Analysis of the Installation of the Equivalent Circuit and Vector Diagram of Transverse Compensation in Electrical Networks

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Abstract. This article analyzes the cross-compensation substitution scheme of reactive power compensation and the construction of a vector diagram. The main purpose of transverse compensation is to improve the power factor. In such compensation, power losses and voltage reductions have been analyzed for their pre-compensation and postcompensation States by placing capacitors in electrical grids. In addition the vector diagram of the transverse capacitance compensation chain and the vector diagram on the voltages at the beginning and end of the transverse compensatory network have been studied. In this case, the question of determining the C capacitance and reactive power Q_{kb} required to increase the power coefficient from cosφ1 to cosφ2 by exceeding the natural value of the consumer's power coefficient from the vector diagram to transverse compensation has been seen.

INTRODUCTION

In general reactive power compensation is the achievement of increasing the power coefficient. One of the important types of compensation is transverse compensation. In the compensating process, the greatest reduction in power losses in electrical networks is achieved by deploying capacitors. This makes it possible to increase the voltage level that is transmitted along with the placement of capacitors. This process will largely depend on the position where the capacitors are located.

It is known that under the influence of transverse compensation, in addition to the current load of the existing elements in the power supply system, it leads to a decrease in the voltage in the network and the appearance of a voltage ratio at the beginning and end of the power grid [1-2, 21-24, 37-39].

If there is a need for transverse capacitance compensation, this is done using capacitor devices installed in certain areas of the power supply system. To this end, it is necessary to consider alternating current electrical circuits to which electricity consumers and parallel capacitor batteries are connected to calculate and analyze cross-compensation as a reactive power source [3-6, 25-27, 35-36].

LITERATURE SURVEY

In cross-compensation analysis, a circuit is obtained in which the electricity consumer and capacitor batteries are connected in parallel. The network currents in Node a of the usbu Circuit Switching Scheme are found based on the equation in which Kirchhoff's first law is constructed (Fig.1) [7-8, 28-31]. According to him IL tok is defined as follows:

$$\dot{I}_L=\dot{I}_d+\dot{I}_{KB} \tag{1}$$

where $\dot{I}_L$, $\dot{I}_d$, $\dot{I}_{KB}$-are the vector values of the currents in the network, charge and capacitor batteries, respectively.

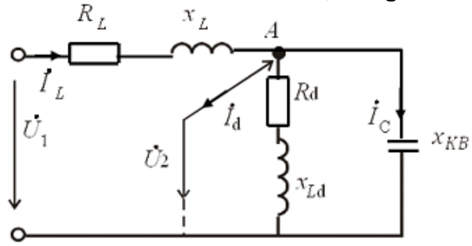

FIGURE 1. Transverse capacitance compensation replacement scheme

In accordance with Kirchhoff's first law (1), the construction of the flow and Vector diagram of the current vectors is shown in Fig.2.

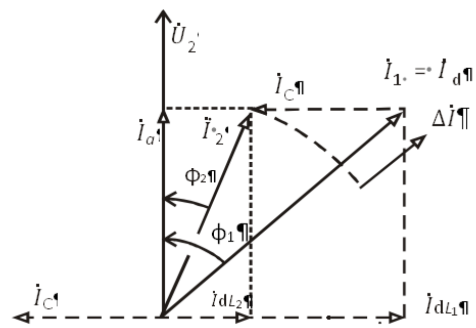

FIGURE 2. Vector diagram of cross-capacitive compensation in a circuit

Transverse compensation, as a vector diagram for a network consisting of a load at the end of the network to which the X_{kb} capacitor battery is connected. Although this does not take into account the active resistance of the capacitor battery. Since the capacitor battery is connected in parallel with the consumer, the consumer's load current to the φ_1-angle φ_2- - angle decreases from the I_1 value to the I_2 value. In this, the amount of current in the network decreases, i.e. $\Delta I = I_1 - I_2$. In the power supply system, the current is reduced by the same amount in electrical consumers as the existing generators and capacitor generate Q_{KB} reactive power from where the batteries are installed. The active and reactive organizers of reactive power waste ΔP_q and ΔQ_q are reduced due to reduced load on the network and generators. As a result, the total reactive power capacitor battery is reduced to Q_{KB} power [7-8, 32-34].

$$\Delta P = \left(\frac{Q_{KB}}{U}\right)^2 \cdot R\,; \qquad \Delta Q = \left(\frac{Q_{KB}}{U}\right)^2 \cdot x \tag{2}$$

here R and X -are the active and reactive resistance of energy system consumers.

The cross-sectional surface of the conductor being selected for the projected network is found as follows.

$$\Delta F = \frac{\Delta I}{j_e} \tag{3}$$

where ΔI- is the decrease in network Current; J_e- is the economic density of network Current.

Accordingly, a voltage drop occurs on the network in accordance with the nominal power reduction of the transformer. As a result, the capacitor connected to the network reduces the voltage drop at the expense of the Q_{KB} of power in the battery and is found as follows [15-18, 40-43]:

$$\Delta U = \frac{P \cdot R + (Q - Q_{KB}) \cdot XU}{U}. \tag{4}$$

However, when the installed capacity of the capacitor banks significantly exceeds the required level, the reactive current may become larger than the consumer's inductive current. In such a case, the inequality $I_{BK} > I_{dI}$ holds, leading to overcompensation and a shift of the power factor into the capacitive region. Then the angle φ_2 is less than zero and the power factor passes through $cos\varphi=1$ and the power is in the quadrant of the capacitance. The result is excessive compensation. Capacitance Current flows from the consumer to the source, and the network Current increases with an increase in I_c capacitance current. In this case, the increase in the capacity of C and the dependence on the I_L network Current corresponds to the angle φ_2 in a certain range, that is, it is recommended to have a limit $\varphi_2 \geq 0$ and $cos\varphi \leq +1$. The vector diagram is shown in Fig.2 [18-21, 44-48].

To increase the natural power factor before applying cross-compensation, it will be necessary to increase the $cos\varphi_1$ power factor at the start of the network to a higher value of the $cos\varphi_2$ power factor at the end of the network.

In this, the vector allows you to determine the reactive power of the C capacitance and capacitor battery, which will be necessary using the diagram, and the I_c current is found as follows:

$$I_C=I_{dL1}-I_{dL1}=I_a tg\varphi_1-I_a tg\varphi_2=I_a\left(tg\varphi_1-tg\varphi_2\right) \tag{5}$$

Thus, it follows that $I_c=\frac{U}{x_{KB}}=U\omega C$ and $I_a=\frac{P}{U}$ taking into account that $U\omega C=\frac{P}{U}\left(tg\varphi_1-tg\varphi_2\right)$ thus, we obtain.

Accordingly, the capacitor is the sig and reactive power of the battery,

$$\left.\begin{aligned} C&=\frac{P}{U^2\omega}\left(tg\varphi_1-tg\varphi_2\right) \\ Q_{KB}&=U^2\omega C=P\left(tg\varphi_1-tg\varphi_2\right) \end{aligned}\right\} \tag{6}$$

For the purpose of bringing the power factor closer together, the load is used to compensate for the capacitive organizers of the I_{KB} current in inductance connected parallel to the load when it is in a capacitive character [49-51].

This can happen in special cases, when enterprises have long-term high-voltage cable lines in the period when the network load is low, and the entire capacity of capacitors only works during the nominal load hours of enterprises. The voltages at the end of the network can be expressed in two ways on a vector diagram (Fig.3) [52].

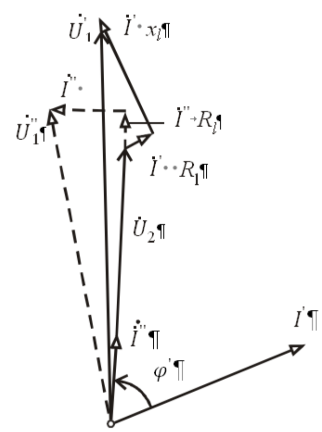

FIGURE 3. Vector diagram on voltage values at the beginning and end of a transverse compensable electrical network

The first is when there is no transverse compensation system across the entire network; the second is when there is a possible compensation that increases the power factor to $cos\varphi_2=1$. Vector diagrams of the voltage U_2 at the end of the power line and the constant voltage values of the active power in the consumer are shown in Figure 3. According to the diagram, the absolute values of the U_1 voltage at the beginning of the transmission network and the U_2 voltage at the end of the transmission network, as well as transverse compensation, cause the angle to change from one φ value to 0 values, so it is observed that the voltage from the U_1 voltage to the U_2 voltage is small [53.

The scheme for connecting to the loading chain of the capacitor device for the transverse compensation process is shown in Fig. 4.

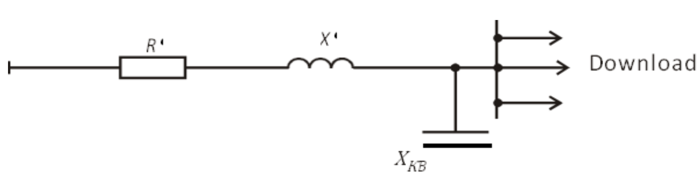

FIGURE 4. Scheme of connecting capacitance to a transverse compensation loading chain

When a sinusoidal voltage is given to the clamps of the circuit shown in the figure, the power of a single-phase capacitor is determined by the following expression:

$$Q=U^2\omega C\,. \tag{7}$$

where U- is the grid voltage; C- is the capacitance of the three - phase capacitor.

In general, the capacity of three-phase capacitor batteries to which the Triangle is connected is also determined as above. In this case, the power of a three-phase capacitor in a star circuit, to which it is connected to a network voltage, is determined by the following ratio:

$$Q=\frac{1}{3}U^2\omega C. \quad (8)$$

where C- is the sum of the capacities of all phases of a three-phase network.

Given the above designations, the power factor up to compensation is expressed in terms of $tg\varphi_1=\frac{Q}{P}$ and the power factor after compensation in terms of $tg\varphi_2=\frac{(Q-Q_{KB})}{P}$. Accordingly, it follows that $cos\varphi_2>cos\varphi_1$ since $tg\varphi_2<tg\varphi_1$.

Active power waste in the pre-compensation network

$$\Delta P_1=3I^2R=\frac{S^2}{U^2}R=\frac{P^2+Q^2}{U^2}R \quad (9)$$

Active power waste in the post-compensation network

$$\Delta P_2=\frac{P^2+\left(Q-Q_{kb}\right)^2}{U^2}R \quad (10)$$

Reduction of active power waste after compensation in the network

$$\Delta P_1-\Delta P_2=\frac{P^2+Q^2}{U^2}R-\frac{P^2+\left(Q-Q_{KB}\right)^2}{U^2}R=\frac{\left(2Q-Q_{KB}\right)\cdot Q_{KB}}{U^2}R. \quad (11)$$

RESEARCH RESULTS

The apparent power prior to compensation can be expressed as

$$S_1=\frac{P}{\cos\varphi_1}$$

whereas after compensation it is determined by

$$S_2=\frac{P}{\cos\varphi_2},$$

Accordingly, the ratio of these quantities is obtained as

$$\frac{S_1}{S_2}=\frac{\cos\varphi_1}{\cos\varphi_2}. \quad (12)$$

From this relationship, it is evident that when $\cos\varphi_2>\cos\varphi_1$, the condition $S_2<S_1$ holds. This implies that the apparent power requirement decreases with the improvement of the power factor after compensation. Hence, the apparent power before compensation is inversely related to the improved power factor [7-8, 54-59].

Voltage drops in the system, both before and after compensation, can be represented in the following form:

$$\Delta U_1=\sqrt{3}\cdot I\,(R\,cos\varphi+X\,sin\,\varphi)$$

or post-substitution are expressed as:

$$\Delta U_1=\frac{P\cdot R+Q\cdot X}{U} \quad (13)$$

while the voltage waste after compensation is

$$\Delta U_2=\frac{P\cdot R+\left(Q-Q_{kb}\right)\cdot X}{U} \quad (14)$$

The decrease in the voltage waste per minute, as well as the decrease in voltage at the end of consumers (13) and (14), taking into account the expressions, will be as follows:

$$\Delta U_1-\Delta U_2=\frac{P\cdot R+Q\cdot X}{U}-\frac{P\cdot R+\left(Q-Q_{kb}\right)\cdot X}{U}=\frac{Q_{kb}\cdot X}{U} \quad (15)$$

A change in the consumer load leads to a change in voltage in the network. Considering the determination of voltage waste at full load before compensation according to the above expression (13), while at full load the voltage waste is calculated as follows:

$$\Delta U'_1=\frac{k\cdot(P\cdot R+Q\cdot X)}{U} \quad (16)$$

where k- is the coefficient proportional to the decrease in load.

Reducing the voltage waste in a state where the network is not at full load is expressed as:

$$\Delta U_1\text{-}\Delta U'_1=\frac{P\cdot R+Q\cdot X}{U}-\frac{k\cdot(P\cdot R+Q\cdot X)}{U}=(1\text{-}k)\frac{P\cdot R+Q\cdot X}{U}=(1\text{-}k)\Delta U_1 \quad (17)$$

At full load, the post-compensation voltage waste, (14) formula is expressed as:

$$\Delta U_2=\frac{P\cdot R+\left(Q\text{-}Q_{kb}\right)\cdot X}{U} \quad (18)$$

When not at full load, the

$$\Delta U'_2=\frac{k\cdot P\cdot R+\left(kQ\text{-}Q_{kb}\right)\cdot X}{U} \quad (19)$$

Reducing the voltage waste of the network during post-compensation and incomplete loading is equivalent to:

$$\begin{aligned}\Delta U_2\text{-}\Delta U'_2&=\frac{P\cdot R+\left(Q\text{-}Q_{kb}\right)\cdot X}{U}-\frac{k\cdot P\cdot R+\left(kQ\text{-}Q_{kb}\right)\cdot X}{U}=\\&=\frac{P\cdot R+\left(Q\text{-}Q_{kb}\right)\cdot X\text{-}k\cdot P\cdot R+\left(kQ\text{-}Q_{kb}\right)\cdot X}{U}=\\&=\frac{PR+QX\text{-}k(PR+QX)}{U}=\frac{(1\text{-}k)(PR+QX)}{U}=(1\text{-}k)\Delta U_1\end{aligned} \quad (20)$$

It follows from the expression (20) induced above that the oscillation of post-compensation voltages when load decreases in the network is like the oscillation of pre-compensation voltages (17) expression. But the voltage level will be greater. In this case, the decrease in voltage waste (15) is determined according to the expression, since the decrease in voltage waste is due to the change in the constant value Q_{kb}s and Xs for electrical devices [7-8, 60-65].

CONCLUSIONS

Analysis shows that the voltage level in the network during the transverse compensation process can increase to a constant value, depending on the capacity of the installed capacitor bank, the installation location, and the reactance of the connected elements. Transverse compensation is recognized as an effective approach for minimizing active power losses while preserving the magnitude of transmitted power. Alternatively, it facilitates an increase in the transmission capacity of the electrical network without a proportional rise in power dissipation.

Moreover, according to established principles of power system analysis, in addition to the processes of reactive power generation and absorption, capacitive and inductive elements of electrical networks inherently exhibit compensatory interactions. This phenomenon is extensively employed in modern power supply systems to achieve reactive power compensation, which not only enhances the stability of voltage profiles but also contributes to a significant reduction in both voltage drops and total power losses.

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