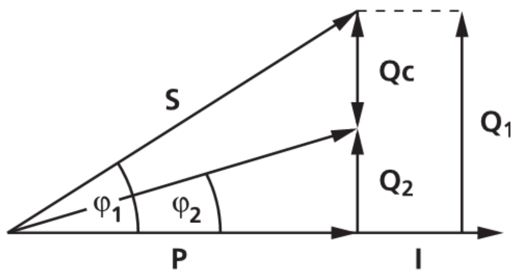

Figure 1. Power triangle illustrating the effect of reactive power compensation

Without compensation, the reactive current circulating between the power source and the consumer is converted into thermal energy in the power distribution system, which means that an additional load is created on generators, transformers, cables and distribution devices [5].

From the point of view of the power supply company, a low power factor leads to an increase in investment and maintenance costs, and these additional costs are passed on to those who are responsible for them, that is, to consumers with a low power factor. Therefore, in addition to the active energy meter, a reactive energy meter is installed [6].

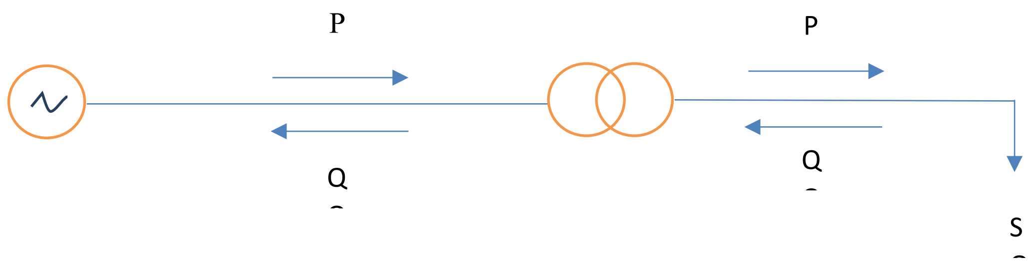

Figure 2. Active and reactive power

With a decrease in the power factor of consumers, losses of electric energy increase not only in the supply networks, but also in transformers and generators installed in power plants, so that with a significant decrease in the power factor, transformers and generators are so loaded with reactive currents that it becomes impossible to obtain from them the active power for which they are designed [7, 8]. At the same time, with a decrease in the power factor, voltage losses in the power supply networks increase due to an increase in current. In addition, with the increase in the power factor by reducing the reactive component of the total current, it is possible to increase its active component by connecting additional electricity consumers, and thereby ensure the full loading of generators and transformers in the power supply system of the production. Thus, the power factor shows what part of the total power is the active power, which is completely converted by the electricity consumer into other types of energy and does not return to the power supply network [9].

For reactive power, concepts such as: consumption, generation, transmission and loss are accepted. It is believed that if the current lags behind the phase of the voltage (inductive nature of the load), the reactive power is consumed, and if the current is ahead of the voltage (capacitive nature of the load), reactive power is generated [10].

3. Energy efficiency research of 0.4 kV power supply systems in the far North districts

The formula of the total power expression [10]:

$$\underline{S} = \dot{U}_{\Phi} \cdot \overset{*}{I} = UIe^{j\varphi} = UIcos\varphi + jUIsin\varphi = \sqrt{P^2 + Q^2}$$

where $\cos\varphi = \frac{P}{Q}$, $\tan\varphi = \frac{Q}{P}$, - are active and reactive power coefficients.

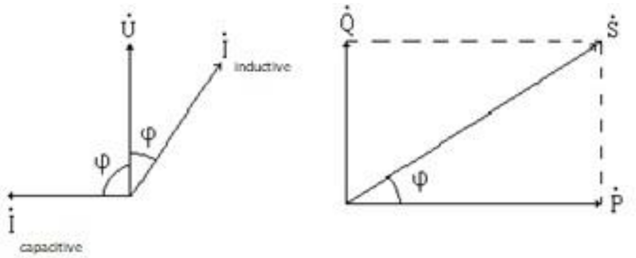

Figure 3. Active and reactive power

In terms of generation and consumption, there are significant differences between reactive and active power. If most of the active power is consumed by the receivers and only a small part is lost in the network elements, the reactive power losses in the network elements are commensurable with the reactive power consumed by the receivers.

The production of additional reactive power amount by power plant generators is not economically feasible for the following reasons:

1) When transmitting active and reactive power through an element of the power supply system with active resistance, the active power losses are:

$$\Delta P = \frac{P^2 + Q^2}{U^2} R = \frac{P^2}{U^2} R + \frac{Q^2}{U^2} R = \Delta P_P + \Delta P_Q$$

Additional active power losses ΔP_P, caused by the flow of reactive power through the network are proportional to its square. Large losses of active power and electricity in all elements of the power supply system require to bring the sources of reactive power closer to the places of consumption and to reduce transmission from electricity sources.

2) There are additional voltage losses. For example, when transferring power P and Q through an element of the power supply system with active and reactive resistance, the voltage losses are:

$$\Delta U = \frac{PR + QX}{U} = \frac{P}{U} R + \frac{Q}{U} R = \Delta U_R + \Delta U_Q$$

where $\Delta U_R, \Delta U_Q$ are voltage losses due to active and reactive power, respectively. As a result, the transfer of a significant amount of reactive power over the network can not be carried out due to an unacceptable voltage drop.

3) Reactive power loading of industrial power supply systems and transformers reduces their throughput capacity and requires an increase in the cross sections of wires and cable lines, an increase in the nominal power or the number of substation transformers, etc. [11, 12].

The following advantages of reactive power compensation can be noted.

Effective use:

- of generators (of power supply company), transformers, cable network, distribution devices;

- reduced losses;
- less voltage drop.

Among a number of advantages from the use of reactive power compensation devices, four main ones can be distinguished:

- Energy consumption saving.
- Increased service life period of equipment.
- Cost savings on the development of power supply networks.
- Improvement of energy supply quality.

The authors consider the measures aimed at reducing power losses on the example of distribution and transformer substation on the enterprise located in the North of the Krasnoyarsk territory. Table 1 presents the data of active and reactive energy consumption for the estimated period of 12 months.

Table 1. Active and reactive power consumption for 2017

Month	Active power, kW		Reactive power, kVAr	
	1st input	2nd input	1st input	2nd input
January	1100321.8	937634.9	973622.3	638393.4
February	1302453.2	1265989.0	1033478.2	947482.2
March	1311757.4	1290732.3	1083392.6	946593.4
April	1410228.1	1387629.2	1284739.3	1037644.7
May	1572965.0	1473294.4	1385955.5	1084946.4
June	1612566.7	1494328.8	1482802.4	1237491.3
July	1893018.4	1593741.1	1590322.2	1284649.5
August	1872673.5	1603465.5	1635351.7	1290733.4
September	1902342.7	1674839.4	1730436.3	1385458.1
October	2021344.1	1874639.8	1790362.1	1538043.4
November	1792452.3	1603623.3	1684733.8	1349402.4
December	1672876.3	1484639.7	1385635.3	1094854.4
Total	19464999.5	17684557.4	17060831.7	13835692.6

Table 2 presents the technical characteristics necessary to calculate the parameters of the line operation mode (the amount of generated reactive power, power factor).

Table 2. Technical data

Data	1st input	2nd input
Length of the cable line , m	3230	3040
Cable core section, mm2	240	240
Number of lines	2	2
Specific resistance Ohm/km	0.135	0.135

According to the Order of Ministry of Industry and Energy of the Russian Federation No. 49 as of 22.02.2007 “About the order of values calculation for the active and reactive power consumption ratio for separate power accepting devices (groups of power accepting devices) of electric power consumers applied to determination of the parties obligations in contracts on rendering services in electric energy transfer (power supply contracts)” the power factor $\tan\varphi$, which for voltage of 6 kV should be equal to 0,4 (it corresponds to $\cos\varphi$ = 0.928) is regulated.

Table 3 shows that the application of the method for energy efficiency improvement of 0,4 kV power supply systems for the enterprise located in the North of the Krasnoyarsk territory allowed reducing energy costs, as well as to decrease the level of reactive power in the network by 48.5% and 45% for the 1st and the 2nd inputs, respectively.

Table 3. Indicators of application of reactive power compensation devices (RPC)

Number of input	Consumption before compensation, kW/h	Consumption after compensation, kW/h	Reduction of active power consumption, kW/h
1st input	56606.98	27473.14	29133.84
2nd input	44654.40	20094.48	24559.92

4. Conclusion
Using reactive power compensation units for power supply networks, the following indicators can be achieved:
- the throughput capacity increase of electric networks;
- unloaded electrical equipment of substations;
- active power loss reduction;
- rational use of electrical energy.

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