DISTURBANCE EMISSION LEVEL ASSESSMENT TECHNIQUES (CIGRE / CIRED JOINT WORKING GROUP C4-109)

Emmanuel DE JAEGER
Laborelec – Belgium
emmanuel.dejaeger@laborelec.com

ABSTRACT

This paper reports on the work accomplished by CIGRE-CIRED JWG C4-109[1] *in the context of the assessment of individual low-frequency disturbances emission levels.*

INTRODUCTION

IEC published in early 2008 Technical Reports 61000-3-6, 61000-3-7 and 61000-3-13 [1], [2], [3] giving guidelines for the assessment of emission limits, respectively for harmonics, flicker and voltage fluctuations, and unbalance. Complementary to the specification of disturbances emission limits, network operators must be in state of verifying if these limits are well respected or not. They should actually be able to identify and – as much as possible - quantify the individual responsibilities of disturbing consumers. In this context, the CIGRE-CIRED Joint Working Group C4-109 was asked to:

- Review and document experience with the application of IEC emission assessment guidelines for the purposes of synthesizing practical recommendations based on actual case studies,
- Provide a state-of-the-art review of existing assessment methods,
- Develop practical guidelines for undertaking an emission assessment.

This paper highlights some concepts and major results of the work accomplished (as of December 2008). The WG will produce a complete report soon.

HARMONICS

The concept of harmonic emission level

In IEC 61000-3-6, the individual emission levels and assigned limits are defined with respect to the impact of a given distorting load or installation on the harmonic voltage at the point of connection.

For this purpose, the harmonic current emission level is defined as the harmonic current established between the considered installation and the network, after connection. On the other hand, the harmonic voltage emission level is defined as the vector difference between the harmonic voltage measured at the point of evaluation (POE) - which can be the point of common coupling or the point of connection or any other point specified by the system operator - when the installation is connected and operating, and the background harmonic voltage (i.e. the harmonic voltage caused by all the other disturbing loads present in the grid).

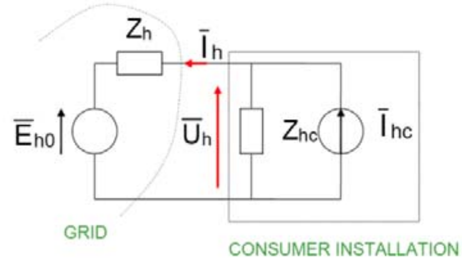

Figure 1 - *Equivalent scheme for the definition of the individual harmonic emission level at the POE.*

Considering the equivalent scheme of , (where $\overline{U}_h$ is the harmonic voltage phasor at the POE, $\overline{I}_h$, the harmonic current phasor, $\overline{E}_{h0}$, the phasor of background harmonic voltage, Z_h and Z_{hc}, the complex network and consumer's harmonic impedances and $\overline{I}_{hc}$, the harmonic sources present in the consumer's installation) established at the POE for the purpose of assessing harmonic emissions, the individual harmonic voltage emission level $\overline{E}_{hc}$ is illustrated in Figure 2.

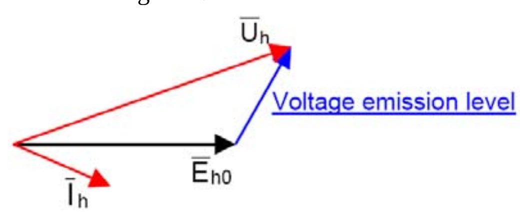

Figure 2 - *Definition of the consumer's individual harmonic emission level* $\overline{\boldsymbol{E}}_{hc} = \boldsymbol{Z}_h \overline{\boldsymbol{I}}_h = \overline{\boldsymbol{U}}_h - \overline{\boldsymbol{E}}_{h0}$

It can immediately be seen that the harmonic current emission consists of two components:

$$\overline{I}_h = \overline{I}_{hc}\frac{Z_{hc}}{Z_h + Z_{hc}} - \frac{\overline{E}_{h0}}{Z_h + Z_{hc}}$$

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. This could happen if, for example, it includes

[1]Membership: D. Arlt, H. Bronzeado, R. Cai, P. Caramia, E. De Jaeger (convenor), Z. Emin, J.L. Gutierrez-Iglesias, M. Halpin, Z. Hanzelka, D. Hirano, F. Klein, R. Koch, A. Lopes Leiria, M. McGranaghan, I. Papic, S. Perera, B. Peterson, H. Renner, F. Zavoda, A. Zobaa

capacitor banks interacting with the network by creating some resonance.
The harmonic voltage emission level is clearly dependent on the harmonic impedance Z_h of the network at the POE ($\bar{E}_{hc} = Z_h \bar{I}_h$). In IEC 61000-3-6, harmonic emission is taken into consideration if and only if the resulting U_h has a greater amplitude than the background E_{h0}. Only in this case, the emission levels (current or voltage) have to be compared with the assigned limits. This comparison is made through a statistical assessment procedure.
The IEC technical reports suggest that the emission levels should be measured for a sufficient long period of time (typically one week) and that statistical indices must be used (e.g. 95th percentile of the 10-minutes r.m.s. values) for comparison with the authorised limits.

Examples of assessment methods

Evaluation by switching the considered installation
This approach of harmonic emission level assessment is based on the comparison of two sets of measurements, which are taken in sequence with the consumer's installation respectively switched off and on. When the installation is switched off, the measurement of the harmonic voltage at the POE gives the background E_{h0}, while the harmonic current emission is obviously equal to zero.
The advantage of the approach is its simplicity but, on the other hand, it provides "instantaneous" results that are only valid at the time of the switching operation. It gives no statistical behaviour of the harmonic emission of the load. Rigorously, one must also take care of the fact that the method relies upon the assumption that the background level remains constant during the switching operation (as well in magnitude as in phase angle), which is not guaranteed at all in every circumstance.

Evaluation without switching
Permanent measurement during longer periods of time are by far better for the assessment of harmonic emission levels. The quantities to be measured should be at least the harmonic currents at the point of evaluation. However, simultaneous measurement of the harmonic voltages brings interesting complementary information.

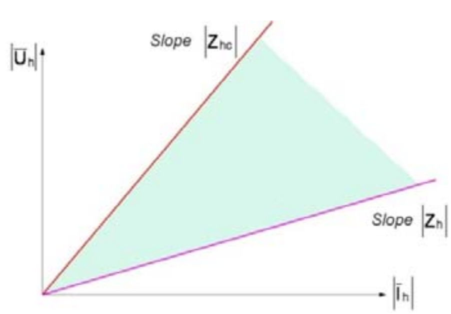

Figure 3 – *Typical plot area of measured harmonic voltage vs. harmonic current at the POE, with indication of the grid and consumer's installation harmonic impedances.*

Figure 3 shows a typical plot area of harmonic voltage vs. the harmonic current. The slopes of the straight lines indicate respectively the harmonic impedance of the network at the POE and the impedance of the transformer connecting the installation to the grid. This one is in fact a lower boundary for the considered consumer's installation harmonic impedance.
Practical examples of such diagrams are given in Figure 4 to Figure 6, showing 10-minutes r.m.s. values, measured according to IEC 61000-4-30 during one week.

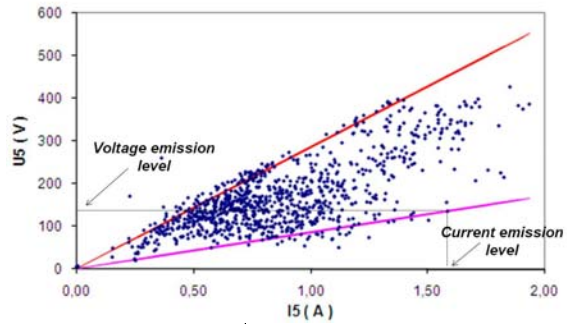

Figure 4 – *Example of 5th harmonic voltage vs. current (130 MVA arc furnace installation, connected at 220 kV)*

In these figures, the harmonic current emission level is the 95th percentile of the values, evaluated over one week. The corresponding voltage emission level appears to be this value multiplied by the modulus of the grid harmonic impedance Z_h ($E_{hc} = Z_h I_h$).
In Figure 4, the experimental points are spread over the area delimited by the two straight lines. This means that the harmonic current and the resulting voltage are actually resulting from the combined influences of the background level and the considered distorting load, without any prevalence of one or the other. In Figure 5, however, the load acts clearly as a rather dominant emitter at the POE: the points are mostly grouped along the straight line of which the slope is equal to Z_h. This means that the influence of the considered installation is greater than the background harmonic level.

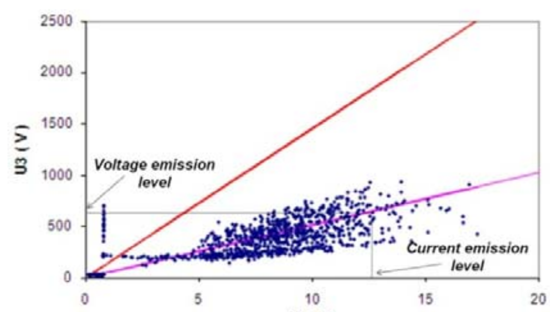

Figure 5 - *Example of 3rd harmonic voltage vs. current (150 MVA arc furnace installation, connected at 220 kV)*

The grid impedance fluctuation in time, together with the fluctuations of the background harmonic voltage E_{h0},

have as consequence that the measured points are not perfectly aligned but dispersed.
In Figure 6, the points are more or less aligned along the second straight line, with slope equal to the modulus of the transformer impedance. The 5th harmonic current is essentially made of current absorbed from the grid into the 5th harmonic filter being part of the installation under study. The grid is the dominant harmonic source at this frequency, in this case.

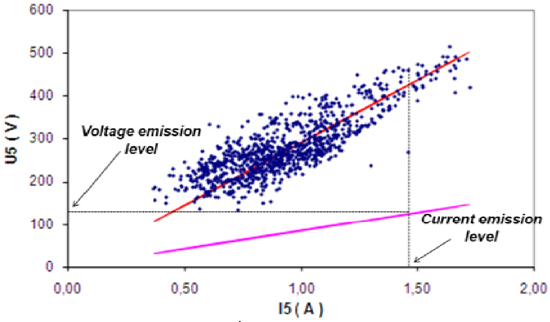

Figure 6 - *Example of 5th harmonic voltage vs. current (100 MVA arc furnace installation, connected at 220 kV)*

Role of the grid harmonic impedance
The grid harmonic impedance appears to be a key parameter in the quantification process of the harmonic voltage emission. Several options exist for the practical processing of the measurement data:

- Using the actual measured value of this impedance (with the difficulty of doing it on-line),
- Using an agreed "contractual" value (either calculated or measured as a one-shot).

The option taken in Figure 4 to Figure 6 is the second one, with a calculated value (based on a simulation model of the network at the POE).

Comparison with other approaches

Other approaches are found in the technical literature. Among these, many authors recommend to focus on the direction of the harmonic active power flow exchanged between the distorting load and the grid. However, this is not necessarily related to the impact on the harmonic voltage at the point of connection.
Some approaches suggest looking only at the harmonic components increasing the background level. The *Harmonic Vector Method* belongs to these ones. Measurement difficulties arise when trying to apply these approaches at HV or MV: one must be able to measure accurately the harmonic voltage and current phase angles differences, taking measurement transducer uncertainties into account.
The IEC 61000-3-6 approach reveals to be more pragmatic, while relying upon an acceptable theoretical basis.
The final report will provide a comparative practical analysis of all these methods.

FLICKER

The concept of flicker emission level

The technical report IEC 61000-3-7 which outlines the principles to assess emission limits for the connection of fluctuating loads to the public network power system, gives the following definition of the flicker emission level: "The emission level from an installation into the power system is the magnitude of flicker which the considered installation gives rise at the point of evaluation (POE). The emission level is required to be less than the emission limit assessed according to the relevant sections in this document". As far as flicker is concerned, emission level must then be interpreted as the level resulting from the considered fluctuating load alone, without any interaction with the other disturbing loads present elsewhere in the grid.

Examples of assessment methods

Evaluation by switching the considered installation
Simple voltage measurements provide only the global effect of all the disturbers present in the network. However, comparative measurements with and without the concerned disturbing load can be useful in order to assess its emission level, provided that some assumptions are made. These assumptions concern the use of statistical summation laws, e.g.

$$P_{st} = \left(\sum_i P_{st\ i}^m \right)^{1/m}$$

(m being typically 3) or the type of statistical distributions.

Statistical approach from simultaneous measurement of flicker and power consumption
If the flicker level is continuously recorded at the POE for a sufficient long period of time, together with the power consumption of the different consumers, a clear distinction can be made between situations with no, one single or more disturbing loads in operation. For each of the possible combinations, all the P_{st} results are put together and statistics (such as $P_{st\ 95\%}$ or $P_{st\ 99\%}$) are calculated. Selecting the P_{st} values according to the energy demand record of the different fluctuating loads seems to be an efficient method to assess the contribution from each individual one. A drawback is that considerable time is often necessary before getting reliable results. The measurement period leading to the equivalent of one-week results (± 1000 P_{st} values) may in fact be very long. Another disadvantage of this kind of methods - linked to the rather long measurement period - is the risk of changes in network topology, possibly leading to significantly different short-circuit levels. The obtained individual P_{sti} values are then no longer related

to a constant short-circuit capacity. However, should a reliable value of the short-circuit level be known for each data, the results could be re-processed in order to be related to a fixed reference short-circuit capacity (e.g. the contractual value).

Direct on-line measurement of flicker emission level

Direct on-line assessment methods have the advantage of not requiring a longer measurement time than strictly required (typically one week). On the other hand, they are insensitive to network fluctuations or topology changes. The price to pay is that more than one simple flicker measurement is needed: at least two voltages, or one voltage and one current, or even complementary signals need to be measured. The data processing is not common and usually not provided in commercially available flickermeters. Various methods have been investigated by the WG.

In the "*Difference Method*", a known impedance, in most cases the transformer impedance feeding the particular load, between points A (= consumer) and B (= point of common coupling) is used to assess the emission of the fluctuating load. Simultaneous voltage measurements in points A and B have to be made to calculate the emission level. The emission level is related to the known impedance Z_2 and must be transposed afterwards to the impedance corresponding with the contractual or agreed short-circuit level.

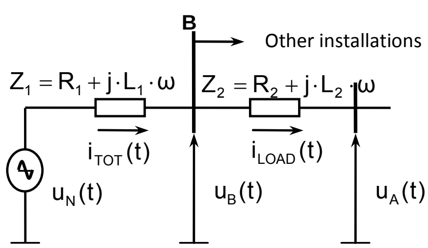

Figure 7 - *Configuration for assessment of the emission with the "difference approach"*

The "*Load Current*" approach relies on simultaneous *waveform* measurements of the *load current* [$i_{LOAD}(t)$] and the voltage [$u_m(t)$] at the POE. The calculation of the emission level of the fluctuating load is done in two steps.

The measured load current $i_{LOAD}(t)$ is injected into an ideal grid model (Figure 8), to determine the emission voltage $u_e(t)$, the voltage which would be obtained at the POE, if the load was the only fluctuating load in the grid. The phase angle of the simulated voltage $u_e(t)$ has, at every moment, to be the same as for the measured voltage $u_m(t)$, to preserve the correct phase angle with the load current $i_{LOAD}(t)$, i.e. to respect the reactive and active power demand of the load at the POE. In the second step, a digital flicker algorithm is used to deduce the instantaneous flicker Pf and the statistical values P_{st} and P_{lt} out of the voltage waveform $u_e(t)$.

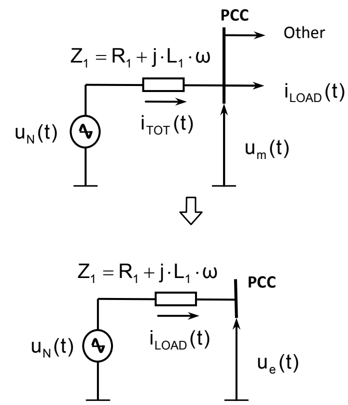

Figure 8 - *Configuration for assessing the emission level with the "load current approach" (measurement configuration - simulation configuration)*

An alternative to this method is provided by determining the consumer's contribution to flicker level at the POE by means of on-site RMS voltage and power measurements (U, P and Q every cycle or half cycle values). The measured values are used in a simulation software to compute the corresponding load impedance fluctuations and voltage fluctuations at the POE, feeding a flickermeter emulation which can accept RMS voltage as input.

UNBALANCE

At the time of publishing this paper, the section devoted to unbalance has not yet been worked out.

CONCLUSION

This paper was aimed at highlighting some basic concepts dealt with by CIGRE-CIRED JWG C4.109, in its task of analysing and comparing LF disturbances emission levels assessment techniques.

The final report (expected to be issued by the end of 2009) will provide a full comparative practical analysis of all the considered methods, together with their full references.

REFERENCES

[1] IEC/TR 61000-3-6, Ed. 2.0, 2008, *Assessment of emission limits for the connection of distorting installations to MV, HV and EHV power systems.*

[2] IEC/TR 61000-3-7, Ed. 2.0, 2008, *Assessment of emission limits for the connection of fluctuating installations to MV, HV and EHV power systems.*

[3] IEC/TR 61000-3-13, Ed. 1.0, 2008, *Assessment of emission limits for the connection of unbalanced installations to MV, HV and EHV power systems.*