EVALUATION OF VOLTAGE DISTURBANCES GENERATED BY LOADS WITH DYNAMICALLY CHANGING DEMAND

european student magazine

Numer 1 / 2023

Maciej **Rzymkowski**

University of Technology and Humanities, Faculty of Transport, Electrical Engineering and Computer Science, Malczewskiego 29, 26-600 Radom, Poland, maciejrzymkowski@gmail.com

Abstract - In a low-voltage network, despite supplier guarantees, disturbances that affect the quality of electric power and supply continuity can arise. Their causes may stem from extreme weather conditions, poor conditions of transmission equipment, and failures resulting from human factors. This article also addresses another factor, namely the impact on power quality in a low-voltage network of a consumer operating loads with dynamically changing demand. An analysis of changes in indicators characterizing power quality was presented and compared to permissible values applicable in Poland for low-voltage networks.

Keywords- power quality, light flicker, high harmonics, damage

INTRODUCTION

As a result of converting various types of primary energy, electrical energy (secondary) can be obtained [29]. Electrical energy is characterized by a range of parameters, including voltage and current intensity, voltage frequency, and voltage curve shape. These parameters are not constant and can vary depending on various factors, resulting in different values.

For electrical devices to function properly, it is necessary to ensure that the parameters of the supplied energy have appropriate values. Otherwise, electrical devices may operate improperly or even become damaged.

In Poland, the permissible values of parameters characterizing the quality of electrical energy in public networks are defined by the Ministerial Regulation of May 4, 2007 [28], which is largely based on the European Standard PN-EN 50160:2010 [27].

The quality of electrical energy is influenced by many aspects. There are situations where disturbances occur despite assurances from the network operator about nominal values of the supplying voltage, which directly affect the parameter values characterizing energy quality and the continuity of power supply to consumers. The causes can include technical failures in the network [4,5], exceptional weather conditions [6], as well as the consumers themselves, who use devices with dynamically changing loads in their households [2,12].

This article is based on research conducted in relation to the thesis titled "Evaluation of the quality of electrical energy in the common attachment point of a selected consumer generating disturbances in the supply network" [21]. The thesis was supervised by Zbigniew Olczykowski, who, in his research activities, focuses on the impact of disturbing loads on energy quality in the power system, including arc furnaces [11,13-17], and electric traction [18,19].

I. TYPES OF SUPPLY VOLTAGE DISTURBANCES

There are several types of disturbances that occur in the power network:

- Changes in voltage values can occur at various stages:
  - During energy generation, voltage changes can arise due to difficulties in maintaining a balance between energy production in power plants and its consumption by consumers.
  - Transmission of electric energy involves changes in network topology, connection operations, regulation, interferences, and numerous failures, all of which can lead to voltage fluctuations.
  - Electrical energy consumers cause irregular network loads by switching various electrical devices on and off.
- Voltage asymmetry in 3-phase systems can occur in two cases. The first case is asymmetrical sources, which may result from voltage imbalances generated in individual generator windings or unequal phase shift angles [1]. The causes of source asymmetry can also include supply system failures, such as incorrect transformer operation, inverter malfunctions, damaged wires, contact looseness, and short circuits. The second cause of voltage asymmetry in the power grid is consumers whose faults can lead to uneven phase loading. Also, uneven loading of a 3-phase network by single-phase loads can lead to asymmetry [5,6,15].
- Voltage fluctuations occur in the form of a series of changes in the effective voltage value. Voltage fluctuations also include a series of changes in the envelope of the voltage waveform over time. This disturbance's characteristics include the amplitude of voltage changes, the frequency of voltage changes,

and the shape of voltage fluctuations. The main cause of voltage fluctuations is the time variability of reactive power from consumers, attributed to heavy industrial machinery such as arc furnaces, rolling mill drives, hoists, etc. Voltage fluctuations also result from starting asynchronous motors, welders, saws, high-power regulators, compressors, pumps, electric hammers, and others. Voltage fluctuations have a direct impact on flicker phenomenon, which significantly affects visual acuity and general human fatigue [3,4,5,7,13].

- Voltage sags are described by two quantitative parameters: the minimum effective voltage value during the sag and the duration of the disturbance. Voltage sags are unpredictable and random voltage drops between 90% and 10% of the rated voltage. As mentioned at a symposium [2], many business owners report that in their industrial plants, contactors disconnect the supply completely when the voltage drops to 50% of the nominal voltage. The duration of voltage sags depends on the speed of protective device operation. The theoretical duration of voltage sag ranges from 10 ms to 1 minute (sometimes 3 minutes), and many faults can be eliminated within 100-500 ms. According to industry literature [8], modern power quality analyzers enable precise measurement of the network state in very short time windows (about one-hundredth of a second) and analysis of the voltage curve shape during that time [8].
- Harmonic distortions indicate the degree of distortion of sinusoidal voltage and current waveforms by nonlinear load consumers. They arise due to the network's loading with nonlinear working devices. Among industrial and individual consumers, harmonic component generators include inverters, transformers and reactors, arc furnaces, induction furnaces, welding equipment, converters, rectifiers, uninterruptible power supply systems (UPS), computers, compact light sources, LEDs, as well as TVs, monitors, printers, video devices, and electronic ballasts. Significant sources of harmonic-related interferences are impulse power supplies, which, despite their low individual power, can be a problem due to their significant presence and widespread use [4,6,16,23].
- Power outages mean a lack of continuous electrical energy supply to consumers. Power supply interruptions can lead to financial losses and even pose a threat to human health or life [20,22]. Power supply interruptions can be classified in two ways:
  1. A decrease in the supply voltage value at the PWP location below 1% of the rated voltage, which practically means a complete voltage loss [9].
  2. A decrease in the supply voltage value at the PWP location to a level below the useful value for powered devices.

In both cases, the devices' ability to perform their functions is lost.

The lowest level of power supply reliability can be observed in rural areas. This is because farms are situated at a significant distance from each other, and the power demand is relatively small. Thus, suppliers use the cheapest and simplest protection systems to prevent consumers from losing power. Power lines in rural areas do not have backup power, as is the case in urban areas. Therefore, breaking an overhead line results in consumers being deprived of electrical energy until the fault is fixed, without the possibility of supply from the operational backup network [24].

- Voltage surges involve a sudden, short-duration voltage increase of at least 10% above the rated value. Voltage surges can have many negative consequences, such as damaging electrical devices and power systems. The sources of voltage surges can be divided into two categories. The first category includes externally generated surges, which result from direct and induced atmospheric discharges. The second category includes internal surges, which include transient surges—these can occur due to sudden disconnection of high-current-consuming devices. Short-circuit surges occur due to ground faults. The final type in this category is switching surges, which occur during the disconnection and reconnection of unloaded lines or during automatic fault clearing. In [25], faults are categorized as electrical and non-electrical. Electrical causes include switching surges, connection errors, atmospheric discharges in the vicinity or direct lightning strikes on power lines, prolonged excessive current loads leading to insulation damage. Non-electrical causes include factory defects in devices, mechanical network component damage, insulation moisture and pollution, natural forces, and animals. To protect electrical devices from damage caused by surges, lightning protection installations and surge limiters are used [26].
- The flicker index is calculated based on the analysis of voltage values, contrary to what its name might suggest, stemming from changes in lighting intensity. Flicker is the main effect of voltage fluctuations [3,4,14]. This phenomenon involves the uncontrolled and abrupt change in the luminance of light sources. Such visual effects can adversely affect human visual systems, causing discomfort, dizziness, rapid fatigue, and even serious nervous system disorders. One of the sources of voltage fluctuations and consequently the flicker phenomenon is the dynamic nature of load changes in high-power electrical devices [11,13,19].

II. QUALITY OF ENERGY EVALUATION CRITERIA

The disturbances in the electric energy parameters mentioned in Chapter I are measurable and have their values, and their permissible levels are described in the standard [27] and the Regulation [28], mentioned in the article's introduction. Adhering to the guidelines and normative values described in these documents is meant to ensure the correct and safe operation of electrical devices. According to these documents, the permissible values of electrical energy parameters are as follows:

- Voltage Frequency

  The average value of the fundamental voltage frequency, measured over 10 seconds, should fall within the range:

  a) 50 Hz ±1%, which is from 49,5 Hz to 50,5 Hz for

99,5% of the measurement time,
b) 50 Hz +4% / -6%, which is from 47 Hz to 52 Hz for 100% of the measurement time.

• Voltage RMS Value
The rated supply voltage value Un is determined based on a set of 10-minute average RMS values each week, during normal network operation. Ninety-five percent of measurement results in each of these sets should not exceed ±10% of the rated voltage value.

• Flicker Index
The long-term flicker severity value Plt resulting from voltage fluctuations, each week, during normal operation, for 95% of the time, should not exceed 1.

• Voltage Asymmetry in Three-Phase Systems
The asymmetry of the supply voltage should be within the range of 0% to 2%, in 10-minute average RMS values, each week, during normal operation, for 95% of the time.

• Voltage Harmonics
The values given in Table 1 are the limit values of voltage harmonics occurring under normal conditions, during each week, for 95% of the measured 10-minute average RMS values.

Table 1. Values of Individual Voltage Harmonics at the Consumer Connection Point

Odd harmonics				Even harmonics	
Not a multiple of 3		being multiples of 3			
Harmonic order (h)	Relative amplitude (u_h)	Harmonic order (h)	Relative amplitude (u_h)	Harmonic order (h)	Relative amplitude (u_h)
5	6,0 %	3	5,0 %	2	2,0 %
7	5,0 %	9	1,5 %	4	1,0 %
11	3,5 %	15	0,5 %	>4	0,5 %
13	3,0 %	>15	0,5 %		
17	2,0 %				
19	1,5 %				
23	1,5 %				
25	1,5 %				
Attention! Values of harmonics of orders greater than 25 are not given because they are small but largely unpredictable due to resonant effects.					

• THD (Total Harmonic Distortion)
The coefficient of distortion by higher voltage harmonics (up to the 40th harmonic inclusive) must not exceed the value of 8%. This coefficient is calculated based on the formulas:

$$THD_U = \frac{\sqrt{\sum_{k=2}^{K=40} U_k^2}}{U_1} \cdot 100\% \tag{1}$$

$$THD_I = \frac{\sqrt{\sum_{k=2}^{K} I_k^2}}{I_1} \cdot 100\% \tag{2}$$

III. CHARACTERISTICS OF THE DISTURBANCE-GENERATING CONSUMER

In the sawmill, machines with various electrical parameters operate five days a week. The two largest machines are the sawmills. They derive their mechanical energy from two 3-phase electric motors, each with a power of 30 kW and 5 kW, respectively.

Figure 1, Figure 2, Figure 3 depict one of the two largest and most energy-intensive machines in the sawmill.

Fig. 1. Sawmill no. 1 with the visible 30 kW motor on the right side, driving the set of vertical saws. [Own work]

Fig. 2. Nameplate of a 3-phase 30 kW motor. [Own work]

Fig. 3. The sawmill no. 1 with the motor (5 kW) visible on the right, driving the log feeder unit. [own work]

Within the sawmill premises, the owner has installed photovoltaic panels, thus becoming a producer-consumer of electrical energy. The photovoltaic panels visible in Figure 4 are capable of generating electrical energy with a power of 40 kW in a 3-phase system, allowing the sawmill to partially cover its energy demand on sunny days.

Fig. 4. Photovoltaic panels integrated with the recipient's network. [own work]

In Figure 5, the inverter and the protection system for operating the photovoltaic installation are visible. In Figure 5, the inverter and the protection system for operating the photovoltaic installation are visible.

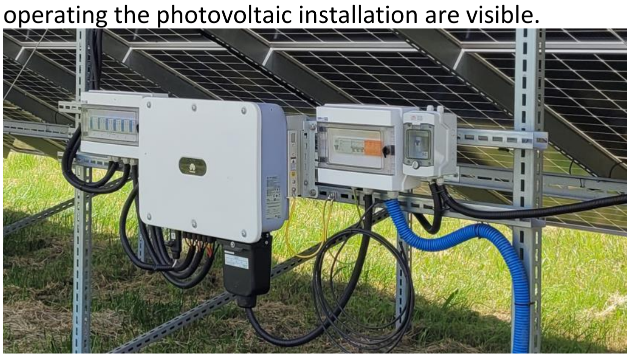

Fig. 5. Inverter and protection system in a photovoltaic installation. [own work]

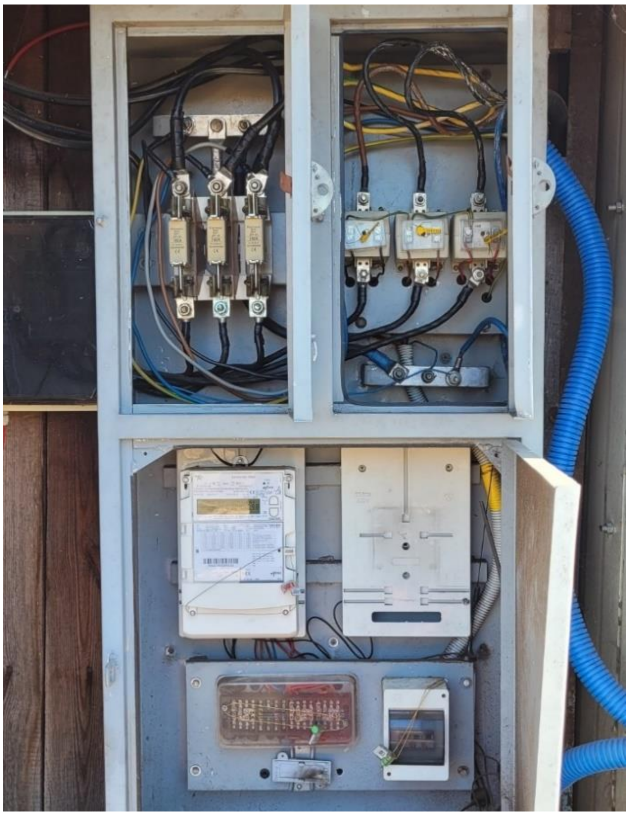

Fig. 6. Interior of the customer's switchboard. [own work]

Figure 6 depicts the contents of the distribution cabinet, which includes power fuses with gG-gL characteristics and permissible current values of 160 A for each phase, current transformers, a three-phase compact disconnect switch, and an electricity consumption meter.

IV. MEASUREMENT METHODOLOGY

To determine the values of the electrical energy parameters described in the second chapter, a series of measurements were conducted. For this purpose, the PQM-710 analyzer from SONEL was used. The studied object, in which receivers with dynamically changing loads operate, was a sawmill, a portion of which along with the distribution cabinet is presented in Figure 7.

Fig. 7. Fragment of the sawmill plant building with a switch cabinet [own work]

The PQM-710 analyzer shown in Figure 8 is an advanced and versatile measurement device equipped with numerous attachments, clamps, probes, and clippers that enable connection to the measuring circuit.

Fig. 8. SONEL PQM-710 portable electricity analyzer with accessories. [own work]

The presented PQM-710 analyzer features a range of conveniences, such as remote monitoring of current measurements through the GSM module, data transfer through the USB port, synchronization with Coordinated Universal Time (UTC) via the built-in GPS module, enabling disturbance analysis with accuracy down to tens of nanoseconds.

The PQM-710 analyzer allows for measurements of various parameters defining the quality of electrical energy. These parameters include:

- Flicker indices (Plt and Pst)
- Powers and energies (active power, reactive power,

apparent power, distortion power, power factor)
- Harmonics (active power of harmonics, reactive power of harmonics)
- THDU, THDI coefficients
- TDD coefficient
- K coefficient
- Interharmonics
- Control signals
- Asymmetry (supply voltage asymmetry, load current asymmetry, receiver asymmetry)
- Sags, swells, and interruptions in voltage
- Rapid voltage changes (RVC)
- Transients and surges
- Phase shifts (cosϕ)

The analyzer has been installed in the distribution panel supplying the sawmill with electrical energy, as depicted in the diagram shown in Figure 9.

In the electrical installation of the tested facility, a TN-C network configuration is present, where the protective conductor and neutral conductor are connected and grounded together.

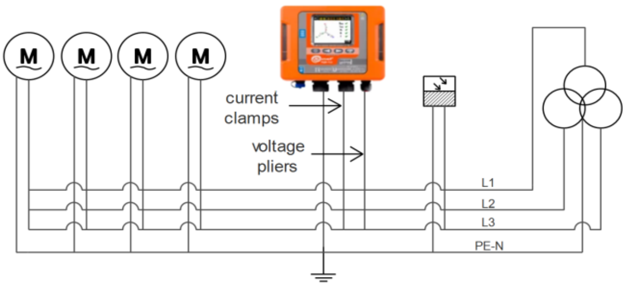

Fig. 9. Connection diagram of the PQM-710 analyzer with the sawmill's electrical installation. [own work]

Flexible clamps F-1A1 were attached to each of the four conductors (L1, L2, L3, PE-N). Similarly, crocodile clips K-01 and K-02 were connected to each of the conductors at the insulated portion of the wire or terminal, as shown in Figure 10.

The measurements were carried out in two stages. During the first stage, measurements were conducted for one hour with a 10-second averaging interval. In the second measurement, following the guidelines of the Minister's Regulation dated May 4th, 2007, the duration was 7 days.

V. MEASURED DATA ANALYSIS

The "SONEL Analysis 4.6.5" computer program was used to analyze the measurement data collected by the PQM-710 analyzer. It allows for transparent analysis of disturbances occurring in the tested network.

5.1. Measurements of electricity disturbance levels in a 1-hour study

Voltage frequency
- Nominal frequency fnom=50,00 Hz
- The minimum frequency value is fmin=49,92 Hz
- The maximum frequency value is fmax=50,04 Hz
- Amplitude of changes 0,12 Hz

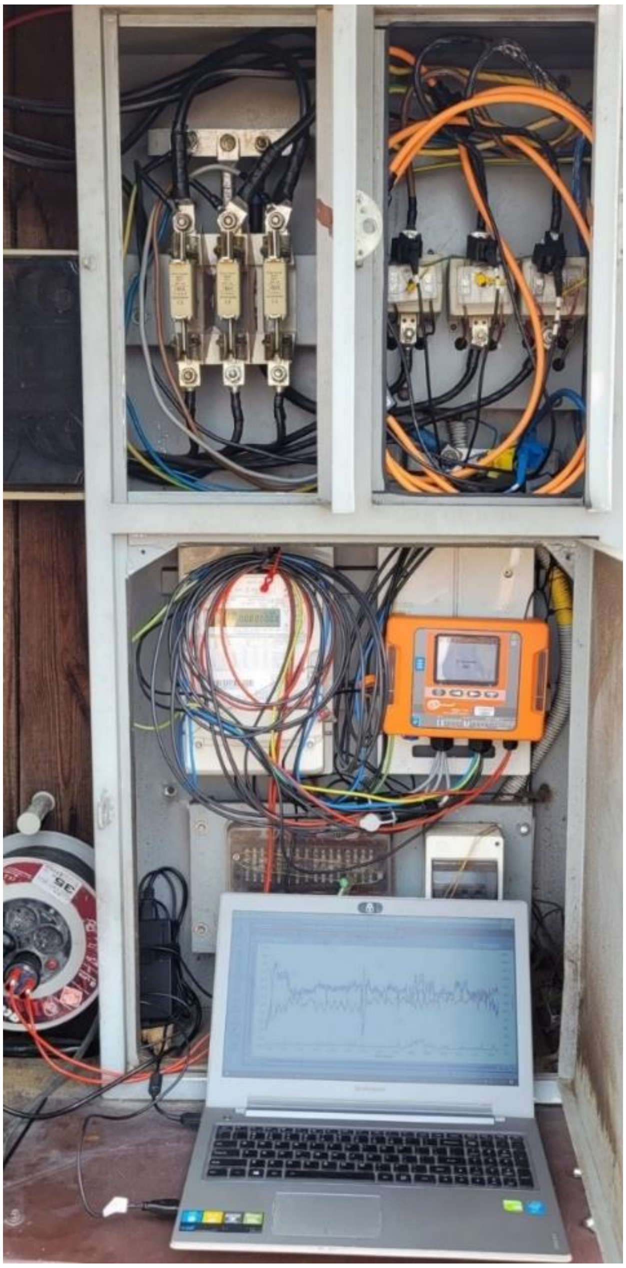

Fig. 10. Complete measurement set during registration [own work]

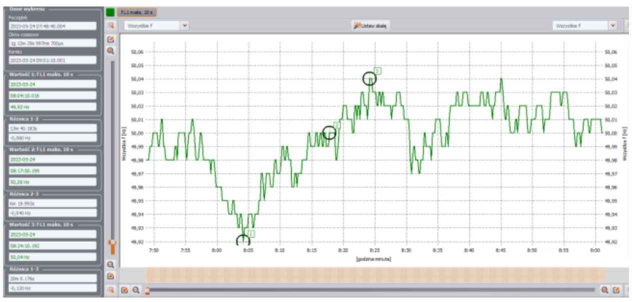

Fig. 11. Changes in the voltage frequency value

<u>The dependence of the voltage value on the value of the current</u>

Analyzing the current values relative to voltage for one of the phases of the tested object, a correct response of these parameters to each other can be observed. An increase in current corresponds to a decrease in voltage, and vice versa. Using the example from Figure 12, the smallest current value of I=65,30 A is accompanied by a simultaneous maximum voltage rise of U=236,60 V. The highest current demand in this study occurred at 08:27:10.196 and reached I=146,1 A.

Fig. 12. Changes in the voltage value with changes in the current value

<u>Current surge phenomenon</u>

During the 1-hour study, the analyzer recorded, in 10-second time intervals, a current surge phenomenon that likely occurred due to the sudden start of a high-power motor. Figure 13 presents a graph and numerical values of the current at the moment of the current surge. During the surge, the current values in the first phase reached the following levels:

I_{min}=92,79 A
I_{avg}=127,9 A
I_{max}=267,8 A

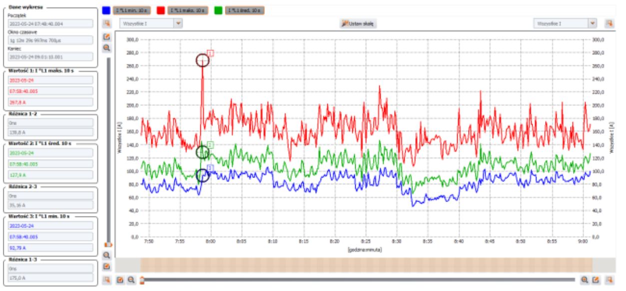

Fig. 13. Waveform showing the phenomenon of current surge

The voltage response to the occurred current surge was also subjected to analysis. As indicated by the data recorded by the analyzer, the voltage at the moment of the surge dropped to 220,3 V, resulting in a voltage decrease of 4,22% compared to the nominal value. Meanwhile, the current during the surge changed from 134,2 A to 267,8 A, representing an increase in current value by 99,6%. Figure 14 illustrates the behavior of current and voltage during the occurrence of the current surge in the form of a graph.

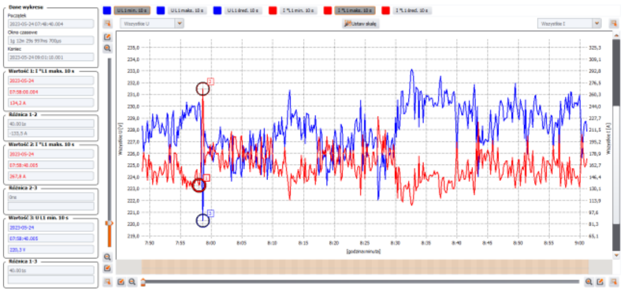

Fig. 14. Changes in values showing the relationship between current and voltage during a current surge

Figure 15 displays a phasor diagram as well as a tabular compilation of the phase shift level of current relative to voltage in each of the three phases.

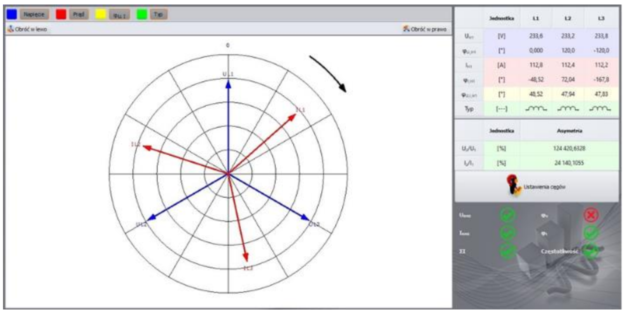

Fig. 15. Phase phasor diagram: L1, L2, L3

<u>Harmonics of currents</u>

Due to the diversity of electrical devices operating in the sawmill, harmonic values were generated in the facility's network. Figures 16 and 17 depict harmonic current values in the form of graphs, respectively for the three phases and the neutral conductor.

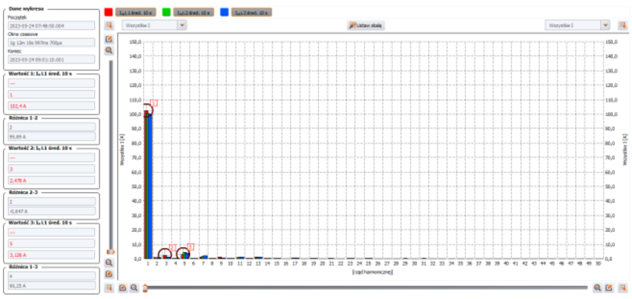

Fig. 16. Current-phase harmonics: L1, L2, L3

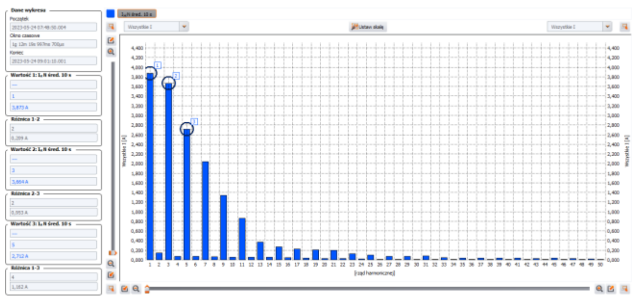

Fig. 17. Current harmonics for the neutral conductor

Based on the harmonic current values provided by the analyzer and utilizing Equation 2 from Chapter 2, the following THD values were obtained:

$THD_{I\ L1}$=4,03 %
$THD_{I\ L2}$=4,81 %
$THD_{I\ L3}$=4,70 %

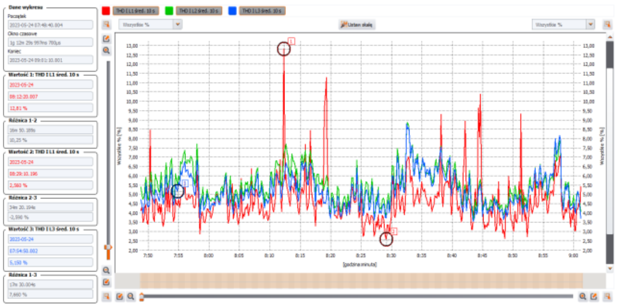

Fig. 18. Waveforms of average THDI values for phases: L1, L2, L3

Tension harmonics

During the one-hour measurement, harmonic voltage values were also recorded, and their plots are visible in Figures 19 and 20.

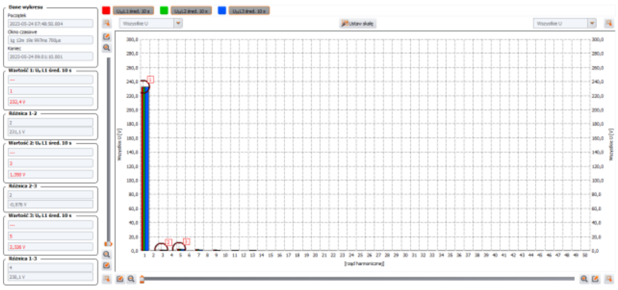

Fig. 19. Voltage harmonics - phases: L1, L2, L3

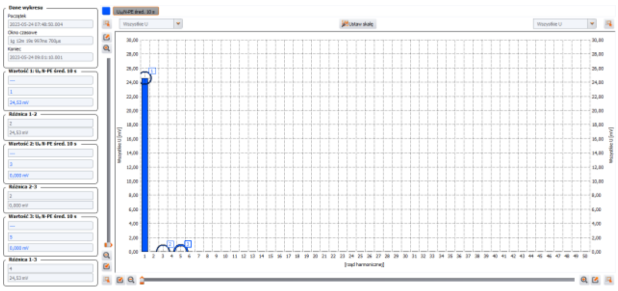

Fig. 20. Voltage harmonics for the neutral conductor

Using the measurement data and formula (1), the following THD values were obtained:

$THD_{U\ L1}$=1,49 %
$THD_{U\ L2}$=1,12 %
$THD_{U\ L3}$=1,12 %

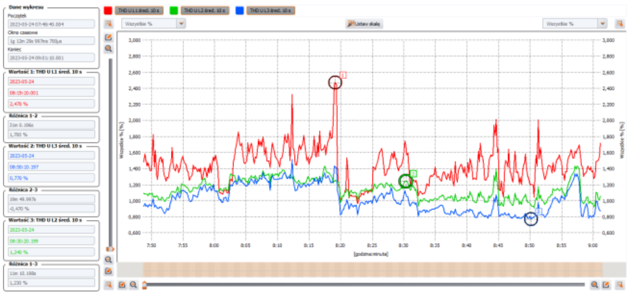

Fig. 21. Changes in the average THDU values for the phases: L1, L2, L3

5.2. Measurements of electricity disturbance levels in a weekly registration cycle

Voltage frequency

- Nominal frequency value fnom=50,00 Hz
- Minimum frequency value fmin=49,90 Hz
- Maximum frequency value fmax=50,10 Hz
- Amplitude 0,20 Hz

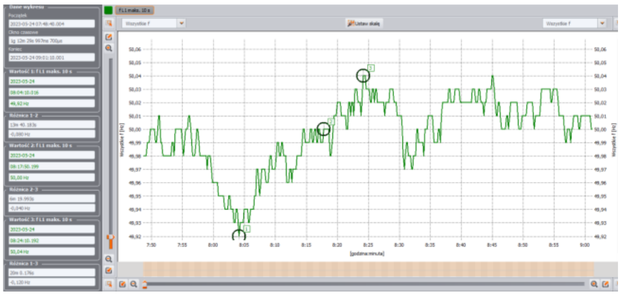

Fig. 22. Changes in the voltage frequency value

RMS voltage

For each phase, the effective voltage values were measured and presented in Figure 23 (in the form of a graph). Table 2 contains the maximum and minimum voltage values for each phase.

Table 2. Effective Voltage Values - Phases L1, L2, L3 [own work]

	L1 [V]	L2 [V]	L3 [V]	% compared to the nominal value
U_{min}	229,08	228,68	228,99	-0,40
U_{avg}	238,40	238,21	238,92	+3,65
U_{max}	246,40	246,92	247,92	+7,13

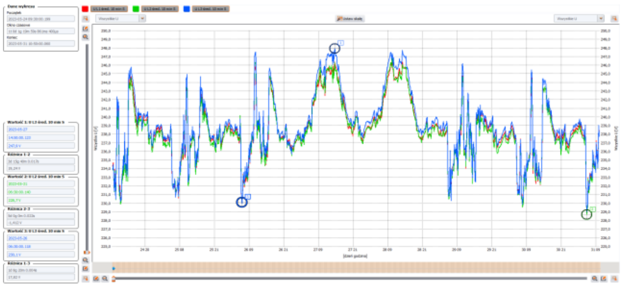

Fig. 23. Effective voltage values for phases: L1, L2, L3

Voltage dip phenomenon

During the 7-day measurement, the analyzer recorded voltage sags in 10-minute time intervals on the first and third phases. Figures 24 and 25 present the plots and numerical values of the voltage during the sag, respectively on phases 1 and 3. In the same time frame, no voltage sag occurred on phase 2, as shown in Figure 26. The plots of all phases during the voltage sag are presented in Figure 27.

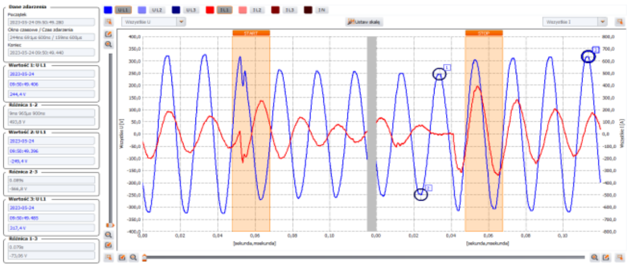

Fig. 24. Voltage dip on the L1 phase

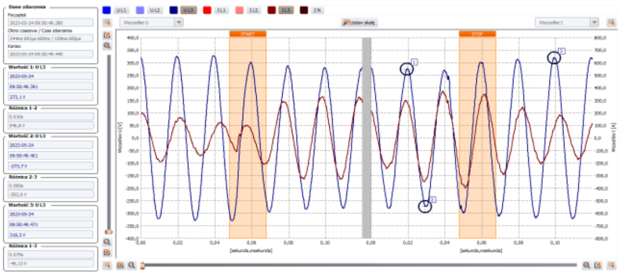

Fig. 25. Voltage dip on the L3 phase

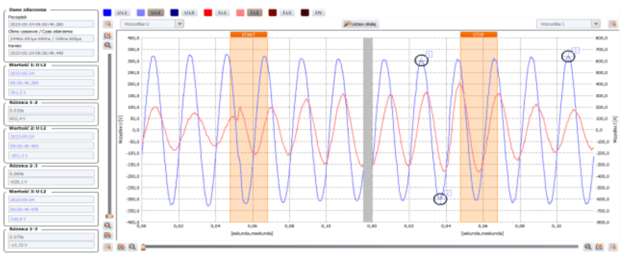

Fig. 26. Oscillograms of current and voltage on the L2 phase at the moment of voltage dip on the L1 and L3 phases

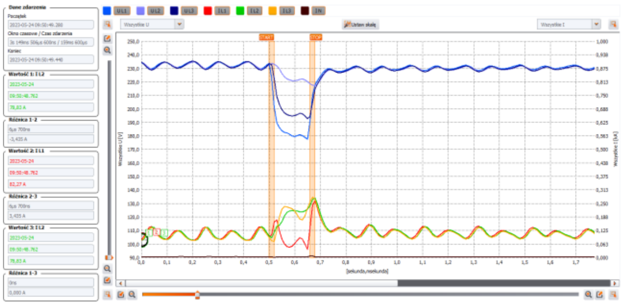

Fig. 27. Changes in voltage and current values during a voltage dip

Influence of photovoltaic installation on grid parameters

The impact of the photovoltaic installation on various electrical energy parameters in the PCC of the sawmill was also analyzed. It becomes most evident when examining active power values, which are drawn from the supplier's grid and, on sunny and non-working days, returned to it. Figure 28 displays the plot of total active powers generated collectively across all phases of the studied facility. The red curves on the plot represent the power consumed by the sawmill, while the green curve illustrates the surplus power generated by the photovoltaic system.

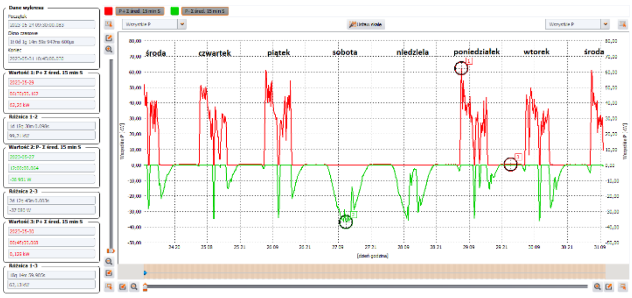

Fig. 28. Changes in total active power values

Analyzing the plot in Figure 28, attention should be drawn to its central portion, within which two distinct shapes of the power P curve are seen below the zero value.
This represents power being fed back into the supplier's grid during the weekend when the sawmill's electrical devices were not operational, resulting in no energy consumption. However, the sunny weather during these two days allowed a substantial amount of electric energy generated by the photovoltaic panels to be returned to the grid. The noticeable power drops during these days are the result of momentary cloud cover, which reduced the amount of sunlight reaching the photovoltaic panels.
Considering the operational nature of the sawmill, it's possible to provide a detailed explanation for some of the distinctive power values visible on the plot in Figure 29.

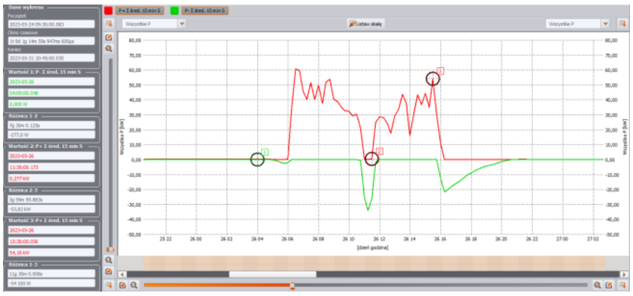

Fig. 29. Changes in active power values recorded during one measurement day

Using the markers on the graph (circles labeled with numbers 1 – 2 – 3) and the horizontal time axis, the analysis of the plot in Figure 29 can be carried out. To clarify, the time axis is marked by vertical grid lines with two numbers: the first number represents the day of the month, and the second number represents the full hour of the day. Marker labeled as number 1 is located around 4:00 AM on May 26, 2023. At this time of day, the sawmill is closed, and no machines are operational, resulting in no electrical energy being consumed. It's still early enough in the day that the sunlight doesn't trigger any response from the photovoltaic system, thus the power values are P+ = 0,00 kW and P- = 0,00 kW.

The situation starts to change around 5:00 AM when sunlight reaches the solar panels, generating electrical energy. As the angle of sunlight hitting the solar panels increases, the power fed back into the grid rises. At 6:00 AM, the sawmill begins its operations, leading to a drastic increase in the power being consumed by the facility. Another significant point on the graph occurs around 11:00 AM when the sawmill workers take their lunch break. The machines stop working, causing a drop in the power consumed by the facility. Up to this point, the angle of sunlight had been steadily increasing, along with the amount of energy being generated by the solar system. As the consumed power drops to near-zero values, the generated power starts to be surplus, which is then fed back into the supplier's grid.

Around 11:30 AM (marker number 2), the workers resume their tasks, restarting the electrical machines. These machines operate under varying configurations and loads until around 3:30 PM (marker number 3), leading to fluctuations in the power distribution. After 3:30 PM, a situation similar to before occurs, where the photovoltaic system generates more electrical energy than the sawmill requires. This surplus energy continues to be "pushed" into the operator's grid until dusk.

Long-term light flicker indicator P_{lt}

The long-term flicker index Plt has been defined by numerical values and is presented in the form of a waveform shown in Figure 30.

$P_{lt\ L1}$=6,70

$P_{lt\ L2}$=6,88

$P_{lt\ L3}$=7,88

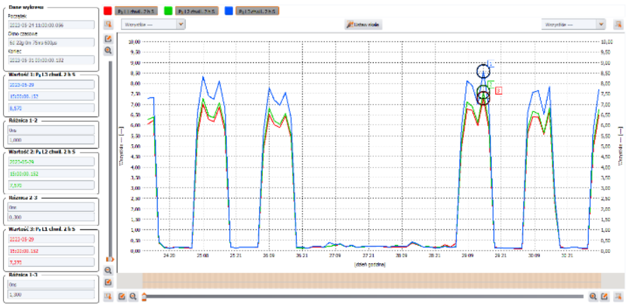

Fig. 30. Changes in the long-term flicker indicator P_{lt}

Short-term light flicker indicator P_{st}

The PQM-710 analyzer also generated data regarding the short-term flicker index. Changes in this index for each phase are presented in Figure 32.

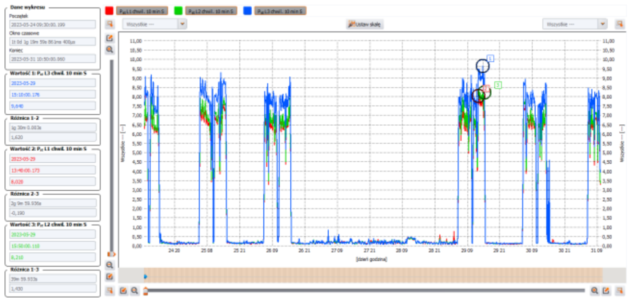

Fig. 31. Changes in the short-term flicker indicator P_{st}

VI. DISCUSSION

The voltage sag phenomenon described in section 5.2 occurred in two out of three phases. This could be attributed to potential motor winding damage or an uneven distribution of load among individual phases due to single-phase devices present within the facility.

A synchronized photovoltaic system connected to the consumer's grid has the potential to effectively mitigate disturbances caused by nonlinear high-power consumers during their operation. It can serve as a buffer to accommodate sudden energy demands.

To address the issue of minimizing disturbances introduced into the grid by the consumer, a viable solution would involve supplying the facility through a dedicated 15/0,4 kV transformer, which would provide galvanic isolation.

VII. CONCLUSIONS

According to the conducted measurements at the point of common connection between the electricity consumer and supplier, the vast majority of electric power quality parameters fall within their specified limit values as defined in the PN-EN 50160:2010 standard and the Ministerial Regulation of May 4, 2007. However, an analysis of the performed measurements of electric power quality revealed that the flicker indices Plt and Pst exceed their acceptable values. According to the limit values specified in the PN-EN 50160:2010 standard and the Ministerial Regulation of May 4, 2007, the long-term flicker index Plt should range from 0,00 to 1,00.

During the seven days of measurement, data was collected from the Power Distribution Company (PWP), indicating that for each of the three phases, this parameter is exceeded. Even though the effective voltage values fluctuate within the limits set by the standard and ministerial regulation, their changes have caused the light flicker index to exceed the norm. The consequence of this situation is that within the sawmill itself, as well as in nearby households, phenomena of repetitive changes in light source luminance may occur. This phenomenon negatively impacts human visual perception, potentially leading to difficulties in perceiving objects and errors during work, as well as irritation.

However, there are mitigating aspects to the light flicker situation. The first aspect is that voltage fluctuations responsible for the light flicker occur during the active operating hours of machinery in the sawmill. These hours are times when artificial lighting is rarely used in the Polish climatic and temporal zone. The second aspect is that currently employed sources of artificial lighting are based on LED technology, making them less sensitive to minor voltage changes. This is in contrast to outdated and no longer used incandescent light sources. Thanks to these two arguments, the impact of the exceeded light flicker index diminishes in terms of the number of individuals experiencing discomfort related to it.

The fluctuation in voltage responsible for exceeding the light flicker indices is undoubtedly attributed to the nonlinear nature of the sawmill's operation. Specifically, when wood undergoes mechanical processing, the circular saws encounter significant resistance, resulting in abrupt and substantial loads on the motors powering the saws. The machines used in the sawmill have been in operation for many years and are powered by older-generation motors without devices such as Softstart to limit current surge.

Ocena Zaburzeń Napięcia Generowanych Przez Odbiorniki o Dynamicznie Zmieniającym się Obciążeniu

Streszczenie - W sieci niskiego napięcia, pomimo gwarancji dostawcy, mogą pojawić się zaburzenia mające wpływ na jakość energii elektrycznej oraz ciągłość zasilania. Ich przyczyny wynikać mogą z ekstremalnych warunków pogodowych, złego stanu urządzeń przesyłowych a także awarii wynikających z czynnika ludzkiego. W artykule poruszony został jeszcze jeden czynnik, tzn. wpływ na jakość energii w sieci niskiego napięcia odbiorcy eksploatującego odbiorniki o dynamicznie zmieniającym się obciążeniu . Przedstawiono analizę zmian wskaźników charakteryzujących jakość energii i odniesiono je do wartości dopuszczalnych, obowiązujących w Polsce dla sieci niskich napięć.

Słowa kluczowe - jakość energii, migotanie światła, wyższe harmoniczne, zaburzenia napięcia

BIBLIOGRAPHY

Books, monographs, publications, scientific articles

[1] Bolkowski S.: Elektrotechnika Wydawnictwo WSiP Warszawa wyd. IX 2016

[2] Hanzelka Z.: Sympozjum „Automatyka elektroenergetyczna czynnikiem doskonalenia jakości zasilania i użytkowania energii elektrycznej" wykład: „Jakość energii elektrycznej (parametry, pomiary, ocena)wyzwaniem dla automatyki elektroenergetycznej" Wrocław 2004

[3] Hanzelka Z.: Automatyka – Elektryka – zakłócenia Vol.2 Nr 3(5). Jakość energii elektrycznej „Wahania napięcia" 2011r

[4] Hanzelka Z.: Jakość dostawy energii elektrycznej. Zaburzenia wartości skutecznej napięcia, Wydawnictwo AGH, Kraków 2013

[5] Kowalski Z.: Jakość energii elektrycznej, Monografie Politechniki Łódzkiej, Wydawnictwo Politechniki Łódzkiej, Łódź 2007

[6] Kowalski Z.: Asymetria w układach elektroenergetycznych PWN, 1987

[7] Kowalski Z.: Wahania napięcia w układach elektroenergetycznych. WNT. Warszawa, 1985

[8] Kosobudzki G.: Prace Naukowe Instytutu Maszyn, Napędów i Pomiarów Elektrycznych Politechniki Wrocławskiej Nr 69 „Pomiary parametrów krótkotrwałych zapadów napięcia" Wrocław 2013

[9] Leszczyński J.: Prace Naukowe Instytutu Maszyn, Napędów i Pomiarów Elektrycznych Politechniki Wrocławskiej Nr 64 „Badanie jakości energii elektrycznej. Analiza porównawcza metod i przepisów" Wrocław 2010

[10] Musiał E.: Czasopismo Automatyka – Elektryka – Zakłócenia Vol.1 Nr 1(1). Jakość energii elektrycznej „Ocena jakości energii elektrycznej w sieciach przemysłowych" 2010

[11] Łukasik Z., Olczykowski Z.: Estimating the impact of arc furnaces on the quality of power in supply systems, Energies 13(6), 2020

[12] Łukasik Z., Olczykowski Z.: Quality and reliability of electricity supply, Faculty of Electrical Engineering and Information Technology, 13 International Conference, ELEKTRO 2020

[13] Olczykowski Z., Łukasik Z.:, Evaluation of Flicker of Light Generated by Arc Furnaces, Energies, 14(13), 1-25, 2021

[14] Olczykowski Z.: Modeling of Voltage Fluctuations Generated by Arc Furnaces, Applied Sciences 11 (7), 1-25, 2021

[15] Olczykowski Z.: Electric Arc Furnaces as a Cause of Current and Voltage Asymmetry, Energies, 14(16), 2021

[16] Olczykowski Z.: Arc Voltage Distortion as a Source of Higher Harmonics Generated by Electric Arc Furnaces, Energies, 10(15), 2022

[17] Olczykowski Z.: Arc Furnace Power-Susceptibility Coefficients, Energies, 10, 2022

[18] Olczykowski Z. Kozyra J.; Propagation of Disturbances Generated by DC Electric Traction, Energies 15 (18), 1-19, 2022

[19] Nowakowski. W., Olczykowski Z., Wojciechowski J.: Supply railway traffic control devices in case of failure of the power system, Transport Systems Telematics Conference, Ustron, April 5-8, 2017, Archives of Transport System Telematics, Volume 10, Issure 4, November 2017 ss-16-20, ISSN 1899-8208
[20] Olczykowski Z. Wojciechowski J. Kolbus Z.: Autobusy – Technika, Eksploatacja, Systemy Transportowe nr 12, „Niezawodność i jakość zasilania w energię elektryczną obiektów użyteczności publicznej – analiza przypadku" 2018
[21] Rzymkowski M., Ocena jakości energii elektrycznej w PWP wybranego odbiorcy generującego zaburzenia do sieci zasilającej, Praca magisterska, Wydział Transportu, Elektrotechniki i Informatyki, UTH, Radom, 2023
[22] Sutkowski T.: Rezerwowe i bezprzerwowe zasilanie w energię elektryczna – urządzenia i układy, Biblioteka COSiW, SEP, Warszawa 2007
[23] Szuberk K.: Zeszyty Naukowe Wydziału Elektrotechniki i Automatyki Politechniki Gdańskiej Nr 50 „Harmoniczne prądu i napięcia w sieciach dystrybucyjnych" Gdańsk 2016
[24] Trojanowska M., Nęcka K:. Inżynieria Rolnicza 5(114) Wahania napięcia w sieciach elektroenergetycznych, Kraków 2009
[25] Wasiak I.: Elektroenergetyka w zarysie. Przesył i rozdział energii elektrycznej" Łódź, 2010
[26] Zydroń P., Bonk M., Fuśnik Ł., Szafraniak B.: Przegląd elektrotechniczny. Wpływ temperatury na parametry warystorów tlenkowych ograniczników przepięć niskiego napięcia badanych metodami spektroskopii impedancyjnej, Kraków 2016

European Standards

[27] PN-EN 50160:2010 p.t.: „Parametry napięcia zasilającego w publicznych sieciach elektroenergetycznych".

Legal acts

[28] Dziennik Ustaw Nr 93, Rozporządzenie Ministra Gospodarki z dnia 4 maja 2007r. „w sprawie szczegółowych warunków funkcjonowania systemu elektroenergetycznego".

Internet sources

[29] ENERGY.GOV artykuł „Źródła energii" https://www.energy.gov/energy-sources [dostęp: 01.06.2023].
[30] Portal komunalny, artykuł „Energia elektryczna złej jakości niszczy urządzenia" https://portalkomunalny.pl/slaby-prad-urzadzenia-330968/ [dostęp: 01.06.2023]