Assessment of the electrical energy quality indicators of 20/0,4kV transformer station

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***Abstract* - The object of study is a 20/0,4 kV transformer station that supplies electrical energy to household customers. The main purpose of the conducted research is to evaluate the quality of electrical energy and total loads of the transformer station. The paper presents the results from a study of the electrical energy quality indicators. An analysis and comparison of the obtained results with the relevant norms given in the regulatory documents [1, 2, 3] have been made.**

Keywords – transformer station, quality of electrical energy, indicators, electrical loads.

I. Introduction

Electric power distribution companies are obliged to supply the customers connected to their networks with electrical energy which has values of the quality indicators (frequency of voltage, voltage deviation, rapid voltage changes, voltage unbalance, harmonic distortion of voltage, voltage dip, and interruptions) as stated in the regulatory documents [1, 2, 3]. These indicators change during the normal operation of the power system due to changes in load, interferences caused by some facilities and fault that occur mainly due to external influences repercussions. The change of indicators for electrical power quality over time has a random character for the individual terminals (feeders). Due to these changes, it can be expected that the levels of these indicators may be outstepped in some cases.

A research of a 20/0,4 kV transformer station, that supplies electrical energy to household customers, has been carried out. The purpose of the conducted research is to evaluate the quality of electrical energy and total loads of the transformer station. The paper presents the results from a study of the electrical energy quality indicators. An analysis and comparison of the obtained results with the relevant norms given in the regulatory documents [1, 2, 3] have been done.

II. Object of research

The object of research is a 20/0,4 kV transformer station, which supplies electricity to residential buildings in the Rila village territory.

The transformer station is supplied by the "Rila" Hydroelectric Power Plant through the 20 kV overhead power line. It is equipped with one transformer type TM-250/20-AL that has rated power of 250 kVA. The low voltage side of the transformer station supplies three outgoing terminals provisory indicated as terminal A, terminal B, and terminal C. These three outgoing feeders supply electricity to household consumers and street lighting.

Terminal A is situated on 15 reinforced concrete electric poles, of which 9 electric poles are on the mainline, which is constructed with aluminum-steel conductors with a cross-section of 5x25 mm^2. The rest of the line is separated into two branches mounted on 3 electric poles each, they are constructed with Al/steel conductors 4x25 mm^2. Terminal B contains 31 reinforced concrete poles, of which 10 poles are the mainline, constructed with copper LV ABC 5x10 mm^2, and five deflections. The first deflection is with 5 poles and copper LV ABC 5x10 mm^2, the second deflection is with 4 poles and Al/steel conductor 4x25 mm^2, the third deflection is with 6 poles and Al/steel conductor 3x25 mm^2, the fourth deflection is wit 3 poles and Al/steel conductor 4x16 mm^2 and the fifth deflection is with 3 poles and Al/steel conductor 4x10 mm^2. Terminal C contains 11 poles and the entire line is constructed with Al/steel conductor 3x25+25 mm^2.

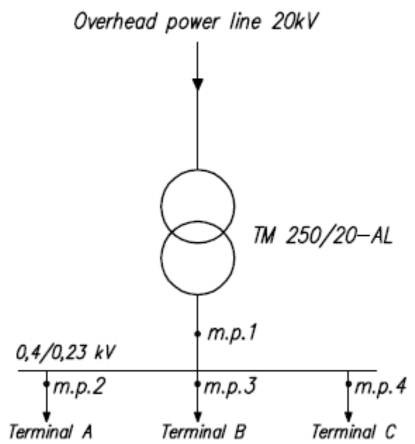

Fig. 1. Single line diagram of the transformer station and measurement points

The measurements were performed at low voltage 0,4/0,23 kV at four measurement points (m.p.) [4], shown in Fig. 1:

- m.p. 1 – on the low voltage side of the transformer;
- m.p. 2 – on terminal A;
- m.p. 3 – on terminal B;
- m.p. 4 – on terminal C.

The measurements have been carried out by using the Meg 30.4 multifunction meter (Fig. 2). For this purpose, the following auxiliary equipment is used ampere clamps and probes for voltage signal [5]. The used measurement instrument allows measurement, calculation, record and analyses of all electrical quantities and indicators of the quality of electrical energy in low voltage networks [4, 5]. The device allows the determination of the direction of

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power flows and the occurrence of events that cause disturbances.

III. Assessment and Analysis of Results

The measurement period is 1 week (from 11.30 am on March 28 to 10.30 am on April 04) with an interval for averaging the measurements of 10 minutes. The information obtained from the measurements was processed by specialized software.

Fig. 2. Multifunction measuring instrument Meg 30.4 and sensors

Fig. 3 shows the variation of the RMS values of phase voltages for the measurement period - for phase L1, phase L2, and phase L3. Interruptions and overvoltages aren't observed in supply voltage.

Table I gives the minimum, average and maximum measured values of the phase voltages.

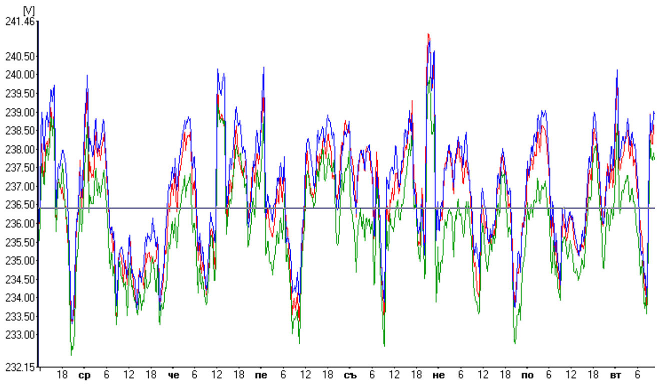


Fig. 3. Phase voltages
L1 – red; L2 – green; L3 - blue

TABLE I. Values of the Phase Voltages

Indicator	Phase	Value		
		Minimum	*Average*	*Maximum*
Phase voltage, V	L1	233,0	236,7	241,3
	L2	232,3	236,0	240,0
	L3	233,3	237,0	240,9

The histograms of the measured values of the three phase voltages, are presented in Fig.4.

Under normal operating conditions for each one week period, 95% of the measured values of the supply voltage must be within ± 10% U_r, in this case between 207 and 253 V. The maximum voltage deviations are + 4,91% for phase L1, + 4,35% for phase L2, and + 4,74% for phase L3. No voltages below the nominal value of 230 V have been registered. The values of the phase voltages, with which the consumers are supplied are within the permissible range in 100% of the measurement period. Therefore this indicator meets the regulations specified in BDS EN 50160 [1].

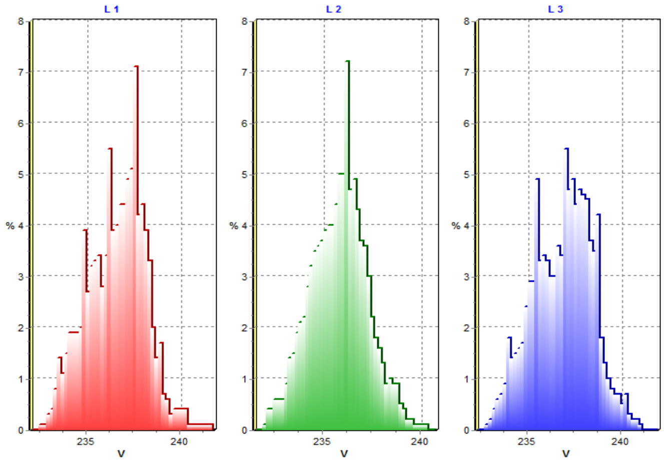


Fig. 4. Histograms of phase voltages

Fig. 5 shows the voltage unbalance for the period of study. The maximum measured value of voltage asymmetry is 0,55%. Therefore, in 100% of the measurement time, the unbalance of voltage is well below the allowable 2%.

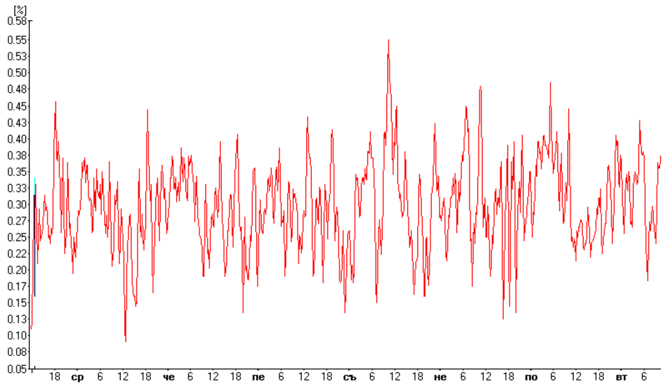


Fig. 5. Voltage unbalance

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

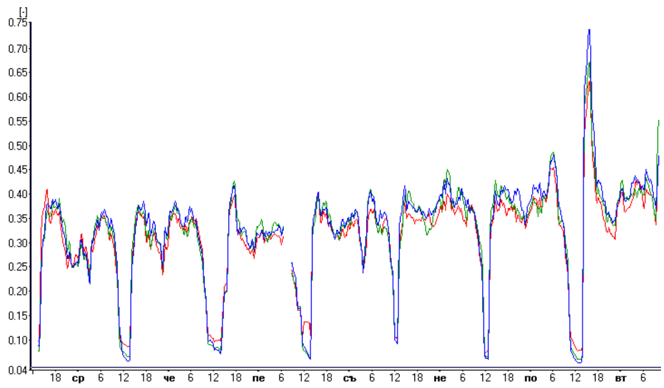


Fig. 6. Values of flicker
L1 – red; L2 – green; L3 - blue

The change of flicker over the measurement period is shown in Fig.6. Values of the flicker are in the range: from 0,07 to 0,67 for phase L1, 0,06 to 0,73 for phase L2, and 0,05 to 0,75 for phase L3. The average measured value is 0,41 for phase L1, and 0,3 for phases L2 and L3, respectively. All measured flicker values are below the permissible value of 1.

Fig. 7 shows the total harmonic distortion of the phase voltages. The measured values of the total harmonic distortion for phase L1 are in the range from 0,68% to 1,06%, for phase L2 from 0,78% to 1,15%, and for phase L3 from 0,58% to 0,94%. It is evident that all measured values are well below the allowable value of 8% for low voltage networks [1, 2, 3, 4].

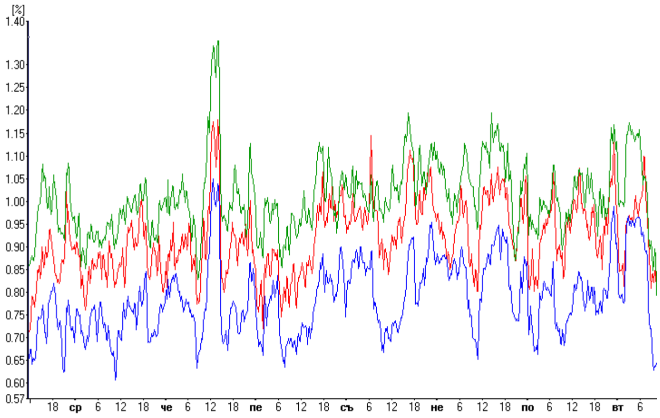
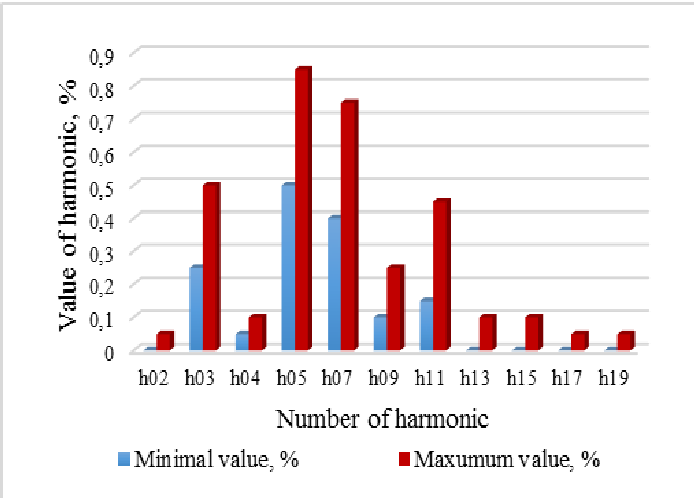


Fig. 7. Total harmonic distortion of voltage
L1 – red; L2 – green; L3 - blue



	h02	h03	h04	h05	h07	h09	h11	h13	h15	h17	h19
Minimum value, %	0,00	0,25	0,05	0,50	0,40	0,10	0,15	0,00	0,00	0,00	0,00
Maximum value, %	0,05	0,50	0,10	0,85	0,75	0,25	0,45	0,10	0,10	0,05	0,05
Norm according to BDS EN 50160, %	2,00	5,00	1,00	6,00	5,00	1,50	3,50	3,00	0,30	2,00	1,50

Fig. 8. Harmonics of voltage

Fig. 8 shows the measured minimum and maximum values of voltage harmonics and their normative values [1, 3, 4].

From the voltage harmonics with an odd number - harmonics from 3 to 19 are observed. From the even harmonics - harmonics 2 and 4 are registered. The maximum values of all voltage harmonics are well below the normative limitations.

The variation of the RMS values of the phase currents, of the transformer station for the measurement period, is presented in Fig.9. Table II shows the average and maximum current values.

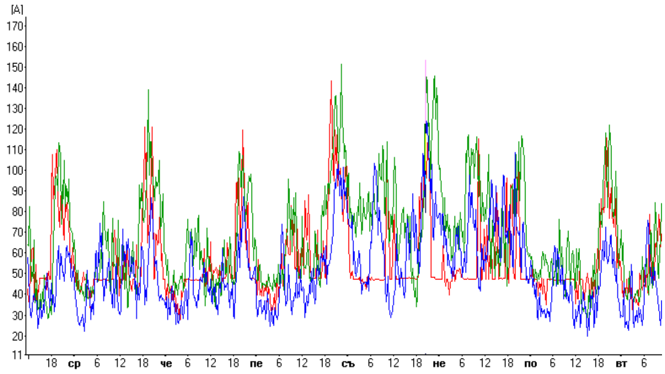


Fig. 9. Phase currents
L1 – red; L2 – green; L3 - blue

TABLE II. VALUES OF THE CURRENT

Indicator	Phase	Value	
		Average	***Maximum***
Current, A	L1	60,25	143,20
	L2	72,77	154,50
	L3	55,15	127,30

The values of the currents in the different phases vary considerably. The maximum measured current values are 143,2 A for phase L1, 154,5 A for phase L2 and 127,3 A for phase L3, respectively. Unbalanced current load of the individual phases is observed. The second phase of L2 is the most loaded. The current in phase L2 is 7,31% higher than the current in phase L1 and 17,61% higher than the current in phase L3.

The presence of phase unbalance leads to the occurrence of voltage in the neutral conductor. In the examined low voltage network that uses TNC earthing system, the measured current in the neutral conductor has an average value of 35,54 A and maximum value 85,8 A. It is necessary to redistribute loads of the three phases in order to reduce the losses and to ensure a uniform load on the three phases.

Table III shows the measured average and maximum values of active and reactive power. Based on them, the apparent power is determined.

The average value of the transformer load factor is 16,32%. The maximum value of the load factor is 36,33%. It appears that the load on the transformer is relatively small compared to the rated power of the installed transformer 250 kVA.

The variation of the RMS values of phase currents measured at terminal A, terminal B, and terminal C of the transformer station, are shown in Fig.10.

TABLE III. ACTIVE, REACTIVE AND APPARENT POWER

Indicator	Phase	Value	
		Average	*Maximum*
Active power, kW	L1	13,21	33,45
	L2	15,46	35,67
	L3	11,94	30,10
	Sum	40,61	90,35
Reactive power, kVAr	L1	0,24	2,59
	L2	2,24	6,03
	L3	1,42	3,10
	Sum	3,90	9,37
Apparentl power, kVAr	L1	13,21	33,55
	L2	15,62	36,18
	L3	12,02	30,26
	Sum	40,80	90,83

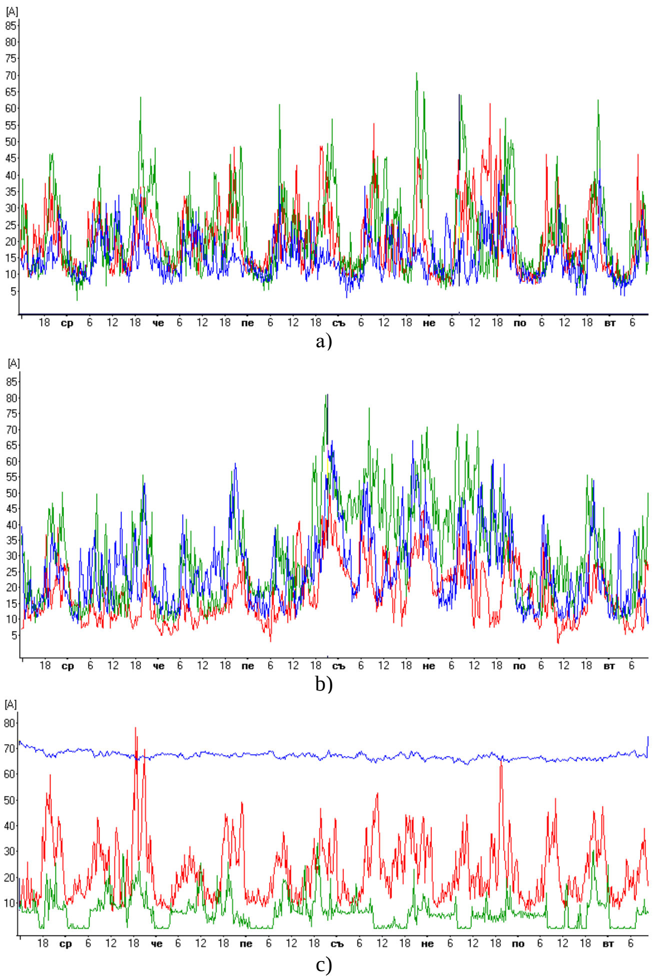


Fig. 10. Currents: a) in terminal A; b) in terminal B; c) in terminal C
L1 – red; L2 – green; L3 - blue

The average and maximum values of phase currents, for each of the three terminals of the transformer station, are given in Table IV.

For terminal A, the second phase L2 is the most loaded with a maximum current of 79,03A and an average value for the period of measurement 26,17A. The average value of the current in phase L2 is 11,6% higher than the current in phase L1 and 34,2% higher than the current in the third phase L3.

For terminal B, the second phase L2 is the most loaded one with a maximum current of 82,76A and an average of 35,1A. The average value of the current in phase L2 is 41,2% higher than the current in the first phase of L1 and 18% higher than the current in the third phase L3.

TABLE IV. VALUES OF THE CURRENT FOR TERMINALS A, B, AND C

Indicator	Phase	Value	
		Average	*Maximum*
Current in terminal A, A	L1	23,13	64,44
	L2	26,17	79,03
	L3	17,23	42,39
Current in terminal B, A	L1	20,65	53,08
	L2	35,10	82,76
	L3	28,78	67,75
Current in terminal C,A	L1	25,98	78,61
	L2	9,48	35,06
	L3	67,24	78,99

For terminal C the most loaded phase is L3. In it, a maximum current value of 78.99A and an average current value of 67,24A, have been measured. The load in phase L3 has a relatively constant of change over time. The other two phases are much less loaded. The average current in phase L1 is 25,98A or 61,4% less than the current in phase L3. The average current in phase L2 is only 9,48A, or 85,9% less than the current in phase L3. Therefore, a significant unbalance in the current loading of the three phases is observed here because the load is not evenly distributed.

IV. CONCLUSION

From the measurements and analysis can be concluded that the values of quality indicators of electrical energy of the transformer station supplying the examined low voltage network correspond to the norms given in BDS EN 50160 and will not adversely affect the normal operation of consumers supplied with it. Unbalanced loading of the individual phases of both the main power supply and the three terminals is observed. A significant value of the current in the neutral conductor has been measured. The typesetting of electrical poles is diverse and old. It is necessary to reconstruct the low-voltage network as well as to recalculate the cross-sections of the conductors for the individual terminals.

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