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POWER QUALITY IN POWER SUPPLY SYSTEMS
Manual for laboratory works

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The manual presents the issues of assessing the power quality using the metering device ERIS-KE.06 (ЭРИС-КЭ.06) allowing to study the parameters and indicators of the power quality in electrical networks, describes the structure of the ERIS-KE.06 database and main indicators, which can be controlled with its help. Methods for improving the power quality are presented. A laboratory complex is described that allows you to simulate the operation of various ways to improve the power quality in power supply systems.

It is intended for students studying in the direction 13.04.02 – ″Power engineering and electrical engineering″.

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CONTENT

POWER QUALITY INDICES (PQI)

Power Quality Indices are determined by the interstate standard GOST 32144-2013. This Standard establishes indexes and quality standards for electrical energy in the power supply networks of general duty with three-phase or single-phase current having the frequency of 50 Hz in the points, where the electrical networks being in the ownership of the different electrical users or electrical energy consumers (points of common connection) connect together.

Glossary

Power supply system of general duty – the combination of electric installations and electric devices of the power supply organization used to provide electrical energy to different users (electrical energy consumers).

Electrical networks of general-duty - power supply organization networks used to transmit electrical energy to different electrical energy consumers.

Feed circuit – distribution substation of plant generator voltage or secondary voltage distribution substation of the power system stepdown substation, which are connected with the distribution networks of this area.

Point of common connection – the point of the electrical network of general-duty, which is electrically closest to the networks of the considered electrical energy consumer (the input devices of the considered electrical energy consumer), to which connect or can be connected the electrical networks of other electrical energy consumer (input devices of other electrical energy consumers).

Electrical energy consumer – artificial or natural person, who uses electrical energy (power).

Conductive electromagnetic interferences in power supply system – electromagnetic interferences propagating along the electrical network elements.

Level of electromagnetic compatibility in power supply system – regulated level of conductive electromagnetic interferences used as a reference for coordination between the allowed level of interferences made by technical equipment of power supply organization and electrical energy consumers and an interference level perceived technical equipment without disrupting it's normal functioning.

Flicker – subjective human`s perception of luminous flux fluctuations of the artificial light sources caused by voltage fluctuations in the electrical network.

Flicker indicator – a measure of the human`s susceptibility to the flicker effects during the fixed time period.

Flicker perception time – minimal time for subjective human`s perception of flicker caused by voltage fluctuations with the defined form.

Root-mean-square (RMS) voltage shape – stepped, time function formed by the RMS-values of voltage discretely defined at each half-cycle of the voltage of the main frequency.

Repetition frequency of voltage fluctuations – number of single voltage changes per time unit.

Duration of voltage fluctuations – the time interval from the beginning of a single voltage change to its final value.

Voltage dip – sudden decrease in voltage value in the point of the electrical network below $0.9U_{rated}$ followed by a voltage recovery to initial or closed to it level through the period of time from ten milliseconds to several tens of seconds.

Voltage dip duration – time interval between beginning of the voltage sag and recovery time of the voltage to its initial or closed to it level.

Frequency of voltage dip occurence – number of **Voltage sag** of certain depth and duration for a certain period of time in relation to the total number of sags over the same period of time.

Surge voltage– abrupt voltage changes in the point of electrical network followed by a voltage recovery to its initial or closed to it level through the period of time from ten milliseconds.

Surge amplitude – the maximum instantaneous value of the voltage pulse.

Surge duration – the time interval between the initial moment of voltage pulse and the recovery time of instantaneous voltage to its initial or closed level.

Temporary overvoltage – voltage increase in the point of electrical network above $1.1U_{rated}$ durating more than 10 ms appearing in power supply systems, when switching or short circuit happen.

Temporary overvoltage factor– magnitude, which is equal to the ratio of the maximum value of the voltage amplitude envelope over the lifetime of temporary overvoltage to the nominal voltage amplitude.

Temporary overvoltage duration– time interval between the initial appearance moment of temporary overvoltage and its disappearance moment.

Standard designations

- δU_{est} - steady-state voltage deviation;
- δU_t - voltage fluctuation swing;
- P_t - flicker dose;
- P_{St} - short-term flicker dose;
- P_{Lt} - long-term flicker dose;
- K_U - voltage total harmonic distortion factor;
- $K_{U(n)}$ - n-th harmonic distortion factor;
- K_{2U} - negative sequence voltage unbalance factor;
- K_{0U} - zero sequence voltage unbalance factor;
- Δf - frequency deviation;
- Δt_{f} - voltage dip duration;
- U_{imp} - surge voltage;
- K_{tov} - temporary overvoltage factor;
- $U_{1(i)}$ - RMS phase-to-phase (or phase-to-ground) voltage of fundamental frequency in *i-th* measuring;
- $U_{AB(1)i}, U_{BC(1)i}, U_{CA(1)i}$ - phase-to-phase RMS voltage of fundamental frequency in *i-th* monitoring;
- $U_{1(1)i}$ - phase-to-phase (or phase-to-ground) positive sequence in *i-th* monitoring;
- U_{avg} - averaged voltage value;
- N - number of measuring;
- U_n - nominal voltage;
- $U_{n.phs}$ - nominal phase-to-ground (phase) voltage;
- $U_{n.lin}$ - nominal phase-to-phase (linear) voltage;
- U_{RMS} - RMS-voltage determined at voltage half-period of fundamental frequency;
- U_i, U_{i+1} - values of successive extremums or extremum and horizontal section of the RMS voltage values envelope of the fundamental frequency;

- U_{ai}, U_{ai+1} - values of successive extremums or extremum and horizontal section of the amplitude voltage values envelope at each half-period of fundamental frequency;
- T – time interval between measurements;
- m - number of voltage changes per time period T;
- $F_{\delta U_t}$ - repetition frequency of voltage fluctuations;
- t_i, t_{i+1} - the initial moments of voltage fluctuations following one by one;
- $\Delta t_{i,i+1}$ - the time interval between the adjacent voltage fluctuations;
- P_s - smoothen flicker level;
- $P_{1s}, P_{3s}, P_{10s}, P_{50s}$ - smoothen flicker levels when cumulative probability is 1,0; 3,0; 10,0; 50,0% respectively;
- T_{sh} - time measurement interval of short-term flicker indicator;
- T_L - time measurement interval of long-term flicker indicator;
- n - number of sinusoidal voltage harmonic;
- P_{Stk} - short -termflicker indicator on k-time interval of T_{sh} time during long period of measuring T_L;
- $U_{(n)i}$ - RMS voltage in *i-th* measuring;
- K_{Ui} - phase-to-phase (or phase-to-ground) voltage total harmonic distortion factor in i-th monitoring;
- $K_{U(n)i}$ - *n-th* harmonic distortion factor in *i-th* monitoring;
- T_{vs} - time interval of measures averaging at measuring the voltage waveform distortion factor in i-th monitoring;
- $U_{2(1)i}$ - the RMS-value of the negative sequence voltage of the fundamental frequency in three-phase voltage system in the i-th monitoring;
- K_{2Ui} - negative sequence voltage unbalance factor in the i-th monitoring;
- $U_{\max(1)i}, U_{\min(1)i}$ - highest and lowest RMS-values of the three phase-to-phase voltages fundamental frequency in the i-th monitoring;
- $U_{0(1)i}$ - RMS-values of the zero sequence voltage of fundamental frequency in three-phase voltage system in the i-th monitoring;

- K_{0Ui} - zero sequence voltage unbalance factor in the i-th monitoring;
- $U_{\max.phs(1)i}, U_{\min.phs(1)i}$ - the largest and smallest of the three RMS-values of phase-to-ground voltages of the of fundamental frequency in the i-th monitoring;
- f_n - nominal frequency value;
- t_{init} - the initial time moment of the sharp decline of the RMS-voltage values envelope;
- t_{end} - the end moment of RMS voltage recovery time;
- δU_s - the depth of the voltage dip;
- Δt_f - the duration of the voltage dip;
- M - the total number of voltage dips over a period of time T of monitoring;
- $m(\delta U_f, \Delta t_f)$ - the number of voltage dips with a depth δU_f and length Δt_f in the reviewed period of monitoring time T;
- F_f - frequence the appearance of voltage dips;
- $t_{init0,5}, t_{end0,5}$ - moments of time corresponding to the intersection curve of the surge voltage by a horizontal line drawn at half the amplitude of the impulse;
- U_a - amplitude of voltage;
- $U_{a\max}$ - maximum amplitude of voltage.

MAIN NORMALLY AND MAXIMUM ALLOWED POWER QUALITY INDICES

Power quality indices are as follows:

- steady-state voltage deviation δU;
- voltage fluctuations swing δU_t;
- flicker indicator P_t;
- voltage total harmonic distortion factor K_U;
- *n-th* harmonic distortion factor $K_{U(n)}$;
- negative sequence voltage unbalance factor K_{2U};
- zero sequence voltage unbalance factor K_{0U};
- frequency deviation Δf;
- voltage dip Δt_d;
- surge voltage U_{imp};
- temporary overvoltage factor K_{overU}.

When determining the values of some united power quality indexes use the following auxiliary parameters of the electrical energy:

- repetition frequency of voltage fluctuations $F_{\delta U_t}$;
- the interval between the adjacent voltage fluctuations $\Delta t_{i,i+1}$;
- the voltage dip depth δU_{d};
- repetition frequency of voltage dips F_{d};
- surge voltage duration at the level of 0,5 its amplitude $\Delta t_{imp\,0,5}$;
- temporary overvoltage duration Δt_{overU}.

Two types of norms are established: normally and maximum allowed. The assessment of power quality indices (PQI) compliance to standard ones is carried out during a time period equal to one week.

<u>**Voltage deviation**</u> is characterized by increased **steady-state voltage deviation**, which has the following rules:

According to the GOST 32144-13 during normal operation modes of the current-using equipment, the voltage deviations from the nominal value **must not**

exceed 10% of the nominal or agreed voltage value U_{nom} for 100% of the time interval of one week. **Voltage fluctuations** are characterized by the following indicators:

- voltage fluctuations swing (peak-to-peak voltage);
- flicker indicator.

The maximum allowed range of peak-to-peak voltage values δU_t at the common connection point of the electrical network with voltage fluctuations, the envelope of which has the meander shape (Fig. 1), depending on the voltage change repetition frequency $F_{\delta U_t}$ or the interval between voltage changes $\Delta t_{i,i+1}$ are equal to values acquired by the curve 1 (Fig. 1). For power consumers with incandescent lamps in the premises, where a significant eyestrain is required, the limit values δU_t are determined by the curve 2. figure 1.

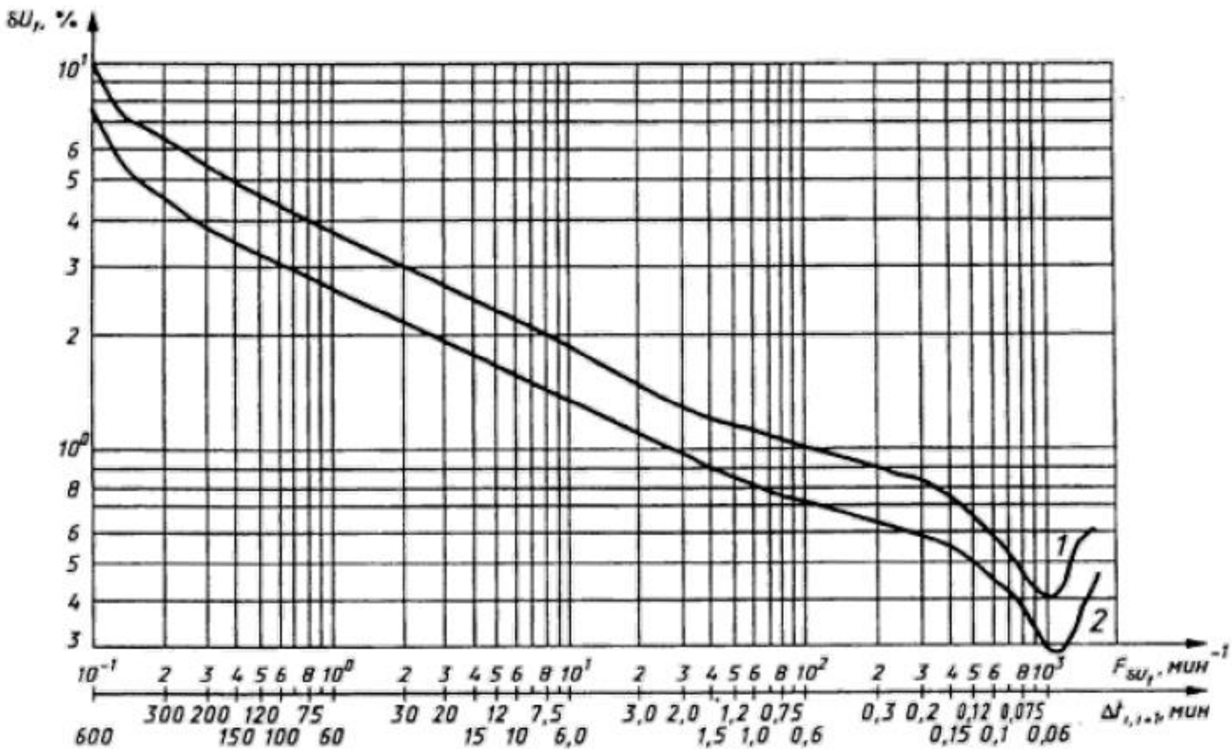


Fig. 1. Maximum allowed magnitude of voltage fluctuation swing (peak-to-peak voltage) depending on the repetition frequency of voltage fluctuations per minute for voltage fluctuations having the meander form

The maximum allowed value of the sum of the steady-state voltage deviation δU voltage fluctuation swing δU_t in the point of connection to electrical networks with voltage 0.38 kV equal to 10% of the nominal voltage.

The maximum allowed value for short-term flicker indicator P_{St} with voltage fluctuations with a shape different from the meander is equal to 1.38, and for long-term flicker indicator P_{Lt} with the same voltage fluctuations is 1.0.

Short flicker indicator is determined by the observation time interval equal to 10 minutes, and long-term flicker indicator 2 hours.

The limit value for short flicker indicator P_{St} in the point of power consumers common connection with incandescent bulbs in areas that require significant eyestrain when voltage fluctuations with a form different from meander, is 1.0, and for long-term flicker indicator P_{Lt} in the same points is equal to 0.74.

Non-sinusoidal voltage is characterized by the following indicators:

- voltage total harmonic distortion factor;
- n-th harmonic distortion factor.

Normally allowed and maximum allowed values of the voltage total harmonic distortion factor in the points of common connection to electrical networks with different rated voltage are given in table 1.

Table 1 – Voltage total harmonic distortion factor in percent

Normally allowed value when U_N, kV				**Maximum allowed value when U_N, kV**			
0.38	6-20	35	110-330	0.38	6-20	35	110-330
8.0	5.0	4.0	2.0	12.0	8.0	6.0	3.0

Normally allowed values of the n-th harmonic distortion factor in the points of common connection to electrical networks with different rated voltage U_N is given in table 2.

The maximum allowed value of the n-th harmonic distortion factor is calculated by the formula:

$$K_{U(n)\max} = 1.5 K_{U(n)norm},$$

where $K_{U(n)norm}$ - the normally allowed value of the -th harmonic distortion factor determined in accordance with table 2.

Voltage unbalance is characterized by the following indicators:

- negative sequence voltage unbalance factor;
- zero sequence voltage unbalance factor.

Normally allowed and maximum allowed values of the negative sequence voltage unbalance factor in points of common connection to electrical networks is equal to 2.0 and 4.0% respectively.

Normally allowed and maximum allowed values of the zero sequence voltage unbalance factor in points of common connection to four-wire electrical networks with rated voltage of 0.38 kV is equal to 2.0 and 4.0% respectively.

Table 2 – N-th sinusoidal component of voltage factor values in percent

Odd harmonics, are not multiples of 3, with U_{nom}, kV					Odd harmonics, multiples of 3 at U_{nom}, kV					Even harmonics at U_{nom}, kV				
n	0.38	6…20	35	110…220	*n*	0.38	6…20	35	110…220	*n*	0.38	6…20	35	110…220
5	6.0	4.0	3.0	1.5	3	5.0	3.0	3.0	1.5	2	2.0	1.5	1.0	0.5
7	5.0	3.0	2.5	1.0	9	1.5	1.0	1.0	0.4	4	1.0	0.7	0.5	0.3
11	3.5	2.0	2.0	1.0	15	0.3	0.3	0.3	0.2	6	0.5	0.3	0.3	0.2
13	3.0	2.0	1.5	0.7	21	0.2	0.2	0.2	0.2	8	0.5	0.3	0.3	0.2
17	2.0	1.5	1.0	0.5	>21	0.2	0.2	0.2	0.2	10	0.5	0.3	0.3	0.2
19	1.5	1.0	1.0	0.4						12	0.2	0.2	0.2	0.2
23	1.5	1.0	1.0	0.4						>12	0.2	0.2	0.2	0.2
25	1.5	1.0	1.0	0.4										
>25	1.5	1.0	1.0	0.4										

Frequency deviation of the AC voltage in electrical networks is characterized by the frequency deviation for which normally allowed and maximum allowed values of frequency deviation equal to 0.2 and 0.4 Hz, respectively.

Voltage dip is characterized by increased duration of the voltage dip that has the following rule: the maximum allowed value of the voltage dip duration in electrical networks with voltage up to 20 kV equal to 60 seconds. The time relay protection and automation automatically fixes the voltage dip duration.

Surge voltage pulse is characterized by surge voltage indicator. (Values of surge voltages for lightning and switching impulses generated in the electrical supply networks of the organization can be found in [1].)

Temporary overvoltage is characterized by temporary overvoltage indicator. (The values of the temporary overvoltages factors occurring in the power supply electrical networks of organization can be found in [1])

The assessment of power quality indicators (PQI) compliance to the established norms is carried out under operating conditions according to the following requirements:

- To determine the compliance of the measured PQ (power quality) values except for the voltage dip duration, surge voltage, the temporary overvoltage factor, the minimum measurement time interval equal to one week is set.
- Highest and lowest values of the steady-state voltage deviation and frequency deviation, determined by taking into account the sign over the estimated period of time must be in the interval bounded by the maximum allowed values. The upper and lower values of these PQ parameters, which are within the boundaries of the interval in which the probability of 95% are the measured PQ values, should be in the range, normally limited to acceptable values.
- The total duration of the PQ indicators measurement should be chosen keeping in mind the mandatory inclusion of workdays and weekends typical for measured PQ indices. The mandatory total duration of measurements is 7 days. A PQ comparison with the rules is produced for each day separately.
- Conformity assessment of voltage dips durations in common connection of consumers to networks of the power supplying organization to the standards is carried out by observation and registration of voltage dips over a long period of time.
- Getting the data on the surge voltage and temporary overvoltage is carried out by long-term observations.

When assessing the PQI compliance, on must take into account the **value of the measurement error**, which should be in the range bounded by maximum allowed values (table 3).

Table 3 - Measurement error of PQI

PQ indicator, unit	PQ norms (standart item)		Acceptable errors threshold measurement of PQ	
	normal allowed	maximum allowed	total	relative, %
steady-state voltage deviation δU , %	-	±10	±5	-
voltage fluctuation swing δU_t	-	Curves 1,2 at fig.1	-	±8
flicker indicator, rel.units short-term P_{St} long-term P_{Lt}	- -	1.38; 1.0 1.0; 0.74	- -	±5 ±5
voltage total harmonic distortion factor K_U , %	by table 1	by table 1	-	±10
n-th harmonic distortion factor $K_{U(n)}$, %	by table 2	by table 2	±0.05 when $K_{U(n)} < 1.0$	±5 when $K_{U(n)} \geq 1.0$
negative sequence voltage unbalance factor K_{2U} , %	2	4	±0.3	-
zero sequence voltage unbalance factor K_{0U} , %	2	4	±0.5	-
frequency deviation Δf , Hz	±0.2	±0.4	±0.03	-
Voltage dip duration Δt_d , sec	-	60	±0.01	-
Surge voltage U_{imp} , kV	-	-	-	±10
temporary overvoltage factor K_{overU} , rel.units	-	-	-	±10

To equip electrical networks by transformers and voltage dividers forming the part of electrical networks equipment, providing together with the measured PQI, it is allowed to carry out the PQ measurement (except Δf) with an accuracy that exceed the stated one by not more than 1.5 times.

To assess the PQI compliance with the norms, the averaging intervals of measured PQI results are defined (table 4).

Table 4 – Averaging interval of measured PQI values

Power quality indicator	Averaging interval, sec
steady-state voltage deviation	60
voltage fluctuation swing	-
flicker indicator, rel.units	-
Voltage total harmonic distortion factor	3
n-th harmonic distortion factor	3
negative sequence voltage unbalance factor	3
zero sequence voltage unbalance factor	3
frequency deviation	20
Voltage dip duration	-
Surge voltage	-
temporary overvoltage factor	-

THE MAIN WAYS OF IMPROVING THE VOLTAGE QUALITY

Types of PQ control

The monitoring of power quality consists in controlling the compliance of PQI with the stated requirements. Based on this definition, the following PQ control objectives can be pointed out.

Control for compliance with GOST 32144-2013 or technical regulations. When performing such control, only measurements power quality indices for voltage and frequency are performed.

The results of PQ control are presented over the entire monitoring interval (not less than 24 hours) and on their basis the conclusion about conformity of power quality to the stated requirements is made.

Diagnostic control is necessary to analyze the causes of PQ deterioration, to determine the culprit of lowering PQ, when checking the compliance with technical conditions for connecting consumers to electrical network, and the contractual terms for power supply. In this case, in addition to the PQI, auxiliary parameters must be measured which characterize the power quality by current and power. The measurement results are conveniently viewed not only numerically but also graphically.

Commercial control can be used as a tool for economic impact on the PQ deterioration culprit. As a result of such control, if it is established by the power supply agreement, the electrical energy cost is estimated taking into account penalties for its quality deterioration. In this case, in addition PQI by voltage, current and power it is necessary to account for the released electrical energy.

Technological control is a PQ control with the duration and (or) measurement error, which can be reduced in comparison with the requirements of GOST 32144-2013. For these purposes, more simple and cheap measuring tools can be used. The task of technological control is to establish the influence of power consumer technological process on the power quality

Depending on the measurement duration, one can distinguish two types of PQ control:

- periodic control, in which controlled parameters measurement and the PQI evaluation occur continuously every 24 hours (or more days) with a constant interval between measurements, determined by the organization performing PQ control, but not less than set by GOST 32244-2013;

- continuous monitoring, in which information about the controlled PQI is analyzed continuously.

The voltage balancing by using a capacitor bank

Changes in the energy consumption structure due to the lower production and an increase in domestic (mainly single-phase) load, makes it difficult to provide a power supply system symmetric mode. Voltage unbalance appearance in three-phase networks leads to additional active power losses, as well as reducing the electrical equipment life and economic indicators of its work. When choosing a means of balancing, the most efficient way in the first place is to use technical means already existing in the power supply system (PSS), in particular a capacitor bank (CB) reactive power compensation installations (RPCI).

The violation of three-phase voltage system symmetry will change energy characteristics of CB branches, which are symmetric by capacity. In the low-voltage distribution networks, which mainly contain the compensational power of electric users, the reactive power (RP) of CB will be limited by so-called available power – Q_{av}, which is proportional to the positive sequence power and smaller than nominal power – Q_{NOM}. Due to uneven RP distribution in the CB branches, the direction of compensation current in separate phases of the network may be the opposite to the required one that will reduce the network capacity and increase the already existing voltage unbalance at the points of common connection. If it is allowed by the RPCI design scheme, in four-wire network with neutral wire, it is possible to reduce the unbalance to an acceptable value of zero sequence voltage unbalance factor– k_{0U} by switching capacitors to different phase voltages of the network. Unlike three-wire (with isolated neutral), four-wire networks have more variants of choosing the load supply phases, but its poise is only possible in case of phase conductance equality. Therefore, in four-wire networks it is necessary to reduce the component of the phase voltages of zero sequence – $I_0 / 3 \cdot Z_0$, which is numerically equal to the module of the shift vector of zero point O of the voltage vector diagram. Here $I_0 / 3$ is the secondary zero-sequence current of power transformer, created by the current unbalance, flowing in the neutral wire and not balanced by the primary current. The transformer windings resistance for the zero sequence currents: $Z_0 = r_2 + jx_{22}$, where r_2 –the transformer secondary winding resistance and the x_{22} – single-phase scattering magnetic flux, mating with the secondary winding in the air (the same with short-circuit fluxes, but much greater in magnitude). In the transformer windings, the additional EMFs, which are the same by phase, are induced that together with the increase in Z_0 due to the line resistance cause the voltage distortion at the load in addition to the negative sequence current distortion. In addition, magnetic fluxes caused by zero sequence currents, hinging through the surface of the tank bottom and the transformer cover, heat it up, worsening the active part cooling.

The transformer resistance of the windings for the zero sequence currents Z_0 differs from their resistance to positive and negative sequence currents. Experimental data show that for the most common in electrical networks of 10-0,4 kV of the Russian Federation transformers with winding connection scheme $Y - Y_0$, the Z_0 value is 5-8 times higher than Z_{SC}. The maximum allowed unbalanced single-phase load is 2-5% of the nominal power of the supply transformer with connection group $Y - Y_0 - 12$ that is approximately 10 times less than when it is set to phase-to-phase voltage (asymmetry in the reverse order).

The parallel connection of CB capacitive conductance directly to the phase voltage will reduce the zero sequence currents and provide the desired load node power factor with a minimum number of compensating elements. For PSS with unbalanced load, the three-channel control is used for single-phase CB by controllers, the adjustment function of which is equivalent to the following equations system:

$$Q_A = K \cdot I_A U_{AN} \cdot \cos(90^\circ - \varphi_A) = K \cdot I_A U_{AN} \cdot \sin\varphi_A \ ;$$
$$Q_B = K \cdot I_B U_{BN} \cdot \cos(90^\circ - \varphi_B) = K \cdot I_B U_{BN} \cdot \sin\varphi_B \ ;$$
$$Q_C = K \cdot I_C U_{CN} \cdot \cos(90^\circ - \varphi_C) = K \cdot I_C U_{CN} \cdot \sin\varphi_C \ .$$

where Q_A, Q_B, Q_C – reactive power (RP) of corresponding phase; K – current transformer transformation factor; φ_A, φ_B, φ_C – the phase angle shift between the line current and the corresponding phase voltage.

Further, each of the controllers independently commutates the capacitor capacitance in the controlled phase in accordance with the angle value φ measured in the four quadrants of the complex plane. At the same time, the minimum balancing RP for single-phase fully compensated load ($\cos\varphi = 1$) is equal to 100% of its capacity.

The parallel connection of the capacitive conductance of the capacitors directly on the phase voltage will reduce the zero sequence currents to an acceptable value and to provide the required power factor ($\cos\varphi$) of the compensated network.

Counter voltage regulation

Modern power supply systems are characterized by a considerable length and multi-stage voltage transformation. In each power supply system branch (line, transformer) there are voltage losses. They depend on both parameters of the equivalent circuit and the load parameters. In peak load modes, the voltage losses are high, while in low load modes, the voltage losses correspondingly reduced.

The voltage mode in the distribution network can be improved, for example by using power transformers with the tap-changers for varying the transformation factor. In this case, so-called *counter voltage regulation* will be provided at the power buses of the individual consumer. The counter voltage regulation is understood as the increase in voltage during peak loads mode up to 5...8% of nominal one and the voltage decrease up to nominal one (or below) in the minimum loads mode at a linear change depending on the load. At the counter voltage regulation, the stable voltage level is provided not on the buses of the center transformer substation (CPS), but on the buses of some remote network point. This point is called the “control” or “fictitious” point.

The automatic regulation of the transformation factor is performed not continuously but with a certain dead zone. The dead zone is some band of voltage change, at which the control equipment does not operate. Its value depends on the control stage, which is understood as the voltage between two adjacent control branches of transformers with an on-load tap-changers. The transformers with a voltage of 10/0,4 kV has no on-load tap changer, and switching the branches can be carried out only at the switched off transformer. When changing branches, you can get an additional voltage of ±2% or ±5%.

When designing the networks, the concept of allowed voltage losses is used. The voltage losses with the counter voltage regulation can reach 10...12% of the rated voltage, and 6...7% without such regulation. In most cases, the real voltage losses are less than allowed, except of long air networks working at a low voltage in rural areas.

Under the voltage regulation, the automatic current voltage change according to the desired law is understood. The automatic control system is a closed circuit, which provides the control and management. The automatic control system contains AR (automatic reclosing) and ALT (automatic load transfer), performing the automatic switching on and off circuit breakers.

If the distance between the object of monitoring, control or regulation and the control point is large, then telemechanics, telecontrol, telecontrol and telecontrol means are used. They differ from the corresponding automation systems by the presence of communication channels, receivers and transmitters.

Voltage regulation by transverse and longitudinal compensation of reactive power using capacitor banks

The power factor (*cosφ*) shows the quality of electrical energy using at the enterprise. Its decrease leads to the increase in the electrical energy consumption and its cost. There are following methods for improving the power factor:

- Natural ways: full load of transformers and electric motors, or replace them with those having a lower power in accordance with the load; the power supply system adjustment to the nominal mode – approximation of mobile sections of step-down substations to the consumers; the replacement of cables and wires with those ones having a larger cross-section; the replacement of unregulated asynchronous electric drive with synchronous one.
- Artificial ways: the use of synchronous compensators which are synchronous motors working in idle mode (*cosφ = 1*; synchronous motors are reactive power generators); using static elements (cosine capacitor banks).

As an additional reactive power source, which serves to supply the consumers with the reactive power in excess of that amount, which is provided by the power system and synchronous motors presented at the enterprise, capacitor banks (CB) are installed. CB units are applied at the voltage of 110-6 kV, are installed only on the surface in the special chamber of the main step-down substation (MSDS). They are flammable, do not require complicated servicing and maintenance, have a low energy consumption. Also they should be protected with the overcurrent protection and interlocked with the main circuit breaker. The CB circuit breaker must have a discharge device.

The transverse reactive power compensation

If CB is connected in parallel to the load, this is a transverse compensation, when it is connected in series, it is longitudinal one. After connecting the capacitance in parallel to the load, the angle φ_1 decreases to the value φ_2. At the same time, the current of power consumer decreases that leads to line unloading by the current. There is also an unloading of power system generators with the same value. Due to CB reactive power generation in the electrical equipment installation place, the losses are reduced. For the designed network, the current reduction allows decreasing the wire cross-section, consequently, the installed transformers capacity also becomes less. The transverse capacitive compensation is performed by packaged condenser units (PCU), which are installed near the transformer substations (MSDS).

The longitudinal capacitive compensation

It is made by in-series connection. Depending on the ratio between the inductive and capacitive impedances the following cases are possible: $X_L > X_C; X_C > X_L; X_C = X_L$. At the voltage resonanc,e in the short circuit mode, short-circuit current can be very large and the voltage across the inductance and capacitance can be unacceptably high. Thus, in the in-series compensation devices, the capacity is selected from the calculations in such a way that the capacitive voltage will be equal to U_c=5-20% U_{nom}. Therefore, the longitudinal compensation capacity compensates only a part of the power. The longitudinal compensation installations are almost not the power sources. Their main purpose is a partial compensation of the inductive reactance in the network sections to reduce the voltage losses in them. The inductive reactance compensation by the capacity leads to higher short-circuit currents in all transformer substation elements that is especially dangerous for the capacitors. To protect the capacitors from the through short-circuit currents, the sintered spark gap switch is used.

The in-series compensation is mainly used as a way for voltage regulation and stabilization, while the transverse compensation is for improving *cosφ*.

Compensation of higher harmonic currents by using filter compensating devices

Ways to reduce the non-sinusoidal voltages can be divided into three groups:

a) circuit solutions: the selection of non-linear loads on a separate bus system; a loads dispersal on various nodes of the power supply system with connecting electric motors in parallel; grouping the converters according to phase multiplication scheme; the load connection to the system with the more power;

b) using filter devices, connecting narrowband resonant filters in-parallel to the load, the inclusion of filter compensating devices (FCD), applying filter balancing devices (FBD), fast static reactive power sources (RPS) containing FCD.

c) using a special equipment characterized by a reduced level of higher harmonics generation, using the "unsaturated" transformers, applying multiphase converters with improved the energy performance.

The development of element base in the power electronics and new high frequency modulation methods has led to the creation (1970s) of new class devices that improve the power quality – **active filters (AF)**. Immediately, the active filters were classified and divided into in-series and in-parallel, as well as into current and voltage sources that resulted in the appearance of four basic schemes. Each of the four structures defines the filter circuit at the operating frequency: switches in the converter and switch types (bidirectional or unidirectional switch). As an energy storage in the converter, which serves as a current source, the inductance is used, while in the converter serving as the voltage source the capacitance is used.

It is known that filter impedance Z at the frequency ω is equal to:

$$Z = X_L - X_C = j\left(\omega L - \frac{1}{\omega C}\right).$$

When $X_L = X_C$ or $\omega L = (1/\omega C)$, the voltage resonance occurs at the frequency ω, that leads to decrease up to zero in the filter resistance for the voltage harmonic with a frequency ω. At the same time, the harmonics with the frequency ω will be absorbed by the filter and not enter the network. The construction principle of resonant filters is based on this phenomenon.

As a rule, canonic harmonics, the number of which is 3, 5, 7, occur in networks with non-linear loads.

Taking into account that $X_{L\nu} = X_L, X_{C\nu} = (X_C / \nu)$ where X_C and X_L - resistance of the capacitor bank and reactor, respectively, at the fundamental frequency, we get:

$$X_F = X_L + X_C = X_C(1 - 1/\nu^2)$$

Such a filter, which, besides filtering harmonics, will generate the reactive power and compensate the power losses in the network is called **filter compensating device - (FCD)**. If the device, in addition to filtering higher harmonics, performs the voltage balancing functions, such a device is called **filter balancing device (FBD)**. Structurally, the FBD represents the asymmetric filter, which is connected to the linear voltage of the network. The choice of linear voltages, to which FBD circuits are connected, and the ratio of capacitors capacities (powers) included in the phases of the filter are determined by voltage balancing conditions.

FCD and FBD type devices impact on several power quality indices (non-sinusoidality, unbalance, voltage deviation). Such devices for improving the power quality are named multifunctional optimizing devices (MOD). The expediency in the development of such devices has arisen from the fact that the abruptly variable loads such as electric arc furnaces cause the simultaneous voltage distortion by the PQI number. The MOD application allows one to solve complexly the power quality problem by several indicators.

The category of such devices include **fast static reactive power sources (RPS)**. According to the reactive power regulating principles, RPS can be divided into two groups: **fast static reactive power sources for direct compensation**, **fast static reactive power sources for indirect compensation**. Such devices having a high operation speed reduce the voltage fluctuations. The phase-by-phase regulation and the presence of filters provide balancing the voltages and reducing the higher harmonics.

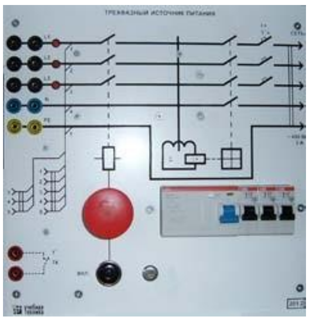
LABORATORY INSTALLATION FOR STUDYING THE POWER QUALITY INDICES

The laboratory installation consists of separate units that simulate all the parameters of the power system elements in real time. This makes it possible to study the influence of various disturbing influences on the energy system and its elements, and to investigate the efficiency of different methods for improving the power quality.

Three-phase power source (TPS.201.2)

Function

The three-phase power source is designed to supply the functional blocks of the educational laboratory complex by three-phase and single-phase alternating current of the fundamental frequency.



Operating procedure

1. Connect the "**TC**" sockets with a wire.
2. Switch on the source circuit breaker and the residual current device if it is disconnected.
3. Press the **ON** button. At the same time, the LEDs should light up, that confirms the presence of output phase-to-phase voltages of the source (about switching it on).
4. To remove the output voltage (switch off) of the source, press the red mushroom-button. In this case, the LED should go out.
5. To remove the output voltage (tripout) of the source, disconnect its circuit breaker.

Technical specifications

Power source from three-phase alternating current circuits with neutral and protective wires: voltage (linear), V; current, A, not more; frequency Hz	380±38, 16, 50±0,5
Outputs: three-phase (linear) voltage, V; single-phase voltage, V; current, A, not more than	380±38 220±22, 10
Protection devices	automatic circuit breaker, residual current device

Single-phase power source (SPS.218)

Function

A single-phase power source is designed to supply the functional blocks of the educational laboratory complex by a single-phase alternating current of the fundamental frequency.

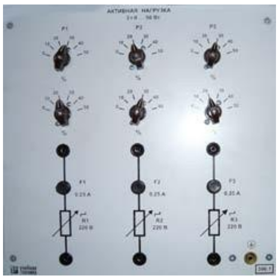
Operating procedure

1. Switch on the source circuit breaker and the residual current device if it is disconnected.
2. To remove the output voltage (switch off) of the source, switch off its circuit-breaker.

Technical specifications

Power source from a single-phase alternating current network with neutral and protective wires: voltage, V current, A, not more than frequency, Hz	 220±22 16 50±0,5
Output: voltage, V current, A, not more than	 220±22 16
Protection devices	automatic circuit breaker, residual current device with a tripping current of 10 mA

Active load (AL.306.1)



Function

The active load is designed to simulate single-phase and three-phase active power consumers with manual control.

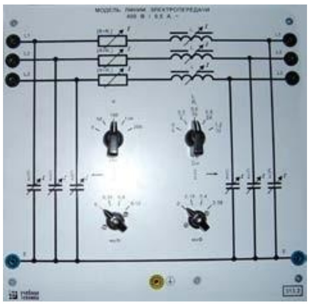
Operating procedure

1. Before operating the load, connect its protective ground terminal marked "⏚" with the symbol to the **"PE"** socket of the three-phase power source.
2. Connect the load sockets to external devices according to the electrical connection scheme of the particular experiment.

Technical specifications

Power consumption, W, not more than	3x50
Number of phases	3
Discreteness of regulation of power consumption in one phase,%	10
Nominal phase-to-ground voltage, V	220
Nominal frequency of voltage, Hz	50
Phase protection from overcurrent is provided by a fuse with a nominal current, A	0,25

Power Line Model (PLM.313.2)



Function

The power line model is designed to simulate AC and DC power lines.

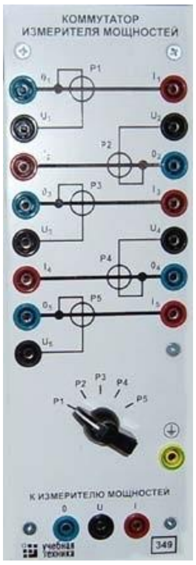
Operating procedure

1. Before operating the model, connect its protective ground terminal marked with the symbol “⏚” to the **"PE"** socket of the three-phase power source.
2. Connect the model sockets to the external devices according to the electrical connection scheme of the particular experiment.

Technical specifications

Nominal voltage, V	220/380
Nominal current, A	0,5
Nominal frequency of current, Hz	50
Number of phases	3
Inductance / phase resistance, HH / Ohm	0...1,5/0..50
Phase-ground capacitance, μF	2x0...0,58

Power Meter Switch (PMS.349)



Function

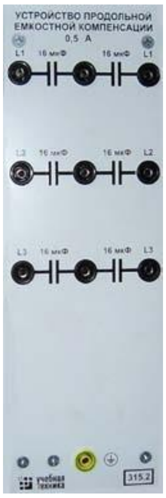
Power Meter Switch is designed to enable the power meter to be connected to various points of the simulated electrical circuit without its changing.

Operating procedure

1. Before operating the unit, connect its protective ground terminal marked with a symbol “⏚” to the "PE" socket of the three-phase power source.
2. Connect the switch sockets to external devices according to the electrical connection scheme of the particular experiment.

***Technical specifications*: ** number of commutated channels - 8

Longitudinal capacitive compensating device (LCCD.315.2)



Function

The device of longitudinal capacitive compensation is designed for modeling the longitudinal capacitive reactance.

Operating procedure

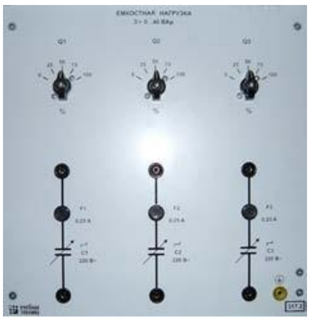
Before operating the device, connect its protective ground terminal marked with a symbol“⏚”, to the **"PE"** socket of the three-phase power source.

Connect the device sockets to external devices according to the electrical connection scheme of the particular experiment.

Technical specifications

Phase Capacitance, µF	2x16
Number of phases	3
Nominal current of phase, A	0,5
Nominal voltage of phase insulation, V	400
Nominal frequency of voltage, Hz	50

Capacitive load (CL.317.2)



Function

The capacitive load is designed to simulate single-phase and three-phase reactive power generators with manual control.

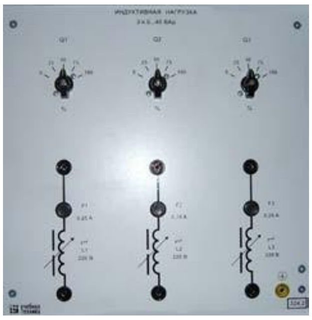
Operating procedure

1. Before operating the load, connect its protective ground terminal marked with the symbol “⏚” to the **"PE"** socket of the three-phase power source.
2. Connect the load sockets to external devices according to the electrical connection scheme of the particular experiment.

Technical specifications

Generated power, VAr, no more than	3x40
Number of phases	3
The discreteness of power consumption regulation by one phase,	25
Nominal voltage, V	220
Nominal frequency of voltage, Hz	50
Nominal protection from overcurrent is provided by a fuse with a nominal current, A	0.25

Inductive load (IL .324.2)



Function

Inductive load is designed for simulating single-phase and three-phase reactive power consumers with manual control.

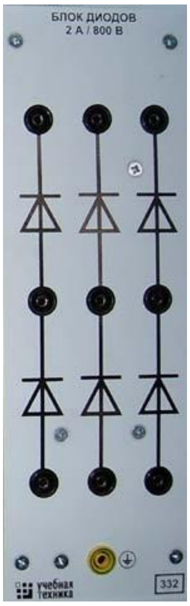
Operating procedure

1. Before operating the load, connect its protective ground terminal marked with the symbol "⏚" to the **"PE"** socket of the three-phase power source.
2. Connect the load sockets to external devices according to the electrical connection scheme of the particular experiment.

Technical specifications

Power consumption, Var, not more than	3x40
Number of phases	3
The discreteness of the regulation of the power consumption in one phase,%	25
Nominal voltage, V	220
Nominal frequency of voltage, Hz	50
Nominal protection from overcurrent is provided by a fuse with a nominal current, A	0.25

Block of diodes (BD.332)



Function

The block of diodes is intended for full-scale simulations of uncontrolled single-phase and three-phase rectifiers of electrical energy.

Operating procedure

1. Before operating the unit, connect its protective ground terminal marked with a symbol "⏚" to the "PE" socket of the three-phase power source.
2. Connect the sockets of the unit to each other and to external devices according to the electrical connection scheme of the particular experiment.

Technical specifications

Number of diodes	6
Maximum constant reverse diode voltage, V	600
The maximum average forward current of the diode, A	2
Diode voltage boundary frequency, Hz	1000

Three-phase transformer group (TTG.347.3)

Function

The three-phase transformer group is designed to change the voltage in the power circuits of a single-phase or three-phase current of the fundamental frequency**.**

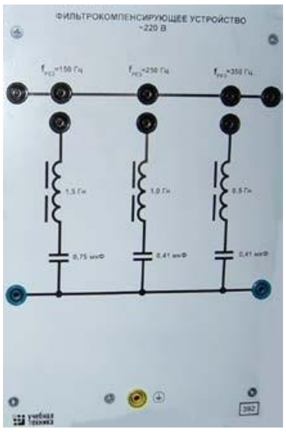
Operating procedure

1. Before operating the transformer group, connect its protective ground terminal marked with a symbol "⏚" to the **"PE"** socket of the three-phase supply source.
2. Connect the sockets of the transformer group to the external devices according to the electrical circuit of the particular experiment.

Technical specifications

Number of single-phase transformers	3
Nominal power, VA	3x80
Primary winding connection scheme	Y_0
Nominal primary phase voltages, V	220/225/230
Nominal secondary phase voltages, V	133/220/225/230/235/240/24
Frequency of voltage, Hz	50±0.5
Short-circuit voltage,%	8
No-load current, A, not more than	0.1

Filter Compensating Device (FCD.392)



Function

The filter compensating device is designed to filter the 3rd, 5th and 7th current harmonics generated by a non-linear load.

Operating procedure

1. Before operating the device, connect its protective ground terminal marked with the symbol “⏚” to the **"PE"** socket of the power source.
2. Connect the device sockets to external devices according to the electrical connection scheme of the particular experiment.

Technical specifications

Number of L-C filters	3
Nominal voltage, V	220
Nominal power of capacitors, VAr	23.9
Resonance frequencies, Hz	150/250/350
Frequency of the first harmonic of voltage, Hz	50±0.5

Power Meter (PM.507.2)

Function

The power meter is designed for measuring active power in direct current circuits, as well as active and reactive power in single-phase AC circuits.

Operating procedure

Connect the meter sockets to external devices according to the electrical connection scheme of the particular experiment.

Technical specifications

Power source from single-phase alternating current circuits with protective wire voltage, V frequency, Hz	 220±22 50±0,5
Power consumption, VA, no more than	20
Limits of measurement: voltage (DC / AC), V current (DC / AC), A current / voltage frequency, Hz	 0...15/60/150/300/600 0...0.05/0.1/0.2/0.5/1 0... 10000
Limits of power measurement: active, W reactive (in the sinusoidal current / voltage circuit),	 0...600 0...600
Nominal current of the fuse in the current circuit, A	1.6
Accuracy of measurement,%, not more than	±2.5

Current transformer (CT.403.1)

Function

The current transformer is designed to convert the current of the sinusoidal form of fundamental frequency into a galvanically isolated normalized current proportional to it.

Operating procedure

The current transformer (ТОП 0.66) is used as the working element. It is forbidden to operate the current transformer with an open and ungrounded secondary winding.

1. Before operating the current transformer, connect its protective ground terminal marked with the symbol“⏚” to the **"PE"** socket of the three-phase power source.

2. Connect the current transformer sockets to the external devices according to the electrical connection scheme of the particular experiment.

Technical specifications

Nominal operating voltage of the primary winding, V	660
Nominal current of the primary winding, A	1
Nominal current of the secondary winding, A	1
Nominal load, VA	5

Voltage transformer (VT.405)

Function

The voltage transformer is designed to convert the sinusoidal voltage of the fundamental frequency into a galvanically isolated normalized voltage from the **network**.

Operating procedure

The transformer (ТПК-50) is used as an operating element. The operation of the voltage transformer with a short-circuited secondary winding is prohibited.

1. Before operating the voltage transformer, connect its protective ground terminal marked by the symbol “⏚” to the **"PE"** socket of the three-phase power source.
2. Connect the voltage transformer sockets to external devices according to the electrical scheme of the particular experiment.

Technical specifications

Voltage class, V	660
Nominal voltage of the primary winding, V	380
Nominal voltage of the secondary winding, V	380/220
Nominal frequency, Hz	50
Accuracy class	1.0
Nominal power, VA	5
Limiting power, VA	12.5
Voltage error at maximum power,% no more	4

Multimeter block (MB.508.2)

Function

The multimeter block is designed for measuring the active resistance of electrical circuit elements, currents and voltages in this circuit.

Operating procedure

1. Connect the sockets to external devices according to the electrical connection scheme of the particular experiment.
2. Switch on the "**NETWORK** (СЕТЬ)" switch.
3. Include the multimeters used in the experiment.
4. Use the multimeter switches to set the limits and types of measured parameters.
5. Readout the data from the multimeter displays.
6. To disable the multimeter block from operation, switch off the "**NETWORK** (СЕТЬ)" switch.

Technical specifications

Power source from single-phase alternating current circuits with protective wire: voltage, V frequency, Hz	 220±22 50+0.5
Power consumption, VA, not more than	20
Number of multimeters	3
Type of multimeter	MY-60

Power quality indices meter (PQIM.525)

Function

The PQI meter is designed for simultaneous recording the active and reactive electrical energy flowing in both directions, synchronous recording of power quality indices (established by GOST 32144-2013, except flicker), registration of emergency and transient regimes, and also for control other automated subsystems at the pace of the process in accordance with the specified control laws.

Operating procedure

On the front panel, there are the PQI meter of **ЭРИС-КЭ.06** type and the sockets for connecting external devices.

1. Before using the meter, connect its protective ground terminal marked with a symbol “⏚” to the **"PE"** socket of the three-phase power source.

2. Connect the meter sockets to external devices according to the electrical scheme of the particular experiment.

Technical specifications

Type of converter Nominal linear voltage, V Nominal current, A	Electronic 380 5
Frequency of the measuring **network**, Hz	47...53
Accuracy class	0.5

THE THREE-PHASE METER OF ACTIVE AND REACTIVE POWER ЭРИС-КЭ.06. POWER QUALITY METER.

Accepted symbols and abbreviations

ADC	alphanumeric display;	IF	interface;
AG	automatic gain control;	MI	measuring instruments;
AHI	archive information;	NVM	non-volatile memory;
ATI	actual information;	PC	personal computer.
AND	analog-to-digital converter;	PLL	phase-locked loop;
CPU	central processing unit;	PQ	power quality;
CT	current transformer;	PQI	power quality indices;
DPMR	device for processing the	PS	power source;
	measurement results;	SP	signal processor;
DT	display tools;	VPAU	voltage pulse analysis unit;
ICD	input circuits block;	VT	voltage transformer;
ID	input device;		

Purpose of the PQI meter

The ERIS-KE.06 meter is designed for simultaneous recording of active and reactive electrical energy, synchronous recording power quality indices (PQI) indicators, registration of emergency and transient regimes, and control of other automated subsystems.

The ERIS-КЭ.06 captures all the main PQI set in GOST 32144-2013 "Norms of power quality in general-purpose power supply systems" (except flicker) in accordance with the requirements of this GOST, including:

- frequency deviation;
- voltage deviation;
- voltage waveform distortion factor;
- factor of n-th sinusoidal voltage component;
- voltage unbalance factor by negative phase sequence;
- voltage unbalance factor by zero phase sequence;
- voltage sag duration;
- voltage pulse;
- temporary overvoltage factor.

In parallel with the account of electricity and registration of the PQI, the following functionalities are provided:

- digital oscilloscope mode, intended for fixing instantaneous currents and voltages in the interval up to 60 fundamental frequency periods, in case of emergency and transient circuit regimes. Instantaneous values of 3 voltages and 3 currents are recorded with a discreteness of 64 points for the fundamental frequency period in the form of blocks of 60 periods continuously. Two periods are recorded before the start of the block memorization and 58 periods after it. The latching mode is activated when the RMS-value in a half-cycle in any phase falls below the threshold of the start of registration **Udo_l (**digital oscilloscope_low), or above the threshold value **Udo_h** (digital oscilloscope_high). The values of **Udo_l** and **Udo_h** are set by the user in the form of settings. Each block contains information on the date and time of its registration. The archive of the "digital oscilloscope" contains 10 blocks with the last registers, updated on a ring basis;
- a mode for recording the fundamental frequency voltages and currents

periodic values in all 3 phases over an interval up to 60 seconds in the event of voltage sag or overvoltages. The latching mode is switched on when the RMS-value for 1 period in any phase falls below the threshold value of **Uso_l (**voltage sag or overvoltages_low), or above the threshold value of **Uso_h (**voltage sag or overvoltages_high). The values **Uso_l** и **Uso_h** are set by the user in the form of settings. Each block contains information about the date and time of its registration. The peripolar values archive contains 10 blocks with the last registers updated according to the ring principle;

- a mode of registering the minute values of fundamental frequency currents, voltages, active and reactive powers in all three phases in the form of one continuous recording unit during the last 34 days. The minute value archive consists of one block, which is updated according to the ring principle. The meter is supplied from a controlled electrical network.

Technical specifications

1. The meter has three channels for measuring the voltage, for nominal values 220, or 100, or 57.735 V, and three channels for measuring current at nominal values of 5 A.

2. The meter provides measurement of characteristics, in three-phase electrical network and power source systems with a grounded and isolated neutral with a nominal frequency of 50 Hz. For networks with a grounded neutral (220/380 V, 110 kV and higher), the values of the energies (powers) are defined as the sum of their respective 3 single-phase energies (powers) in each phase.

3. For networks with a grounded neutral (6-10-35 kV), the values of the energies (powers) are defined as the sum of their respective 2 interphase energies (powers) at 2 measured line voltages.

4. Voltage measurement channels can be connected directly to a network with a nominal voltage of 220 V, or through voltage measuring transformers (VT) 100 or 57.735 V, for networks with a rated voltage of 6 kV and higher.

5. The meter measures the averaged values of the characteristics at fixed time intervals (averaging intervals). The measuring ranges, the limits of the permissible errors in the measurement and the averaging intervals are given in Table 5.

6. The meter provides its characteristics under the following conditions:

amplitude voltage value V, no more than 390;

amplitude current value A, no more than 10.

7. The meter contains a clock and provides a real time value (hours, minutes, seconds) and a calendar (day, month, year).

Table 5. Nomenclature of measured characteristics and metrological characteristics

The name of the measured value		**Measurement range**	**Limits of the allowed basic error**		**The averaging interval**
			Absolute	**relative,%**	
1 Steady-state voltage deviation Δ ***Uy***, %		-20 - +20	± 0,2	-	60
2 Voltage waveform distortion factor ***KU***, %		0,1- 15	± 0,05 at ***KU*** < 1	± 5 at ***KU*** □ 1	3
3 Factor of n-th sinusoidal voltage component for n from 2 to 40 ***KU(n)***, %		0 – 10 for ***n*** < 16 0 – 5 for ***n*** < 30 0 – 2 for ***n*** □	± 0,05 at ***KU(n)*** < 1	± 5 at ***KU(n)*** □ 1	3
4 Voltage unbalance factor by negative phase sequence ***K2U***,		0,1 - 15	± 0,2	-	3
5 Voltage unbalance factor by zero phase sequence ***K0U***, %		0,1 - 15	± 0,2	-	3
6 Frequency deviation Δ ***f***, Hz		-3 - +3	± 0,02	-	20
7 The amplitude of the voltage pulse ***Upulse***, kV	thunderstorm	1 – 6,0	-	± 10	3
	switching	1 – 4,5	-	± 10	3
8 Pulse duration Δ t_{pulse}, μs	thunderstorm	5…50	-	± 10	3
	switching	50…2000	-	± 10	3
9 Temporary overvoltage factor ***Kover U***		1,1 - 1,2	-	± 10	3
10 Temporary overvoltage duration Δ *tover U*, sec		0,01 - 60	± 0,01	-	3
11 Voltage sag depth, %		10-90	-	± 2	3

12 Voltage sag duration Δ ***tf***, sec	0,01 - 60	± 0,01	-	3
13 Voltage RMS-value ***U***, V	(0,8 – 1,2)·***Uном***	-	± 0,2	3
14 Current RMS-value ***I***, A	(0,02 – 1,2)·***Iном***	-	± 0,2	3
15 Active, reactive power ***P; Q*** kW, kVAr	(0,01-1,2) ***Uном Iном***	-	0,5	3
16 Active, reactive energy with all distortions ***WPS; WQS*** kW · h, kVAr · h	up to 10^9	-	0,5	3
17 Fundamental frequency active, reactive energy ***WP1; WQ1*** kW · h, kVAr · h	up to 10^9	-	0,5	3
18 The phase angle of the shift between the fundamental	-180 º …+180º	±3	-	3

8. The meter provides calculation of the integral value of discounts - supplements to the tariff for the non-normative value of the QEEI and the cost of consumed electrical energy, both taking into account the fixed QEEI and without taking them into account by the results of each calendar month.

9. Connection with PC or other automated systems and installations is foreseen. The meter is equipped with 2 independent communication channels RS-485.

10. The meter provides a display on the built-in alphanumeric (AND) display and PC of the actual (ALM) and archive (AVM) measurement results, it contains a built-in independent power source that allows the device to store the measured values in the event of power failure.

11. There is the possibility of simultaneous and independent use of one automated system of commercial electricity metering (ASCEM) by two independent users.

Within a day it is possible to set tariffs for each half-hour.

12. ASCEM monitors not only the values of electricity supplied or consumed, but also the specified regime parameters during the day, for example, real voltage regulation charts, PQI, etc.

13. When operating in the ASCEM system, the device can, on demand, in the "real-time" mode, give the current values of currents and voltages, allows you to control the disconnection of the lines and sections of the tires on which it is installed.

The meter is controlled using the built-in 16-key keyboard, or from a computer.

In the mode of viewing current measurements on the meter or computer, the information about the measured parameters is OUTput:

- voltage (or current) for the selected phase: A, B, C

U = xxx V, RMS-value U

dU = xxx V, deviation U absolute

σU = xxx%, deviation U relative

- frequency f = xxx Hz, RMS-value f

df = xxx Hz, absolute deviation f

σf = xxx%, relative deviation f

- voltage harmonics, from 2 to 40 for the selected phase: A, B, C

Harmonics number: xxx

Value: xxx%

•voltage waveform distortion factor for the selected phase:
A, B, C - KU = xxx%

•voltage unbalance factor by negative phase sequence - К2 = xxx%

•voltage unbalance factor by zero phase sequence - K0 = xxx%

•active power, total and for each selected phase: A, B, C - P = xxx kW

•reactive power, total and for each selected phase: A, B, C - Q = xxx kVAr

•active total energy, total and for each selected phase: A, B, C - WPS = xxx kWh

•reactive total energy, total and for each selected phase: A, B, C - WQS = xxx kVap / h

•active energy in the fundamental frequency - WP1 = xxx kW / h

•reactive energy at the fundamental frequency - WQ1 = xxx kVAr / h

•the phase shearing angles of the voltage and current , relative to the phase-A voltage vector, which is assumed to be zero.

The computer displays: the wiring diagram; reference voltage; coefficient of current transformation.

From the keyboard of the device archival records are displayed: the archive of 30 minutes, the archive of the day, the archive of months, the archive of failures, the archive of excesses, the archive of pulses

The following files are displayed from the control computer:

•**archive of digital oscilloscope**

•**archive of currents, voltages and powers period values**

•**archive of currents, voltages and powers minute values**

•**archive consumed WPS, WQS, WP1, WQ1,** which is divided into 3 separate tables - half-hour, daily and monthly values. The table of half-hour values contains the results of half-lives for 2 months. In the table of daily values, the results of power consumption for days, for 2 months. The monthly values table contains 2 lines corresponding to the number of months taken into account. The total amount of information in all tables is 2 months. All tables are divided into 8 columns.

WPS	ΔWPS	WQS	ΔWQS	WP1	ΔWP1	WQ1	ΔWQ1
The RMS-value of the consumed active energy with all the distortion powers at the end of the given half-hour (day, month)	The value of this consumed energy for the given half-hour (day, month)	The RMS-value of the consumed reactive energy, with all powers of distortion at the end of the given half-hour (day, month)	The RMS-value of this consumed energy for the given half-hour (day, month)	The RMS-value of the consumed active energy at the fundamental frequency at the end of the given half-hour (day, month)	The value of this consumed energy for the given half-hour (day, month)	The RMS-value of the consumed reactive energy at the fundamental frequency at the end of this half-hour (day, month)	The value of this consumed energy for a half-hour (a day, a month)

➢ **Half-hour archives (on days)**

There are six types of blocks in a half-hour archive:

- (1) basic, which contains information on daily electricity consumption and the cost of consumed electricity, taking into account and without taking into account the PQI;
- (2) the frequency block Δf, which contains the PQI in frequency and the cost of consumed electricity taking into account this PQI;
- (3) voltage deviation block δU, which contains the QEEI in frequency and the cost of consumed electricity taking into account this PQI;
- (4) negative phase sequence K2, which contains data on this PQI and the cost of consumed electricity with its account;
- (5) zero phase sequence block K0, which contains data on this PQI and the cost of consumed electricity with its account;
- (6) non-sinusoidal-harmonic block KU, which contains data on this PQI and the cost of consumed electricity with its account;

<u>1. The main half-hour archive (block)</u>

<u>The table contains the following columns:</u>

- **ΔWP_I** - active electricity consumed for the current half hour (MWh).

- **Cost_P_I** - tariff for active electricity in this time of the day (rubles / kWh).

- **Cost_P_I** - the cost of active electricity consumed for the current half-hour without taking into account the PQI (thousand rubles).

-**ΔWP_I_NR** - the amount of active electricity consumed in the current half-hour that does not meet the requirements of GOST (MWh-h).

-**ΔCost_R_□_I** - the total value of the reduction in the cost of active electricity consumed for the current half-hour, due to inconsistency of all PQI (thousand rubles /%).

- **ΔWQ_I** - reactive electricity consumed for the current half hour (MVAr).

-**Cost_Q_I** - tariff for reactive electricity in this zone of the day (rubles /kVAr * h).

-**Cost_Q_I** - the cost of active electricity consumed for the current half-hour without taking into account the PQI (thousand rubles).

-**ΔWQ_I_H** - the amount of reactive power consumed in the current half-hour that does not meet the requirements of GOST (MWh-h).

-**ΔCost_Q_Σ_I** - the total value of the reduction in the cost of reactive electricity consumed for the current half-hour, due to inconsistency of all PQI (thousand rubles /%).

2. Half-hour archive Δf (frequency)

- Δf_av_I - the average value of the frequency deviation over a period of half an hour (Hz).

- **Δf_max_I** - maximum frequency value the half hour period (Hz).

- Δf_min_I - minimum frequency value for the half hour period (Hz).

-**T1f_high_I** - percentage of the output of the frequency deviation values for the upper normal limit for the current half-hour (%).

-**T2f_high_I** - percentage of the output of the frequency deviation values for the upper maximum allowable limit for the current half-hour (%).

-**T1f_low_I** - percentage of the output of the frequency deviation values for the lower normal limit for the current half-hour (%).

-**T2f_low_I** - percentage of the output of the frequency deviation values for the lowest maximum allowable limit for the current half-hour (%).

-ΔWP_Δf_T1_I_NR - the amount of active electricity consumed for the current half-hour, which does not meet the requirements of GOST, due to the frequency mismatch in **T1** (MWh-h).
-ΔCost_P_Δf _T1_I - the value of the reduction in the cost of active electricity consumed for the current half-hour, due to frequency mismatch in T1 (thousand rubles /%).
-ΔWP_Δf _ T2_I_NR - the amount of active electricity consumed in the current half-hour that does not meet the requirements of GOST, due to the frequency mismatch in **T2** (MWh-h).
-ΔCost_R_Δf _T2_I - the value of the reduction in the cost of active electricity consumed for the current half-hour, due to frequency mismatch in T2 (thousand rubles /%).
-ΔWP_Δf _ Σ_I_NR - the amount of active electricity consumed for the current half-hour, which does not meet the requirements of GOST, due to the frequency mismatch in T1 and T2 together (MWh-h).
-ΔCost_R_Δf _Σ_I is the value of the decrease in the cost of active electricity consumed for the current half-hour, due to frequency mismatch, total for T1 and T2 (thousand rubles /%).
-ΔWQ_Δf _ T1_I_NR - the amount of reactive power consumed in the current half-hour that does not meet the requirements of GOST, due to a non-response of the frequency according to T1 (MWh-h).
-ΔCost_Q_Δf _T1_I is the value of the decrease in the cost of reactive electricity consumed for the current half-hour, due to the frequency mismatch in T1 (thousand rubles /%).
-ΔWQ_Δf _ T2_I_НК - the amount of reactive electricity consumed in the current half-hour that does not meet the requirements of GOST, due to a non-response of the frequency according to T2 (MWh-h).
-ΔCost_Q_Δf _T2_I is the value of the reduction in the cost of reactive electricity consumed for the current half-hour, due to the frequency mismatch in T2 (thousand rubles /%).
-ΔWQ_Δf _ Σ_I_NR - the amount of reactive electricity consumed for the current half-hour that does not meet the requirements of GOST, due to the frequency mismatch in T1 and T2 together (MWh-h).
-ΔCost_Q_Δf _Σ_I - value of reduction in the cost of reactive electricity consumed for the current half-hour, due to frequency mismatch, total for **T1** and

T2 (thousand rubles /%)

A comment

T1f_high_I, T2f_high_I, T1f_low_I, T2f_low_I - time of exceeding (in % relative to the current half hour) of the PQI above respectively the normally permissible and maximum allowable values for each half-hour interval. Their sum per day gives daily values of T1 and T2 in % relative to the day:

T1f_high_J = Σ (T1f_high_I) / 48;

T1f_low_J = Σ (T1f_low_I) / 48;

T2f_high_J = Σ (T2f_ high _I) / 48;

T2f_low_J = Σ (T2f_low_I /) 48;

(the sum for all half-hour intervals given to days)

3. Half-hour archive δU (voltage deviations)

- δU_cp_I – average value of the voltage deviation for the half-hour period (%).

-δ U_max_I - maximum value of the voltage deviation for the half-hour period (%).

- δ U_min_I - minimum value of the voltage deviation for the half-hour period (%).

-T1U_в_I – percentage of voltage deviation values beyond the upper normally allowed limit for current half-hour period (%).

-T2U_в_I - percentage of voltage deviation values beyond the upper maximum allowed limit for current half-hour period (%).

-T1U_н_I - percentage of voltage deviation values beyond the lower normally allowed limit for current half-hour period (%).

-T2U_н_I - percentage of voltage deviation values beyond the lower maximum allowed limit for current half-hour period (%).

- Δ WP_ δ U_ T1_I_НК – active energy consumed for current half-hour period inconsistent with National state standard requirements due to a discrepancy of voltage deviations in T1 (MWh).

- Δ Cт_P_ δ U_T1_I – value of the reduction in the cost of active energy consumed for the current half-hour period, due to a discrepancy of voltage deviation in T1 (thousand rubles /%).

- Δ WP_ δ U_ T2_I_НК - active energy consumed for current half-hour period inconsistent with requirements due to a discrepancy of voltage deviation in T2 (MWh).

- Δ Ст_P_ δ U_T2_I - value of the reduction in the cost of active energy consumed for the current half-hour period, due to a discrepancy of voltage deviation in T2 (thousand rubles /%).

- Δ WP_ δ U_ Σ _I_НК - active energy consumed for current half-hour period inconsistent with requirements due to a discrepancy of voltage deviation in T1 and **T2** in common (MWh).

- Δ Ст_P_ δ U_ Σ _I - value of the reduction in the cost of active energy consumed for the current half-hour period, due to a discrepancy of the voltage deviation , total for **T1** and **T2** (thousand rubles /%).

- Δ WQ_ δ U_ T1_I_НК – reactive energy consumed for current half-hour period inconsistent with requirements due to a discrepancy of voltage deviation in **T1** (MWh).

- Δ Ст_Q_ δ U_T1_I - value of the reduction in the cost of reactive energy consumed for current half-hour period, due to a discrepancy of the voltage deviation in T1 (thousand rubles/%).

- Δ WQ_ δ U_ T2_I_НК – reactive energy consumed for current half-hour period inconsistent with National state standard requirements due to a discrepancy of voltage deviation in T2 (MWh).

- Δ Ст_Q_ δ U_T2_I - value of the reduction of the cost of reactive energy consumed for current half-hour period, due to a discrepancy of the voltage deviation in T2 (thousand rubles/%).

- Δ WQ_ δ U_ Σ _I_НК - reactive energy consumed for current half-hour period inconsistent with National state standard requirements due to a discrepancy of voltage deviation in T1 and **T2** in common (MWh).

- Δ Ст_Q_ δ U_ Σ _I - value of the reduction of the cost of reactive energy consumed for current half-hour period due to a discrepancy of the voltage deviation, total in T1 and **T2** (thousand rubles/ %).

Note

T1U_in_I , T2U_in_I , T1U_n_I , T2U_n_I - excess time (at % relative to the current half-hour period) of the indicator of power quality (IPQ) is higher than the normal permissible and maximum permissible values for each half-hour interval, respectively . Their sum per day gives daily values of T1 and T2 in % relative to the day:

T1U_в_J = Σ (T1U_6_I) / 48 ;

T1U_в_J = Σ (T1U_n_I) / 48 ; T2U_в_J = Σ T (2U_в_I /) 48 ; T2U_в_J = Σ T (2U_n_I /) 48 ;

(the sum of all half-hour intervals reduced to days).

4. Half-hour K2 archive (negative sequence)

-K2_ср_I - average value of the negative sequence ratio for a half-hour period (%).

-K2_макс_I - maximum value of the negative sequence ratio for a half-hour period (%).

-K2_мин_I - minimum value of the negative sequence ratio for a half-hour period (%).

-T1_K2_I - percentage of negative sequence ratio values beyond the normally permissible limit for current half-hour period (%).

-T2_K2_I - percentage of negative sequence ratio values beyond the maximum permissible limit for current half-hour period (%).

- Δ WP_K2_ T1_I_НК – active electrical energy consumed for current half-hour period inconsistent with National state standard requirements due to a discrepancy of negative sequence ratio in T1 (MWh).

- Δ Cт_P_K2_T1_I - value of the reduction in the cost of active electric energy consumed for the current half-hour period, due to a discrepancy of the negative sequence ratio in T1 (thousand rubles /%).

- Δ WP_K2_ T2_I_НК - active electrical energy consumed for current half-hour period inconsistent with National state standard requirements due to a discrepancy of negative sequence ratio in T2 (MWh).

- Δ Cт_P_K2_T2_I - value of the reduction in the cost of active electric energy consumed for the current half-hour period, due to a discrepancy of the negative sequence ratio in T2 (thousand rubles /%).

- Δ WP_K2_ Σ _I_НК - active electrical energy consumed for current half-hour period inconsistent with National state standard requirements due to a discrepancy of negative sequence ratio in T1 and **T2** in common (MWh).

- Δ Cт_P_K2_ Σ _I - value of the reduction in the cost of active electric energy consumed for the current half-hour period, due to a discrepancy of the negative sequence ratio, total in T1 and **T2** (thousand rubles /%).

- Δ WQ_K2_ T1_I_НК – reactive electrical energy consumed for current half-hour inconsistent with National state standard requirements due to a discrepancy of negative sequence ratio in T1 (MWh).

- Δ Cт_Q_K2_T1_I - value of the reduction in the cost of reactive electric energy consumed for the current half-hour period, due to a discrepancy of the negative sequence ratio in T1 (thousand rubles/ %).

- Δ WQ_K2_ T2_I_НК - reactive electrical energy consumed for current half-hour period inconsistent with National state standard requirements due to a discrepancy of negative sequence ratio in T2 (MWh).

- Δ Cт_Q_K2_T2_I - value of the reduction in the cost of reactive electric energy consumed for the current half-hour period, due to a discrepancy of the negative sequence ratio in T2 (thousand rubles/ %).

- Δ WQ_K2_ Σ _I_НК - reactive electrical energy consumed for current half-hour period inconsistent with National state standard requirements due to a discrepancy of negative sequence ratio in T1 and **T2** in common (MWh).

- Δ Cт_Q_K2_ Σ _I - value of the reduction in the cost of reactive electric energy consumed for the current half-hour period, due to a discrepancy of the negative sequence ratio, total in T1 and **T2** (thousand rubles/ %);

Note

T1_K2_I, T2_K2_I , - excess time (at % relative to the current half-hour period) of the IPQ is higher than the normal permissible and maximum permissible values for each half-hour interval, respectively . Their sum per day gives daily values of T1 and T2 in % relative to the days:

T1_K2_J = Σ (T1_K2_I) / 48;

T2_K2_J = Σ (T2_K2_I) / 48;

(the sum of all half-hour intervals reduced to days)

5. Half-hour archive K0 (zero sequence)

-K0_ср_I - average value of the zero-sequence ratio for a half-hour period (%).

-K0_макс_I - maximum value of the zero-sequence ratio for a half-hour period (%).

-K0_мин_I - minimum value of the zero-sequence ratio zero-sequence ratio for a half-hour period (%).

-T1_K0_I -.percentage of zero-sequence ratio values beyond the normally permissible limit for current half-hour period (%).

-T2_K0_I - percentage of zero-sequence ratio values beyond the maximum permissible limit for current half-hour period (%).

- Δ WP_K0_T1_I_НК - active electrical energy consumed for current half-hour period inconsistent with National state standard requirements due to a discrepancy of zero-sequence ratio in T1 (MWh).

- Δ Cт_P_K0_T1_I – the value of reduction in the cost of active electric energy consumed for the current half-hour period, due to a discrepancy of the zero-sequence ratio in T1 (thousand rubles/ %).

- Δ WP_K0_T2_I_НК - active electrical energy consumed for current half-hour period inconsistent with National state standard requirements due to a discrepancy of zero-sequence ratio in T2 (MWh).

- Δ Cт_P_K0_T2_I – the value of reduction in the cost of active electric energy consumed for the current half-hour period, due to a discrepancy of the zero-sequence ratio in T2 (thousand rubles/ %).

- Δ WP_K0_ Σ _I_НК - active electrical energy consumed for current half-hour period inconsistent with National state standard requirements due to a discrepancy of zero-sequence ratio in T1 and **T2** in common (MWh).

- Δ Cт_P_K0_ Σ _I - the value of reduction in the cost of active electric energy consumed for the current half-hour period, due to a discrepancy of the zero-sequence ratio, total in T1 and **T2** (thousand rubles/ %).

- Δ WQ_K0_T1_I_НК - reactive electrical energy consumed for current half-hour period inconsistent with National state standard requirements due to a discrepancy of zero-sequence ratio in T1 (MWh).

- Δ Cт_Q_K0_T1_I - the value of reduction in the cost of reactive electric energy consumed for the current half-hour period, due to a discrepancy of the zero-sequence ratio in T1 (thousand rubles/ %).

- Δ WQ_K0_T2_I_НК - reactive electrical energy consumed for current half-hour period inconsistent with National state standard requirements due to a discrepancy of zero-sequence ratio in T2 (MWh).

- Δ Cт_Q_K0_T2_I - the value of reduction in the cost of reactive electric energy consumed for the current half-hour period, due to a discrepancy of the zero-sequence ratio in T2 (thousand rubles/ %).

- Δ WQ_K0_ Σ _I_НК - reactive electrical energy consumed for current half-hour period inconsistent with National state standard requirements due to a discrepancy of zero-sequence ratio in T1 and **T2** in common (MWh).

- Δ Cт_Q_K0_ Σ _I - the value of reduction in the cost of reactive electric energy consumed for the current half-hour period, due to a discrepancy of the zero-sequence ratio, total in T1 and **T2** (thousand rubles/ %).

Note

T1_K0_I, T2_K0_I, - excess time (at % relative to the current half-hour period) of the IPQ is higher than the normal permissible and maximum permissible values for each half-hour interval, respectively . Their sum per day gives daily values of T1 and T2 in % relative to the days:

T1_K0_J = Σ (T1_K0_I) / 48;

T2_K0_J = Σ (T2_K0_I) / 48;

(the sum of all half-hour intervals reduced to days)

6. Half-hour KU archive (nonsinusoidality - harmonics)

-KU_ср_I - average value of the nonsinusoidality ratio for a half-hour period (%).

-KU_макс_I - maximum value of the nonsinusoidality ratio for a half-hour period (%).

-KU_мин_I - minimum value of the nonsinusoidality ratio for a half-hour period (%).

-T1_KU_I - percentage of nonsinusoidality ratio values beyond the normally permissible limit (%).

-T1_KU (i) _max_I – maximum percentage of harmonic factor values beyond the normally permissible limit (%).

-Ni_T1_max_I - harmonic number with maximum T1.

-T1_KU_ Σ _I - final maximum percentage of the nonsinusoidality ratio and harmonic factor beyond the normally permissible limit (%).

-T2_KU_I - percentage of the nonsinusoidality ratio and harmonic factor beyond the maximum permissible limit (%).

-T2_KU (i) _max_I - maximum percentage of harmonic factor values beyond the maximum permissible limit (%).

-Ni_T2_max_I - harmonic number with maximum T2.

-T2_KU_ Σ _I - final maximum percentage of the nonsinusoidality ratio and harmonic factor beyond the maximum permissible limit (%).

- Δ WP_KU_T1_I_НК - active electrical energy consumed for current half-hour period inconsistent with National state standard requirements due to a discrepancy of the nonsinusoidality ratio and harmonic factor in **T1** (MWh).

- Δ Ст_P_KU_T1_I - the value of reduction in the cost of active electric energy consumed for the current half-hour period, due to a discrepancy of the nonsinusoidality ratio and harmonic factor in **T1** (thousand rubles/ %).

- Δ WP_KU_T2_I_НК - active electrical energy consumed for current half-hour period inconsistent with National state standard requirements due to a discrepancy of the nonsinusoidality ratio and harmonic factor in **T2** (MWh).

- Δ Ст_P_KU_T2_I - the value of reduction in the cost of active electric energy consumed for the current half-hour period, due to a discrepancy of the nonsinusoidality ratio and harmonic factor in T2 (thousand rubles/ %).

- Δ WP_KU_ Σ _I_НК - active electrical energy consumed for current half-hour period inconsistent with National state standard requirements due to a discrepancy of the nonsinusoidality ratio and harmonic factor in **T1** and **T2** in common (MWh).

- Δ Ст_P_KU_ Σ _I - the value of reduction in the cost of active electric energy consumed for the current half-hour period, due to a discrepancy of the nonsinusoidality ratio and harmonic factor, total in **T1** and **T2** (thousand rubles/%).

- Δ WQ_KU_T1_I_НК - reactive electrical energy consumed for current half-hour period inconsistent with National state standard requirements due to a discrepancy of the nonsinusoidality ratio and harmonic factor in **T1** (MWh).

- Δ Ст_Q_KU_T1_I - the value of reduction in the cost of reactive electric energy consumed for the current half-hour period, due to a discrepancy of the nonsinusoidality ratio and harmonic factor in T1 (thousand rubles/ %).

- Δ WQ_KU_T2_I_НК - reactive electrical energy consumed for current half-hour period inconsistent with National state standard requirements due to a discrepancy of the nonsinusoidality ratio and harmonic factor in **T2** (MWh).

- Δ Cт_Q_KU_T2_I - the value of reduction in the cost of reactive electric energy consumed for the current half-hour period, due to a discrepancy of the nonsinusoidality ratio and harmonic factor in T2 (thousand rubles/ %).
- Δ WQ_KU_ Σ _I_НК - reactive electrical energy consumed for current half-hour periodinconsistent with National state standard requirements due to a discrepancy of the nonsinusoidality ratio and harmonic factor in T1 and **T2** in common (MWh).
- Δ Cт_Q_KU_ Σ _I - the value of reduction in the cost of reactive electric energy consumed for the current half-hour period, due to a discrepancy of the nonsinusoidality ratio and harmonic factor, total in T1 and **T2** (thousand rubles/ %).

Note

T1_KU_I , T2_KU_I , - excess time (at % relative to the current half-hour period) of the IPQ is higher than the normal permissible and maximum permissible values for each half-hour interval, respectively. Their sum per day gives daily values of T1 and T2 in % relative to the days:

T1_KU_J = Σ (T1_KU_I) / 48;

T2_KU_J = Σ (T2_KU_I) / 48;

(the sum of all half-hour intervals for the nonsinusoidality reduced to days)

- **Daily archives (by months)**
- **Monthly archives (by years)**
- **Short display of monthly power consumption results**

The meter provides the input of operational settings

All configurable options are input directly on device using the keyboard or programmatically with a PC. Possibility of browsing of these options on device display and via PC is provided. **All** setup data input are password-protected in order to prevent unauthorized access and are fixed within device at "non-volatile" memory for ensuring the additional monitoring capabilitiy.

-CP_I [48], QQ_I [48] – current tariffs for active and reactive electrical energy for each half-hour interval during the day (rubles / kWh, kVArh).

-CP_I_n [48], CQ_I_n [48] - new tariffs for active and reactive electrical energy for each half-hour interval during the day (rubles / kWh, kVArh).
-D_tr_n - the date of new tariffs implementation (year, month, day).

Note. At the beginning of every day (after the end of the 48th half-hour period) it is checked whether the date of the current new day coincides with **D_tr_n.** If not - calculations continue unchanged. If they coincide, the values of the new tariffs are assigned to current tariffs and calculation continues with new tariffs values. The variable **D_tr_n** in this case is reset to zero.

-CкP_ Δ f_T1 , CкP_ δ U_T1 , CкP_KU_T1 , CкP_K2_T1 , CкP_K0_T1 - values of currently active tariff discounts (surcharges) for consumed active electrical energy in case of discrepancy of power quality in frequency, voltage deviation, nonsinusoidality, unbalance of the negative and zero sequence (p.u.) with discrepancy of IPQ in T1. So it shows how much less % customer must pay for consumed electrical energy in comparison with normal tariff, if T1 is more than 5 %.
-CкP_ Δ f_T2 , CкP_ δ U_T2 , CкP_KU_T2 , CкP_K2_T2 , CкP_K0_T2 - values of currently active tariff discounts (surcharges) for consumed active electrical energy in case of discrepancy of power quality in frequency, voltage deviation, nonsinusoidality, unbalance of the negative and zero sequence (p.u.) with discrepancy of IPQ in T2. So it shows how much less % customer must pay for consumed electrical energy in comparison with normal tariff, if T2 is more than 0 %.
-CкQ_ Δ f_T1, CкQ_ δ U_T1, CкQ_KU_T1, CкQ_K2_T1, CкQ_K0_T1 - values of currently active tariff discounts (surcharges) for consumed reactive electrical energy in case of discrepancy of power quality in frequency, voltage deviation, nonsinusoidality, unbalance of the negative and zero sequence (p.u.) with discrepancy of IPQ in T1. So it shows how much less % customer must pay for consumed electrical energy in comparison with normal tariff, if T1 is more than 5 %.
-CкQ_ Δ f_T2, CкQ_ δ U_T2, CкQ_KU_T2, CкQ_K2_T2, CкQ_K0_T2 - values of currently active tariff discounts (surcharges) for consumed reactive electrical energy in case of discrepancy of power quality in frequency, voltage deviation, nonsinusoidality, unbalance of the negative and zero sequence (p.u.)

with discrepancy of IPQ in T2. So it shows how much less % customer must pay for consumed electrical energy in comparison with normal tariff, if T2 is more than 0 %.

- Δ f_1_в, Δ f_2_в, Δ f_1_н, Δ f_2_н – values of normally permissible and maximum permissible frequency deviations for the upper and the lower limits (Hz).

- δ U_1_in_нб, δ U2_v_нб, δ U_1_н_нб, δ U_2_н_нб – values of currently active discounts of normally permissible and maximum permissible voltage deviations for the upper and the lower limits (%) in on-peak operation conditions.

- δ U_1_v_нм, δ U_2_v_нм, δ U_1_n_нм, δ U_2_n_нм - values of currently active discounts of normally permissible and maximum permissible voltage deviations for the upper and the lower limits (%) in off-peak operation conditions.

- (T1n_нб, T1k_нб), (T2n_нб, T2k_нб) - 2 limits of currently active zones (multiple of 0.5 hour - hour interval, min.) for maximum load. All the rest of time of day corresponds to the minimal load.

-KU_1, KU_2 - values of the normally permissible and maximum permissible nonsinusoidality ratio (%).

-K2_1, K2_2 – values of currently active discounts of normally permissible and maximum permissible negative sequence unbalance factor (%).

-K0_1, K0_2 - values of currently active discounts of normally permissible and maximum permissible unbalance factor in zero-sequence (%).

-СкР_ Δ f_T1_n, СкР_ δ U_T1_n, СкР_KU_T1_n, СкР_K2_T1_n, СкР_K0_T1_n - values of new tariff discounts (surcharges) for consumed active electrical energy in case of discrepancy of power quality in frequency, voltage deviation, nonsinusoidality, unbalance of the negative and zero sequence (p.u.) with discrepancy of IPQ in T1. So it shows how much less % customer must pay for consumed electrical energy in comparison with normal tariff, if T1 is more than 5 %.

-СкР_ Δ f_T2_n , СкР_ δ U_T2_n , СкР_KU_T2_n , СкР_K2_T2_n , СкР_K0_T2_n - values of new tariff discounts (surcharges) for consumed active electrical energy in case of discrepancy of power quality in frequency, voltage deviation, nonsinusoidality, unbalance of the negative and zero sequence (p.u.) with discrepancy of IPQ in T2. So it shows how much less % customer must pay for consumed electrical energy in comparison with normal tariff, if T2 is more than 0%.

.-**СкQ_ Δ f_T1_n , СкQ_ δ U_T1_n , СкQ_KU_T1_n , СкQ_K2_T1_n , СкQ_K0_T1_n** - values of new tariff discounts (surcharges) for consumed reactive electrical energy in case of discrepancy of power quality in frequency, voltage deviation, nonsinusoidality, unbalance of the negative and zero sequence (p.u.) with discrepancy of IPQ in T1. So it shows how much less % customer must pay for consumed electrical energy in comparison with normal tariff, if T1 is more than 5 %.

-СкQ_ Δ f_T2_n , СкQ_ δ U_T2_n , СкQ_KU_T2_n , СкQ_K2_T2_n , СкQ_K0_T2_n - values of new tariff discounts (surcharges) for consumed reactive electrical energy in case of discrepancy of power quality in frequency, voltage deviation, nonsinusoidality, unbalance of the negative and zero sequence (p.u.) with discrepancy of IPQ in T2. So it shows how much less % customer must pay for consumed electrical energy in comparison with normal tariff, if T2 is more than 0%.

- Δ f_1_в_n, Δ f_2_в_n, Δ f_1_н_n, Δ f_2_н_n - values of new normally permissible and maximum permissible frequency deviations for the upper and the lower limits (Hz).

- δ U_1_в_нб_n, δ U2_в_нб_n, δ U_1_н_нб_n, δ U_2_н_нб_n - values of new normally permissible and maximum permissible voltage deviations for the upper and the lower limits (%) in on-peak operation conditions.

- δ U_1_в_нм_n, δ U_2_в_нм_n, δ U_1_н_нм_n, δ U_2_н_нм_n - values of new normally permissible and maximum permissible voltage deviations for the upper and the lower limits (%) in off-peak operation conditions.

-(T1н_нб_n, T1к_нб_n), (T2н_нб_n, T2к_нб_n) - 2 limits of new zones (multiple of 0.5 hour - hour interval, min.) for maximum load. All the rest of time of day corresponds to the minimal load.

-KU_1_n , KU_2_n - values of new normally permissible and maximum permissible nonsinusoidality ratios (%).

-K2_1_n , K2_2_n - values of the normally permissible and maximum permissible negative sequence unbalance factors in (%).

-K0_1_n, K0_2_n - values of the normally permissible and maximum permissible unbalance factors in zero sequence (%).

-D_dpe_n – the date of implementation (year, month, day) of new power supply agreement (new discounts-surcharges, new IPQ standards etc.)

Note. At the beginning of every day (after the end of the 48th half-hour period) it is checked whether the date of the current new day coincides with **D_tr_n.** If not - calculations continue unchanged. If they coincide, the values of the new parameters are assigned to current parameters and calculation continues with new parameter values. The variable **D_tr_n** in this case is reset to zero.

The RS-485 interface is used to transfer the archive and measured information.

The meter provides protection from unauthorized access to information by: entering a password when changing operating settings, at the beginning and end of a measurement cycle, setting a password (factory password: 2222); fixing of time and content changes carried out by password in the memory of the meter; display of the date and values of the operational settings that were in effect during the measurement while viewing the archive information.

The time for setting the operating mode of the meter after connecting the power supply is **not more than 1 min.**

Supply of the meter is provided by the measured AC network.

Input circuits of the meter withstand the impact of impulse noise on voltage supply circuits: up to 10 kV - with a duration of not more than 20 μs, up to 6 kV - with a duration of not more than 10 μs.

The meter provides registration of parameters shown in Table 4 at a depth of voltage dips up to 90% and with a temporary overvoltage up to 120%.

The input impedance of voltage measurement channels is (450 + 10) kOhm, the input capacitance is not more than 30 pF.

The input resistance of current measurement channels is not more than 0.035 Ohm.

The power consumed by the meter on the power circuit is not more than 10 W.

The specified life of the meter is 10 years.

Overall dimensions of the meter are (270x180x130) mm.

A meter weight is not more than 4 kg.

Devices and operation of the meter

1. The meter is a measuring and computing facility. The structure diagram of the meter is shown in the Fig. 2.

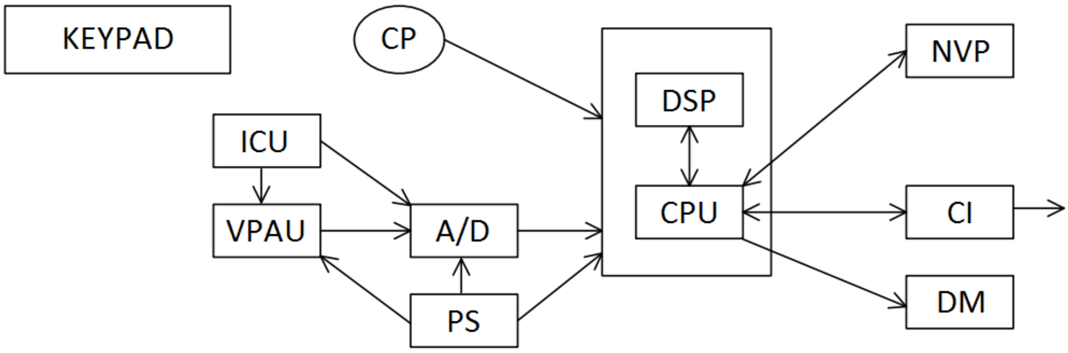


Fig. 2. Structure diagram of the meter

2. The meter consists of an **analog** and a **digital** part.

The analog part includes:

- ICU (input circuits unit (3 voltage channels and 3 current channels));
- VPAU (voltage pulse analysis unit);
- A/D (analog-to-digital converter).

The digital part includes:

- CPU (central processing unit);
- DSP (digital signal processor);
- NVP (non-volatile memory);
- CI (communication interface);
- DM (display means);
- PS (power supply);
- Keyboard;
- CP (calculation and measurement data processing device).

3. Display means (DM) are located on the front panel of the meter:

- alphanumeric display (AND);
- 16-key keyboard.

4. The measured voltages and currents are applied to the input terminals of the corresponding ICU channels. Normalized analog signals of the input parameters are registered from ICU channels output.

5. From the broadband outputs of the ICU, the signals arrive at the VPAU, in which, by analog processing, signals proportional to the parameters of the input pulse voltage are generated.

6. Signals of voltages and currents of the main frequency (50 Hz) from the narrow-band ICU outputs as well as pulse signals from the outputs of the VPAU are entered to the A/D inputs. In the A/D circuit, mutual timing of the input signals and their digitization are carried out. Digitization is performed based on 256 samples of 12-bit code for the base frequency period for each narrow-band signal. The A/D is equipped with a frequency control device (FCD) that keeps the number of digitizing steps equal to (256) when the frequency is varied in the range (50 ± 3) Hz.

Digitized signals codes are entered to the digital part of the meter.

The CPU and the DSP process the information received from the A/D in accordance with the programs stored in ROM.

Measurements of the harmonic components and total harmonic distortions of input (voltage and current) signals of the meter are carried out continuously within the "gap" with a duration of eight periods of the fundamental frequency.

The final values of the measured characteristics are recorded in the NVP for storage (if the "archive recording" command is entered) and are output to DM.

DM includes an alphanumeric (AND) liquid crystal display and a PC monitor.

With the help of RS-485 type CI, the measurement results are OUTPUT via communication channels to the control unit.

The meter is powered by a controlled AC network on one or three phases.

The keyboard is used to control the meter when you set it up and view measurement results.

Operating procedure

Notation conventions of the device keys in the instruction:

«B1» key **SELECT →**	**7**	**8**	**9**
«B2» key **SELECT ←**	**4**	**5**	**6**
«.» key ●	**1**	**2**	**3**
«UI» key	OUTPUT	0	INPUT
U↔I			

Preparation of device

The device is powered from the A phase voltage. When a voltage is applied to this phase, display backlight is turned on and after 1-2 seconds the Main Menu appears on display. The display backlight in any mode is automatically turned off 30 seconds after the last pressing of any key and is turned on again when any key is pressed.

Main menu

The first line of the display shows the current date and time. The second shows a name of the device and version number of the software. In the bottom line, a user selects the operation mode with the "B1" and "B2" keys. To enter the selected mode, press the "ENTER" key.

«Effective values» mode

Selection of a viewed IPQ is carried out by the "B1" and "B2" keys, return to the Main Menu by the "CANCEL" key. Phase selection keys do not work when the "One phase" connection circuit is selected.

-*Voltage / current / phase angle*

The effective value of the selected phase voltage or current is displayed. The phase is selected by the "1", "2", "3" keys. Switching the current to voltage and vice versa is made by pressing the "UI" key. Absolute and relative nominal deviations for the voltage from are also output. Information updating is made 1 time per minute. Voltage is output in volts or kilovolts, current is output in amperes. To view the phase angle (relative to A phase voltage) of the selected voltage or current vector, press the "." key. To return to viewing the effective value, press the "." key again. The angle value is displayed in degrees.

-*Frequency*

The effective frequency, absolute and relative nominal deviations (50 Hz) are displayed. Information updating is effected every 20 seconds.

-*Voltage harmonics*

The effective value of the harmonic factors of the selected voltage phase from the 1st to the 40th in percent is displayed. The harmonic selection is carried out by the keys"4" (increase in the harmonic number) and "6" (decrease in the harmonic number). Phase selection is done with the "1", "2", "3" keys. Information updating is effected every 3 seconds.

-Nonsinusoidality ratio

The effective value of the selected phase nonsinusoidality ratio in percent is displayed. The phase is selected by the "1", "2", "3" keys. Information updating is effected every 3 seconds.

The negative sequence unbalance factor (for the "Star" and the "Triangle" connection circuits).

The effective value of K2 in percent is displayed. Information updating is effected every 3 seconds.

The zero-sequence unbalance factor (for the "Star" connection circuit)

The effective value of K0 in percent is displayed. Information updating is effected every 3 seconds.

-Active power

The effective value of the total active power in watts is displayed. The phase is selected by the "1", "2", "3" keys. The "0" key selects the display of the total power of all three phases. Information updating is effected every 3 seconds.

-Reactive power

The effective value of the total reactive power in the vares is displayed. The phase can be selected using the "1", "2", "3" keys. The "0" key selects the display of the all three phases total power. Information updating is effected every 3 seconds.

«Archive view» mode

Archive type selection is made by the "B1" and "B2" keys, the return to the Main Menu is made by the "CANCEL" key.

- Archives of 30 minutes, days and months

The type of record search selection is made by pressing the "."key. To start viewing the selected archive, press the "ENTER" key.

-Search records by time

Enter the desired record date and time with the numeric keys. To confirm the entry, press the "ENTER" key, to cancel - press the "CANCEL" key. Unfilled fields are considered to be zero. After pressing "ENTER", a search is performed and either the message "No records" or the first component of a record is displayed.

-*All records view*

Two bottom lines of the display show the date and time of all this type available records, starting with the last one. Select the record using the "B1" and "B2" keys. To view the selected record press "ENTER", to cancel viewing press "CANCEL". If the end of the list of records is reached, the message "No records" appears as well as if there is not a selected type record.

-*View a selected or found record*

The display first line shows the record date and time, the second line displays the parameter name, the third line presents its value, in the fourth the unit of measurement is output. Record element (parameter) selection is made by the "B1" and "B2" keys, return to the search mode is done by the "CANCEL" key.

-*Short display of monthly consumption archives*

Switching the active / reactive energy viewing is done by pressing the "." key. After pressing the "ENTER" key, the month is selected in the same way. After pressing "ENTER" again, four lines with the energy consumption data stored in the selected record are displayed. The active energy is output in kWh, the reactive energy is output in kVArh. Return to the search mode is done by pressing the "CANCEL" key.

- *Dips, excesses and voltage pulses archives*

These archives store records of the moment of occurrence of the corresponding event, the duration of the failure, overvoltage (exceeedance) or impulse and amplitude (in percent relative to the nominal value).

«Setup» mode

When entering the "Setup" mode, a user password is requested. Depending on the entered password, access to device different settings is granted. The password is an integer up to 9 characters. To confirm password input press the "ENTER" key, to refuse input press the "CANCEL" key. If the password is entered incorrectly, it returns to the Main Menu.

Specific setting selection is done with the "B1" and "B2" keys, entering this setting is done with the "ENTER" key, returning to the Main Menu is made by pressing the "CANCEL" key.

-*Time and date*

Set the current hour, minute, second, day, month and year by moving the blinking cursor and pressing the number keys. To confirm input press the "ENTER" key, to refuse the date / time change press the "CANCEL" key. The cursor moves either automatically when the numeric keys are pressed, or by the "B1" and "B2" keys.

-*Change Password*

«Setpoint adjustment» mode

Entering a password with the required level of access allows you to change the setpoints for calculating half-hour, daily and monthly archives data, as well as emergency state operation thresholds.

«Power» mode

In this mode the total energy (with S index) passed through the meter is output in four display lines:

1) total active energy, including all WPS distortion powers
2) total active energy, including all WQS distortion powers
3) active energy in the main (50 Hz) harmonic WP1
4) reactive energy in the main (50 Hz) harmonic WQ1

The active energy is output in kWh, the reactive energy is output in kVArh. Return to the Main Menu is done by pressing the "OUTPUT" key. It is possible to view the energy consumed by only one device phase (for the "Star" connection circuit). For this purpose, press the "0" key, then "1", "2" or "3" and the "S" index will be replaced by the corresponding phase name. To return to viewing the total consumed energy, press the "0" key.

"Phases testing" mode

After selecting this menu item, the menu for selecting the type of load connected to the device (capacitive, active-inductive and inductive) appears on the display. Press the "1", "2" or "3" keys to select the desired type or cancel the testing with the "0" key. A diagnostic message will appear on the display indicating incorrect connection of voltages / currents, incorrect polarity of currents, or the message "Connection OK" will appear if all connections are correct. Exit to the Main Menu with the "0" key, turn off the device, correct the connection errors, turn on the device and repeat the phase testing (until the message appears "Connection OK").

Switching off the device

When the voltage is removed from A phase, the device stores data at the time of switching off (in half-hour, daily and monthly archives) in a non-volatile memory, stores the consumed energy data and automatically switches into "sleeping" mode. The device is returned to the active state when the voltage is applied to A phase. In the "sleeping" mode the device can be for unlimited time, but at the same time it is necessary to turn the device on not less once every month (supply voltage to A phase) for at least 3 hours to prevent a full discharge and battery failure.

Appendix

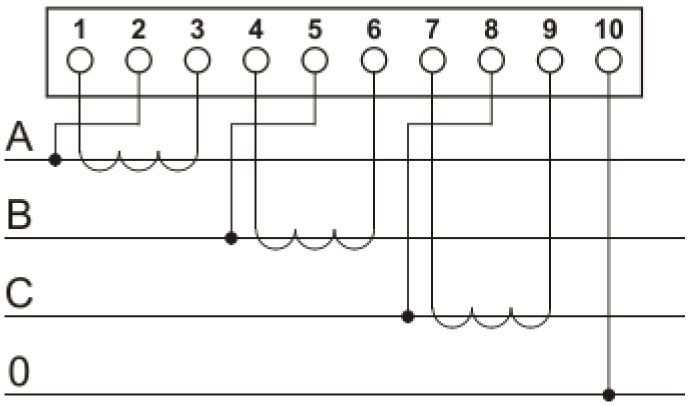


Fig. 3. The device connection diagram for voltage and current (power, energy) measurements in a four-wire network 380/220 (100/57, 73) V.

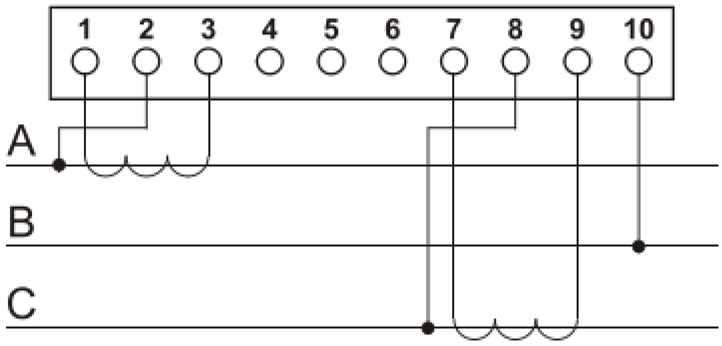


Fig. 4. The device connection diagram for voltage and current (power, energy) measurements in a three-phase circuit with a grounded midpoint and two current transformers.

Report preparation and content guidelines

The report should contain a laboratory work aim description, technical characteristics of the used devices and equipment, performed test results in the form of tables, graphs, as well as the necessary diagrams and calculations. Conclusions for all conducted test points should be presented in the report. The report is made on A4 sheets in a text editor.

Contents of the report:

1. Objective.
2. Connection diagram.
3. Tables with data.
4. Graphs.
5. Conclusions.

Laboratory work No. 1. Voltage balancing using a capacitor bank

Objective:

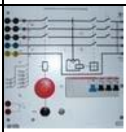
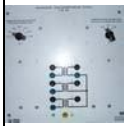
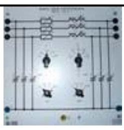
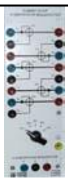
- To study the method of voltages balancing using capacitor banks.
- For an electrical system with unbalanced active-inductive consumers connected to phase voltages, calculate the capacitor banks capacitance connected in the "star" circuit from the low voltage side for balancing it and check on the model.

Brief work description

The connection diagram is shown in the figure 5.

- **G1** source simulates a power supply system connected, for example, to 6-10 / 0.4 kV substation 6-10 kV busbars.
- The **A1** transformer group simulate a step-down transformer of a 35-220 / 6-10 kV substation.
- The **A2** transformer group simulate a step-down transformer of a 6-10 / 0.4 kV substation.
- The **A3** transmission line model imitates the 6-10 kV transmission line of the distribution system.
- **A5** and **A6** loads simulate the active and inductive 0.4 kV line loads.
- **A7** load simulates a capacitor bank.
- **A8** switch allows measuring active and reactive power flows using the **P1** meter and voltages using the **P3** unit voltmeter at the end of the **A3** power line model without a circuit reassembling.

Equipment list

Schematic symbol	**Type**	**Photo**	**Name**	**Parameters**
G1	201.2		Three-phase power supply	400 V ~; 16 A
A1,A2	347.1		Three-phase transformer bank	3 x 80 V A; 242, 235, 230, 126, 220, 133, 127 V/
A3	313.2		Power transmission line model	400 V ~; 3 x 0.5 A
A5	306.1		Active load	220/380 V; 50 Hz 3x50 W;
A6	324.2		Inductive load	220/380 V; 50 Hz 3x40 VAr
A7	317.2		Capacitive load	220/380 V; 50 Hz 3x40 VAr
A16	349		Power meter switch	5 positions
P2	507.2		Power meter	15; 60; 150; 300; 600 V,0.05;0.1; 0.2; 0.5 A.
P3	508.2		Multimeter unit	3 multimeters 0..1000 V~; 0...10 A-; 0...20 MOhm

Task

1. For shown asymmetric phase loads, calculate the capacitor banks capacitance for the phase voltages balancing.

2. To assemble the circuit on the stand, to take readings of devices with specified loads with / without capacitor banks. Select the capacitance values for phase voltage balancing and check with the calculated capacitance values.

3. Analyze the data.

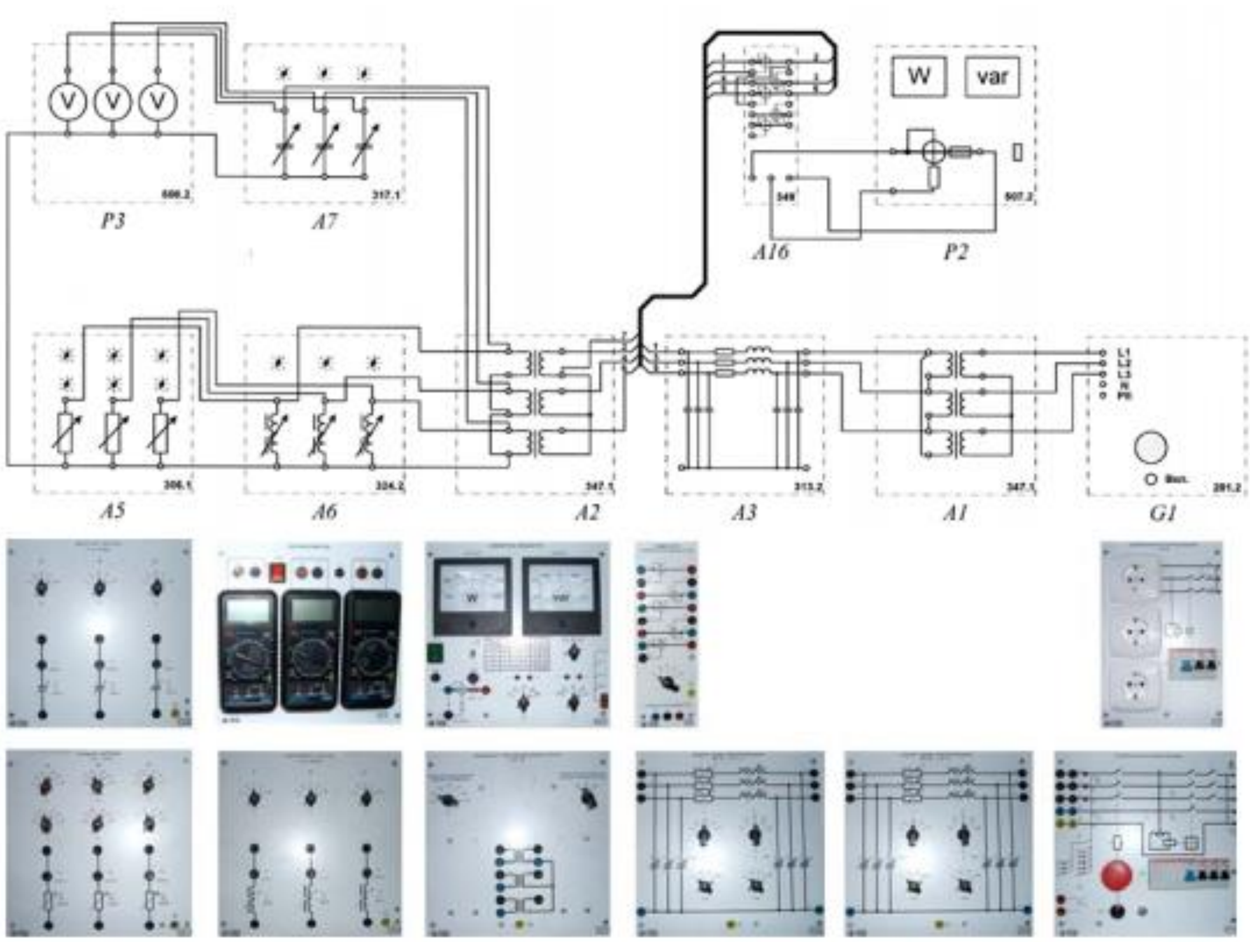


Fig. 5. Scheme for voltage balancing using a capacitor bank

Experiment procedure

1. Make sure that the devices used in the experiment are disconnected from the power supply.
2. Connect the safety-ground jacks of the devices used in the experiment to the "**PE**" jack of the **G1** source.
3. Connect power-demanding units to a single-phase three-wire 220 V laboratory network by power cords.
4. Connect the equipment in accordance with the connection diagram.
5. Using switch set the required voltage value of the **A1** and **A2** transformer group secondary windings, *for example 220 V.*
6. Using switches set desired parameters of the **A3** transmission lines model, *for example, R = 100 Ω and L = 1.2 GH.*
7. Using switches set the desired **A5** load **1, 2,** and **3** phase parameters, *for example, 80, 100 and 100%.*
8. Using switches set the desired **A6** load **1, 2** and **3** phase parameters, *for example, 25, 25 and 25%.*
9. Using switches set the desired **A7** load **1, 2** and **3** phase parameters, *for example, 50, 50 and 50%.*
10. Turn on the "**NETWORK**" switches of the **P2** power meter and the **P3** multimeter unit.
11. Turn on the **G1** power supply. Glowing lights should signal the presence of voltages at its output.
12. By changing the **A16** switch position from **1** to **2** via the **P2** meter determine the active and reactive power flow values, as well as the voltage at the beginning and end of the **A3** transmission line.
13. By changing the **A7** capacitive load switches position, make the power system voltage balancing. (*In this example, an acceptable degree of voltage balancing is achieved when the 1,2 and 3 phases capacities of the A7capacitive load are 0.0 and 50%, respectively*).
14. At the end of the experiment, disconnect the **G1** source and "**NETWORK**" switches of the **P2** power meter and the **P3** multimeter unit.

Test questions

1. What is the method for voltage balancing using capacitor banks?
2. What types of capacitor banks are used for phase voltage balancing?
3. Preferred use areas of the method for balancing voltages using capacitor banks.
4. Automatic balancing systems.

Laboratory work No. 2. Counter voltage regulation

Objective:

➢ Study the counter voltage regulation method.

➢ Check the counter voltage regulation method on the model.

Brief work description

➢ Source **G1** simulates supply network system, connected, e.g., to buses 6-10 kV main substation.

➢ Transformer group **A1** simulates step-down transformer of substation 6-10 / 0.4 kV.

➢ Models of the power lines **A3**, **A4** imitate the power lines 6-10 and 0.4 kV in pursuant to distribution network.

➢ Loads **A5** and **A6** simulate resistive and inductive loads of 0.4 kV network.

➢ Switch **A8** allows measuring active and reactive power flows using the **P1** meter and voltages using the **P3** unit voltmeter in intended positions in the electrical network.

Equipment list

Designation	Name	Type
G1	Three-phase power supply	201.2
A1	Three-phase transformer group	347.1
A3, A4	Power line model	313.2
A5	Active load	306.1
A6	Inductive load	324.2
A16	Power meter switch	349
P2	Power meter	507.2
P3	Multimeters unit	508.2

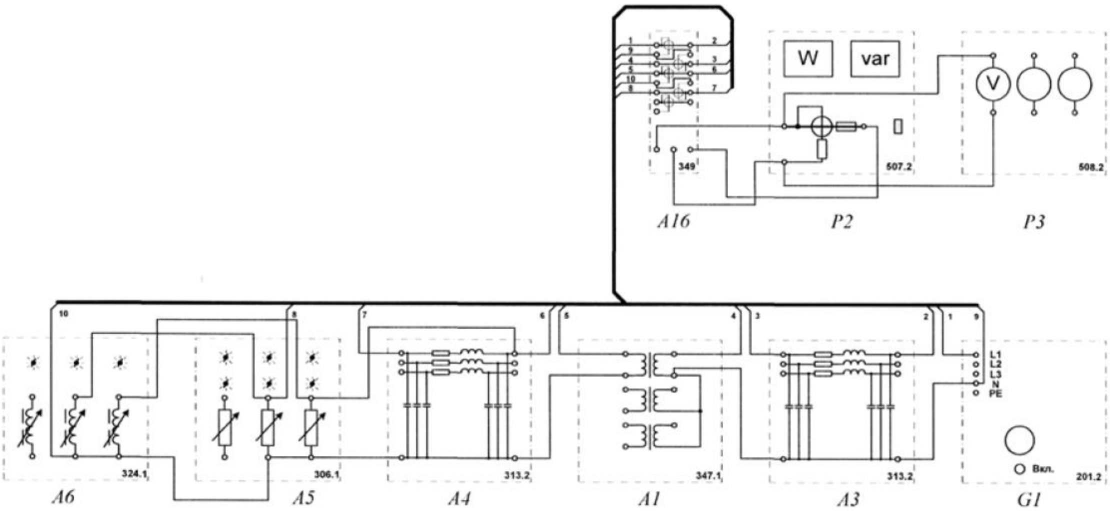


Fig. 6. Scheme for counter voltage regulation

Task

1. Build the scheme (fig. 6) on a stand, take the readings for various parameters of elements.

2. Analyze the obtained results.

Experiment procedure

1. Make sure that the devices used in the experiment are disconnected from electrical network.

2. Connect the protection earth socket devices used in experiment with socket "PE" of source **G1**.

3. Connect the units that require power with single-phase three-wire laboratory network 220 V by the powerline cord.

4. Connect devices in accordance with the electrical wiring scheme.

5. Set up desired voltage value of the secondary windings of transformers group **A1** by the switch, e.g. 220 V.

6. Set up the desired parameters of the models the **A3**, **A4** power lines, e.g., R = 0 and L = 0,3 H and loads **A5**, **A6**, e.g., 30, 25% respectively.

7. Turn on the "NETWORK" switches of the **P2** power meter and the **P3** multimeter unit.

8. Turn on the power supply **G1**. The level of voltage on its output will be signalized by glowing light bulb.

9. By changing the position of switch **A16** from 1 to 4, using meter **P2** determine the active and reactive power, and voltage at the beginning and end of the power lines **A3** and **A4**.

10. By changing the position of the three-phase transformer group **A1** change the transformation ratio or the used transformer, thereby realize counterload voltage control method.

11. At the end of the experiment, disconnect the **G1** source and "NETWORK" switches of the **P2** power meter and the **P3** multimeter unit.

Control questions

1. What is the counter voltage regulation method?
2. At what points is the voltage level controlled?
3. Why does the dead zone occur?
4. How does the automatic control system work?

Laboratory work No. 3. Voltage regulation by the longitudinal compensation using a capacitor bank

Objective:

➢ Study the method of voltage regulation by the longitudinal compensation using capacitor banks.

➢ Check voltage regulating operation by the longitudinal compensation using capacitor banks on the model.

Brief work description

➢ Source **G1** simulates supply network system, connected, e.g., to buses 6-10 kV main substation.

➢ Transformer group **A1** simulates step-down transformer of substation 6-10 / 0.4 kV.

➢ Models of the power line **A3** imitate the power line 0.4 kV of distribution network.

➢ Loads **A5** and **A6** simulate resistive and inductive loads of 0.4 kV network.

➢ The capacitive series compensation device **A17** simulates series capacitor bank.

➢ Switch **A8** allows measuring active and reactive power flows using the **P1** meter and voltages using the **P3** unit voltmeter in intended positions in the electrical network.

Equipment List

Designation	**Name**	**Type**
G1	Three-phase power supply	201.2
A1	Three-phase transformer group	347.1
A3	Power line model	313.2
A5	Active load	306.1
A6	Inductive load	324.2
A16	Power meter switch	349
A17	Series capacitor bank	315.2
P2	Power meter	507.2
P3	Multimeters unit	508.2

Task

1. Build the scheme (fig. 7) on a stand, take the readings for various parameters of elements.

2. Analyze the obtained results.

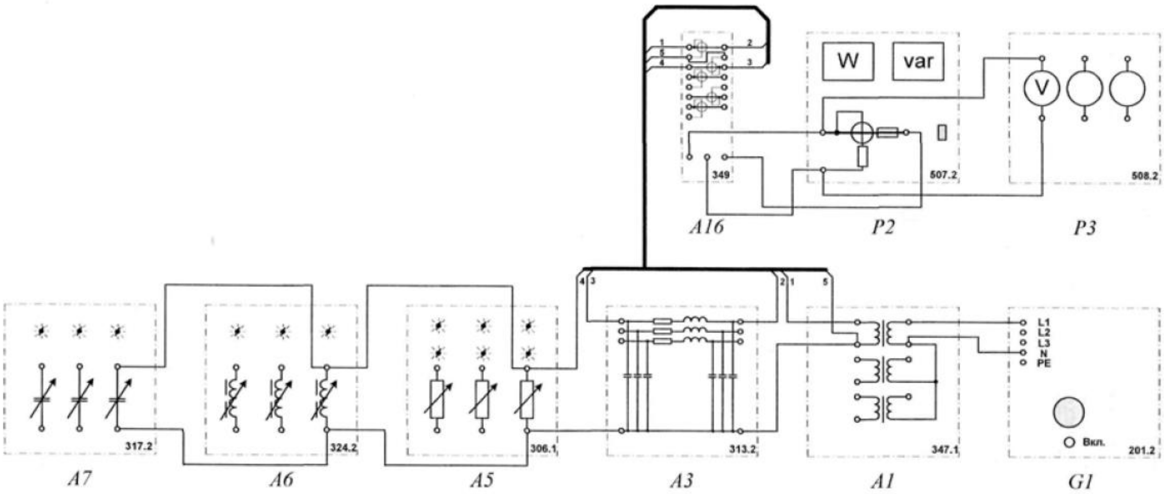


Fig. 7. Scheme for the longitudinal compensation using a capacitor bank

Experiment procedure

1. Make sure that the devices used in the experiment are disconnected from electrical network.

2. Connect the protection earth socket devices used in experiment with socket "PE" of source **G1**.

3. Connect the units that require power with single-phase three-wire laboratory network 220 V by the powerline cord.

4. Connect devices in accordance with the electrical wiring scheme.

5. Set up desired voltage value of the secondary windings of transformers group **A1** by the switch, e.g. 220 V.

6. Set up the desired parameters of the models the **A3** power line, e.g., R = 50 Ohm and L = 0,3 H and loads **A5**, **A6**, **A7**, e.g., 50, 75 and 25 % respectively.

7. Turn on the "NETWORK" switches of the **P2** power meter and the **P3** multimeter unit.

8. Turn on the power supply **G1**. The level of voltage on its output will be signalized by glowing light bulb.

9. By changing the position of switch **A16** from 1 to 4, using meter **P2** determine the active and reactive power, and voltage at the beginning and end of the power line **A3**.

10. By changing the capacitance of the **A17** (source **G1** should be turned off) perform voltage regulation by method of series capacitor bank.

11. At the end of the experiment, disconnect the **G1** source and "NETWORK" switches of the **P2** power meter and the **P3** multimeter unit.

Control questions

1. What is the method of voltage regulation by the longitudinal compensation using capacitor banks?

2. How do the capacitor banks connect with each other in voltage regulation by the longitudinal compensation method?

3. Name the areas of a preferred application of voltage regulation by the transverse and the longitudinal compensation methods with capacitor bank.

Laboratory work No. 4. Higher harmonic currents compensation by harmonic filter

Objective:

➢ Study the method of higher harmonic currents compensation using a harmonic filter.

➢ Check the method on the model.

Brief work description

➢ Source **G1** simulates supply network system, connected, e.g., to buses 6-10 kV substation 6-10 / 0.4 kV.

➢ Transformer group **A1** simulates step-down transformer of substation 35-220 / 6-10 kV.

➢ Transformer group **A2** simulates step-down transformer of substation 6-10 / 0.4 kV.

➢ Model of the power line **A3** imitates the power line 6-10 kV of distribution network.

➢ Model of the power line **A4** imitates the power line 0.4 kV of distribution network.

➢ Diode unit A6 simulates six-pulse rectifier.

➢ Load A5 simulates the load of 0.4 kV network.

➢ Load A7 simulates the capacitor bank.

➢ Meter **P1** allows measuring power quality indexes and parameters at a predetermined reference point of three-phase distribution network model.

Equipment List

Designation	Name	Type
G1	Three-phase power supply	201.2
A1, A2	Three-phase transformer group	347.1
A3, A4	Power line model	313.2
A5	Active load	306.1
A6	Diode unit	332
A7	Capacitive load	317.2
A9…A11	Current transformer	403.1
A15…A17	Harmonic filters	392
P1	Quality power meter	525

Task

1. Build the scheme (fig. 8) on a stand, take the readings for various parameters of elements.

2. Analyze the obtained results.

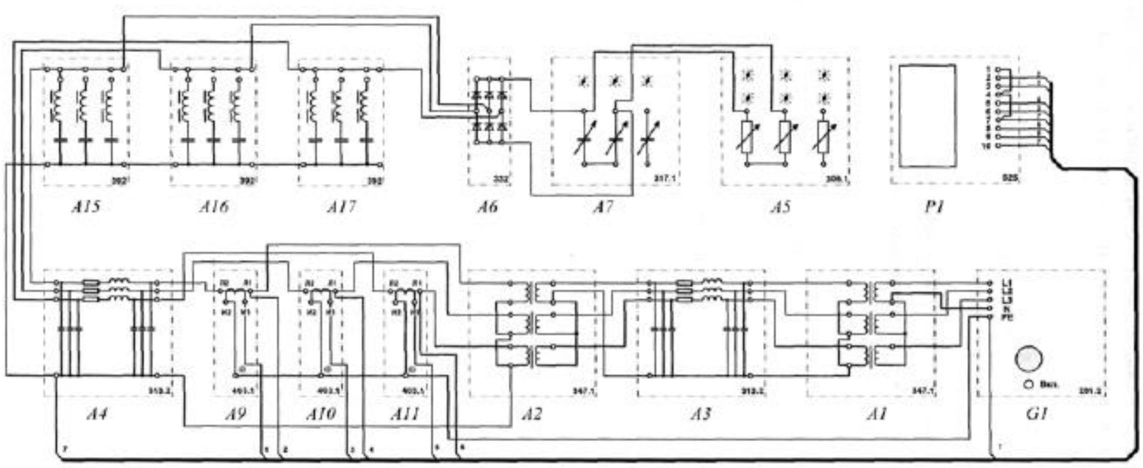


Fig. 8. Scheme for higher harmonic currents compensation using a filter device

Experiment procedure

1. Make sure that the devices used in the experiment are disconnected from electrical network.

2. Connect the protection earth socket devices, used in experiment, with socket "PE" of source **G1**.

3. Connect the units that require power with single-phase three-wire laboratory network 220 V by the powerline cord.

4. Connect devices in accordance with the electrical wiring scheme (Variant 1).

5. Set up desired voltage value of the secondary windings of transformers groups **A1** and **A2** by the switch, e.g. 220 V.

6. Set up the desired parameters of the models the A3, A4 power lines, e.g., R = 0 Ohm and L = 1,2 H.

7. Set up the desired load phase parameters for the phase **1, 2** on load **A5**, e.g., 100 and 100%.

8. Set up desired load phase parameters for the phase **1, 2** on load **A7**, e.g., 50 and 50%.

9. Turn on the power supply **G1**. The level of voltage on its output will be signalized by glowing light bulb.

10. Alternately connecting the branches of harmonic filters measure parameters of the network mode and power quality indexes and parameters by the meter **P1**.

11. At the end of the experiment turn off the power supply **G1**.

Control questions

1. What methods of higher harmonic currents compensation using harmonic filters do you know?

2. How do active filters, harmonics filters and balancing filters work?

3. Operation principle of fast static reactive power sources.

METERS OF POWER QUALITY

<table>
<tr><th colspan="2">Multifunctional electrical testers АКИП-8401, АКИП-8402 АКИП™</th></tr>
<tr>
<td></td>
<td>
➢ Combined instruments for measuring parameters of electrical networks and monitoring electrical safety standards of equipment

➢ Continuity checking and measuring PE and neutral wires (current > 200 mA)

➢ Measurement RCD parameters (AC, A - total and selective type): tripping time, interrupted current, touch potential, total ground circuit resistance without tripping RCDs (current 15 mA)

➢ Total circuit resistance measurement of circuit "P-P", "P-N" and loop "P-G", the calculation of the expected short-circuit current (Up to 41.5 kA)

➢ Measurement of insulation resistance up to 2 GOhm (50 V,100 V, 250 V, 500 V, 1000 V)

➢ “Automeasure” function (total ground circuit resistance + RCD test + measurement of insulation resistance)

➢ Determination of the correct connection and phase sequence (readout)

➢ surface-leakage current measurement

➢ measurement in single-phase networks: AC current and voltage (TRMS), active / reactive / total power, power factor, current and voltage harmonics (optional for АКИП-8402)

➢ The measurement of environmental parameters: temperature, humidity, illuminance,
</td>
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</table>

	sound/ noise level **(optional for АКИП-8402)** ➢ Internal memory (500 tests) ➢ LCD display, battery-powered, auto power off, help menu ➢ Optical USB interface (optional: Software Analysis + cable) ➢ Version with double-insulated meter body (Class 2)

Analyzer – recorder of power quality with flicker measurement function REN-700	
	Digital analyzer-recorder REN-700 is designed for registration with transmitting the measurement data to the computer power quality indexes and parameters (in accordance with GOST 13109-97) Flicker – subjective human perception of fluctuations of the luminous flux artificial light sources caused by voltage fluctuations in the electrical main supplying these sources.

Recorder of power quality indexes "ПАРМА РК 3.02"	
	The instrument is designed to measure and record power quality indexes according to GOST 13109 in electrical networks of power supply three-phase and single-phase AC current systems of general purpose. ПАРМА РК 3.02 allow organize monitoring PQI in distribution networks in the region, area, large industrial facilities.

Recorder of power quality indexes "ПАРМА РК 3.01"	
	The instrument is designed to measure and record power quality indexes according to GOST 13109 in electrical networks of power supply three-phase and single-phase AC current systems of general purpose.

Portable standard meter, power quality analyzer, comparator and a recorder in one device Энергомонитор 3.3	
	Measurement and registration of the power quality indexes; meter verification;energy audit of enterprises

<table>
<tr><td colspan="2">Electricity analyzer AR.5</td></tr>
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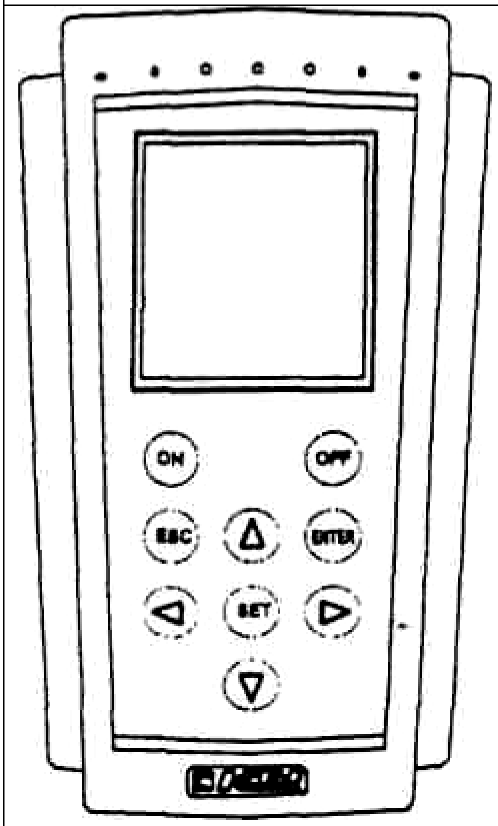

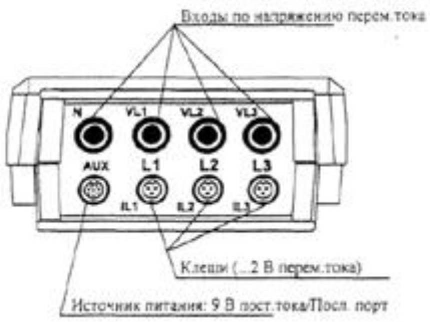

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AR5 series analyzers are programmable instruments that measure, calculate and collect in the memory the main parameters of the three-phase electrical networks.

Measurement by three inputs for AC voltage and three alternating current inputs (through clamp meter ... 12 V AC), which provide a simultaneous analysis of the voltage, current, and active power for three phases, and frequencies in power mains.

Calculations implemented through the built processor, which calculates the remaining electrical parameters, such as power factor, inductive or the capacitive power of three phases, the active and reactive (inductive and capacitive) power.

Collecting data on the internal memory (256 KB or1 MB in accordance with the model) for further loading to the computer. The measured and calculated data periodically stored in a memory in defined by user time interval (from 1 second to 4 hours)
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