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The usage of voltage and current fluctuation for localization of disturbing loads supplied from power grid

Abstract. *The paper discusses a set of the most frequently used measures of voltage fluctuation, which are useful in searching for disturbing loads. A procedure appropriate for searching the loads causing voltage fluctuation is proposed. The procedure utilizes two measures of fluctuation: P_{st} indicator as well as minimal and maximal values of voltages and currents. An analysis is included of four exemplary measuring results, recorded in a LV network. The effect of this analysis is a conclusion whether a disturbing load appears or not. The first Example illustrates the state in which it was possible to designate a disturbing load. The other Example shows a situation in which an unequivocal conclusion is impossible. In Examples 3 and 4 it was found that the loads under investigation are not dominant sources of voltage fluctuation. By means of the hereby analysis of measurement data the authors prove the diagnostic potential of the proposed procedure for searching for disturbing loads.*

Streszczenie. *W pracy zestawiono najczęściej stosowane miary zmienności napięcia, pomocne w poszukiwaniu odbiorników niespokojnych: wskaźnik P_{st}, wskaźniki wahań napięcia, wartości maksymalne i minimalne wartości skutecznej napięcia oraz wskaźnik ΔV_{10}. Zwrócono uwagę na możliwości diagnostyczne wartości maksymalnych i minimalnych prądu. Zaproponowano metodę postępowania podczas poszukiwania odbiorników wywołujących zmienność napięcia wykorzystującą wskaźnik P_{st} oraz wartości maksymalne i minimalne napięcia i prądu. Metodę tę zilustrowano z wykorzystaniem czterech przykładowych wyników pomiarów zarejestrowanych w sieci elektroenergetycznej niskiego napięcia. Efektem analizy wyników pomiarów było wnioskowanie o występowaniu bądź nie odbiornika niespokojnego. Pierwszy przykład obrazuje stan, w którym możliwe było wytypowanie niespokojnego odbiornika. Przykład drugi pokazuje sytuację, w której niemożliwe jest jednoznaczne wnioskowanie. W przykładach trzecim i czwartym stwierdzono, że badane odbiorniki nie są dominującymi źródłami zmienności napięcia. Za pomocą zamieszczonej analizy danych pomiarowych wykazano możliwości diagnostyczne przedstawionego sposobu poszukiwania odbiorników niespokojnych.* ***(Zastosowanie zmienności napięć i prądów w lokalizacji odbiorników niespokojnych zasilanych z sieci elektroenergetycznej)***

Keywords: disturbing load, voltage and current fluctuation, P_{st} indicator
Słowa kluczowe: odbiornik niespokojny, zmienność napięcia i prądu, wskaźnik P_{st}

Introduction

The evaluation of the power quality is a complex measuring task. It utilizes a set of quantities describing selected features of voltage. The measures of voltage quality can be divided into the following groups: for obligatory usage, standard, and supplementary. In the groups of measures for obligatory usage and in the standard group the short-term flicker severity indicator P_{st} is mentioned as a measure for estimating the voltage fluctuation in power network. Among the supplementary group we can count the maximal and minimal values of the rms value of voltage. In the paper the procedure was presented during the search for disturbing load with the use of the previously mentioned measures of voltage fluctuation, jointly with the maximal and minimal values of the rms value of current. The proposed procedure was presented in the course of analysing exemplary results of measurements obtained for four selected measuring points in LV network.

Measures of voltage and current fluctuation in power network

Measurement and estimation of voltage fluctuation in power network is a complex measuring task. As the most frequently applied measures of fluctuation can be mentioned: P_{st} indicator, voltage fluctuation indexes, maximal and minimal values of voltages, and ΔV_{10} index [1].

The short-term flicker severity indicator P_{st} and its measurement is specified in document [2]. A meter of flicker [3] popularly named “flickermetr” is used for measuring this indicator [4]. A detailed block diagram and sparse set of points of conversion characteristic of flickermeter are contained in standard [2]. A simplified block diagram of flickermeter is shown in Fig. 1.

Flicker, and actually its severity, is measured indirectly on the basis of voltage fluctuation. The structure of flickermeter signal line represents the cascade: light source-eye-brain. The value of the indicator describes the severity of flicker, caused by voltage fluctuation in defined measurement conditions (e.g. coiled filament gas-filled lamp 60 W). This value depends on the frequency, amplitude and shape of the voltage envelope [5]. The greater value of P_{st} indicator informs about much greater flicker severity, evoked with voltage fluctuation. At constant frequency and shape of the envelope, the value of P_{st} indicator is approximately linearly dependent upon the envelope amplitude [5, 6]. The dependence of P_{st} indicator on frequency, with fixed constant amplitude and shape of the envelope, is nonlinear. The influence of the envelope parameters onto the value of P_{st} can be estimated with the use of mathematical models placed in work [5]. Fig. 2 presents a diagram $P_{st} = \mathrm{f}(f_m)$ for a modulation of amplitude with sinusoid and rectangular signals with constant modulation depth $\left(\frac{\Delta U}{U}\right)$.

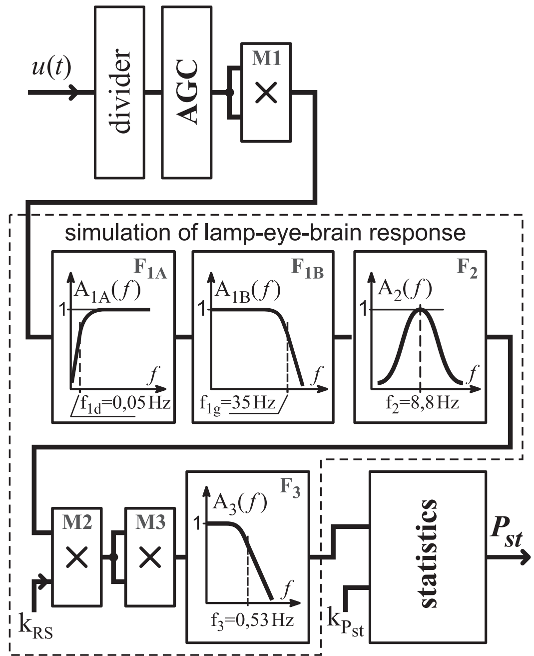


Fig. 1. Simplified block diagram of IEC flickermeter; $u(t)$ – input voltage; “divider” – input voltage divider, AGC – auto gain control; M1–M3 – multipliers; $\mathrm{F_{1A}}$, $\mathrm{F_{1B}}$, $\mathrm{F_2}$ and $\mathrm{F_3}$ – filters; $\mathrm{k_{RS}}$ and $\mathrm{k_{Pst}}$ – scaling coefficient, “statistics” – statistical conversion block; P_{st} – output signal

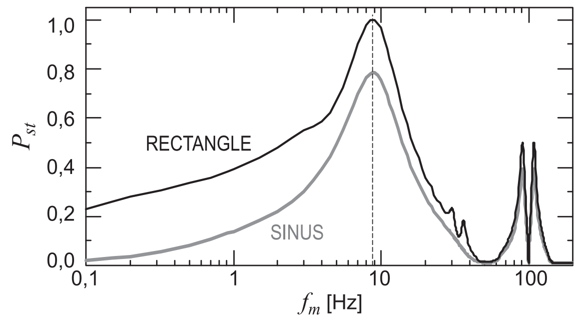


Fig. 2. Chart $P_{st} = \mathrm{f}\left(f_m, \left(\frac{\Delta U}{U}\right) = 0.2805\%\right)$ for amplitude modulation

In the characteristic shown in Fig. 2 there are three basic local extrema: for f_m =8.8; 91.2 and 108.8 Hz. The frequency for those extrema does not depend on the shape of modulating signal and modulation depth. The greatest value of P_{st} occurs for modulation frequency $f_m = 8.8\ \mathrm{Hz}$, which proves that for this value of frequency flicker is particularly severe for the recipient. The value $f_m = 8.8\ \mathrm{Hz}$, corresponding to the perceptibility maximum, is a specific feature IEC of flickermeter. The analysis of the characteristic indicates that it is possible to decrease the value of P_{st} indicator by changing the frequency of modulating signal. It means that a change in the rate of voltage fluctuation can decrease the flicker severity. For example, if the rate of voltage fluctuation corresponds to frequency $f_m = 4\ \mathrm{Hz}$, then by deceasing the value of this rate we can decrease the flicker severity. If the decrease of the rate of voltage fluctuation is not possible, e.g. due to the operation principle of the device generating the voltage fluctuation, we can limit the flicker severity by adequately increasing that fluctuation. When we intend to estimate the flicker severity occurring if a number of receivers working randomly are connected, or when a flicker source with long and changeable working cycles should be considered (e.g. arc furnaces), we apply the long term flicker severity P_{lt}. The value of this indicator is determined on the basis of dependence 1):

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

The indexes of voltage fluctuations, the amplitude and frequency of voltage fluctuations, are the measure of changes in the voltage rms value [7, 8]. Up to a certain boundary value of frequency, the amplitude and frequency of fluctuations describe directly the amplitude and frequency of the voltage envelope. The estimation of flicker severity, determined on the basis of these parameters, is more complex than in the case of P_{st} indicator. It is possible, instead, to estimate the severity for different measurement conditions (e.g. for different light sources). Fig. 3 shows acceptable voltage fluctuation limits for incandescent lights used by a large number of utilities. Two curves show how the acceptable voltage fluctuation magnitude depends on the frequency of occurrence. The lower curve shows a borderline where people begin to detect flicker. The upper curve is the borderline where some people will find the flicker objectionable [9].

The maximal value $U_{\max}$ and minimal value $U_{\min}$ of the rms value of voltage describe changes by means of the greatest and the smallest value in the discrimination period. Information such as: intermediate values, frequency and velocity of changes, are then omitted. However, when one dominant load has an influence, it is a diagnostically effective and easy to use measure. Useful from the diagnostic point of view are also the maximal value $I_{\max}$ and minimal value $I_{\min}$ of the rms value of current. The maximal and minimal values are subject to measurement and recording in most analysers of electric power quality. When using the maximal and minimal values, it is recommended to pay attention to the method of determining them in a given meter.

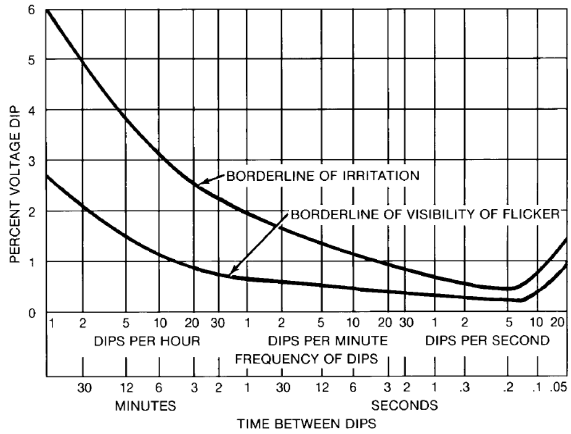


Fig. 3. Chart of voltage fluctuation limits for incandescent lights [9]

ΔV_{10} index is the measure of fluctuation severity, applied in the Far East countries. The value of this index is computed according to the following dependence [10]:

(2) $$\Delta V_{10} = \sqrt{\sum_n \left(a_n \cdot \Delta v_n\right)^2}$$

where: Δv_n - amplitude of sub/interharmonic component with frequency f_n, expressed relatively, a_n - scale factor for frequency f_n.

Fig. 4 presents a dependence of scale factor a_n in the function of frequency f_n for indicator ΔV_{10}. Analysing this characteristic, we can draw a very significant conclusion that for this indicator the extremum is localized for frequency $f_n = 10\ \mathrm{Hz}$, i.e. different than in case of P_{st} indicator.

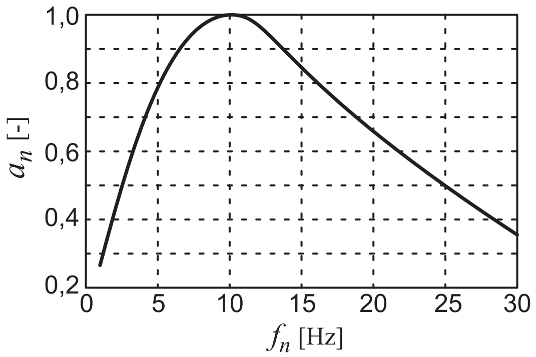


Fig. 4. Dependence $a_n = \mathrm{f}(f_n)$ the scale factor for frequency f_n (2) [11]

The value of this index is calculated on the basis of the values of sub/interharmonics. A considerable impediment in practical utilization of this measure are the difficulties in measuring the sub/interharmonics.

Examples of searching for disturbing loads in power network

The notion of disturbing load should be understood as an electric load characterised with repeated rapid changes in load [7]. The search for disturbing load in power network is discussed with the use of the measurement results recorded in four LV circuits. The measurements were carried out using a Power Quality Analyser – Topas 1000 [12]. With this meter it possible to measure the values of P_{st} indicator and the maximal and minimal values of voltages and currents. The maximal and minimal values are determined on the basis of rms values, determined at every half-period for the half-period of voltage. Taking into consideration the measurement potential of the device applied to analysing the recorded measurement results, the authors determined the waveform and mutual dependences of the following quantities: P_{st} indicator and the differences of maximal and minimal values of voltages $(U_{\max} - U_{\min})$ and currents $(I_{\max} - I_{\min})$, determined in 10-minute periods. For the purpose of standard and legal evaluation the electric energy quality, according to the recommendations contained in [13, 14], the research should be carried out within the period of at least one week. However, if the researchers' aim is to e.g. search for disturbing loads, the measurement duration can be shorter and adapted to diagnostic needs. Taking into consideration the clarity of the presented data, on the plots the measurement results were presented in shortened time intervals on the plots. Owing to the found phase symmetry, diagrams for one selected phase were placed.

Example 1

Figure 5 shows a waveform of the maximal, mean and minimal values of voltage U_f and phase current I_f.

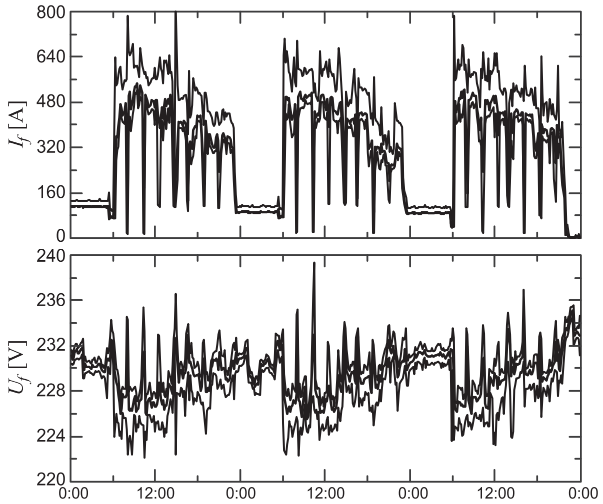


Fig. 5. Waveform of maximal, mean and minimal values of voltage U_f and phase current I_f

The way of presenting the measurement data shown in Fig. 5 is not optimal. Due to poor clarity, it is difficult to determine the relation between the fluctuations of voltage and current. It is easier to analyse the waveform of the differences of voltages $(U_{\max} - U_{\min})$ and currents $(I_{\max} - I_{\min})$. Figure 6 presents the plots of the differences of voltage and current for recorded measurement data from Fig. 5.

Comparison of the plots of the differences of voltage and current indicates their similarity. The decrease in current fluctuation is accompanied with the decrease in voltage fluctuation. A similar situation occurs when the current fluctuation increases, with an increase in the voltage fluctuation. The relation between the fluctuation of voltage and current can be evaluated on the basis of characteristics $(U_{\max} - U_{\min}) = \mathrm{f}\,(I_{\max} - I_{\min})$. Figure 7(a) shows such characteristic for the recorded values of voltage and current of investigated load. It indicates a correlation between the fluctuations of

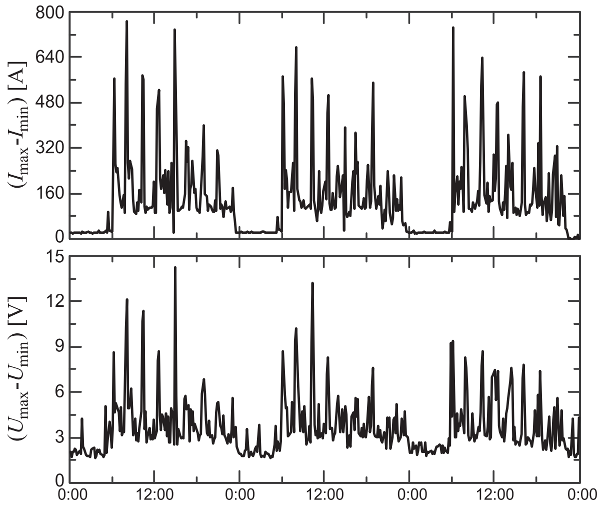
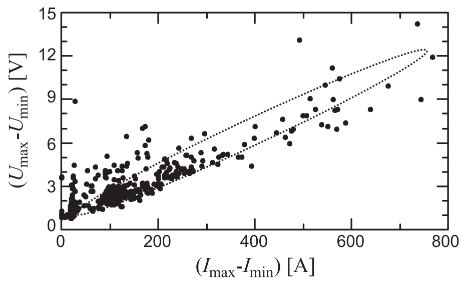
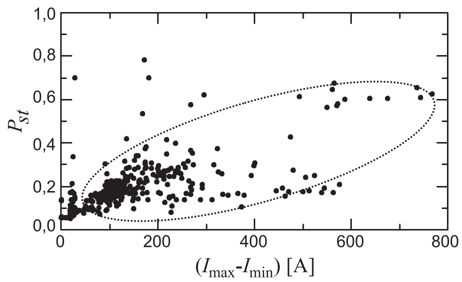


Fig. 6. Waveform of the differences of voltage $(U_{\max} - U_{\min})$ and phase current $(I_{\max} - I_{\min})$

voltage and current. Therefore, we can conclude that a load with the recorded current is the source of voltage fluctuations. It means that the search for disturbing load was ended with its designation. A complement to the dependence from Fig. 7(a) is characteristic $P_{st} = \mathrm{f}\,(I_{\max} - I_{\min})$, put in Fig. 7(b).



(a) $(U_{\max} - U_{\min}) = \mathrm{f}\,(I_{\max} - I_{\min})$



(b) $P_{st} = \mathrm{f}\,(I_{\max} - I_{\min})$

Fig. 7. Dependences $(U_{\max} - U_{\min}) = \mathrm{f}\,(I_{\max} - I_{\min})$ and $P_{st} = \mathrm{f}\,(I_{\max} - I_{\min})$ of the investigated load

The measuring points shown in Figs. 7(a) and 7(b) indicate that there is a function dependence between these variables. The correlation of P_{st} indicator and the difference of currents $(I_{\max} - I_{\min})$ from Fig. 7(b) is smaller than the correlation between the values of the differences of voltage and current. It may be caused by the fact that P_{st} indicator depends not only on the amplitude but also on the frequency and shape of the voltage envelope. Because the value of P_{st} indicator does not exceed the value of 0.8, the designated load is not severe.

Example 2

Figure 8 presents the plots of the fluctuation of voltage and current in the switching station of a big office building.

Based on a comparison of the plots presented in Fig. 8 it is difficult to estimate unequivocally the relation between

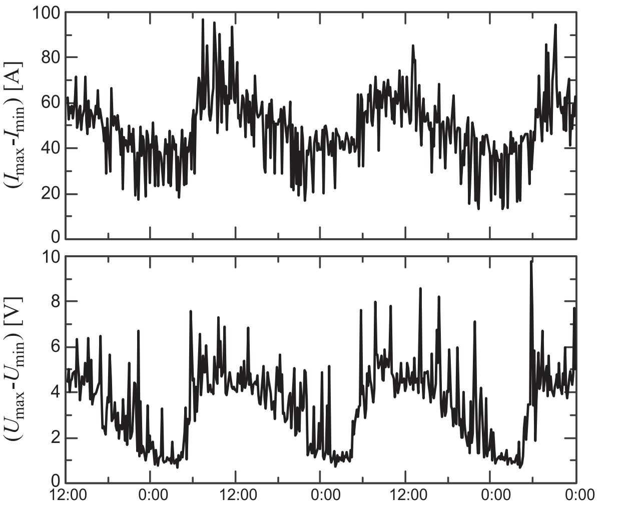
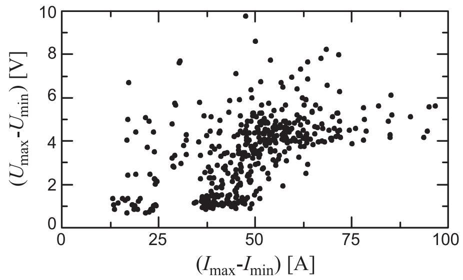
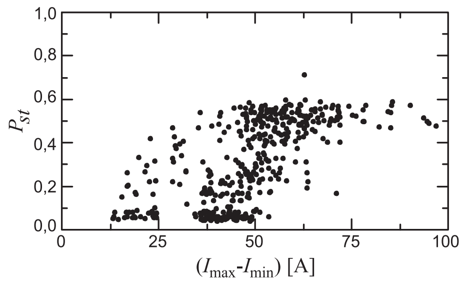


Fig. 8. Plots of differences of voltage $(U_{\max} - U_{\min})$ and phase current $(I_{\max} - I_{\min})$

the differences of voltage and current. It is indispensable to refer to dependences $(U_{\max} - U_{\min}) = \mathrm{f}\,(I_{\max} - I_{\min})$ and $P_{st} = \mathrm{f}\,(I_{\max} - I_{\min})$, shown respectively in Figs. 9(a) and 9(b).



(a) $(U_{\max} - U_{\min}) = \mathrm{f}\,(I_{\max} - I_{\min})$



(b) $P_{st} = \mathrm{f}\,(I_{\max} - I_{\min})$

Fig. 9. Dependences $(U_{\max} - U_{\min}) = \mathrm{f}\,(I_{\max} - I_{\min})$ and $P_{st} = \mathrm{f}\,(I_{\max} - I_{\min})$ of the investigated load

The distribution of measuring points shown in does not allow us to confirm or exclude unequivocally whether there is a dependence between the fluctuations of voltage and current. The gathered measurement results are not sufficient to unequivocally designate the disturbing load. It can mean that there is no influence of a dominant disturbing load. In Fig. 10 characteristic $P_{st} = \mathrm{f}\,(U_{\max} - U_{\min})$ was given.

The analysis of characteristic $P_{st} = \mathrm{f}\,(U_{\max} - U_{\min})$ proves that an increase in the value of P_{st} indicator is caused mainly by the increase in voltage fluctuation, and more exactly - increase in the envelope amplitude.

Example 3

In Fig. 11 the plots of the differences of voltages $(U_{\max} - U_{\min})$ and currents $(I_{\max} - I_{\min})$ were given, recorded in the LV switching station of a galvanizing plant.

The plots presented in Fig. 11 prove that there is no con-

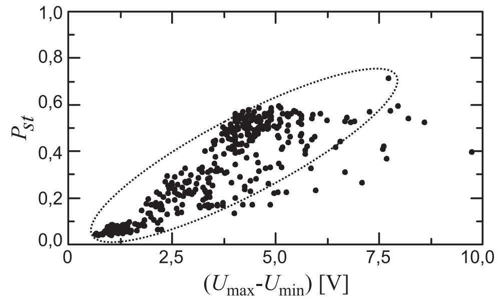


Fig. 10. Dependence $P_{st} = \mathrm{f}\,(U_{\max} - U_{\min})$ of the investigated load

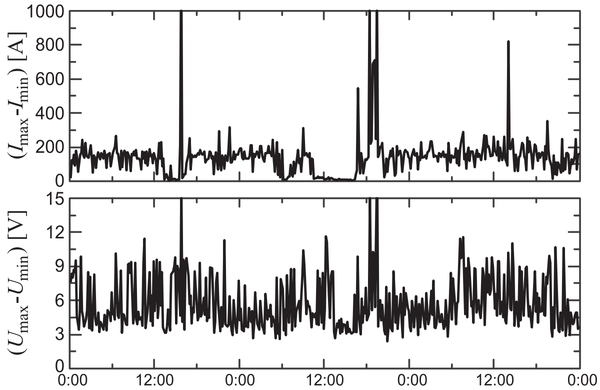
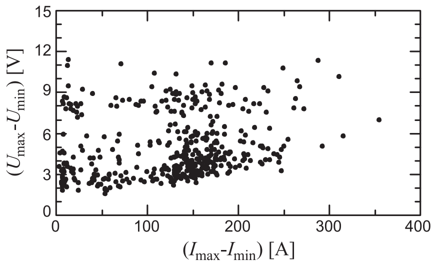
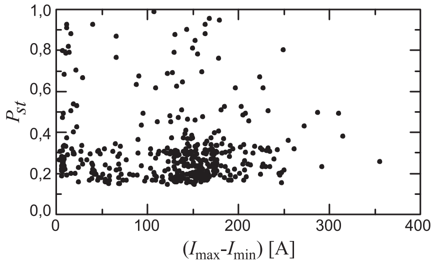


Fig. 11. Plots of differences of voltage $(U_{\max} - U_{\min})$ and phase current $(I_{\max} - I_{\min})$

siderable time correlation of the differences $(U_{\max} - U_{\min})$ and $(I_{\max} - I_{\min})$. This fact is confirmed in the dependences $(U_{\max} - U_{\min}) = \mathrm{f}\,(I_{\max} - I_{\min})$ and $P_{st} = \mathrm{f}\,(I_{\max} - I_{\min})$, shown in Figs. 12(a) and 12(b).



(a) $(U_{\max} - U_{\min}) = \mathrm{f}\,(I_{\max} - I_{\min})$



(b) $P_{st} = \mathrm{f}\,(I_{\max} - I_{\min})$

Fig. 12. Dependences $(U_{\max} - U_{\min}) = \mathrm{f}\,(I_{\max} - I_{\min})$ and $P_{st} = \mathrm{f}\,(I_{\max} - I_{\min})$ of the investigated load

The analysis of the diagrams shown in Figs. 11, 12(a) and 12(b) allows us to draw a conclusion that the investigated load, for which the values of currents, voltages and P_{st} indicator were recorded, is not the dominant disturbing load. The fact that voltages and currents are not correlated in the whole analysed period does not exclude such correlation in shorter periods. However, this problem will not be analysed in this paper.

Example 4

In Fig. 13 the plots of the differences of voltages $(U_{\max} - U_{\min})$ and currents $(I_{\max} - I_{\min})$ were given, which were recorded since Friday till Sunday in the LV switching station of a coffee-roasting room.

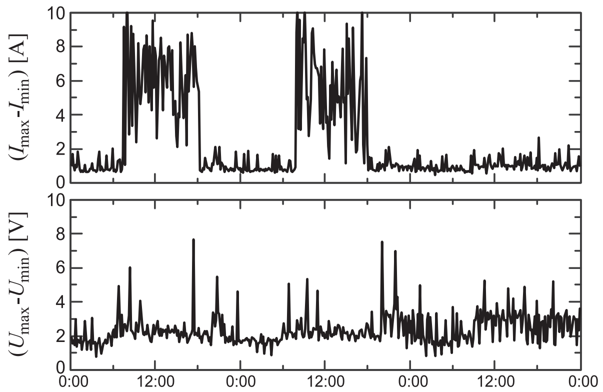
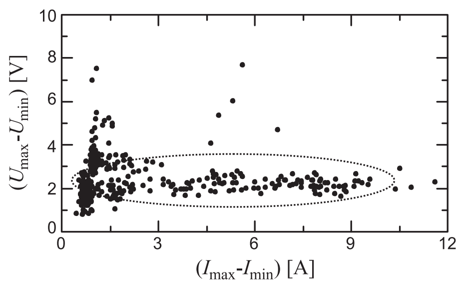
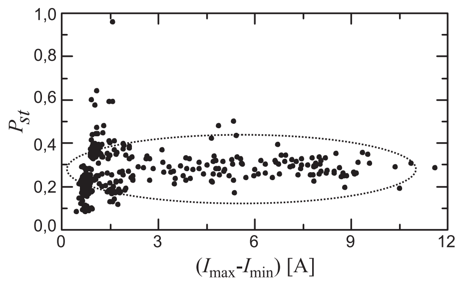


Fig. 13. Plots of differences of voltage $(U_{\max} - U_{\min})$ and phase current $(I_{\max} - I_{\min})$

The plots shown in Fig. 13 indicate that there is no periodic increase in the value of current fluctuation without correlated, considerable increase in voltage. In order to ensure a more exact determination of the influence of current fluctuation onto voltage fluctuation, characteristics $(U_{\max} - U_{\min}) = \mathrm{f}\,(I_{\max} - I_{\min})$ and $P_{st} = \mathrm{f}\,(I_{\max} - I_{\min})$ were given, which were presented in Figs. 14(b) and 14(b), respectively.



(a) $(U_{\max} - U_{\min}) = \mathrm{f}\,(I_{\max} - I_{\min})$



(b) $P_{st} = \mathrm{f}\,(I_{\max} - I_{\min})$

Fig. 14. Dependences $(U_{\max} - U_{\min}) = \mathrm{f}\,(I_{\max} - I_{\min})$ and $P_{st} = \mathrm{f}\,(I_{\max} - I_{\min})$ of the investigated load

The distribution of measuring points in characteristics $(U_{\max} - U_{\min}) = \mathrm{f}\,(I_{\max} - I_{\min})$, Fig. 14(a), and $P_{st} = \mathrm{f}\,(I_{\max} - I_{\min})$, Fig. 14(b), confirms the prior notice that there is no correlation between the fluctuation of voltage and current, as well as between the value of P_{st} indicator and current changes. It allows us to draw a conclusion that a load with the analysed current fluctuation is not the source of recorded voltage fluctuation, thus not being the disturbing load.

Summary

The paper presents examples of searching for disturbing loads in power network, with the use of recorded fluctuations of voltages and currents. The authors show a procedure that can be helpful in identifying the reasons which cause the lowering of the electric energy quality. The procedure utilizes two measures of voltage fluctuation: the short-term flicker severity indicator P_{st} and the maximal and minimal rms values. In Example 1 - based on the analysis of recorded measurement results - a disturbing load was designated unequivocally. The measurement results from Example 2 are not sufficient to unequivocally determine whether there was a disturbing load at the place where the experiment was run. By turns, the analysis of recorded data in Examples 3 and 4 allows us to draw a quite probable conclusion that the analysed loads are not disturbing loads.

The maximal and minimal values are available among the measurement results of most power quality analyser. However, they are usually omitted in the process of searching for disturbing loads. Based on the analysis of exemplary measurement results, the authors demonstrate that the maximal and minimal values are useful in the diagnostics of the power network condition. Together with P_{st} indicator, the maximal and minimal values of voltages and currents are a useful diagnostic tools.

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