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ALMATY UNIVERSITY OF POWER ENGINEERING AND TELECOMMUNICATIONS NAMED AFTER GUMARBEK DAUKEEV

Power Plants, Networks and Systems Department

ELECTRICAL NETWORKS AND SYSTEMS

abstract of lectures for students of educational program

6B07119 - "Electric power systems"

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Introduction

Electric energy is the most universal type of energy. It can be also very simply and economically transformed into other types of energy – thermal, mechanical, light, etc. Electrical energy finds considerable application in devices of automatic equipment, electronics, etc. without modern devices and technical constructions are impossible. Therefore, now electric energy is widely used in all branches of economic activity of our republic.

Questions of drawing up power balance, defining prospects of development of certain areas and use of raw material resources, the choice of power and location of power plants, placements of the large power-intensive enterprises, and associations of power supply systems can't be solved without electric networks. At the same time it is impossible to choose separately the most favorable parameters of power plants, electric networks, etc. These issues need to be resolved in a complex taking into account mutual influence so that the most effective and rational use of the available energy resources will be provided. Only after that it is possible to conduct design engineering of separate elements of electric systems: power plants, electric networks of various voltage, devices of protection and automatic equipment, etc.

Discipline «Electric networks and systems» – is one of basic in which the foundation for special training of students of specialty «5B071800 – Power industry» is laid. The purpose of studying discipline is formation of knowledge of the theory calculation and analysis of modes of electrical networks and systems, providing them with the design and operation efficiency, reliability and power quality.

The main objectives of discipline is to teach bases calculation of operating modes of electric networks of various configuration; to teach bases of design of electric networks and systems and methods of increase their profitability, reliability and quality of the electric power; to acquaint with working hours of electrical power systems; to acquaint with physical essence of the phenomena accompanying process of production, distribution and electricity consumption.

Contents based on the knowledge of higher mathematics, physics, theoretical bases of electrical engineering, computer programming, electrical machines, power engineering mathematical problems.

Lecture № 1. Equivalent circuit parameters of overhead lines and cables

The content of lecture: equivalent circuit parameters of lines with single wires and split parameters of cable lines.

The purpose of the lecture: the definition of the parameters of overhead lines and cables of equivalent circuits.

Overhead power transmission lines of 110 kV and above up to 300-400 km are usually presented П - shaped equivalent circuit.

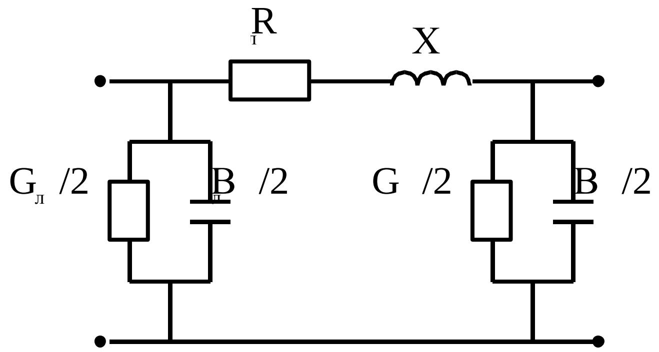


Figure 1.1 - Equivalent circuit overhead line

Active resistance wires and cables are determined by the current-carrying material of rand and their sections. Set the resistance (to 1 km length) for naked wires and cables at + 20°S determined:

$$r_0 = \frac{\rho}{F}, \tag{1.1}$$

where ρ - the resistivity of the conductor material $\left(\frac{Ohm \cdot mm^2}{km}\right)$;

F - cross-section of conductor, mm^2.

Active resistance line, length l is determined by:

$$R_l = r_0 \cdot l.$$

Reactance. The value of running inductive resistance of the line is defined:

$$x_0 = w \cdot (4{,}6 \cdot \lg \frac{D_{avr}}{r_w} + 0{,}5\mu) \cdot 10^{-4}, \tag{1.2}$$

where ω = 314 - angular frequency at 50 Hz;

D_{cp} - average geometrical distance between the wires;

$r_{п}$ - the radius of the wire.

For wires from non-ferrous metal (μ = 1) at power frequency of 50 Hz, formula (1.2) takes the form:

$$x_0 = 0{,}144 \cdot \lg \frac{D_{avr}}{r_w} + 0{,}016. \tag{1.3}$$

Average geometrical distance between the wires single-circuit line:

$$D_{avr} = \sqrt[3]{D_{12} \cdot D_{13} \cdot D_{23}},$$

where D_{12}, D_{13}, D_{23} - distance between wires of individual phases.

At an arrangement of wires by options of an equilateral triangle all wires are at identical distance relatively each other, and average geometrical distance of D_{avr} = D (figure 1.2).

Wires in horizontal arrangement (figure 1.3).

$$D_{avr} = \sqrt[3]{D \cdot D \cdot 2D} = D\sqrt[3]{2} = 1{,}26D.$$

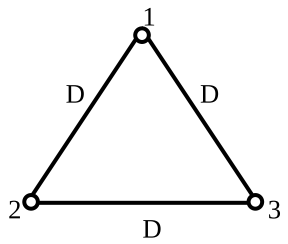


Figure 1.2

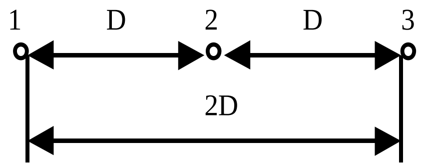


Figure 1.3

On the lines of 330 kV and above split wires are used. On these lines, each phase has not one, but several cables. This leads to increased phase range, which is defined on expression:

$$r = \sqrt[n]{r_n \cdot a^{n-1}}, \tag{1.4}$$

where r_n - the radius of the individual wires included in a split phase line;

n - the number of wires in the same phase;

a - the distance between wires in phase.

The inductive resistance of the line with the split wires:

$$x_0 = 0{,}144 \cdot \lg \frac{D_{avr}}{r} + \frac{0{,}016}{n}.$$

For the line length l inductive reactance:

$$x = x_0 \cdot l.$$

The active lines caused by the conductivity of the active power loss by leakage of currents through the insulation and the power of the crown on the wires. If a leak in the lines of neglected, the conductance due to the crown, determined by:

$$g_0 = \frac{\Delta P_c}{U^2_{nom}} \quad , \tag{1.5}$$

where ΔP_c - the loss of power to the crown, kW / km;

U_{nom} - rated voltage.

The main measures on decrease losses in the crown are the increase in the cross sections of wires, splitting or use of hollow wires.

Reactive conductivity is due to the capacity between wires and earth and has a capacitive character. It is determined by the known expression:

$$b_0 = \omega \cdot C_0,$$

where C_0 - working capacity of the line, F / km.

Working capacity of the line depends on the diameter of wires, their relative position, the distance between them and the dielectric constant of the medium.

In practical calculations electrical three-phase networks operating capacity overhead line with one wire per phase is given by:

$$C_0 = \frac{0{,}024}{\lg \frac{D_{avr}}{r_w}} \cdot 10^6. \tag{1.6}$$

At a frequency of 50 Hz AC, capacitive conductivity of the whole line:

$$b_0 = \frac{7{,}58}{\lg \frac{D_{avr}}{r_w}} \cdot 10^6. \tag{1.7}$$

Capacitive conductivity of the entire line:

$$B = b_0 \cdot l.$$

Charging current line. Under the influence of the applied AC line voltage to the line capacitance in an alternating electric field occurs and the reactive current. This current is called capacitive or charging current of the line:

$$I \cdot b_0 = U_f \cdot b_0 = \frac{U_{nom}}{\sqrt{3}} b_0. \qquad (1.8)$$

Knowing the capacitive current line, it is easy to determine the capacitive charging or power lines.

$$Q_b = \sqrt{3} \cdot U \cdot I \cdot b_0 = \sqrt{3} \cdot U \cdot \frac{U}{\sqrt{3}} \cdot b_0 = U^2 \cdot b_0, \qquad (1.9)$$

where U - the operating line voltage, kV.

Cable power lines are the same U-shaped equivalent circuit as overhead lines. Loop active r0 and reactive x0 resistance is determined by the lookup tables in the same manner as for the air. From the expressions (1.3) and (1.7) it is shown that x0 decreases, and b0 increases during the approach phase conductors. For the distance between the phases of cable lines is much less than x0, and the air is very small. The calculations modes for cable networks 10 kV and below can be taken into account only active resistance. The capacitive charging current and the power cable lines than in the air. The high voltage cable lines allow for Q. Conductance G to allow for cables of 110 kV and above.

Lecture № 2. Equivalent circuits parameters of transformers and autotransformers

The content of lecture: equivalent circuit parameters of two-winding, three-winding transformers and autotransformers.

The purpose of the lecture: the definition of the parameters of equivalent circuits of transformers and autotransformers.

Double-wound transformers are usually T- shaped equivalent circuit (figure 2.1)

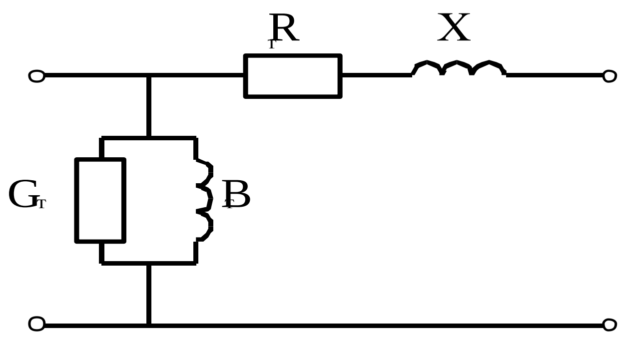


Figure 2.1- Equivalent circuit two-winding transformer

The main parameters of transformers are: $\Delta P_{sh.c}$ losses of short circuit, ΔP_{xx} idling loss, $U_{sh\%}$ voltage of short circuit and current of idling of $i_{xx}\%$. These data allow to determine all resistance and conductivity of an equivalent circuit of the transformer.

The active power consumed by the transformer in experience of short circuit almost entirely is spent for heating of his windings:

$$\Delta P_{sh.c} = 3 \cdot I_{nom}^2 \cdot R_т = \frac{S_{nom}^2}{U_{nom}^2} \cdot R_т,$$

hence:

$$R_т = \frac{\Delta P_{sh.c} \cdot U_{nom}^2}{S_{nom}^2}. \tag{2.1}$$

Voltage short circuit U consists of two components: the voltage drops in the active and inductive resistance of the current flowing in the short circuit mode. In today's large transformers, the first component is much smaller than the second, since RT << XT. Neglecting the voltage drop in the active resistance of the transformer, can be considered:

$$U_{sh.c\%} \approx U_{r\%} = \frac{I_{nom} \cdot X_т}{U_{nom}} \cdot 100, \tag{2.2}$$

hence:

$$X_т = \frac{U_{sh.c\%} \cdot U_{nom}}{I_{nom} \cdot 100} = \frac{U_{sh.c\%} \cdot U_{nom}^2}{100 \cdot S_{nom}}. \tag{2.3}$$

Conductivity GT and BT of the transformer equivalent circuit are determined by the results of the idling experiment in which the open-secondary winding to the primary winding rated voltage is applied:

$$\Delta P_{i.l} \approx U_{nom}^2 \cdot G_т;$$

$$\Delta Q_{i.l} \approx U_{nom}^2 \cdot B_т,$$

hence:

$$G_ò = \frac{\Delta Ð_{i.l}}{U_{nom}^2}; \tag{2.4}$$

$$B_т = \frac{\Delta Q_{i.l}}{U_{nom}^2}. \quad (2.5)$$

S $_{ixx}$ power in relative units is an idling current as a percentage, which is indicated in the passport data transformers:

$$I_{i.l\%} = \frac{I_{i.l}}{I_{nom}} \cdot 100 = \frac{\sqrt{3} \cdot I_{i.l} \cdot U_{nom}}{\sqrt{3} \cdot I_{nom} \cdot U_{nom}} \cdot 100 = S_{i.l\%}.$$

Three-winding transformers is a diagram of the replacement in the form of a three-beam star (figure 2.2).

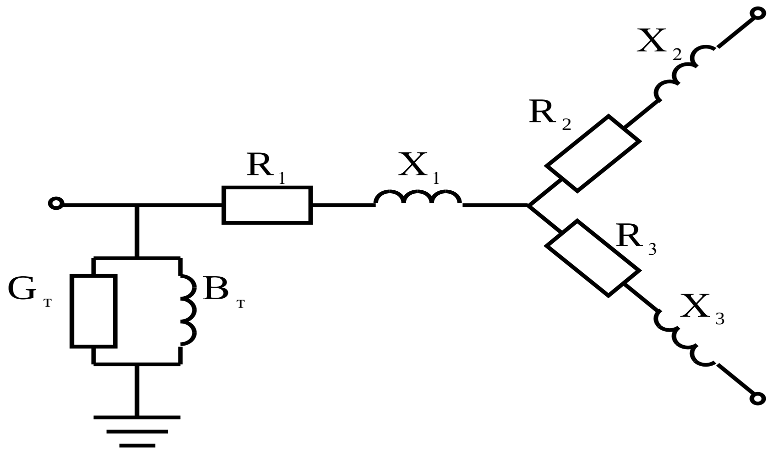


Figure 2.2 - Equivalent circuit of a three-winding transformer

Modern triple-wound transformer windings are carried out with a ratio of capacity 100/100/100%, i.e., each of the windings intended for the transmission of all power.

Active resistance of the star in a three-winding transformer equivalent circuit is determined by the total resistance of the transformer.

In case of equal power windings:

$$R_1 = R_2 = R_3 = 0{,}5R_{total}.$$

The total resistance of the transformer R_{total} determined by the formula (2.1), in which $\Delta P_{sh.c}$ maximum power losses of short circuit at nominal load the LV windings, indicated in the passport of the transformer data.

For a three-winding transformer short-circuit voltage are plants for each pair of windings as a percentage of nominal $U_{sh.c1\text{-}2\%}$, $U_{sh.c1\text{-}3\%}$, $U_{sh.c2\text{-}3\%}$.

According to the equivalent circuit of the transformer replacement rays at one of the windings, which remains open, we can write:

$$\left.\begin{aligned} U_{sh.c1\text{-}2} &= U_{sh.c1} + U_{sh.c2} \\ U_{sh.c1\text{-}3} &= U_{sh.c1} + U_{sh.c3} \\ U_{sh.c2\text{-}3} &= U_{sh.c2} + U_{sh.c3} \end{aligned}\right\}. \tag{2.6}$$

Deciding together these equations with respect to $U_{sh.c1}$, $U_{sh.c2}$, $U_{sh.c3}$, find:

$$\left.\begin{aligned} U_{sh.c1} &= 0{,}5(U_{sh.c1\text{-}2} + U_{sh.c1\text{-}3} - U_{sh.c2\text{-}3}) \\ U_{sh.c2} &= 0{,}5(U_{sh.c1\text{-}2} + U_{sh.c2\text{-}3} - U_{sh.c1\text{-}3}) \\ U_{sh.c3} &= 0{,}5(U_{sh.c1\text{-}3} + U_{sh.c2\text{-}3} - U_{sh.c1\text{-}2}) \end{aligned}\right\}. \tag{2.7}$$

Substituting these values in the expression (2.2), we obtain an inductive resistance of each winding of the transformer.

The conductivity is independent of the number of windings of the transformer and are defined the same as for two-winding.

Autotransformers as well as transformers characterized by nominal voltage and rated wattage. Under the rated power of the autotransformer refers to maximum power that can be transmitted through the auto-transformer on the side of higher voltage:

$$S_{nom} = \sqrt{3} \cdot I_1 \cdot U_1 .$$

Figure 2.3 shows a connection diagram of windings of one phase transformer.

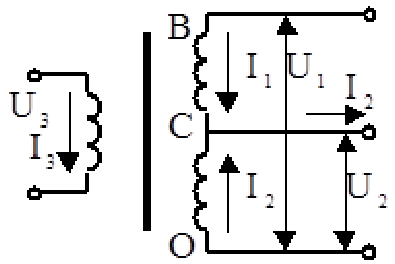


Figure 2.3 - Equivalent circuit of auto-transformer

The scheme shows that some of the high-voltage winding of the BCO, concluded between points C and O is the average winding voltage U_2 is called a common winding and the other part of the BC is a serial winding. Thus, the autotransformer winding of medium voltage part of high-voltage winding, i.e., these windings are electrically connected to each other, and the lower coil voltage U3 has a magnetic connection with them. For autotransformers specifications introduced the concept of a standard power, which is calculated on the series winding.

$$S_т = \sqrt{3} \cdot I_1 (U_1 - U_2). \tag{2.8}$$

Multiply and divide this expression on U_1, we obtain:

$$S_т = \sqrt{3} \cdot I_1 \cdot U_1 (1 - \frac{U_2}{U_1}) = S_{nom} \cdot \alpha, \qquad (2.9)$$

where $\alpha = 1 - \frac{U_2}{U_1}$ coefficient of profitability of autotransformer.

In the step-down transformer winding current total is equal to the difference between the current high and medium voltage windings, i.e.:

$$I_0 = I_2 - I_1.$$

Therefore, this winding is calculated on the current less than the rated transformer current flowing at the highest winding. Design capacity of the coil is less than the nominal power of the autotransformer and it is typical of power. Low voltage winding as calculated on the types of transmission power.

Equivalent circuit of the autotransformer as well as in the three-winding, in the form is three-beam star. When the ratio of the autotransformer winding capacity of 100/100/50% of active resistance rays are determined:

$$R_1 = R_2,$$

$$R_3 = 2R_1 = 2R_2.$$

Inductive resistance is determined in the same manner as for the three-winding transformer.

Lecture № 3. Losses of power and energy in elements of electrical networks

Content of lecture: losses of power and energy in elements of electrical networks.

Lecture purpose: study methods of calculation of losses power and energy in lines and transformers.

Losses of power and energy in lines

By transmission of electrical energy in all links of electrical networks there are losses of the active power and energy. These losses arise both in the air and cable lines, and in transformers reducing and the raising substations.

Losses of the active power on a section of the three-phase line with the pure resistance of R make:

$$\Delta P = 3 \cdot I^2 \cdot R, \qquad (3.1)$$

where I – current of the load.

If we express the current through the power, we will receive:

$$I = \frac{S}{\sqrt{3} \cdot U}.$$

We will add value of current in (3.1), and we receive:

$$\Delta P = 3\left(\frac{S}{\sqrt{3} \cdot U}\right)^2 \cdot R = \frac{S^2}{U^2} \cdot R = \frac{P^2 + Q^2}{U^2} \cdot R. \tag{3.2}$$

We will similarly receive losses of reactive power:

$$\Delta Q = \frac{P^2 + Q^2}{U^2} \cdot X. \tag{3.3}$$

Losses of the active energy on a network can be defined, having increased losses of the active power by a network operating time with this loading. However, loading of customers fluctuates within a day and a season therefore also the extent of value of losses of power changes.

Thus, determination of losses of energy will be made for each line by summing (integration) of values of losses of power for infinitesimal elements of time, i.e.:

$$\Delta A = \int_0^t \Delta P dt$$

or, adding ΔP value from a formula (3.2), we receive:

$$\Delta A = \int_0^t \frac{S^2}{U^2} \cdot R \cdot dt = \frac{R}{U^2} \int_0^t S^2 \cdot dt,$$

where S – the ultimate power transferred on the line and representing function from t time.

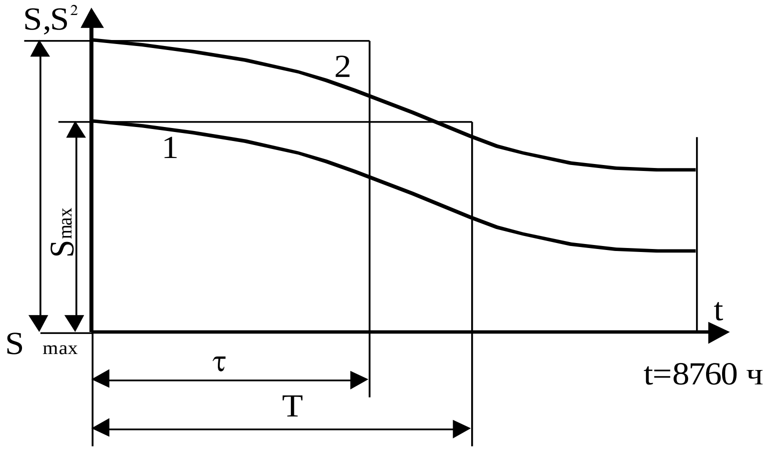


Figure 3.1 - Annual load graph on duration

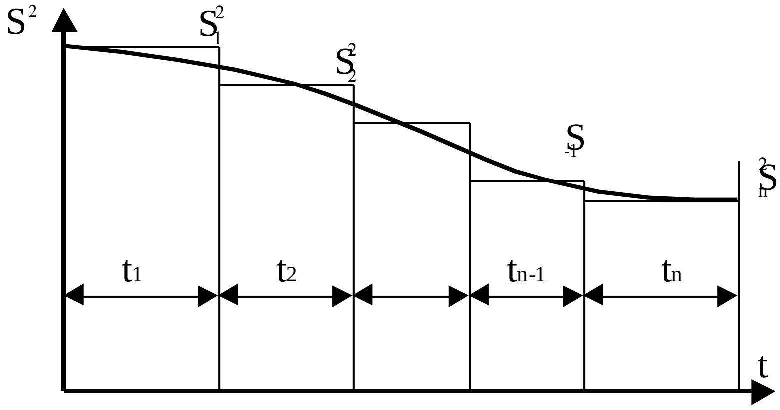


Figure 3.2 - Step load graph on duration

This function is figured usually in the form of the diagram on duration (figure 3.2). This diagram shows period of operation of a network with this loading (curve 1). In case of invariable electrical power factor of loading the area restricted to this curve shows the amount of energy transferred on a network within a year in some scale and expresses a formula:

$$A = \int_0^t Pdt = \cos\varphi_a \int_0^{t=8760} Sdt,$$

where $\cos\varphi_a$ - the average electrical power factor accepted approximately to constants throughout a year.

If the curve of 1 graphics (figure 3.1) to rebuild a curve in the square curves 2 expressing the S_2=f (t) function, then losses easily are determined in some scale by the area restricted to this curve:

$$\Delta A = \frac{R}{U^2}\int_0^t S^2 dt.$$

From this it follows that for the determination of power losses are sufficient to measure the area bounded by the curve 2. In practice, this can be approximated by replacing the load curve for the duration of a stepped schedule with sufficiently small segments of time t_1, t_2, ... t_n, and the corresponding values of S_1, S_2 loads ... S_n (figure 3.2). Then the energy losses are determined by summing the values :

$$\Delta A = \frac{R}{U^2}(S_1^2 \cdot t_1 + S_2^2 \cdot t_2 + \ldots + S_{n-1}^2 \cdot t_{n-1} + S_n^2 \cdot t_n). \quad (3.4)$$

It is possible to enter values into this expression:

$$S_{sp} = \sqrt{\frac{S_1^2 \cdot t_1 + S_2^2 \cdot t_2 + \ldots + S_n^2 \cdot t_n}{8760}},$$

then:

$$\Delta A = \frac{R}{U^2} S_{sp}^2 \cdot 8760. \quad (3.5)$$

Value of S_{sp} wears the name of mean square power, and the method of determination of losses of power on a formula (3.4) called as method of determination losses on mean square power.

This method of approximate determination of losses possesses a row of inconveniences, and is applicable only in the presence of the load graph. Therefore, the so-called method of determination of losses is more widespread on time of the maximum losses which considerably simplifies calculations.

For the annual load graph on duration (curve 1 figure 3.1) can be found such time T during which on the line working with a maximum load of S_{max} the same amount of energy that is transferred on it actually within a year in case of the changing loading of S=f (t) would be transferred.

In case of invariable electrical power factor this condition can be written as follows:

$$A = P_{max} \cdot T = S_{max} \cdot \cos\varphi_a \cdot T = \cos\varphi_a \int_0^{t=8760} S dt, \quad (3.6)$$

here:

$$T = \frac{\int_0^{t=8760} S dt}{S_{max}}. \quad (3.7)$$

Value of T is called a usage time of a maximum load. Knowing the annual amount of energy transferred lines and the maximum resistive load R_{max} from a formula (3.6) it is possible to define a usage time of a maximum load:

$$T = \frac{A}{P_{max}} = \frac{A}{S_{max} \cos\varphi_a}. \quad (3.8)$$

For each customer the value of a usage time of a maximum load is characteristic. In case of calculation this value is accepted based on statistical and handbook data.

Value of a usage time of a maximum load should be known to define losses of the electric power. For this purpose, use value of τ - time of the maximum losses, i.e. time during which the line, working with an invariable maximum load, has losses of the electric power, equal to the valid annual losses of the electric power by operation according to the annual load graph. Replacing the area restricted to a curve 2 (figure 3.1), the area of a rectangle with the sides of τ and S^2_{max}, we receive:

$$\Delta A = \frac{R}{U^2} \int_0^t S^2 dt = \frac{R}{U^2} S^2_{max} \tau. \quad (3.9)$$

Here we receive time of the maximum losses:

$$\tau = \frac{\int_0^t S^2 dt}{S^2_{max}}. \quad (3.10)$$

Practically value of τ is received from T time as in between there is certain dependence.

Apparently from formulas (3.10) and (3.7), τ and T depend on nature of change of the load graph, i.e. on the S=f (t) function which is in these formulas under a sign of integration. For finding the dependence of t on T it is possible to integrate a row of the load graphs having different values of T for different customers and the same to make with square curves of S = f (t) of the same diagrams, and then, using formulas (3.10) and (3.7), to set dependences of τ and T for different cosφ values. Results of calculations are presented in a figure 3.3 in the form of family of curves. These curves can use for determination of losses of energy method of time of the maximum losses.

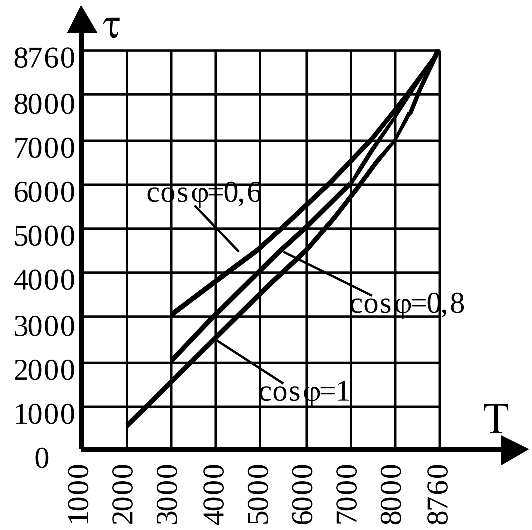


Figure 3.3 - Curve τ = f (t)

Process for calculating following. Knowing the active resistance of the considered line R, a maximum load of S_{max}, cosφa and a usage time of a maximum load for this category of customers on a curve (a figure 3.3) for the given $\cos\varphi_a$ known for T, we find time of the maximum losses of τ. Further we define losses of the electric power:

$$\Delta A = \frac{P^2 + Q^2}{U^2} R \cdot \tau . \qquad (3.11)$$

If on the considered section of the line power to different customers of P_{1max}, P_{2max}, P_{3max} is transferred, etc., that in case of determination of losses it is necessary to accept the average value of a usage time of a maximum load defined taking into account summary value of the transferred energy.

$$T_a = \frac{A}{P_{max}} = \frac{P_{1max} \cdot T_1 + P_{2max} \cdot T_2 + \ldots + P_{nmax} \cdot T_n}{P_{1max} + P_{2max} + \ldots + P_{nmax}} = \frac{\sum_1^n P_{imax} \cdot T_i}{\sum_1^n P_{imax}} \qquad (3.12)$$

For a diagram of the peak form value of τ is determined by an empirical formula:

$$\tau = (0{,}124 + \frac{T}{10000})^2 \cdot 8760 . \qquad (3.13)$$

3.2 Losses of power and energy in transformers

Losses of power through the transformer are always connected to losses of power in the active and reactive resistance of its windings and the losses connected to magnetization of steel. The losses arising in windings depend on the current proceeding on them. The losses going for magnetization are defined by applied voltage and can be accepted invariable and equal to idling losses.

In double-coiled transformers of loss of power are defined as:

$$\Delta P_{т} = \Delta P_{im} + 3 \cdot I^2 \cdot R_{т} = \Delta P_{im} + \frac{S^2}{U^2} R_{т}; \qquad (3.14)$$

$$\Delta Q_{т} = \Delta Q_{im} + 3 \cdot I^2 \cdot X_{т} = \Delta Q_{im} + \frac{S^2}{U^2} X_{т}. \qquad (3.15)$$

In cases where the voltage U is unknown, take it to the rated voltage of the transformer, which lists its resistance RT and XT. In parallel operation of n identical transformers equivalent resistance is reduced n times, and the loss in magnetization increases n times:

$$\Delta P_{т} = n \cdot \Delta P_{i.l} + \frac{1}{n} \cdot \frac{S^2}{U_{nom}^2} R_{т}; \qquad (3.16)$$

$$\Delta Q_{т} = n \cdot \Delta Q_{i.l} + \frac{1}{n} \cdot \frac{S^2}{U_{nom}^2} X_{т}. \qquad (3.17)$$

Power loss can be found directly in catalog parameters of transformers without calculating resistances r_T and x_T. Since the loss of short-circuit $\Delta P_{sh.c}$ determined at the rated current of the transformer:

$$\Delta P_{sh.c} = 3 \cdot I_{nom}^2 \cdot R_{т},$$

in case of any other current, losses of the active power in windings:

$$\Delta P_{м} = 3 \cdot I^2 \cdot R_{т},$$

dependence is fair:

$$\frac{\Delta P_{sh.c}}{\Delta P_{м}} = \frac{I_{nom}^2}{I^2} = \frac{S_{nom}^2}{S^2}.$$

So, when one transformer:

$$\Delta P_{м} = \Delta P_{sh.c} \cdot \frac{S^2}{S_{nom}^2}, \tag{3.18}$$

and in parallel operation n identical transformers:

$$\Delta P_{т} = n \cdot \Delta P_{sh.c} + \frac{\Delta P_{sh.c}}{n} \cdot \frac{S^2}{S_{nom}^2}. \tag{3.19}$$

Substituting the value of the reactance (3.12) to (3.17), we obtain:

$$\Delta Q_{т} = n \cdot \Delta Q_{i.l} + \frac{1}{n} \cdot \frac{U_{sh.c\%}}{100} \cdot \frac{S^2}{S_{nom}^2}. \tag{3.20}$$

From (3.20) it follows that S = S_{nom} short-circuit voltage U is numerically equal to the loss of reactive power in the windings of the transformer, expressed as a fraction of its nominal capacity. The three-winding transformers and autotransformers active power losses are determined by summing the power loss in each of the windings:

$$\Delta P_{т} = n \cdot \Delta P_{i.l} + \frac{1}{n}\left(\frac{S_1^2}{U_{nom}^2} \cdot R_1 + \frac{S_2^2}{U_{nom}^2} \cdot R_2 + \frac{S_3^2}{U_{nom}^2} \cdot R_3\right), \tag{3.21}$$

where S_1, S_2, S_3 - respectively the power flowing through the windings of the higher, middle and lower voltages.

Reactive power losses are determined by:

$$\Delta Q_{т} = n \cdot \Delta Q_{i.l} + \frac{1}{n}\left(\frac{S_1^2}{U_{nom}^2} \cdot X_1 + \frac{S_2^2}{U_{nom}^2} \cdot X_2 + \frac{S_3^2}{U_{nom}^2} \cdot X_3\right). \tag{3.22}$$

Losses of energy in transformers defined as follows:

$$\Delta A_{т} = n \cdot \Delta P_{i.l} \cdot 8760 + \frac{1}{n} \cdot \left(\frac{S^2}{U_{nom}^2} R_{т}\right) \cdot \tau. \tag{3.23}$$

Lecture № 4. Calculation of line with the load at the end for the loss of voltage

The content of lecture: the calculation of the load on the line at the end of a loss of voltage.

The purpose of the lecture: introduction to the calculation of simple open-loop network. Consider the simplest three-phase AC line with a balanced load on the end (figure 4.1).

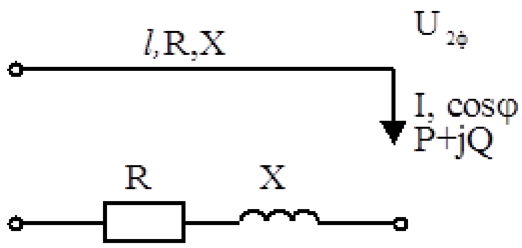


Figure 4.1

Loading is set by current of I and cosφ at a phase tension of U_{2f} on the end of the line, or power S = P + jQ.

The calculation is performed using the vector diagram of current and voltage lines for a single phase, which is allowed because the load is symmetric in all phases.

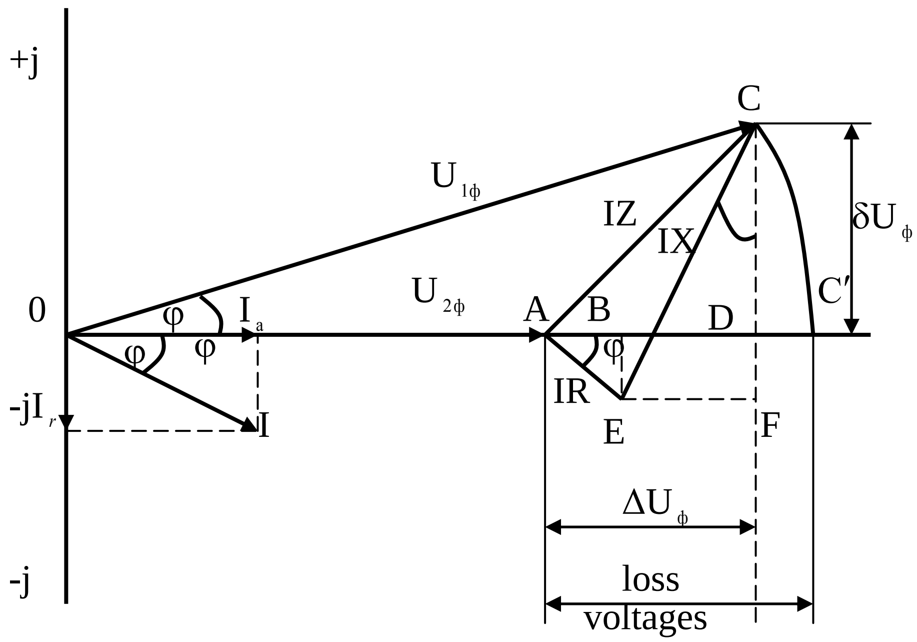


Figure 4.2 - Vector diagram of the line with loading on the end

Current of loading of I, cosφ and tension of U_{2f} are known. It is necessary to define U_{1f}. On the transverse axis we postpone a vector of the given tension at the end of the U_{2f} (OA) line. From origin of coordinates we postpone a vector of current of I at an angle φ. Its active component is directed to the transverse axis I, and reactive components – jI_r-on an imaginary axis in the negative direction. Thus, in case of the accepted layout of a vector of tension and current on the vector diagram the negative sign at an imaginary part of a complex of current characterizes the inductive (lagging behind) current of loading of a customer.

Next, from point A parallel to postpone the vector current I vector of the voltage drop in the active line resistance IR (AB) and 900 to his side the lead - vector voltage drop in the reactance IX (BC). By connecting point A to point C, we obtain the vector of the total voltage drop in the line in question IZ (AU). To find U_{1f} voltage, connect the point C to the origin, we obtain the vector of phase voltage at the beginning of the line U_{1f} (OC).

The voltage drops in the line:

$$IZ = \sqrt{(IR)^2 + (IX)^2}\ .$$

It can be decomposed into components:

a) longitudinal $\Delta U_f = AD$;

b) transverse $\delta\ U_f = DC$ i.e. $IZ = \Delta U_f + j\delta\ U_f$.

We define these components. For this drop perpendiculars from the points B and C on the real and imaginary axis. A result we obtain segments:

$$AE = IR\cos\varphi; \qquad ED = BF = IX\sin\varphi;$$
$$CF = IX\cos\varphi; \qquad BE = DF = IR\sin\varphi.$$

Hence, the longitudinal component:

$$\Delta U_f = AD = AE + ED = IR\cos\varphi + IX\sin\varphi = Ia\ R + Ir\ X; \tag{4.1}$$

$$\delta\ U_f = DC = CF - DF = IX\cos\varphi - IR\sin\varphi = Ia\ X + Ir\ R. \tag{4.2}$$

sending end voltage:

$$\dot{U}_{1f} = U_{2f} + \Delta U_f + j\delta U_f,$$

and tension module:

$$U_{1f} = \sqrt{(U_{f2} + \Delta U_f)^2 + \delta U_f^2}\ . \tag{4.3}$$

As a result of the construction of the chart above was obtained by the vector of the total voltage drop in the line. Note that the voltage drops at the geometric realizes the potential difference between the beginning and end of the line.

When calculating the nets and below 35 kV are usually administered simplification consisting of the fact that at the beginning of the line voltage is not determined by the voltage drop, and for loss of voltage. Under voltage loss understand algebraic difference of the absolute values of the voltages at the beginning and end of the line.

To determine the voltage loss in the diagram is compatible with the OC section of the axis of the actual measurements (segment O).

The segment $AC' = OC'$-OA=U_{1f}-U_{2f} is voltage loss. As for the network of 35 kV and below the angle between U_{1f} and U_{2f} are very small, which means that small and segment DC' it can be assumed that the voltage drop is approximately equal to the longitudinal component of the voltage drop:

$$AD \approx AC' \approx \Delta U_f \approx IR\cos\varphi + IX\sin\varphi. \tag{4.4}$$

Loss of line voltage;

$$\Delta U = \sqrt{3}\Delta U_f = \sqrt{3}I(R\cos\varphi + X\sin\varphi). \tag{4.5}$$

Vector diagram line voltages will look similar to the diagram of the phase voltages.

When you set the load of active and reactive power P + jQ value of the voltage loss is determined as follows:

Since $I_a = I\cos\varphi = \frac{P}{\sqrt{3U}}$ and $I_r = I\sin\varphi = \frac{Q}{\sqrt{3}U'}$ then, substituting these values in (4.5), we obtain:

$$\Delta U = \sqrt{3}(IR\cos\varphi + IX\sin\varphi) = \sqrt{3}\left(\frac{PR}{\sqrt{3}U} + \frac{QX}{\sqrt{3}U}\right)$$

or

$$\Delta U = \frac{PR+QX}{U}. \tag{4.6}$$

Often, when calculating the voltage at the consumer is unknown, it can be taken instead of the actual nominal voltage at the end of the line:

$$\Delta U = \frac{PR+QX}{U_{nom}}. \tag{4.7}$$

In calculating the net with multiple load voltage value loss is determined as the sum of the voltage loss on all parts of the network:

$$\Delta U = \sum_i^n \frac{P_iR_i+Q_iX_i}{U} \tag{4.8}$$

Lecture № 5. Calculations of the modes of the opened electric networks

Content of lecture: calculations of networks 110 – 220 kV according to the beginning and according to the end.

Lecture purpose: studying methods of calculation of the opened electric networks.

The problem of calculating the network mode, the main assumptions

The main task of calculating the network mode is the definition of mode parameters. As already mentioned, such parameters are: the currents on the network portions, active and reactive power, the voltage at the network nodes, and other frequency. Initial data for calculation are: the design load capacity, given the voltage value at certain points, the circuit electrical connection network, characterizing the mutual relationships of its elements and other values.

The basic method for the calculation of the electrical network is a method of successive approximations (iterations), which provides for a gradual transition from a rough answer to the challenge to more accurate decisions. The first approximation (zero iteration) at the same time can be obtained on the basic of certain ideas about the possible values of the unknown quantities. With regard to the power grids as a first approximation take equal voltages at all points of the rated voltage. This allows to determine the load current, and other parameters of the network mode, including the voltage at the load terminals. To find voltage is already the second approximation to the true solution. It can be found again on the basic of the currents and perform calculations continue as long as the results of subsequent approximations are given with an accuracy different from the previous results.

Practically when carrying out calculations of electric networks it is possible to be limited to the second and first iterations. Calculations of networks of 35 kV and below, and in some cases – design calculations of networks of 110 and 220 kV are among such calculations. In the analysis of the modes of networks of 35 kV and are limited to the first approach below. It is connected by that requirements of consumers to quality of tension defines need to provide for all points of such networks to tension a little differing from nominal which are accepted at calculations of the first approach. The mistake received thus lies within calculation accuracy. The mistake received at restriction of calculations of networks 110kV and 220kV with the second approach also appears within calculation accuracy.

Calculation of a network in two stages

At calculation of the mode of networks 110 – 220 kV can be allocated two characteristic settlement cases: calculation of a network for the set tension at the end of the line (or calculation for data of the end) and calculation in which tension at the beginning of the line (calculation for data of the beginning) is set.

In figure 5.1 the settlement scheme of the opened network with n loadings (and) and its equivalent circuit is submitted.

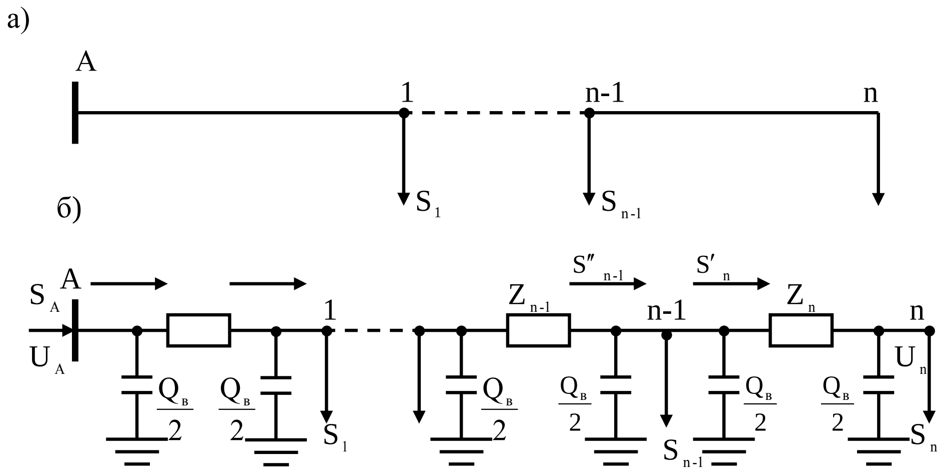


Figure 5.1 - Settlement scheme and equivalent circuit of a network

We will consider a case of calculation for data of the end. Basic data are: tension at the end of the line U, settlement capacities of loadings, and also network parameters. Calculation is conducted from the end of the line. Losses of power on the last site of the line n are determined by the known tension of U:

$$\left.\begin{aligned} \Delta P_n &= \frac{P_n^2 + Q_n^2}{U_n^2} R_n, \\ \Delta Q_n &= \frac{P_n^2 + Q_n^2}{U_n^2} X_n \end{aligned}\right\}. \tag{5.1}$$

We find the power at the beginning of section n:

$$S'_n = P'_n + jQ'_n = P_n + \Delta P_n + j(Q_n + \Delta Q_n - Q_{bn}), \tag{5.2}$$

where Q_{bn} - charging power on a site n.

Power at the end of a site (n-1) in knot (n-1) is determined by balance of power:

$$S''_{n-1} = P''_{n-1} + jQ''_{n-1} = P'_n + P_{n-1} + j(Q'_n + Q_{n-1}). \tag{5.3}$$

Power failure on a trailer site n is defined:

$$\Delta U_n = \Delta U_n + j\delta U_n = \frac{P_n R_n + Q_n X_n}{U_n} + j\frac{P_n X_n - Q_n R_n}{U_n}. \tag{5.4}$$

According to a well-known voltage Un and voltage drop at the site n is determined by the voltage at node n-1 U:

$$\dot{U}_{n-1} = \dot{U}_n + \Delta\dot{U}_n = U_n + \Delta U_n + j\delta U_n \tag{5.5}$$

or voltage module:

$$U_{n-1} = \sqrt{(U_n + \Delta U_n)^2 + \delta U_n^2}\,. \tag{5.6}$$

Calculation of the mode of a trailer site of a network comes to an end with determination of tension of $\dot{U}_{n-1}$. Thus, there are known all necessary data for calculation of the following site. Calculation of a site of n-1 is carried out on the same formulas, as for a site n. Calculations for all other sites are similarly conducted. The end of calculation is determination of power of $\dot{S}_A$ and tension of $\dot{U}_A$.

The network according to data the calculations beginning in which a known quantity is the voltage at the power the U, the method of successive approximations, the calculations are carried out in two stages. As a first approximation (in the first step of calculation) it is assumed that the voltage at all nodes is equal to the nominal voltage. Under this condition, there is a power distribution network. In accordance to the notation in figure 5.1 the calculation is as follows. Determines the power loss on the end part of the network:

$$\Delta P_n = \frac{P_n^2 + Q_n^2}{U_{nom}^2} R_n;$$

$$\Delta Q_n = \frac{P_n^2 + Q_n^2}{U_{nom}^2} X_n\,. \tag{5.7}$$

Further, the power $\dot{S}_n^`$ is determined at the beginning of this section, in accordance with (5.2). Power balance at the node (n-1) is determined at the end portion of the power n-1 (5.3). Similarly, calculation is carried out and to all the other sections of the network. The calculation continues as long as the determined $\dot{S}_n^`$.

The next step is determined by calculating the voltage $\dot{U}_A$ at the nodes of the load in the second approximation. Initial data for calculation are: stress and results in the previous stage of the power calculation at the end of each section.

To head area network:

$$\dot{U}_1 = \dot{U}_A - \Delta\dot{U}_1, \tag{5.8}$$

where $\Delta \dot{U}_1$ - the voltage drop at the main site network.

$$\dot{U}_1 = \dot{U}_A - \Delta U_1 - j\delta U_1. \quad (5.9)$$

in the opened form:

$$\dot{U}_1 = U_A - \frac{P_1^{`} R_1 + Q_1^{`} X_1}{U_A} - \frac{P_1^{`} X_1 - Q_1^{`} R_1}{U_A}. \quad (5.10)$$

Tension module in a point 1:

$$U_1 = \sqrt{(U_A - \Delta U_1)^2 + \delta U_1^2}. \quad (5.11)$$

Similarly tension in other nodal points of a network is defined.

Lecture № 6. Calculations of the modes of ring networks

The content of lecture: calculations ring operating modes of electric networks.

The purpose of the lecture: introduction to methods of calculation of simple closed networks.

The simplest closed network is a ring network. It has a closed loop (figure 6.1, a). As a nutritional point can be either power or bus system substation. If such a network is cut by a power source and deploy, it will look like a two-way power line, in which the voltage at the ends are equal in magnitude and phase (figure 6.1, b).

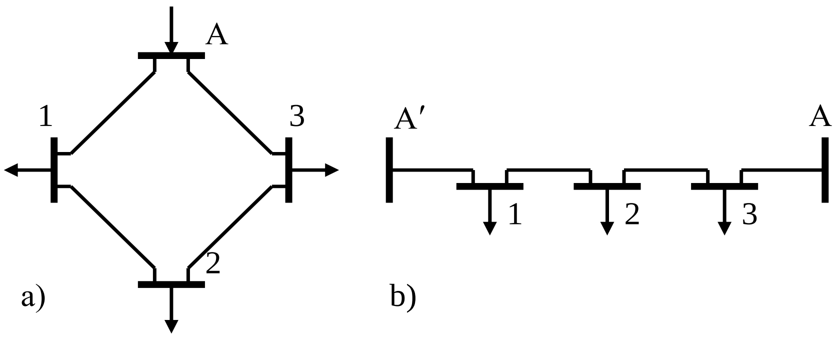


Figure 6.1 - Scheme of simple closed networks

To calculate the net takes diagram shown in figure 6.2. Here power $\dot{S}_1, \dot{S}_2, \dot{S}_3$ - settlement loadings of substations. The direction of the power flow on the web sites accepted conditionally. The actual direction is determined by calculation.

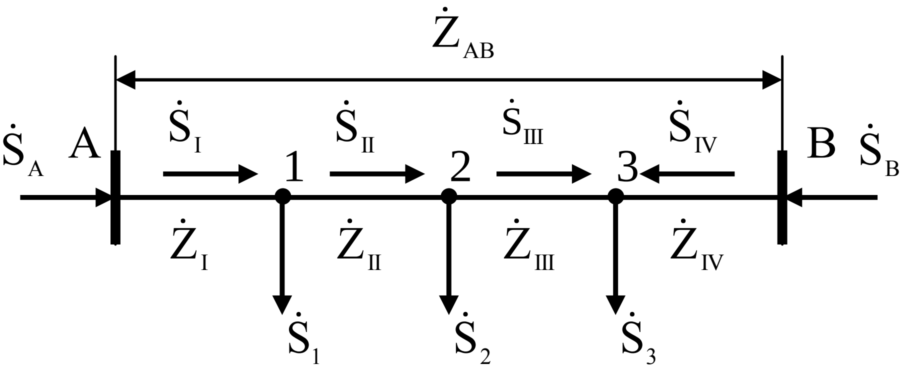


Figure 6.2 - Scheme of a two-way power line

Initial data for the calculation of the network is the voltage at the center of power, load capacity, the network settings. Since the voltage at the load node is unknown, then the calculation must be performed using the method of successive approximations.

As well as the calculation of opening networks take the stress condition of equality along the line. This voltage shall be equal to the nominal. Under these assumptions, the current network plot is determined by:

$$\dot{I}_n = \frac{\dot{S}_n}{\sqrt{3}U_{nom}}.$$

The condition of equality of tension on the ends of the line means equality to zero power failure in the scheme (figure 6.2).

On the basic of the second law of Kirchhoff we will write down:

$$\frac{\dot{S}_I}{\sqrt{3}U_{nom}}\dot{Z}_I + \frac{\dot{S}_{II}}{\sqrt{3}U_{nom}}\dot{Z}_{II} + \frac{\dot{S}_{III}}{\sqrt{3}U_{nom}}\dot{Z}_{III} - \frac{\dot{S}_{IV}}{\sqrt{3}U_{nom}}\dot{Z}_{IV} = 0,$$

or

$$\dot{S}_I\dot{Z}_I + \dot{S}_{II}\dot{Z}_{II} + \dot{S}_{III}\dot{Z}_{III} - \dot{S}_{IV}\dot{Z}_{IV} = 0. \qquad (6.1)$$

We express in this equation capacity 2,3 and 4th sections of the line through the power of $\dot{S}_I$ and S1 power known loads, $\dot{S}_1, \dot{S}_2, \dot{S}_3$.

When account is taken the power loss can be written:

$$\dot{S}_I + \dot{S}_{IV} = \dot{S}_1 + \dot{S}_2 + \dot{S}_3,$$

hence:

$$\dot{S}_I = \dot{S}_1 + \dot{S}_2 + \dot{S}_3 - \dot{S}_{IV}. \qquad (6.2)$$

On the basic of the first law of Kirchhoff:

$$\dot{S}_{II} = \dot{S}_{I} - \dot{S}_{1}; \tag{6.3}$$

$$\dot{S}_{III} = \dot{S}_{I} - \dot{S}_{1} - \dot{S}_{2}. \tag{6.4}$$

Substituting (6.2 - 6.4) in the original equation (6.1) and, after transformations we obtain:

$$\dot{S}_{I}(\dot{Z}_{I} + \dot{Z}_{II} + \dot{Z}_{III} + \dot{Z}_{IV}) - \dot{S}_{1}(\dot{Z}_{II} + \dot{Z}_{III} + \dot{Z}_{IV}) - \dot{S}_{2}(\dot{Z}_{III} + \dot{Z}_{IV}) - \dot{S}_{3}\dot{Z}_{IV} = 0,$$

from taking into account designations on the scheme:

$$\dot{S}_{1} = \dot{S}_{A} = \frac{\dot{S}_{1}\dot{Z}_{1\text{-}B} + \dot{S}_{2}\dot{Z}_{2\text{-}B} + \dot{S}_{3}\dot{Z}_{3\text{-}B}}{\dot{Z}_{AB}}. \tag{6.5}$$

It is similarly possible to receive:

$$\dot{S}_{1V`} = \dot{S}_{B} = \frac{\dot{S}_{1}\dot{Z}_{1\text{-}A} + \dot{S}_{2}\dot{Z}_{2\text{-}A} + \dot{S}_{3}\dot{Z}_{3\text{-}A}}{\dot{Z}_{AB}}. \tag{6.6}$$

Generally, at n loadings on a ring network:

$$\left.\begin{aligned} \dot{S}_{A} &= \frac{\sum_{m=1}^{n}\dot{S}_{m}\dot{Z}_{mB}}{\dot{Z}_{AB}} \\ \dot{S}_{B} &= \frac{\sum_{m=1}^{n}\dot{S}_{m}\dot{Z}_{mA}}{\dot{Z}_{AB}} \end{aligned}\right\}, \tag{6.7}$$

where $\dot{Z}_{mA}$ and $\dot{Z}_{mB}$ - resistance from a point of m in which some intermediate loading of $\dot{S}_{m}$, to points of food of A and B respectively is included.

After determination of the capacities proceeding on head sites of a network capacities on other sites by means of Kirchhoff's law are defined. On the first stage of calculation of the mode of this line comes to end. At the second stage losses of power and tension in nodal points of a network are defined. Let's say that as a result of the first stage of calculation distribution of capacities, as shown in figure 6.3, a.

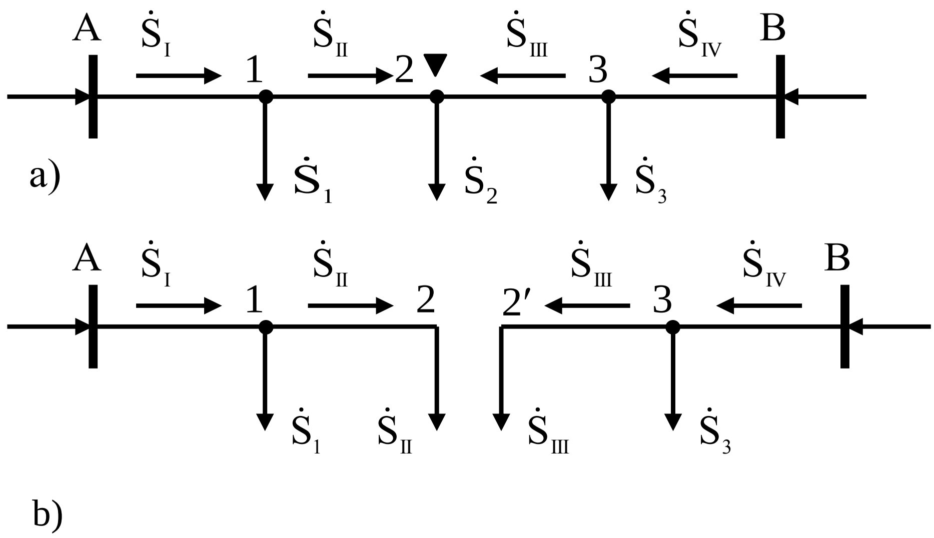


Figure 6.3 - Results of calculation of the first stage and scheme of calculation of the second stage

At point 2 powers are delivered to the two sides. This point is called a point and figure thread-section different solid triangles. To calculate the voltage at the nodal points of conventionally cut the diagram (figure 6.3, a) point thread-section (figure 6.3, b).We obtain a circuit consisting of two independent parts, each of which is characterized by open-loop network with a given load and voltage $U_A = U_B$ to the common power supply rails. Therefore, further calculations ring network should be carried out as well as for open-loop network according to the start. For networks of 110-220 kV power losses are taken into account and are determined by the voltage at the nodal points. For networks 35 kV or lower voltage power is calculated without taking into account losses. In some cases, it appears that after the first stage of the calculation can be thread-section two points: one for active and one for reactive power (figure 6.4, a).

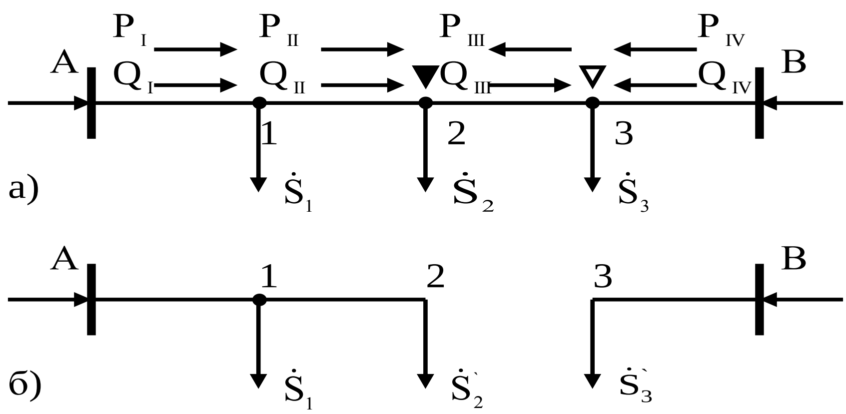


Figure 6.4

Point 2 - thread-section point for active power and the point 3 - for reactive power. In this case, the ring network is also suspended on cut thread-section points and is represented by two-open lines (figure 6.4, b).

In this case, the power loss in the area defined between the points thread-section:

$$\Delta P_{III} = \frac{P_{III}^2 + Q_{III}^2}{U_{nom}^2} R_{III};$$

$$\Delta Q_{III} = \frac{P_{III}^2 + Q_{III}^2}{U_{nom}^2} X_{III}.$$

The load at point 2 receive equal:

$$\dot{S}_2^{`} = P_2 + jQ_{II} = P_{II} + j(Q_{II} + \Delta Q_{III}).$$

At point 3:

$$\dot{S}_3^{`} = P_3^{`} + jQ_3^{`} = P_{II} + \Delta P_{III} + jQ_{IV}.$$

Further calculation is carried out for the two of open lines.

Lecture № 7. Calculation of the difficult closed networks

Content of lecture: calculations of equivalent circuits of the difficult closed networks.

Lecture purpose: acquaintance with calculations of the difficult closed networks by means of a transformation method.

In some cases, at design, and also at operation of networks of small complexity there is a need of carrying out one-time calculations without use of the PC, one of widespread ways of the manual account – consecutive simplification of the scheme of a difficult network on a method of transformation network.

The essence of a method of transformation is to bring the set difficult network by gradual transformations to the line with bilateral food in which find distribution of capacities already known method. Then, after determination of linear capacities on each site of the transformed scheme, by means of consecutive return transformations find the valid distribution of capacities in the initial scheme of a network.

Making equivalent parallel lines on any parts of the closed network are only possible when there is no load attached to these lines. To close area network with two parallel lines (figure 7.1).

$$\dot{S}_э = \dot{S}_1 + \dot{S}_2;$$

$$\dot{Z}_э = \frac{\dot{Z}_1 \cdot \dot{Z}_2}{\dot{Z}_1 + \dot{Z}_2}.$$

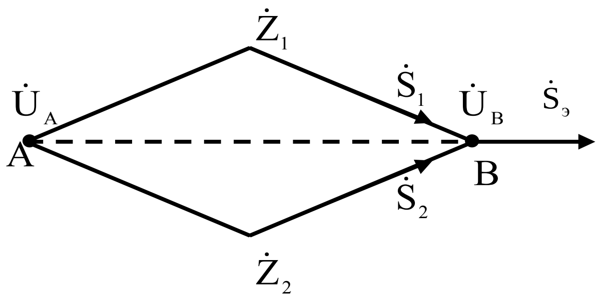


Figure 7.1 - Network plot is with two parallel lines

If in the scheme there are intermediate loadings, the equivalent can't be carried out. For this purpose, do so-called transfer of loadings in other points of a network. Thus, the network mode before transfer and after has to remain invariable.

The conclusion of the dependences determining sizes of variable loadings can be made of the general case when between networks points to which it is required to transfer loading, there are some consumers of energy (figure 7.2).

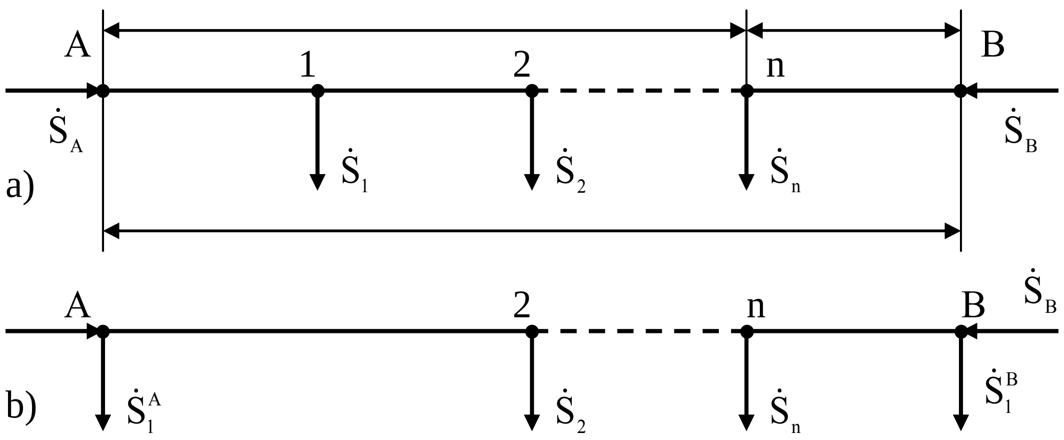


Figure 7.2 - Settlement scheme of a network

Considering the network as dual feed line and taking the voltage at all nodes of the same magnitude and phase determines the power emanating from points A and B:

$$\dot{S}_A = \frac{\dot{S}_1\dot{Z}_{1B} + \dot{S}_2\dot{Z}_{2B} + \ldots + \dot{S}_n\dot{Z}_{nB}}{\dot{Z}_{AB}}; \tag{7.1}$$

$$\dot{S}_B = \frac{\dot{S}_1\dot{Z}_{1A} + \dot{S}_2\dot{Z}_{2A} + \ldots + \dot{S}_n\dot{Z}_{nA}}{\dot{Z}_{AB}}. \tag{7.2}$$

If the $\dot{S}_1$ load transfers points A and B, the network circuit portion takes the form (figure 7.2, b), and the power $\dot{S}_A$ and $\dot{S}_B$ are determined by:

$$\dot{S}_A^{`}=\frac{\dot{S}_1^A\dot{Z}_{AB}+\dot{S}_2\dot{Z}_{2B}+\ldots+\dot{S}_n\dot{Z}_{nB}+\dot{S}_1^B\dot{Z}_{BB}}{\dot{Z}_{AB}}; \tag{7.3}$$

$$\dot{S}_B^{`}=\frac{\dot{S}_1^A\dot{Z}_{AA}+\dot{S}_2\dot{Z}_{2A}+\ldots+\dot{S}_n\dot{Z}_{nA}+\dot{S}_1^B\dot{Z}_{BA}}{\dot{Z}_{AB}}, \tag{7.4}$$

where $\dot{Z}_{AA}=\dot{Z}_{BB}=0$.

Since the load application should not change the network mode, located outside the boundaries of the site, then $\dot{S}_A=\dot{S}_A^{`}$ and $\dot{S}_B=\dot{S}_B^{`}$. Equating equation (7.1) and (7.3) and (7.2) and (7.4), we obtain:

$$\dot{S}_1^A=\dot{S}_1\frac{\dot{Z}_{1B}}{\dot{Z}_{AB}} \qquad \text{and} \qquad \dot{S}_1^B=\dot{S}_1\frac{\dot{Z}_{1A}}{\dot{Z}_{AB}}.$$

Similarly, in general, can be found out any intermediate load:

$$\left.\begin{aligned}\dot{S}_n^A&=\dot{S}_n\frac{\dot{Z}_{nB}}{\dot{Z}_{AB}}\\ \dot{S}_n^B&=\dot{S}_n\frac{\dot{Z}_{nA}}{Z_{AB}}\end{aligned}\right\}. \tag{7.5}$$

Sometimes the calculation of the network is required to produce a triangle transformation into an equivalent star and back (figure 7.3).

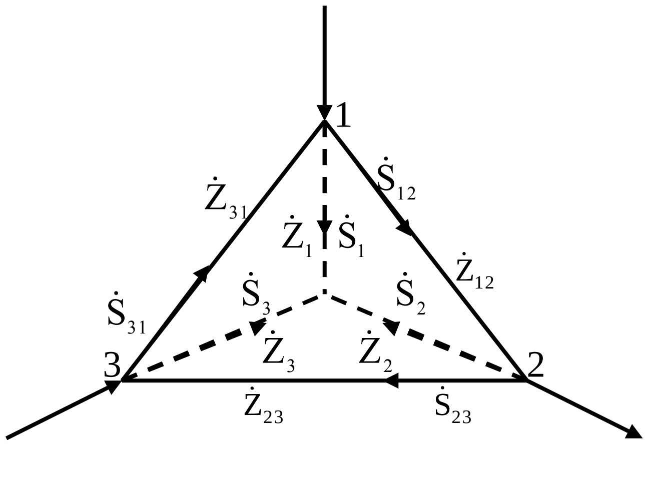


Figure 7.3 - Conversion of the triangle in the star equivalent and back again

Resistance rays equivalent to the star are determined:

$$\begin{gathered}\dot{Z}_1 = \frac{\dot{Z}_{12} \cdot \dot{Z}_{13}}{\dot{Z}_{12} + \dot{Z}_{13} + \dot{Z}_{23}}; \\ \dot{Z}_2 = \frac{\dot{Z}_{12} \cdot \dot{Z}_{23}}{\dot{Z}_{12} + \dot{Z}_{13} + \dot{Z}_{23}}; \\ \dot{Z}_3 = \frac{\dot{Z}_{13} \cdot \dot{Z}_{23}}{\dot{Z}_{12} + \dot{Z}_{13} + \dot{Z}_{23}}.\end{gathered} \tag{7.6}$$

Inverse transformation:

$$\left.\begin{aligned}\dot{Z}_{12} &= \dot{Z}_1 + \dot{Z}_2 + \frac{\dot{Z}_1 \cdot \dot{Z}_2}{\dot{Z}_3}, \\ \dot{Z}_{13} &= \dot{Z}_1 + \dot{Z}_3 + \frac{\dot{Z}_1 \cdot \dot{Z}_3}{\dot{Z}_2}, \\ \dot{Z}_{23} &= \dot{Z}_2 + \dot{Z}_3 + \frac{\dot{Z}_2 \cdot \dot{Z}_3}{\dot{Z}_1}.\end{aligned}\right\}. \tag{7.7}$$

When you deploy changes to the original scheme is necessary to find the distribution of power on the sides of the triangle on the resulting distribution of power in the light of the equivalent the star. We assume conditionally that received power distribution in the light of the stars in accordance to figure 7.3. Power on the sides of the triangle we find the basis of equality of vectors of voltage drops on either side of the triangle adjacent to it and the rays of the star. Set the direction of power on the sides of the triangle and defining the currents in the areas of the rated voltage network, we get:

$$\frac{\dot{S}_{12}}{\dot{U}_н} \dot{Z}_{12} = \frac{\dot{S}_1}{\dot{U}_н} \dot{Z}_1 - \frac{\dot{S}_2}{\dot{U}_н} \dot{Z}_2,$$

hence:

$$\left.\begin{aligned}\dot{S}_{12} &= \frac{\dot{S}_1 \dot{Z}_1 - \dot{S}_2 \dot{Z}_2}{\dot{Z}_{12}} \\ \dot{S}_{23} &= \frac{\dot{S}_2 \dot{Z}_2 - \dot{S}_3 \dot{Z}_3}{\dot{Z}_{23}} \\ \dot{S}_{31} &= \frac{\dot{S}_3 \dot{Z}_3 - \dot{S}_1 \dot{Z}_1}{\dot{Z}_{31}}\end{aligned}\right\}. \tag{7.8}$$

If the result turns out with a negative sign, conditionally accepted direction of power on this party of a triangle should be changed in the return.

Lecture № 8. The balance of active power and its relation with frequency regulation

Content of lecture: imbalance of active capacities at change of frequency in a power supply system.

Lecture purpose: study of the causes of imbalance active powers and its consequences.

In a power supply system the balance of active capacities is observed at any moment:

$$\sum P_G = \sum P_C + \sum \Delta P_T ,$$

where $\sum P_G$ – the total power of generators of power plants;

$\sum P_C$ - the power of consumers of a power supply system;

$\sum P_T$ - total losses of power in electric networks.

If, for example, reduce the supply of an energy (steam, water) to the turbine, power of $\sum P_G$ will become less, and at the same load of consumers of $\sum P_H$ will begin impossible to rotate engines with a former speed. They will start being decelerate and according to static characteristics of loading on the frequency of P =f (f) (figure 8.1) will begin to consume smaller active power. Thus, there will come the balance of active capacities with a frequency of f_1 which is less than initial frequency of f_H.

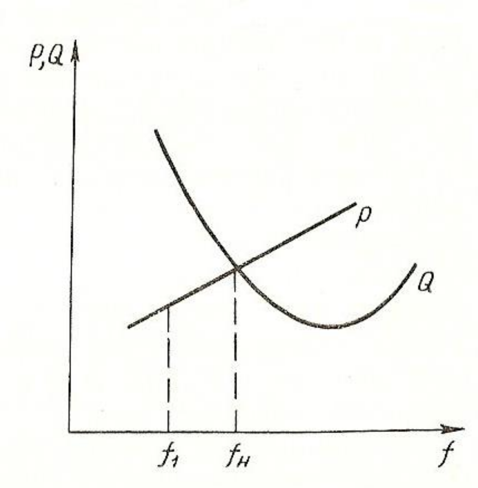


Figure 8.1 - Static characteristics of loading on frequency

Thus, with any frequency the power generated by power plants is equal to power consumption. Thus, nominal frequency in a power supply system testifies that the generated power is sufficient for a covering of normal requirement of electro- receivers. The lowered frequency in comparison with the nominal indicates deficiency of the generated power, and raised – surplus of a power the power plants. It follows that the frequency deviation can come from the nominal at:

a) change the power of stations without change of the included power of electro receivers;

b) change power the electro receivers and constancy of the generated power;

c) simultaneous uncoordinated change of loading stations and consumers.

We consider nature of change frequency at sharp violations of balance active capacities (figure 8.2). Sharp decrease in frequency happens at sudden failure of the generating power and lack of a reserve or at an emergency shutdown of the loaded intersystem lines and division of system into nonsynchronous parts to deficiency of power.

Let in an initial time point to nominal frequency in f_H system there corresponds load of consumers P_{1H} equal to loading of all P_{1G} generators.

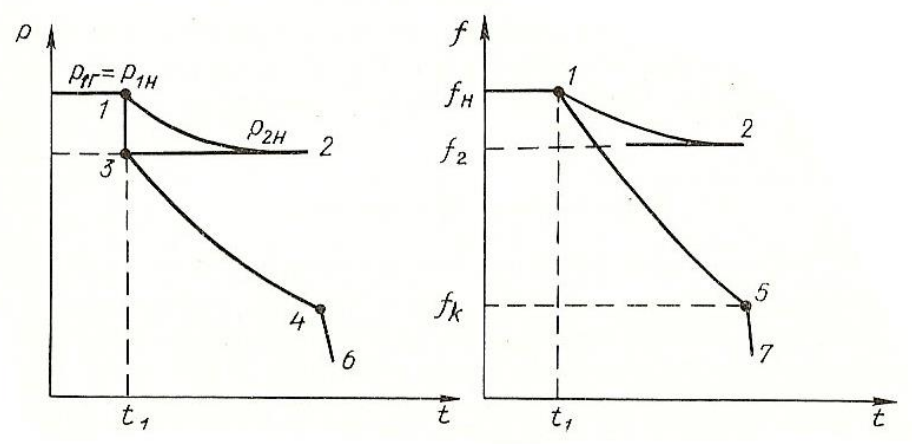


Figure 8.2- Change of frequency at sharp violations of balance of active power

We will assume that all generators are loaded completely and the reserve of active power in system is absent. Let now for some reason in t1 time point (a point 1) there was a deficiency of the active generated power, equal $P_{2G} – P_{1G}$ (a point 3). It will lead to violation of balance, and load of consumers according to the frequency static characteristic will seek to restore it with the lowered frequency. If the power of stations didn't depend on frequency, process would go on a curve 1 – 2. Here smooth change of loading and consumers are explained by inertia of system. At achievement the load of consumers of $P_{2H} = P_{2G}$ would be restored balance with the new lowered f_2 frequency.

However, decrease in frequency and lack of a reserve generating power will lead to reduction of power of all thermal stations on a curve 3-4, and a curve 3-4 more cool, then 1-2, because of a big static pressure at mechanisms of own needs power plants. Therefore, the difference between the consumed and generated capacities will increase that will lead to further decrease in frequency on a curve 1-5. At achievement of critical frequency of f_k the power of thermal stations decreases to zero and frequency sharply falls (curves 4 – 6 and 5 – 7). There is a process of an avalanche of frequency. Thus, the engines and generators remained in work sharply slow down. Engines start consuming the increased jet power, and generators can't give out it because of reduction in the rate of rotation and reduction of EMF there is a sharp under voltage in a network.

Regulation of frequency in electric systems

In the normal mode of a power supply system the frequency deviations caused by change of structure and power of consumers are subject to regulation generally. These changes of power within days make 20–50%.

Regulation frequency of the turbine of power plants is supply with speed regulators. Adjusting ability of the turbine is defined by the characteristic of speed. Figure 8.3 shows the static characteristic of the speed controller.

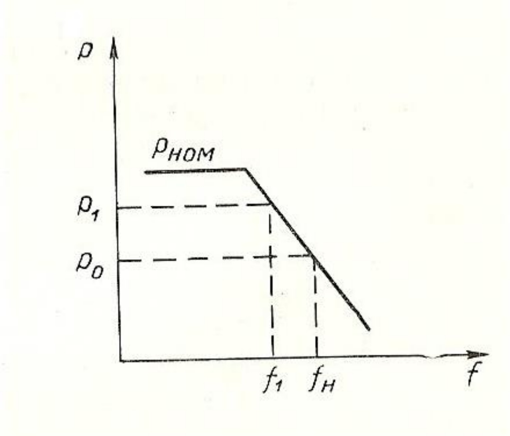
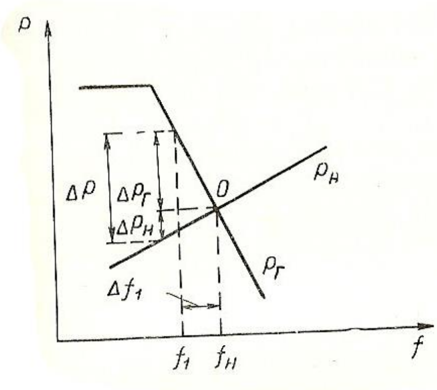


Figure 8.3 - Static characteristic of the regulator of speed

The principle of regulation is that at change of frequency turbine power respectively changes so that to restore former frequency. So, for example, at decrease in frequency from f_n to f_1 there is an automatic set of loading to P_0 to P_1. At further decrease in frequency the power of the generator will grow until becomes equal nominal $P_{НОМ}$.

Consider the frequency control process, build in the same graph characterization of the active load of the turbine speed controller P = f (f) the frequency and static characteristic of consumers $P_н$ = f (f) (figure 8.4).



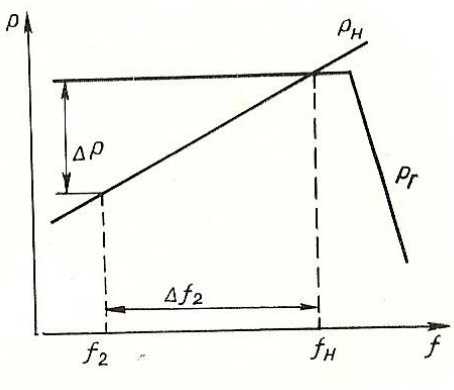


Figure 8.4 Figure 8.5

When the rated frequency f_H at the point (O) load capacity is equal to the power generators: $P_H = P_G$. Suppose that for some reason (for example, due to reduction of load of the stations) to decrease the frequency and Δf_1 becomes equal to f_1. Then, by the static characteristic P_H load capacity is reduced by the amount of ΔP_H and power generators will increase by ΔP_G and overall power shortage will be:

$$\Delta P = \Delta P_G + \Delta P_H .$$

The process of changing power generators and consumers as the frequency deviation, trying to preserve the old frequency, called the primary regulation. Hence the important practical conclusion: while reducing the frequency of complete deficiency of capacity cannot be judged only by the increase in the power generators. It should also take into account the change of load on the static characteristics of consumers.

If at the time of reducing the frequency generators no power reserve, the same reduction in generating capacity ΔP will lead to greater reduction Δf_2 frequency (figure 8.5). With full use of primary frequency regulation power plants it occurs only due to changes in consumer power.

When performing regulators speed turbines with static characteristics primary regulation of frequency doesn't provide maintenance of nominal frequency in system. Therefore, in addition apply secondary regulation. It consists in shift of characteristics of regulators speed of turbines parallel to itself. Secondary regulation can be carried out manually or automatically.

We will consider joint process of primary and secondary regulation of the frequency (figure 8.6).

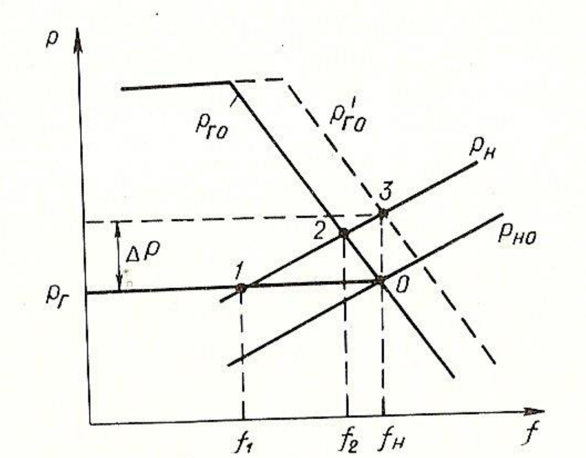


Figure 8.6 – Joint process of primary and secondary regulation of frequency

The average characteristic of regulators speed of generators of system P_{GO} and the static characteristic of load of P_{HO} are known. In a point of O the balance of active capacities is observed with f_H frequency. If there are no primary regulators of speed, with a growth load consumer the power of generators of P_G remains invariable and frequency will decrease to f_1, and the characteristic of loading will move to a point 1 and will reach position of P_H.

When this switch is on speed generators rack up part of the load, and the intersection of the characteristics of the P-th and $P_н$ the will be at 2, and the frequency will be f_2, with $f_1 < f_2 < f_H$. When the secondary control knobs P th generators feature will move up as long as the frequency becomes equal to the nominal f_H (point 3, the characteristic of Pth '). As a result, the entire load will increase ΔP the station generators.

To perform the secondary regulation system frequency typically emit one or more stations, as all the other constant load support and participate in the process only the primary frequency control.

Lecture № 9. Balance of reactive power and its communication with regulation of tension

The content of lecture: imbalance of reactive power when changing the voltage at the load nodes.

The purpose of the lecture: study of the causes of imbalance of reactive power in the load nodes and its consequences.

The power system must be observed operating balance of reactive power:

$$\sum Q_G + \sum Q_{ch} + \sum Q_{c.d} = \sum Q_c + \sum \Delta Q_n, \qquad (9.1)$$

where $\sum Q_G$ – the reactive power of generators of stations;

$\sum Q_{ch}$ – the charging power of power lines;

$\sum Q_{cd}$- the power of the compensating devices;

$\sum Q_c$ – the reactive power of consumers;

$\sum \Delta Q_n$ – losses of jet power in electric networks.

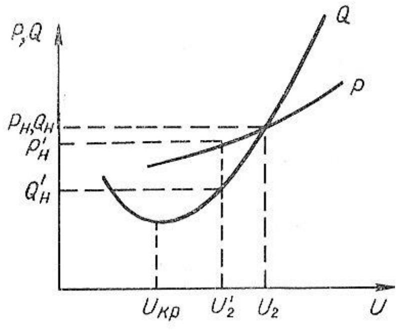


Figure 9.1

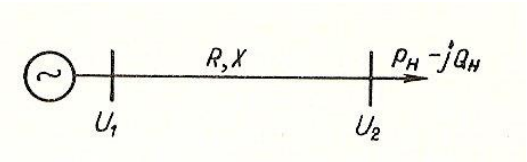


Figure 9.2

This balance constantly remains due to change of the generated power According to static characteristics of loading on tension (figure 9.1).

The condition balance of reactive power is directly connected with sizes of tension in an electric network. We will consider this communication on the example of the scheme of one element of a network (figure 9.2). Let in an initial time point balance of reactive power and tension at the beginning of the line there was U_1, and at the end of its U_2. To this tension according to static characteristics their corresponded load of consumers of $P_н+JQ_н$. Tension at the end of the line can be determined:

$$U_2 = U_1 - \frac{Đ_T R + Q_T \tilde{O}}{U_2}.$$

If due to unloading a source of jet power to reduce U_1 tension to $U_{1'}$, there will be a voltage drop in U_2 loading knot to $U_{2'}$. Thus according to static characteristics, the power of consumers will decrease to $P_{н'}$ + $JQ_{н'}$ (figure 9.2) and tension at the end of the line:

$$U_2' = U_1' - \frac{Đ_T' R + Q_T' \tilde{O}}{U_2}.$$

Change of tension of U_2 will happen because of voltage drop at the beginning of the line and change the loss the tension. Static characteristics of reactive power much more coolly than characteristics of active power. For each percent of change of tension there is a change the active power for 0,6–2%, and reactive for 2-5%. Therefore, at voltage drop of U_1 there is a decrease in loss of tension. As a result, change of U_2 will be less, than change of U_1:

$$U_2 – U_{2'} < U_1 – U_{1'}.$$

Thus, due to change the load of consumers according to static characteristics there is some regulation of tension U_2. This process is called as the regulating effect of loading on tension. As a result of such regulation and $U_{2'}$ will correspond to new values of tension $U_{1'}$ a new condition the balance of jet power.

The regulating effect of loading will be shown only up to some critical tension of $U_{кр}$. If tension of U_2 appears below critical, there will be the return phenomenon: voltage drop will cause growth of reactive load of consumers that will lead to growth losses of tension and further voltage drop U_2. There comes the avalanche of tension and there is a violation balance of reactive power (figure 9.3).

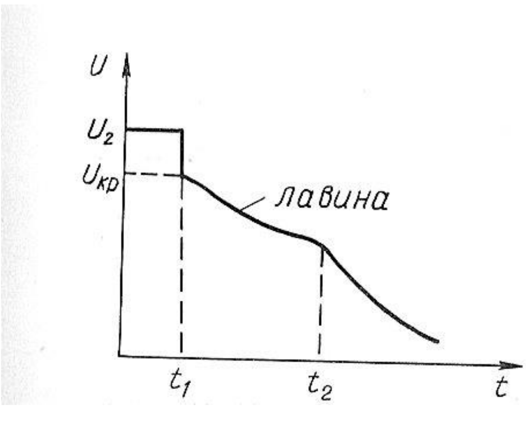


Figure 9.3 - Process of an avalanche of voltages

Here t_1-the voltage drop moment to U_{kp}, and $t_2 – t_1$ time interval development of an avalanche (some seconds). The avalanche of tension is resulted by violation of stability of loading which is expressed in self-unloading of consumers. After their shutdown tension is restored.

For knots with the mixed character of consumers critical tension makes 0,8 – 0,75 rated voltage of a network. The avalanche of tension can come both in all power supply system, and in separate knots in which there is a deficiency of reactive power. Apply special measures to prevention of an avalanche of tension.

Lecture № 10. Quality of electric energy

Content of lecture: influence of quality of the electric power on operation of electro receivers and electro devices. Indicators of quality of the electric power.

Lecture purpose: studying and calculation of indicators of quality of the electric power in electric networks.

10.1 Influence of quality of the electric power on operation of electro receivers and electro devices

Quality of the electric power is characterized by the certain indicators relating to the frequency of alternating current and the mode of tension. Quality of the electric power influences operation of electro receivers, and also for operation of electric devices, attached to electric networks. All electro receivers and devices are characterized by certain nominal parameters (f_{nom}, U_{nom}, I, etc.). It is usually supposed that work at these parameters is the most expedient from the technical and economic points of view. Now there are a lot of electro receivers (rolling mills, electric arc furnace, rectifier installation, electrified transportation, electrolysis) with sharply varying loadings or unevenness of their distribution on phases and existence of not sinusoidal currents and tension. All this leads to violation of quality of the electric power.

10.2 Indicators of quality of the electric power

Indicators of quality of the electric power are subdivided into two groups: the main and additional. The main indicators define the properties of the electric power characterizing its quality.

Treat the main indicators of quality of the electric power for which admissible values are established: frequency deviation, tension deviation, fluctuation of tension, coefficient of γ-th of a harmonious component, coefficient of the return sequence of tension, coefficient of zero sequence of tension.

The deviation of frequency is a difference between the valid and nominal rate of frequency:

$$\Delta f = f - f_{nom}.$$

Deviation of frequency identical to all power supply system as value of frequency of time is defined at present by the frequency rotation of generators. In the normal set modes, all generators have synchronous frequency. Therefore, the deviation of frequency is an all-system indicator of quality of the electric power.

In the real modes of electric networks of tension in nodal points always differ from the nominal. Therefore, indicators of quality of tension have different values in various points of an electric network.

The deviation of tension is a difference between the valid value of tension and its nominal rate:

$$\delta U_y = U - U_{nom}.$$

percentage of the nominal:

$$\delta U_y = \frac{U - U_{nom}}{U} \cdot 100. \qquad (10.1)$$

Fluctuation of tension is a difference between the greatest and smallest value of tension, in % from nominal:

$$\Delta U_{t\%} = \frac{U_{max} - U_{min}}{U_{nom}} \cdot 100. \qquad (10.2)$$

The coefficient of the return sequence of tension is the indicator of quality defining asymmetry of tension of %:

$$K_{2U} = \frac{U_{2(1)}}{U_{nom}} \cdot 100, \qquad (10.3)$$

$U_{2(1)}$ - the operating value, tension of the return sequence of the main frequency of three-phase system of tension.

Similarly, the coefficient of zero sequence of tension of K_{OU} of three-phase four-wire system is defined. The coefficient of K_{OU} is defined similarly (10.3), only instead of $U_{2(1)}$ the operating value of zero sequence of the main frequency of $U_{0(1)}$is used.

The coefficient is not sinusoidal voltage curve:

$$K_{HCU} = \frac{\sqrt{\sum_{\gamma=2}^{n} U_\gamma^2}}{U_{nom}} \cdot 100,$$

the operating γ-th value of a harmonious component of tension;

γ - order of a harmonious component of tension;

n – an order of the last from the considered harmonious components of tension.

Table 10.1

Admissible values of indicators of quality of the electric power: Normal Maximum		
The established deviation of tension, % Coefficient of a not sinusoidal, % not more, in an electric network tension	± 5	±1 0
to 1 kV	8	12
6-20 kV	5	8
35 kV	4	6
110 kV and higher than	2	3
Coefficient of the return sequence tension, %, no more than	2	4
Coefficient of zero sequence tension, %, no more than	2	4
Deviation of frequency, Hz	±0,2	±0,4

Lecture № 11. Regulation of voltage in electrical networks

The content of the lecture: methods of regulation and voltage changes in the network.

The purpose of the lecture: introduction to the voltage control means in electrical networks.

11.1 The problem of voltage regulation in electric networks

For providing requirements imposed to quality of voltage by electro receivers and electro devices, values of voltage in each point of an electric network have to be in certain admissible limits. The practical admissible mode of voltage without use of special control devices can be provided only provided that total losses of voltage in a network rather small. It takes place in electric networks of small length with small number of intermediate transformations.

Problem of regulation of voltage is intended change the mode of voltage in separate points of a network under in advance set laws. Economic automatic control of voltage is more reliable. Laws the regulation of voltage have to be established from conditions of providing the most economic joint sources of reactive power, electric networks and electro receivers attached to them.

Problems regulation of voltage are differently solved in the conditions of design and operation of electric networks.

In the course of design the electric networks means of regulation, adjusting ranges, steps of regulation, an installation site of the corresponding devices, systems of automatic control are chosen.

Problems regulation of tension in use of electric networks are connected with the fullest and economic use of the available means. Due to the current change of operating conditions of an electric network (change of loadings, the equipment of a network, her parameters and schemes of connections) requires holding the relevant activities for improvement of the mode of tension. Treat them: change of coefficients of transformation at transformers, unregulated under loading, additional automation of already available devices, change of installations of automatic regulators of tension and the applied systems of automatic control of tension, etc. Sometimes also carrying out reconstruction of a network is required.

11.2 Ways of change and regulation of tension in a network

We will consider on the example of the distributive network attached to tires of the center of food (CF) what ways of change and regulation of tension can be applied to providing technically tolerances of tension at electro receivers. The size of these deviations depends on many factors: the mode of tension in the center of food, loss of tension in elements of a network, existence in this network of additional control devices.

In figure 11.1 the scheme of a distributive network is submitted.

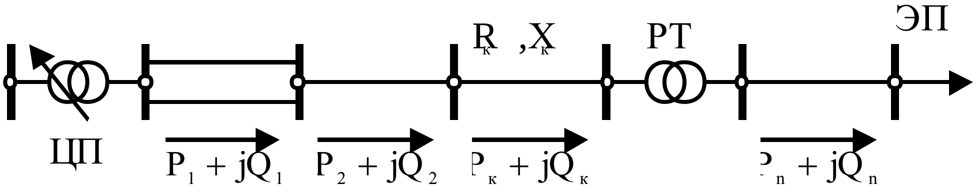


Figure 11.1 - Scheme of a distributive network

For this scheme we will write down the expression connecting a deviation of tension of V on tires of the center of food and tension deviation at the electro receiver (ER):

$$V_{ER} = V_{CF} - \Delta U_{CF\text{-}ER} + \sum_{1}^{m} E_x \,, \tag{11.1}$$

where V_{CF} and V_{ER} - the current values of a deviation from rated voltage;

$\Delta U_{CF\text{-}ER}$ - the sum of values of losses of tension in n network elements (lines, transformers) which are switched on consistently between the center of food and the electro receiver:

$$\Delta U_{CF\text{-}ER} = \frac{100}{U_{nom}^2} \cdot \sum_{1}^{n} (P_к R_к + Q_к X_к) \,, \tag{11.2}$$

where $\sum_{1}^{m} E_x$ - the sum of the voltage of additives produced by selecting various transformation ratios at m connected in series in the area of CF-ER unregulated and regulated transformers or autotransformers;

Pк and Qк - respectively active and reactive power at the site «k» network;

Rк and Xк - resistance and reactance k-th element of the network.

Formula (11.1) is valid for the maximum and minimum modes for:

$$V_{ER}^{max} = V_{CF}^{max} - \Delta U_{CF\text{-}ER}^{max} + \sum_{1}^{m} E_x^{max}; \quad (11.3)$$

$$V_{ER}^{min} = V_{CF}^{min} - \Delta U_{CF\text{-}ER}^{min} + \sum_{1}^{m} E_x^{min}. \quad (11.4)$$

Subtracting (11.3) from (11.3 and) we will receive expression for the possible range of deviations of tension on electro receiver tires in the considered conditions:

$$d = V_{ER}^{max} - V_{ER}^{min} = V_{CF}^{max} - V_{CF}^{min} - (\Delta U^{max} - \Delta U^{min})_{CF\text{-}ER} + \sum_{1}^{m} (E_x^{max} - E_x^{min}). \quad (11.5)$$

From the analysis of the given formulas it is visible that for providing some in advance preset values of deviations of tension at the electro receiver the next ways can be used:

a) change the mode of tension or regulation of tension on tires of the center of food;

b) change value of loss of tension in separate elements of a network (lines, transformers) or on several sites of a network at the same time;

c) change coefficient of transformation of the unregulated and adjusted under loading transformers and autotransformers included in the center of food electro receiver on network sites. At the same time sizes of the corresponding additives of tension change.

Voltage regulation at the center of power usually leads to a change in the stress regime in the whole attached to the center of the power supply. Therefore, this method is called centralized regulation voltage regulation. All other methods are the so-called local voltage regulation, resulting in a change in voltage mode to a limited part of the distribution network. Load changing consumer not only during the day, but also throughout the year. For example, the maximum load during the year is during the autumn-winter peak, the lowest - in the summer. In this case, there is a so-called counter-voltage regulation. It is the change in voltage depending not only on the daily, and then also from seasonal load variations during the year. It provides for the maintenance of high-voltage electric power stations on buses during peak hours and its reduction to the nominal during off-peak. The largest load operation to increase the voltage values:

$$U_2 = 1{,}05U_{nom}, \tag{11.6}$$

and a least load conditions:

$$U_2 = 1{,}0U_{nom}. \tag{11.7}$$

Lecture № 12. Ways and means of voltage regulation in electric networks

Lecture content: ways and means to control the voltage in electrical networks.

Purpose of the lecture: study of ways and means of voltage regulation in electric networks.

12.1 Regulation of the voltage change in the transformation ratio of transformers and autotransformers

Transformers and auto-transformers, in addition to the main branches are also additional regulation branch. By changing these branches, the transformation ratio can be changed (within 10-20%).

On a design distinguished two types of transformers: switching of adjusting tap without excitation, i.e., to disconnect from the network (transformers with WSP); switching load tap adjustment (transformers with tap changer). Adjusting branches are executed on the side of a higher voltage transformer. At the same time the switching device is facilitated. Currently, all the transformers of 35 kV and above have the tap-changer. To switch regulating tap in the transformer with the WSP, it must be disconnected from the network. Such switching is only rarely the seasonal load changes.

Transformers, switching adjustment tap without excitation are made of the main and some additional branches. The main branch has a voltage equal to the nominal voltage of the network to which are attached the data transformers (6, 10 kV). At the main branch of the transformation ratio of the transformer is called nominal. When using four additional branches the coefficient of transformation differs from nominal rate on +5; +2.5;-2.5 and –5%.

Transformers with integrated switching adjusting load tap different from the switching transformer tap adjustment without having to bring the existence of a special switching device, as well as the increased number of branches and levels adjustment value adjustment range. For example, a transformer with a rated voltage of 115 kV main branch regulations HV winding provides a range of ± 16% at ± 9 levels of regulation by 1.78% each.

Figure 12.1 is a schematic diagram of a switching transformer load tap adjustment.

HV winding of this transformer consists of two parts - an unregulated "a" and the variable "b".

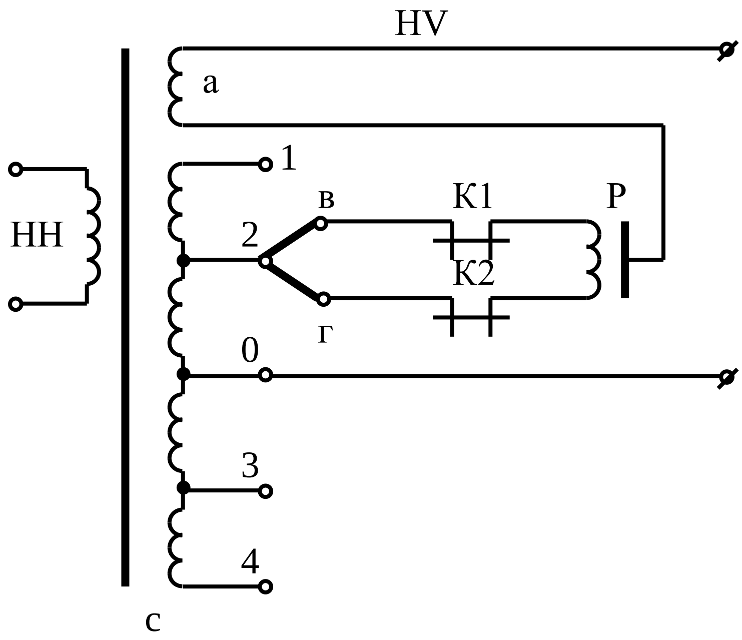


Figure - 12.1 Scheme transformer load tap changer

On adjustable part there are a number of branches to motionless contacts 1-4. Branches 1-2 correspond to part of the rounds included agrees with rounds of the main winding. At inclusion of branches 1-2 coefficient of transformation of the transformer increase. Branches 3-4 correspond to part of the rounds connected opposite in relation to rounds of the main winding. Their inclusion reduces transformation coefficient as compensates action of part of rounds of the main winding. The main conclusion of a winding of HV of the transformer is the point 0. The number of the rounds operating according to and opposite with rounds of the main winding can be unequal.

On the regulated part "b" of the switching device has a winding consisting of a movable contacts "в" and "г", the contactors K1 and K2 and the reactor R. The middle of the reactor winding is connected to the unregulated part of the winding "a" transformer. In an alternating voltage winding load current mode is distributed equally between the halves of the reactor winding. Therefore, the magnetic flux is small and the voltages drop in a small reactor.

Assume that you want to switch the tap-changer to the branch 2 to 1. In this case, disconnect the contactor K1, translate the movable contact "c" on the branch terminal 1 and again include contact K1. Thus, section 1-2 of the winding is closed to the coil reactor R. Much reactor inductance limits the surge current that occurs as a result of the presence of voltage on the winding section 1-2. Then disconnect the contactor K2, turn the movable contact on the branch contact and include 1 contactor K2.

The reactor and all fixed and mobile contacts switching devices place in a transformer tank. The contactors place in the separate steel casing is filled in with oil and strengthened outside of a transformer tank. Such design facilitates carrying out audit of contacts and change of oil.

At reconstruction of the existing networks in which there are transformers without adjustment under loading use so-called linear adjusting transformers (LA). For regulation of tension they join consistently with the unregulated transformer (figure 12.2, a). For regulation of tension on the departing lines linear regulators turn on directly in the line (figure 12.2, b).

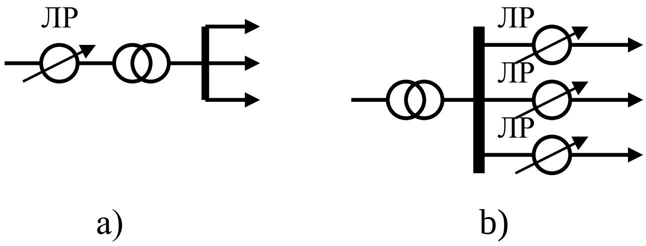


Figure 12.2

Autotransformers 220 kV and above are available with switching under load adjustment tap, built at the end of a linear medium-voltage windings. In this case, you can change the load transformation ratio only for winding high and medium voltage. If you need to simultaneously change the load transformation ratio between the windings of higher and lower voltages, it is necessary to install an additional linear regulator in series with the low voltage winding autotransformer. For economic reasons, this solution is more appropriate than the manufacture autotransformers with two embedded devices with switching adjusting load tap.

12.2 Regulation of the voltage change of the reactive power flows on the network

Reactive power can be generated not only generators stations, but also other sources of reactive power compensation devices CD, as might be used capacitor bank, synchronous compensators (engines).

The power compensating device for network installation is determined by the specific technical and economic calculations, taking into account the reactive power balance in the corresponding node of the electrical system. Setting the compensating device can improve the voltage in the network mode and consumers.

Figure 12.3 shows a simplified diagram of an electrical circuit consisting of line resistances R and X. At the end of the line parallel to the load included uncontrolled battery BC capacitors, generating reactive power jQ_k. When switched capacitor bank line is transmitted on a lower reactive power equal to Q_n-Q_k, which leads to lower losses and voltage stress regime change in the network. Loss of line voltage at the battery installation of capacitors is determined by:

$$\Delta U = \frac{P_н R + (Q_н - Q_к) X}{U_{nom}}. \tag{12.1}$$

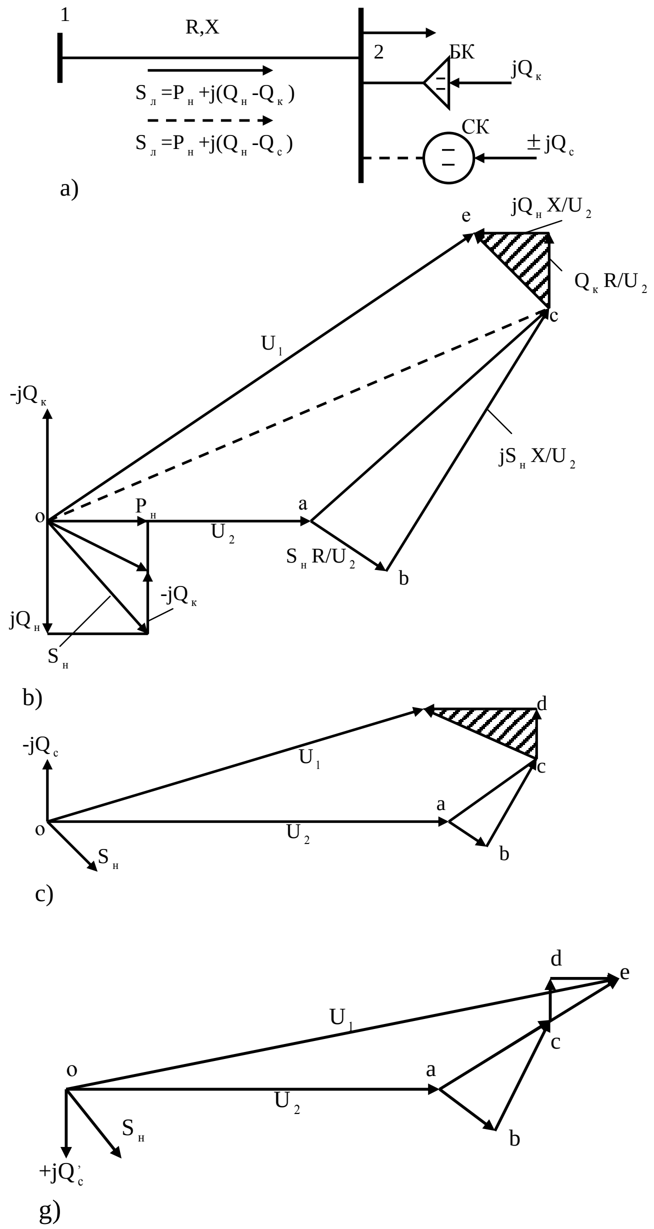


Figure 12.3

In figures 12.3 b, in vector diagram of tension and power respectively for the modes of the maximum and minimum loads are provided.

From the chart is visible that in the modes of the maximum loads in the presence the battery of condensers power failure value in a network decreases (OS equal to a geometrical difference of pieces and OA in the absence of the battery of condensers and pieces of OS and OA in the presence of the battery of condensers). Thus, at some set U_1 tension at the beginning of the line in the presence of the battery of condensers the mode of tension at the end of the line improves.

In the modes of small loadings the sizes of a triangle power failures abc corresponding to loading power sharply decrease. At the same time the sizes of a triangle of power failure cde corresponding to the power of the battery of condensers remain almost invariable. In these modes tension at the end of the line can exceed U_1 tension that can sometimes be undesirable or inadmissible.

From this it follows that it is possible and expedient to change automatically the power of the battery of condensers for regulation of tension in a network.

Similar change of the mode of voltage in a network takes place in case of use as the compensating device of synchronous compensators (engines). The overstimulation mode synchronous compensators generates reactive power jQ_c and excitation mode consumes jQ_c. This property of the synchronous compensator can be used both to raise and to lower the tire to the load voltage at a constant voltage value at the beginning of the line.

Influence of synchronous compensators on the mode of voltages in a network is shown in figure 12.3, c.g. This conventionally accepted that the power of the compensating device in the mode of maximum load is equal to the power of a capacitor bank, i.e. $jQ_c = jQ_k$. In low load conditions, synchronous condensers jQ_c consumes reactive power (figure 12.3, g).

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