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Individual emission assessment of electromagnetic disturbances based on aggregated data

***Abstract**. The paper presents a comparison of methods for assessing individual harmonic and voltage fluctuations emissions, based on aggregated 10-minute values. IEC technical reports suggest that measurements of the aggregated 10-minute RMS current and voltage, used to assess individual harmonic emissions, should be performed for a sufficiently long time - a minimum of a week. The work used real measurements made in the distribution network. The obtained results confirm the legitimacy of using 10-minute data to assess the emissions of the analysed disturbances.*

***Streszczenie.** W pracy przedstawione zostało porównanie metod oceny indywidualnej emisji harmonicznych i wahań napięcia, na podstawie zagregowanych 10 minutowych wartości. Zaprezentowane przykłady wykorzystania opisanych metod bazują na pomiarach wykonanych w sieci dystrybucyjnej. Otrzymane wyniki potwierdzają zasadność wykorzystania danych 10-minutowych do oceny emisji analizowanych zaburzeń. (**Ocena indywidulanej emisji zaburzeń na podstawie danych zagregowanych**).*

Keywords: electromagnetic disturbances, voltage harmonics, voltage fluctuations, individual emission assessment.
Słowa kluczowe: zaburzenia elektromagnetyczne, harmoniczne napięcia, wahania napięcia, ocena indywidualnej emisji.

Introduction

Individual emission of a disturbance is one whose only source is the considered disturbing load, without considering other sources of emission. The perspective of installing an increasing number of renewable energy sources and increasing number of non-linear loads in the power grid makes the process of assessing individual emission of disturbances more complicated. It is necessary to develop an effective methodology for such an assessment. Ideally, the assessment should be carried out using existing metering infrastructure (stationary and mobile power quality analyzers). The paper presents two methods for assessing individual harmonic emissions and a method for assessing individual emission of voltage fluctuations.

Voltage harmonics emission

The IEC 61000-3-6 [1] standard defines the emission levels of individual harmonics at the Point of Connection (PoC). The voltage harmonic emission level is defined as the vector of the difference between the voltage measured at the Point of Common Coupling (PCC) joint connection and the harmonic voltage of the background. The level of voltage harmonic emission depends on the harmonic impedance of the network. IEC technical reports [1,2] suggest that the measurements of the aggregated 10 minute RMS current and voltage, used to assess individual harmonic emission, should be carried out for a sufficiently long time: a minimum of a week.

One method for assessing individual harmonic emission based on aggregated 10-minute data is the CIRED / CIGRE C4.109 method [4]. The method is based on a long (minimum one week) observation of 10-minute RMS voltage and current at the PoC. Figure 1 shows a diagram of the network for assessing individual emission of harmonics.

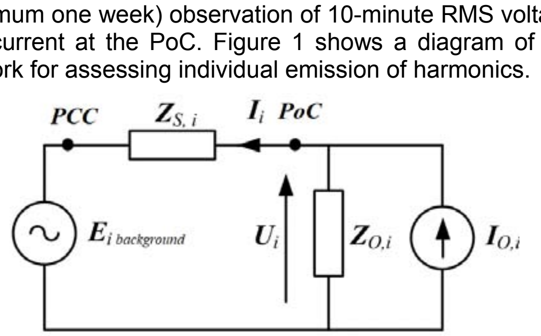

Fig.1. Equivalent network diagram for the definition of the harmonic emission level at the PoC [5] where:

$\boldsymbol{U_i}$ –The harmonic voltage phasor at the PoC for i-th harmonic.
$\boldsymbol{I_i}$ – The harmonic current phasor for i-th harmonic.
$\boldsymbol{E_{i\ background}}$ - 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.

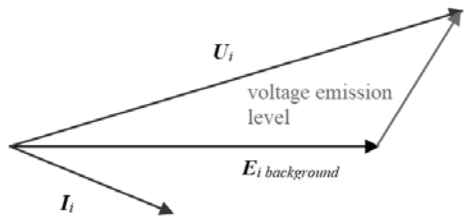

Fig.2. Definition of the consumer's individual harmonic emission level.

It can immediately be 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 clearly caused by the harmonic sources present in the considered installation, while the second one results from the interaction between the harmonic sources present elsewhere in the grid and the harmonic impedance of the load. It is important to note that, considering this approach, even a load without harmonic source can have a harmonic emission level defined.

The location of the dominant energy source at the PoC results from the location of measurement points on the harmonic voltage to harmonic current characteristic (Figure 3). If the points are aligned around the network's impedance, the load is the dominant harmonic source. The power supply network is the dominant source of disturbances if the points on the characteristic are aligned around the load impedance. When the points are aligned between the impedance lines, both the supplier and the customer are responsible for harmonic emission.

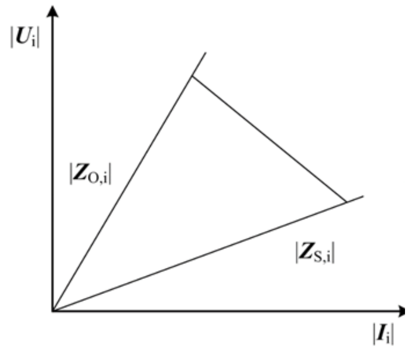

Fig.3. An example of the wide figure inserted into the text

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, as in [3]:

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

As it was pointed in [3], the grid harmonic impedance appears to be a key parameter in the quantification process of the harmonic voltage emission. One way of getting an information about impedances is using the actual measured value of this impedance, but it can be difficult and complex because it creates the necessity of online measurements and calculation. Second way is using an agreed "contractual" value (either calculated or measured as a one-shot).

In some cases, this reasoning can lead to erroneous conclusions [5, 6]. When energy is generated by distributed renewable sources, it may not be possible to assess emissions. Harmonics of different characters can add together in an unknown way, introducing high uncertainty into the evaluation of voltage harmonic emission, as illustrated in Figure 4.

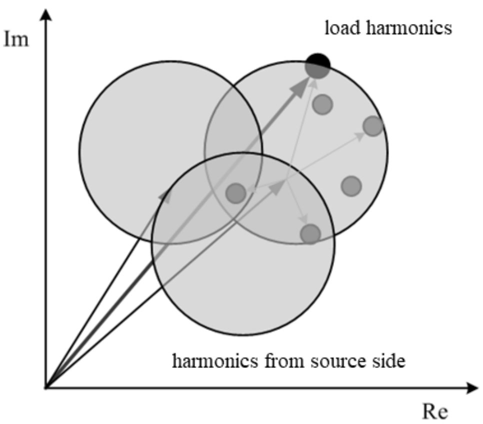

Fig.4. Example of an unknown way of adding harmonics.

(3) $$U_i = \sqrt[\alpha]{\sum_n U_{i_n}^{\alpha}} = \sqrt[\alpha]{\left(U_{i_n}^{\alpha}\right)_{background} + \left(U_{i_n}^{\alpha}\right)_{emission}}$$

where:
U_i – The harmonic voltage phasor at the PoC for i-th harmonic, U_{i_n} – individual emission level, α - parameter.

Table 1 presents the values of the α exponent for individual harmonics. The values in the table result from experimental research and are included in the standard [1].

Table 1. The parameters of the sensor

α	Harmonic number
1	i<5
1,4	5≤i≤10
2	i>10

Generation of Flicker

Voltage measurement provides information about the sum of fluctuations coming from all disturbed loads present in the supply network and affecting the level of disturbance at the considered point. In order to assess whether the emission of voltage fluctuations, caused by the operation of an specific load, does not exceed the emission level that was granted at the stage of determining the technical conditions of connection, it is necessary to develop appropriate control methods [8].

Literature [1, 5, 6] recommends using the method based on the law of summation for the assessment of individual emission of voltage fluctuations. The dependence on the resultant value of the short-term light flicker indicator caused by several emission sources was empirically determined:

(4) $$P_{st} = \sqrt[\alpha]{\sum_n P_{st_n}^{\alpha}}\ \ P_{lt} = \sqrt[\alpha]{\sum_n P_{lt_n}^{\alpha}}\ ,$$

where: P_{st} (P_{lt}) - flicker indicators from individual, independently working sources of the distortion [7].

The α factor takes values depending on the characteristics of the source of fluctuations:

- α = 4 used to add voltage fluctuations from arc furnaces that operate in a manner that eliminates simultaneous melting;
- α = 3 commonly used for most types of voltage changes when the probability of simultaneous operation of sources is low;
- α = 3.2 used for the straight part of the characteristic P_{st} = 1;
- α = 2 used when convergence of work of different sources is possible, e.g. with simultaneous operation of several arc furnaces or continuous operation of several wind farms connected at a short distance;
- α = 1 used for adding up compatible voltage changes (high probability of simultaneous operation of disturbed loads).

Empirical studies have shown that the law of summation, which best corresponds to the measurement results, depends on the value of the percentile used to assess the distortion [3]. For example, in the case of two arc furnaces, the summation is practically linear (α = 1) up to a probability level (p) of 50%, while it becomes square (α = 2) for p ≈ 90%. For p ≥ 95%, it is very difficult to assume values of α coefficient, and the measured level of voltage fluctuations is almost exclusively caused by the load (α ≥ 4) which causes the biggest disturbances .

In the assessment of the emission level, based on a comparative analysis of measurements, with the disturbing load under consideration (P_{st} with the load) and without it (Pst background, without the load), the law of aggregation of emissions can be used:

(5) $$P_{st} = \sqrt[\alpha]{\sum_n P_{st_n}^{\alpha}} = \sqrt[\alpha]{\left(P_{st}^{\alpha}\right)_{background} + \left(P_{st}^{\alpha}\right)_{emission}}$$

However, this method raises some concerns. Measurements of parameters were not carried out at the same time and the result may be disturbed by possible changes in the operating conditions of other disturbing loads, or changes in the configuration of the power supply network (changing in particular the short-circuit power).

Individual emission assessment of voltage harmonics

The number of samples for each phase is M_{L1}, M_{L2}, M_{L3} = 2159. The rated voltage at the point is U_N = 110 kV. The harmonic analyzed is i = 27.

Figures 5, 6 and 7 show the dependence of the 27 harmonic voltage on the 27 harmonic current and the 27 harmonic voltage on the average current value for the L1, L2 and L3 phase respectively. The impedance line determined from the short-circuit power S_{zw} is marked in red.

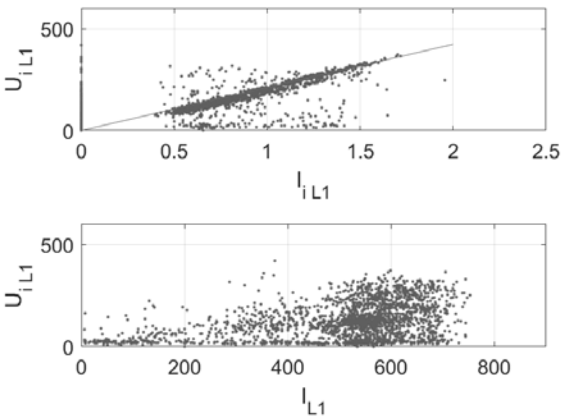

Fig.5. Example of 27th harmonic voltage vs. current and harmonic voltage vs. RMS current for the L1 phase.

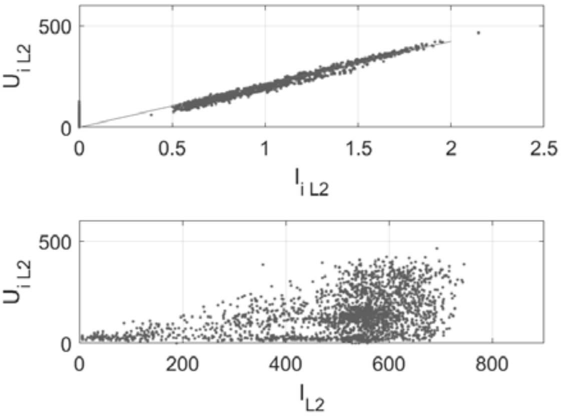

Fig.6. Example of 27th harmonic voltage vs. current and harmonic voltage vs. RMS current for the L2 phase.

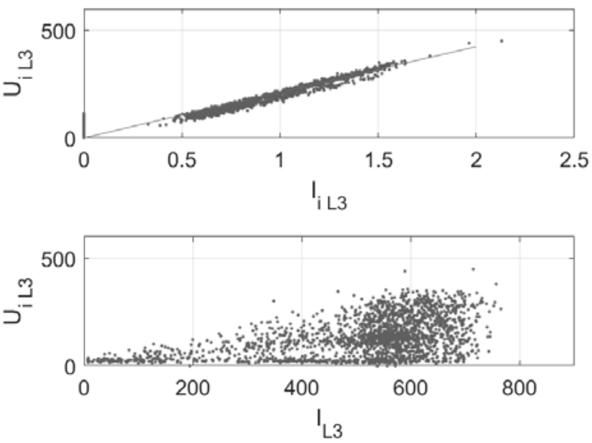

Fig.7. Example of 27th harmonic voltage vs. current and harmonic voltage vs. RMS current for the L3 phase.

In the analyzed case, most of the data is grouped around the impedance line. It means the load is responsible for the disturbance, so the individual emission of the load is possible. The location of the source of disturbances also indicates the stability of short-circuit power during measurements. The 95th percentile of the harmonic current CP95 {I_i} and the 95th percentile of the harmonic voltage CP95 {U_i} were determined, followed by the maximum effective value of the load current $Imax$. The total voltage is the CP95 value of the harmonic voltage, determined for the current range from 0 to 10% $Imax$.

Table 2 presents the results of the individual emission assessment using the CIRED / CIGRE C4.109 method (I) as well as the method based on the law of summation (II), described in the IEC 61000-3-6 standard, using values of α = 2 recommended in the standard.

The differences between the results of both implemented methods are small, reaching up to a tenth of the percent. The analysis showed that the source of harmonics at the examined point is the load. It has been calculated that the recipient is responsible for approximately 80% to 90% of the disorder in individual phases.

Table 2. The parameters of the sensor

	CP95 {I_i} [A]	CP95 {U_i} [V]	Max {I_{RMS}} [A]	N	$E_{i\ background}$ [V]	I [%]	II [%]
L1	1,36	288,2	752,9	78	74,2	79,6	78,97
L2	1,58	341,4	745,1	83	46,8	87,7	87,84
L3	1,36	765,3	765,3	77	36,3	89,0	88,94

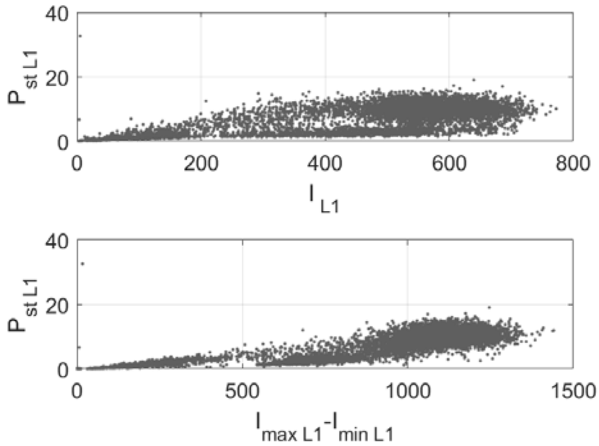

Fig.8. Flicker vs. RMS current and Flicker vs. I_{max} – I_{min} for the L1 phase.

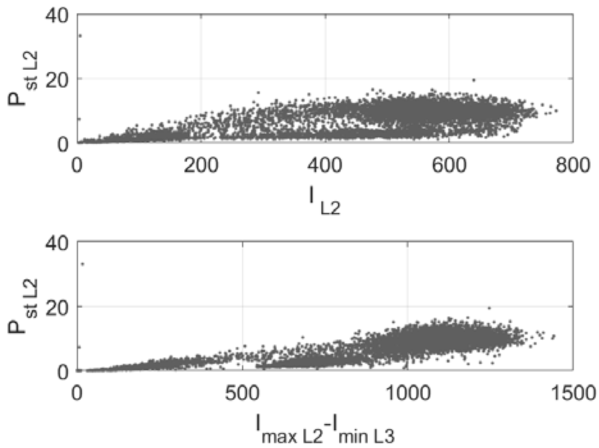

Fig.9. Flicker vs. RMS current and Flicker vs. I_{max} – I_{min} for the L2 phase.

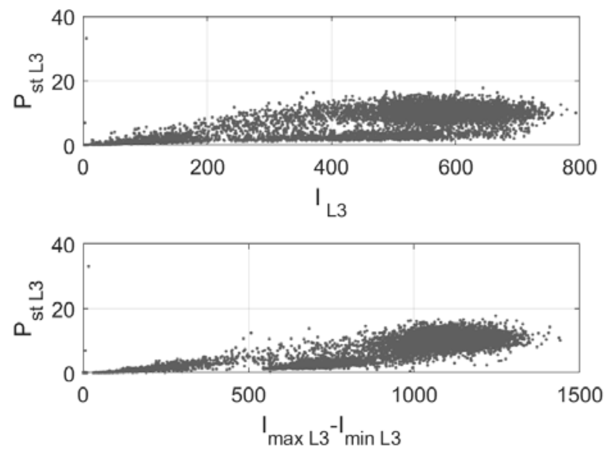

Fig.10. Flicker vs. RMS current and Flicker vs. I_{max} – I_{min} for the L3 phase.

Individual emission assessment of flicker

Number of samples for individual phases are M_{L1}, M_{L2}, M_{L3} = 8641. The rated voltage at the point is U_N = 110 kV. Figure 8,9 and 10 shows the dependence of the P_{st} flicker indicator on the aggregated RMS current and the dependence of the P_{st} flicker indicator on the difference in the maximum values of Imax current and minimum values of I_{min} current for phase L1, L2 and L3 respectively.

The impact of the load on the level of voltage fluctuations is confirmed by the dependence of the P_{st} indicator on the difference between the max and min current values. As can be seen in Figure 8, the relationship is strong. For algorithmizing of the problem, the correlation coefficient can be used. The load can by identified as the dominant source of the distortion. A similar situation occurs for the other two phases. The 95th percentile CP95 voltage fluctuation {P_{st}} was determined. Then the maximum effective current of the recipient I_{max} was determined.

It is very important for the correct conclusion to choose the current value, below which it is assumed that the load generating the disturbance is not working. The current limit should result from practice (observation of the load over a long time scale). The P_{st} background was calculated as the value of the voltage fluctuation percentile (P_{st}), determined for the current range from 0 to 10% I_{max}.

As a rule, it should be assumed that the value of this current should be as low as possible in relation to the maximum current of the load in the analyzed period. Additionally, the number of recorded measurement data, during such defined lack of disturbing load operation, will be large enough to determine a reliable statistical measure in form of the CP95 percentile. In the presented implementation, the current limit value was defined as 10% of the measured maximum current value. The results of the individual emission assessment are presented in Table 3. In each phase, the recipient is the main source of voltage fluctuations and his individual emission in individual phases ranges from 94.18% to 95.14%.

Table 3. The parameters of the sensor

	CP95 {P_{st}}	Max {I_{RMS}}	N	$P_{st\ background}$	Ind. Emission [%]
L1	12,6895	793,71	1432	0,78	94,18
L2	12,2731	772,53	1447	0,68	94,74
L3	12,9883	790,64	1426	0,66	95,14

Conclusions

The paper presents selected methods for the assessment of individual emission of voltage fluctuations and voltage harmonics. The described methods have been implemented and tested on the basis of real measurements in the power grid. The obtained results confirm the legitimacy of using 10-minute data to assess the emissions of the analyzed disturbances.

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REFERENCES

[1] Electromagnetic compatibility (EMC)—limits—assessment of emission limits for distorting loads in MV and HV power systems, IEC Tech. Rep. 61000-3-6, 1996.
[2] Electromagnetic compatibility (EMC)—limits—assessment of emission limits for fluctuating loads in mv and hv power systems, IEC Tech. Rep. 61000-3-7, 1996.
[3] Jaeger E. D. E.:, Disturbance Emission Level Assessment Techniques (CIGRE / CIRED Joint Working Group C4-109), in 20th International Conference on Electricity Distribution, 2009, No. 0470, 8–11
[4] Assesment of emission limits for the connection of disturbing installtions to power systems, JointWorking Group CIGRE/CIRED C4.103 (formely CIGRE C4.06), 2007, Final Rep.
[5] Peterson B., Rens J., Botha G., and Desmet J.: A Discriminative Approach to Harmonic Emission Assessment," in *IEEE International Workshop on Applied Measurements for Power Systems (AMPS)*, 2015, no. June.
[6] Peterson B., Rens J., Botha G., and Desmet J.: On The Assessment of Harmonic Emission in Distribution Networks: Opportunity for the Prevailing Harmonic Phase Angle, *2016 IEEE International Workshop on Applied Measurements for Power Systems (AMPS)*, 2016
[7] Guide to quality of electrical supply for industrial installations, Part 5: Flicker, UIEPQ 1999
[8] Wiczyński G.: Voltage-fluctuation-based identification of noxious loads in power network, *IEEE Trans. on Instrumentation and Measurement*, 58 (2009), No. 8, 2893–2898.