CONNECTION RULES FOR POSSIBLY DISTURBING LOADS IN LV NETWORKS

Michèle DE WITTE, Laborelec, michele.dewitte@laborelec.com
Christian PIRENNE, Netmanagement Wallonie
Serge MAGNUS, SIBELGA
Piet LAUWERS, EANDIS
Emmanuel DE JAEGER, Laborelec
BELGIUM

ABSTRACT

Nowadays there is no international standard or technical report dealing with the assessment of emission limits for large disturbing loads or installations to be connected to Low Voltage (LV) power systems. This paper presents the procedures set up in Belgium by the distribution grid operators to deal with this issue. Some basics concerning fluctuating and distorting loads are recalled, together with the associated standards. The workflow is briefly commented and examples are given.

INTRODUCTION

The limitation of disturbances caused by fluctuating and distorting loads of small size, at Low Voltage (LV), is ruled by product standards, concerning appliances with input current ≤16 A. For larger equipment or installations, the grid operator has a key role to play, in the assessment of the impact of the loads on his network, in order to keep the global disturbance levels under control. There is still actually no international standard or technical report dealing with this issue. This paper explains and illustrates the technical procedures set-up in Belgium [1].

LOW-VOLTAGE DISTURBANCES

Voltage fluctuations and flicker

Main sources and examples

Rapid voltage changes in LV networks are mainly caused either by fluctuating loads in consumer's installations, operation of transformer tap changers or other operational adjustments in the system (e.g. capacitor bank switching).

Any fluctuating electrical load is, by essence, able to cause voltage changes and, possibly, flicker. In LV grids, the major disturbers are: HVAC applications (electrical heating systems, compressors used in cooling systems, heat pumps, air conditioning systems etc.), electrical tools, especially machines with an alternating torque (wood and metal workshop machines, welding machines, drilling machines, sawing mills, cranes etc.), electrical ovens, some tertiary or medical appliances (copy machines, lifts, X-ray apparatus etc.) and, finally, dispersed generators (photovoltaic cells).

The phenomenon of voltage variations and flicker already exists for a reasonably long time, although power electronics offer better opportunities for loads to be started and controlled more softly.

Nuisance effects

Except when they induce high currents that can provoke the tripping of protections, voltage variations mainly cause problems on lighting, and "visible" effects are the main cause of complaints. But even if the voltage variations are spaced in time, they can be experienced as "embarrassing" to the network users.

However, some other possible consequences are sometimes experienced: annoying fluctuating torques in electrical motors, malfunction of electronic devices.

In low-voltage networks, a large number of possibly disturbing loads can provoke a higher flicker level, and this especially in weak networks. In general, the disturbing effects are the most important in the installation of the network user's own plant. This does not mean – of course – that other network users will not be disturbed at all.

Compatibility levels & planning levels

The standards are quite vague about compatibility levels for voltage changes and fluctuations. In fact, according to IEC 61000-2-2 (compatibility levels for LV public networks), voltage changes should not exceed 3% of nominal supply voltage under normal circumstances, although greater values (even up to 10%) can be infrequently observed. However, the same standard specifies precise compatibility levels for flicker (P_{st} = 1 and P_{lt} = 0,8)

Limits

The existing international EMC standards dealing with limits for voltage changes, voltage variations and flicker produced by LV appliances are *product standards*.

IEC 61000-3-3 is dedicated to appliances having a rated input current ≤16 A per phase while IEC 61000-3-11 [2] is applicable to all equipment with a rated current >16A and ≤75A per phase.

A parameter of paramount importance in order to understand the mechanism leading to voltage fluctuations and assess their severity is the *network impedance*. It is in fact well known that the relative voltage change associated with a load variation is given by:

$$\frac{\Delta U}{U} = \frac{R\,\Delta P + X\,\Delta Q}{U^2} \qquad (1)$$

where U is the voltage at the point of connection, ΔP and ΔQ, respectively the active and reactive power variation, and R and X, the resistance and reactance of the network at that point. It is important to note that, at LV, the ratio X/R may take values between 0,5 and 1 depending on the type of cable or line.

In the context of IEC 61000-3-3, limit values of allowed voltage fluctuations and flicker correspond to a fixed reference impedance Z_{ref} (defined in IEC 60725), which was initially chosen in order to represent an upper boundary value for 95% of the actual distribution networks.

On the other hand, according to IEC 61000-3-11, the manufacturers must declare the maximum value of the impedance at the connection point, in order to meet the acceptable limit values (which are basically the same as in IEC 61000-3-3). This impedance may obviously have a modulus smaller than Z_{ref}.

Harmonics

Main sources and examples

Harmonics are mainly caused by non-linear loads. This non-linearity can be intrinsic (electrical arcs, for instance) but can also be the result of repeated commutations of power electronic components. A non-linear load, even when submitted to a sinusoidal voltage, will draw a non-sinusoidal current. The absorbed harmonic components depend only on the characteristics of the load, and not on the grid; thus they behave like sources of harmonic currents. Well known LV examples include all power electronics converters (e.g. Variable Speed Drives used in many machines or industrial applications, soft starters for electrical motors, rectifiers for heating applications, Uninterruptible Power Supplies, converters for the grid connection of Dispersed Generators such as photovoltaic, etc.), televisions, computers, dimmers for lighting appliances, welding machines.

The harmonic voltages are a result of the harmonic currents injected by the non-linear loads in so far that the grid has significant harmonic impedance for each harmonic frequency.

Nuisance effects

One distinguishes usually 2 kinds of effects of harmonics:

- Immediate effects: Controllers of electronic systems can be perturbed due to a change of the zero crossings; ripple control receptors can be perturbed, as also relays that are used for distance controllers; dimmers can also be affected.
- Long-term effects: Some long-term effects are heating of capacitors, cables, equipment, transformers and rotating machines; noise and vibrations can also be provoked (by rotating harmonic fields). For capacitor banks we can see two different effects: harmonic currents will provoke a heating of the capacitor bank and harmonic voltages can provoke problems with it's insulation.

Compatibility levels

IEC 61000-2-2 specifies the compatibility levels for individual harmonic voltages in LV, up to the 50^{th} order.

Limits

The existing international EMC standards dealing with limits for harmonics produced by LV appliances are *product standards*.

IEC 61000-3-2 provides individual harmonic current limits for appliances with a rated input current ≤16 A per phase, while IEC 61000-3-12 [3] deals with all equipment having a rated input current >16A and ≤75A per phase.

IEC 61000-3-12 proposes an assessment procedure in three stages, with individual currents emission limits, essentially depending upon the *short-circuit ratio* at the connection point (defined here for a balanced three-phase equipment):

$$R_{sce} = \frac{S_{sc}}{S_{equ}} \qquad (2)$$

where S_{sc} is the short-circuit and S_{equ} is the rated apparent power of the equipment. This approach relies on the assumption that the LV network harmonic impedance is mainly inductive, excluding any resonance.

CONNECTION RULES APPLIED IN BELGIUM

Voltage fluctuations and flicker

The basic principle of the connection rules is to find an acceptable compromise between the “strength” of the network on one hand (i.e. its ability to withstand fluctuating loads) and the disturbance level caused by consumer’s installations, on the other hand. The key element in finding this compromise is the evaluation of the network impedance. The approach relies on the assessment procedure of IEC 61000-3-11.

Having analysed the consumer’s installation and located the major disturbing loads, the workflow proposed in Figure 1 is applied.

A first stage evaluation is systematically performed. If the user of the fluctuating loads is able to present IEC 61000-3-11-compliance declarations, the procedure consists essentially in calculating the network impedance at the connection point and comparing it with the maximum acceptable one, according to the manufacturers.

If there is no available compliance declaration, a theoretical computation of the voltage fluctuations and flicker has to be done. The final assessment is made using the IEC 61000-3-11 criteria.

In order to implement this procedure, two easy-to-use calculation worksheets have been created which incorporate the different variables and calculations to be executed for the assessment.

If the disturbing loads don't meet those criteria, a supplementary evaluation stage (directly called stage 3, by similitude with procedures used for MV and HV loads) is considered. At this level, other evaluation methods and criteria could be used, resulting from a dialogue between the consumer and the grid operator.

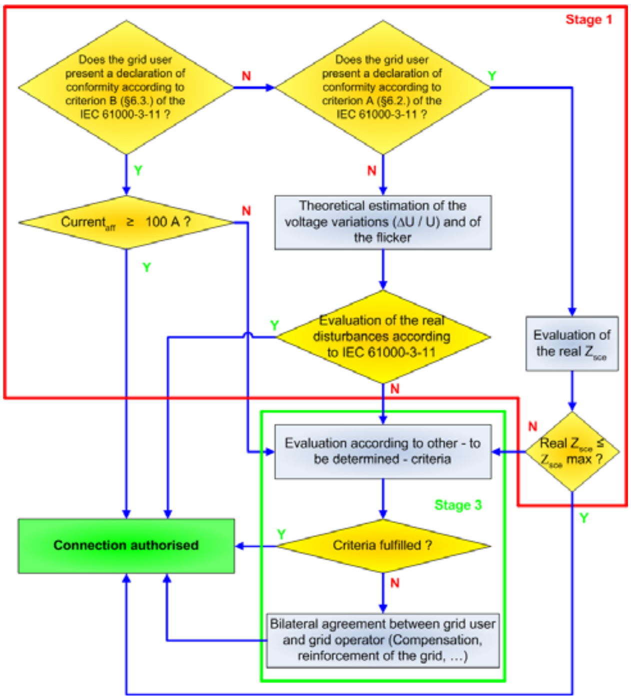


Figure 1 – Workflow for the connection assessment of a fluctuating load

Necessary data

In any case, some information about the grid has to be collected to be able to determine the network impedance at the point of coupling: the short-circuit level at the MV/LV substation feeding the consumer, the transformer characteristics, the length and type of cables or lines that connect the load to this substation. This information is normally straightforward for grid operators.

If a realistic evaluation of the voltage fluctuations has to be done, the pattern of load variation must be known. This information can be obtained from the manufacturers or result from simulation.

In practice, simplified and schematic patterns are used. For instance the load can be represented by a triangular pulse, a sinusoidal variation, a pulse train, etc. It must be noted that it is not always easy to obtain this kind of information, or at least not all of it, so that realistic assumptions have sometimes to be made. Alternatively, measurements can be performed on other similar existing installations.

Harmonics

The basic principle of the connection rules is to find an acceptable compromise between the "strength" of the network on one hand (i.e. its ability to absorb harmonic currents) and the harmonics level caused by consumer's installations, on the other hand. The key element in finding the compromise is the evaluation of the short-circuit ratio. The approach relies on the assessment procedure of IEC 61000-3-12.

Having analysed the consumer's installation and located the major sources of harmonics, the workflow proposed in Figure 2 is applied.

If the user of the distorting loads is able to present IEC 61000-3-12-compliance declarations, the procedure consists essentially in evaluating R_{sce} at the connection point and comparing it with the minimum needed, according to the manufacturers.

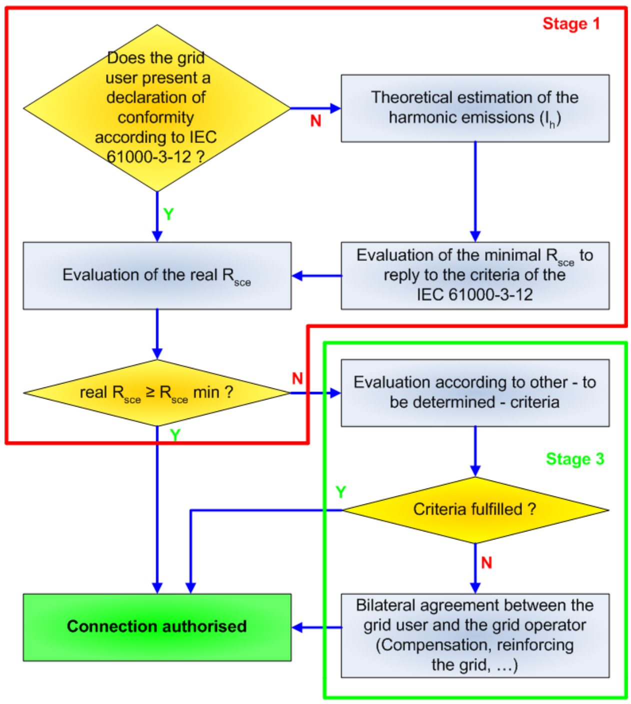


Figure 2 - Workflow for the connection assessment of a distorting load

If there is no available compliance declaration, a theoretical computation of the harmonic currents injected by the load must be done. Knowing these harmonic characteristics, the minimum needed R_{sce} is obtained using the IEC 61000-3-12 criteria and must be compared with the actual one.

If the disturbing loads don't meet those criteria, a supplementary evaluation stage (directly called stage 3, by similitude with procedures used for MV and HV loads) is considered. At this level, other evaluation methods and criteria could be used, resulting from a dialogue between the consumer and the grid operator.

Necessary data

In any case, some information about the grid has to be collected to be able to determine the short-circuit ratio R_{sce} at the point of coupling. This information is normally straightforward for grid operators.

Characteristic harmonic currents, if needed, should be obtained from the manufacturer, or evaluated theoretically from a model of the load. Alternatively, measurements can be performed on other similar existing installations.

EXAMPLES

Two examples of the harmonic assessment will be given as an appetizer - one where the minimum R_{sce} is given (example 1), and another where it has to be determined by introducing the known harmonic currents (example 2) - as well as one example of a fluctuating load (example 3).

The grid data are the same for all the examples:

- Short-circuit power at the MV substation: 400 MVA
- Voltage of the substation: 15 kV
- Transformer: 15kV/400V; S_{sc} =630 kVA; u_{cc} = 8%
- 1 aluminium cable of 200 m and Ø = 150 mm²
- 1 copper cable of 50 m and Ø = 95 mm²

The load is a three-phase balanced load, fed at 400 V and with a nominal current of 56 A.

Case 1

Min. needed R_{sce} as specified by the manufacturer = 58

Case 2

Given harmonic currents:

H5	H7	H11	H13	THD	PWHD
15	10	5	3.5	12	24

Case 3

Pulse train with a duration of 0.3 s; 8 changes per train; a nominal current of 56A; cosφ = 0.8; start-up current is 7 times I_{nom}; 6 trains per 10 minutes.

Common calculations for the three cases

The result of the calculation of the short-circuit power S_{sc} is 2415 kVA with an angle of 43.63° at the point of coupling of the load.

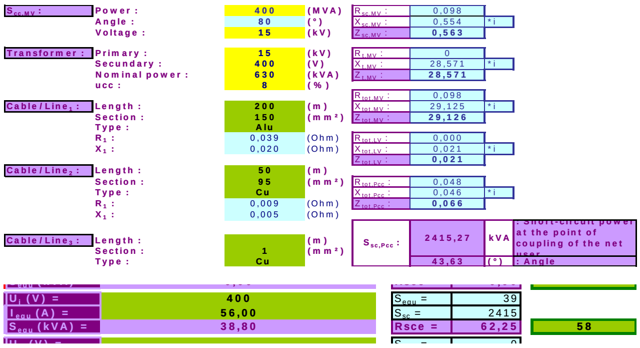
Also, a load fed at 400 V and with a rated current of 56 A gives way to an equivalent power S_{equ} of 39 kVA.

The resulting short-circuit ratio R_{sce} at the point of coupling is thus about 62.25.

From here on, the calculations will be differentiated.

- Case 1

  The given minimum R_{sce} of the manufacturer is 58. This value is lower than the 62.25 that is at disposal at the point of common coupling. The load can thus be connected at this point in the grid.

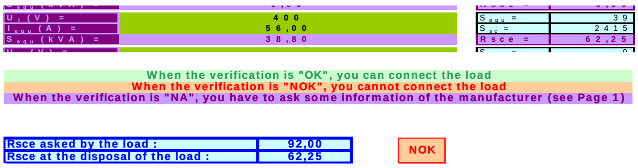


- Case 2

  The harmonic currents given by the manufacturer lead to a needed minimum R_{sce} of 92. But, as there is only 62.25 at our disposal, this load cannot be connected at this point of the grid.

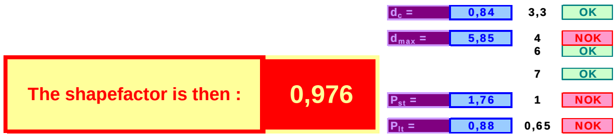
Table B :
THREE-PHASED BALANCED equipment

	R_{sce} of I_5	R_{sce} of I_7		R_{sce} of I_{11}	R_{sce} of I_{13}	R_{sce} of THD	R_{sce} of PWHD
		I_7		I_{11}	I_{13}	THD	PWHD
	15	10		5	3,5	12	24
	77,78	83,33		75,00	92,00	27,27	53,33
$R_{sce\ min}$ =	92,00						



- Case 3

  When introducing all the data in the sheets the result is that we cannot connect the load at this point in the network.



CONCLUSIONS

In the absence of international standards dealing with emission limits for disturbing installations connected to LV power systems, the Belgian grid operators have prepared a procedure, based on the product standards IEC 61000-3-11 and -3-12. This procedure was briefly presented in this paper. A technical report dealing with the same issue is actually under study, at IEC level (future IEC 61000-3-14).

REFERENCES

[1] www.synergrid.be

[2] IEC 61000-3-11: EMC – Part 3-11: Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems – Equipment with rated current ≤75 A and subject to conditional connection

[3] IEC 61000-3-12: EMC – Part 3-12: Limits – Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current >16 A and ≤75 A per phase