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TECHNICAL REPORT

BASIC EMC PUBLICATION

Electromagnetic compatibility (EMC) –
Part 3-13: Limits – Assessment of emission limits for the connection of unbalanced installations to MV, HV and EHV power systems

IEC/TR 61000-3-13:2008(E)

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CONTENTS

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ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 3-13: Limits – Assessment of emission limits for the connection of unbalanced installations to MV, HV and EHV power systems

FOREWORD

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IEC/TR 61000-3-13, which is a technical report, has been prepared by subcommittee 77A: Low frequency phenomena, of IEC technical committee 77: Electromagnetic compatibility.

It has the status of a basic EMC publication in accordance with IEC Guide 107 [12][1].

This first edition of this technical report has been harmonised with IEC/TR 61000-3-6 [10] and IEC/TR 61000-3-7 [11].

1 Figures in square brackets refer to the bibliography.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
77A/577/DTR	77A/616/RVC

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

A list of all parts of the IEC 61000 series, under the general title *Electromagnetic compatibility (EMC)*, can be found on the IEC website.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

INTRODUCTION

IEC 61000 is published in separate parts according to the following structure:

Part 1: General

General considerations (introduction, fundamental principles)

Definitions, terminology

Part 2: Environment

Description of the environment

Classification of the environment

Compatibility levels

Part 3: Limits

Emission limits

Immunity limits
(in so far as they do not fall under the responsibility of product committees)

Part 4: Testing and measurement techniques

Measurement techniques

Testing techniques

Part 5: Installation and mitigation guidelines

Installation guidelines

Mitigation methods and devices

Part 6: Generic standards

Part 9: Miscellaneous

Each part is further subdivided into several parts published either as International Standards or as technical specifications or technical reports, some of which have already been published as sections. Others will be published with the part number followed by a dash and a second number identifying the subdivision (example: IEC 61000-6-1).

ACKNOWLEDGMENT

In 2002, the IEC subcommittee 77A made a request to CIGRE Study Committee C4 and CIRED study committee S2, to organize an appropriate technical forum (joint working group) whose main scope was to prepare, among other tasks, a technical report concerning emission limits for the connection of unbalanced installations to public supply systems at MV, HV and EHV.

To this effect, joint working group CIGRE C4.103/CIRED entitled ''*Emission Limits for Disturbing Installations*'' was appointed in 2003. Some previous work produced by CIGRE JWG C4.07/CIRED has been used as an input to the revision, in particular the planning levels and associated indices. Addition survey data was also collected by the Joint Working Group in the process of setting indicative planning levels.

Subsequent endorsement of the document by IEC was the responsibility of SC 77A.

ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 3-13: Limits – Assessment of emission limits for the connection of unbalanced installations to MV, HV and EHV power systems

1 Scope

This part of IEC 61000 provides guidance on principles which can be used as the basis for determining the requirements for the connection of unbalanced installations (i.e. three-phase installations causing voltage unbalance) to MV, HV and EHV public power systems (LV installations are covered in other IEC documents). For the purposes of this report, an unbalanced installation means a three-phase installation (which may be a load or a generator) that produces voltage unbalance on the system. The connection of single-phase installations is not specifically addressed, as the connection of such installations is under the control of the system operator or owner. The general principles however may be adapted when considering the connection of single-phase installations. The primary objective is to provide guidance to system operators or owners on engineering practices, which will facilitate the provision of adequate service quality for all connected customers. In addressing installations, this document is not intended to replace equipment standards for emission limits.

The report addresses the allocation of the capacity of the system to absorb disturbances. It does not address how to mitigate disturbances, nor does it address how the capacity of the system can be increased.

Since the guidelines outlined in this report are necessarily based on certain simplifying assumptions, there is no guarantee that this approach will always provide the optimum solution for all unbalanced load situations. The recommended approach should be used with flexibility and judgment as far as engineering is concerned, when applying the given assessment procedures in full or in part.

The system operator or owner is responsible for specifying requirements for the connection of installations which may cause unbalance on the system. The disturbing installation is to be understood as the complete customer's installation (i.e. including balanced and unbalanced parts).

Problems related to unbalance fall into two basic categories.

- Unbalanced installations that draw negative-sequence currents which produce negative-sequence voltages on the supply system. Examples of such installations include arc furnaces and traction loads (typically connected to the public network at HV), and three phase installations where the individual loads are not balanced (typically connected at MV and LV). Negative-sequence voltage superimposed onto the terminal voltage of rotating machines can produce additional heat losses. Negative-sequence voltage can also cause non-characteristic harmonics (typically positive-sequence 3rd harmonic) to be produced by power converters.
- Unbalanced installations connected line-to-neutral can also draw zero-sequence currents which can be transferred or not into the supply system depending on the type of connection of the coupling transformer. The flow of zero-sequence currents in a grounded neutral system causes zero-sequence unbalance affecting line-to-neutral voltages. This is not normally controlled by setting emission limits, but rather by system design and maintenance. Ungrounded-neutral systems and phase-to-phase connected installations are not, however, affected by this kind of voltage unbalance.

This report gives guidance only for the coordination of the negative-sequence type of voltage unbalance between different voltage levels in order to meet the compatibility levels at the point of utilisation. No compatibility levels are defined for zero-sequence type of voltage unbalance as this is often considered as being less relevant to the coordination of unbalance levels compared to the first type of voltage unbalance. However, for situations where a non-zero impedance exists between neutral and earth with the system still being effectively grounded (i.e., where the ratio between zero-sequence, X_0 and positive sequence reactance X_1 is $0 < X_0/X_1 \leq 3$), this type of voltage unbalance can be of concern especially when the type of connection of the coupling transformer allows zero-sequence path to flow from MV to LV and vice-versa.

NOTE The boundaries between the various voltage levels may be different for different countries (see IEV 601 01-28) [9]. This report uses the following terms for system voltage:

– low voltage (LV) refers to Un ≤ 1 kV;

– medium voltage (MV) refers to 1 kV < Un ≤ 35 kV;

– high voltage (HV) refers to 35 kV < Un ≤ 230 kV;

– extra high voltage (EHV) refers to 230 kV < Un.

In the context of this report, the function of the system is more important than its nominal voltage. For example, a HV system used for distribution may be given a "planning level" which is situated between those of MV and HV systems.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050(161), *International Electrotechnical Vocabulary – Chapter 161: Electromagnetic compatibility*

3 Terms and definitions

For the purpose of this part of IEC 61000, the following definitions apply as well as the definitions in IEC 60050(161).

3.1
agreed power
value of the apparent power of the disturbing installation on which the customer and the system operator or owner agree. In the case of several points of connection, a different value may be defined for each connection point

3.2
customer
a person, company or organisation that operates an installation connected to, or entitled to be connected to, a supply system by a system operator or owner

3.3
(electromagnetic) disturbance
any electromagnetic phenomenon which, by being present in the electromagnetic environment, can cause electrical equipment to depart from its intended performance

3.4
disturbance level
the amount or magnitude of an electromagnetic disturbance measured and evaluated in a specified way

3.5
electromagnetic compatibility (EMC)
ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment

NOTE 1 Electromagnetic compatibility is a condition of the electromagnetic environment such that, for every phenomenon, the disturbance emission level is sufficiently low and immunity levels are sufficiently high so that all devices, equipment and systems operate as intended.

NOTE 2 Electromagnetic compatibility is achieved only if emission and immunity levels are controlled such that the immunity levels of the devices, equipment and systems at any location are not exceeded by the disturbance level at that location resulting from the cumulative emissions of all sources and other factors such as circuit impedances. Conventionally, compatibility is said to exist if the probability of the departure from intended performance is sufficiently low. See Clause 4 of IEC 61000-2-1 [7].

NOTE 3 Where the context requires it, compatibility may be understood to refer to a single disturbance or class of disturbances.

NOTE 4 Electromagnetic compatibility is a term used also to describe the field of study of the adverse electromagnetic effects which devices, equipment and systems undergo from each other or from electromagnetic phenomena.

3.6
(electromagnetic) compatibility level
specified electromagnetic disturbance level used as a reference level in a specified environment for co-ordination in the setting of emission and immunity limits

NOTE By convention, the compatibility level is chosen so that there is only a small probability (for example 5 %) that it will be exceeded by the actual disturbance level.

3.7
emission
phenomenon by which electromagnetic energy emanates from a source of electromagnetic disturbance

[IEV 161-01-08 modified]

NOTE For the purpose of this report, emission refers to phenomena or conducted electromagnetic disturbances that can cause voltage unbalance due to unequal currents on the three phases.

3.8
emission level
level of a given electromagnetic disturbance emitted from a particular device, equipment, system or disturbing installation as a whole, assessed and measured in a specified manner

3.9
emission limit
maximum emission level specified for a particular device, equipment, system or disturbing installation as a whole

3.10
generating plant
any equipment that produces electricity together with any directly connected or associated equipment such as a unit transformer or converter

3.11
immunity (to a disturbance)
the ability of a device, equipment or system to perform without degradation in the presence of an electromagnetic disturbance

3.12
immunity level
the maximum level of a given electromagnetic disturbance on a particular device, equipment or system for which it remains capable of operating with a declared degree of performance

3.13
normal operating conditions
operating conditions of the system or of the disturbing installation typically including all generation variations, load variations and reactive compensation or filter states (e.g. shunt capacitor states), planned outages and arrangements during maintenance and construction work, non-ideal operating conditions and normal contingencies under which the considered system or disturbing installation has been designed to operate

NOTE Normal system operating conditions typically exclude: conditions arising as a result of a fault or a combination of faults beyond that planned for under the system security standard, exceptional situations and unavoidable circumstances (for example: force majeure, exceptional weather conditions and other natural disasters, acts by public authorities, industrial actions), cases where system users significantly exceed their emission limits or do not comply with the connection requirements, and temporary generation or supply arrangements adopted to maintain supply to customers during maintenance or construction work, where otherwise supply would be interrupted

3.14
planning level
level of a particular disturbance in a particular environment, adopted as a reference value for the limits to be set for the emissions from the installations in a particular system, in order to co-ordinate those limits with all the limits adopted for equipment and installations intended to be connected to the power supply system

NOTE Planning levels are considered internal quality objectives to be specified at a local level by those responsible for planning and operating the power supply system in the relevant area.

3.15
point of common coupling (PCC)
point in the public supply system, which is electrically closest to the installation concerned, at which other installations are, or could be, connected. The PCC is a point located upstream of the considered installation

NOTE A supply system is considered as being public in relation to its use and not its ownership.

3.16
point of connection (POC)
point on a public power supply system where the installation under consideration is, or can be connected

NOTE A supply system is considered as being public in relation to its use and not its ownership.

3.17
point of evaluation (POE)
point on a public power supply system where the emission levels of a given installation are to be assessed against the emission limits. This point can be the point of common coupling (PCC) or the point of connection (POC) or any other point specified by the system operator or owner or agreed upon

NOTE A supply system is considered as being public in relation to its use and not its ownership.

3.18
short circuit power
a theoretical value expressed in MVA of the initial symmetrical three-phase short-circuit power at a point on the supply system. It is defined as the product of the initial symmetrical short-circuit current, the nominal system voltage and the factor $\sqrt{3}$ with the aperiodic component (DC) being neglected

3.19
spur
feeder branch off a main feeder (typically applied on MV and LV feeders)

3.20
supply system
all the lines, switchgear and transformers operating at various voltages which make up the transmission systems and distribution systems to which customers' installations are connected

3.21
system operator or owner
the entity responsible for making technical connection agreements with customers who are seeking connection of load or generation to a distribution or transmission system

3.22
transfer coefficient (influence coefficient)
the relative level of disturbance that can be transferred between two busbars or two parts of a power system for various operating conditions

3.23
transposition
a change of the relative positions of the phase conductors of the line

3.24
unbalanced installation
a customer's installation as a whole (i.e. including balanced and unbalanced parts) which is characterized according to its operation by unequal line currents, either magnitude and/or phase angle, which can give rise to voltage unbalance on the supply system. For the purpose of this report, all references to unbalanced installations do not only include loads, but generating plants as well

NOTE For the purpose of this report, all references to unbalanced installations not only include loads, but also generating plants.

3.25
voltage unbalance (imbalance)
in a polyphase system, a condition in which the magnitudes of the phase voltages or the phase angles between consecutive phases are not all equal (fundamental component) [IEV 161-08-09 modified].

NOTE In three phase systems, the degree of inequality is usually expressed as the ratio of the negative and zero sequence components to the positive sequence component. In this technical report, voltage unbalance is considered in relation to three-phase systems and negative sequence only.

3.26
phenomena related definitions
the definitions below that relate to unbalance are based on the analysis of system voltages or currents by Fortescue's transformation matrix and the Discrete Fourier Transform method (DFT) for the purpose of extracting the fundamental frequency components for the calculation of the unbalance factor. (The DFT is the practical application of the Fourier transform as defined in IEV 101-13-09 [8]).

3.26.1
fundamental frequency
frequency in the spectrum obtained from a Fourier transform of a time function, to which all the frequencies of the spectrum are referred. For the purpose of this technical report, the fundamental frequency is the same as the power supply frequency

NOTE In the case of a periodic function, the fundamental frequency is generally equal to the frequency of the function itself.

3.26.2
fundamental component
component whose frequency is the fundamental frequency

3.26.3
positive-sequence component of 3-phase voltages (or currents)
defined as the symmetrical vector system derived by application of the Fortescue's transformation matrix, and that rotates in the same direction as the power frequency voltage (or current). This is given mathematically by:

$\underline{U}_1 = \frac{1}{3}(\underline{U}_a + \mathbf{a}\cdot\underline{U}_b + \mathbf{a}^2\cdot\underline{U}_c)$ where $a = 1\angle 120° = -\frac{1}{2} + j\frac{\sqrt{3}}{2}$ and $\underline{U}_a$, $\underline{U}_b$, $\underline{U}_c$ are line to neutral voltages (fundamental component)

NOTE Phase-to-phase voltages may also be used.

3.26.4
negative-sequence component of 3-phase voltages (or currents)
defined as the symmetrical vector system derived by application of the Fortescue's transformation matrix, and that rotates in the opposite direction to the power frequency voltage (or current). This is given mathematically by:

$\underline{U}_2 = \frac{1}{3}(\underline{U}_a + \mathbf{a}^2\cdot\underline{U}_b + \mathbf{a}\cdot\underline{U}_c)$ where $a = 1\angle 120° = -\frac{1}{2} + j\frac{\sqrt{3}}{2}$ and $\underline{U}_a$, $\underline{U}_b$, $\underline{U}_c$ are line to neutral voltages (fundamental component)

NOTE Phase-to-phase voltages may also be used.

3.26.5
zero-sequence component of 3-phase voltages (or currents)
defined as the in-phase symmetrical vector system derived by application of the Fortescue's transformation matrix. This is given mathematically by:

$\underline{U}_0 = \frac{1}{3}(\underline{U}_a + \underline{U}_b + \underline{U}_c)$ where $\underline{U}_a$, $\underline{U}_b$, $\underline{U}_c$ are line to neutral voltages (fundamental component).

NOTE Phase-to-phase voltages cannot be used as the zero-sequence component in this case will be zero.

3.26.6
voltage unbalance factor (u)
defined as the ratio of the modulus of the negative-sequence to the positive-sequence components of the voltage at fundamental frequency, expressed as a percentage

$$u_2 = \frac{|\underline{U}_2|}{|\underline{U}_1|}.100 = \frac{|\underline{U}_a + \mathbf{a}^2\underline{U}_b + \mathbf{a}\underline{U}_c|}{|\underline{U}_a + \mathbf{a}\underline{U}_b + \mathbf{a}^2\underline{U}_c|}.100 \quad \%$$

NOTE Phase-to-phase voltages may also be used instead of line to neutral voltages

NOTE For simplicity in this document u has been used to denote the voltage unbalance factor instead of u_2.

An equivalent formulation is given by [3]:

$$u_2 = \sqrt{\frac{1-\sqrt{3-6\beta}}{1+\sqrt{3-6\beta}}}.100\% \text{ with } \beta = \frac{|\underline{U}_{ab}|^4 + |\underline{U}_{bc}|^4 + |\underline{U}_{ca}|^4}{\left(|\underline{U}_{ab}|^2 + |\underline{U}_{bc}|^2 + |\underline{U}_{ca}|^2\right)^2}$$

3.26.7
current unbalance factor (IUF)
defined as the ratio of modulus of the negative-sequence to the positive-sequence components of the current at fundamental frequency

$$i_2 = \frac{|\underline{I}_2|}{|\underline{I}_1|}.100 = \frac{|\underline{I}_a + \mathbf{a}^2\underline{I}_b + \mathbf{a}\underline{I}_c|}{|\underline{I}_a + \mathbf{a}\underline{I}_b + \mathbf{a}^2\underline{I}_c|}.100 \quad \%$$

4 Basic EMC concepts related to voltage unbalance

The development of emission limits for individual equipment or a customer's total installation should be based on the effect that these emissions will have on the quality of the voltage. Some basic concepts are used to evaluate voltage quality. In order for these concepts to be used for evaluation at specific locations, they are defined in terms of where they apply (locations), how they are measured (measurement duration, sample times, averaging durations, statistics), and how they are calculated. These concepts are described hereafter and illustrated in Figures 1 and 2. Definitions may be found in IEV 60050(161).

4.1 Compatibility levels

These are reference values (see Table 1) for co-ordinating the emission and immunity of equipment which is part of, or supplied by, a supply system in order to ensure the EMC in the whole system (including system and connected equipment). Compatibility levels are generally based on the 95 % probability levels of entire systems, using statistical distributions which represent both time and space variations of disturbances. There is allowance for the fact that the system operator or owner cannot control all points of a system at all times. Therefore, evaluation with respect to compatibility levels should be made on a system-wide basis and no assessment method is provided for evaluation at a specific location.

The compatibility levels for voltage unbalance in LV and MV systems are reproduced in Table 1 from references IEC 61000-2-2 [1] and IEC 61000-2-12 [2].

Table 1 – Compatibility levels for voltage unbalance in low and medium voltage systems reproduced from references IEC 61000-2-2 and IEC 61000-2-12

Voltage unbalance factor C_{uLV} and C_{uMV} (%)
2 %*
*Up to 3 % may occur in some areas where predominantly single-phase loads are connected.

NOTE 1 It is also worthwhile noting that the above compatibility levels refer to steady state heating effects of voltage unbalance. Higher values may be recorded over a short period of time (100 % of voltage unbalance during a short-circuit, for example), but these short-duration high unbalance levels do not necessarily produce a significant heating effect on equipment.

NOTE 2 The specification of unbalance protection requirements within installations should take the compatibility level and the instantaneous unbalance effects into consideration.

NOTE 3 The level of 3 % may occur typically on LV networks and MV networks which supply smaller installations by connecting these at single-phase (or between phases).

Compatibility levels are not defined by IEC for HV and EHV systems.

4.2 Planning levels

4.2.1 Indicative values of planning levels

These are voltage unbalance levels that can be used for the purpose of determining emission limits, taking into consideration all unbalanced installations. Planning levels are specified by the system operator or owner for all system voltage levels and can be considered as internal quality objectives of the system operator or owner and may be made available to individual customers on request. Planning levels for voltage unbalance are equal to or lower than compatibility levels and they should allow coordination of voltage unbalances between different voltage levels. Only indicative values may be given because planning levels will differ from case to case, depending on system structure and circumstances. Indicative values of planning levels for voltage unbalance are shown in Table 2.

Table 2 – Indicative values of planning levels for voltage unbalance (negative-sequence component) in MV, HV and EHV power systems

Voltage level	Planning level L_{u2} (%)
MV	1,8
HV	1,4
EHV	0,8

NOTE 1 The above indicative values allow that a contribution from LV customers and unbalanced installations can be accommodated for a compatibility level of 2 % at LV (see Table 1). For MV systems where a 3 % compatibility level applies (i.e.1,5 times the 2 % compatibility level), the value of the planning level can be selected as 1,5 times the planning level indicated in Table 2 (i.e. a value of 2,7).

NOTE 2 The above indicative values 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. A discussion is provided in Annex A on how more appropriate planning levels can be defined for a specific system. In some countries, the allocation may not be equal between voltage levels.

NOTE 3 The planning levels in Table 2 are not intended to control unbalance arising from uncontrollable or exceptional events such as equipment malfunctions, short-circuits, switching operations, etc.

NOTE 4 In some countries, planning levels are defined in national standards or guidelines.

NOTE 5 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). These should be coordinated with the planning levels. In considering these, the nature of the system should be taken into consideration (e.g. HV AC traction supplies).

NOTE 6 For the purpose of rating equipment or apparatus in a customer's installation, the declared supply voltage characteristics have to be considered.

Where national circumstances make it appropriate depending on system characteristics, intermediate values of planning levels may be needed between the MV and HV values, and between HV and EHV values as well due to the possibly wide range of voltage levels included in those.

The remainder of this report outlines procedures for using these planning levels to establish the emission limits for individual customers unbalanced installations.

4.2.2 Assessment procedure for evaluation against planning levels

The measurement method to be used for voltage unbalance measurements is the class A method specified in IEC 61000-4-30 [3]. The data flagged in accordance with this standard should be removed from the assessment. For clarity, where data is flagged the percentile used in calculating the indices defined below is calculated using only the valid (unflagged) data.

The minimum measurement period is one week with normal business activity. The monitoring period should include some part of the period of expected maximum voltage unbalance levels.

One or more of the following indices may be used to compare the actual unbalance levels with the planning levels. More than one index may be needed for planning levels in order to assess the impact of higher emission levels allowed for short periods of time such as during bursts or start-up conditions.

- The 95 % weekly value of u_{2sh} (voltage unbalance factor at fundamental frequency over "short" 10 min periods) should not exceed the planning level.
- The greatest 99 % probability daily value of u_{2vs} (voltage unbalance factor at fundamental frequency over "very short" 3 s periods) should not exceed the planning level times a multiplying factor (for example: 1,25 to 2 times) to be specified by the system operator or owner, depending on the characteristics of the system and the very-short term capability of the equipment along with their protection devices.

NOTE 1 For voltage unbalance measurements, the accuracy of the whole measurement chain needs to be considered. On MV, HV and EHV systems, potential transformers are often used for metering and protection purposes. It is thus important to stress that due to measurement inaccuracies of potential transformers or due to unbalanced secondary load-burden, and inaccuracies in other parts of the measurement chain, the overall accuracy of the measurement system may be limited especially in the case of voltage unbalance because of the large impact on results even from small errors.

NOTE 2 It is also important to note that in accordance with IEC 61000-4-30, only the fundamental frequency positive and negative-sequence components should be used when assessing the voltage unbalance factor (harmonics should be extracted as some negative-sequence harmonics can alter the measurement results).

4.3 Illustration of EMC concepts

The basic concepts of planning and compatibility levels are illustrated in Figures 1 and 2. They are intended to emphasize the most important relationships between the basic variables.

Within an entire power system, it is inevitable that some level of interference will occur on some occasions, hence there is a risk of overlapping between the distributions of disturbance levels and immunity levels (see Figure 1 below). Planning levels for voltage unbalance are generally equal to or lower than the compatibility level; they are specified by the operator or owner of the system. Immunity test levels are specified by relevant standards or agreed upon between manufacturers and customers.

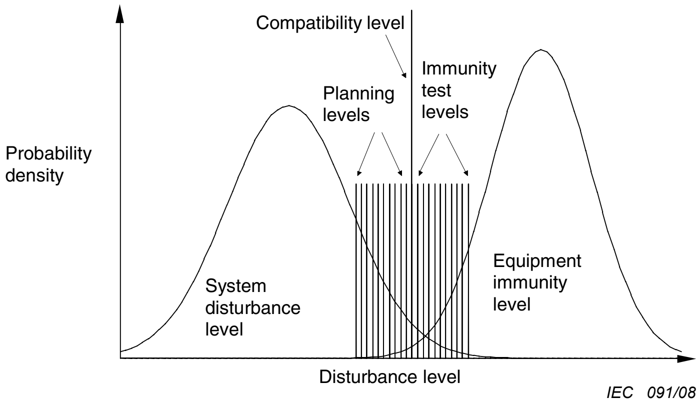


Figure 1 – Illustration of basic voltage quality concepts with time/ location statistics covering the whole system

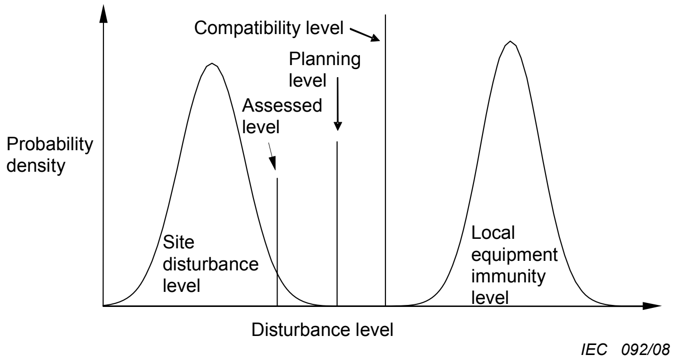


Figure 2 – Illustration of basic voltage quality concepts with time statistics relevant to one site within the whole system.

As Figure 2 illustrates, the probability distributions of disturbance and immunity levels at any one site are normally narrower than those in the whole power system, so that at most locations there is little or no overlap of disturbance and immunity level distributions. Interference is therefore not generally a major concern, and equipment is anticipated to function satisfactorily. Electromagnetic compatibility is therefore more probable than Figure 1 appears to suggest.

4.4 Emission levels

The co-ordination approach recommended in this report relies on individual emission levels being derived from the planning levels. For this reason, the same indices are applied both when evaluating actual measurements against the emission limits and against the planning levels.

One or more of the following indices can be used to compare the actual emission level with the customer's emission limit. More than one index may be needed in order to assess the impact of higher emission levels allowed for short periods of time such as during bursts or start-up conditions.

- The 95 % weekly value of u_{2sh} (or i_{2sh}), voltage (or current) unbalance factor at fundamental frequency over "short" 10 min periods, should not exceed the emission limit.
- The greatest 99 % probability daily value of u_{2vs} (or i_{2vs}), voltage (or current) unbalance factor at fundamental frequency over "very short" 3 s periods, should not exceed the emission limit times a multiplying factor (for example: 1,25 - 2 times) to be specified by the system operator or owner, depending on the characteristics of the system and the very-

short term capability of the equipment along with their protection devices. (Use of the very-short time index for assessing emissions is only needed for installations having a significant impact on the system, so use of this index could be dependant on the ratio between the agreed power of the installation and the short-circuit capacity of the system i.e. S_i/S_{sc}).

In order to compare the level of voltage unbalance emission from a customer's installation with the emission limit, the minimum measurement period should be one week. However, shorter measurement periods might be needed for assessing emissions under specific conditions. Such shorter periods should represent the expected operation over the longer assessment period (i.e. a week). In any case, the measurement period must be of sufficient duration to capture the highest level of unbalance emission which is expected to occur. If the unbalance emission level is dominated by one large item of equipment, the period should be sufficient to capture at least two complete operating cycles of this equipment. If the unbalance emission level is caused by the summation of several items of equipment, the period should be at least one operating shift.

Where significant, the following factors should also be taken into account when assessing the emission level (see also 6.2).

- The variation of unbalance from an installation as a function of the single-phase load characteristics (e.g., variations of the load, type of connection).
- The balancing effect of 3-phase rotating machines operating simultaneously with the unbalanced load or equipment.
- Connection of single-phase and two-phase spurs on MV feeders (i.e. single-phase or two phase connections coming off the main 3-phase MV feeder – typically used when supplying smaller installations).
- Unbalance emission levels that vary randomly with time (as is the case for arc furnaces) versus stable unbalance due to the connection of single-phase loads.
- Unbalance originating in the system due to factors such as untransposed transmission lines, (where the line length is long or the power levels are high); parallel three phase lines operating over long distances in the same right-of-way; single-phase voltage regulators, and other unbalanced installations present in the system.

The measurement method to be used is the Class A measurement method defined in IEC 61000-4-30 [3] for voltage unbalance. The data flagged in accordance with this standard should be removed from the assessment. For clarity, where data is flagged, the percentile used in assessing the indices defined in this report is calculated using only the valid (unflagged) data.

NOTE 1 If the flagging concept is not built in the measurement device, a reference voltage should be used instead of the fundamental voltage in order to avoid inflating the percentage of voltage unbalance during abnormally low voltage conditions. High values of unbalance due to switching should also be removed from measured values.

NOTE 2 It is also important to note that the fundamental frequency positive and negative-sequence components should be used in order to assess the voltage unbalance factor (harmonics should be extracted as some negative-sequence harmonics can alter the measurement results).

The emission level from an unbalanced installation is the voltage unbalance (or current unbalance causing voltage unbalance) assessed according to the subclauses of Clause 6.

5 General principles

The proposed approach for setting emission limits for unbalanced installations depends on the agreed power of the customer, the power of the unbalanced installation, and the system characteristics. An important aspect to consider in the case of voltage unbalance is the fact that the power system itself can also contribute to voltage asymmetries (e.g. untransposed, non-perfectly transposed lines, and lines in parallel rights of way), so the share of emissions should allow for an equitable share of emissions for the power system as a source of possible emissions too (see Clause 8). The objective is to limit the injection from the total of all individual customer installations and the system's inherent sources of unbalance to levels that will not result in voltage unbalance levels that exceed the planning levels. Three stages of evaluation are defined which may be used in sequence or independently.

5.1 Stage 1: simplified evaluation of disturbance emission

It is generally acceptable for a customer to install a small installation or small appliances that produce unbalance within an installation without specific evaluation of unbalance emission by the supply company.

It is possible to define conservative criteria for quasi-automatic acceptance of small size unbalanced installations on MV and HV systems. If the total unbalanced installation, or the customer's agreed power, is small relative to the short circuit power at the point of evaluation, it should not be necessary to carry on detailed evaluation of the unbalance emission levels.

In 8.1 and 9.1, specific criteria are recommended for applying stage 1 evaluation.

5.2 Stage 2: emission limits relative to actual system characteristics

If an installation does not meet stage 1 criteria, the specific characteristics of the unbalanced load within the customer's installation should be evaluated together with the absorption capacity of the system. The absorption capacity of the system is derived from the planning levels taking into account the inherent system sources of asymmetries, and is apportioned to individual unbalanced installations according to their demand with respect to the total system capacity. The disturbance level transferred from upstream voltage levels of the system to lower voltage levels should also be considered when apportioning the planning levels to individual customers.

The principle of this approach is that, if the system is fully utilised to its designed capacity and all customers are injecting up to their individual limits, the total disturbance levels will be equal to the planning levels taking into account system inherent unbalance sources, transfer factors between different voltage levels and the summation effect of various unbalanced installations. A procedure for apportioning the planning levels to individual customers is outlined in 8.2 and 9.2 for MV and HV systems respectively.

NOTE If the capacity of the system increases in the future, the emission levels of individual customers should become lower. It is important therefore, where possible, to consider future expansions of the system.

5.3 Stage 3: acceptance of higher emission levels on a conditional basis

Under some circumstances, a customer may require acceptance to emit levels of unbalance beyond the basic limits allowed in stage 2. In such a situation, the customer and the system operator or owner may agree on special conditions that facilitate connection of the unbalanced installation. A careful study of the actual and future system characteristics will need to be carried out in order to determine these special conditions.

5.4 Responsibilities

In the context of this report from the EMC point of view, the following responsibilities are defined.

- The customer is responsible for maintaining the emission level at the specified point of evaluation below the limit specified by the system operator or owner.
- The system operator or owner is responsible for the overall control of disturbance levels under normal operating conditions in accordance with national requirements. For evaluation purposes, the system operator or owner should, when required, provide relevant system data such as the system short-circuit power or impedance and existing levels of unbalance. The evaluation procedure is designed in such a way that the emissions of voltage unbalance from the customers and the system inherent unbalance

should not cause the overall system voltage unbalance levels to exceed the planning and compatibility levels. However, given specific local conditions and the assumptions that are necessary in this evaluation procedure, there is no guarantee that the recommended approach will always avoid exceeding the levels.

- Finally, the system operator or owner and customers should co-operate when necessary in the identification of the optimum method to reduce emissions. The design and choice of method for such reduction are the responsibility of the customer where these are related to the unbalance contribution of the installation and the responsibility of the system operator or owner where these are related to the unbalance contribution of the system.

NOTE This report is mainly concerned with emissions. However, absorption of negative-sequence currents may also be a problem if equipment is connected without due consideration for its rating given the unbalance voltage normally present in the power system. The problem of negative-sequence current absorption (i.e. the impact on equipment) is also part of the customer's responsibility.

6 General guidelines for the assessment of emission levels

6.1 Point of evaluation

The point of evaluation (POE) is the point where the emission levels of a given customer's installation are assessed for compliance with the emission limit. This is also a point within the considered power system at which the planning level is defined. This point could be the point of connection (POC) or the point of common coupling (PCC) of the unbalanced installation or any other point specified by the system operator or owner, or agreed upon. More than one point of evaluation may also be specified for a given customer's installation depending on the system structure and characteristics of the installation; in this case, the evaluation should be made considering the system characteristics and agreed powers applicable to the different points of evaluation.

NOTE 1 It should be noted, however, that for the determination of the emission limit and for the evaluation of the emission levels it is often necessary to take account of system characteristics beyond the point of evaluation.

NOTE 2 Depending on the location of the point of common coupling compared to the point of connection of the unbalanced installation, voltage unbalance level might be higher at the latter.

NOTE 3 It should be remembered that, as voltage characteristics or contracted limits generally apply at the point of connection, these should be taken into consideration in discussions between the parties.

6.2 Definition of unbalance emission level

The unbalance emission level from an installation into the power system is the magnitude of the voltage (or current) unbalance vector (i.e. $|\underline{U}_{2i}/\underline{U}_1|$), which the considered installation gives rise to at the point of evaluation. This is illustrated in Figure 3 by the emission vector $\underline{U}_{2i}/\underline{U}_1$ and its contribution (together with the unbalance caused by other sources of unbalance when the installation under consideration is not connected to the system) to the measured unbalance at the point of evaluation, once the installation has been connected.

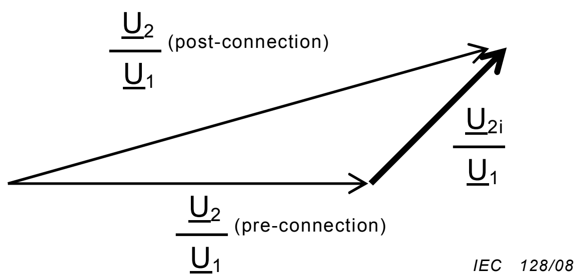


Figure 3 – Illustration of the emission vector $\underline{U}_{2i}/\underline{U}_1$ and its contribution to the measured unbalance at the point of evaluation

Where this unbalance vector component results in increased levels of unbalance on the network, the emission level as defined above (i.e. $|\underline{U}_{2i}/\underline{U}_1|$) is required to be less than the emission limit assessed according to the relevant clauses in this document.

NOTE 1 The interaction between the supply system and installation may result in a reduction of the voltage unbalance (i.e. due to the balancing effect of rotating machines, or where the phase connection of the installation gives rise to reduced levels of voltage unbalance on the system). In this case, the current unbalance may be significant, but the actual impact on the voltage needs to be taken into consideration in the assessment of the emission levels.

NOTE 2 Unbalance produced by different installations might not be in phase. This is addressed in Clause 7.

NOTE 3 Connection of an installation to the supply system might in some cases result in increased unbalance levels at the point of evaluation, where the plant itself is a balanced load (i.e. due to the effect of untransposed lines). As this document addresses the EMC co-ordination requirements, the contribution of balanced loading to the level of unbalance at the point of evaluation is considered as the unbalance emission level of the power system, and not as the emission of the unbalanced installation.

6.3 Assessment of emission levels from unbalanced installations

This subclause is intended to provide general guidance on the assessment of voltage unbalance caused by unbalanced installations, taking account of various operating conditions. Further guidance may be found in [4].

The pre-connection assessment of the unbalance emission level for an installation can be determined using basic assumptions about the characteristics of the system and the customer‘s installation. However, this calculated value is likely to be different from the actual emission level that will be observed when the installation is connected to the system, i.e. the actual emission level could be higher or lower than the calculated value. Therefore, it may be necessary to assess the level of emissions that will be present when the installation is connected to the system.

The assessment of emission levels from an unbalanced installation should consider the worst normal operating conditions including asymmetries and contingencies for which the system or the customer’s installation is designed to operate and that may last for a specified percentage of the time, for example more than 5 % of time, based on a statistical average (an example is the prolonged outage of a single phase induction furnace in an otherwise three-phase installation or the prolonged outage of one circuit on a double-circuit line supplying an installation). Additionally, for large installations compared to the system size (e.g. S_{sc}/S_i <30; note that the ratio of 30 can be adjusted to meet specific conditions), it may also be necessary to assess emission levels for occasional operating conditions lasting less than 5 % of time. However, higher emission limits may be allowed under such occasional conditions or during start-up or unbalanced burst conditions (for example 1,25–2 times) depending on the characteristics of the system and the very-short term capability of the equipment along with their protection devices.

7 General summation law

The co-ordination of conducted disturbances requires the adoption of hypotheses relevant to the summation of the disturbances produced by various installations. In the case of voltage unbalance due to randomly connected unbalanced installations, or due to unbalance levels that change randomly with time, the actual voltage unbalance (or current) at any point on a system is the result of the vector sum of the individual components of each unbalanced installation.

On the basis of experience, a general summation law can be adopted for both voltage and current unbalance, where a large number of unbalanced installations (e.g. a number greater than 10 is considered), or where the unbalance changes randomly with time. The law for resulting voltage unbalance factor is:

$$u = \sqrt[\alpha]{\sum_i u_i^{\alpha}} \tag{1}$$

where

u is the magnitude of the resulting voltage unbalance factor, for the considered aggregation of sources (probabilistic value),

u_i is the magnitude of the various individual emission levels to be combined,

α is an exponent depending mainly upon 3 factors:

- the chosen value of the probability for the actual value not to exceed the calculated value;
- the degree to which individual voltage unbalances vary randomly in terms of magnitude and phase;
- the number of random variations considered (either the number of summated sources or the variation in time).

Taking into account that

- unbalance emission co-ordination mainly refers to 95 % non-exceeding probability values,
- load unbalance contributing to voltage unbalance is mostly due to MV/LV single phase distribution loads and major HV-EHV unbalanced loads such as induction furnaces, arc furnaces, etc. However, most of these load unbalances are unlikely to produce simultaneous or in-phase imbalance.

On the basis of the information available to date, in the absence of further specific information (see notes 1 and 2 below) the exponent α shown in Table 3 can be adopted for adding numerous randomly varying sources of unbalance.

Table 3 – Indicative value of exponent for the summation of general unbalanced installations

α = 1,4

NOTE 1 The summation law is only intended to be used to assess the overall impact on the system of numerous random or uncontrolled sources of unbalance, including the impact of numerous randomly connected single-phase installations that more or less randomly fluctuate with time. When it is known that unbalances are likely to be in phase and coincident in time, a summation exponent α closer to 1 should be used instead.

NOTE 2 In the case of a large single-phase installation where the optimum phases to which to connect the installation can be selected, the physical connection characteristics should be used to assess its impact on the system instead of adjusting the coefficient of the general summation law.

NOTE 3 The indicative value for the summation exponent is not based on measurement results, but has been proposed based on a uniform distribution of random vectors with a random phase variation of 360 degrees, and a magnitude range of 0,1 to 1 p.u.. This value is also based on the fact that, in the case of unbalance, the unbalance vectors are likely to cluster in phase around 0 degrees, 60 degrees, 120 degrees etc, depending on the phases connected, i.e. phase-to-phase or phase-to-ground, and on the power factor of the unbalance sources.

NOTE 4 This indicative summation exponent may be conservative in the case of randomly fluctuation installations such as arc furnaces.

8 Emission limits for unbalanced installations in MV systems

8.1 Stage 1: simplified evaluation of disturbance emission

In stage 1, the connection of small installations can be accepted without detailed evaluation of the emission characteristics or the supply system response.

If the following criterion is fulfilled the installation may be connected to the system without further examination:

$$\frac{S u_i}{S_{sc}} \leq 0{,}2\,\% \qquad (2)$$

NOTE This formula is also valid for line-to-neutral connected installations.

where

S_{ui} = single phase power equivalent of the unbalanced installation i (line-to-neutral equivalent),

S_{sc} = three-phase short-circuit power at the point of evaluation (see IEC 60909 [13]).

If it is not fulfilled, connection should be considered under the following stage 2 approach.

NOTE S_{sc} may be calculated (or measured) for the specific point of evaluation, or may be estimated for typical MV systems with similar characteristics to that under consideration.

8.2 Stage 2: emission limits relative to actual system characteristics

Considering the actual absorption capacity of the system, due to the transfer factor and phase differences of the unbalanced currents as well as the system impedance and future load, higher emission limits than those according to stage 1 may be granted.

In this stage, the allowable global contribution to the overall level of disturbance is apportioned to each individual installation in accordance with its share of the total capacity of the supply system (S_t) to which this installation is connected. This ensures that the disturbance level due to the emissions of all customers connected to the system will not result in voltage unbalance level that exceeds the planning level. The approach is based on the general summation law.

8.2.1 Global emission to be shared between the sources of unbalance

Consider a typical MV system as illustrated in Figure 4, which can supply a total load (S_t) made up of both local MV loads (S_{MV}) and LV loads (S_{LV}). The aim is to set emission limits at MV.

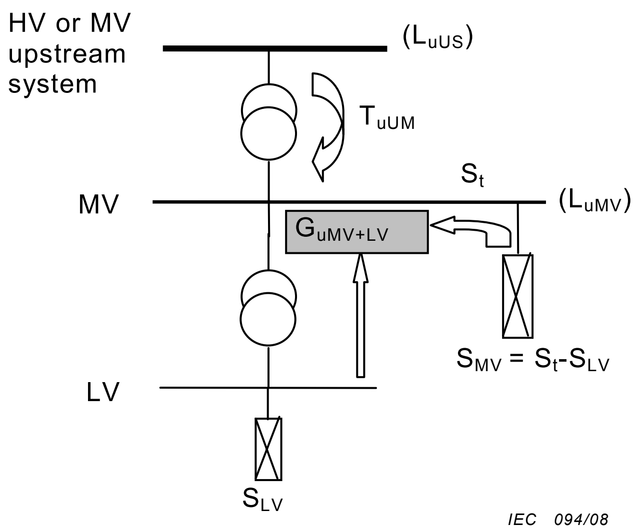


Figure 4 – Example of a system for sharing global contribution at MV

Firstly an application of the summation law (equation 1) is necessary to determine the acceptable global contribution of all unbalance sources present in a particular MV system. Indeed, the actual voltage unbalance in a MV system results from the vector summation of the voltage unbalance coming from the upstream system (note that upstream system may be a HV or another MV system for which intermediate planning levels have been set before) and due to unbalanced installations connected to the considered system at MV and LV. This total voltage unbalance should not exceed the planning level of the MV system given by

$$L_{uMV} = \sqrt[\alpha]{G^{\alpha}_{uMV+LV} + \left(T_{uUM} \cdot L_{uUS}\right)^{\alpha}} \qquad (3)$$

And by algebraic manipulation, equation (3') gives the global contribution to voltage unbalance that can be allocated to the MV system inherent asymmetries, as well as to the total of MV and LV unbalanced installations that can be supplied from the considered MV busbar:

$$G_{uMV+LV} = \sqrt[\alpha]{L^{\alpha}_{uMV} - \left(T_{uUM} \cdot L_{uUS}\right)^{\alpha}} \qquad (3')$$

where

- G_{uMV+LV} is the maximum global contribution to the voltage unbalance at MV of the MV system inherent asymmetries and of the total of MV and LV unbalanced installations that can be supplied from the considered MV busbar (expressed in terms of the voltage unbalance factor u_2),
- L_{uMV} is the planning level for voltage unbalance in the MV system (see Table 2),
- L_{uUS} is the planning level for voltage unbalance in the upstream system (note that upstream system may be a HV or another MV system for which intermediate planning levels have been set before),
- T_{uUM} is the transfer coefficient of voltage unbalance from the upstream system to the MV system under consideration. T_{uUM} can be determined by simulation or measurements. For an initial simplified evaluation, the transfer coefficient T_{uUM} from the upstream system on a MV system can be taken as equal to 1. In practice, however, it can often be less than 1 due to the balancing effect of three-phase rotating machines connected to the downstream system. It is the responsibility of the system operator or owner to determine the relevant values depending on the system characteristics (Guidelines for determining T_{uUM} are provided in Annex A).
- α is the summation law exponent (see Table 3 and the discussion in Clause 7).

8.2.2 Individual emission limits

For each customer only a fraction of the global emission limit G_{uMV+LV} can be allowed. A reasonable approach is to take the ratio between the agreed power S_i and the total supply capacity S_t of the MV system. Such a criterion is related to the fact that the agreed power of a customer installation is often linked with the customer's share of the contribution to the investment costs of the power system.

Additionally, it is important to consider that a fraction of the global contribution to voltage unbalance should also be allocated for system-caused imbalance (e.g. line impedance asymmetries) by reducing accordingly the amount of emissions that will be allowed to unbalanced installations. A factor k_{uE} is introduced in the following equation, representing the fraction of global unbalance emission contribution that can actually be allocated to unbalanced installations for the MV and LV distribution system. It will be up to the system operator or owner to determine the fraction (k_{uE}) that can be allowed to unbalanced installations depending on the system characteristics, line length and configuration, etc. Annex A discusses a method for estimating a k_{uE} factor. In any case the fraction k_{uE} should allow an equitable share of the global contribution to voltage unbalance between the unbalanced installations and the system inherent sources of imbalance present in the considered power system.

$$E_{ui} = \sqrt[\alpha]{k_{uE}} \cdot G_{uMV+LV} \cdot \left(\sqrt[\alpha]{\frac{S_i}{S_t}} \right) \tag{4}$$

NOTE In the above equation, the global emission level is proportionally allocated according to the relative size of the installations. Depending on the system characteristics, a reallocation of the global emission level may be considered between MV and LV installations (e.g. where the LV system is more likely to contribute to unbalance at the MV busbar, a greater proportion of the global emission level may be allocated to LV).

where

- E_{ui} is the voltage unbalance emission limit of the installation (i) directly supplied at MV (%),
- k_{uE} represents the fraction of the global contribution to voltage unbalance that can be allocated for emissions from unbalanced installations in the MV and LV distribution systems being considered (conversely $\langle 1\text{-}k_{uE} \rangle$ represents the fraction that accounts for system inherent voltage unbalance). A single value for k_{uE} cannot be given and should be determined by the system operator or owner. It can be different at different voltage levels, and will in most cases be less than 1. Annex A discusses a method for estimating a k_{uE} factor,
- G_{uMV+LV} is the maximum global contribution to the voltage unbalance at MV of the MV system inherent asymmetries and of the total of MV and LV unbalanced installations that can be supplied from the considered MV busbar (expressed in terms of the voltage unbalance factor u_2),
- $S_i = P_i / \cos\varphi_i$ is the agreed apparent power of customer installation i, or the MVA rating of the considered unbalanced installation (either load or generation),
- S_t is the total supply capacity of the considered system including provision for future load growth (in principle, S_t is the sum of the capacity allocations of all installations including that of downstream installations that are or can be connected to the considered system, taking diversity into consideration). 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,
- α is the summation law exponent (see Table 3).

It may happen at some locations that the pre-existing level of unbalance is higher than the normal share for the existing installations. In this case the emission limit for any new installations can be reduced, a reconsideration of the allocation of the planning levels between the different voltage levels could be considered, or the system current unbalance absorption capacity could be increased.

For customers having a low agreed power, equation 4 may yield impractically low limitations. If the voltage unbalance emission limit becomes smaller than 0,2 %, it shall be set equal to 0,2 % (this is considered from the practical measurement point of view).

It may be preferred to specify negative-sequence current limits to the unbalanced installation, even if the aim is to limit the voltage unbalance in the system. It will be the responsibility of the system operator or owner to provide data concerning the negative-sequence fundamental frequency impedance of the system, in order to enable expressing these limits in terms of negative-sequence currents:

$$E_{I_2 i} = \frac{E_{ui}}{Z_2} \tag{5}$$

where

E_{ui} is the acceptable negative-sequence voltage emission level of the installation,

$E_{I2\ i}$ is the acceptable negative-sequence current emission level of the installation,

Z_2 is the negative-sequence fundamental frequency impedance of the system at the point of evaluation assessed for converting voltage to current unbalance emission limits. (Methods of calculating this impedance can be found in IEC 60909).

NOTE Where no large rotating machines are connected nearby and where the system impedance is dominated by transformer and line impedances, then the negative-sequence impedance may be approximated by the positive-sequence system impedance.

8.3 Stage 3: acceptance of higher emission levels on a conditional basis

Under some circumstances, the system operator or owner may accept an unbalanced installation to emit levels of unbalance beyond the basic limits allowed in stage 2. This is especially the case when stage 2 limits are generic limits derived using typical but conservative system characteristics. The following factors may leave a margin on the system for allowing higher emission limits, for example:

- some customers do not produce significant levels of unbalance because they operate balanced 3-phase installations of significant magnitude. Therefore some of this unused unbalance capacity of the system may be available for utilization on a temporary basis;
- the general summation law may be too conservative in some instances. In some cases, the (known or estimated) angle between the different sources of unbalance can be taken into consideration by the system operator or owner to allow higher unbalance emission levels from a specific customer on a conditional basis;
- it may happen that some unbalanced installations never operate simultaneously, due to system or load constraints;
- the actual transfer coefficient may be less than that hypothesized;
- in some cases, higher global contribution may be defined after reallocation of the planning levels between MV and HV-EHV systems, to take account of local phenomena such as special attenuation effects or absence of unbalanced installations at a certain voltage level;
- in some cases, an unbalanced installation may comply to its emission limit in normal system configurations, while exceeding the stage 2 emission limit only occasionally under degraded configurations (e.g. when a nearby generation plant is out of service);
- the pre-existing unbalance level on the system might be used to allow more emissions when the phase angle of the voltage unbalance caused by an installation can be controlled such as to oppose the background level of voltage unbalance pre-existing on the system (this can apply for part of the background unbalance level which is not randomly varying and for installations where the connection of a given single-phase installation make it possible to choose to which phase to connect the unbalanced installation so as to cancel part of the background level).

In all the cases, when appropriate, the system operator or owner may decide to allocate higher emission limits under stage 3. A careful study of the connection should always be carried out, taking account of the pre-existing levels of unbalance and of the expected contribution from the considered installation for different possible operating conditions. Acceptance of higher than normal emission limits may be given to customers only on a conditional basis and limitations may be specified by the system operator or owner, for instance:

- temporary stage 3 limits may apply for
  - as long as spare supply capacity remains available in the system for allowing more emissions,
  - as long as most other customers do not make full use of their normal stage 2 emission limits,

  – the time needed for a new installation, in order to implement additional corrective measures whenever needed.

- Reduced or non-operation of the unbalanced installations for some supply system or customer configurations.

In some cases, where other unbalanced installations are connected to the system, it is important for the system operator or owner to specify which phases the unbalanced installation is to be connected to.

8.4 Summary diagram of the evaluation procedure

Figure 5 below gives an overview of the evaluation procedure presented so far in this report.

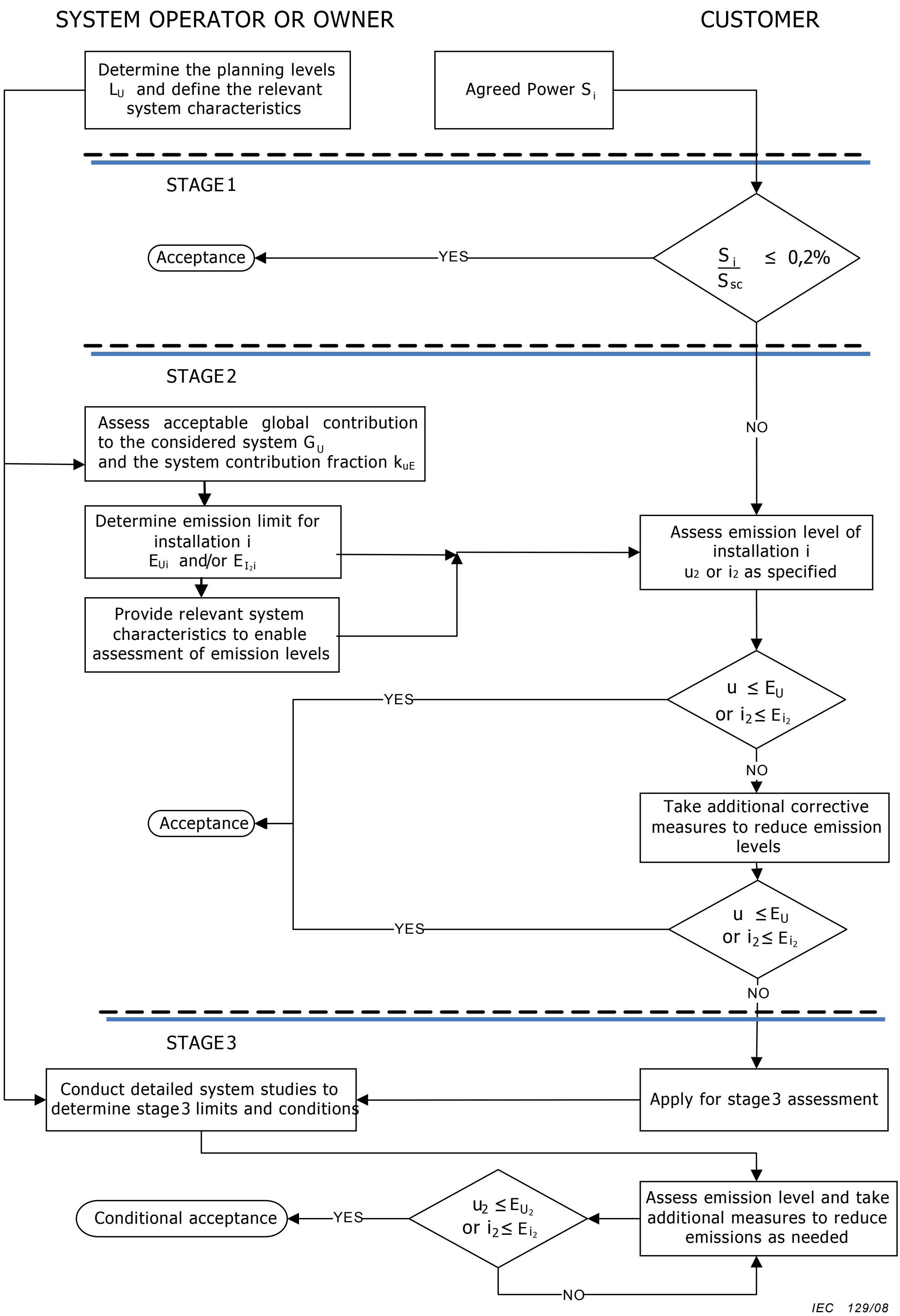


Figure 5 – Diagram of evaluation procedure

9 Emission limits for unbalanced installations in HV or EHV systems

9.1 Stage 1: simplified evaluation of disturbance emission

The same criterion for connection at stage 1 as given in 8.1 can be used at HV-EHV.

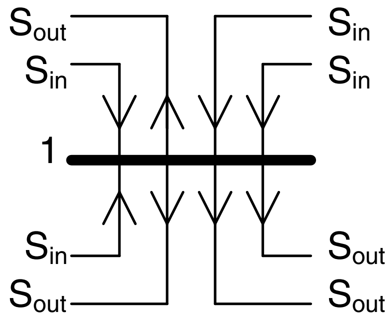
9.2 Stage 2: emission limits relative to actual system characteristics

9.2.1 Assessment of the total available power

Calling S_i the agreed apparent power or the MVA rating of installation i and S_t the total available power of the system at the point of evaluation (total supply capacity), the S_i/S_t ratio is the basic quantity for the determination of the emission limit following the stage 2 procedure.

9.2.1.1 First approximation

Assessing S_t is much more difficult in HV and EHV systems than for the MV case. The suggested approach is the following: when considering the case of an installation connected at a given HV or EHV substation, the basic information is the forecast of power flows taking account of the system evolution in the future.



IEC 096/08

Figure 6 – Determination of S_t for a simple HV or EHV system

The assessment is simply:

$$S_t = \Sigma\, S_{out} \tag{6}$$

where

- S_t in this case is an approximation of the total power of all installations for which emission limits are to be allocated to in the foreseeable future. In this case it is estimated as the sum of the power flows (in MVA) leaving the considered HV-EHV busbar (including provision for future load growth).

This first approximation of S_t is intended to remain conservative. The more detailed second approximation is recommended where such conservative assumptions lead to unrealistic emission limits.

NOTE This first approximation assumes that unbalance emissions caused by installations connected at other connected busbars directly impact the considered busbar (i.e. the influence factors used in the second approximation is unity).

9.2.1.2 Second approximation

The simple approach may not be correct if important unbalanced installations are present or are likely to be in the vicinity of the considered substation. In case of doubt, it is recommended to proceed as follows:

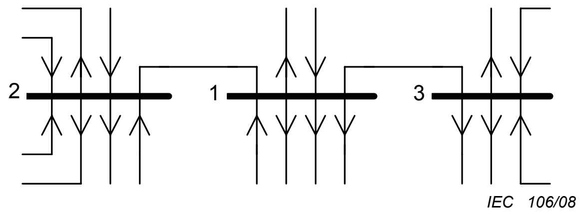


Figure 7 – Determination of S_t for a meshed HV or EHV system

Calling 1 the considered node and 2, 3... the other nodes located in the vicinity of the first one, the values of S_{t1}, S_{t2}, S_{t3}... will be calculated according to equation (6), while ignoring all power flows S_{out} between two of these nodes.

The influence coefficients $K_{u2\text{-}1}$, $K_{u3\text{-}1}$... will be calculated (the influence coefficient $K_{un\text{-}m}$ is the voltage unbalance which is caused at node m when a 1 p.u. (per unit) negative-sequence voltage unbalance source is applied at node n; the calculation of $K_{un\text{-}m}$ usually requires the use of a computer program).

Equation (6) will be replaced by:

$$S_t = S_{t1} + (K_{u2\text{-}1})^{\alpha} S_{t2} + (K_{u3\text{-}1})^{\alpha} S_{t3} + \ldots \tag{7}$$

adding $(K_{un\text{-}m})^{\alpha} S_{tn}$ terms as long as they remain significant as compared to S_{t1}.

9.2.2 Individual emission limits

The acceptable global contribution of the considered system inherent asymmetries and of all the unbalanced installations that can be supplied from a given substation at HV including the unbalanced installations supplied from downstream voltage levels is given by

$$G_{uHV+DV} = \sqrt[\alpha]{L_{uHV}^{\alpha} - \left(T_{UH} \cdot L_{uEHV}\right)^{\alpha}} \tag{8}$$

where

- G_{uHV+DV} is the maximum global contribution to the voltage unbalance at HV of the HV system inherent asymmetries and of all downstream voltage levels (DV) unbalanced installations that can be supplied from the considered HV system (expressed in terms of the voltage unbalance factor u_2),
- T_{uUH} is the transfer coefficient of voltage unbalance from the upstream system to the HV system under consideration (it could be determined by simulation or measurements),
- L_{uEHV} and L_{uHV} are the planning levels for voltage unbalance in the EHV or HV system (see Table 2),
- α is the summation law exponent (see Table 3).

Each unbalanced installation i will be allowed a contribution (E_{ui}) to global contribution of voltage level HV (G_{uHV+DV}) or of the planning level at EHV (L_{uEHV}) in the considered system according to the ratio between its power (S_i) and the corrected total available power (S_t) of the system.

Additionally, it is important to consider that a fraction of the global contribution to voltage unbalance should also be allocated for system-caused imbalance (e.g. line impedance asymmetries) by reducing accordingly the amount of emissions that will be allowed to unbalanced installations. A factor k_{uE} is introduced in the following equation and it represents the fraction of global unbalance emission contribution that can actually be allocated to unbalanced installations for the HV or EHV system. It will be up to the system operator or owner to determine that fraction (k_{uE}) that can be allowed to unbalanced installations depending on the system characteristics, line length and configuration, etc. Annex A discusses a method for estimating a k_{uE} factor. In any case the fraction k_{uE} should allow an equitable share of the global contribution to voltage unbalance between the unbalanced installations and the various other sources of imbalance present in the considered power system.

$$E_{u\,i\,HV} = \sqrt[\alpha]{k_{uE}} \cdot G_{uHV+DV} \cdot \left(\sqrt[\alpha]{\frac{S_i}{S_t}} \right) \qquad (9)$$

or for EHV:

$$E_{u\,i\,EHV} = \sqrt[\alpha]{k_{uE}} \cdot L_{uEHV} \cdot \left(\sqrt[\alpha]{\frac{S_i}{S_t}} \right) \qquad (10)$$

where

- E_{ui} is the emission limit of the unbalanced installation i (HV or EHV),
- k_{uE} represents the fraction of the global contribution to voltage unbalance that can be allocated for emissions from unbalanced installations supplied by the HV system being considered (conversely $\langle 1\text{-}k_{uE} \rangle$ represents the fraction that accounts for system inherent asymmetries also contributing to voltage unbalance). It is worth noting that k_{uE} may have different values depending on the voltage level. Annex A discusses a method for estimating a k_{uE} factor,
- G_{uHV+DV} is the maximum global contribution to the voltage unbalance at HV of the HV system inherent asymmetries and of all downstream unbalanced installations that can be supplied from the considered HV system (expressed in terms of the voltage unbalance factor u) (see equation 8 above),
- L_{uEHV} is the planning level for voltage unbalance in the EHV system (see Table 2),
- S_i is the agreed apparent power or the MVA rating of the considered installation,
- S_t is the corrected total available power of the system at the point of evaluation, see equations 6 or 7,
- α is the summation law exponent (see Table 3).

It may happen at some locations that the pre-existing level of unbalance is higher than the normal share for the existing installations. In this case the emission limit for any new installation can be reduced, a reconsideration of the allocation of the planning levels between the different voltage levels could be considered, or the system current unbalance absorption capacity could be increased.

For customers having a low agreed power, equations 9 or 10 may yield impractically low limitations. If the voltage unbalance emission limit becomes smaller than 0,2 %, it shall be set equal to 0,2 %.

It may be preferred to specify a negative-sequence current limit to the unbalanced installation, even if the aim is to limit the voltage unbalance in the system. Equation 5 and the associated considerations at the end of 8.2.2 may be applied to determine current emission limits.

9.3 Stage 3: acceptance of higher emission levels on a conditional basis

The considerations presented in 8.3 apply equally to stage 3 at HV-EHV.

Annex A
(informative)

Guidance for setting planning levels and emission limits

Planning levels are internal objectives that can be used for evaluating the impact on the supply system of all sources of voltage unbalance. Additionally, planning levels should allow coordination of voltage unbalance emissions between different voltage levels so that the compatibility level of 2 % is not exceeded at LV. Only indicative values may be given because planning levels will differ from case to case, depending on the system structure and circumstances.

A.1 Sources of unbalance

It may be worthwhile first reviewing some of the characteristics of the sources of unbalance.

- At MV, unbalance is partly caused by the numerous single-phase installations supplied at LV. Despite the application of good practices for equally distributing single-phase installations between all phases, the installations randomly fluctuate thus a residual level of unbalance is inevitable. Larger unbalanced installations at MV such as induction furnaces can also contribute to voltage unbalance. These sources of unbalance are considered as being random. In some countries, single-phase or dual-phase MV feeder spurs may also be applied – resulting in an additional complexity in ensuring that installations are balanced across the three phases into the future.
- In addition to unbalanced installations, the system inherent asymmetries (e.g. non-transposed lines) at different voltage levels will also contribute to voltage unbalance [6]. However, line unbalance at different voltage levels or parts of the system is not necessarily independent owing to the design and construction practices. Note that long transmission lines are normally transposed, but where additional substations are added with time, transposition may not be fully corrected, leaving some level of residual unbalance at EHV.

  NOTE Unbalance can be produced by short lines. As an example of the effect of line unbalance, let us consider a 20 km, 100 kV-line which carries a current of 825 A∠−15° at peak load. Assuming the sub-transmission line is untransposed and has a horizontal conductors arrangement for which Z_{12} = 0,035 Ω/km∠30°, and ignoring the load unbalance, the contribution of the line itself can be obtained as follows.

$$\frac{V_2}{V_1} \cong \frac{Z_{12}\cdot \ell \cdot I_1}{(1\times 10^5)/\sqrt{3}} = \frac{0{,}035\ \angle 30^\circ\ x\ 20\ x\ 825\ \angle -15^\circ}{57736\ V}\cdot 100\ \% = 1\%\ \angle 15^\circ$$

  If the line is partially transposed at half-length, the voltage unbalance will reduce by half and phase angle will shift by ±60°. For a line of that length (20 km), full transposition requires at least two transpositions, which may often be impractical.

  In the case of an untransposed 20 kV distribution line having the same arrangement and value of mutual impedance Z_{12}, the voltage unbalance would be in the same order as above if the MV line carries a mean current of about 165 A over that same distance. Except for dedicated feeders, line transposition as such is generally not common practice on distribution lines because the frequent changes in geometry due to corners and junctions often make the additional effect of transposition irrelevant.

A.2 Share of unbalance between system and unbalanced installations

In view of the above considerations, it is reasonable to consider some level of system inherent unbalance, in particular for sub-transmission and distribution systems. In 8.2.2 and 9.2.2, coefficient k_{uE} was introduced to define the contribution to voltage unbalance that can be allocated to unbalanced installations. Conversely $\langle 1\text{-}k_{uE}\rangle$ represents the fraction that account for system inherent asymmetries.

A single value for k_{uE} (or $\langle 1\text{-}k_{uE}\rangle$) cannot be given and it should be determined by the System operator or owner depending on the system characteristics, line length and configuration, etc.

It can be different at different voltage levels, and will in most cases be less than 1. Table A.1 below gives indications of possible values.

Table A.1 – Portion of unbalance for accounting for the system inherent asymmetries

System characteristics	Indicative values of the fraction $\{1-k_{uE}\}$ accounting for system asymmetries
• Highly meshed system with generation locally connected near load centres. • Transmission lines fully transposed, otherwise lines are very short (few km). • Distribution systems supplying high density load area with short lines or cables and meshed systems.	0,1 − 0,2
• 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)	0,2 − 0,4
• Long transmission lines generally transposed, generation mostly remote. • Generally radial subtransmission lines partly transposed or untransposed. • 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 (e.g. 10 %).	0,4 − 0,5 [a]
[a] Coefficient k_{uE} or $\{1-k_{uE}\}$ should allow an equitable share of emissions between the unbalanced installations and the various system inherent sources of imbalance present in the considered power system.	

A.3 Summation of sources of unbalance

Unbalance due to a large number of varying loads is generally random and independent. Line unbalance depends on the construction practices adopted for a particular system. It is not random although it also varies with the load.

Table A.2 provides indications on the summation of different sources for assessing their impact on the system.

Table A.2 – Summation of unbalance from different sources

Sources of unbalance	Summation
• Numerous randomly fluctuating single-phase LV loads seen from MV or HV. • Residual unbalance from numerous 3-phase installations at MV, HV. • Unbalance resulting from downstream installations seen from HV or EHV or residual unbalance level of a number of lines partly transposed.	Unless specific information is available, use the general summation law $u_2 = \sqrt[\alpha]{\sum_i u_{2i}^{\alpha}}$ where α = 1,4 to 2 for 95% probability [a]
• Line unbalances due to untransposed lines that have similar conductor arrangements.	Line unbalance in a particular part of a system should be assessed taking into account the actual physical arrangement of the line conductors. The overall impact of the line asymmetries and the random unbalances of the installations may, however, be assessed by using the above summation law.
• Few large unbalanced installations that may be dominating in some part of a system (e.g. large traction loads).	The impact of such installations should be assessed by taking into consideration the physical connection and the load characteristics.

[a] Referring to [5], the summation of vectors whose magnitudes vary from 0 to 1 and whose phase angles vary by ±180° follows the summation law where α = 2 at 95 % probability. However, if the magnitudes of all vectors are assumed to be equal to 1, the summation law has an exponent α = 1,4 at 95 % probability. The first case is representative of numerous unbalanced loads such as at LV or MV. The second case would be more applicable in the case of about 8 or more dominating unbalanced installations.

A.4 Transfer coefficient

The transfer coefficient from MV to LV may be approximated by the following equation.

$$T_{uML} = \frac{1}{\left|1 + k_m \cdot \left(\frac{k_s - 1}{k_{sc} + 1}\right)\right|} \quad \text{(A.1)}$$

where

- k_{sc} is the ratio between the short circuit power at LV busbar (in MVA) and the total LV load (in MVA) connected at this busbar,
- k_m is the ratio between the rated motor load (in MVA) and the total load (in MVA) connected to the LV busbar,
- k_s is the ratio between the positive and negative sequence impedances of the motors (i.e. approximated by the ratio between the starting current and full load current of the motor).

Figure A.1 shows the reduction of unbalance from MV to LV as a function of the amount of motor loading (km) relative to the total loading at LV, assumptions made on the ratio between positive and negative sequence impedances of the motors (ks), and as a function of the ratio between the short-circuit power and the total loading on the LV busbar (ksc).

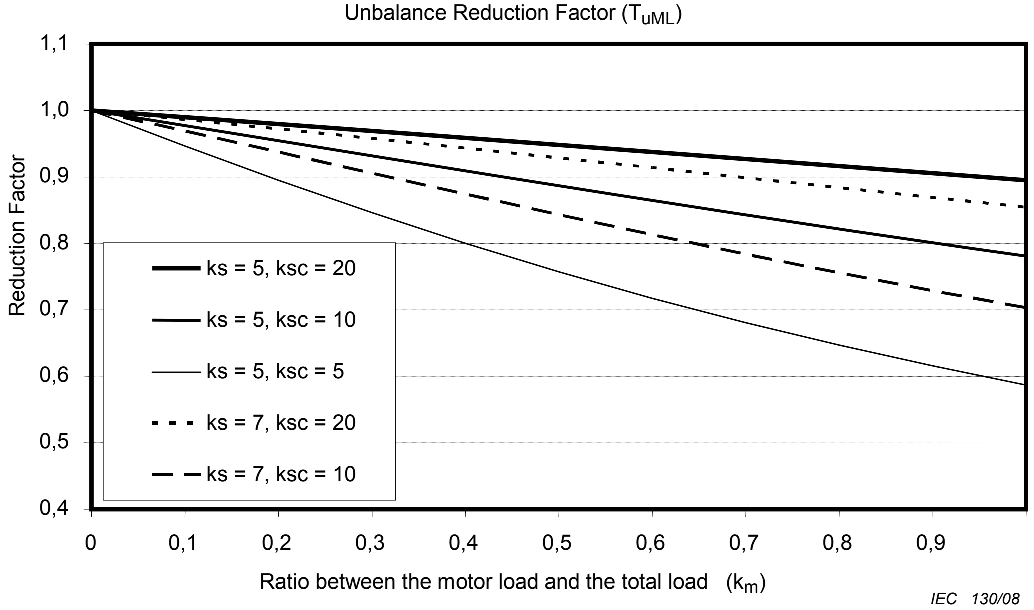


Figure A.1 – The reduction factor T_{uML} as a function of the factors k_m, k_s, and k_{sc}

Figure A.2 shows an example of unbalance measurements taken at the HV and MV bus of a remote mining load with significant motor loading. In this case HV unbalance levels are significant due to long un-transposed EHV and HV lines, and these vary according to loading on these networks. What can be seen form the measurements is that the ratio of unbalance measured at MV to HV is initially 0,5 (i.e. a 50 % reduction of the unbalance levels on the HV bus). This reduction reduces to a ratio of 0,7 (i.e. a reduction of only 30 % when the mining load is reduced by 50 %).

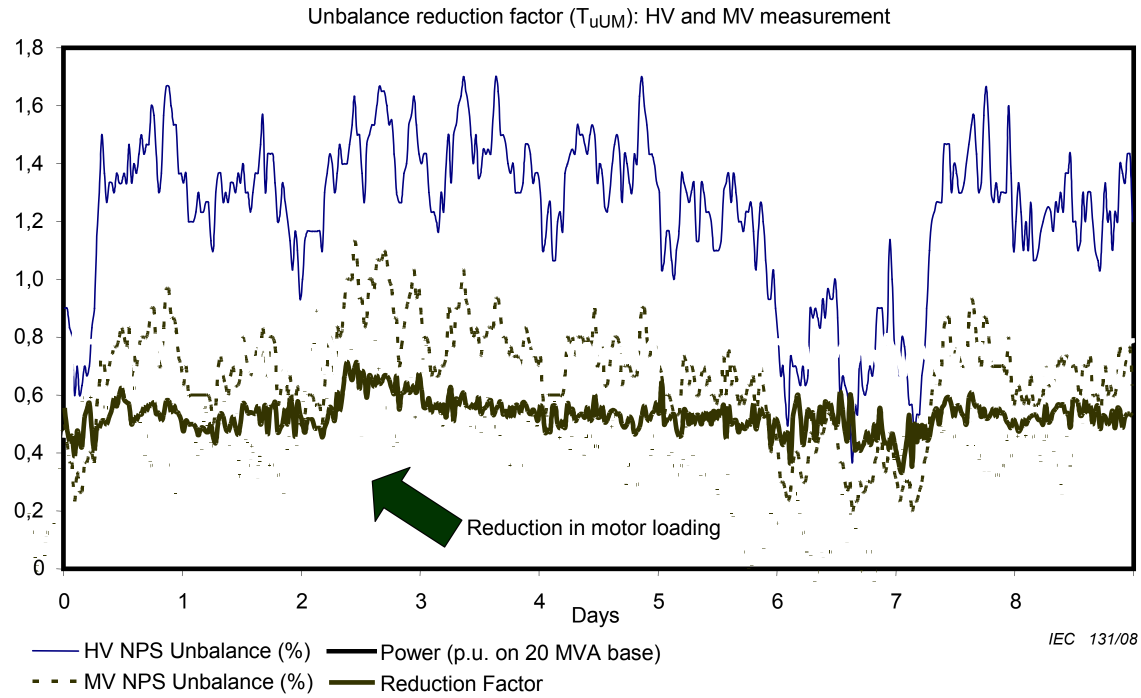


Figure A.2 – Example of unbalance ratio measurement for a remote mine with largely motor loading

A.5 Sharing of planning levels for setting emission limits

Using the summation law and equations 3' and 8 that were introduced in 8.2.1 and 9.2.2, a range of possible values of planning levels can be determined when considering the following basic assumptions:

- equal share of global contributions to voltage unbalance G_u between EHV, HV, MV and LV systems while complying with the compatibility level of 2 % at LV;
- the summation law exponent can vary between 1,4 and 2;
- the transfer coefficient from upstream to downstream voltage levels (T_{uUD}) can vary between 0,8 and 1,0 depending on the system characteristics (conservative values used for stage 2.

A range of planning levels meeting the above criteria is shown in Table A.3.

Table A.3 – Range of values of planning levels given different parameters

	Case A	**Case B**	**Case C**
Summation exponent α	1,4	1,7	2
Transfer factor T_{uUD}			
EHV-HV	1,00	1,00	1,00
HV-MV	0,95	0,95	1,00
MV-LV	0,90	0,95	1,00
Planning level L_U			
EHV	0,82	0,94	1,00
HV	1,35	1,42	1,41
MV	1,75	1,74	1,73
Compatibility level at LV	2,00	2,00	2,00
Global contribution G_U			
EHV	0,82	0,94	1,00
HV	0,82	0,94	1,00
MV	0,82	0,94	1,00
LV	0.,82	0,94	1,00
NOTE The transfer factor is applied consecutively, i.e. first from EHV to HV and then HV to MV (i.e. the equivalent transfer factor from EHV to LV is the product of the individual transfer factors).			

Annex B
(informative)

Calculation examples for determining emission limits

The example below illustrates the application of Stage 2 guidelines in this report.

A customer with an agreed apparent power of 4 MVA is to be connected to an MV busbar in a small industrial area. The MV busbar is supplied by two HV/MV transformers from a meshed HV system. The MV system is designed to supply 40 MVA to this area.

The first requirement is to calculate the acceptable global contribution of the MV system inherent asymmetries and the local MV and LV unbalanced installations to the voltage unbalance in the MV system (G_{uMV+LV}). For this purpose, the following parameters are selected.

- The planning level for the MV system is (from Table 2): L_{uMV} = 1,8.
- The planning level for the upstream system is (from Table 2): L_{uUS} = 1,4.
- The transfer coefficient from the upstream system to the MV system under consideration can be considered to be less than 1 due to the balancing effect of three-phase rotating machines connected in the industrial area. Based on the guidelines in Annex A, a reasonable choice of T_{uUM} is 0,9.
- The summation exponent is (from Table 3): α = 1,4.

Using equation 3', the acceptable global contribution can now be calculated as follows:

$$G_{uMV+LV} = \sqrt[\alpha]{L^{\alpha}_{uMV} - (T_{uUM} \cdot L_{uUS})^{\alpha}}$$

$$= \sqrt[1,4]{(1,8)^{1,4} - (0,9 \text{ x } 1,4)^{1,4}} \qquad \text{(B.1)}$$

$$= 0,9 \text{ \%}$$

The allowed emission limit (E_{ui}) can now be calculated using the following parameters:

- the agreed apparent power of the new installation is S_i = 4 MVA;
- the total future capacity of the MV system is S_t = 40 MVA;
- the fraction that accounts for system inherent voltage unbalance ⟨1-k_{uE}⟩ is not expected to be significant given the nature of the MV system (high density load area with short lines or cables), and therefore a value for ⟨1-k_{uE}⟩ of 0,2 is selected, i.e. k_{uE} = 0,8.

$$E_{ui} = \sqrt[\alpha]{k_{uE}} \cdot G_{uMV+LV} \cdot \left(\sqrt[\alpha]{\frac{S_i}{S_t}} \right)$$

$$E_{ui} = \sqrt[1,4]{0,8} \cdot (0,9) \cdot \left(\sqrt[1,4]{\frac{4}{40}} \right) \qquad \text{(B.2)}$$

$$E_{ui} = 0,15\%$$

As this value is smaller than the minimum value equal to 0,2 % (see 8.2.2), it is finally be set equal to 0,2 %.

Annex C
(informative)

List of principal letter symbols, subscripts and symbols

C.1 Letter symbols

a	vectorial operator (**a** $=1\angle 120°$) used for calculating the symmetrical components of three-phase quantities.
α	exponent of the summation law
C	compatibility level
E	emission limit
G	acceptable global contribution of emissions in some part of a system
I	current
K or k	coefficient or ratio between two values (general meaning)
L	planning level
PCC	Point of Common Coupling
POC	Point of Connection
POE	Point of Evaluation
P	active power
S	apparent power
T	transfer coefficient
U	voltage
Z	impedance

C.2 List of subscripts

a,b,c	phases identifier on a 3-phase system
i	single customer
D or DV	Downstream system voltage
LV	low voltage
MV	Medium voltage
2	negative-sequence
US	Upstream system
UH	Upstream to HV system
UM	Upstream to MV system
m, n	Node, station or busbar number in a given system.
u	unbalance

C.3 List of main symbols

(Self-explaining symbols are not listed)

C_{uLV}	voltage unbalance compatibility level for LV
E_{ui}	voltage unbalance emission limit for the customer (i)
$E_{I2\ i}$	negative-sequence current emission limit for the customer (i)

G_{uHV+DV} maximum global contribution to the voltage unbalance at HV of the HV system inherent asymmetries and of all downstream voltage levels (DV) unbalanced installations that can be supplied from the considered HV system (expressed in terms of the voltage unbalance factor u_2)

G_{uMV+LV} maximum global contribution to the voltage unbalance at MV of the MV system inherent asymmetries and of the total of MV and LV unbalanced installations that can be supplied from the considered MV busbar (expressed in terms of the voltage unbalance factor u_2)

i_2 current unbalance factor (see 3.26.7)

k_{uE} represents the fraction of the global contribution to voltage unbalance that can be allocated for emissions from unbalanced installations supplied by the considered voltage level (conversely $\langle 1-k_{uE} \rangle$ represents the fraction that accounts for system inherent asymmetries contributing to voltage unbalance)

K_{un-m} influence coefficient given by the voltage unbalance at node m of a system when a 1 p.u. negative sequence voltage source is applied at node n.

L_{uHV} voltage unbalance planning level at HV

L_{uMV} voltage unbalance planning level at MV

P_i agreed active power of the individual customer (i)

S_i $S_i = P_i / \cos\varphi_i$ agreed apparent power of customer installation i, or the MVA rating of the considered installation (either load or generation)

S_{LV} total power of the installations supplied directly at LV (including provision for future load growth) through the station HV/MV transformer(s)

S_{MV} total power of the installations directly supplied at MV (including provision for future load growth) through the HV/MV station transformer

S_{sc} short-circuit power (3-phase)

S_t S_t is the total supply capacity of the considered system including provision for future load growth (in principle, S_t is the sum of the capacity allocations of all installations including that of downstream installations that are or can be connected to the considered system, taking diversity into consideration). 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 power as well.

S_{ui} single phase power equivalent of the unbalanced installation i (line-to-neutral equivalent)

T_{uUD} transfer coefficient of voltage unbalance from upstream to downstream system; value depending on system characteristics

T_{uUH} transfer coefficient of voltage unbalance from upstream to HV system; value depending on system characteristics

T_{uUM} transfer coefficient of voltage unbalance from upstream to MV system; value depending on system characteristics

U voltage (generic)

$\underline{U}_1$ positive sequence voltage vector

$\underline{U}_2$ negative sequence voltage vector

u voltage unbalance factor (see 3.26.6)

Z_2 negative-sequence impedance of the supply system at the point of evaluation (POE) where the emission of customer installation (i) is to be assessed (ohms at fundamental frequency).

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