Estimation of the electrical energy quality indicators in the power supply system of an optical cable manufacturer

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***Abstract* - The report gives results of measuring and analyzing the quality indicators of electrical energy in the power supply system of an optical cable manufacturer. The purpose of the survey is to evaluate the quality indicators of electrical energy and to prove or disapprove the good quality of the electrical energy supplied to the company.**

***Keywords* – power supply system, electrical energy quality, supply voltage, harmonics.**

I. INTRODUCTION

A major task for electricity suppliers and their customers is to ensure supply with high-quality electrical energy. For customers, the economic impact of power supply interruptions may range from several hundreds of euros to millions of euros for repair or replacement of in-use electrical equipment, production losses of unprofitable or poor quality output, inconvenience to customers, etc.

With the introduction and widespread use of sensitive electronic equipment, the users of electrical energy have become much more sensitive to peaks, dips, voltage interruptions, and other anomalies. Used devices with a non-linear V-A characteristic generate current and voltage harmonics that can affect both the customer's equipment and the power supply system. It is no longer used only to provide power supply. As a result, there is an increase in end-user problems. In order to identify the source of these problems, different tools are used by customers and electricity companies to easily monitor, record and analyze electrical energy quality indicators. After analyzing the results obtained, various methods can be proposed to eliminate or limit the power supply problems.

Controlling the quality of electrical energy requires analyzing the structure, parameters and operating modes of the power supply system and conducting experimental measurement and testing [1]. The report gives results of measuring and analyzing the quality indicators of electrical energy in the low-voltage power supply system of an optical cable manufacturing company. The purpose of the survey is to evaluate the quality indicators of electrical energy and to prove or disapprove the good quality of the electrical energy supplied to the company.

II. MEASUREMENT POINT

The object of the study is the quality of the electrical energy in an optical cable manufacturing company. The distribution of the electrical energy is made by the Main Distribution Panel. It is divided into two fields, called "DIESEL" and "NORMAL". The measurement was conducted at low voltage terminal in Main Distribution Panel, field "DIESEL". The power supply is carried out at a low voltage of 0,4/0,23 kV with cables, and a diesel generator is used to provide a continuous power supply. The diesel unit switches on automatically when the external power supply fails. The "DIESEL" field supplies 100% of the lighting in the office part of the building, up to 30% of the lighting in the warehouses, the terminals for the supply of communication and alarm systems. The "NORMAL" field is not reserved and supplies mainly ventilation and air-conditioning equipment and all installations whose exclusion will not lead to disturbance of the production process.

From the main switchboard, "DIESEL" sections are fed into the floor panels. The installed power in the panel is 147,7 kW and the working current is 213,2 A.

A portable power quality analyzer according to EN 50160 [2] was used for the purpose of the measurement to detect and track potential defects and failures in the network. The meter complies with IEC 61000-4-30: "Power Quality Measurements" [3]. The device enables the recording of: phase and linear voltages, currents, active power, reactive power, total power, frequency of supply voltage, voltage deviation, harmonic components of the voltage and current, total harmonic distortion of voltage and current, voltage and current unbalance, rapid voltage changes, flicker, voltage sags and voltage interruptions.

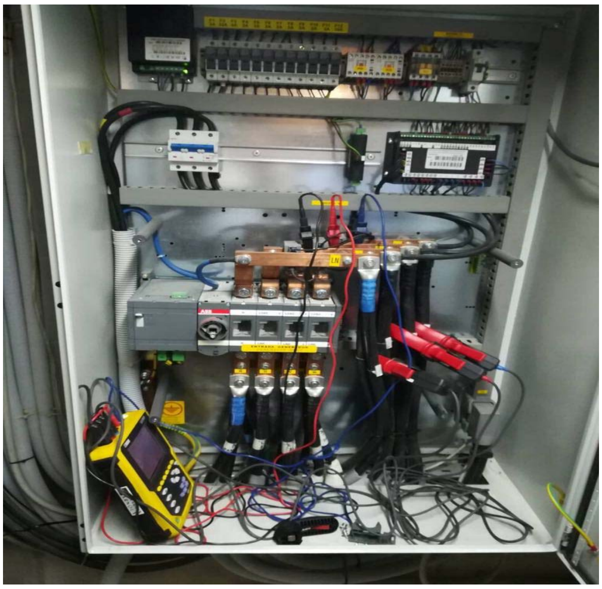

Fig. 1. Measurement in the Main Board

The meter's input is three-phase, directly to the supply voltage, via ampere clamps and voltage probes as it’s shown on Fig. 1.

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III. DETERMINATION OF THE ELECTRICAL ENERGY QUALITY INDICATORS

The measurement period is one week from 31.05.2018 to 07.06.2018, with an averaging period of 10 minutes. The estimation of the measurement takes into account the limit values of the electrical energy quality indicators according to [1, 2, 4]. For each 10-minute period, the minimum, mean and maximum values of the studied quantities are determined. For the time period, 1008 data were collected for each of the indicators. 721 of them being on a working day, as the company works on 3 shifts, morning, afternoon and regular in the hours of 6 to 23 hours and 287 at night from 23 to 6 hours. In this way, different modes of operation of the company are covered. The measurement information obtained is processed with specialized software.

A. Frequency

The frequency of the supply voltage over the measurement period is almost constant, with average value 50 Hz. The maximum frequency is 50.08 Hz and the minimum is 49.94 Hz. The maximum frequency deviation is +0,08 Hz (+0,16%). Therefore, in 100% of the measurements, the values of the frequency of the supply voltage fully correspond to the norm from 50Hz ± 1% (49,5Hz to 50,5Hz) range over the one week period given in [1, 2, 4].

B. Supply voltage

The rated voltage used for the back-up voltage is 230 V and 400 V. According to BDS EN 50160 under normal operating conditions, except for cases due to faults or voltage interruptions, 95% of the average values of the supply voltage for 10 minutes should be in the range $\pm 10\% U_H$ for each period of one week, i.e. in the range of 207 to 253 V and 360 to 440 V.

The minimum, average and maximum values of phase and line voltages are given in Table I. The maximum deviations of the phase voltages are: 4,70% for L1, 4,52% for L2 and 4,17% for L3. The maximum deviations of the line voltages respectively are: 4,15% for L12, 3,78% for L23 and 4,23% for L13.

TABLE I. VALUES OF THE VOLTAGES

Indicator	Phase	Value		
		Minimum	***Average***	***Maximum***
Phase voltage, V	L1	227,5	234,5	240,8
	L2	226,9	234,1	240,4
	L3	225,7	233,2	239,6
Line voltage, V	L12	393,7	405,9	416,6
	L23	391,2	404,0	415,1
	L13	393,0	405,8	416,9

The changes of the measured values of the phase voltages are shown on Fig. 2 and of the line voltages on Fig. 3.

Fig. 4 shows the histograms of the three phase voltages. The mean values of phase voltages at night are 238,7V for L1, 238,2V for L2 and 237,4V for L3 and during the day are 232,9V for L1, 232,5V for L2 and 231,5V for L3. The mean values of line voltages at night are 413,0V for L12, 411,3V for L23, and 413,1V for L13, and during the day are 403,1V for L12, 404,1V for L23, and 402,9V for L13.

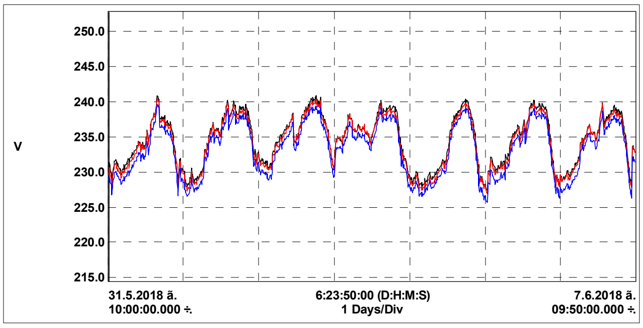

Fig. 2. Phase voltages
L1 – black; L2 – red; L3 - blue

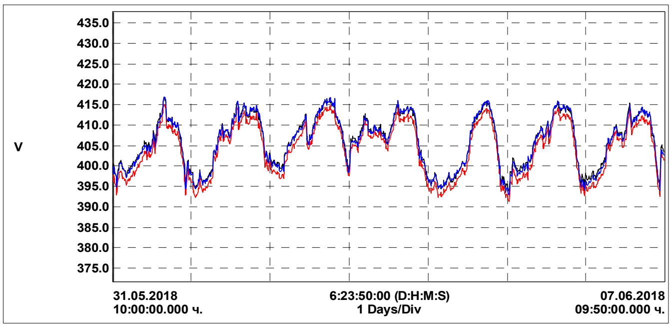

Fig. 3. Line voltages
L12 – black; L23 – red; L13 - blue

The histograms of the three line voltages are shown on Fig. 5.The standard deviation of the voltage at the night is less than during the day; with less dispersion. The standard deviations of the phase voltages are: at night 1,053V for L1, 1,025V for L2 and 1,063V for L3, during the day 2,890V for L1, 2,949V for L2 and 3,007V for L3. The standard deviations of the line voltages are: at night 1,785V for L12, 1,796V for L23, and 1,865V for L13, during the day 5,003V for L12, 5,202V for L23, and 5,120V for L13.

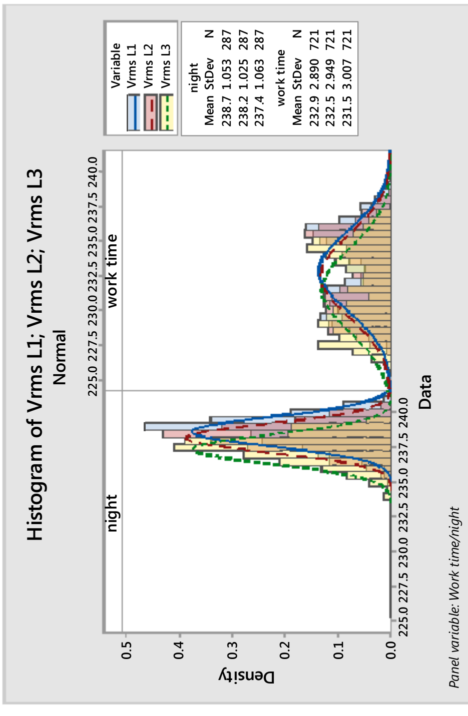

Fig. 4. Histogram of the phase voltages

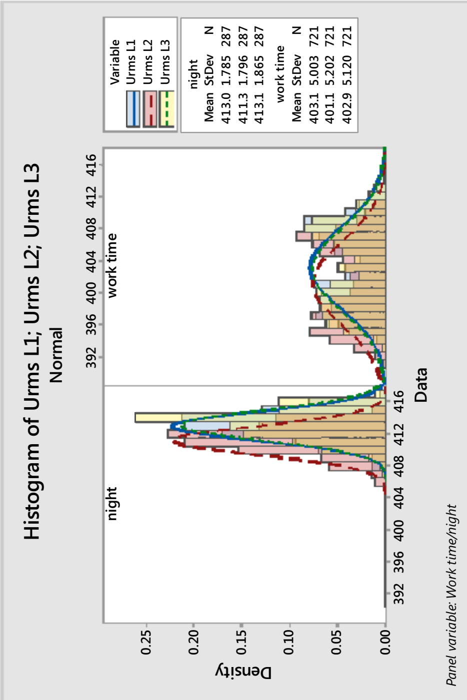

Fig. 5. Histogram of the line voltages

It can be seen that at night (non-working time), the three voltages are normally distributed and are offset to the right. The voltages are not normally distributed during the day (working time), with two distinct tips being noted. The analysis of the data shows that the two tips are related to the start and finish hours of regular shift, as well as the physiological breaks made during the day.

C. *Flicker*

Rapid voltage variations are estimated by the value of the flicker and its severity over a long time period.

Table II gives the minimum, average and maximum values of the flicker and Fig. 6 shows its variation over the measurement period.

TABLE II. VALUES OF THE FLICKER

Indicator	Phase	Value		
		Minimum	***Average***	***Maximum***
Flicker	L1	0,17	0,34	0,89
	L2	0,17	0,34	0,82
	L3	0,19	0,37	0,89

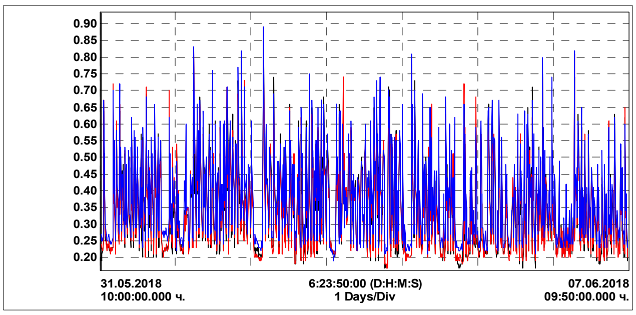

Fig. 6. Flicker
L1 – black; L2 – red; L3 - blue

According to BDS EN 50160, under normal operating conditions, rapid changes in voltage must be no greater than $5\% U_H$ or varied till $10\% U_H$, with a short duration occurring several times a day under certain conditions. The flicker must be $P_{lt} \le 1$ for 95% of a week period [1, 2, 4]. In this case, 100% of the flicker's measured values are below the admissible value of 1.

D. *Currents*

Fig. 7 shows the current variation in the three phases. The minimum, maximum and average values of the currents for the measurement period are given in Table III. The maximum load of phase L1 is 124,4A, phase L2 is 148,6A, and phase L3 is 107,2A.

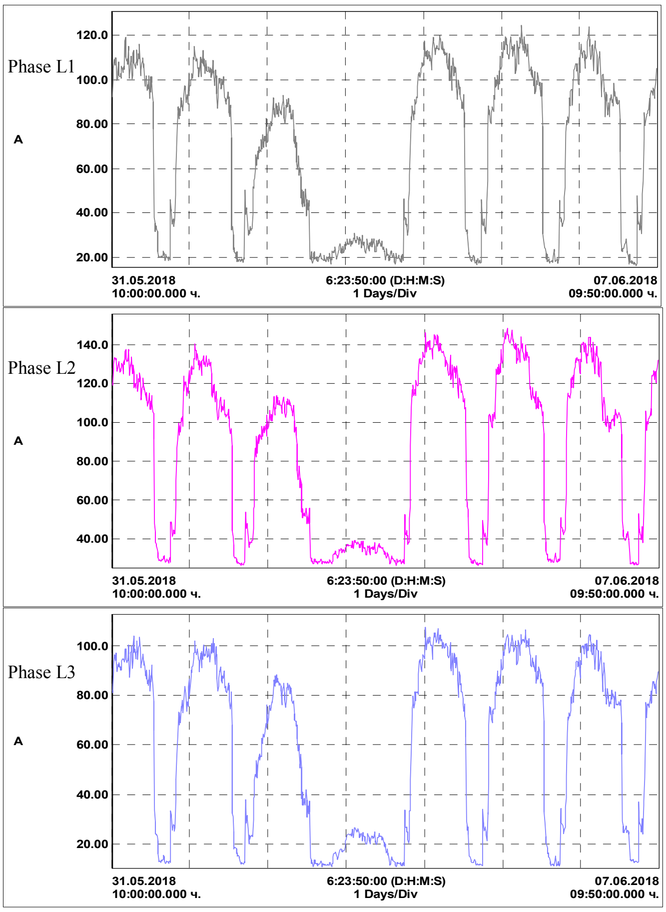

Fig. 7. Phase currents

TABLE III. VALUES OF THE CURRENT

Indicator	Phase	Value		
		Minimum	***Average***	***Maximum***
Current, A	L1	16,3	68,69	124,4
	L2	26,5	85,12	148,6
	L3	10,7	59,74	107,2

It can be seen that the load in the three phases is different. The most loaded is second phase with measured a maximum current value of 148,6A. The first phase current is 16,55% less than the current in the second phase. The third phase current is 27,9% less than the current in the second phase. The difference in current values is large, as a reason for this may be the distribution of single-phase loads between the phases. The second phase is much more loaded than the other two, which can lead to heating the power cable. The minimum currents are measured at night when the load is less, and on Sunday when there is no production. Maximum values are measured in the peak hours of production when the consumption is greatest.

Table IV shows the change in current (maximum, minimum and average) at night and on a non-working day (Sunday) when the company is not operating.

TABLE IV. VALUES OF THE CURRENT DURING THE NIGHT AND NON WORKING DAY

Indicator	**Phase**	**Value**		
		Minimum	***Average***	***Maximum***
Current during the night, A	L1	16,3	33,3	50,3
	L2	26,5	40,2	53,8
	L3	10,7	24,5	38,2
Current during the non working day, A	L1	16,8	24,0	31,2
	L2	27,1	33,0	38,9
	L3	10,9	18,9	26,8

E. Voltage and current unbalance

Under normal operating conditions for one week, 95% of the mean values over 10 minutes should be in the range of 0 to 2% [1, 2, 4]. A maximum value of the voltage unbalance of 0,4% and a minimum value of 0,1% are measured. Therefore, 100% of the measured voltage unbalance values are below the 2%.

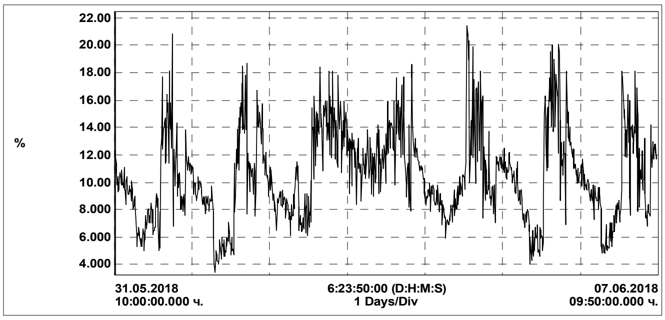

Fig. 8. Current unbalance

Fig. 8 shows the current unbalance for the measurement period. For most of the time, the current's asymmetry ranges from 6 to 16%. At certain times, very high values are recorded during the working day, but with little duration.

F. Harmonics of the voltage and current

The total harmonic distortion of the phase voltages is shown on Fig. 9. The measured maximum values are 4,9% for phase L1, 5,0% for phase L2 and 5,1% for phase L3 respectively. Therefore, in 100% of cases, the magnitude of the total harmonic distortion of the supply voltage does not exceed the allowed 8% rate for low voltage grids given in BDS EN 50160 [1, 2, 4].

Fig. 10 gives the histograms of the total harmonic distortion of the phase voltages for the three phases, respectively during the day (working time) and during the night (non-working time). The means of total harmonic distortion of phase voltages at night are 4,087% for L1, 4,049% for L2 and 4,179% for L3. The means of total harmonic distortion of phase voltages at the days are 2,581% for L1, 2,474% for L2 and 2,735% for L3. The standard deviation during the night is less than that during the day, with less dispersion. All three phases show a slight increase in the values of the voltage total harmonic distortion in the night.

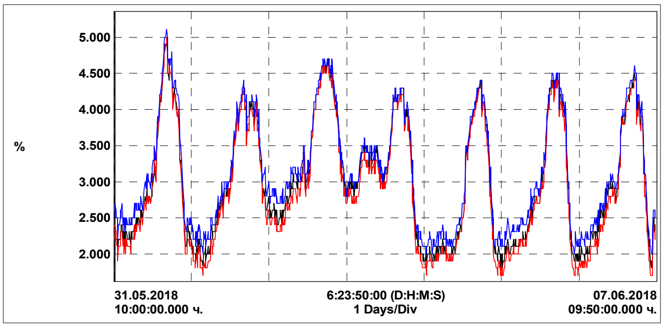

Fig. 9. Total harmonic distortion of the phase voltages
L1 – black; L2 – red; L3 - blue

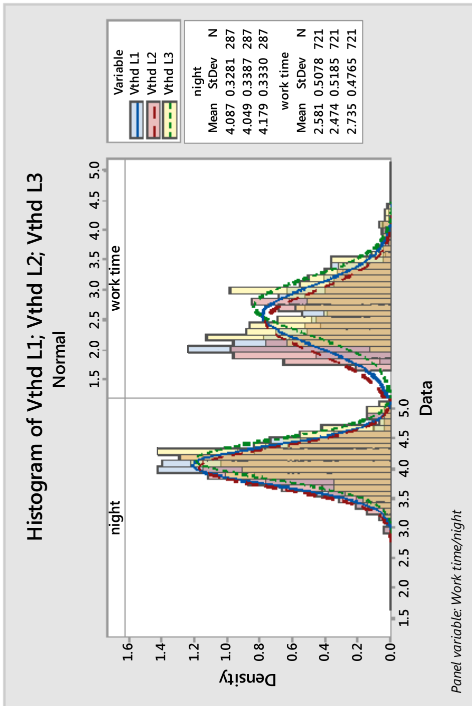

Fig. 10. Histograms of the total harmonic distortion of the phase voltages

Fig. 11 shows the total harmonic distortion of the phase currents, and in Table V the minimum, average and maximum values are given.

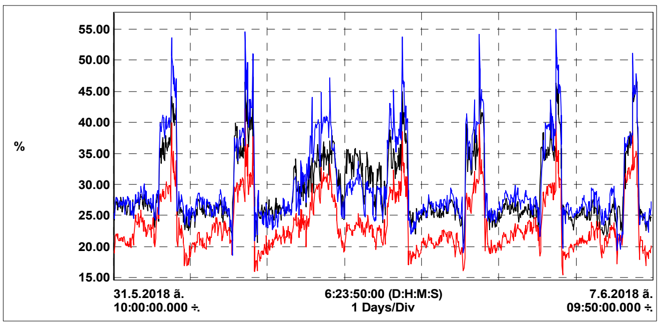

Fig. 11. Total harmonic distortion of the phase currents
L1 – black; L2 – red; L3 - blue

TABLE V. VALUES OF THE TOTAL HARMONIC DISTORSION OF THE PHASE CURRENTS

Indicator	Phase	Value		
		Minimum	*Average*	*Maximum*
THDI, %	L1	20,4	29,1	47,3
	L2	15,4	23,6	42,3
	L3	18,6	30,1	55,0

The maximum measured values are 47,3% for L1, 42,3% for L2 and 55,0% for L3 respectively. Over 80% of the total harmonic current distortion measured over a week is higher than the 25% allowance given in IEC 61000-3-4 [5] for low voltage grids.

Fig. 12 shows the histograms of the total harmonic distortion of the phase currents for the three phases respectively for working time and at night.

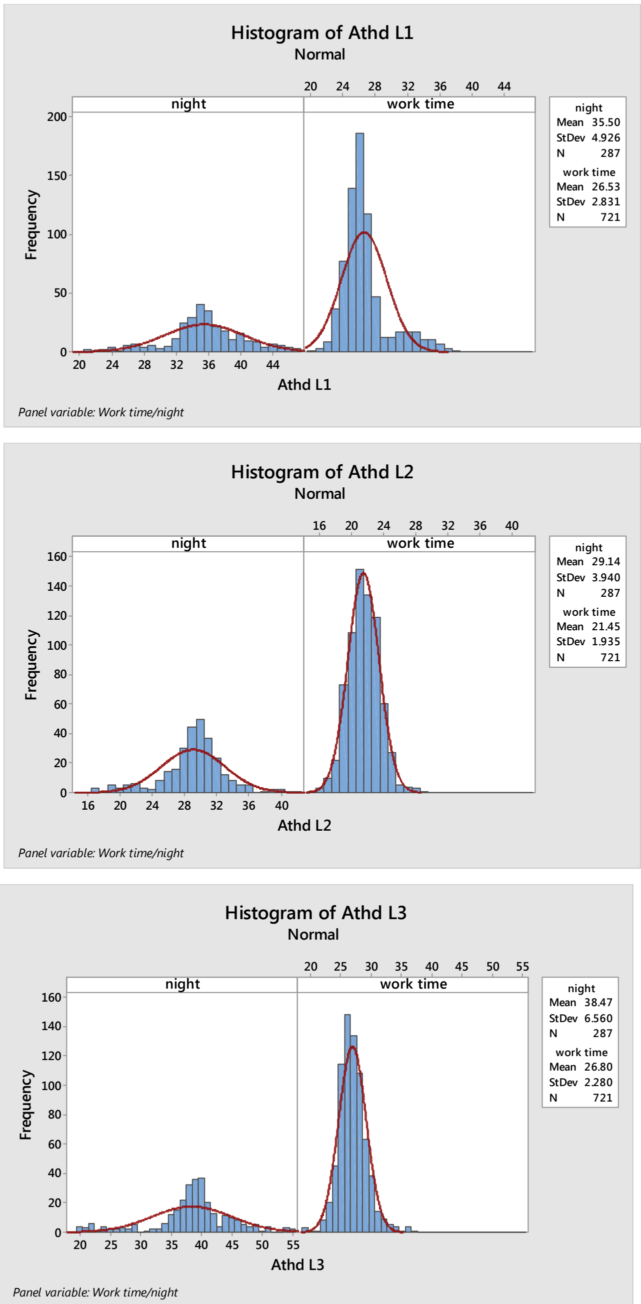

Fig. 12. Histograms of the total harmonic distortion of the phase currents

The total harmonic distortion of the phase currents has a normal distribution, with less dispersion during the working time, and the values of the total harmonic distortion are lower than those at night.

Table VI gives the maximum measured values of the voltage harmonics and their norms. We observe odd harmonics of 3 to 25 harmonic. The 5[th] and 7[th] harmonics are the highest, with a maximum values of 5,1% and 1,4%, respectively. All measured values of the voltage harmonics are much lower than the allowed norms. Even voltage harmonics are not observed.

TABLE VI. HARMONICS OF THE VOLTAGE

	Number of harmonic											
	3	*5*	*7*	*9*	*11*	*13*	*15*	*17*	*19*	*21*	*23*	*25*
Maximum value, %	0,5	5,1	1,4	0,2	0,4	0,5	0,2	0,5	0,4	0,2	0,7	0,5
Norm according to BDS EN 50160, %	5,0	6,0	5,0	1,5	3,5	3,0	0,3	2,0	1,5	0,2	1,5	1,5

Table VII lists the maximum measured values of current harmonics and their norms [5]. All odd harmonics up to 25 harmonics are observed. It is noted that in addition to 3[th] harmonic current, all others are much higher than the allowable values. There are also even current harmonics, but they are all below the allowable values.

TABLE VII. HARMONICS OF THE CURRENT

	Number of harmonic											
	3	*5*	*7*	*9*	*11*	*13*	*15*	*17*	*19*	*21*	*23*	*25*
Maximum value, %	21,5	43,2	31,0	11,0	12,8	10,2	5,0	10,0	9,9	2,3	7,7	5,4
Norm according to IEC 61000-3-4, %	21,6	20,7	7,2	3,8	3,1	2,0	0,7	1,2	1,1	0,6	0,9	0,8

G. Power factor, active, reactive and total power

In Fig. 13 are given the measured values of the power factor of the individual phases In Table VIII the minimum, maximum and average values are shown. It can be seen that with the increase of the harmonics of the current, the power factor decreases. The average power factor is greater than 0,93.

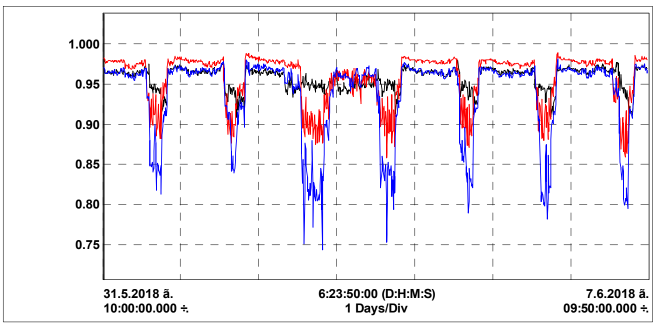

Fig. 13. Power factor
L1 – black; L2 – red; L3 - blue

TABLE VIII. VALUES OF POWER FACTOR

Indicator	Phase	Value		
		Minimum	***Average***	***Maximum***
Power Factor	L1	0,908	0,958	0,980
	L2	0,858	0,958	0,989
	L3	0,743	0,937	0,982

Power factor values are high during the time when different machines and aggregates are running. The minimum power factor values are noticed at night and on the weekend (Sunday) when there is no consumption. Then there is no reactive power consumption and this worsens the power factor.

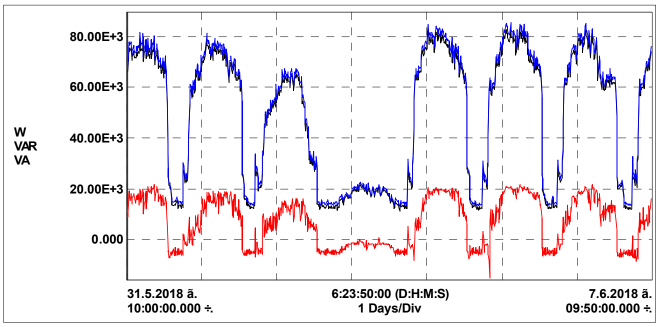

Fig. 14. Active, reactive and total power
P, W – black; Q, VAr – red; S, VA - blue

TABLE IX. ACTIVE, REACTIVE AND TOTAL POWER

Indicator	Phase	Value		
		Minimum	***Average***	***Maximum***
P, kW	L1	3,63	15,42	27,90
	L2	5,45	19,24	33,29
	L3	1,95	13,27	23,62
	Sum	11,26	47,93	82,65
Q, kVAr	L1	-5,36	3,62	7,45
	L2	-5,79	0,73	7,56
	L3	-4,00	2,45	6,93
	Sum	-15,15	6,80	21,66
S, kVA	L1	3,90	16,02	28,78
	L2	6,33	19,81	34,10
	L3	2,57	13,84	24,52
	Sum	12,97	49,67	85,31

The L1 phase power factor is most constant, while in L2 and L3 are observed reduction due to the return of reactive power, as can be seen in Fig. 14 and in Table IX, where the total active, reactive and complex power are given. The return of reactive power is at the time when the company non working - mainly at night, resulting in additional losses, over-compensation and pay for additional energy. Also during these periods a power factor of less than 0,9.

IV. CONCLUSION

After the measurements and analysis it is clear that the quality of the electrical energy supplying the company is good. The operation of the company and the used electrical equipment does not influence on the frequency and voltage deviation, and they are within the permissible limits throughout the measurement period. There are no interruptions, drops and overvoltage of the supply voltage. There is no flicker above the allowable value. Voltage imbalance is within the permissible limits.

The current load on the three phases is different. Significant asymmetry of the current is observed. For this purpose, it is necessary to shift the single phase users, if it’s possible.

The total harmonic distortion of the voltage is within the permissible norms and does not exceed 8%. Only odd harmonics of voltage are observed, all of which are well below the permissible norms. The total harmonic current distortion is well above the norm of 25%. All harmonics of the current, with the exception of the third harmonic, are well above the permissible values. This is due to the fully fluorescent lighting in the company, the use of computer equipment, air conditioning and ventilation systems and furnaces for cables. The maximum values of current harmonics are in the evening and Sunday when there is no consumption and production.

There is a return of reactive energy at night due to over-compensation. The transmission of reactive power over the grid is associated with a number of negative consequences, such as increased losses in power transmission facilities and losses of active power. Since the return of reactive power is not too high, its reduction could be achieved by properly selecting the electrical equipment during design, arranging the process for sealing the load schedule or other means.

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