менее 25 % от общемирового объёма производства электроэнергии в рамках стремлений к созданию чистого и надёжного низкоуглеродистого мирового энергобаланса.

5. Рассмотрены три глобальных альтернативных сценарии развития мировой энергетики до 2060, разработанных Всемирный энергетическим Советом: «Джаз модерн» (Jazz modern), «Неоконченная симфония» (Unfinished symphony), «Хард рок» (Hard rock). По этим сценариям ядерная энергетика будет частью мирового энергобаланса, однако каждый сценарий предполагает различную долю ядерной энергетики в мировом энергобалансе и довольно отличные друг от друга пути развития.

6. Темпы и направления глобального перехода к безуглеродистой энергетике являются частью гораздо более широкого комплекса общемировых изменений. В настоящее время идёт процесс так называемого «Большого перехода» (Grand Transition), который предполагает фундаментальный социально-экономический сдвиг в свете грядущей эры цифровой и экологической эффективности. В более широком контексте перспективы атомной и других форм производства энергии определяются сложным и непредсказуемым взаимодействием глобальных факторов, таких как децентрализация, декарбонизация, цифровизация и геополитика. Появляются многочисленные развилки на пути к успешному общемировому переходу к низкоуглеродистой энергетике.

7. Всё больше признаётся тот факт, что ядерная энергия займёт своё место в будущем мировом энергобалансе и будет способствовать устойчивому развитию.

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Qurbonalizoda S.SH.
Dr., Deputy Director of cascade
Varzob's HPPs OSHC «Barqi Tojik», Tajikistan
Candidate of Technical Sciences, Deputy Director
cascade of Varzob HPPs, OJSCHK "Barki Tojik", Tajikistan
Kurbonalizoda Saidabdullo Shamsullo

THE QUALITY OF ELECTRIC ENERGY IN POWER SUPPLY SYSTEMS AND GENERAL STANDARDS

Курбонализода Саидабдулло Шамсулло
кандидат технических наук, Заместитель Директора
каскада Варзобских ГЭС ОАХК «Барки Точик», Таджикистан

КАЧЕСТВА ЭЛЕКТРИЧЕСКОЙ ЭНЕРГИИ В СИСТЕМАХ ЭЛЕКТРОСНАБЖЕНИЯ И НОРМЫ ОБЩЕГО НАЗНАЧЕНИЯ

Summary. This article discusses indicators of the quality of electricity and their impact on the operation of the main types of electrical equipment, issues of monitoring and improving the quality of electricity. In turn, the normal operation of electrical equipment depends on the quality of electricity. The mutual influence of electrical equipment and supply networks is called electromagnetic compatibility. The solution to the problem of electromagnetic compatibility is associated with the determination and maintenance of optimal indicators of the quality of electricity, at which the technical requirements are met with minimal cost.

Аннотация. В данной статье рассматриваются показатели качества электроэнергии и их влияние на работу основных видов электрооборудования, вопросы контроля и улучшения качества электроэнергии. В свою очередь нормальная работа электрооборудования зависит от качества электроэнергии. Взаимное влияние электрооборудования и питающих сетей называется электромагнитной совместимостью. Решение проблемы электромагнитной совместимости связано с определением и поддержанием оптимальных показателей качества электроэнергии, при которых выполняются технические требования с минимальными затратами.

Key words: electricity, frequency, voltage, technical, electrical network, loss, quality.

Ключевые слова: электроэнергии, частота, напряжения, технический, электрических сеть, потери, качества.

Electromagnetic interference in electrical networks of industrial enterprises, caused by powerful nonlinear, asymmetric and shock loads, degrade the operation of power electrical installations, automation systems, communications and relay protection, which can lead to a decrease in the reliability of power supply, an increase in power losses, a deterioration in quality and a decrease in the number of products. In this regard, the problem of the quality of electricity arises, the study of which is given much attention in industrialized countries.

Electricity is a special type of product and has certain characteristics that make it possible to judge its suitability. The set of characteristics at which power receivers are able to perform their functions are united by the general concept of power quality, which is assessed by indicators of power quality.

Power quality affects power consumption, reliability of power supply systems, and the technological process. Low-quality electricity causes damage caused by damage to materials, disruption of the technological process, deterioration in product quality, reduced productivity, etc. - technological damage. In addition, there is electromagnetic damage from low-quality electricity, which is characterized by an increase in electricity losses, failure of electrical equipment, disruption of automation, telemechanics, communications, etc. Ensuring the proper quality of electricity leads to an increase in production efficiency. Solving this problem, one should proceed from a comparison of the expected effect of improving the quality of electricity and the inevitable additional costs.

Modern production is characterized by the use of such consumers of electrical energy, which affect the quality of electricity supply networks. These include: high-power rectifiers, electric arc steel-making furnaces, welding machines, etc.

Electricity quality indicators: GOST 13109-97 "Standards for the quality of electrical energy in general-purpose power supply systems" establishes the following power quality indicators (PQE):

1) steady-state voltage deviation; δU_y;

2) the range of voltage change; δU_t;

3) the dose of flicker; P_t;

4) the distortion factor of the sinusoidal voltage curve; K_U;

5) voltage harmonic coefficient; $K_{U(\nu)}$;

6) coefficient of voltage unbalance in the reverse sequence;

7) zero-sequence voltage unbalance factor; K_{0U};

8) frequency deviation; Δf;

9) the duration of the voltage dip; Δt_n;

10) impulse voltage; $U_{\text{имп}}$;

11) temporary overvoltage factor. $K_{\text{пер}U}$.

When determining the PQE values, the following auxiliary parameters of electricity are used:

- frequency of repetition of voltage changes; $F_{\delta U_t}$;
- the interval between voltage changes; $\Delta t_{i,i+1}$;
- the depth of the voltage dip; δU_n;
- the frequency of voltage dips; F_n;
- pulse duration at the level of 0.5, its amplitude; $t_{\text{имп}0.5}$;
- the duration of temporary overvoltage. $\Delta t_{\text{пер}U}$.

The value of the PQE in the normal operation of the electrical network should not go beyond the maximum permissible values and, at the same time, for at least 95% of the time of each day, it should remain within the normally permissible values specified in GOST 13109–97.

Control over the observance of the requirements of the standard by power supply organizations and consumers of electric energy is carried out by supervisory bodies and test laboratories for the quality of electric power accredited in the prescribed manner.

Electricity quality control (CE) at the points of general connection of electricity consumers to general-purpose power supply systems is carried out by power supply organizations.

Control points are selected in accordance with regulatory documents.

The frequency of PQE measurements is set as follows. For steady-state voltage deviation - at least twice a year, and in the presence of automatic counter voltage regulation in the power center - at least once a year. For other indicators - at least once every two years with the unchanged network layout and a slight change in the load that affects the quality of electricity.

Frequency deviation: The frequency deviation in hertz is the difference between the average $f_у$and nominal $f_{ном}$ frequency values: $\Delta f = f_у$-$f_{ном}$.

The averaged value of the frequency is calculated as a result of averaging Nobservations f_i over a time interval of 20 s using the formula

$$f_у = \frac{\sum_{i=1}^{N} f_i}{N}, \qquad (1)$$

where is f_i the actual value of the frequency for the th i observation.

The number of observations must be at least 15.

Normally permissible and maximum permissible values of frequency deviation are equal to $\pm 0{,}2$and $\pm 0{,}4$Hz, respectively.

All frequency deviation values measured within 24 hours should not exceed the maximum permissible value, and 95% of all measured values should not exceed the normally permissible value.

The electromagnetic component of the damage is caused by an increase in active power losses and an increase in active and reactive power consumption. Reducing the frequency by 1% increases network losses by 2%. For an induction motor, the expression [5] is valid:

$$U \approx E_1 = 4{,}44 f_1 W_1 k_{об1} \Phi_{макс}, \qquad (2)$$

where is $U, \;\; E_1$ the supply voltage and the EMF of the stator winding; f_1- power supply frequency; W_1- the number of turns of the stator winding; $k_{об1}$- winding ratio of the stator winding; $\Phi_{макс}$- Is the flow amplitude.

With constant voltage, lowering the frequency will increase the flow. As a result, saturation increases, no-load current increases, and losses in steel increase.

An increase in frequency leads to a decrease in flow. This means that at a constant load torque, the currents of the rotor and stator will increase. Active power losses increase and motor heating increases. For an asynchronous motor, permissible frequency change $\Delta f = \pm 2{,}5\%$. The above formula is also valid for the transformer ($k_{об1}$= 1).

A decrease in frequency leads to an increase in the transformer flux, an increase in no-load current and losses in steel.

The technological component of the damage is mainly caused by under-production by the enterprise and the cost of additional work time to fulfill the plan. The value of technological damage is an order of magnitude higher than the electromagnetic one. The main reason for the damage is a decrease in the productivity of technological lines and mechanisms due to a decrease in the speed of drive electric motors, mainly asynchronous ones. To determine the damage, it is necessary to know the dependence of the change in the rotational speed of the asynchronous motor on the change in the network frequency and the dependence of the performance of the technological lines on the rotational speed of the induction motor.

Annual economic damage from frequency reduction (in rubles) [2]:

$$У = C_у \left[\Pi(T-T_1) - \sum_{i=1}^{k} \int_0^{T_i} \Pi_n dt \right] \qquad (3)$$

where are $C_у$ the planned unit costs per unit of production when operating at the nominal frequency, rubles; P - productivity of technological lines per hour at rated frequency; T- duration of work per year, h; T_1- duration of operation per year at nominal frequency; k - the number of frequency changes per year; T_i- duration of frequency change, h; P_n- the dependence of the performance of the lines on the frequency of rotation of the asynchronous motor.

The rotational speed of an induction motor with a fan torque of the load can be determined by the formula

$$n = n_1 \left(1 - \frac{\gamma^2 k_f^4 s_{НОМ}}{\alpha^2 k_u^2} \sqrt{\frac{k_3^2 - k_{i0}^2}{1 - k_{i0}^2}} \right) \qquad (4)$$

where is n_1 the synchronous rotation frequency at $f \;\; = f_{ном}$; γ , α - correction factors taking into account saturation of the magnetic circuit (1.05 - 1.15); $k_f = f \,/\, f_{ном}$ $S_{ном}$; - rated slip; $k_u = U/U_{ном}$; $k_3 = I/I_{ном}$ - load factor; - $k_{i0} = I/I_{1ном}$ multiplicity of no-load current.

$$n = n_1 \left(1 - \frac{\gamma^2 k_f^2 s_{НОМ}}{\alpha^2 k_u^2} \sqrt{\frac{k_3^2 - k_{i0}^2}{1 - k_{i0}^2}} \right) \qquad (5)$$

At constant moment of resistance

Determination of damage, knowledge of its structure makes it possible to develop scientific and technical measures to reduce the negative consequences of frequency changes. Maintaining a normal frequency is a purely technical challenge. The main way to solve it is to create power reserves in the power system.

Voltage deviation: Voltage deviation is a measure of the steady-state voltage deviation. This is the difference between the actual and rated voltage, the first being the average value of the positive sequence voltage of the fundamental frequency over a set period of time.

The normally permissible and maximum permissible values of this PQE are 5 and 10%, respectively. It is defined as follows.

For each i th observation over a period of time equal to 24 hours, the effective value of the linear (phase) voltage of the positive sequence of the fundamental frequency is determined $U_{1(1)i}$. It is allowed to use the formula

$$U_{1(1)i} = \frac{1}{3}\left(U_{AB(1)i} + U_{BC(1)i} + U_{CA(1)i}\right) \qquad (6)$$

where are the $U_{AB(1)i}, \;\; U_{BC(1)i}, \;\; U_{CA(1)i}$ effective values of the line voltages of the fundamental frequency in the i-th observation, V, kV.

Calculate the value of the averaged voltage U_y value as a result of averaging Nobservations $U_{(1)i}$ or $U_{1(1)i}$ for a time interval of 1 min:

$$U_y = \sqrt{\frac{\sum_{i=1}^{N} U_i^2}{N}} \quad (7)$$

where is $U_i$the voltage value $U_{(1)i}$or$U_{1(1)i}$ in the i -th observation, V, kV.

The number of observations for 1 min must be at least 18.

Next, the steady-state voltage deviationδU_y in percent is calculated:

$$\delta U_y = \frac{U_y - U_{ном}}{U_{ном}} \cdot 100 \quad (8)$$

The quality of electrical energy for the steady-state voltage deviation at the point of common connection to the electrical network is considered to be in compliance with the requirements of the standard if all the steady-state voltage deviation values measured for each minute within 24 hours are within the range limited by the maximum permissible value, and not less than 95% of the values are within an interval limited by a normally permissible value.

The main reason for the voltage deviation is the change in the load in the networks. Large deviations (and fluctuations) in the voltage in the supply network occur when powerful (in relation to the short-circuit power) power consumers operate, the load of which is of a sharply variable nature (electric arc steel-making furnaces, welding machines and powerful valve converters).

When the voltage deviates, the performance of the electrical equipment deteriorates. Let's consider some of its types.

Lighting installations: When the voltage drops by 10%, the luminous flux of incandescent lamps is reduced by 30%, and when the voltage is increased by 10%, the lamp life is reduced by 5 times. The electrical network must be designed so that in the event of an emergency shutdown of a network element, the voltage on the lighting lamps does not decrease by more than 12%.

Asynchronous motors: Let's analyze expression (14). Let's assume that the load torque is constant and the mains frequency is constant. Then a change in voltage leads to a proportional change in flux. A decrease in flux causes an increase in current, which in turn leads to an overload of the motor, an increase in losses in power lines and transformers. A 10% reduction in voltage causes a 19% reduction in torque. An increase in flux leads to an increase in no-load current and an increase in losses in steel. In asynchronous motors, when the supply voltage changes, the rotor speed and the consumption of reactive and active power change. Because of this, the reduced costs of work change in comparison with the working conditions at rated voltage by the value [2]

$$\Delta З_{АД} = k\Delta Q + \beta(\Delta P + \Delta P_{пот}) + У_{\Delta n} + У_u \quad (9)$$

Where ΔQ and ΔP increment of consumed reactive and active power; - $\Delta P_{пот}$increment of active power losses; $У_{\Delta n}$- damage from changes in engine speed; β - the cost of 1 kWh of electricity; $У_u$- additional costs associated with a change in the life of the engine; k - unit cost of 1 kvar of reactive power.

Synchronous motors: With voltage deviation, reactive power changes and, accordingly, active power losses:

$$\Delta P_{СД} = Д_1\left(\frac{Q}{Q_{ном}}\right) + Д_2\left(\frac{Q}{Q_{ном}}\right)^2 \quad (10)$$

where $Д_1$and$Д_2$ are constant loss factors; Q and $Q_{ном}$- current and rated reactive power.

When the mains voltage rises, the reactive power supplied to the mains by the synchronous motor decreases, and when the voltage decreases, it increases.

Valve converters: When the voltage rises, the automatic control system increases the control angle, which leads to a deterioration in the power factor. Thus, an increase in voltage by 1% leads to an increase in the consumption of reactive power by the converter by (1 ÷ 1.4)%. Other indicators improve with increasing voltage. It is beneficial to increase the voltage within the permissible range.

Electric furnaces: Lowering the voltage by 7% leads to a 1.5-fold deterioration in the melting process. Increasing the voltage above 1.05 $U_{ном}$leads to excessive consumption of electricity.

With a decrease in voltage, losses in the networks increase due to an increase in current, and the service life of the insulation decreases.

For more details on the influence of voltage deviation on electrical networks and electrical equipment, see [4].

Voltage fluctuations

General provisions: Voltage fluctuations mean rapid changes in its effective value, occurring at a rate of at least 1% per second.

Voltage fluctuations are characterized by the voltage swing and the flicker dose. In addition, when evaluating these PQEs, such auxiliary parameters as the frequency of voltage changes and the interval between voltage changes are used.

The voltage range - the difference between the following one after another extrema of the envelope of the effective voltage values - in percentage is calculated by the formula

$$\delta U_t = \frac{|U_i - U_{i+1}|}{U_{ном}} \cdot 100 \quad (11)$$

where $U_i, U_{i+1}$are the values of the following extrema or extremum and the horizontal section of the envelope of the effective values of the voltage of the fundamental frequency, determined at each half-period (Fig. 1).

It is allowed with a voltage distortion factor of sinusoidality not exceeding 5%, to be determined as a percentage by the formula

$$\delta U_t = \frac{|U_{ai}\text{-}U_{ai+1}|}{\sqrt{2}U_{ном}} \cdot 100 \qquad (12)$$

where U_{ai}, $U_{ai+1}$are the values of the following one after the other extrema or extremum and the horizontal section of the envelope of the amplitude values of the voltage, determined at each half-period of the fundamental frequency, V, kV.

The repetition rate of voltage changes during periodic oscillations is calculated by the formula

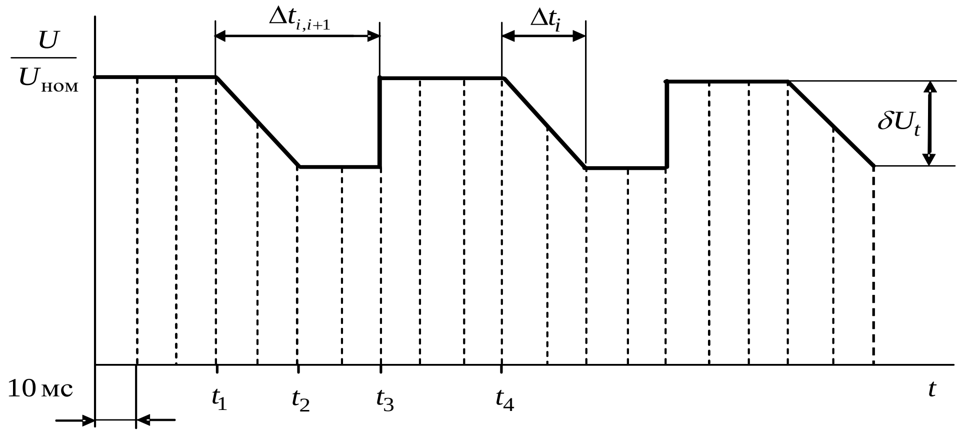
$$F_{\delta Ut} = \frac{m}{T} \qquad (13)$$

where m - is the number of voltage changes over time T; T - measurement time interval, taken equal to 10 min.

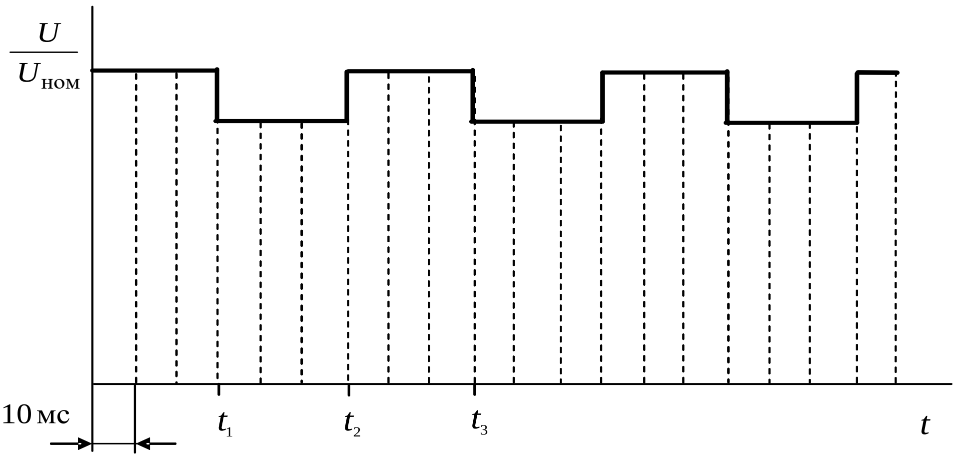
The interval between voltage changes in seconds or minutes

$$\Delta t_{i,i+1} = t_{i+1}\text{-}t_i \qquad (14)$$

where are the initial moments of the following changes $\Delta t_{i,i+1}$ one after another, s, min.



a)



б)

Figure 1. Voltage fluctuations of arbitrary shape (a) and having the shape of a meander (b)

If the interval between the end of one change and the beginning of the next, occurring in the same direction, is less than 30 ms, these changes are considered as one.

If the envelope of the voltage swing has a meander shape (rectangular), the maximum permissible values are determined δU_tdepending on the frequency of repetition of voltage changes $F_{\delta Ut}$ or the interval between voltage changes $\Delta t_{i,i+1}$ [1] along curve 1, and for electricity consumers with incandescent lamps in rooms where significant visual voltage - along curve 2, shown in Fig. 2.

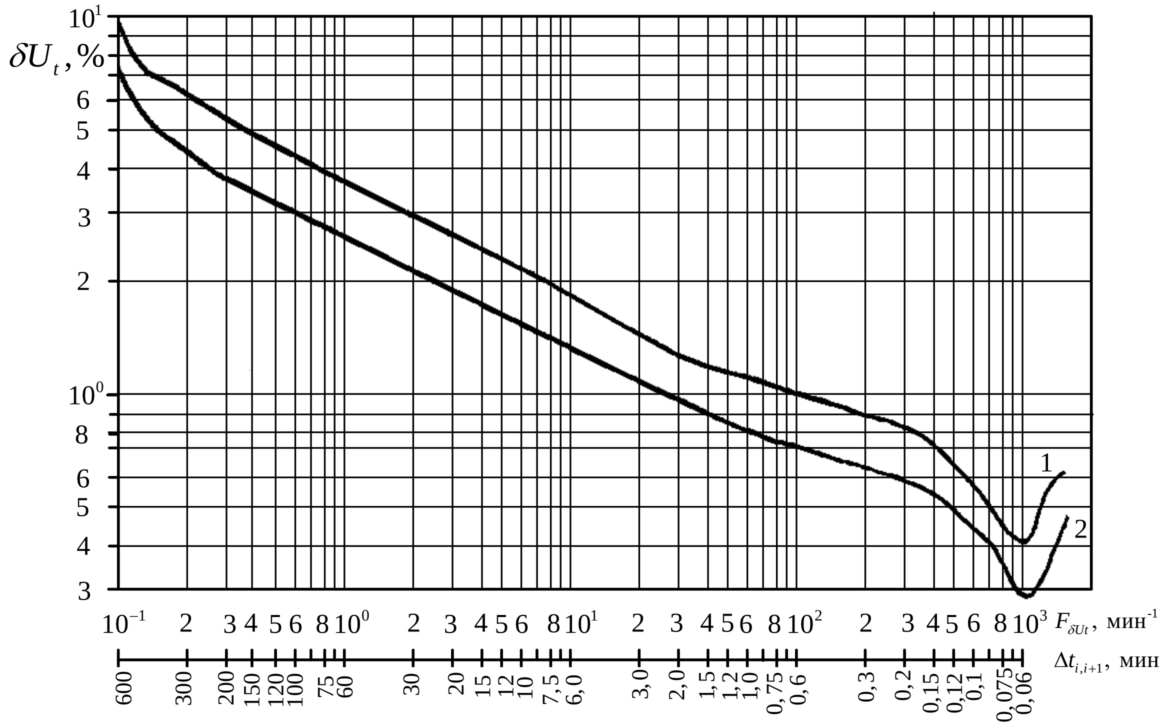


Figure 2. Maximum permissible range of voltage changes

The measured peak-to-peak value must not exceed the values determined from the curves.

The maximum permissible value of the sum of the steady-state voltage deviation $\delta U_y$and the voltage swing for networks $\delta U_t$with a voltage of 0.38 kV is equal to 10% of the rated voltage.

The flicker dose is a measure of a person's susceptibility to the effects of fluctuations in the luminous flux (flicker) of artificial light sources caused by voltage fluctuations over a set period of time.

It characterizes the power of voltage fluctuations taking into account human perception of fluctuations in the luminous flux of incandescent lamps and is determined by the integral [4].

$$P_t = \frac{k}{\theta}\int_{t-\theta}^{t} dt \int_0^{35} g^2\,(f) G(f,t) df \qquad (15)$$

Where $g(f)$ are the values of the amplitude-frequency characteristic (AFC) of the visual analyzer; $G(f,t)$ - frequency spectrum of the process of voltage change at time t; θ - averaging interval, taking into account the effect of memory of perception, θ = 300 ms; k - the coefficient is chosen in such a way that the value corresponds to $P_t = 1$the visual sensitivity threshold.

The short-term dose of flicker is normalized P_{St}, determined at an observation time T_{Sh}interval of 10 minutes, and a long-term dose of flickerP_{Lt}, determined at a time interval T_L of 2 hours. When the voltage waveform is different from the meander, the maximum permissible value of the short-term dose of flicker is 1.38, and long-term dose of flicker - 1.0. At the points of general connection of consumers with incandescent lamps in rooms where significant visual stress is required, the maximum permissible values of the short-term and long-term dose of flicker are 1.0 and 0.74, respectively.

The flicker dose (short-term and long-term) for voltage fluctuations of any form is determined as follows:

1. Measure with a flickermeter for a time interval T_{Sh}equal to 10 minutes flicker levels (%) 2, corresponding to the integral probability of 0.1; 0.7; 1.0; 1.5; 2.2; 3.0; 4.0; 6.0; 8.0; 10.0; 13.0; 17.0; 30.0; 50.0; 80.0%.

2. Determine with a flicker meter or calculate smoothed flicker levels P_S:

$$P_{1S} = \frac{P_{0,7}+P_{1,0}+P_{1,5}}{3}; P_{3S} = \frac{P_{2,2}+P_{3,0}+P_{4,0}}{3};$$

$$P_{10S} = \frac{P_6+P_8+P_{10}+P_{13}+P_{17}}{5}; P_{50S} = \frac{P_{30}+P_{50}+P_{80}}{3}, \qquad (16)$$

where are P_{1S}, P_{3S}, P_{10S}, P_{50S}smoothed flicker levels at integral probabilities of 1, 3, 10, and 50%, respectively.

3. Determine using a flickermeter or calculate the short-term dose of flicker P_{St}, p.u., at a time interval of 10 minutes:

$$P_{St} = \sqrt{0{,}0314 \cdot P_{0,1} + 0{,}0525 \cdot P_{1S} + 0{,}0657 \cdot P_{3S} + 0{,}28 \cdot P_{10S} + 0{,}08 \cdot P_{50S}} \qquad (17)$$

4. Determine using a flickermeter or calculate the long-term dose of flicker P_{Lt}, p.u., over a time interval T_L of 2 hours:

$$P_{Lt} = \sqrt[3]{\frac{1}{12}\sum_{n=1}^{12} P_{Stn}^3} \qquad (18)$$

where is P_{Stn} the short-term dose of flicker at the n-th time interval during T_{Sh} the observation period T_L.

The quality of electrical energy in terms of the flicker dose is considered to comply with the requirements of the standard if each short-term and long-term dose of flicker, determined by measuring within 24 hours or by calculation, does not exceed the maximum permissible values.

Analytical methods for assessing the quality of electricity with periodic and non-periodic voltage fluctuations are described in [1].

The influence of voltage fluctuations on electrical equipment: Voltage fluctuations in networks occur as a result of the operation of powerful abruptly variable loads: electric arc steel-making furnaces, welding units, valve converters, etc. They adversely affect the operation of electrical consumers.

Blinking of lighting lamps (flicker) causes an unpleasant psychological effect, eye and body fatigue and, as a result, a decrease in labor productivity. The most powerful effect is the blinking of light with a frequency of 3-10 Hz. With the same voltage fluctuations, incandescent lamps have a greater effect on a person than gas-discharge lamps.

The voltage swing $\delta U_t = 10\%$ can lead to extinguishing of gas discharge lamps.

If $\delta U_t > 15\%$ the magnetic systems of the starters may fall off.

If $\delta U_t = 10 \div 15\%$capacitors and rectifier units can fail.

Voltage fluctuations in the mains supply to the electric arc furnace will increase the melting time.

The operation of continuous rolling mills is disrupted due to the impossibility of maintaining the ratio of the mill stands' speeds unchanged. The quality of rolling is deteriorating. The misalignment of the mill drive speeds occurs at δU_t> 5%. Possible marriage, under-production. The same effects cause voltage fluctuations in the paper and textile industry.

Voltage fluctuations affect small induction motors (torque fluctuations).

Oscillation of the turbine generators can occur, resulting in effects on the turbine blades and regulators. This affects the efficiency of the station. Voltage fluctuations can cause erratic performance.

Voltage fluctuations lead to increased electrode wear and reduced service life of electrolysis plants.

Voltage fluctuations have an effect on resistance welding. At δU_t> 3 ÷ 5%, the quality of welding and the reliability of equipment operation (welding control schemes) decrease. The duration of permissible voltage fluctuations (3 ÷ 5)% is limited to no more than 0.2 s in order to avoid false operation of the control equipment.

Voltage fluctuations can cause radio interference, disrupt the operation and shorten the life of radios, and distort images on TV screens.

Voltage fluctuations at δU_t= 1 ÷ 1.5% can cause malfunction of the computer.

The question of the influence of voltage fluctuations on individual electrical installations is poorly understood. There is only accumulated statistical material. Therefore, when designing networks with abruptly varying loads, technical and economic analysis is difficult.

Calculation of voltage fluctuations: Let us consider the occurrence of voltage deviations and fluctuations using the example of load operation with a powerful valve converter. The equivalent resistance of the supply network contains inductive $X_c$and active $R_c$components. Ratio $X_c/R_c = 10 \div 30$. The vector diagram of the network is shown in Fig. 3.

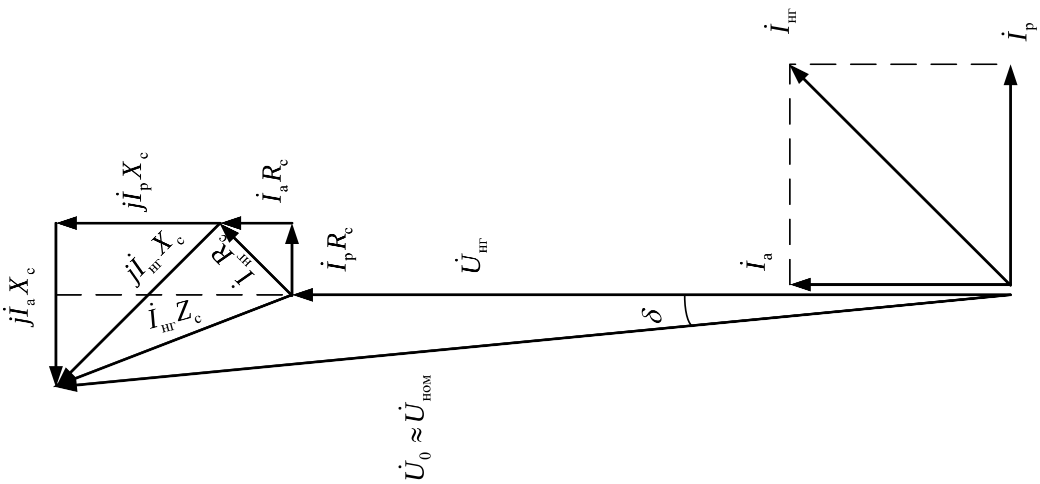


Figure 3. Vector diagram of the power supply network

When the valve converter is off, the bus voltage is equal to the open circuit voltage, and assuming there is no other load, it is equal to the system voltage. When the load is switched on, the load current creates a voltage drop across the system resistances, which leads to a change in the voltage on the buses both in phase and in amplitude.

The voltage change is represented by vectors $\dot{I}_a R_c$, $j\dot{I}_a X_c$, $\dot{I}_p R_c$, $j\dot{I}_p X_c$, and the voltage decrease is mainly determined by the vectors $\dot{I}_a R_c$ and $j\dot{I}_p X_c$ ($\delta \leq 10°$). With a sufficient degree of accuracy, the voltage deviation δU and range of change δU_t can be determined (in relative units) by the formula

$$\delta U = \delta U_t \approx \frac{I_a R_c + I_p X_c}{U_{ном}} \qquad (19)$$

The difference between deflection and voltage fluctuations is only in the rate of voltage change.

The numerator and denominator are multiplied by $3U_{ном}/X_c$

$$\delta U = \delta U_t \approx \frac{\frac{3U_{ном} I_a}{X_c} R_c + 3U_{ном} I_p}{\frac{3U_{ном}^2}{X_c}} = \frac{P\frac{R_c}{X_c} + Q}{S_к} \qquad (20)$$

Where P and Q - active and reactive power of the load; $S_к$ - short-circuit power on power buses.

A change in load also leads to a change in voltage. Therefore, for $Q = \Delta Q$ and $P = \Delta P$ we get

$$\delta U = \delta U_t \approx \frac{\Delta P\frac{R_c}{X_c} + \Delta Q}{S_к} = \frac{\Delta P(0{,}03 \div 0{,}1) + \Delta Q}{S_к} \qquad (21)$$

For approximate calculations, you can take,%,

$$\delta U = \delta U_t \approx 100\frac{\Delta Q}{S_к} \qquad (22)$$

When determining the permissibility of voltage fluctuations at the design point of the network, the initial data are load graphs. If the load fluctuations are different in value, then the equivalent voltage fluctuation is determined. The range of the equivalent voltage fluctuation,%, [2]

$$\delta U_{tэ} = \frac{100}{S_к}\sqrt{\frac{\sum_{i=1}^{n}\delta Q_i^2}{n}} \qquad (23)$$

where δQ_i the value of the i --th range of reactive power, determined according to the schedule; n - the total number of swings during the calculation cycle. To check the permissible $\delta U_{tэ}$, the average vibration frequency is calculated by the formula

$$f_{cp} = \frac{n}{T} \qquad (24)$$

where T - is the cycle time of the load according to the graph of changes in the consumed reactive power.

Reducing voltage fluctuations in electrical networks: Voltage fluctuations that occur during abruptly alternating loads are practically proportional to fluctuations in reactive power. Therefore, to eliminate voltage fluctuations, it is necessary to use compensating devices that meet the following conditions:

a) have a speed corresponding to a change in the reactive power graph;

b) have sufficient reactive power to compensate for the alternating component (voltage fluctuations) and the direct component (improving the power factor);

c) in case of a sharp voltage asymmetry, for example, during the operation of electric arc furnaces, it is necessary to control compensating devices in phases.

Longitudinal capacitive compensation of parameters allows to reduce the inductive $X_л$ and impedance $Z_л$ of the line. It is carried out by including capacitors in the line cut. The use of longitudinal compensation units (UPK) is most effective at a large ratio $X_л/R_л$, as well as at low values of the power factor. UPK are used for power supply of welding installations and ore-thermal furnaces.

Load sharing helps to reduce voltage fluctuations. The simplest is the scheme with a double reactor: quiet and fast-changing loads are connected to different sections of the reactor (Fig. 4). The voltage drop across each of the sections is reduced due to the mutual inductive coupling.

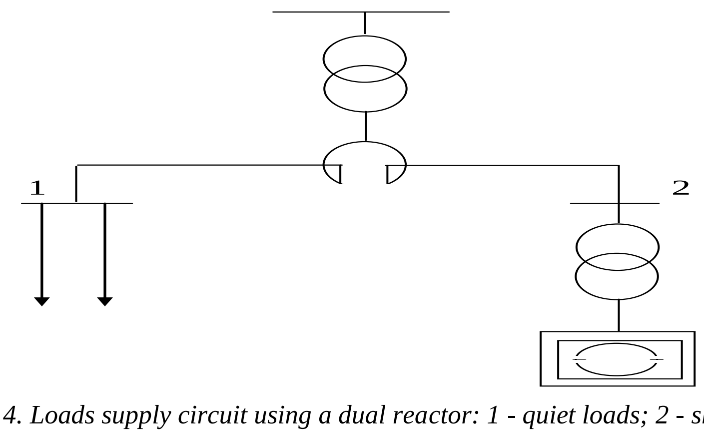


Figure 4. Loads supply circuit using a dual reactor: 1 - quiet loads; 2 - shock loads

We assume that the load currents of the sections $\dot{I}_1$ и $\dot{I}_2$ are equal, the inductive resistance of the reactor section X_L, and the coefficient of mutual inductive coupling $k_м = M/L = 0{,}5 \div 0{,}6$. Then the voltage drop across the sections

$$\Delta\dot{U} = X_L(\dot{I}_1 - k_м\dot{I}_2) = X_L(\dot{I}_2 - k_м\dot{I}_1) = X_L\dot{I}_{1(2)}(1 - k_м)$$

decreases by about half, which leads to a decrease in voltage fluctuations on the buses of a quiet load.

Split-winding transformers are also used for load sharing. The relationship between the voltage drops on the low side ΔU_2 and ΔU_3 can be represented as [2]:

$$\Delta U_2 = \Delta U_3 \frac{4-k_р}{4+k_р} \tag{25}$$

where is $k_p = U_{к(2-3)}/U_к$ the splitting coefficient, on average equal to 3.5; $U_{к(2-3)}$ - short-circuit voltage between the split secondary windings of the transformer; - $U_к$voltage of the through short-circuit transformer.

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Rakunov Y.P.
PhD. Tech. Sci.
Abramov V.V.
Dr. of Tech. Sci., professor
Rakunov A.Y.
Engineer;
National Research Moscow State University of Civil Engineering

THEORETICAL AND PRACTICAL MEHTODES FOR DETERMINING THE OPTIMAL CUTTING CONDITIONS FOR METALS AND ALLOYS USING UNIFIED CUTTERS

Ракунов Юрий Павлович
канд. техн. наук, доцент
Абрамов Валерий Васильевич
д-р техн. наук, профессор
Ракунов Александр Юрьевич
инженер; Национальный исследовательский Московский государственный строительный университет, Россия.

ТЕОРЕТИЧЕСКИЕ И ПРАКТИЧЕСКИЕ МЕТОДЫ ОПРЕДЕЛЕНИЯ РЕЖИМОВ ОПТИМАЛЬНОГО РЕЗАНИЯ МЕТАЛЛОВ И СПЛАВОВ УНИФИЦИРОВАННЫМИ РЕЗЦАМИ

Summary. The article considers the scientific and technical approaches to the problem of determining the cutting speed during the machining of the working surfaces of machine parts with a unified tool on CNC machines. A comparison was made of the optimum cutting temperatures obtained during steel turning with the temperatures of their structural–phase α–γ transformations. Methodological errors of researchers on the purpose of tool life and cutting speed, based on Taylor's formulas, are analyzed. Accelerated methods for determining the optimal cutting