Co-published by
Institute of Fluid-Flow Machinery
Polish Academy of Sciences
Committee on Thermodynamics and Combustion
Polish Academy of Sciences

http://www.imp.gda.pl/archives-of-thermodynamics/

ARCHIVES OF THERMODYNAMICS

The influence of seasonality of microgrids connected to the power system on selected power quality parameters

Marta Bątkiewicz-Pantuła

Wrocław University of Science and Technology, Faculty of Electrical Engineering, Institute of Electrical Power Engineering.
Wybrzeże Wyspiańskiego Str. 27, 50-370 Wroclaw, Poland
Author email: marta.batkiewicz-pantula@pwr.edu.pl

Received: 29.12.2023; revised: 30.12.2024; accepted: 09.02.2025

Abstract

The article presents an assessment of the parameters of power quality obtained from renewable sources. The assessment was based on the Decree of the Minister of Climate and Environment of March 22, 2023 on detailed conditions for the operation of the electricity system (Dz. U. 2023 r., 819) and the EN 50160: 2010 standard – Parameters of supply voltage in public power grids. The analysis was carried out on the example of actual measurements of power quality parameters. The measurements were made with a Fluke 1760 power quality analyser. The analyser was installed at the point of connection to the renewable energy grid. The article analyses and compares renewable energy sources. The assessment of power quality parameters was carried out on the basis of the discussed analyses. The article presents the influence of seasonality on the parameters of power quality.

Keywords: Seasonality; Power quality; Microgrid; Power system

Vol. 46(2025), No. 1, 185–191; doi: 10.24425/ather.2025.154192

Cite this manuscript as: Bątkiewicz-Pantuła, M. (2025). The influence of seasonality of microgrids connected to the power system on power quality parameters. *Archives of Thermodynamics*, 46(1), 185–191.

1. Introduction

Electricity has gained the status of the most popular and most frequently used form of energy [1, 2]. The process of generating, transmitting and using electricity is fully mastered. Energy has become an object of purchase and sale. The main factor determining the price the consumer must pay is, of course, the amount of energy he uses. However, the feature that determines its usefulness for electrical loads is its quality [3].

The best power quality is one in which the voltage curve is uninterrupted and perfectly sinusoidal, and its frequency is rated. The value of the rated voltage is equal to the root mean square (RMS) voltage [4]. The ideal state is impossible to achieve, so for each customer, sufficient electricity quality parameters are determined that do not adversely affect the operation of the facility. All deviations from the ideal are subject to examination and evaluation [5–7]. The basic place of measurement, observation and testing is most often the point of connection to the power grid. The next measurement place is the point on the loads terminals [8].

Power quality is one of the most serious dilemmas in the modern world [9]. It is expected that in the near future, the vast majority of electricity users will have to face, to a greater or lesser extent, complications caused by the issue of energy quality.

2. Power quality parameters

The dynamic development of devices containing high-power semiconductor elements has begun a new and most dynamically

Nomenclature

a – initial value at $t = 0$
b – function trend
n – speed, rpm
P_{st} – short-term light flicker
P_{lt} – long-term light flicker
p – number of analysed data
r – height, m
S_{Oi} – cleaned seasonality indicators
S_t^i – difference between empirical and model values
T – time, month
t – time, month
$\hat{y}$ – regression function
$\hat{y}^*$ – regression function taking into account seasonality
$\hat{y}_T^P$ – forecasting

Abbreviations and Acronyms

HV – high voltage
LV – low voltage
MV – medium voltage
RES – renewable energy sources
RMS – root mean square

developing chapter in the field of power quality. The focus began to be on removing potential sources of power quality degradation by introducing new technical solutions [10–13].

Power quality is an interdisciplinary field that is difficult to interpret clearly. It means something different to the supplier and the consumer of energy, and manufacturers of electrical equipment understand the concept of power quality even differently. The most appropriate definition of power quality is as follows [3]:

"Power quality is a set of parameters describing the properties of the process of supplying energy to the user under normal operating conditions, determining the continuity of the power supply (long and short interruptions in the power supply) and characterizing the supply voltage (value, asymmetry, frequency, shape of the time course)". The normal operating conditions described in the definition mean:

- a state in which power produced is equal to demand,
- connection works in networks proceed without disruptions,
- short circuits are removed by automatic protection equipment,
- factors such as did not occur:
  - temporary electricity supply contracts,
  - a non-compliance with standards or technical requirements by users of electrical installations and devices (connections and operation),
  - extraordinary events:
    - events caused by nature (difficult atmospheric conditions, natural disasters), power shortage resulting from external events,
    - undesirable actions of third parties,
    - actions of public authorities,
    - strikes,
    - forces majeure.

The term power quality is often replaced by electromagnetic compatibility, which is not entirely correct. This is most likely due to the mutual overlap of fields, for example in the context of the emissivity of conducted disturbances and their impact on voltage parameters [14].

The PN-EN 50160 [15–17] standard applies mainly to energy suppliers and specifies the parameters of the supply voltage in terms of value, frequency, correct shape and phase voltage asymmetry. The standard also specifies the permissible levels of deviations of power quality parameters from the rated voltage.

The standard regarding electromagnetic compatibility of electrical devices PN-EN IEC 61000-4-11:2020-11 [18] describes the levels of interference emission for loads. Electromagnetic compatibility applies not only to disturbances and the impact of electrical equipment on the power quality, but also to the condition of the power system.

2.1. Power quality assessment

The measurement of quality parameters should be continuous for a period of at least one week that is representative for a given network [19]. Each measured parameter is averaged over 10 minutes. The concept of a representative week refers to the normal state of network operation (normal network operation and no emergency events). If emergency events occur, they should be omitted in the assessment of power quality parameters.

There are three methods of assessment:

- specifying the number or percentage of values that exceed the permissible values,
- comparison of maximum measured values with permissible values,
- comparison of statistical parameters of measured quantities with limits.

Permissible limits define parent and child documents. The superior document in the process of assessing the power quality is the Decree of the Minister of Climate and Environment of March 22, 2023 on detailed conditions for the operation of the electricity system (Dz. U. 2023 r., 819) [20]. A subordinate document is the PN-EN 50160 standard: Parameters of supply voltage in public distribution networks, which has been updated six times so far, i.e. in 2008, 2010, 2015, 2018, 2020 and 2023 [17].

The basic disorders encountered in installations are:

- voltage fluctuations,
- voltage dips,
- voltage increases,
- power outages.

Voltage fluctuations occurring for various reasons in low voltage (LV), medium voltage (MV) and high voltage (HV) networks are transferred to the low-voltage network, causing the phenomenon of flickering light (flicker). It is the impression of instability of visual perception caused by a light stimulus whose luminance or spectral distribution changes over time. Measuring the flicker phenomenon is an indirect way of assessing voltage fluctuations [21–23].

The measure of the nuisance of light flicker is the short-term light flicker severity factor (P_{st}) and long-term light flicker severity factor (P_{lt}). The nuisance of light flickering caused by voltage fluctuations depends on both the amplitude of the fluctuations and the frequency of their occurrence.

Table 1 specifies the permissible limits of the power quality parameter [17].

Table 1. Permissible limits for light flicker.

Parameter	**Factor**	**Time**	**Permissible limits**	
			Regulation [20]	**Standard PN-EN50160 [17]**
Flicker	P_{st}	10 min	–	Up to 35 kV: 1.2 for 95% measurement data set Over 35 kV: 1.0 for 95% measurement data set
	P_{lt}	2h	$P_{lt} \leq 1$ for 95% measurement time	Up to 35 kV: 1.0 for 100% measurement data set Over 35 kV: 0.8 for 100% measurement data set

Analysing Table 1, it can be seen that the limit value of the power quality parameter has been increased in standard PN-EN 50160 [17] compared to previous regulations and the period fulfilling the set limit values has been increased from 95% to 100% of the observation time. Additionally, limit values have been defined for the P_{st} coefficient.

3. Evaluation of power quality parameters for renewable energy sources

Connecting renewable energy sources (RES) to the power system results in decentralized generation, which involves [24]:

- bidirectional energy flow,
- access to a large number of power electronic devices (inverters, controllers),
- stochastic nature of renewable energy generation.

The quality of energy in a microgrid is influenced by three sides at the same time:

- load side,
- distributed generation side,
- energy network site.

This approach significantly complicates the analysis and control of the power system [25]. Therefore, attention to the issue of power quality in microgrids is becoming increasingly common [26–34].

Analysis of selected power quality parameter was carried out for two different renewable energy sources: a wind farm and a hydroelectric power plant.

The analysis of only one selected parameter, which is flicker, i.e. an indirect way of assessing voltage fluctuations, was carried out due to the expected basic disturbances encountered in the network cooperating with RES. Only the values of indicators related to voltage fluctuations are analysed, while other qualitative parameters such as the value of the voltage asymmetry coefficient, voltage distortion and power are not its purpose and will not be included in this analysis. Due to the specific nature of the studied objects, it was assumed that variable weather conditions and changes in load or energy production may lead to voltage fluctuations in the grid cooperating with RES, and the analysed P_{st} and P_{lt} are key parameters in the analysis of voltage fluctuations.

Figure 1 shows the general conceptual diagram of the measurement system for all analysed renewable sources.

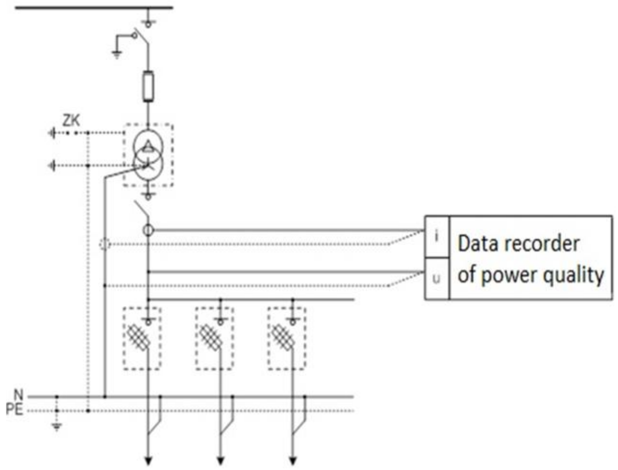

Fig. 1. General conceptual diagram of the measurement system.

The analysed wind farms consist of two wind turbine towers with a height of 24.5 m. Three-propeller wind turbines of the type: VESTAS HSW 250 T (250 kW) and VESTAS V-20-100 (100 kW) with dimensions r = 8.75 m, total height 33.50 m and a 0.4 kV cable line from two wind turbine towers and a 0.4 kV cable-distribution cabinet.

The VESTAS V 20-100 wind farm is equipped with an asynchronous generator with a power of 110 kW, generator voltage 400 V, frequency 50 Hz. Synchronous rotation speed n = 45.05 rpm. Speed in generator operation: n = 45.86 rpm.

The HSW 250T power plant is equipped with two asynchronous generators with a capacity of 80 kW and 250 kW. The generator voltage is 400 V, frequency 50 Hz. The generator is equipped with a set of protections that control the parameters of the power grid and prevent the generator from island operation. The generator protections will cause it to be switched off in the event of an increase or decrease in voltage and an increase in the generator frequency above 50.5 Hz and a decrease in frequency below 49.8 Hz.

The analysed small hydroelectric power plants are equipped with two asynchronous generators with a capacity of 200 kW each. The first power plant is equipped with Francis and Kaplan turbines, in a vertical arrangement with a transmission belt, while the second is equipped with Kaplan turbines, in a vertical arrangement with a transmission belt. Connection to the network via a MV/LV transformer 21000/400 400 kVA. The system is equipped with fully automated capacitor banks. Control of switching the turbines on and off is fully automated, e.g. in the event of voltage failures on the network side. Operation is sometimes switched to manual control, e.g. during maintenance activities.

The full observation time of the recorded parameters was one week, which is consistent with the assumption [17] regarding the assessment of the quality parameters of electric power concerning a representative measurement period.

The measurements of the quality of electric power for two wind power plants and two hydroelectric power plants presented in the work were carried out at the same measurement time for a given group of RES sources. The mentioned power plants of a given type were installed in similar locations. The measurement points designated in this way were intended to check the impact of the power system on the mentioned power plants and to exclude any possible interference from the network on the discussed selected parameters of the quality of electric power.

Figures 2 and 3 show sample graphs for a representative measurement period for two different wind farms. In Figs. 2 and 3, P_{lt} is marked in red, while the P_{st} coefficient is marked in blue. The description of the *X*-axis data in Figs. 2 and 3 is the measurement time in the format day, hour.

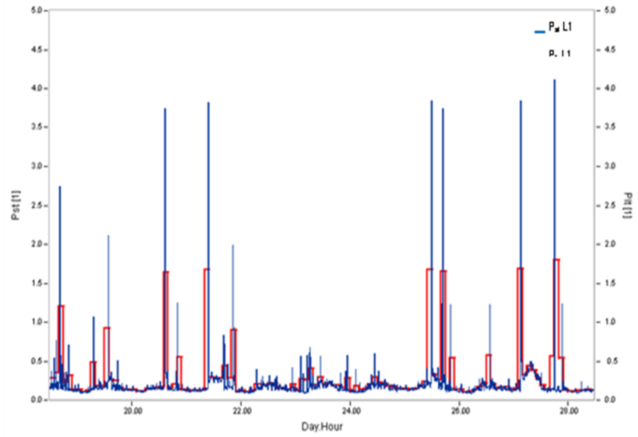

Fig. 2. An example graph for a representative measurement period for the first wind farm.

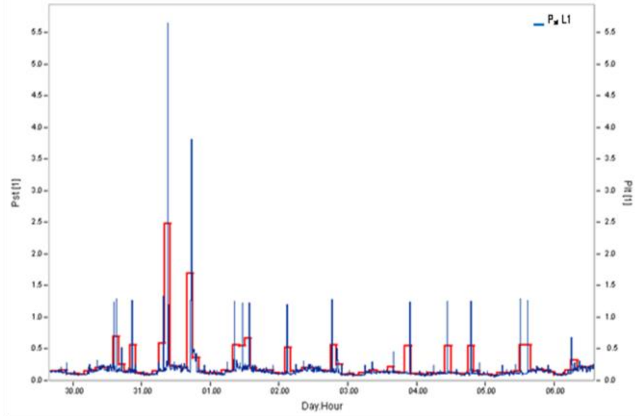

Fig. 3. Sample graph for a representative measurement period for the second wind farm.

Analysing Figs. 2 and 3, it can be seen that increasing most of the limit values of power quality parameters significantly affects the conditions for meeting the normative restrictions, resulting in their failure to meet them.

Figures 4 and 5 show sample graphs for a representative measurement period for two different hydropower plants. In Figs. 4 and 5, P_{lt} is marked in red, while the P_{st} coefficient is marked in blue. The description of the *X*-axis data in Figs. 4 and 5 is the measurement time in the format day, hour.

Analysing Fig. 4, it can be seen that despite exceeding the P_{st} coefficient in some measurement data values, the coefficient meets the standard requirements for 95% of the measurement data set. Analysing Fig. 5, it can be seen that increasing most of the limit values of power quality parameters significantly affects the conditions for meeting the normative restrictions, resulting in their failure to meet them.

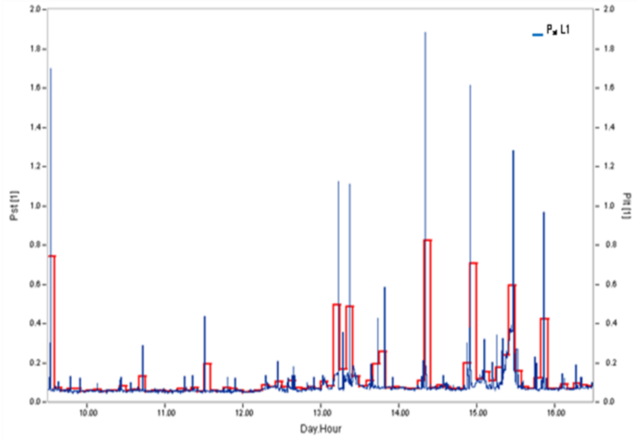

Fig. 4. Sample graph for a representative measurement period for the first hydroelectric power plant.

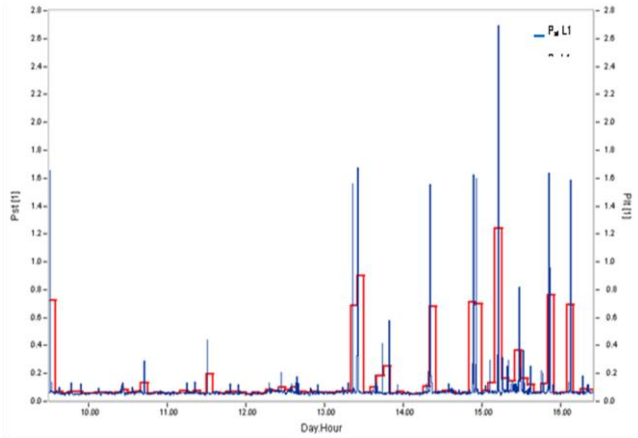

Fig. 5. Sample graph for a representative measurement period for the second hydroelectric power plant.

4. Seasonality of renewable energy sources

One type of statistical series is a time series, which can be defined as a sequence of observations of a phenomenon in subsequent units of time, e.g. years, quarters, months [35,36]. The phenomenon under consideration may be subject to certain regularities, the detection and description of which is the aim of time series analysis [37].

The basic functions of the time series include:

- the regression function described by the formula:

$$\hat{y} = a + bt, \tag{1}$$

- the difference between empirical and model values described by the formula:

$$S_t^i = y_t - \hat{y}_t, \tag{2}$$

- seasonality index described by:

$$S_i = \frac{\sum_{i=1}^{m} S_t^i}{p}, \tag{3}$$

- determination of modified theoretical values taking into account seasonality described by:

$$\hat{y}^* = \hat{y} + S_{Oi}, \tag{4}$$

- forecasting described by:

$$\hat{y}_T^P = b \times T + a + S_{Oi}. \tag{5}$$

Based on the observations of the flicker P_{st} variability, the type of seasonality can be identified. In the example discussed, it is additive in nature.

Figures 6 and 7 show example charts of the seasonality function for two different wind farms. Analysing the charts (Figs. 6 and 7) it can be observed that the seasonality function has a positive trend. The measure of model fit is low. This is most likely due to the nature of changes in the flicker coefficient for a wind farm.

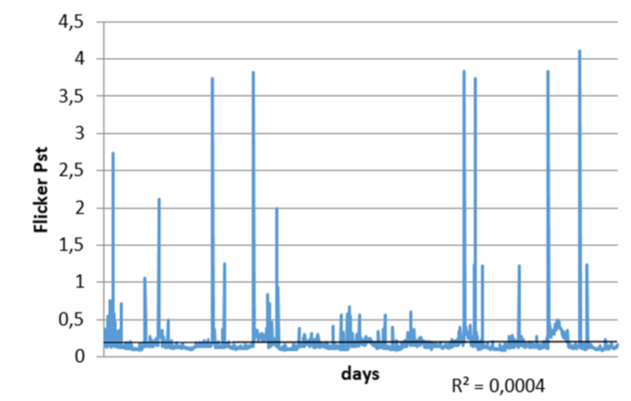

Fig. 6. An example chart of the seasonality function for the first wind farm.

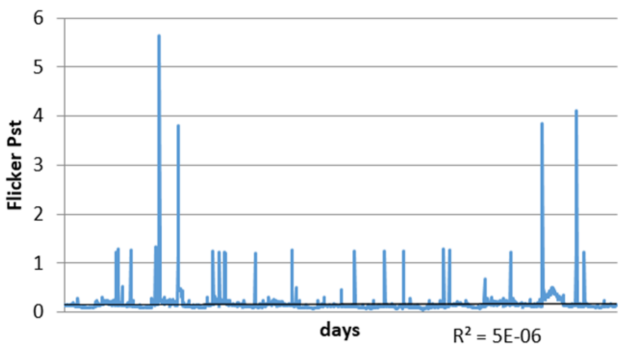

Fig. 7. An example of a chart of the seasonality function for the second wind farm.

Figures 8 and 9 show example charts of the seasonality function for two different hydropower plants. Analysing the charts (Figs. 8, 9) it can be observed that the seasonality function has a positive trend. The model fit measure is higher. This is most likely due to lower variability of changes in the flicker coefficient for a hydropower plant.

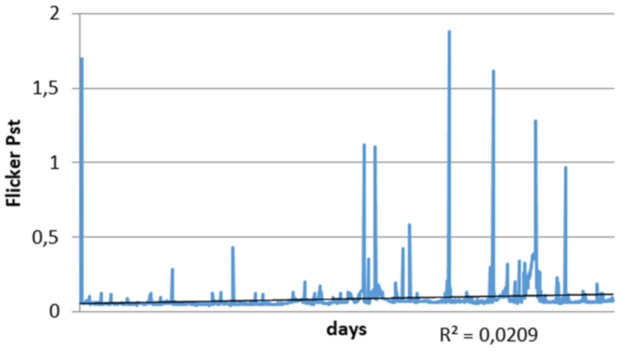

Fig. 8. An example of a seasonality function chart for the first hydroelectric power plant.

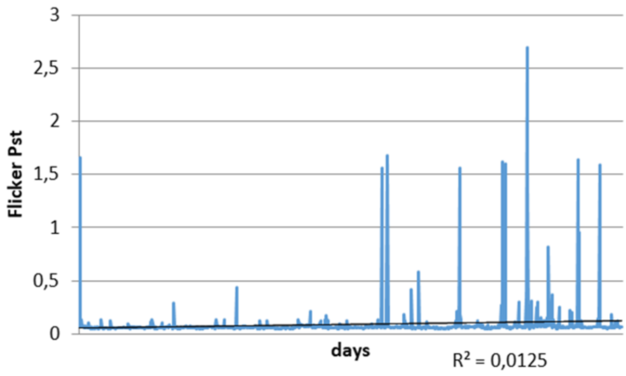

Fig. 9. An example chart of the seasonality function for the second hydroelectric power plant.

By determining the basic functions of time series in accordance with the relationship (1) and (5), the regression function and forecasting take the form:

- for wind power plants:
  - first power plant:

$$\hat{y} = 0.19 + 0.00021t, \tag{6}$$

$$\hat{y}_T^P = 0.00021 \times 24 + 0.19 + 0.005 = 0.20004, \tag{7}$$

  - second power plant:

$$\hat{y} = 0.17 + 0.00019t, \tag{8}$$

$$\hat{y}_T^P = 0.00019 \times 24 + 0.17 + 0.007 = 0.1815, \tag{9}$$

- for hydroelectric power plants:
  - first power plant:

$$\hat{y} = 0.09 + 0.00015t, \tag{10}$$

$$\hat{y}_T^P = 0.00015 \times 24 + 0.09 + 0.072 \ = \ 0.1656, \quad (11)$$

- second power plant:

$$\hat{y} = 0.09 + 0.00015t, \quad (12)$$

$$\hat{y}_T^P = 0.00015 \times 24 + 0.09 + 0.0071 \ = \ 0.1646. \quad (13)$$

From the analyses performed, it can be concluded that the seasonality for hydropower plants is constant and remains at the same level. The forecast growth of flicker for a period of 24 months is 0.16.

Data for wind farms are more volatile. This is directly related to the nature of the installation's operation. The forecast growth of flicker for a period of 24 months is between 0.18–0.20.

5. Conclusions

The seasonality of microgrids connected to the power system affects the power quality parameters only for specific renewable sources.

From the analyses carried out, it can be concluded that for wind farms, the tightening of normative requirements has an impact on the flicker, resulting in a failure to meet the requirements. Connecting the installation does not affect the values of other parameters. Based on such a modified seasonality model for a wind farm, future values can be predicted with greater precision, but the forecast accuracy is not high.

However, for a hydroelectric power plant, there are no power quality parameters that are influenced by the installation despite the stricter requirements. Flicker has no influence on the seasonality of network operation. Based on such a modified seasonality model for a hydropower plant, future values can be forecast with much greater precision and accuracy.

Research and assessment of the power quality are an important and necessary element in the reliability and safety of the power system operation [38]. In installations using renewable energy sources, various loads with non-linear current-voltage characteristics are often used. Loads such as power electronic devices, due to their widespread use and non-linear characteristics, are the most common cause of poor power quality [39]. The share of non-linear loads in the overall balance of power installed at a single consumer increased to the level that new phenomena appeared in the supply voltage. It can therefore be concluded that the structure of microgrids may be a source of additional problems with power quality. The designated measurement points were intended to exclude any possible interference from the network on the selected parameters of the power quality discussed. The measurements of selected parameters of the power quality conducted and presented in the article are the first approach to the analysis of the mutual influence of various RES located in similar locations. The analysis of selected parameters of the power quality conducted was intended to verify the need for mutual, synchronous measurements in the future in order to determine the characteristic features of the given RES. The conducted studies were also intended to check whether similar RES, located close to each other, negatively affect each other, which was not observed in the studied measurement period.

References

[1] Cierpiał-Wolan, M. (2023). *Statistics Poland. Energy consumption in households in 2021*. Warszawa, Rzeszów. Issued by the Spokesperson for the President of Statistics Poland.

[2] Marszałek, M. (2015). Freedom of business activity of the producer – seller of electric energy. *Legal Monographs*.

[3] Hanzelka, Z. (2002). *Power Quality, part 1*, online: http://twelvee.com.pl/pdf/Hanzelka/cz_1_pelna.pdf (in Polish). [accessed 06 Nov. 2023].

[4] Hanzelka, Z. (2013) *Quality of the Electricity Supply-Disturbances of the Voltage RMS Value*. AGH University of Krakow, Kraków (in Polish).

[5] Golla, M., Sankar, S., & Chandrasekaran, K. (2021). Renewable Integrated UAPF Fed Microgrid System for Power Quality Enhancement and Effective Power Flow Management. *International Journal of Electrical Power & Energy System*, 133, 107301. doi: 10.1016/j.ijepes.2021.107301

[6] Ding, Y. (2020). Analysis of Operation and Maintenance of Power Distribution Network Management Technology under the Background of Big Data Era. In *Big Data Analytics for Cyber-Physical System in Smart City. BDCPS 2019. Advances in Intelligent Systems and Computing*, vol 1117 (pp. 610-615). Springer: Singapore. doi: 10.1007/978-981-15-2568-1

[7] Jasiński, M., Sikorski, T., & Borkowski, K. (2019). Clustering as a Tool to Support the Assessment of Power Quality in Electrical Power Networks with Distributed Generation in the Mining Industry. *Electric Power Systems Research*, 166, 52–60. doi: 10.1016/j.epsr.2018.09.020

[8] Piątek, K., Firlit, A., Chmielowiec, K., Dutka, M.; Barczentewicz, S., & Hanzelka, Z. (2020). Optimal Selection of Metering Points for Power Quality Measurements in Distribution System. *12th International Conference and Exhibition on Electrical Power Quality and Utilisation (EPQU)*, 14-15 September, Kraków, Poland.

[9] Lange, A., Pasko, M., & Grabowski, D. (2021). Selected aspects of wind and photovoltaic power plant operation and their cooperation, *Bulletin of the Polish Academy of Sciences Technical Sciences*, 69(6). doi: 10.24425/bpasts.2021.139793

[10] Heping, P., Wenxiong, M,. Yong, W., Le, L., & Zhong, X. (2022). Identification method for power quality disturbances in distribution network based on transfer learning. *Archives of Electrical Engineering*, 71(3), 731−754. doi: 10.24425/aee.2022.141682

[11] Khoa, N.M., Dai, L.V., Tung, D.D, & Toan, N.A. (2021). An advanced IoT system for monitoring and analysing chosen power quality parameters in micro-grid solution. *Archives of Electrical Engineering*, 70(1), 173−188. doi: 10.24425/aee.2021.136060

[12] Nair, D.R., Nair, M.G., & Thakur, T.A (2022). Smart Microgrid System with Artificial Intelligence for Power-Sharing and Power Quality Improvement. *Energies*, 15(15), 5409. doi. 10.3390/en15155409

[13] Guo, X.-H., Chang, C.-W., & Chang-Chien, L.-R. (2022). Digital Implementation of Harmonic and Unbalanced Load Compensation for Voltage Source Inverter to Operate in Grid Forming Microgrid. *Electronics*, 11, 886. doi: 10.3390/electronics11060886

[14] Hanzelka, Z., & Kowalski, Z. (1999). Electromagnetic Compatibility (EMC) and Electrical Power Quality in Standards, *Jakość i Użytkowanie Energii Elektrycznej*, 5(1), 93−107 (in Polish).

[15] EN 50160:2010. *Voltage characteristics of electricity supplied by public electricity networks.*

[16] EN 50160:2019. *Voltage characteristics of electricity supplied by public electricity networks.*

[17] EN 50160:2023 *Voltage characteristics of electricity supplied by public electricity networks.*

[18] EN IEC 61000-4-11:2020-11 *Electromagnetic compatibility (EMC) – Part 4–11: Testing and measurement techniques – Voltage dips, short interruptions and voltage variations immunity tests for equipment with input current up to 16 A per phase.*

[19] Klajn, A., & Bątkiwicz-Pantuła, M., (2013). *Application Note - Standard EN 50 160: Voltage characteristics of electricity supplied by public electricity network.* European Copper Institute, Cu0147(02), 1− 30.

[20] *Decree of the Minister of Climate and Environment of March 22, 2023 on detailed conditions for the operation of the electricity system.* Dz. U. 2023 r., 819 (in Polish).

[21] EN 61000-4-15: 2011 *Electromagnetic Compatibility (EMC) – Test and Measurement Methods – Flicker Meter – Functional and design specifications.*

[22] EN 61000-4-30:2015 *Electromagnetic compatibility (EMC) – Part 4-30: Testing and measurement techniques – Power quality measurement methods.*

[23] "Power Quality" Working Group WG2. (2000). *Guide to Quality of Electric Supply for Industrial Installations. Part 5, Flicker and Voltage Fluctuations*.

[24] Dragicevic, T., Vazquez, S., & Wheeler, P. (2019). Advanced Control Methods for Power Converters in Distributed Generation Systems and Microgrids. *IEEE Transaction on Industrial Electronics*, 66(11), 8866–8869. doi: 10.1109/TIE.2019.2914846

[25] Liao, J., Zhou, N., Wang, Q., Li, C., & Yang, J. (2018). Definition and Correlation Analysis of Power Quality Index of DC Distribution Network. *Proc. Chinese Society for Electrical Engineering*, 38(23), 6847–6860. doi: 10.13334/j.0258-8013.pcsee.181276

[26] Ostrowska, A., Michalec, Ł. Skarupski, M., Jasiński, M., Sikorski, T., Kostyła, P., Lis, R., Mudrak, G., & Rodziewicz, T. (2022). Power Quality Assessment in a Real Microgrid-Statistical Assessment of Different Long-Term Working Conditions. *Energies*, 15, 8089. doi: 10.3390/en15218089

[27] Parol, M., Kapler, P., Marzecki, J., Parol, R., Połecki, M., & Rokicki, Ł. (2020). Effective approach to distributed optimal operation control in rural low voltage microgrids. *Bulletin of the Polish Academy of Sciences Technical Sciences*, 68(4), 661−678. doi: 10.24425/bpasts.2020.134178

[28] Shi, H., Zhuo, F., Yi, H., & Geng, Z. (2016). Control Strategy for Microgrid under Three-Phase Unbalance Condition. *Journal of Modern Power Systems and Clean Energy*, 4, 94–102. doi: 10.1007/s40565-015-0182-3

[29] Li, Y., & Nejabatkhah, F. (2014). Overview of Control, Integration and Energy Management of Microgrids. *Journal of Modern Power Systems and Clean Energy*, 2, 212–222. doi: 10.1007/s40565-014-0063-1

[30] Wang, N., Zheng, S., & Gao, W. (2022). Microgrid Harmonic Mitigation Strategy Based on the Optimal Allocation of Active Power and Harmonic Mitigation Capacities of Multi-Functional Grid-Connected Inverters. *Energies*, 15(17), 6109. doi: 10.3390/en15176109

[31] Arbab-Zavar, B., Palacios-Garcia, E.J., Vasquez, J.C., & Guerrero, J.M. (2019). Smart Inverters for Microgrid Applications: A Review. *Energies*, 12(5), 840. doi: 10.3390/en12050840

[32] Liu, B., Zhao, X., Liu, Y., Zhu, Y., & Chen, J. (2020). Control Strategy of Clustered Micro-Grids for Grid Voltage Unbalance Compensation without Communications. *IET Generation. Transmission & Distribution*, 14(20), 4410–4415. doi: 10.1049/iet-gtd.2020.0421

[33] Zhang, M., Li, Y., Liu, F., Li, W., Peng, Y., Wu, W., & Cao, Y. (2019). Cooperative Operation of DG Inverters and a RIHAF for Power Quality Improvement in an Integrated Transformer-Structured Grid-Connected Microgrid. *IEEE Transaction on Industry Applications*, 55, 1157–1170. doi: 10.1109/TIA.2018.2882504

[34] Golkhandan, N.H., Ali Chamanian, M., & Tahami, F. (2018). A New Control Method for Elimination of Current THD under Extremely Polluted Grid Conditions Applied on a Three Phase PWM Rectifier. *INTELEC. International Telecommunications Energy Conference*, 7–11 October, Torino, Italy. doi:10.1109/INTLEC.2018.8612432

[35] Kot, S., Jakubowski, J., & Sokołowski, A. (2011). *Statistics*, (2nd ed.). Difin S.A. Warszawa (in Polish).

[36] Sokołowski, A. (2010). *Time series analysis and forecasting, Statistics in research and teaching statistics*. StatSoft Polska. Kraków (in Polish).

[37] Ręklewski, M. (2020). *Descriptive statistics. Theory and examples.* State Vocational University in Włocławek (in Polish).

[38] IEA Publications. (2023). *Management Seasonal and Interannual Variability of Renewables*. https://www.iea.org/reports/managing-seasonal-and-interannual-variability-of-renewables [accessed 06 Nov. 2023].

[39] Chojnacki, A.Ł., & Kończak, Z. (2023). Seasonality and causes of damage to power distribution networks. *Elektro.info*, 7–8, 67–71 (in Polish).