Marta Bątkiewicz-Pantuła
Wrocław University of Technology, Faculty of Electrical Engineering, Institute of Electrical Power Engineering
27 Wyspiańskiego Quay, 50-370 Wrocław, marta.batkiewicz-pantula@pwr.edu.pl

EVALUATION OF QUALITY OF ELECTRIC ENERGY COOPERATING WITH HYDROELECTRIC POWER PLANT - SELECTED FEATURES

Abstract
The article presents evaluation of the quality of electricity in the network cooperating with hydroelectric power plant. The assessment was based on the Decree of the Minister of Economy dated 4 May 2007 on detailed conditions for the operation of the power system and the norm PN-EN 50160: 2010 – Voltage characteristics of electricity supplied by public distribution systems. The analysis was based on actual measurements made by power quality recorder Fluke 1760. The analysis particular emphasis has been to:

- values of higher harmonics and voltage distortion factor (THD_U)
- Power factor cosφ.
- Active power.

Assessment of quality of electric energy will be discussed based on the analysis of the measurements.

Key words
the quality of electric power, hydroelectric power plant, harmonics, cosφ, active power

Introduction

Presenting the electric power quality parameters, the attention should be paid to two documents in which they are listed today, i.e. Minister of Economy Decree dated 4 May 2007 on detailed conditions for the operation of the power system [1] and the norm PN-EN 50160: 2010 [2]. In the first position, section 10, the following quality parameters of electricity were mentioned:

- the value of average frequency
- average effective voltage value
- long-term flicker P_{lt}
- symmetrical components for order of symmetric and individual harmonic supply voltage
- distortion factor of higher harmonic voltage THD

The second position specifies an even greater amount of electric energy quality parameters:

- network frequency
- the value of supply voltage
- supply voltage variation
- rapid voltage changes, which include: the value of rapid voltage changes and flicker
- supply voltage dip
- a short power outage
- a long power outage
- casual overvoltage of constant frequency voltage between live conductors and earth
- transient overvoltage between live conductors and earth
- asymmetry of supply voltage
- voltage harmonics
- interharmonics voltage
- voltage signal to transmit information imposed on the supply voltage

Considering all the aforementioned parameters, all kinds of classification can be made. They can be divide them into those which are random (caused by problems with weather, traffic accidents, etc.) and determined (type of receiver, power supply system, etc.). Electromagnetic interference can be divided due to the effect which they cause: disorders that cause immediate effects, e.g. malfunction of protection systems equipment; disorders of the long-term effects, e.g. acceleration of the process of aging and degradation of the insulation of electrical machines and cables.

Taking into account that the quality of electricity is a set of numerical values (quality parameters), the following classification can be made:

- parameters corresponding to normal operating conditions of the power system, e.g. the voltage value and frequency of supply voltage
- parameters related to disorders of normal operating conditions of the system, e.g. overvoltage's flickering lights
- parameters related to supply voltage waveforms, e.g. transient overvoltage's voltage dip

Considering topic quality parameters of electricity must be taken into mind that for the degraded conditions of power supply is not responsible only supplier of electricity but also the recipient of this energy (in figure 1). The most influence on disorders have electrical devices that consume distorted current from the network.

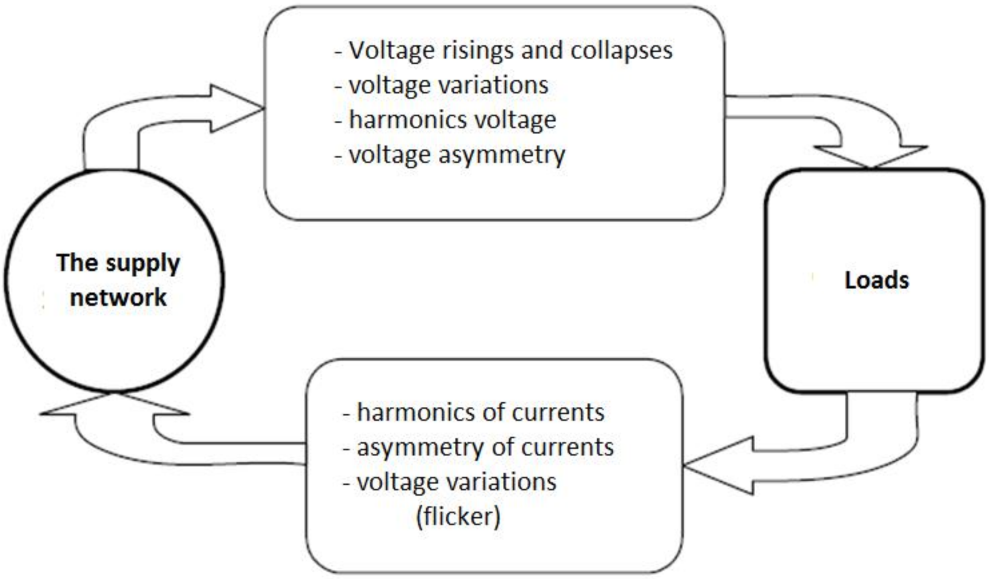

Fig. 1. Sources of typical disturbances in electric power quality
Source: [3]

Place of measurement
The measurements were made by the three-phase power quality recorder Fluke 1760, which is compliant with the class A standard IEC 61000-4-30 (in figure 2). Measurements of electrical energy quality parameters were made in the hydroelectric power plant during its normal operation. The period of observation covered the whole week. The first day of measurement was Friday.

Fig. 2. Connecting measuring instruments
Source: Author's

Analyzed Hydroelectric Power Plant is equipped with two asynchronous generators with a power of 200kW each (in figure 3). Generators are installed on the turbines Francis and Caplan vertically with the transmission belt. Connected to the network via a transformer 21000/400V, 400kVA the active power delivery. System is equipped with a capacitor batteries - fully automated. Control system (like on and off) of the turbines are fully automated, e.g. in case of power outages on the network side. Sometimes the control is switched to manual control, e.g. the maintenance activities such as cleaning the channel.

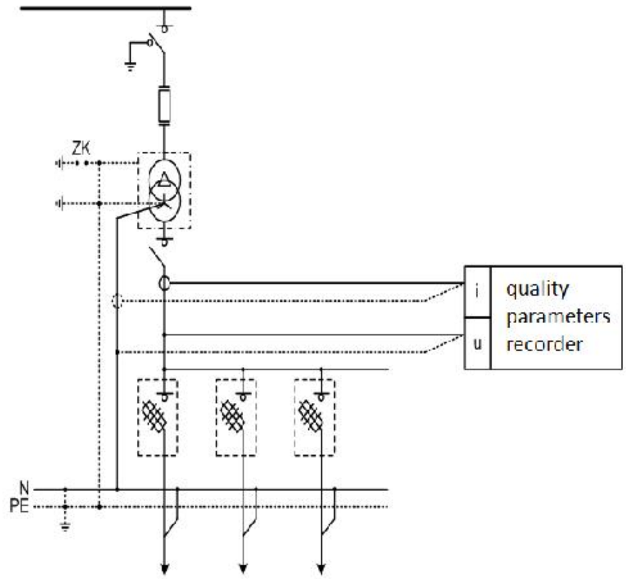

Fig. 3. Wiring diagram of measuring instruments
Source: Author's

The values of higher harmonics and voltage distortion factor (THD_U)

The first parameter of electric energy which has been analysed is the harmonic content in the course of the supply voltage. The harmonics are responsible for distortion sine waves of AC voltage. Even preliminary tables (in Table 1) indicate the patterns in the general factor of voltage waveform distortion (presence of harmonics).

Table 1. Harmonic contents in the voltage waveforms in reference to the time required for 95% of the measurements.

Total harmonic distortion				
Designation	**Tolerance range**	**L1**	**L2**	**L3**
	[%]	[%]	[%]	[%]
THD	0.00 - 8.00	100.00	100.00	100.00
Harmonics				
Order	**Tolerance range**	**L1**	**L2**	**L3**
Nr.	[%]	[%]	[%]	[%]
2	0.00 - 2.00	100.00	100.00	100.00
3	0.00 - 5.00	100.00	100.00	100.00
4	0.00 - 1.00	100.00	100.00	100.00
5	0.00 - 6.00	100.00	100.00	100.00
6	0.00 - 0.50	100.00	100.00	100.00
7	0.00 - 5.00	100.00	100.00	100.00
8	0.00 - 0.50	100.00	100.00	100.00
9	0.00 - 1.50	100.00	100.00	100.00
10	0.00 - 0.50	100.00	100.00	100.00
11	0.00 - 3.50	100.00	100.00	100.00
12	0.00 - 0.50	100.00	100.00	100.00
13	0.00 - 3.00	100.00	100.00	100.00
14	0.00 - 0.50	100.00	100.00	100.00
15	0.00 - 0.50	100.00	100.00	100.00
16	0.00 - 0.50	100.00	100.00	100.00

17	0.00 - 2.00	100.00	100.00	100.00
18	0.00 - 0.50	100.00	100.00	100.00
19	0.00 - 1.50	100.00	100.00	100.00
20	0.00 - 0.50	100.00	100.00	100.00
21	0.00 - 0.50	100.00	100.00	100.00
22	0.00 - 0.50	100.00	100.00	100.00
23	0.00 - 1.50	100.00	100.00	100.00
24	0.00 - 0.50	100.00	100.00	100.00
25	0.00 - 1.50	100.00	100.00	100.00

Source: Author's

The overall Harmonics content in the voltage THD is within the tolerance range, which is 0.00 - 8.00% for 95% of the measurement time (in Table 1). The exact value of this coefficient for each phase (L1, L2, L3) is: 2.71%, 2.99% and 2.89% (in Table 2).

Table 2. Harmonic contents in the voltage waveform - average harmonic content

Total harmonic distortion							
		95%-values			**Maximum values**		
Designation	**Tolerance range**	**L1**	**L2**	**L3**	**L1**	**L2**	**L3**
	[%]	[%]	[%]	[%]	[%]	[%]	[%]
THD	0.00 - 8.00	2.71	2.99	2.89	3.23	3.52	3.36
Harmonics in % of Un							
		95%-values			**Maximum values**		
Order	**Tolerance range**	**L1**	**L2**	**L3**	**L1**	**L2**	**L3**
Nr.	[%]	[%]	[%]	[%]	[%]	[%]	[%]
2	0.00 - 2.00	0.01	0.01	0.01	0.02	0.02	0.02
3	0.00 - 5.00	0.16	0.25	0.16	0.18	0.26	0.17
4	0.00 - 1.00	0.01	0.01	0.01	0.02	0.02	0.02
5	0.00 - 6.00	0.72	0.66	0.60	0.91	0.93	0.90
6	0.00 - 0.50	0.02	0.02	0.02	0.06	0.04	0.06
7	0.00 - 5.00	2.67	2.94	2.87	3.21	3.50	3.29
8	0.00 - 0.50	0.03	0.03	0.03	0.04	0.04	0.05
9	0.00 - 1.50	0.26	0.15	0.18	0.37	0.29	0.27
10	0.00 - 0.50	0.03	0.03	0.03	0.04	0.04	0.05
11	0.00 - 3.50	0.26	0.28	0.29	0.40	0.40	0.43
12	0.00 - 0.50	0.01	0.01	0.01	0.01	0.01	0.01
13	0.00 - 3.00	0.09	0.09	0.09	0.11	0.13	0.12
14	0.00 - 0.50	0.01	0.01	0.01	0.01	0.01	0.01
15	0.00 - 0.50	0.01	0.01	0.01	0.01	0.01	0.02
16	0.00 - 0.50	0.01	0.01	0.01	0.01	0.01	0.01
17	0.00 - 2.00	0.02	0.02	0.02	0.04	0.05	0.05
18	0.00 - 0.50	0.00	0.00	0.00	0.01	0.01	0.01
19	0.00 - 1.50	0.01	0.01	0.01	0.01	0.02	0.02
20	0.00 - 0.50	0.00	0.00	0.00	0.01	0.01	0.01
21	0.00 - 0.50	0.01	0.01	0.01	0.01	0.01	0.01
22	0.00 - 0.50	0.01	0.01	0.01	0.01	0.01	0.01
23	0.00 - 1.50	0.01	0.01	0.01	0.03	0.03	0.02
24	0.00 - 0.50	0.00	0.00	0.00	0.00	0.00	0.00
25	0.00 - 1.50	0.01	0.01	0.01	0.01	0.01	0.01

Source: Author's

The period of measurement was one week. Fig. 4 shows the course of THD supply voltage, we can deduce at what time Hydroelectric Power Plant worked. Also can be observe the work of the analysed object on the so-called “idle run”. The specificity of the test object does not require any work on certain days of the week. Operation of the object depends on the level of flowing water.

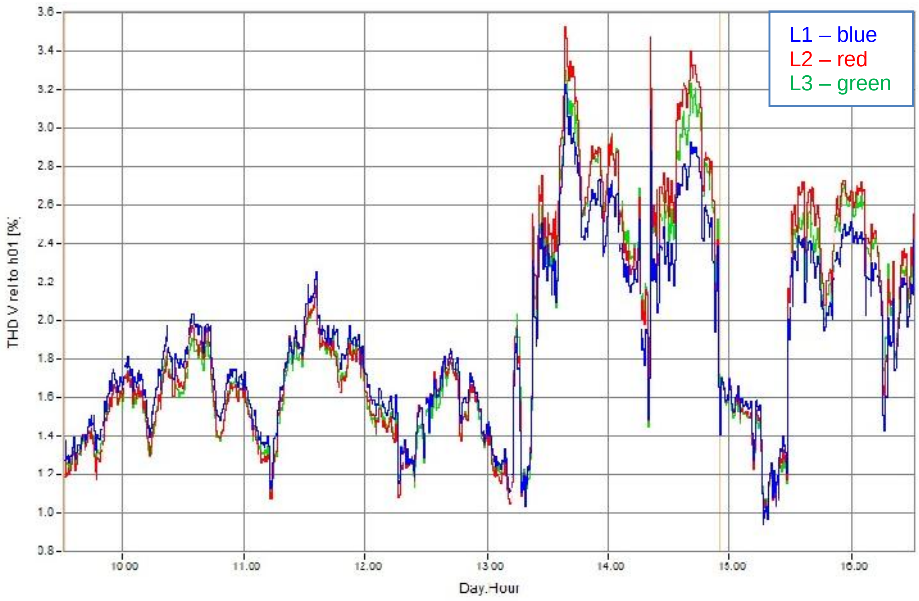

Fig. 4. THDu (relative to the basic harmonic h1 (day:hour))
Source: Author’s

Figure 5 shows all of the harmonics of voltage (from the second harmonic h2 to h50 fiftieth). It is clear that with increasing harmonic number decreases its participation in the course of the supply voltage. The highest values take the fifth harmonic h5 and seventh h7.

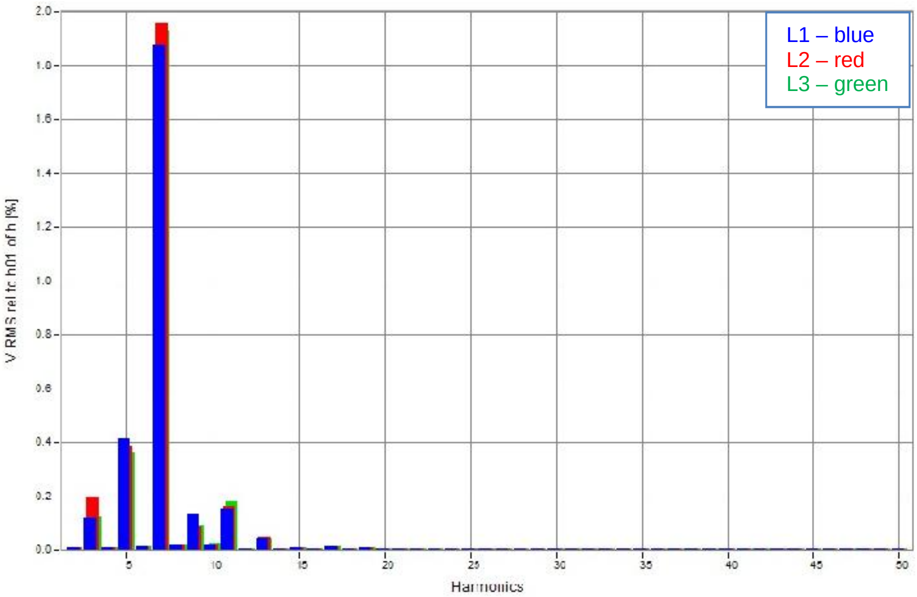

Fig. 5. Spectrum of harmonic
Source: Author’s

Analysis of the fifth harmonic H5 (with respect to the fundamental voltage waveform h1) concluded it can be that the examined harmonics (in figure 6) and its value does not come from the analysed object. It is a harmonic, which, based on the preliminary analysis in accordance with norm DIN EN 50160, course does not coincide with the course of the total THD (in figure 4), it is more aligned. In contrast to the total THD, harmonic fifth h5 have no influence for the work analyzed hydroelectric power.

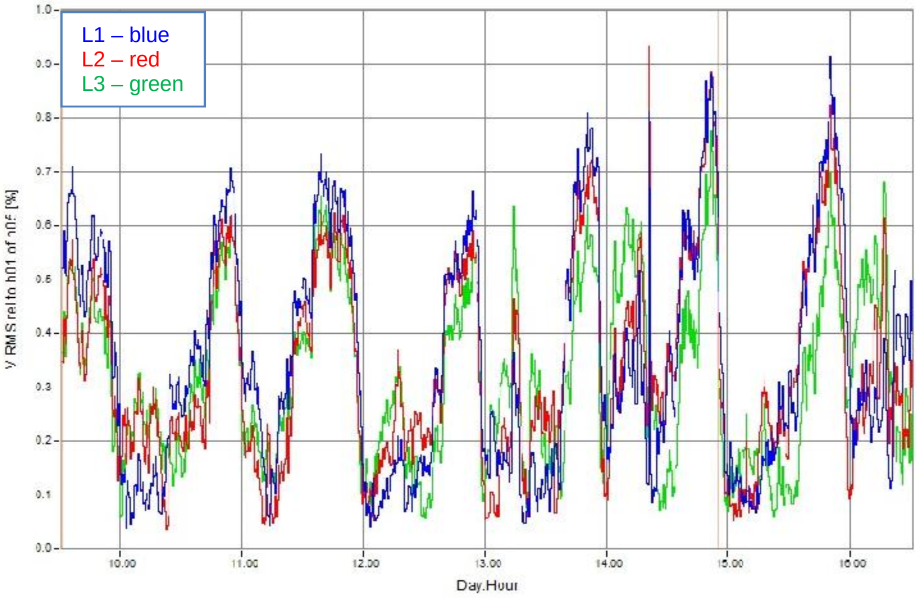

Fig. 6. Higher harmonics (relative to the basic harmonic h1 (day:hour)) - Harmonic 5
Source: Author's

Then was analysed the seventh harmonic h7 (in relation to the basic harmonic voltage waveform h1), for which on the basis of a preliminary analysis in accordance with norm DIN EN 50160 concluded the largest share (in figure 5). In accordance with the norm PN-EN 50160 limit values of 5% (in table 2) has not been exceeded and is 2.67%, 2.94% and 2.87% (corresponding to phase L1, L2 and L3). Number presented in Figure 7 coincides with the total course of THD (in figure 4). Total THD and harmonic seventh h7 reach maximum values in the fifth and sixth day of measurement. It can be also found that all phases of the analysed object are loaded evenly. The time of day did not affect the value of harmonic H7. It can be concluded that the harmonic h7 is directly related to the work of the analysed hydroelectric power.

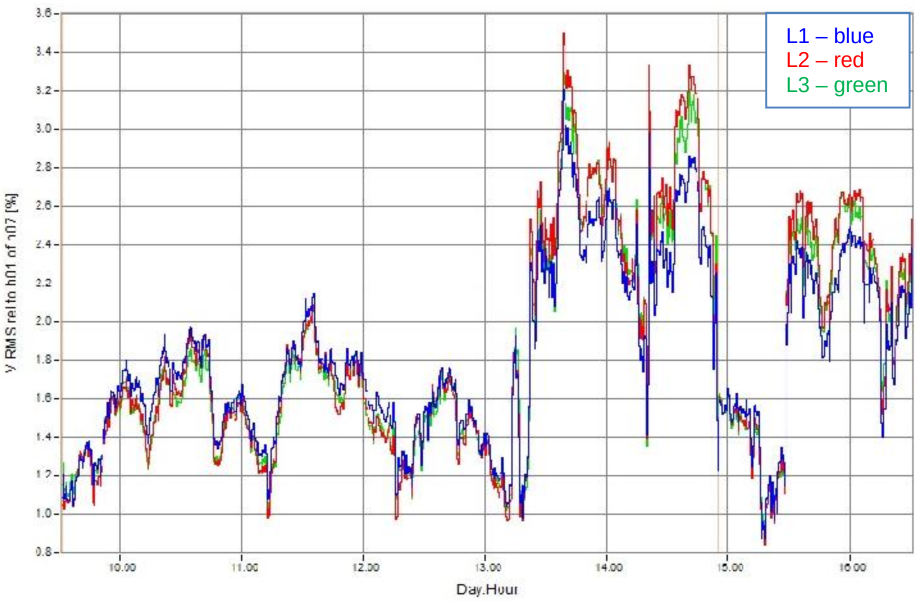

Fig. 7. Higher harmonics (relative to the the basic harmonic h1 (day:hour)) - Harmonic 7
Source: Author's

The power factor cosφ

The parameter used to characterize objects is a factor cosφ, the power factor. In the case of a building where took place the measurements of the parameters, this factor is between 0,96-0,99 (in figure 8b). On the presented course (in figure 8a) it can be observed a voltage dip which was registered at the end of the sixth day of the measurement. Voltage collapses occurred in three phases at the same time. The figure 8b clearly shows cyclical changes in the coefficient cosφ in different times of work and linearity (lower volatility) in the times of stoppage work of the analysed power plant. These changes are dictated by load-associated changes with the normal operation of hydroelectric power plant. There are no variations of the coefficient cosφ related to the supply system phases.

a)

b)

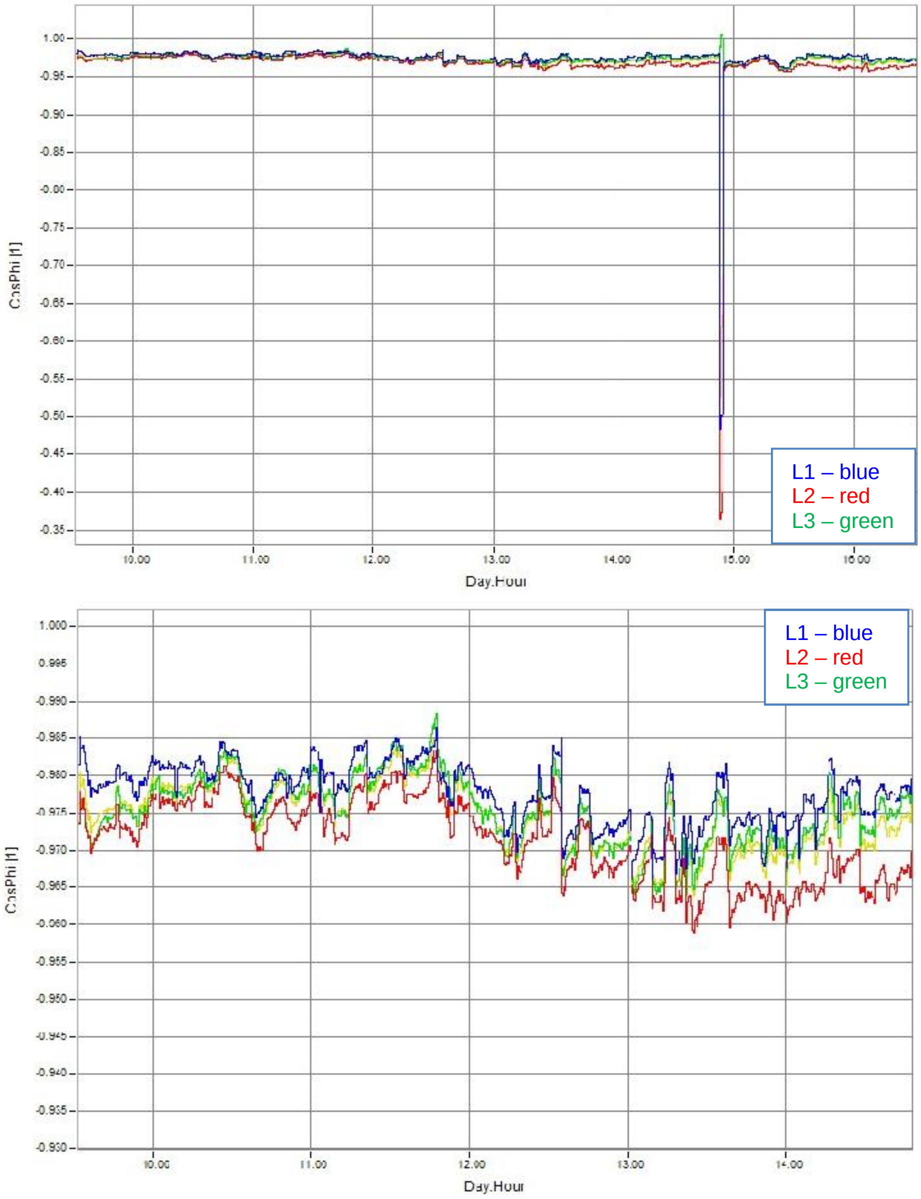

Fig. 8. The power factor cosφ (day:hour) :

a) the entire measurement period b) the measuring period without voltage dip

Source: Author's

The active power consumption

Analysing the hydroelectric power plant in terms of electric power supply, the power waveforms cannot be ignored. This is the primordial parameter, on the basis of which the analysis of all quality parameters of electricity was carried out. Waveforms of delivered active power are reflected to others waveforms presented in the article. Observing the course of time the power consumed by the supply system (in figure 9) we are able to tell when the plant is running, i.e. it is used to perform specific tasks which are activated the main consumers of power.

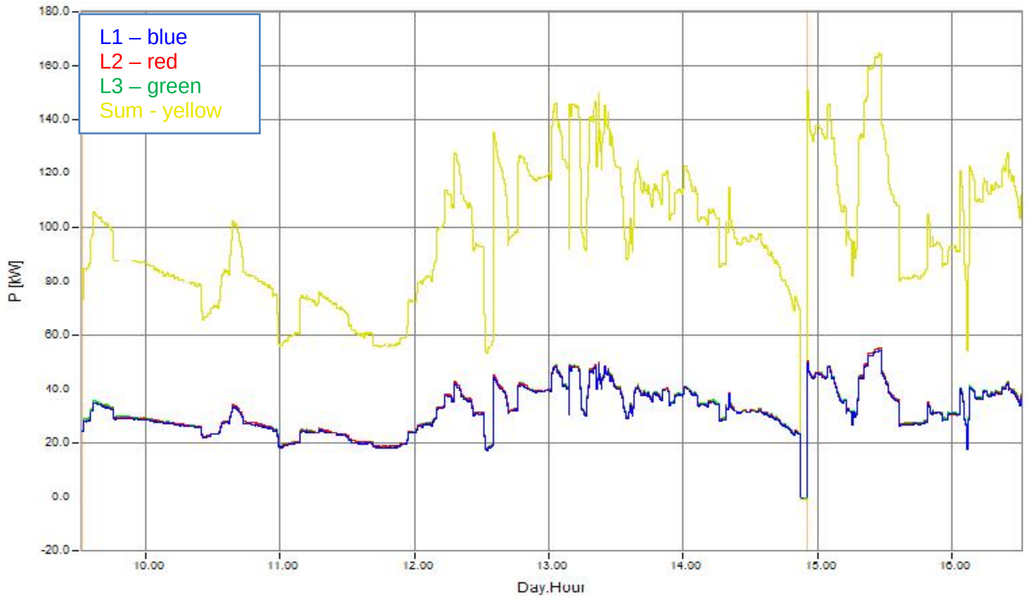

Fig. 9. The active power consumption during the entire measurement period (day:hour)
Source: Author's

Analysing the course of active power, we see the cyclical changes in value relating to the work of the object. The illustrated waveforms are average values of the measurement, the yellow color is the total power consumed by all three phases of the supply. In figure 9 there was observed an occurrence of the sixth day of the voltage dip. The total (max) power demand for electric energy is approx. 160kW (seventh day of the test, in figure 9), while the minimum power falls below 60kW. It can be noticed that the analysed water power plant takes power even outside times at which the normal work is provided. There are also differences between the peak of the day and night valley.

Summary and conclusions

For the analysed actual hydropower the following conclusions can be formulated:

- Research and evaluation of the quality of electricity are becoming more common and are intended to increase the reliability and safety of the electrical installations that are powered by the plant, and energy power supply systems;
- analysis of the results of measurements of electrical power parameters may be useful to locate possible sources of disturbance values of individual parameters in the electrical installation;
- on the basis of measurements there can be created the energy characteristics of the building, which may have an impact on the possible modernization of the structure of the electrical installation or changes in the management of existing loads turned on to this installation in order to balance the load daily.

References

[1] Regulation of the Minister of Economy dated 4 May 2007 on detailed conditions for the operation of the power system (Dz. U. dated 29 May 2007, item 623).

[2] PN-EN 50160:2010, Parameters of the supply voltage in the public power networks.

[3] I. Wasiak, Electrical power engineering at a glance. Transmission and distribution of electricity, Lodz, 2010.