UDC 621.311

O.G. Gryb, D.A. Gapon, T.S. Ierusalimova, D.V. Borodin, A.V. Diachenko

# MONITORING OF ELECTRICAL ENERGY QUALITY ON THE TRACTION SUBSTATION INPUT

***For the implementation of measures to maintain the quality of the energy industrial enterprises have to spend a significant material and monetary assets. In this regard, significant is the feasibility study of the allocation of such funds and, primarily, the determination of the economic damage arising from low quality of electricity. The reliability of the electricity metering system, relay protection and automation of modern digital substations depends on the quality of electrical energy. At the present time to improve the reliability of the substation operation it is necessary to monitor indicators of quality of electric energy, allowing you to take organizational and technical solutions for their improvement. Monitoring the power quality at the input traction substation has shown that indicators such as the coefficient of the n-th harmonic component of the voltage does not meet the standards GOST 13109-97. The source of higher harmonics is a voltage Converter used on the locomotive. To eliminate higher harmonics in the supply network for traction substations will need to install power filters. Today, the USB-analyzer of power quality «Digital system for the measurement of electrical energy quality» type of DSMEEQ of accuracy class 0.2. Work energy requires reliable and quality electricity supply to consumers. The new model of balancing energy market are bilateral contracts. The main task of this market, it ensure the stable and reliable operation of the unified energy system of Ukraine, that is, transmission and supply of electricity of appropriate quality.*** References 4, tables 1, figures 10.
*Key words:* **quality, higher harmonics, electrical energy, substation, monitoring, losses.**

***Надежность работы системы учета электроэнергии, релейной защиты и автоматики на современных цифровых подстанциях зависит от качества электрической энергии. В настоящее время для повышения надежности работы подстанции необходимо контролировать показатели качества электрической энергии, что позволяет принимать организационные и технические решения по его повышению.*** Библ. 4, табл. 1, рис. 10.
*Ключевые слова:* **качество, высшие гармоники, электрическая энергия, подстанция, мониторинг, потери.**

**Introduction.** In the process of the scientific and technological progress, novel technologies creation, increase of the energetic security of Ukraine the reliable and qualitative delivery of electrical energy to customers plays an important role. A new model of the electrical energy market which represents a market of bilateral contracts and a balancing market is introduced in Ukraine. One of tasks of the new market model is to create a market operating to guarantee stable and reliable operation of the consolidated power system of Ukraine, transmission and delivery of electrical energy of appropriate quality [1].

**Problem definition.** To carry out measures to hold the electrical energy quality, industrial enterprises are forced to spend huge material and financial means. Therefore, technical and economical assessment of such expenses is important, first of all to determine economical losses arising as a result of low electrical energy quality.

In conditions of the market economy, a network enterprise and a customer are equal partners, subjects of the indivisible process of the distribution and demand of electrical energy [2]. Change of the attitude of power supply companies as well as of customers to problems of electrical energy quality is determined, first of all, by losses sustained by the enterprise and the power network proper as a result of utilization of electrical energy of low quality. Losses which can arise as a result of low electrical energy quality should be divided into material, labor, financial, temporal, and special ones.

Material losses become apparent in unforeseen additional losses or direct ones of equipment, property, production, low materials, or energy. In industry material losses are directly connected with loss of fixed and circulating capital.

Labor losses represent working time losses caused by unforeseen circumstances. At the direct measurement labor losses are expressed in man-hours, man-days or just in hours of the working time. Translation of labor losses to cost or money equivalent is carried out by multiplication of man-hours by cost (price) of one hour.

Financial losses are direct money loss connected with unforeseen payments, penalties, additional taxes, losses of money and securities. Besides, financial losses can be resulted when they receive less or do not receive money from foreseen sources, by failure to return the debt, when purchaser does not pay for production supplied, by the decrease of receipts as a result of the decrease of prices for production and services.

Time losses exist when the process of the economical activity proceeds slowly than it was planned. Direct assessment of such losses is carried out in hours, days, weeks, months of delay in obtaining the result scheduled. To translate the time losses estimation to the cost quality it is necessary to determine in which losses of income and profit the time losses can result [2].

Losses because of 1 hour of downtime resulted by voltage deviations are the following:

- airlines booking centers – USD 67,000 – 112,000;
- commodity exchange – USD Mio 5.6 – 7.3;
- a network of automates and services – USD 12,000-17,000;
- credit card sale – USD Mio 2,2 – 3,1;
- voltage undershoot at the paper mill stops the production for 1 day, losses are USD 250,000;
- cycling production interruption in the glass industry costs USD 200,000.

When de-energization takes place enterprises loss:

- USD 1477 during 1 s of de-energization;
- USD 2107 during 3 min of de-energization;
- USD 7795 during 1h of de-energization.

By the data of more than 200 large commercial and industrial customers at the de-energization during 4 h without preliminary notification, average loss in the USA is about USD 75,000. During 1 h without notification – USD 40,000. During 1 h with notification – USD 23,000. Loss by the voltage drop of 10-20% is estimated as USD 7,500, loss of sudden outage during 2 s – USD 11,000..

**Materials of investigations.** Main integral indicator of the electrical energy quality is suitability calculated on the base of the measured values of the electrical energy quality indicators determined by the Standard GOST 13109-97: suitability of each electrical energy quality indicator is calculated as a ratio of numbers of measurements situating in normally permitted by GOST 13109-97 bounds, and total numbers of measurements for the period under review. If the value of the electrical energy quality indicator corresponds to GOST 13109-97, the value of the suitability is equal or more than 0.95: if not – less than 0.95. The suitability by the indicator which has passed out the maximum allowable values is supposed to equal zero and does not correspond the requirements of GOST 13109-97. The electrical energy quality is characterized by the following properties:

- voltage deviation;
- voltage oscillations;
- voltage undershoot;
- temporal overvoltage;
- voltage non-sinusoidality;
- non-symmetry of three-phase voltage system;
- frequency error;
- pulsed voltage.

In the correspondence with [1] the electrical energy quality indicator correspond these properties:

- steady-state voltage deviation $\delta U_y$;
- voltage swing $\delta U_t$;
- flicker doze $P_t$;
- distortion coefficient of the voltage curve sinusoidality $K_U$;
- coefficient of the $n$-th voltage harmonic component $K_{U(n)}$;
- coefficient of the voltage non-symmetry by the reverse sequence $K_{2U}$;
- coefficient of the voltage non-symmetry by the zero sequence $K_{0U}$;
- frequency error $\Delta f$;
- duration of the voltage undershoot $\Delta t_{п}$;
- pulsed voltage $U_{имп}$;
- coefficient of the temporal overvoltage $K_{перU}$.

Currently, an analyzer of the electrical energy quality «Digital system for the measurement of electrical energy quality» (DSMEEQ) of the accuracy class 0.2 is developed (see Fig. 1) [3, 4].

Experimental investigations of the electrical energy quality are carried out at the substation 330/110 kV from which a traction substation of mainline electrical transport by the line 110 kV is supplied (Fig. 2-4).


Fig. 1. Digital system for the measurement of electrical energy quality (DSMEEQ)

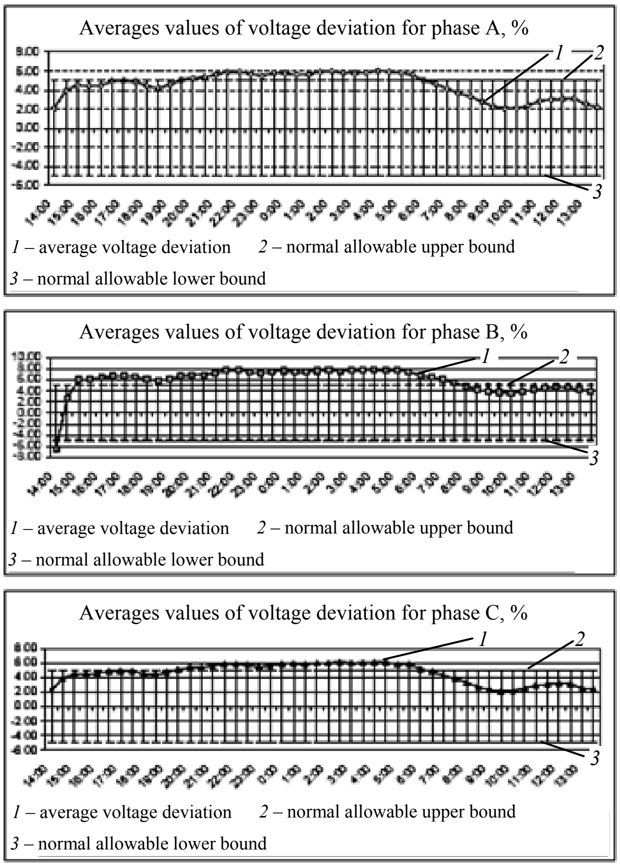


Fig. 2. Steady-state voltage deviation for phases A, B, C

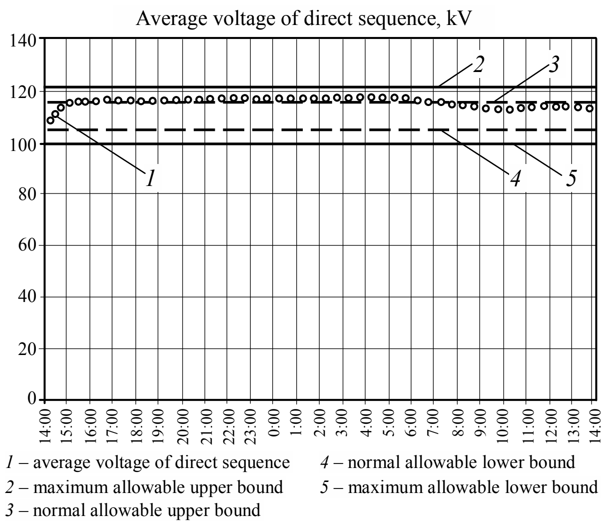


Fig. 3. Average voltage of direct sequence

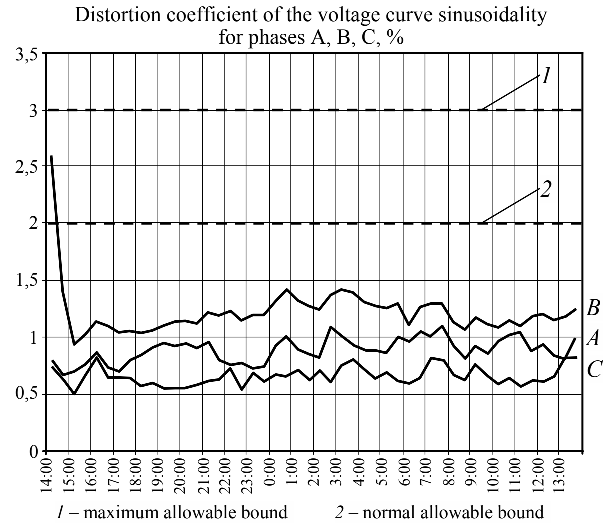


Fig. 4. Distortion coefficient of the voltage curve sinusoidality for phases A, B, C

In Fig. 5-10 graphic charts and test record sheets for coefficients of the *n*-th harmonic voltage component in phases A, B, C at the traction substation 330/110 kV of the line 110 kV are presented. Measurements are carried out at the bound of the balance belonging of the supplier and customer of electrical energy.

| *n* | Coeff. $K_{U(n)}$, % |
|---|---|
| 2 | 0.021 |
| 3 | 0.685 |
| 4 | 0.017 |
| 5 | 0.318 |
| 6 | 0.008 |
| 7 | 0.349 |
| 8 | 0.007 |
| 9 | 0.172 |
| 10 | 0.005 |
| 11 | 0.083 |
| 12 | 0.002 |
| 13 | 0.046 |
| 14 | 0.002 |
| 15 | 0.026 |
| 16 | 0.002 |
| 17 | 0.055 |
| 18 | 0.001 |
| 19 | 0.028 |
| 20 | 0.001 |
| 21 | 0.019 |
| 22 | 0.001 |
| 23 | 0.014 |
| 24 | 0.001 |
| 25 | 0.025 |
| 26 | 0.002 |
| 27 | 0.017 |
| 28 | 0.001 |
| 29 | 0.019 |
| 30 | 0.001 |
| 31 | 0.023 |
| 32 | 0.001 |
| 33 | 0.014 |
| 34 | 0.001 |
| 35 | 0.009 |
| 36 | 0.001 |
| 37 | 0.011 |
| 38 | 0.001 |
| 39 | 0.014 |
| 40 | 0.001 |

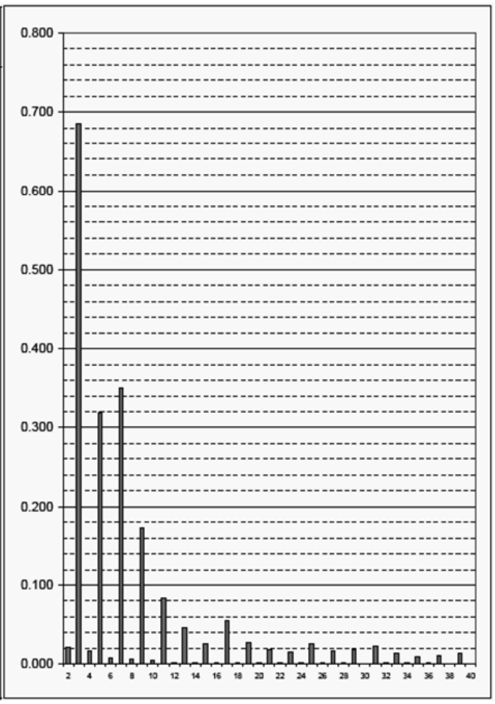


Fig. 5. Graphic chart for the *n*-th harmonic voltage component in the phase A

From the total record sheet for coefficients of the *n*-th harmonic voltage component in the phase A at the traction substation 330/110 kV of the line 110 kV in the phase A during 24 hours it is shown that the coefficient of the *n*-th harmonic voltage component corresponds the normative by GOST 13109-97(see Fig. 5, 6).

From the total record sheet for coefficients of the *n*-th harmonic voltage component in the phase B at the traction substation 330/110 kV of the line 110 kV in the phase B during 24 hours it is shown that the coefficient of

| No. of harmonic | Allowable values | | No. of measure-ments | No. of passes out | | Availability |
|---|---|---|---|---|---|---|
| | normal % | maximum % | | normal allowable values | maximum allowable values | |
| 2 | 0.50 | 0.75 | 28 799 | 0 | 0 | 1.000 |
| 3 | 1.50 | 2.25 | 28 799 | 0 | 0 | 1.000 |
| 4 | 0.30 | 0.45 | 28 799 | 0 | 0 | 1.000 |
| 5 | 1.50 | 2.25 | 28 799 | 0 | 0 | 1.000 |
| 6 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 7 | 1.00 | 1.50 | 28 799 | 0 | 0 | 1.000 |
| 8 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 9 | 0.40 | 0.60 | 28 799 | 107 | 0 | 0.996 |
| 10 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 11 | 1.00 | 1.50 | 28 799 | 0 | 0 | 1.000 |
| 12 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 13 | 0.70 | 1.05 | 28 799 | 0 | 0 | 1.000 |
| 14 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 15 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 16 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 17 | 0.50 | 0.75 | 28 799 | 0 | 0 | 1.000 |
| 18 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 19 | 0.40 | 0.60 | 28 799 | 0 | 0 | 1.000 |
| 20 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 21 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 22 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 23 | 0.40 | 0.60 | 28 799 | 0 | 0 | 1.000 |
| 24 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 25 | 0.40 | 0.60 | 28 799 | 0 | 0 | 1.000 |
| 26 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 27 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 28 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 29 | 0.37 | 0.56 | 28 799 | 0 | 0 | 1.000 |
| 30 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 31 | 0.36 | 0.54 | 28 799 | 0 | 0 | 1.000 |
| 32 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 33 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 34 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 35 | 0.34 | 0.51 | 28 799 | 0 | 0 | 1.000 |
| 36 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 37 | 0.33 | 0.50 | 28 799 | 0 | 0 | 1.000 |
| 38 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 39 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 40 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |

Fig. 6. Test record sheet for coefficients of the *n*-th harmonic voltage component in the phase A

the *n*-th harmonic voltage component does not correspond the normative by GOST 13109-97(see Fig. 7, 8). Let us analyze harmonics presented in the phase B.

| *n* | Coeff. $K_{U(n)}$, % |
|---|---|
| 2 | 0.025 |
| 3 | 1.032 |
| 4 | 0.018 |
| 5 | 0.449 |
| 6 | 0.010 |
| 7 | 0.297 |
| 8 | 0.005 |
| 9 | 0.106 |
| 10 | 0.005 |
| 11 | 0.102 |
| 12 | 0.004 |
| 13 | 0.047 |
| 14 | 0.003 |
| 15 | 0.024 |
| 16 | 0.002 |
| 17 | 0.042 |
| 18 | 0.001 |
| 19 | 0.018 |
| 20 | 0.001 |
| 21 | 0.014 |
| 22 | 0.001 |
| 23 | 0.012 |
| 24 | 0.003 |
| 25 | 0.025 |
| 26 | 0.002 |
| 27 | 0.010 |
| 28 | 0.001 |
| 29 | 0.014 |
| 30 | 0.001 |
| 31 | 0.014 |
| 32 | 0.001 |
| 33 | 0.012 |
| 34 | 0.002 |
| 35 | 0.012 |
| 36 | 0.001 |
| 37 | 0.011 |
| 38 | 0.002 |
| 39 | 0.007 |
| 40 | 0.001 |

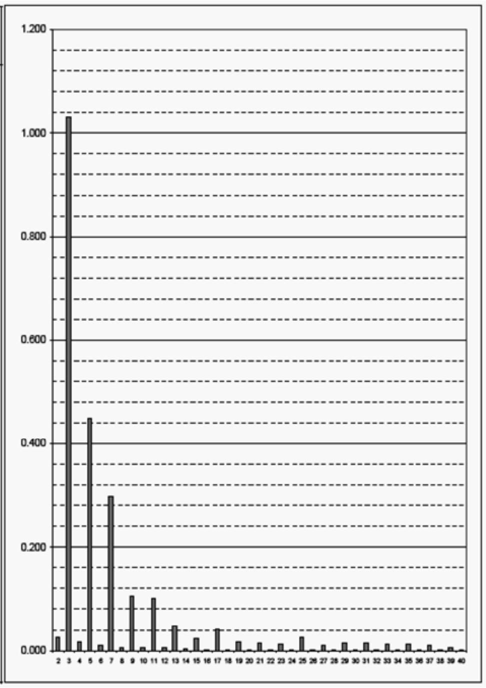


Fig. 7. Graphic chart for the *n*-th harmonic voltage component in the phase B

In this phase even and odd harmonics which passed out the maximum allowable values (*mav*) are presented:

Harmonics 2 – *mav* (0.75) – 3.11; 3.12; 3.21; 3.34.

Harmonics 6 – *mav* (0.30) – 0.36; 0.35.

Harmonics 10 – *mav* (0.30) – 0.34; 0.33; 0.32.

Harmonics 3 – *mav* (2.25) – 8.59;8.61; 8.63; 10.03.

| No. of harmonic | Allowable values | | No. of measure-ments | No. of passes out | | Availability |
|---|---|---|---|---|---|---|
| | normal % | maximum % | | normal allowable values | maximum allowable values | |
| 2 | 0.50 | 0.75 | 28 799 | 0 | 100 | 0.000 |
| 3 | 1.50 | 2.25 | 28 799 | 8 | 99 | 0.000 |
| 4 | 0.30 | 0.45 | 28 799 | 0 | 0 | 1.000 |
| 5 | 1.50 | 2.25 | 28 799 | 0 | 99 | 0.000 |
| 6 | 0.20 | 0.30 | 28 799 | 0 | 99 | 0.000 |
| 7 | 1.00 | 1.50 | 28 799 | 0 | 99 | 0.000 |
| 8 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 9 | 0.40 | 0.60 | 28 799 | 0 | 99 | 0.000 |
| 10 | 0.20 | 0.30 | 28 799 | 15 | 84 | 0.000 |
| 11 | 1.00 | 1.50 | 28 799 | 0 | 99 | 0.000 |
| 12 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 13 | 0.70 | 1.05 | 28 799 | 0 | 99 | 0.000 |
| 14 | 0.20 | 0.30 | 28 799 | 99 | 0 | 0.997 |
| 15 | 0.20 | 0.30 | 28 799 | 0 | 99 | 0.000 |
| 16 | 0.20 | 0.30 | 28 799 | 99 | 0 | 0.997 |
| 17 | 0.50 | 0.75 | 28 799 | 0 | 99 | 0.000 |
| 18 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 19 | 0.40 | 0.60 | 28 799 | 0 | 99 | 0.000 |
| 20 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 21 | 0.20 | 0.30 | 28 799 | 0 | 99 | 0.000 |
| 22 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 23 | 0.40 | 0.60 | 28 799 | 13 | 0 | 1.000 |
| 24 | 0.20 | 0.30 | 28 799 | 90 | 0 | 0.997 |
| 25 | 0.40 | 0.60 | 28 799 | 0 | 0 | 1.000 |
| 26 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 27 | 0.20 | 0.30 | 28 799 | 93 | 0 | 0.997 |
| 28 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 29 | 0.37 | 0.56 | 28 799 | 0 | 0 | 1.000 |
| 30 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 31 | 0.36 | 0.54 | 28 799 | 0 | 0 | 1.000 |
| 32 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 33 | 0.20 | 0.30 | 28 799 | 44 | 0 | 0.998 |
| 34 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 35 | 0.34 | 0.51 | 28 799 | 0 | 0 | 1.000 |
| 36 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 37 | 0.33 | 0.50 | 28 799 | 0 | 0 | 1.000 |
| 38 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 39 | 0.20 | 0.30 | 28 799 | 3 | 0 | 1.000 |
| 40 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |

Fig. 8. Test record sheet for coefficients of the *n*-th harmonic voltage component in the phase B

Harmonics 5 – *mav* (2.25) – 2.65; 2.59; 2.56; 2.54.
Harmonics 7 – *mav* (1.50) – 3.10; 3.08; 3.15.
Harmonics 9 – *mav* (0.60) – 2.34; 2.36; 2.35; 2.48.
Harmonics 11 – *mav* (1.50) – 1.93; 1.91; 1.88; 1.89.
Harmonics 13 – *mav* (1.05) – 1.47; 1.46; 1.44; 1.43.
Harmonics 15 – *mav* (0,30) –1.29; 1.28; 1.30; 1.35.
Harmonics 17 – *mav* (0.75) – 0.93; 0.92; 0.97.
Harmonics 19 – *mav* (0.60) – 0.73; 0.72; 0.70.
Harmonics 21 – *mav* (0.30) – 0.53; 0.52; 0.51.
Harmonics 23 – *mav* (0.40) – 0.40; 0.41; 0.42.

| *n* | Coeff. $K_{U(n)}$, % |
|---|---|
| 2 | 0.013 |
| 3 | 0.427 |
| 4 | 0.019 |
| 5 | 0.295 |
| 6 | 0.008 |
| 7 | 0.282 |
| 8 | 0.006 |
| 9 | 0.146 |
| 10 | 0.005 |
| 11 | 0.099 |
| 12 | 0.003 |
| 13 | 0.048 |
| 14 | 0.003 |
| 15 | 0.038 |
| 16 | 0.002 |
| 17 | 0.047 |
| 18 | 0.002 |
| 19 | 0.031 |
| 20 | 0.001 |
| 21 | 0.013 |
| 22 | 0.002 |
| 23 | 0.025 |
| 24 | 0.001 |
| 25 | 0.023 |
| 26 | 0.004 |
| 27 | 0.025 |
| 28 | 0.001 |
| 29 | 0.013 |
| 30 | 0.001 |
| 31 | 0.027 |
| 32 | 0.001 |
| 33 | 0.020 |
| 34 | 0.001 |
| 35 | 0.012 |
| 36 | 0.001 |
| 37 | 0.014 |
| 38 | 0.001 |
| 39 | 0.017 |
| 40 | 0.001 |

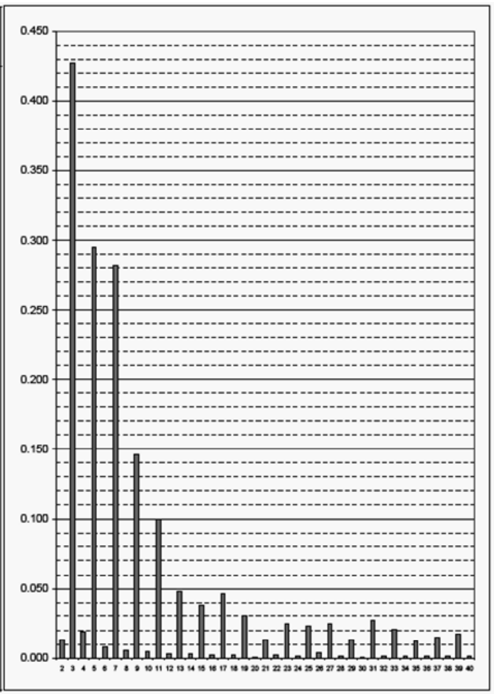


Fig. 9. Graphic chart for the *n*-th harmonic voltage component in the phase C

Besides, even and odd harmonics which passed out the normal allowable values (*nav*):

Harmonics 14 – *nav* (0.20) – 0.26; 0.25; 0.23.
Harmonics 16 – *nav* (0.20) – 0.24; 0.23; 0.25.
Harmonics 24 – *nav* (0.20) – 0.20; 0.21.
Harmonics 27 – *nav* (0.20) – 0.21; 0.22; 0.23.
Harmonics 33 – *nav* (0.20) – 0.22; 0.21
Harmonics 39 – *nav* (0.20) – 0.21; 0.20.

| No. of harmonic | Allowable values | | No. of measure-ments | No. of passes out | | Availability |
|---|---|---|---|---|---|---|
| | normal % | maximum % | | normal allowable values | maximum allowable values | |
| 2 | 0.50 | 0.75 | 28 799 | 0 | 0 | 1.000 |
| 3 | 1.50 | 2.25 | 28 799 | 0 | 0 | 1.000 |
| 4 | 0.30 | 0.45 | 28 799 | 0 | 0 | 1.000 |
| 5 | 1.50 | 2.25 | 28 799 | 0 | 0 | 1.000 |
| 6 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 7 | 1.00 | 1.50 | 28 799 | 0 | 0 | 1.000 |
| 8 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 9 | 0.40 | 0.60 | 28 799 | 38 | 9 | 0.000 |
| 10 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 11 | 1.00 | 1.50 | 28 799 | 0 | 0 | 1.000 |
| 12 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 13 | 0.70 | 1.05 | 28 799 | 0 | 0 | 1.000 |
| 14 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 15 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 16 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 17 | 0.50 | 0.75 | 28 799 | 0 | 0 | 1.000 |
| 18 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 19 | 0.40 | 0.60 | 28 799 | 0 | 0 | 1.000 |
| 20 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 21 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 22 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 23 | 0.40 | 0.60 | 28 799 | 0 | 0 | 1.000 |
| 24 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 25 | 0.40 | 0.60 | 28 799 | 0 | 0 | 1.000 |
| 26 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 27 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 28 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 29 | 0.37 | 0.56 | 28 799 | 0 | 0 | 1.000 |
| 30 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 31 | 0.36 | 0.54 | 28 799 | 0 | 0 | 1.000 |
| 32 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 33 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 34 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 35 | 0.34 | 0.51 | 28 799 | 0 | 0 | 1.000 |
| 36 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 37 | 0.33 | 0.50 | 28 799 | 0 | 0 | 1.000 |
| 38 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 39 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |
| 40 | 0.20 | 0.30 | 28 799 | 0 | 0 | 1.000 |

Fig. 10. Test record sheet for coefficients of the *n*-th harmonic voltage component in the phase C

From the total record sheet for coefficients of the *n*-th harmonic voltage component in the phase C at the traction substation 330/110 kV of the line 110 kV in the phase C during 24 hours it is shown that the coefficient of the *n*-th harmonic voltage component does not correspond the normative by GOST 13109-97(see Fig. 9, 10). Let us analyze harmonics presented in the phase C.

In this phase there is odd harmonic which passes out the normal allowable value: the 9-th harmonic – (0.40) – in the range 0.42; 0.45; 0.46; 0.43; 0.49.

In Table 1 the generalized results of measurements of the *n*-th harmonic voltage component C at the traction substation 330/110 kV on the feeder of the line 110 kV are presented.

**Conclusions.**

1. Operation of power engineering at modern conditions requires reliable and qualitative electrical energy supply to customers. The main new model of the balancing power energy market is bilateral contracts. The main task of this market is to guarantee stable and reliable operation of the consolidated power system of Ukraine, i.e. transmission and supply of electrical energy of appropriate quality.
2. The carried out monitoring of the electrical energy quality on the traction substation input is shown that such an indicator as the coefficient of the *n*-th voltage

harmonic component does not correspond the normative by GOST 13109-97. The source of higher harmonics is a voltage changer used in the electric locomotive. To remove higher harmonics in the supply main it is necessary to install power filters at the traction substation.

Table 1

| Traction substation 330/110 kV on the feeder of the line 110 kV | | | |
|---|---|---|---|
| № | No. of harmonic | No. of passes out the normal allowable values | No. of passes out the maximum allowable values |
| 1 | 2 | 0 | 100 |
| 2 | 3 | 8 | 99 |
| 3 | 5 | 0 | 99 |
| 4 | 6 | 0 | 99 |
| 5 | 7 | 0 | 99 |
| 6 | 9 | 145 | 108 |
| 7 | 10 | 15 | 84 |
| 8 | 11 | 0 | 99 |
| 9 | 13 | 0 | 99 |
| 10 | 14 | 99 | 0 |
| 11 | 15 | 0 | 99 |
| 12 | 16 | 99 | 0 |
| 13 | 17 | 0 | 99 |
| 14 | 19 | 0 | 99 |
| 15 | 21 | 0 | 99 |
| 16 | 23 | 13 | 0 |
| 17 | 24 | 90 | 0 |
| 18 | 27 | 93 | 0 |
| 19 | 33 | 44 | 0 |
| 20 | 39 | 3 | 0 |

REFERENCES

**1.** *GOST 13109-97. Elektricheskaya energiya. Sovmestimost' tehnicheskih sredstv elektromagnitnaya. Normy kachestva elektricheskoi energii v sistemah elektrosnabzheniya obschego naznacheniya* [State Standard 13109-97. Electrical energy. Technical equipment electromagnetic compatibility. Quality standards for electrical energy in general use power systems]. Minsk, IPK Publishing house of standards, 1998. 30 p. (Rus).

**2.** *Kachestvo elektricheskoy energii. Tom 1. Ekonomiko-pravovaya baza kachestva elektricheskoy energii v Ukraine i Evrosoyuze. Pod redaktsiei Griba O.G.* [The quality of electric power. Vol.1. Economic and legal framework of quality of electric energy in Ukraine and the EU. Edited by Gryb O.G.]. Kharkiv, Monograph PP Graf-X, Publ., 2014. 300 p. (Rus).

**3.** *Kachestvo elektricheskoy energii. Tom 2. Kontrol kachestva elektricheskoy energii. Pod redaktsiei Griba O.G.* [The quality of electric power. Vol.2. Monitoring of power quality. Edited by Gryb O.G.]. Kharkiv, Monograph PP Graf-X, Publ., 2014. 244 p. (Rus).

**4.** Gryb O.G, Prahovnik A.V., Tesik Y.F., Zharkin A.F., Novskiy V.O., Kalinchik V.P., Karasinskiy O.L., Dovgalyuk O.M., Lazurenko O.P., Hodakivskiy A.M., Vasilchenko V.I., Svetelik O.D. *Avtomatyzovani systemy obliku ta yakosti elektrychnoyi enerhiyi* [The automated systems of the account and quality of electric energy. Edited by Gryb O.G.]. Kharkiv, Ranok-NT Publ., 2012. 516 p. (Ukr).

*Received 16.10.2015*

*Gryb O.G.*[1], *Gapon D.A.*[1], *Ierusalimova T.S.*[1], *Borodin D.V.*[2], *Diachenko A.V.*[1]

[1] National Technical University «Kharkiv Polytechnic Institute», 21, Frunze Str., Kharkiv, 61002, Ukraine.
phone +38 057 7076551, e-mail: Ierusalimovat@mail.ru

[2] O.M. Beketov National University of Urban Economy in Kharkiv, 12, Revolution Str., Kharkiv, 61002, Ukraine.