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Assessing electric power quality parameters in street lighting system using LED-type light sources

Abstract. *The article evaluates electrical power quality parameters and presents the adverse effects associated with the presence of LED light sources in the power system on the basis of measurements at the transformer/switching station which powers LED-type street lights. The article discusses the measurement methodology, presents characteristics of the measuring instruments, and analyses selected results from the point of view of compliance with the standards for power quality.*

Streszczenie*. Tematem artykułu jest ocena parametrów jakości energii elektrycznej i przedstawienie niekorzystnych zjawisk związanych z obecnością w systemie elektroenergetycznym źródeł światła LED na podstawie wykonanych pomiarów w stacji transformatorowej GPZ, z której zasilane jest oświetlenie uliczne wykonane źródłami LED. W artykule omówiono metodę pomiarów, przedstawiono charakterystykę przyrządów pomiarowych, a także zamieszczono wybrane wyniki analizy uzyskanych danych pomiarowych pod kątem ich zgodności z normami dotyczącymi jakości energii elektrycznej.* ***(Ocena parametrów jakości energii elektrycznej przy realizacji oświetlenia ulicznego z wykorzystaniem źródeł światła LED)***

Keywords: electric power quality, interaction on the mains supply, LED light source.
Słowa kluczowe: jakość energii elektrycznej, oddziaływanie na linię zasilającą, źródła światła LED

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Introduction

Nowadays, electric energy is an inherent and indispensable component of human life. It is the most convenient and, at the same time, the most accessible type of energy thanks to its properties, among which such should be mentioned as e.g. relatively low production cost, possibility to transfer over long distances, easy conversion into other kinds of energy and, last but absolutely not least in this day and age, tolerably low harmfulness to the natural environment.

Distribution of electric power from producer to recipient is possible via electric power systems, and whereas the electric power is considered a commodity, expectations of each of the parties in the whole process including production, transmission, and utilization, include meeting the requirement that the quality of this specific product will be as high as possible.

Unfortunately, still more and more receivers connected to the electric power supply network have nonlinear voltage-current characteristics, thus changing the rate of nonlinear-to-linear receivers and deteriorating the overall electric power quality. Lower quality of electric power may have adverse effect on correct operation of other receivers connected to the same network. This may manifest itself e.g. in deterioration of operating parameters of or even permanent damage to electric appliances, and even worse, occurrence of direct safety hazard to the users.

Energy-saving light sources, including those of LED-type, constitute a continually growing group of receivers with nonlinear characteristics that drive older types of lamps out from the market. Use of LEDs for street lighting become more and more popular in Poland's towns; this type of light sources are used to illuminate streets, squares, parking lots, parks, bridges, and other components of city infrastructure. LED lamps successfully replace conventional light sources as they are characterized with high power efficiency that undoubtedly results in reduction of costs related to provision of lighting to urban and rural areas.

Studies on individual types of energy-saving light sources have revealed that receivers of that type result in significantly distorted currents being transmitted along the supply line that may be a cause of voltage distortions in the line. Among such receivers, light sources based on the light emitting diode (LED) technology show particularly adverse interaction with the network [1].

An important question arises: what is the effect of these unfavorable properties of LED-type light sources on the electric power quality? To assess parameters characterizing the electric power quality in lines supplying lighting system based on LEDs, it is possible to use different types of electric power quality recorders and analyzers.

The purpose of this paper is to assess individual electric power quality parameters and present unfavorable phenomena related to presence of LED-type light sources in the electric power system on the grounds of measurements made in a transformer/switching station (TSS), one line of which is used to supply street lighting made exclusively out of LED sources.

The paper discusses the measurement method with a schematic diagram of the setup in which the measurements were taken, presents characteristics of the instruments used for measurements and software employed for analyzing the results, and characterizes selected results of the analysis from the point of view of their conformity with standards concerning the electric power quality.

Electric power quality parameters

A review of definitions of the electric power quality proposed in the literature leads to the observation that most frequently the quantity is defined by reference to quantities concerning voltage, namely: voltage level, higher harmonics content, supply asymmetry and frequency values. With respect to voltage level, such quantities are analyzed as e.g.: voltage rms value, fluctuations, voltage surges, voltage dips, and short and long voltage decays. Description of the voltage waveform distortion resulting from presence of higher harmonics is possible by giving values of such parameters as order, amplitude, and phase of individual harmonics characterized by their indexes. The indicators most commonly used and recommended by P.N.-EN 50160 standard [2] include the *h*-Th harmonic share ratio,

(1) $$k_{h_U} = \frac{U_h}{U_1},$$

where U_h is the rms value of *h*-th harmonic voltage, and the voltage relative harmonic content known also as the total harmonic distortion and defined as

(2) $$THD_U = \frac{\sqrt{\sum_{h=2}^{\infty} U_h^2}}{U_1}.$$

A measure of asymmetry between negative- and positive-phase sequence components is the quantity

$$n_u = \frac{U_{\mathrm{neg}}}{U_{\mathrm{pos}}} \cdot 100\% , \quad (3)$$

where U_{neg} and U_{pos} are rms values of negative- and positive-phase sequence symmetrical voltage components, respectively.

As far as the supply voltage rated frequency equaling 50 Hz is concerned, its average value measured every 10 seconds should be contained within a range determined in PN-EN 50160 standard.

To determine the electric power quality in a specific case and at a determined point of the electric power system, it is necessary to measure a number of parameters that characterize it and check whether they are consistent with applicable standards.

Purpose of and the method used in measurements by means of electric power quality recorders

The fundamental purpose of the measurements consisted in making an attempt to determine the effect of introducing LED-type light sources to street lighting systems on the electric power quality. One of the street lighting supply lines has been loaded with LED-type light sources that replaced the lighting used previously.

To monitor the electric power quality at selected points of the electric power supply network, two electric power quality analyzers, Fluke 1760 and Fluke 435, have been used. The devices allow for continuous measurement of numerous quantities, including voltage, current, power (active, reactive, and apparent), power factor, energy, asymmetry, frequency and harmonics. Knowledge of these quantities is essential for monitoring of the power distribution system and supervising operation of the whole network or its selected components. The instruments operate within Class A regime, i.e. they meet requirements set out in IEC 61000-4-30 standard. Analysis of the obtained data was carried out with the use of software dedicated for the instruments used: Power Log program version 2.9 for Fluke 435 and PQ Analyse version 1.8.8 for Fluke 1760.

The measurements have been carried out in the setup shown in Figure 1.

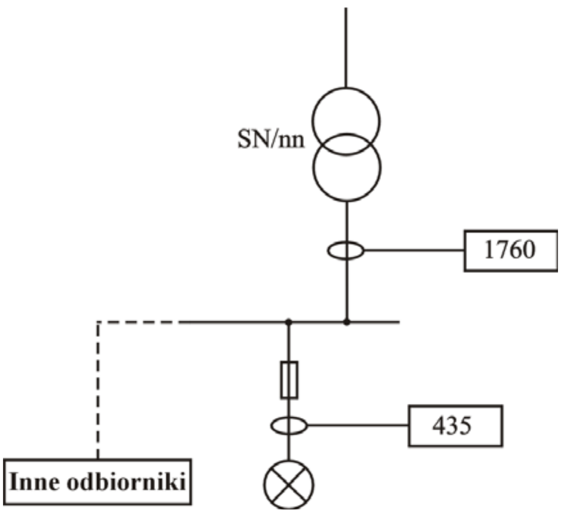

Fig. 1. Connection points for electric power quality recorders Fluke 1760 and Fluke 435

One of the analyzers, namely Fluke 435, was located on the line supplying the street lighting system in which LED-type light sources were employed, while the second one (Fluke 1760) has been connected on the secondary winding side of the medium-to-low voltage transformer inside the TSS — in order to measure selected parameters and determine the electric power quality. Before introduction of said change to the street lighting system, the electric power quality measured by means of Fluke 1760 meter was conforming with PN-EN 50160 standard and virtually no operating problems existed in this area.

Measurement results were registered within the space of one week, from November 13, 2012, 0:00 a.m., to November 20, 2012, 0:00 a.m., with measurement interval of 10 minutes.

As a basic measurement equipment for the present study, two instruments of a very high class and a very wide range of measuring options were available, but regrettably of two different types. This is a source of some difficulties in presenting results of the measurements and limitations concerning possibility to compare the obtained measurement results.

Example results of some electric power quality parameter measurements made at the TSS supplying the street lighting made of LED-type light sources

Figures 2, 4, 8, 10, and 12÷15 present selected results of measurements carried out at measurement points on the electric power network shown in Figure 1. Only results obtained with Fluke 1760 recorder are presented that show values of electric power quality parameters measured in order to determine the power quality at a selected measuring point. Through lack of space, analysis of measurements taken with the use of Fluke 435 is not shown here; it will be presented in another paper.

Apart from electric parameter measurement results, Figures 3, 5, 6, 7, 9, and 11 presents the related issues from the field of statistics — currently more and more used in the are of electric power quality.

To organize the figures with respect to individual electric quantities, they could be grouped in the following manner: Figures 2÷7 concern the supply voltage; Figures 8÷11 — the current; and Figures 12÷15 illustrate issues related to both reactive power and apparent power and the power factor PF.

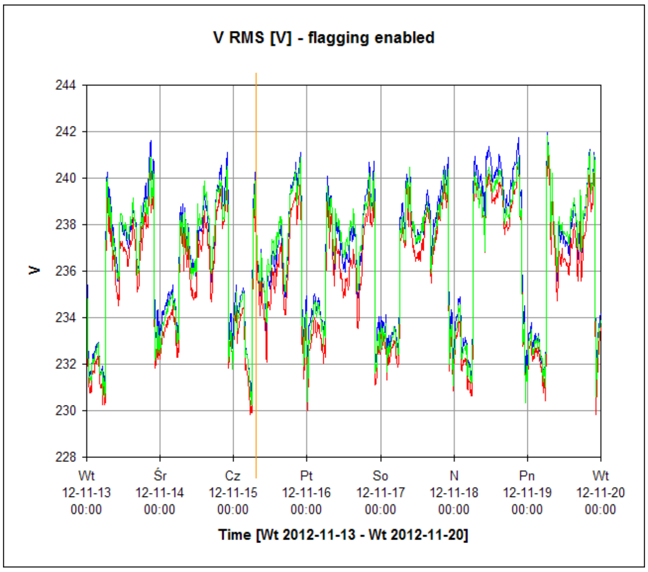

Fig. 2. Week's voltage rms values in three phases

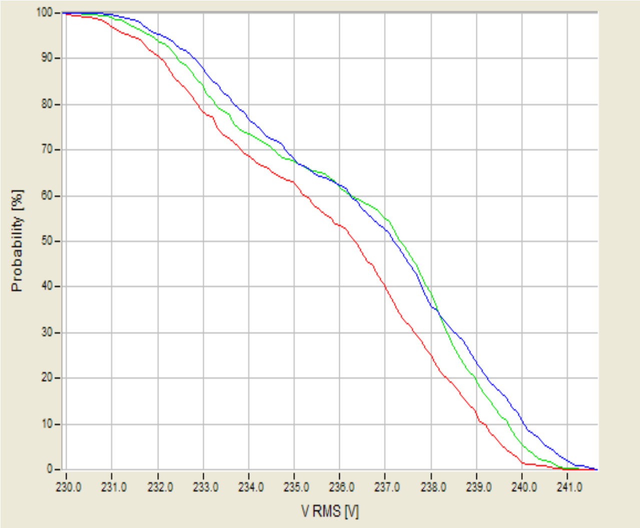

Fig. 3. Probability of occurrence of a given rms voltage value in the three phases

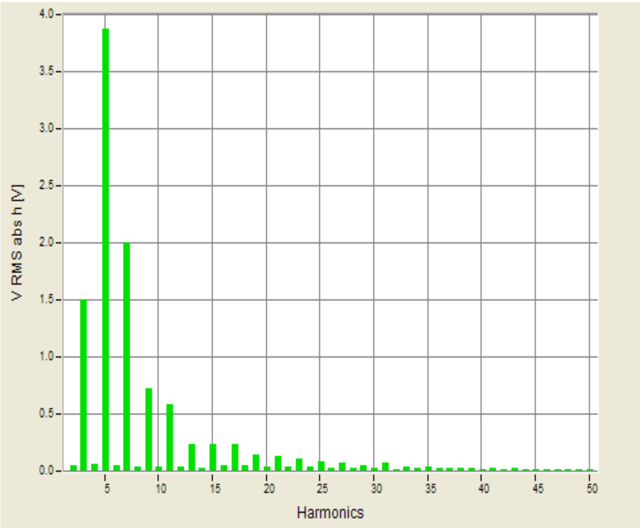

Fig. 4. An example spectrum of voltage harmonics in phase L3

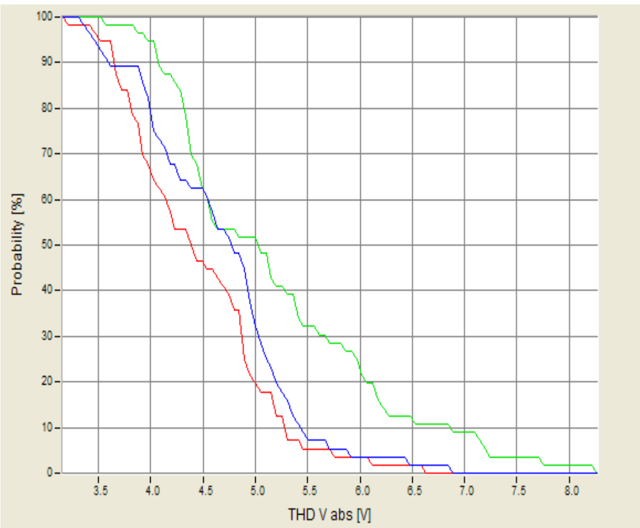

Fig. 5. Probability of occurrence of a given THD_U coefficient value

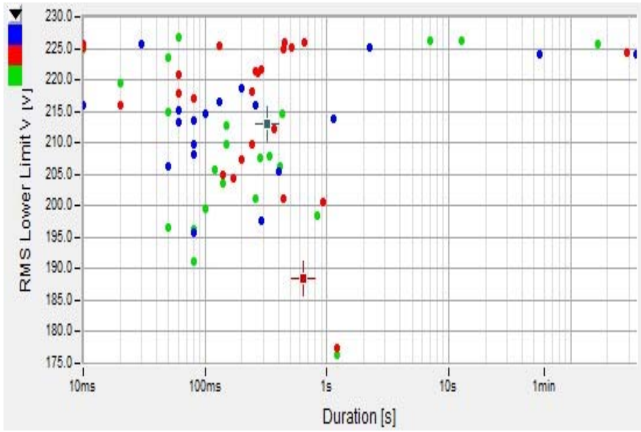

Fig. 6. Number and duration of rms voltage value fluctuations below the rated value

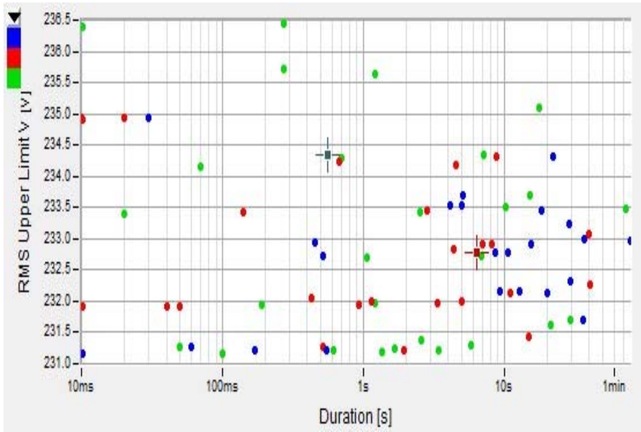

Fig. 7. Number and duration of rms voltage value fluctuations below the rated value

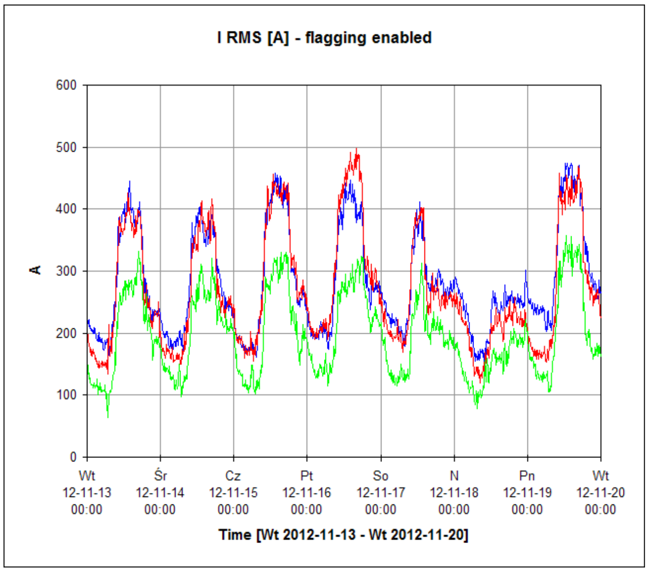

Fig. 8. Week's current rms values in three phases (L1 — blue, L2 — red, L3 — green) measured with Fluke 1760

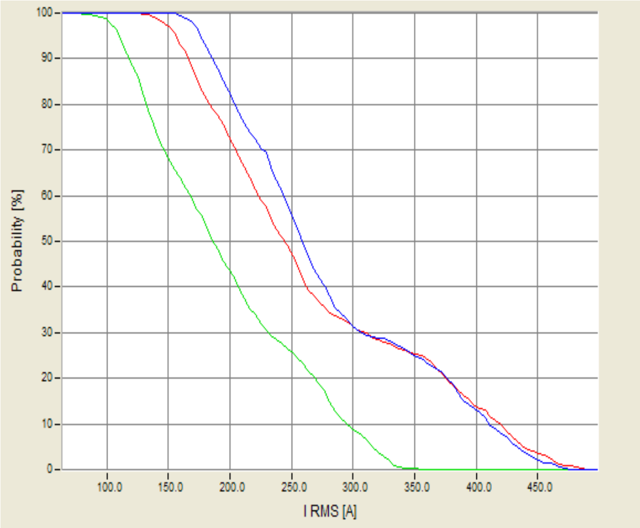

Fig. 9. Probability of occurrence of a given rms current value in three phases

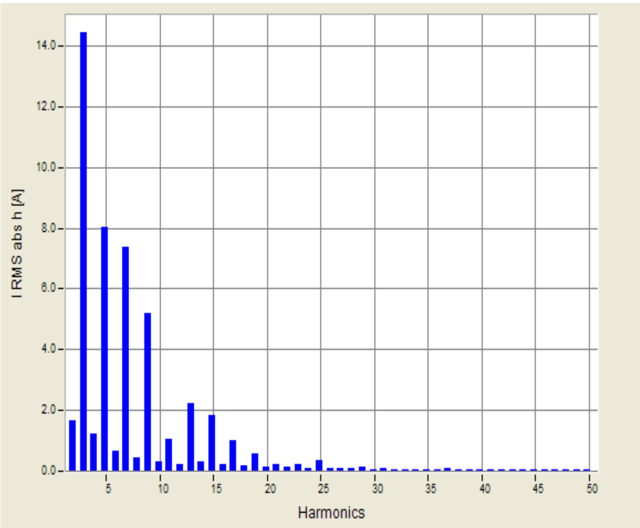

Fig. 10. An example spectrum of current harmonics in phase L1

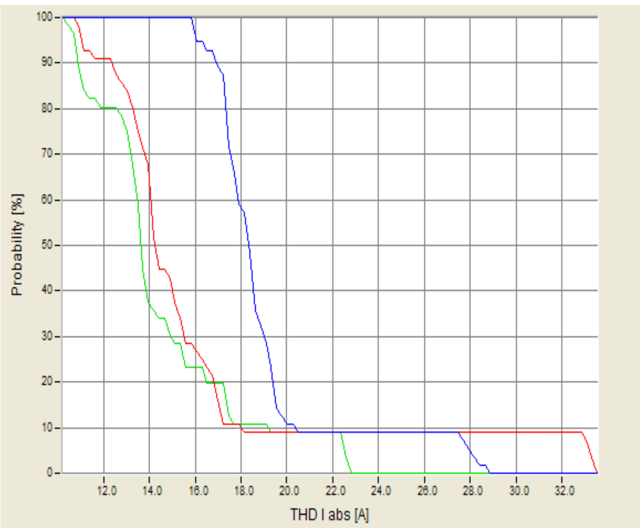

Fig. 11. Probability of occurrence of a given THD_I coefficient value

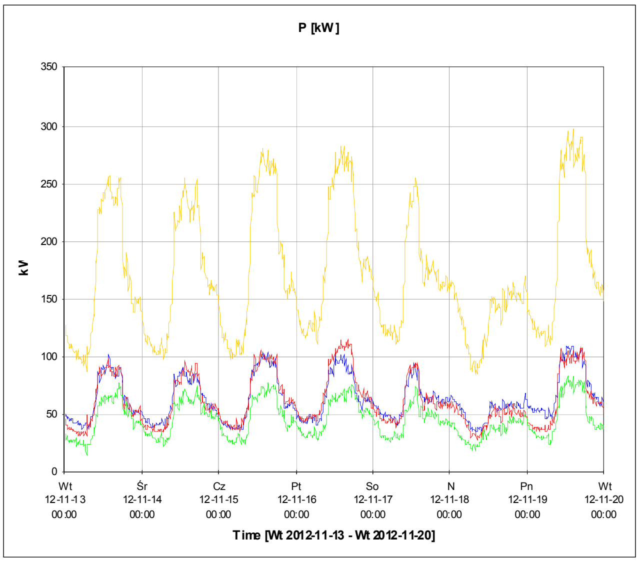

Fig. 12. A week's distribution of active power in each of the three phases and in total measured with Fluke 1760

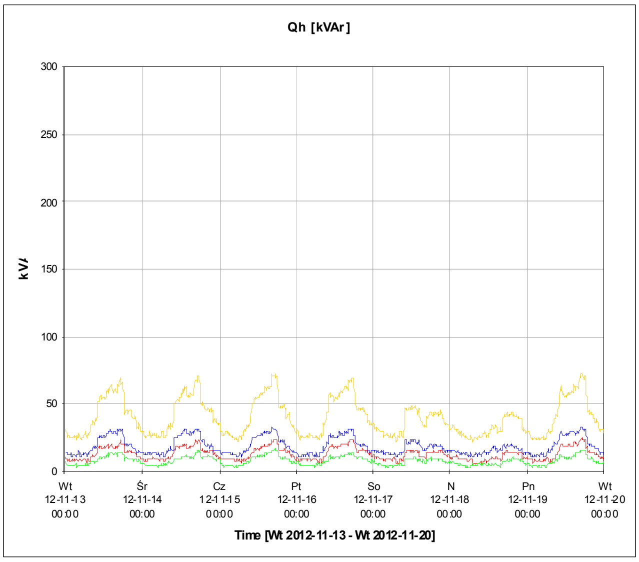

Fig. 13. A week's distribution of reactive power in each of the three phases and in total measured with Fluke 1760

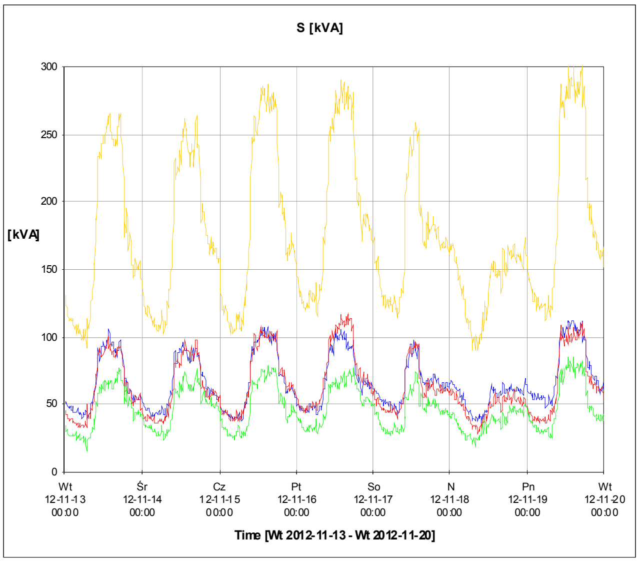

Fig. 14. A week's distribution of apparent power in each of the three phases and in total measured with Fluke 1760

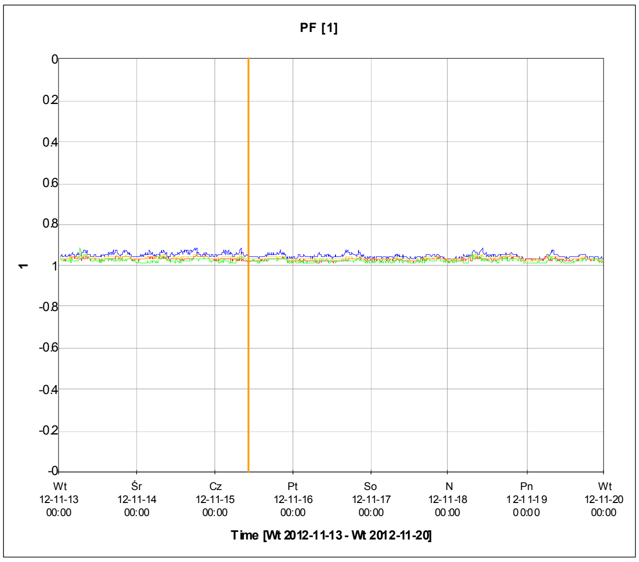

Fig. 15. Week's values of power factor (PF) values in each of the three phases and in total, measured with Fluke 1760

Summary

The study presented in this paper concerned the issue of the electric power quality. Measurement data for the analysis have been acquired in cooperation with PGE Rzeszów and were used for assessment of the electric power quality on the secondary winding side of medium/low voltage transformer at the TSS after introducing LED-type light sources to the street lighting system (powered from the TSS in question).

The measurements described above were of the piloting nature and were aimed at determining whether changes such as introduction of LED technology to the street lighting system will result in any significant deterioration of the electric power quality.

The fears of that nature arose in relation to tests carried out with individual LED-type light sources (bulbs and strips) of different rated powers revealed their adverse effect on the supply line. The result is the increased content of higher harmonics in voltage and current, resulting in higher THD coefficient values, as well as occurrence of reactive power comparable with, and in some cases even higher than the received active power. Relevant measurements show that the power factor PF can decrease significantly, to values of the order 0.3–0.6 [1].

To give a detailed answer to the question concerning the effect (either favorable or unfavorable) of introducing LED-type light sources to a street lighting system, more extensive measurement project is required with simultaneous recording of all types or receivers supplied from the TSS in question, as the fact may obviously affect the final conclusions.

It would be also advisable to collect material allowing to conduct a comparison of the status before and after lighting modernization, but regretfully neither studies nor measurements have been conducted in the past that could be used as a reference material.

It follows from a preliminary analysis of the performed measurements that at the measuring point where Fluke 1760 meter was installed, the electric power quality-related requirements are met. Some deviations from normal network parameters were observed, however they still have fallen within limits acceptable in the light of PN-EN 50-160 standard. However, meeting requirements of this standard alone does not mean necessarily that all adverse interaction of LED-type sources on the power supply network are eliminated.

Advantages connected with the use of LED-based light sources, such as electric power saving or much lower thermal emission, are unquestionable, but on the other hand, switching to light sources of that type on a larger scale will result in appearance of an enormous number of nonlinear receivers in the electric power supply system.

Another question that would require consideration concerns benefits related to the light effect and efficiency of light sources of that type, but these issues go beyond the scope of research carried out by the present author.

To sum up, in the face of the expected rapid wave of transitions to LED sources in street lighting systems, motivated mainly by reduction of both energy and operating costs, this issue should be definitely monitored in affected electric power supply systems.

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