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Voltage unbalance emission limits for installations: general guidelines and system specific considerations

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Abstract
Guidelines for developing voltage unbalance emission limits for installations connected to EHV, HV, and MV power systems have recently been published as a technical report by the International Electrotechnical Commission (IEC). These guidelines, based on the work of Joint Working Group CIGRE/CIRED C4.103, are intended to provide a common basis for the development of similar guidelines or standards in specific countries. This paper reviews these international guidelines and the background to the development of specific recommendations made in the technical report. It also considers elements of these guidelines that may relate to specific network considerations, and therefore may be of interest to countries wishing to develop local guidelines or standards. Additional information relating to the evaluation of such specific considerations is referenced.

Keywords
Voltage, unbalance, emission, limits, for, installations, general, guidelines, system, specific, considerations

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Voltage Unbalance Emission Limits for Installations – General Guidelines and System Specific Considerations

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Abstract **– Guidelines for developing voltage unbalance emission limits for installations connected to EHV, HV, and MV power systems have recently been published as a technical report by the International Electrotechnical Commission (IEC). These guidelines, based on the work of Joint Working Group CIGRE/CIRED C4.103, are intended to provide a common basis for the development of similar guidelines or standards in specific countries. This paper reviews these international guidelines and the background to the development of specific recommendations made in the technical report. It also considers elements of these guidelines that may relate to specific network considerations, and therefore may be of interest to countries wishing to develop local guidelines or standards. Additional information relating to the evaluation of such specific considerations is referenced.**

***Index Terms*— power quality, voltage unbalance, emission limits**

I. Introduction

Joint working group CIGRE/CIRED C4.103 entitled "Emission limits for disturbing installations" was formed in late 2003 with the scope of preparing four technical reports deliverable to the International Electrotechnical Commission (IEC) for updating, simplifying, and supplementing international recommendations on how to set and apply emission limits for the connection of disturbing installations. Some 32 experts from 19 countries were appointed to the working group (WG) to prepare four technical reports. Three of these reports have been published by the IEC in early 2008, after further work by IEC Sub-Committee 77A, Working Group 8 [1], [2], [3].

The primary objective of these reports is to provide guidance to system operators or owners on engineering practices related to emission limits that facilitate the provision of adequate service quality for all connected customers. In the reports, the allocation of the capacity of the system to absorb disturbances is addressed. The aim is to coordinate the disturbance levels between different voltage levels in order to meet the compatibility levels at the points of utilisation of electricity across the system.

One of the reports published (IEC 61000-3-13), is a new report addressing the development of voltage unbalance emission limits for installations connected to EHV, HV, and MV networks [3]. Although based on the same principles as the reports for harmonics and voltage fluctuations, some elements peculiar to unbalance are addressed in this technical report. This paper reviews the background to these guidelines and focuses on elements that may be specific to certain systems or circumstances - and therefore of interest to countries wishing to develop specific local guidelines or standards based on IEC 61000-3-13. Being a technical report, it is important to note that the various assumptions made in the recommended procedures may need to be more strictly defined where countries wish to implement standards rather than guidelines.

II. Basic Concepts

Emission limits for individual equipment or a customer's installation should be developed based on the impact that these emissions will have on the quality of the voltage. The following concepts are used to coordinate the emission of disturbances with the voltage quality objectives.

A. Compatibility levels

Compatibility levels are reference values for coordinating the emission and immunity of equipment or installations which are part of, or supplied by, a supply system in order to ensure the EMC in the whole system. These are generally based on the 95 % probability levels of entire systems, using distributions which represent both time and space variations of disturbances. The compatibility levels for disturbances in public LV and MV power systems are given in the standards IEC 61000-2-2 [4] and IEC 61000-2-12 [5].

B. Planning levels

Planning levels may be considered as "internal" quality objectives of the system, and should facilitate the co-ordination of disturbance levels between different voltage

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levels. They are equal to or lower than compatibility levels. Planning levels may differ from case to case, depending on system structure and circumstances. Indicative values for voltage unbalance at MV,HV and EHV are given in IEC 61000-3-13. They are based on compatibility levels at MV and on existing HV-EHV practices, and consider the need to provide margin between LV, MV and HV-EHV for the purposes of overall EMC coordination. The results of an international survey on which these were based are reported on in [6].

C. Emission levels

The emission level from an unbalanced installation into the power system is defined as the magnitude of the unbalanced voltage (or current) vector which the considered installation gives rise to at the point of evaluation. This is illustrated by the vector U_{UBi} in Fig. 1.

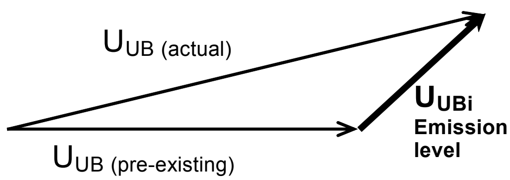

Fig. 1. Emission vector as defined in IEC 61000-3-13

The post-connection measurement and assessment of emission levels from installations is currently the subject of Joint Task Force CIGRE/CIRED C4.109.

D. Assessment methods

Methods and indices for assessing measured data against the planning levels are recommended. The recommended indices are characterised by their time integration interval (e.g. measured over 10-minutes intervals as defined in IEC 61000-4-30 [7]) and a statistical value – percentile value over the observation period – to be used for comparison against the planning level (e.g. the 95% weekly values), as recommended in [8]. The recommended co-ordination approach relies on individual emission limits being derived from the planning levels. For this reason, it is recommended that the same indices be applied when assessing emission levels (i.e. $|U_{UBi}|$) against the corresponding emission limits, and when assessing the actual (measured) voltages (i.e. $|U_{d(actual)}|$) against the planning levels.

III. General Principles

The objective is to limit the total voltage unbalance caused by all unbalanced installations to levels that will not result in voltage unbalance levels that exceed the planning levels. For this purpose, the following steps are required: (i) adoption of a general summation law for combining the unbalance arising from various sources; (ii) determination of the allowed global contribution from all sources of unbalance at a given voltage level in the system - in order to ensure co-ordination between different parts or voltage levels of a system; (iii) assignment of emission limits to specific installations based on equitable sharing of the global contribution, taking into consideration the contribution of the system itself to emission levels.

IV. Summation of Numerous Sources of Unbalance

A. Summation law

It is important to note that IEC 61000-3-13 addresses the allocation of unbalance emission levels for 3-phase installations. The single- or dual-phase phase connection of installations is considered under the control of the system operator – i.e. the phase connections can be optimised to minimise the global impact on the system. The global level of unbalance due to random unbalance emission levels from 3-phase installations is the result of the vector summation of each individual source of unbalance. The following general summation law can be adopted:

$$U_{UB} = \sqrt[\alpha]{\sum_i U_{UBi}^{\ \alpha}} \qquad (1)$$

where: U_{UB} is the magnitude of the resulting unbalance level after the aggregation of various sources; U_{UBi} is the magnitude of the unbalance level produced by one of the various sources of unbalance to be combined; α is an exponent depending upon: (i) the type of unbalance sources, (ii) the chosen value of the probability for the actual value not to exceed the calculated value, and (iii) the degree to which individual unbalance sources vary randomly in magnitude and phase.

B. Implications for standardisation in specific countries

Under the assumption of many individual sources of unbalance being present on the system, the indicative value for the summation law exponent α provided in IEC 61000-3-13 is equal to 1.4. Further work is required to determine suitable summation exponents applicable to specific systems.

V. Allowed Global Contribution

The principles recommended for determining the global unbalance contributions in an MV substation are illustrated in Fig. 2. The level of voltage unbalance at the MV busbar is the sum of the emissions from all installations and equipment connected at LV, MV, and the unbalance which propagates from the upstream (US) HV system.

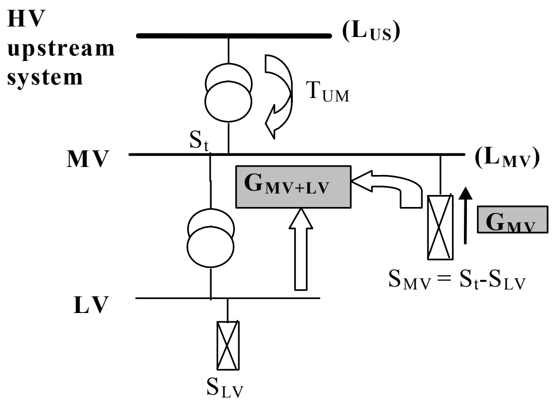

Fig. 2. Example of a system for sharing global contributions at MV (see the definitions below)

Once the planning levels are set, the global contribution to the voltage unbalance that can be allocated to all MV and LV installations supplied from the considered system is given by:

$$G_{uMV+LV} = \sqrt[\alpha]{L_{MV}^{\alpha} - (T_{UM}.L_{US})^{\alpha}} \tag{2}$$

where: G_{uMV+LV} is the acceptable global contribution of the local MV and LV installations (S_{MV} and S_{LV} respectively) to the voltage disturbance in the MV system when the total capacity of the MV system (S_t) is utilised; L_{US} is the planning level for the upstream system (different planning levels may be needed for intermediate voltage levels between MV and HV-EHV - this is why the general term of upstream system planning level is used); T_{UM} is the transfer coefficient of the unbalance levels from the upstream system to the MV system under consideration (determined by simulation or measurements); L_{MV} is the planning level for the considered MV system; and α is the summation law exponent.

A. Implications for standardisation

The assumption that T_{UM}=1,0 is only relevant for some systems. In practice, T_{UM} needs to be assessed for specific networks. IEC 61000-3-13 provides some guidance on estimating this coefficient where it can be significantly lower than 1,0 in cases where a large portion of the load is made up of induction motors (field measurements have shown cases where T_{UM} is as low as 0,5 [6]). More recent studies have been undertaken for other load types (for a example constant power single phase balanced loads) which indicate that this factor may be even greater than 1,0 (i.e. unbalance arising in the upstream network gives rise to increased levels of unbalance at the MV and LV voltage levels) [9]. Specific guidelines on the selection of T_{UM} may be required for different systems. It should be noted that a high value of T_{UM} (i.e. 1,0 and above) will impact the coordination of planning levels between different system voltages (implying that the selected HV and EHV planning levels need to be low if sufficient global contribution is allowed at MV and LV).

VI. Determining the Contributions of the System and of Individual Installations

In order to leave room for emission for every customer's installation, only a portion of the global contribution to disturbance G_{uMV+LV} is allocated to any individual disturbing installation connected to the considered MV system. A reasonable approach is to apply a proportional allocation based on the ratio between the agreed power S_i of the installation under consideration and the total supply capability S_t of the system. Such a criterion is justified based on the fact that the agreed power of an installation is often linked with the customer's share in the investment costs of the power system.

As power systems are not generally perfectly symmetrical, it is necessary to make a provision for inherent asymmetries associated with the system (e.g. line impedance asymmetries). A factor k_{uE} is introduced to account for the system contribution, and hence the portion of the allowed global unbalance level that can be allocated to unbalanced installations (conversely 1- k_{ue} accounts for the system inherent asymmetry) . The emission limit for an installation to be connected to an MV system is therefore:

$$E_{u\,i} = \sqrt[\alpha]{k_{uE}}\ .G_{uMV+LV}\sqrt[\alpha]{\frac{S_i}{S_t}} \tag{3}$$

where: E_{ui} is the voltage unbalance emission limit of installation i directly supplied at MV;k_{uE} is the fraction of the global contribution to voltage unbalance that can be allocated for emissions from unbalanced installations in the considered system (guidelines for the selection of an appropriate value for k_{uE} are given in the report); G_{uMV+LV} is the acceptable global contribution to the voltage unbalance in the MV system arising as a result of MV system inherent asymmetries and the unbalanced installations supplied at MV and LV; $S_i = P_i /cos\varphi_i$ is the agreed power of customer installation i, or the MVA rating of the considered installation (either load or generation); S_t is the total supply capacity of the considered system including provision for future load growth (S_t might also include the contribution from dispersed generation, however more detailed consideration will be required to determine its firm contribution to S_t and its effective contribution to the short-circuit level as well); and α is the summation law exponent

A. Assessment of the k_{uE} Factor

Examples of typical k_{uE} factors for different systems are given in Table II .

TABLE II
INDICATIVE RANGE OF VALUES FOR K_{UE}

System characteristics	k_{uE}
• Highly meshed system with generation locally connected near load centers. • Transmission lines fully transposed, otherwise lines are very short (few km). • Distribution systems supplying high density load area with short lines or cables.	0,8-0,9

• Mix of meshed system with some radial lines either fully or partly transposed. • Mix of local and remote generation with some long lines. • Distribution systems supplying a mix of high density and suburban area with relatively short lines (<10 km).	0,6-0,8
• Long transmission lines generally transposed, generation mostly remote. • Generally radial sub-transmission lines partly transposed or un-transposed. • Distribution systems supplying a mix of medium and low density load area with relatively long lines (>20 km). • 3φ motors account for only a small part of the peak load (eg. 10%).	0,5-0,6

More recently, practical techniques for the assessment of the system contribution to unbalance have been developed for complex systems – i.e. to determine the specific contribution of individual lines in a meshed system [10], [11]. These techniques further allow engineers to assess the most appropriate methods of minimising the system contribution at a given point. What is important to note is that the system contribution is not only associated with long transmission lines – some heavily loaded distribution feeders can also have a substantial contribution to unbalance. Simulations and measurements on a short (16 km) 88kV dual circuit line supplying a load of nearly 300MW in South Africa have also revealed a system contribution to unbalance levels of nearly 1% due to this line alone.

B. *Implications for standardisation*

Some countries may wish to limit the allowed network contribution. This in turn will precipitate design requirements for power systems (in particular transposition requirements for lines or alternatives such as installing active compensation devices). In setting limits on the allowed k_{uE} factor, the costs associated with such designs need to be considered in relation to the costs that customers may need to incur to meet the assessed emission limits.

VII. Selection of Planning Levels

IEC 61000-3-13 provides indicative planning levels for different system voltages (given in Table II). The selection of planning levels is dependent on: (i) the maximum unbalance allowed at the various voltage levels (voltage characteristics exist in some countries for MV, HV and EHV systems that are quasi-guaranteed levels - e.g. 2 % for HV and MV systems and 1,5% for EHV systems); (ii) the chosen summation exponent (α); and (iii) the transfer coefficient T_{UM}. The indicative values in Table 1 are based on transfer coefficients of 0,9 from MV to LV and of 0,95 from HV to MV, and a summation law exponent of 1,4. The allocation is based on an equal share of unbalance contribution at each of the voltage levels - in some countries the allocation may be chosen to be unequal between voltage levels.

TABLE II
Indicative Planning Levels (%) Defined in IEC 61000-3-13

MV	HV	EHV
1,8%	1,4%	0,8%

VIII. Conditional Acceptance of Higher Emission Levels

The guidelines described above are based on simplifying assumptions that may not provide the optimum solution for all situations, so they should be used with flexibility and judgment as far as engineering is concerned. Under some circumstances, the system operator or owner may accept an unbalanced installation to emit disturbances beyond the basic limits set using the above procedures.

This so-called stage 3 assessment considers that various factors may leave a margin on the system for accepting higher emission limits. For example, some of the available supply capacity of the system may not be utilised for a period of time, the general summation law may be too conservative, or higher levels of unbalance may be allowed in some part of the system after reallocation of planning levels. To this end, a detailed study should be carried out, taking account of the pre-existing disturbance levels and of the expected contribution from the considered installation for different operating conditions. As a result, the parties may agree on special conditions that facilitate connection of the disturbing installation

IX. Conclusion

The newly published IEC 61000-3-13 technical report on assessing unbalance emissions for installations forms a good general basis for development of local guidelines or standards for the connection of installations to the public system. This paper has highlighted areas in which more specific recommendations may need to be developed when establishing local standards, or addressing specific network types. These considerations include: (i) assumptions to be used on the transfer factor, (ii) methods for assessing the system contribution (as well as possibly placing a limit of this contribution), (iii) the selection of the summation exponent, and (iv) the selection of planning levels. Contributions to further developing these recommendations, made since the publication of the technical report, have been referenced, and may assist countries in developing such standards and local guidelines.

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XII. BIOGRAPHIES

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