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Individual emission assessment of harmonics in DSO environment

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***Abstract*—The paper presents the propagation assessment and power quality parameters improvement system in power distribution grid. In this work main functionalities of the system are described focusing on the individual assessment module. The module is using CIRED/CIGRE C4.109 method which is based on the 10-minutes aggregated data. Three cases of individual emission assessment using real measurement data in the distribution system operator environment ware analyzed. The obtained results confirmed the legitimacy of using 10-minute data to assess the emissions of harmonics.**

***Keywords*—individual emission assessment; voltage harmonics; voltage fluctuations**

I. Introduction

DURING the ongoing energy transformation in Poland, distribution network operators are facing increasingly new challenges. The growing complexity of the distribution system requires operators (DSOs) to enhance their capabilities in monitoring, controlling, and development of distribution networks. One of the key factors influencing the paradigm shift in the operation of distribution networks is the increasing number of distributed energy sources in the system. These include both sources above 10 kW and a significant number of prosumer installations. Distributed energy sources in some circumstances can be a source of electromagnetic disturbances in the system, especially if they operate alongside nonlinear loads as it is shown in [1].

The localization and subsequent individual emission assessment of electromagnetic disturbances can significantly facilitate the DSO in dealing with the aforementioned issues [2-4]. The question remains, based on what data this approach can operate. In [5] methods of individual emission assessment rely on 10-minute aggregated data. This data is obtained from analyzers and energy meters with the ability to measure power quality parameters. The number of power quality analyzers and energy meters with power quality parameters measurement capabilities is constantly rising due to regulations introduced in Poland [6]. Therefore, the development of the system that will be able to put this information into use is both possible and necessary.

One of the Poland's DSO TAURON Dystrybucja S.A. developed a prototype system for monitoring, localization and individual emission assessment of electromagnetic disturbances. In this paper a developed prototype will be described as well as the results of its operation will be presented, focusing especially on the problem of individual emission of harmonics. The results of assessment will be presented based on the anonymized data from the distribution system.

II. System SOPJEE

Project SOPJEE – 'The propagation assessment and power quality parameters improvement system in power distribution grid' was conducted by TAURON Dystrybucja S.A. and Procom System S.A. in cooperation with AGH University of Science and Technology in Cracow.

The main goal of the project was to build an expert tool for managing the quality of electricity supply in TAURON. Main tasks of the system are:

- collecting information about the power quality status at selected measurement points or in a specific area of the power grid,
- analysis focused on the localization of electromagnetic disturbances sources and their individual emissions in the power system using the diagnostic modules,
- analysis of the impact of planned customer connections in terms of availability and compatibility levels,
- assessment of the impact of changes in the network structure,
- assessment of benchmarking power quality based on indicators W1-W4,
- analysis of trends in power quality changes over time (months, climatic seasons, years) and forecasting areas at higher risk for power supply degradation, taking into account the development of renewable energy sources.

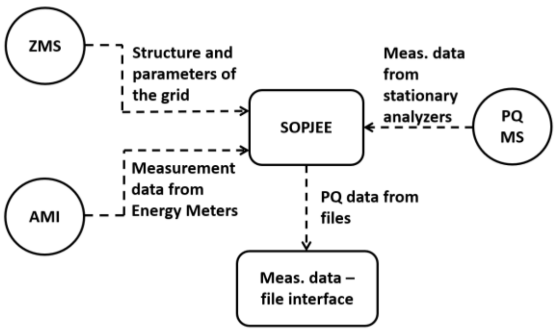

Fig. 1. Architecture of SOPJEE (ZMS – database with the information, AMI – Advanced Metering Infrastructure database, PQ MS – power quality monitoring systems)

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In the Fig. 1. architecture diagram of SOPJEE system is presented.

Most important parts of the system are: ZMS - which is a database with structure and parameters of the power grid, network facilities and boundaries of areas and regions; AMI – which contains measurement data from energy meters, including active and reactive energy, voltages, currents, and W1-W4 indices as well as the power quality parameters; PQ MS - Power Quality Monitoring Systems based on stationary power quality analyzers. In the presented system there is also a possibility of importing data with file interface.

System SOPJEE user interface consists of several modules:

- area indicators W1-W4,
- localization of power quality disturbances,
- localization of voltage sags,
- individual emission assessment of electromagnetic disturbances,
- voltage estimation,
- statistical analysis of area power quality indicators,
- management of compatibility levels.

In the Fig. 2 an example of user interface with the area indicators W1-W4 module is presented.

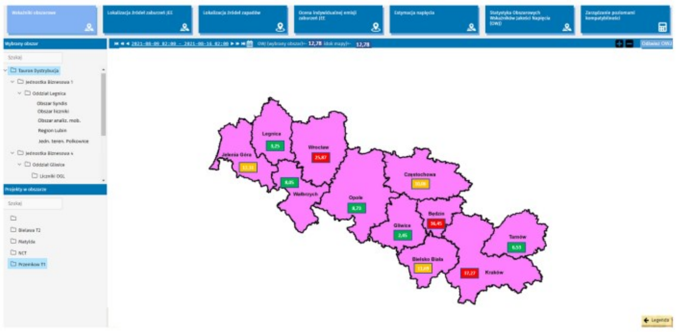

Fig. 2. User Interface of SOPJEE using area indicators module

In the Fig. 3 an example of user interface for localization of power quality disturbances module is presented. Using this module can be the first step first step before using module of individual emission.

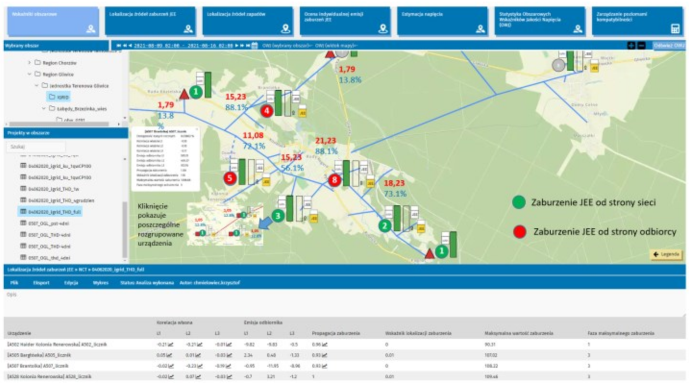

Fig. 3 User Interface of SOPJEE using localization of power quality disturbances module

In the Fig. 4 an example of user interface with the individual emission assessment of electromagnetic disturbances module is presented. User interface allows to identify the specific point of the system that is placed on map. After identifying the point user can perform analysis.

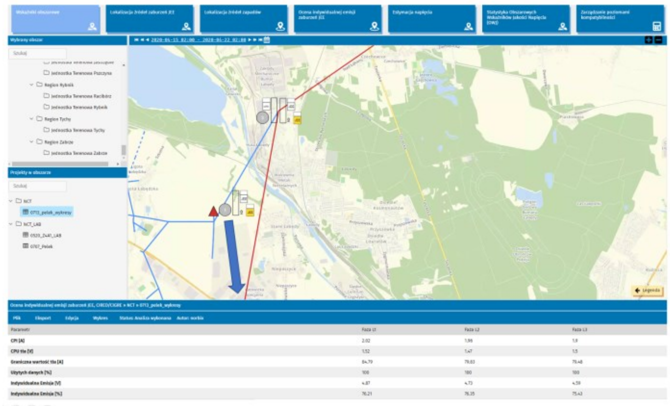

Fig. 4. User Interface of SOPJEE using individual emission assessment of electromagnetic disturbances module

III. Individual Emission Assessment Methods

Individual emission of disturbance refers to emissions that are solely caused by the considered disturbed load, without taking into account other emission sources [7-9]. In this work one of the individual emission of harmonics assessment method used in the system SOPJEE will be presented.

The IEC 61000-3-6 standard [10] defines the emission levels of individual harmonics at the Point of Common Coupling (PCC). The voltage harmonic emission level is defined as the vector difference between the voltage measured at the Point of Common Coupling (PCC) and the background harmonic voltage. The emission level of voltage harmonics depends on the harmonic impedance of the network. As it is shown in technical reports of IEC [7,8] for aggregated 10-minute data a period used for the analysis should be at least a weak.

A method used for assessing individual harmonic emissions is the CIRED/CIGRE C4.109 method [12,13]. The method is based on observation voltage and current values at the Point of Common Coupling (PCC). Fig. 5 presents a simplified network diagram for assessing individual emissions for each harmonic.

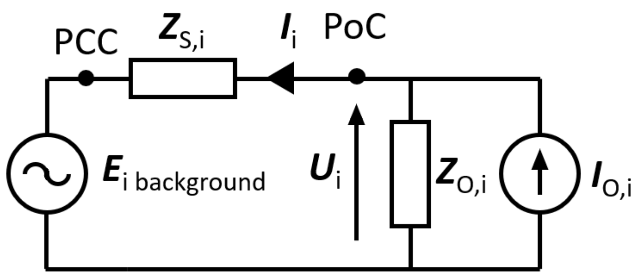

Fig. 5. Equivalent network where

$\boldsymbol{U_i}$ –the harmonic voltage phasor at the PoC for i-th harmonic.

$\boldsymbol{I_i}$ – the harmonic current phasor for i-th harmonic.

$\boldsymbol{E_{i\,bcg}}$ - the background (in the supply system) harmonic voltage phasor at Point of Common Coupling (PCC) for i-th harmonic.

$\boldsymbol{I}_{O,i}$ – the harmonic sources in the consumer's installation for i-th harmonic.
$\boldsymbol{Z}_{S,i}$ – the complex supply impedance for i-th harmonic,
$\boldsymbol{Z}_{O,i}$ – the harmonic sources in the consumer's side for i-th harmonic.

It is seen that the harmonic current emission consists of two components:

$$I_i = I_{O,i}\frac{Z_{O,i}}{Z_{S,i}+Z_{O,i}} - \frac{U_i}{Z_{S,i}+Z_{O,i}} \quad (1)$$

The first component is caused by the harmonic, while the second one results from the interaction between the harmonic sources elsewhere in the grid and the harmonic impedance of the load. It is worth mentioning that with this approach, even a load without harmonic source can have a harmonic emission level defined.
The localization of the dominant source of energy at the PCC is determined by the positioning of points on the voltage harmonics characteristic from the current harmonics (Fig. 6). If the points concentrate around the network impedance shown in the Fig. 6 with the blue stars, the load is the dominant source of harmonics. Distribution side is the dominant source if the points on the characteristic concentrate around the load impedance shown in the Fig. 6 with black crosses. When the points lie between the impedance lines, both the supplier and the load are responsible for harmonic emissions.

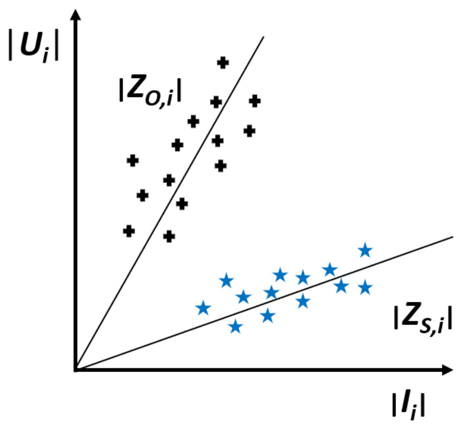

Fig. 6. An example of the wide figure inserted into the text

The assessment of voltage harmonic emission is based on the 95th percentile of the recorded harmonic current I_i, multiplied by the corresponding harmonic impedance Z_S, [9]:

$$\Delta\boldsymbol{U} = \boldsymbol{U}_i - \boldsymbol{E}_{i\,background} = \boldsymbol{Z}_S\,\boldsymbol{I}_i. \quad (2)$$

As it was pointed in [12], the grid harmonic impedance is a key parameter in the quantification process of the harmonic voltage emission.
Fig. 7 shows the algorithm of CIRED/CIGRE C4.109 method. A presented block diagram shows the process for a single phase analysis.

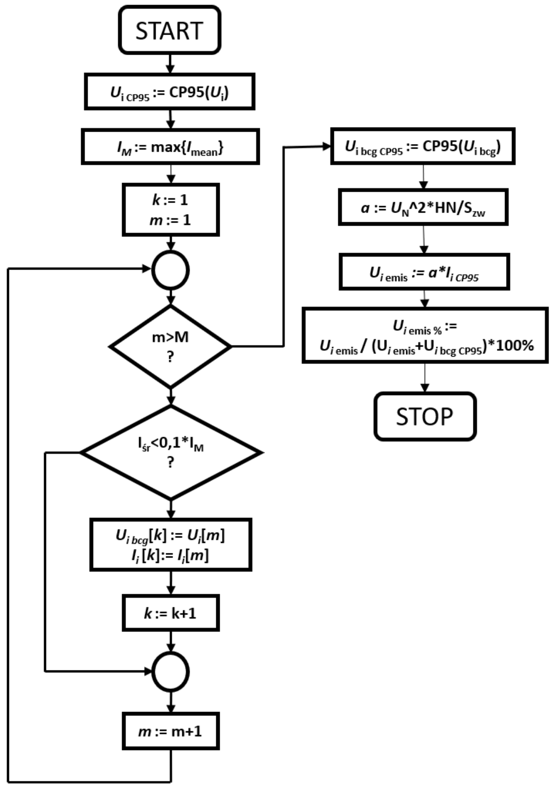

Fig. 7. Block diagram of CIRED/CIGRE C4.109 method

IV. Results

Analysis of three specific cases of individual emission assessment where performed with the use of SOPJEE application.

A. Distribution side domination #1

First analyzed case is individual emission assessment of 17th harmonic in the period of one month. Fig. 8 presents a screen view of parametrization for CIRED/CIGRE method. Name and a specific time of the measurement is anonymized. Short-circuit power used for harmonic impedance Z_S calculation is 200 MVA.

Fig. 8. Screen view of parameterization for analysis based on the CIRED/CIGRE method

Fig. 9 presents a characteristic of 17th harmonic of voltage and current. A black line in figure represents a grid impedance. Measurement points are clearly cumulated around the impedance line which shows that the dominating side in case of 17th harmonic emission is distribution side.

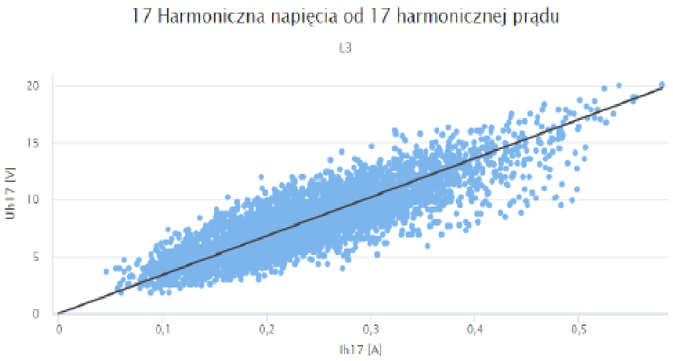

Fig. 9. Characteristic of 17th harmonic of voltage and current

Fig. 10 presents results screen of the analysis performed with the use of SOPJEE system. For phase L3 a 62,35% of 17th harmonic comes from the distribution side.

Parametr	Faza L1	Faza L2	Faza L3
CPI [A]	0.38	0.36	0.39
CPU tła [V]	7.58	9.17	8.04
Graniczna wartość tła [A]	139.14	138.03	137.54
Użytych danych [%]	100	100	100
Indywidualna Emisja [V]	12.9	12.39	13.32
Indywidualna Emisja [%]	62.98	57.48	62.35

Fig. 10. Results screen of the analysis

B. *Distribution side domination #2*

Second case is individual emission assessment of 13th harmonic. Observation period equals three months. Fig. 11 presents a screen view of parametrization for CIRED/CIGRE method. Name and a specific time of the measurement is anonymized. Short-circuit power used for harmonic impedance Z_S calculation is 133 MVA.

Fig. 11. Screen view of parameterization for analysis based on the CIRED/CIGRE method.

Fig. 12 presents a characteristic of 17th harmonic of voltage and current. A black line in figure represents a grid impedance. Measurement points are not clearly cumulated around the impedance line. It is worth to mention that most of the measurement points are under the Z_s harmonic impedance. However, we can be sure, that points are not cumulated around the harmonic impedance of source which is supposed to be higher then the first one. Taking into account that CIRED/CIGRE method is a method based on the aggregated data which in some case can be seen as a lossy compression, a user of this method can assume that in this case a source of the harmonic is on the distribution side.

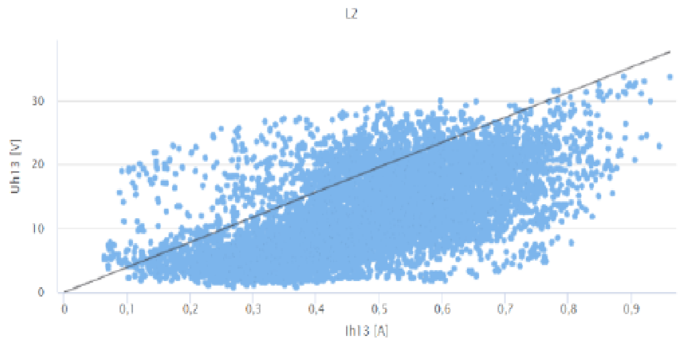

Fig. 12. Characteristic of 13th harmonic of voltage and current

Fig. 13 presents results screen of the analysis performed with the use of SOPJEE system. For phase L2 a 70,03% of 13th harmonic comes from the distribution side.

Parametr	Faza L1	Faza L2	Faza L3
CPI [A]	0.77	0.74	0.82
CPU tła [V]	12.63	12.93	13.76
Graniczna wartość tła [A]	69.7	69.29	69.59
Użytych danych [%]	100	100	100
Indywidualna Emisja [V]	30.28	28.82	32.15
Indywidualna Emisja [%]	70.56	69.03	70.03

Fig. 13. Results screen of the analysis

C. *Load side domination - two operating points*

In the last case individual emission assessment of the 5th harmonic was performed. Observation period used for the analysis was three months. Fig. 14 presents a screen view of parametrization for CIRED/CIGRE method. Name and a specific time of the measurement is anonymized. Short-circuit power used for harmonic impedance ZS calculation is 150 MVA.

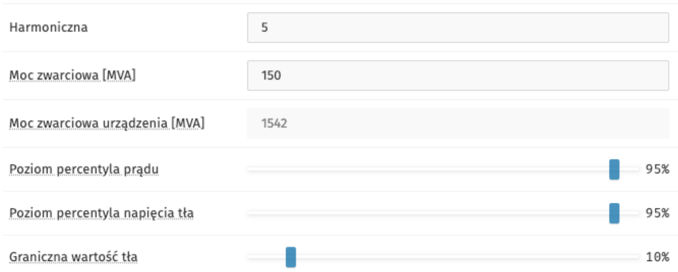

Fig. 14. Screen view of parameterization for analysis based on the CIRED/CIGRE method

In the Fig. 15 a characteristic of 5th harmonic of voltage and current is presented. There are no points around the impedance line as well as measurement points on the characteristic are clustered in two groups over the impedance line. Measurement points exhibit linearity especially in case of higher currents. Taking this into consideration it is highly probable that the source of the 5th harmonic is on the consumer side.

A phenomenon of two clusters of measurement point in the can be explained by the probable presence of the capacitor on the load side of the analyzed point. To determine a nature of the operation of the load in the analyzed point, in the Fig. 16 and 17 a profiles of total harmonic distortion and THD and I_{rms} are presented respectively. As it is seen there are two states of the operation for the analyzed point. There are two ranges of THD and I_{rms} in the profiles.

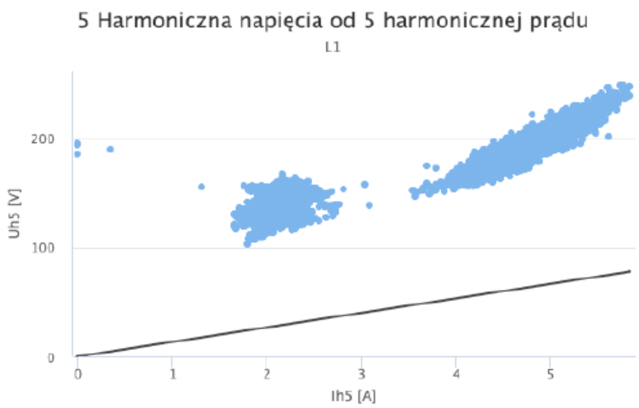

Fig. 15. Characteristic of 5th harmonic of voltage and current

Fig. 16. Profile of THD

Fig. 17. Profile on I_{rms} in the measurement point

CONCLUSION

The paper presents the propagation assessment and power quality parameters improvement system in power distribution grid which was build by TAURON Dystrybucja SA lead consortium. The architecture, main functionalities and user interface of the system were described and presented.

In this work a main focus was on CIRED/CIGRE C4.109 individual assessment method. The described method with a specified algorithm was implemented and integrated within the monitoring SOPJEE system.

Using the SOPJEE system three cases of individual emission of harmonics assessment ware performed. Measurements used for the analysis ware carried out for at least a period of one month, which fulfilled one the most important requirements for using aggregated data for the proper analysis. Frist two cases showed that the system can be positively used for assessing emission. In these two cases the main contributor of harmonics was on distributor side. In the third case the biggest contribution of harmonics was on the consumer side. Moreover, an interesting phenomenon of two separate clusters of measurement points was observed.

The obtained results confirmed the legitimacy of using 10-minute data to asses the emission of harmonics. Additionally, the usefulness of the prototype SOPJEE system was presented.

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