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ON THE NEED TO CONTROL POWER QUALITY IN POLISH ELECTRICAL NETWORKS

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Summary: **The paper provides some results of power quality tests performed in nodes of Polish electrical power networks: a thermal-electric power station low voltage network, industrial low voltage network and a distribution substation 220/110/15 kV. Power quality characteristics obtained during tests have been compared with the requirements of European Standard EN 50160 and Polish regulations.**

1. INTRODUCTION

Why is electrical power quality getting deregulated? The answer to that question seems to be known. For many years opinions were formulated that bad power quality is caused mainly by non-linear and frequently variable loads of big nominal powers exploited in industrial consumers networks. The rapid development of electronic audio-video devices, energy saving light sources and computer installations resulted in the bigger influence of individual consumers on power quality. Also, in auxiliary systems of power stations (energy sources) thyristor based devices are applied more and more often for controlling work of basic technological systems. The most frequently used are converter drives of band conveyors, supply-water pumps, air and flue gases fans and electro-filter supply systems. They can cause power quality deregulation as early as at the stage of energy production.

Bad power quality influences operation of electrical appliances making their work condition worse or even making their operation impossible. This obviously results in decreasing reliability of supply. Another unfavourable effect of bad power quality is increasing network losses, which should also be mentioned.

Usually, engineers do not know what quality power supply is in any particular point of the network, because no systematic quality measurements are made. Only when there is something wrong happening in the power system equipment work and if bad power quality is suspected to be responsible for that, voltage recording is performed and power quality characteristics are assessed.

To examine power quality, the authors did tests in various points of Polish electrical networks of different capacity: distribution and industrial. Their results and analysis have been described in details in [5, 6, 7, 8, 9]. The tests proved that problems with maintaining good power quality might occur at almost every stage of energy delivery to consumers.

The paper provides some results of measurements performed in: a thermal-electric power station low voltage network, industrial low voltage network and a distribution substation 220/110/15 kV. Power quality characteristics have been evaluated and compared with the requirements of the normative documents. The main aim of this paper is to show some phenomena, which resulted from worse quality of power supply and to draw attention to the need of systematic controlling of power quality characteristics. The results given here should be regarded as an example.

2. POWER QUALITY CHARACTERISTICS

Power quality problems are reflected in international and native standards and regulations [1, 2, 3, 4]. These documents usually deal with the supply voltage characteristics in medium and low voltage networks. The basic one is European Standard EN 50160 [3], which is obligatory in the countries of the European Union. Moreover, in other countries separate regulations have been worked out. In Poland power quality standards have been defined in [1, 2].

The quality of supply can be defined as any deviation from the characteristic values of the ideal sinusoidal voltage waveform. Most often, the following supply voltage characteristics determine electrical power quality:

—voltage changes in relation to a declared voltage value for each phase,

$$U_{L\%} = \frac{U_L}{U_c} 100\% \quad (1)$$

—asymmetry factor of the three-phase system,

$$\mathrm{ASYM}_{\%} = \frac{U_{1-}}{U_{1+}} 100\% \quad (2)$$

—relative values of voltage higher harmonics for each phase,

$$U_{h\%} = \frac{U_h}{U_c} 100\% \quad (3)$$

—THD factor for each phase voltage,

$$\mathrm{THD}_{\%} = \frac{\sqrt{\sum_{h=2}^{40} U_h^2}}{U_1} 100\% \quad (4)$$

—long term flicker severity

$$P_{lt} = \sqrt[3]{\frac{\sum_{i=1}^{12} P_{st_i}^3}{12}} \quad (5)$$

where:

U_L —data window mean rms. value of the supply voltage,
U_c —declared voltage at the measurement point (point of the common coupling),
U_{1-} —data window mean rms. value of the negative sequence component of the supply voltage basic harmonic,
U_{1+} —data window mean rms. value of the positive sequence component of the supply voltage basic harmonic,
U_h —data window mean rms. value of the voltage h—harmonic ($h = 1, \ldots, 40$),
P_{st} —data window mean short term flicker severity (measured with the instrument fulfilling requirements of the Standard EN 60868 [4]).

For the time being it is not known, which from the characteristics mentioned has a decisive influence on power quality evaluation.

The normative documents give admissible values of power quality characteristics at the point of common coupling the consumer network to the distribution network. They do not regulate the phenomena, which occur either inside the industrial networks or in the distribution network nodes.

3. TESTS RESULTS

3.1. Electrical power quality in the thermal power plant low voltage network [9]

The examined object was the electro-filter supply systems of one thermal power station in Lodz. The influence of electro-filters on power quality was investigated, with particular attention paid to voltage deformation, including harmonic contents and asymmetry. Each electro-filter was supplied by the transformer-rectifier unit. The three units were delta connected and coupled to the low voltage side of the supply transformer 15/0,4 kV of nominal power 500 kVA. The short-circuit power of the supply network was 214 MVA. The diagram of the system for one phase is presented in Figure 1.

The electro-filters with their supply units are a non-linear and asymmetrical load for the supply network. They affect the supply voltage in the degree dependent on both load asymmetry of individual units and capacity of the network.

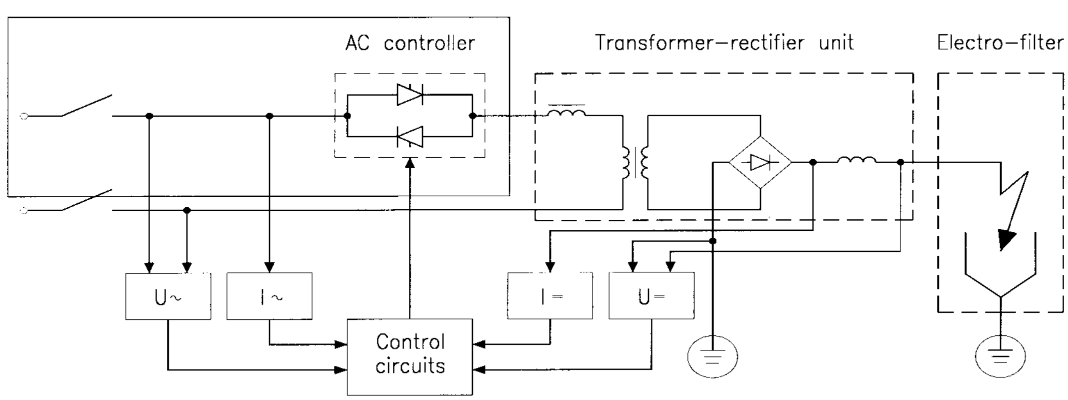


Fig.1. Electro-filters supply unit

Table 1. Supply voltage characteristics

No	Characteristic	Supply voltage level			Asymmetry factor	THD factor		
	Value	U_{L1}	U_{L2}	U_{L3}	ASYM	THD_{L1}	THD_{L2}	THD_{L3}
—	—	%	%	%	%	%	%	%
1	Maximum	103.07	102.76	102.65	2.86	2.98	3.21	3.07
2	Minimum	99.33	98.92	98.70	0.68	0.33	0.28	0.30
3	Mean	101.76	101.53	100.86	1.81	1.40	1.08	1.33

Tests were performed on the low voltage side of the supply transformer. The impact of electro-filters supply units was examined in various conditions of operations. Results obtained for the following cycle have been chosen for presentation:

—all electro-filters are switched off,

—the first electro-filter unit is switched on,

—the second electro-filter unit is switched on (operation of two units),

—the third electro-filter unit is switched on (operation of the three units),

—all electro-filters are switched off.

Statistical values of the supply voltage characteristics are given in Table 1, and their changeabilities in time are presented in Figures 2, 3, 4. One can easily notice the characteristic intervals referring to the consecutive electro-filters operation systems. During the asymmetrical loads (one or two units switched on) an increased distortion of the voltage and asymmetry factor is observed. They are substantially influenced by the lack of mutual compensation of odd higher harmonics multiplies of 3.

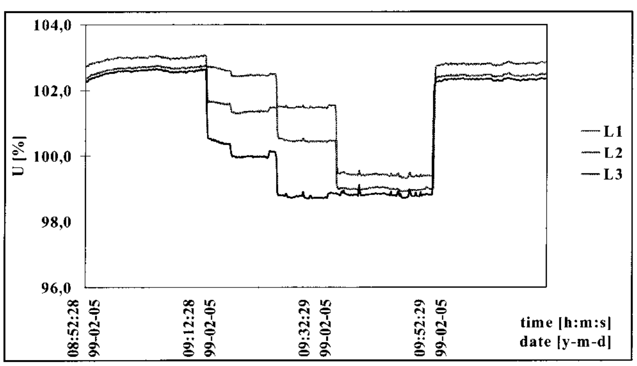


Fig. 2. Changes of the supply voltages during switching on the successive electro-filter supply units

Spectrums of higher harmonics in phase voltages for individual intervals of operation are shown in Figures 5, 6, 7, 8.

When analysing the results presented we can conclude that under asymmetrical electro-filter supply units operation the supply voltage characteristics deteriorated. It refers mainly to the THD and asymmetry factors. Thus, asymmetrical work of electro-filters can cause disturbances in other receivers work.

3.2. Electrical power quality in industrial network [6, 8]

Tests were performed in low voltage network of one Polish industrial work. The network was supplied from the two-section switchboard of the substation 15/0,4 kV. Some receivers which influenced electrical power quality were connected to the switchboard buses. They were as follows: the drive system of the press forming machine, the rectifier station for charging battery-operated truck and the capacitor bank for reactive power compensation. The bank was supplied with automatic power control system in the function of power factor. The measurements aimed at determining whether malfunctioning of the drive system of newly installed press machine for metal elements press forming was caused by industrial loads or inadequate quality of supply from the public electrical network. Special attention was paid to the mutual interaction of rectifiers and capacitor bank.

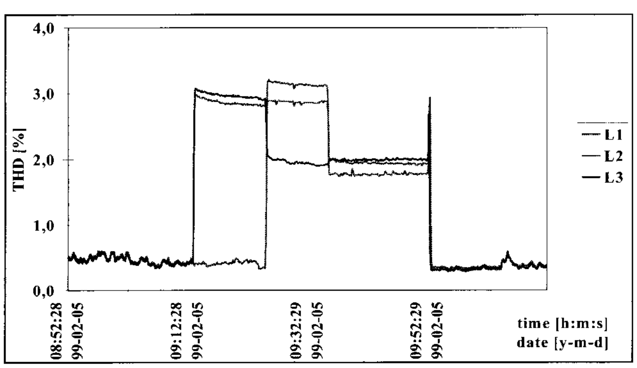
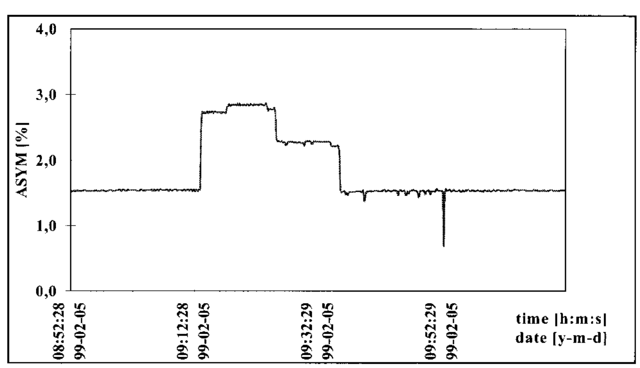


Fig. 3. Total THD factor of the supply voltages during switching on the successive electro-filter supply units



Rys. 4. Asymmetry factor of the supply voltages during switching on the successive electro-filter supply units

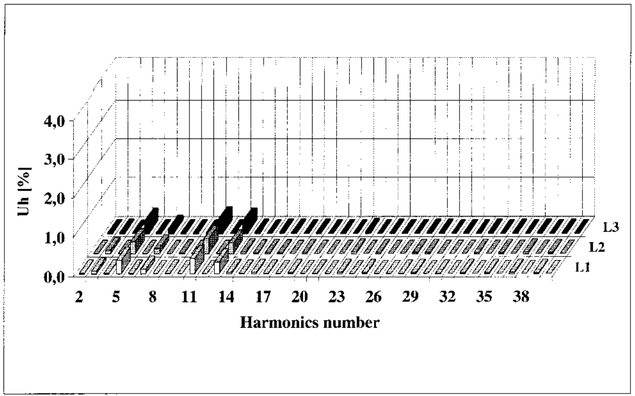


Fig. 5. Spectrum of harmonics in the supply voltages for all units switched off

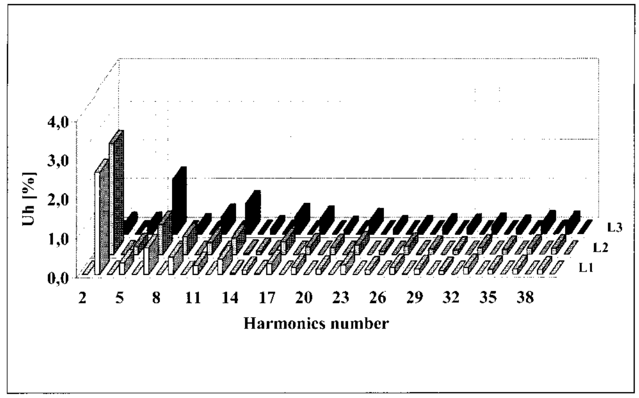


Fig. 7. Spectrum of harmonics in the supply voltages for two units switched on

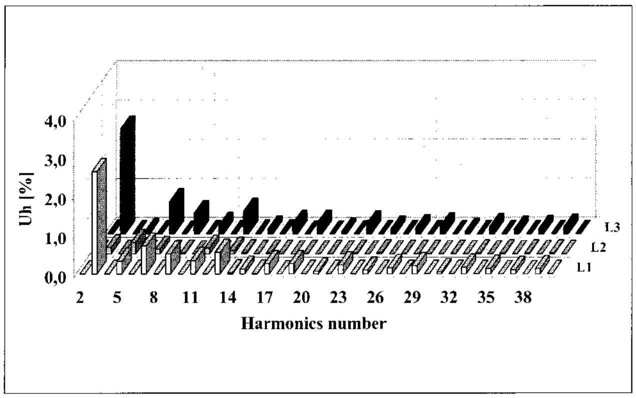


Fig. 6. Spectrum of harmonics in the supply voltages for one units switched on

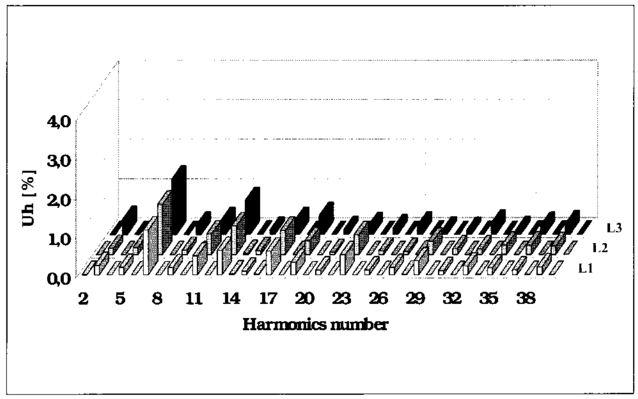


Fig. 8. Spectrum of harmonics in the supply voltages for all units switched on

A number of measurement cycles have been performed, and two of them have been chosen for presentation.

I. During the measurement cycle, after all the receivers had been put off, the press machine was switched on and the starting and braking of the drive system of this press were tested several times.

II. During the cycle there was a simultaneous performance of: the boiler station receivers, rectifier station and capacitor bank in automated control mode. The switching on and off of subsequent steps of the bank was forced.

Table 2 presents the basic results obtained in the measurement cycle I. For the same cycle, changes in time and systematic graph of THD distortion factor of phase voltages have been illustrated in Fig. 9. Moreover, Fig. 10 shows the band of harmonics distorting phase voltage waveform (for L1 phase).

Measurements were carried out under the conditions of higher supply voltage (transformer tap switch in –5% position) and of the lack of other loads switched on the examined section.

When analysing the test results, we can conclude that the drive system of the press machine, especially during transient processes, which take place in starting and braking, has a significant influence on supply voltage distortion.

The evidence for this is in high maximum value of THD factor, coming up to 11%.

Such an apparent supply voltage distortion is seen in the wide range of higher harmonics (Fig. 10), which arise during the examined dynamic states, basically the so-called harmonics characteristic of three- phase rectifier bridge.

Table 2. Supply voltage characteristics in the cycle I

No	Characteristic	Supply voltage level			Asymmetry factor	THD factor		
	Value	U_{L1}	U_{L2}	U_{L3}	ASYM	THD_{L1}	THD_{L2}	THD_{L3}
—	—	%	%	%	%	%	%	%
1	Maximum	109.73	109.55	109.75	1.54	10.17	10.98	11.12
2	Minimum	107.40	107.34	107.44	1.44	1.58	1.42	1.68
3	Mean	109.16	108.99	109.20	1.48	2.74	2.74	2.86

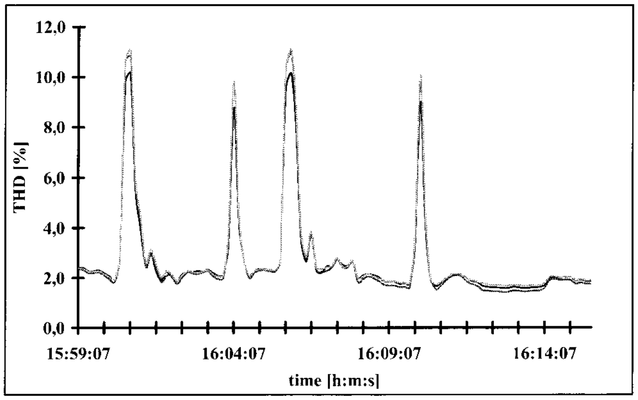


Fig. 9. THD factor for three phases

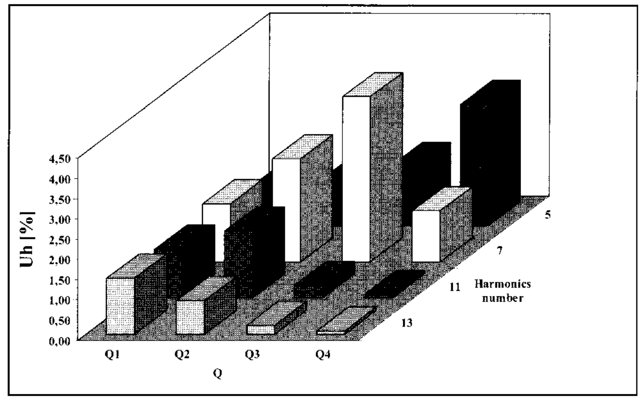


Fig. 11. Values of selected higher harmonics in resonant condition (cycle II)

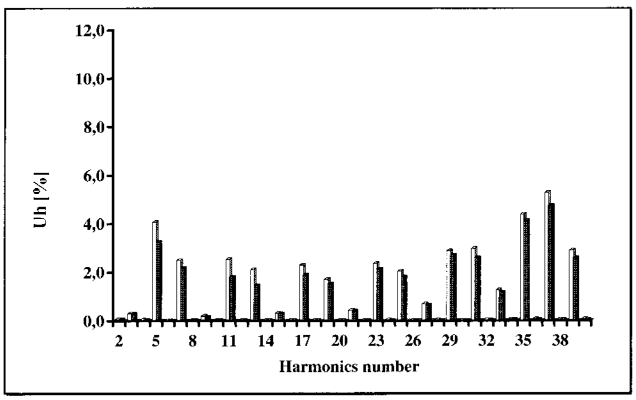


Fig. 10. Band of harmonics in L1 phase voltage: □ — maximum value, ■ — 95% level

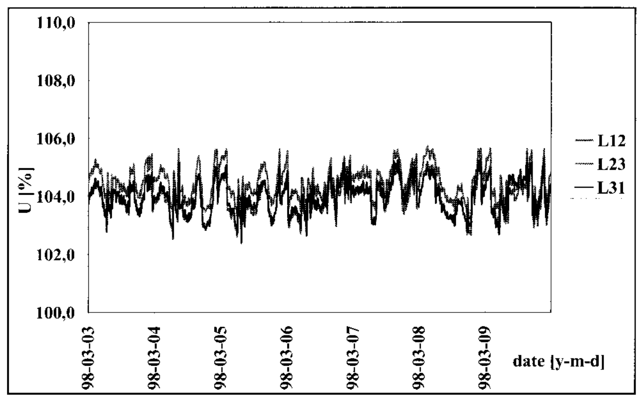


Fig. 12. Changes of line voltages

To illustrate the phenomena, which take place during reactive power compensation in the network with non-linear receivers, the results of measurement cycle II were chosen. The non-linear receiver is represented by the group of three-phase rectifiers, designed for loading battery-operated trucks, which performs practically under constant load. The switch-on of subsequent steps of capacitor bank in automatic control operating mode was forced (by adequate positioning of $\cos\varphi$ regulator). The bank had 23 steps of adjustment, each of 20 kVAr. In the process of switching on the capacitor bank, the appearance of resonance phenomena was observed successively for 13, 11, 7 and 5 harmonics, i.e. for harmonics characteristic for the 6-pulse three-phase rectifier bridge. The analysis was carried out for such measurement instants, when individual harmonics (from 5, 7, 11 13 sets) reached the maximum values. Fig. 11 illustrate the above-mentioned phenomenon; values of selected harmonics are correlated with the growth of capacitor bank power (Q1<Q2<Q3<Q4).

We can conclude than, that in networks with non-linear receivers, reactive power compensation using a capacitor bank with automatic control of the power may lead to resonance for some higher harmonics, and the higher the accuracy of regulation, the higher the probability of this phenomenon occurring.

3.3. Electrical power quality in distribution network substation [5, 7]

Tests were performed at the substation of 220/110/15 kV of the site distribution network of Lodz on a separated section of the 15 kV busbars. The section was supplied from the transformer 110/15 kV of the nominal power S_N = 16 kVA. The short-circuit power on 15 kV busbars was 96 MVA. The only load supplied from the section was a traction substation with the maximum power not exceeding 4 MVA. According to the Standard [3], quantities characterising power supply quality were recorded over the period of a week with the time of average value evaluation equal 10 min. In this way one can obtain 1008 measurement values for each characteristic. The Standard requires that 95% of the results should be within the range of U_n ±10%.

Statistical values of voltage characteristic: maximum, minimum, mean and 95% level are shown in Tables 3 and 4. Results are also presented in Figures 12–16. The spectrum of higher harmonics in the line voltage is presented in Fig. 17 for the phase L_1. Changes in time graph has been made for fifth harmonic only (Fig. 18), for which the twenty-four hour character of variation is clearly visible.

On the basis of the results given we can conclude that the voltage distortion is quite visible, even when the nominal power of the non-linear load is relatively small. In particular, the values of the THD factor as well as individual harmonics are bigger than their normative values given in [1],

Table 3. Supply voltage characteristics

No.	Characteristic	Supply voltage level			Asymmetry factor	THD factor		
—	Value —	U_{L12} %	U_{L23} %	U_{L31} %	ASYM %	THD_{L12} %	THD_{L23} %	THD_{L32} %
1	Maximum	105.74	105.20	105.34	1.83	3.91	3.85	3.88
2	Minimum	103.07	102.41	102.46	1.57	0.53	0.35	0.44
3	Mean	104.47	103.91	103.99	1.69	1.45	1.31	1.42
4	95% level	105.43	104.87	104.91	1.78	2.46	2.34	2.42
5	Admissible value [3]	90.00 ÷ 110.00			0.00 ÷ 2.00	0.00 ÷ 8.00		
6	Admissible value [1]	90.00 ÷ 105.00			Not standardised	0.00 ÷ 1.50		

Table 4. Flicker severity indices

No.	Index	Long term flicker severity			Short term flicker severity		
	Value	$P_{lt,L12}$	$P_{lt,L23}$	$P_{lt,L31}$	$P_{st,L12}$	$P_{st,L23}$	$P_{st,L31}$
1	Maximum	0.93	0.73	0.78	1.98	1.27	1.37
2	Minimum	0.22	0.19	0.22	0.10	0.10	0.10
3	Mean	0.46	0.47	0.49	0.42	0.42	0.44
4	95% level	0.62	0.63	0.66	0.71	0.72	0.76
5	Admissible value [3]	0.00–1.00			Not standardised		

i.e. 1,5 % for THD factor and 1 % for any higher harmonic. The requirements of Polish regulations seem to be too restrictive in that case in comparison with the European Standard and will probably not be satisfied in many network nodes. In connection with this the utility permits establishing arbitrary power quality standards in contracts for energy sale.

4. CONCLUSION

Direct monitoring of supply voltages enables the assessment of electrical power supply quality and estimation of the influence of non-linear and frequently variable loading receivers on the supply voltage. In particular, it seems to be necessary in examination of resonance phenomena, which take place in reactive power compensation, when rectifier type receivers are present. Power quality characteristics measurements enable the assessment of the quality of service provided by utilities to their consumers. It will be needed in the conditions of competitive energy markets.

As systematic monitoring of voltages and currents in electrical networks has not been a usual practice so far, therefore little is known about the quality of supply, and values of power quality characteristics usually are not known. In such a situation, when normative quality standards are established and power quality improvement is technically, economically and even socially justified, there is an urgent need for power quality characteristics controlling. In the authors' opinion, it is time now to start monitoring and measuring power quality characteristics in a more systematic way.

For the proper power quality assessment, both the methodolo-

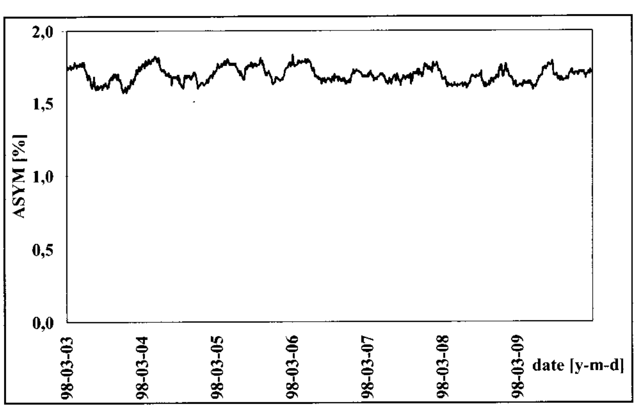


Fig. 13. Asymmetry factor

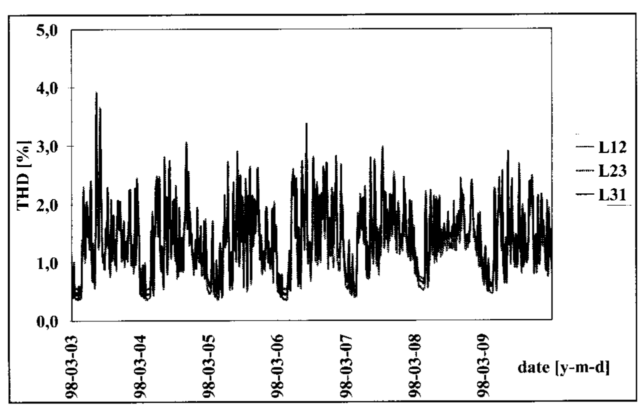


Fig. 14. THD factor

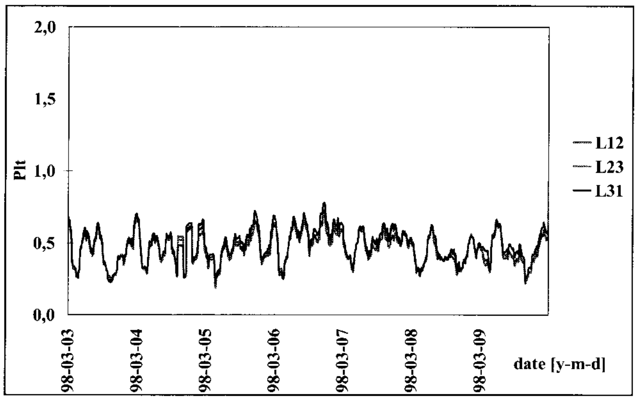


Fig. 15. Long time flicker severity

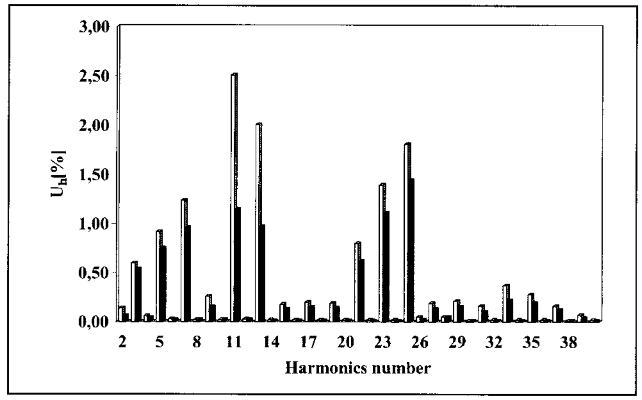


Fig. 17. Spectrum of harmonics in the phase L_{12} of the supply voltage □ — maximum value, ■ — 95% level

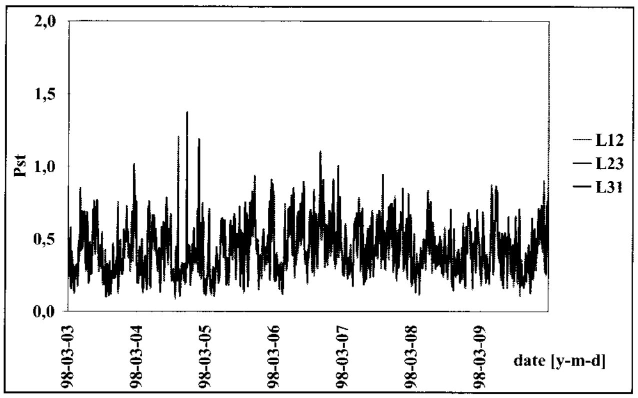


Fig. 16. Short time flicker severity

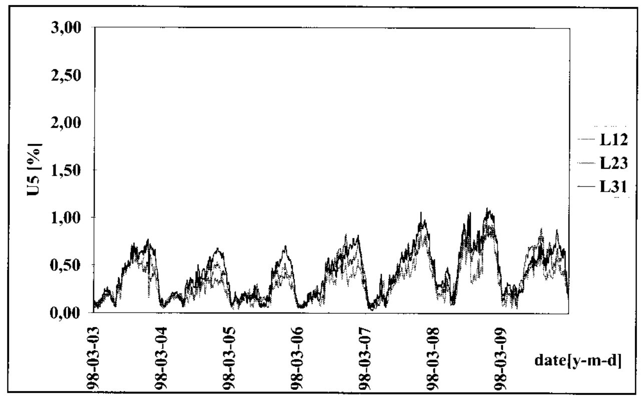


Fig. 18. Fifth harmonic voltage

gy of measurement points selection and the method of measurement must be precisely defined. Those questions are not touched in Polish regulations. It is not clear what value of determined characteristics (maximum, or occurring with a defined probability) their admissible values given in [1] are referred to.

The requirements of Polish regulations in comparison with European Standard seem to be very restrictive, especially with respect to the harmonic contents, and are not justified. On the basis of the work done, the authors think that meeting this requirements will be difficult and in many cases just impossible.

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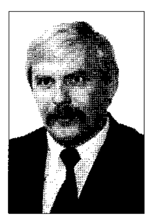

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