Electric Power Quality Indicators in a Company Producing Power Electronics

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***Abstract* — The paper presents a study of the quality of electrical energy in the power supply system of a power electronics production company. An analysis and comparison of the obtained results for each of the measured indicators for electricity quality with the respective normative documents is made.**

Keywords— quality of electrical energy, power electronics

I. Introduction

In recent years, more and more attention has been paid to the quality of electrical energy. Power supply with high-quality electrical energy reduces power consumption and energy losses. This requires extensive research and analysis at each stage of the use of electrical energy in order to reduce the factors influencing its quality and maintaining its characteristics within certain limits. [1, 2, 3].

The increased requirements for the quality of electrical energy are also related to the development of equipment and technologies. Today, more and more appliances and equipment are used that are sensitive to electrical interferences of electrical energy. Worsened quality of electrical energy can cause disturbances or damage to electrical appliances and equipment, which can have severe economic consequences or even become dangerous for people and service personnel.

The answer to the growing requirements for the quality of electrical energy should be searched for in finding an adequate assessment of the quality of electrical energy and subsequent effective control.

The paper presents a study of the quality of electricity in the power supply system of a power electronics production company. An analysis and comparison of the obtained results for each of the measured indicators for electricity quality with the respective normative documents is made [1, 2, 4].

II. Object of Survey

The company performs the installment of electronic components on printed circuit boards. The finished assemblies are assembled to finished products. The components used are of two types - conventional and for surface mounting.

The technological process is organized in several production centers. The first production center was built of lines for manual conventional assembly of electronic components ending in "wave soldering".

"Wave soldering" system consists of several blocks - main system, heaters, and heating pot. The predominant part of the units is heaters, due to which "Wave solder" is mainly an active load. The machine works in the interval from 3:00 to 22:30, provided by an automatic clock. There are no special requirements for the power supply network. The required operating voltages are provided by a step-down transformer.

The second technology center consists of two automated lines for mounting SMD components. The first line consists of a printer for solder paste, two machines for surface mounting, eight zone furnace convector types, and transport conveyors. The second line consists of a printer, a surface mounting machine, six-zone convector furnaces, and transport conveyors between them.

The solder paste printers start working at 6:00 am and end at 9:30 pm. The main electrical equipment of solder paste printers is a computer unit and actuators driven by stepper motors. They have no special requirements for the power supply network. The required operating voltages are provided by a step-down transformer.

The surface mounting machines start working at 6:00 and end at 22:30. The main electrical equipment of the machines is computer units and actuators driven by stepper motors. They have no special requirements for the power supply network. The required operating voltages are provided by a step-down transformer. In the event of an emergency power failure, the operation of the main computer is ensured by a built-in UPS.

The furnaces start operating at 6:00 and end at 22:30. The main electrical equipment of the machines consists of a control unit, a conveyor, and heating sections. The controller of the heating sections has an optimization program for smooth adjustment of the load when starting the machine. For the furnace's proper functioning, the voltage between each phase and the neutral must be within the limits. The required operating voltages are provided by a step-down transformer. The operation of the transport conveyor is ensured by a built-in UPS, ensuring the completion of the production process.

An electrical test of the manufactured units is performed at the next technological center. The center is equipped with two automated testers. The testers turn on at 6:00 am and finish work at 10:30 pm. Normal operation requires a working external vacuum - 67.7 kPa (0.677 bar) and flow - 0.85 m3 / min. The required operating voltages are provided by switching power supplies. For the correct operation of the test machine, each phase's frequency must be in the range of

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47-63 Hz. In the presence of larger deviations, the tester may be damaged.

The final assembly of the products is performed on five production conveyors ending with specialized testers simulating the real working conditions of the products. The testers consist of a battery pack, a motor-generator set, and a control console. The batteries are charged through chargers - a total of 40 in number. The chargers work continuously. For proper operation of the chargers, the frequency of the supply voltage should be in the range of 47-63 Hz.

The production process uses an ultrasonic welding press, a template cleaning machine, a screen printing machine, resin filling equipment, and a universal furnace. To ensure the quality of production, a tester is installed to check the ionic contamination of the printed circuit boards.

The template cleaning machine is switched on at 6:00 and switched off at 22:30, during which the detergent is heated and remains in "standby" mode. Its use during the working day depends on the needs. The required operating voltages are provided by a switching power supply. Voltage deviations can be in the range of 208 - 240 VAC.

The transfer of the production between the floors is done through an internal loading platform.

Air compressors and vacuum pumps are installed to carry out the normal production process. The air conditioning system of the enterprise company consists of a heat pump, 2 boilers, a central heat exchanger, and convector plates located in the working premises. The heat pump operates in two operating modes - cooling or heating. The boilers are used for additional heating in harsh winter conditions. The ventilation system consists of a central injection centrifugal fan supplying air to the production workshop. For special technological needs, 6 local suction centrifugal fans with explosion-proof motors have been installed. Ventilation in the room for storage of flammable materials is carried out with 2 centrifugal fans, which are mutually reserved.

The company for producing power electronic components is category III in terms of power supply security. The power supply is provided by a nearby transformer station 10kV/630kVA, with cable NA2XSY 3x1x50mm^2. The transformer station is equipped with one power transformer, the rated data for which, are given in Table I. Also, a power factor (cosφ) correction module with a rated power of 100 kVAr is installed on the low voltage side of the substation.

TABLE I. RATED DATA OF THE POWER TRANSFORMER

Type	Rated power, *kVA*	Primary voltage, *kV*	Secondary voltage, *kV*	Winding vector group	S.C. Impedance, %
TM	630	10 ± 1x2,5%	0,4/0,231	$\Delta/Y5$	6

Consumers' power supply is provided via a main electrical switchboard, placed in a special technical room located in the ground level part of the building. The power supply is accomplished by 2x2 cable lines NYY 3x185+95mm2.

The measurements were performed with a three-phase power quality analyzer QUALISTAR C.A 8332B, allowing for measurement, calculation, recording, and analysis of all electrical quantities and indicators of the quality of electrical energy, according to BDS EN 50160 [1]. Specialized software (Data Viewer Professional and QualiStar View V2) is used to process the information obtained from the measurements.

The measurement period is 7 days. The power supply network is three-phase, three-wire with isolated neutral. The measurements are performed in the main electrical switchboard of the busbar "Electric power supply to production hall". The production process starts at 6:00 and ends at 22:30.

III. DETERMINATION OF INDICATORS FOR THE QUALITY OF ELECTRICAL ENERGY

A. Supply voltage frequency

For the entire measurement period, the frequency of the supply voltage is almost constant with an average value of 50.00 Hz. The maximum value of the frequency is 50.07 Hz, and the minimum - 49.92 Hz. These values fully comply with the requirement of 50Hz ± 1% (49.5Hz to 50.5Hz) given in [1, 2].

B. Supply voltages

The minimum, average, and maximum values of the phase voltages (U_1, U_2, U_3) and line-to-line voltages (U_{12}, U_{23}, U_{13}), are given in Table II.

TABLE II. VALUES OF SUPPLY VOLTAGES

Quantity	Value		
	Minimum	**Average**	**Maximum**
U_1, V	225,1	230,8	236,1
U_2, V	226,4	232,0	237,4
U_3, V	226,4	232,1	237,4
U_{12}, V	390,4	400,4	409,8
U_{23}, V	392,2	401,9	411,4
U_{13}, V	391,3	401,3	410,4

The maximum deviations of the phase and line-to-line voltages are respectively:

- for U_1 (-2,1 %, +2,7%), for U_2 (-1,6%, +3,2%), for U_3 (-1,6%, +3,2%);
- for U_{12} (-2,4%, +2,5%), for U_{23} (-2,0%, +2,8%), for U_{13} (-2,2%, +2,6%).

Therefore, for the whole measurement period, the voltage deviations are in the permissible range of ± 10% of the rated phase voltage (230V) and the rated line-to-line voltage (400 V), regulated by BDS EN 50160 [1].

No overvoltages or rapid voltage sags of the supply voltage are observed. Also, there aren't any accidental power supply interruptions registered during the time of the measurement.

C. Currents

The changes of current in the three phases are represented in Fig.1, while Table III shows the minimum, average and maximum value of the current.

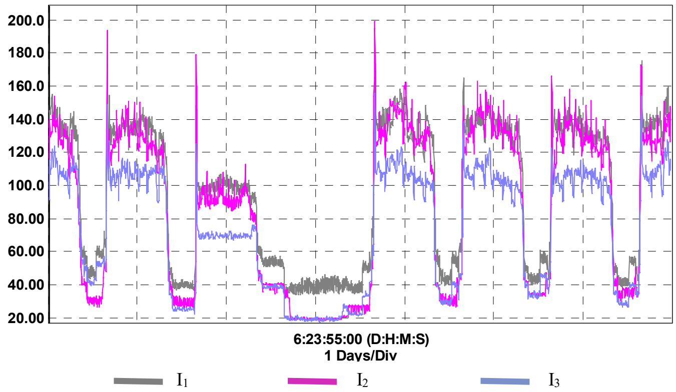

Fig. 1. RMS values of the phase currents.

TABLE III. VALUES OF SUPPLY VOLTAGES

Quantity	Value		
	Minimum	**Average**	**Minimum**
I_1, A	33,3	95,6	194,9
I_2, A	18,8	85,8	199,1
I_3, A	17,6	72,3	156,0

D. Rapid voltage changes and flicker

Rapid voltage changes are assessed by the value of the flicker and its severity. The measured values of the flicker for the three phases are shown in Fig.2. The maximum value reached by the flicker is 0.89, which is below the permissible value of 1 [1].

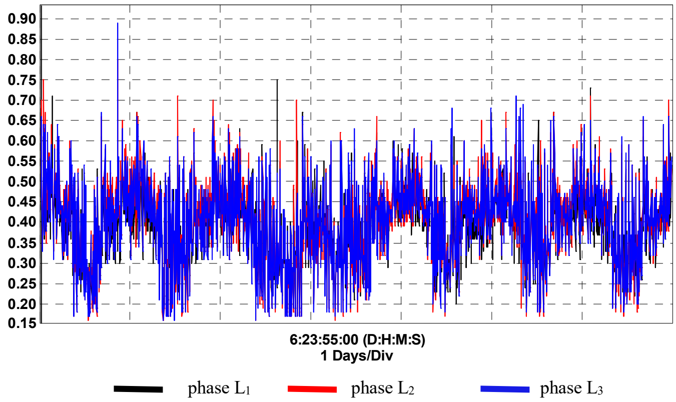

Fig. 2. Flicker

E. Harmonics of voltage and current

Fig. 3 and Fig. 4 show the total harmonic distortion, of the line-to-line and phase voltages respectively, in% of the rated voltage.

The largest measured values of the total harmonic distortion, both for the line-to-line voltages (for U_{12} - 4.3%, for U_{23} - 4.3%, and for U_{13} - 4.4%) and for the phase voltages (for U_1 - 4.5%, for U_2 - 4.2%, and for U_3 - 4.4%) meet the norms given in BDS EN 50160 [1], that regulates the magnitude of the total harmonic distortion of the supply voltage which should not exceed 8%.

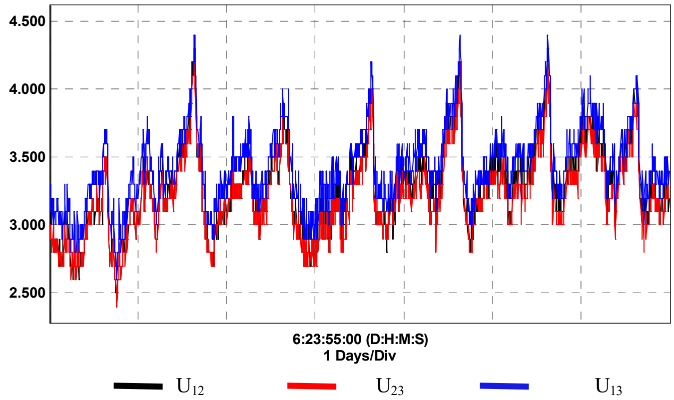

Fig. 3. Total harmonic distortion of line-to-line voltages

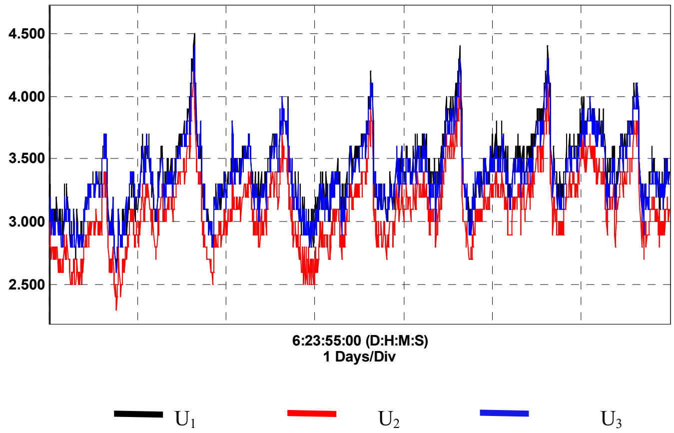

Fig. 4. Total harmonic distortion of phase voltages

The total harmonic distortion of the currents in the three phases is shown in Fig.5. The maximum measured values are respectively: 22.2% of the current in the first phase I1, 28.4% of the current in the second phase I2, and 16.1% of the current in the third phase I3. The value of the total harmonic current distortion in the second phase I2 is higher than the permissible value of 25% regulated in IEC 61000-3-4 [3, 4].

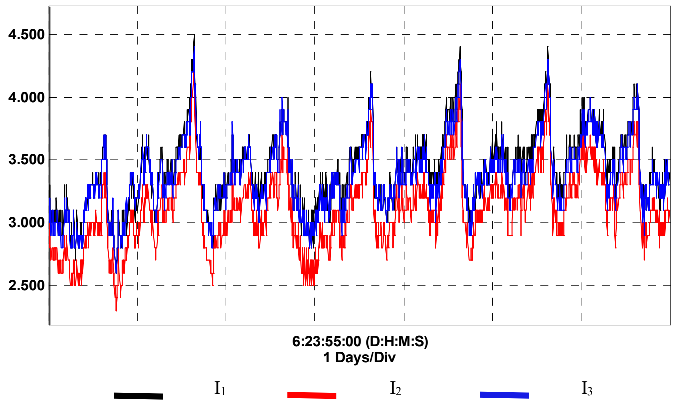

Fig. 5. Total harmonic distortion of currents

Table IV gives the maximum measured values of the supply voltage harmonics. Even voltage harmonics are not observed. The levels of the measured voltage harmonics are much lower than the permissible norms given in BDS EN 50160 [1].

TABLE IV. HARMONICS OF VOLTAGE

Harmonic number	Permissible value in IEC 61000-3-4, %	Maximum measured value, %		
		U_1	U_2	U_3
3	5	0,5	0,6	0,5
5	6	4,3	4,3	4,4
7	5	1	1	1
9	1,5	0	0,1	0,1
11	3,5	0,2	0,2	0,2
13	3	0,5	0,4	0,4
17	2	0,1	0,2	0,2
19	1,5	0,1	0,2	0

Table V shows the measured maximum values of current harmonics. Odd current harmonics up to 23 harmonics are observed, and all measured maximum values are above the permissible values given in IEC 61000-3-4 [3, 4]. Of the even harmonics, 18 current harmonics are observed, and its value is below the permissible of 0.6%.

TABLE V. HARMONICS OF CURRENT

Harmonic number	Permissible value in IEC 61000-3-4, %	Maximum measured value, %
3	21,6	23,7
7	7,2	9,7
9	3,8	6,2
15	0,7	3,2
16	0,5	0,6
17	1,2	2,2
18	0,6	0,5
19	1,1	2,7
21	0,6	1,2
23	0,9	1

F. Unbalance of voltage and current

The maximum value of the voltage unbalance is 0.6%, which is well below the permissible value of 2% in 100% of the measurement period. The maximum and average values of the current unbalance are 64% and 6.1%, respectively.

G. Power consuption

Table VI gives the minimum, average and maximum values of the measured active, reactive and full power for the measurement period.

The average value of the power factor for the operating time, in sinusoidal mode is 0.91, and in non-sinusoidal mode is 0.907.

The consumed active energy for the measurement period is 9,025 MWh, the reactive energy is 3,516 MVArh, and the total electricity is 9,848 MVAh.

TABLE VI. MEASURED POWERS

Quantity	Value		
	Minimum	Minimum	Minimum
P_1, kW	7,425	20,55	43,37
P_2, kW	4,047	18,45	44,7
P_3, kW	3,031	14,72	34,52
Q_1, kVAr	0,9886	7,102	12,61
Q_2, kVAr	1,116	6,462	12,33
Q_3, kVAr	1,836	7,365	12,4
S_1, kVA	7,732	22,01	44,62
S_2, kVA	4,35	19,85	45,78
S_3, kVA	4,086	16,76	35,97

IV. CONCLUSION

Most of the consumers, in the company under consideration, have switched-mode power supplies that have non-linear volt-ampere characteristics. This type of consumers are sources of electromagnetic energy of non-sinusoidal nature and are considered as sources of harmonics of current in the power supply system. Harmonics of current are not subject to mandatory norms, but their presence can lead to deterioration of the quality of electrical energy in the electric power supply system of the production plant. They may lead to disturbances in the communication and measuring circuits of the test equipment used.

The presence of current unbalance is also a major disadvantage, and it is advisable to pay attention to it. Improving the balance of the load-current will reduce the company's energy losses.

From the conducted measurements and analysis, it can be said that the electrical energy with the thus measured indicators of electrical energy quality meets the standards given in BDS EN 50160.

Based on the measurements and analysis made, the following recommendations can be made:

- Detailed measurements of the indicators for the quality of electrical energy of each consumer have to be made;
- The distribution of load current has to be optimized;
- Filters for compensation of harmonic distortions of current should be installed.

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