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Edition 1.0 2011-10

TECHNICAL REPORT

BASIC EMC PUBLICATION

Electromagnetic compatibility (EMC) –
Part 3-14: Assessment of emission limits for harmonics, interharmonics, voltage fluctuations and unbalance for the connection of disturbing installations to LV power systems

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ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 3-14: Assessment of emission limits for harmonics, interharmonics, voltage fluctuations and unbalance for the connection of disturbing installations to LV power systems

FOREWORD

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The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a technical report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

IEC 61000-3-14, which is a technical report, has been prepared by subcommittee 77A: Low frequency phenomena, of IEC technical committee 77: Electromagnetic compatibility.

It forms part 3-14 of IEC 61000. It has the status of a basic EMC publication in accordance with IEC Guide 107.

The first edition of this technical report has been harmonised with IEC/TR 61000-3-6, IEC/TR 61000-3-7 and IEC/TR 61000-3-13.

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

Enquiry draft	Report on voting
77A/741/DTR	77A/748/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.

The committee has decided that the contents of this publication will remain unchanged until the stability 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- withdrawn,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).

ACKNOWLEDGEMENT

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 disturbing installations to LV public supply systems.

To this effect, joint working group CIGRE C4.103/ CIRED entitled ‘’*Emission Limits for Disturbing Installations*’’ was appointed in 2003. The working group held 11 formal meetings dedicated to the revision of IEC/TR 61000-3-6 and IEC/TR 61000-3-7, and the preparation of two other technical reports on emission limits for voltage unbalance (IEC/TR 61000-3-13) and emission limits for disturbing installations connected at LV (this report).

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

ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 3-14: Assessment of emission limits for harmonics, interharmonics, voltage fluctuations and unbalance for the connection of disturbing installations to LV power systems

1 Scope

This part of IEC 61000, which is informative in its nature, provides guidance on principles that can be used as the basis for determining the requirements for the connection of disturbing installations to low voltage (LV) public power systems. For the purposes of this part of IEC 61000, a disturbing installation means an installation (which may be a load or a generator) that produces disturbances: harmonics and/or interharmonics, voltage flicker and/or rapid voltage changes, and/or voltage unbalance. The primary objective is to provide guidance to system operators or owners for engineering practices, which will facilitate the provision of adequate service quality for all connected customer installations. In addressing installations, this report is not intended to replace equipment standards for emission limits.

NOTE 1 In this report, low voltage (LV) refers to $U_n \leq 1$ kV.

This 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.

This technical report only applies to installations connected to LV public power systems that supply or may supply other LV loads or installations. It is intended to apply to large installations exceeding a minimum size. This minimum size (S_{min}) is to be specified by the system operator or owner depending on the system characteristics.

NOTE 2 Due to this minimum size, this report generally does not apply to residential customer's installations.

This technical report is not intended to set emission limits for individual pieces of equipment connected to LV systems. The emission limits for LV equipment are specified in the applicable IEC product family standards. The limits specified in these standards have been determined based on assumptions of the number, type and usage of equipment producing disturbances in an installation connected to a supply system and based on the reference impedance given in IEC 60725 considered to be representative of the source impedance for small residential installations. The assumptions may not apply to larger LV installations. Hence, the guidelines in this report are intended to provide methods for developing emission limits for such large installations.

NOTE 3 Compliance with emission limits determined by application of the methods in this report does not preclude any requirement to comply with equipment emission limits (as determined by national or regional regulatory requirements.

This technical report deals with low-frequency conducted disturbances emitted by LV installations. The disturbances considered are:

- harmonics and interharmonics;
- flicker and rapid voltage changes;
- unbalance (negative-sequence component).

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 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 disturbing installations to the system. The disturbing installation is to be understood as the customer's complete installation (i.e. including disturbing and non-disturbing parts).

This report provides recommended procedures for developing emission limits for large LV installations. In order for any network operator or owner to fully apply this report, an expert would need to derive appropriate factors for the specific types of LV networks operated.

NOTE 4 Simplification of emission limits by setting one set of tables for all LV networks may, in some cases, result in excessively conservative limits.

The main part of this report gives the general procedure to allocate emission limits for harmonics, voltage fluctuation and unbalance to large installations connected at LV.

Annexes to this report give additional information. In particular,

- Annex A gives a practical example of technical application at distribution expert level or national regulation level, in order to derive their own limits tailored on the specific characteristics of their networks from the general method.
- Annex B gives an example of practical application at distribution operator level for the connection of specific installations based on the local parameters of the LV network.
- Annex C and Annex D give details on the theoretical basis for the derivation and the understanding of the procedures in this report.

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 60050-161:1990, *International Electrotechnical Vocabulary – Chapter 161: Electromagnetic compatibility*
Amendment 1 (1997)
Amendment 2 (1998)

IEC/TR 60725, *Consideration of reference impedances and public supply network impedances for use in determining disturbance characteristics of electrical equipment having a rated current ≤75 A per phase*

IEC/TR 61000-2-1:1990, *Electromagnetic compatibility (EMC) – Part 2-1: Environment – Description of the environment – Electromagnetic environment for low-frequency conducted disturbances and signalling in public power supply systems*

IEC 61000-2-2:2002, *Electromagnetic compatibility (EMC) – Part 2-2: Environment – Compatibility levels for low-frequency conducted disturbances and signalling in public low-voltage power supply systems*

IEC 61000-3-2, *Electromagnetic compatibility (EMC) – Part 3-2: Limits – Limits for harmonic current emissions (equipment input current ≤16 A per phase)*

IEC 61000-3-3, *Electromagnetic compatibility (EMC) – Part 3-3: Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤16 A per phase and not subject to conditional connection*

IEC/TR 61000-3-6:2008, *Electromagnetic compatibility (EMC) – Part 3-6: Limits – Assessment of emission limits for the connection of distorting installations to MV, HV and EHV power systems*

IEC/TR 61000-3-7:2008, *Electromagnetic compatibility (EMC) – Part 3-7: Limits – Assessment of emission limits for the connection of fluctuating load installations to MV, HV and EHV power systems*

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

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

IEC/TR 61000-3-13:2008, *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 61000-4-15, *Electromagnetic compatibility (EMC) – Part 4-15: Testing and measurement techniques – Flickermeter – Functional and design specifications*

3 Terms and definitions

For the purposes of this document, the following definitions apply as well as the definitions in IEC 60050(161).

3.1
95 % (99 %) probability weekly (daily) value
value that is not exceeded during 95 % (99 %) of the time over one week (day)

3.2
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

3.3
customer
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

3.4
(electromagnetic) disturbance
any electromagnetic phenomenon which, by being present in the electromagnetic environment, can cause electrical equipment to devite from its intended performance

3.5
disturbance level
the amount or magnitude of an electromagnetic disturbance measured and evaluated in a specified way

3.6
disturbing installation
electrical installation as a whole (i.e. including disturbing and non-disturbing parts) which can cause a disturbance of the voltage or current into the supply system to which it is connected

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

3.7
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/TR 61000-2-1.

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.

3.8
(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.

3.9
emission

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

[IEC 60050-161:1990, 161-01-08 modified]

NOTE For the purpose of this report, emission refers to phenomena or conducted electromagnetic disturbances that can cause distortions, fluctuations or unbalance on the supply voltage.

3.10
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

3.11
emission limit

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

3.12
generating plant

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

3.13
immunity (to a disturbance)

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

3.14
immunity level
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

3.15
installation size

3.15.1
large installation
installation with an agreed power greater than or equal to a value specified by the system operator or owner

NOTE This specified value is named S_{min} in this report.

3.15.2
small installation
installation with an agreed power lower than a value specified by the system operator or owner

NOTE This specified value is named S_{min} in this report.

3.16
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.

3.17
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.

3.18
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.

3.19
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.

3.20
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.

3.21
public low-voltage power system

a low-voltage power system that supplies or may supply several installations or customers

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

3.22
short circuit power

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

3.23
spur

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

3.24
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

3.25
system operator or owner

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

3.26
transfer coefficient (influence coefficient)

relative level of disturbance that can be transferred between two busbars or two parts of a power system for various operating conditions

3.27
phenomena related definitions
harmonics

definitions 3.27.1 to 3.27.9 relate to harmonics. They are based on the analysis of system voltages or currents by the Discrete Fourier Transform method (DFT); this is the practical application of the Fourier transform as defined in IEC 60050-101:1998, 101-13-09

NOTE 1 The Fourier Transform of a function of time, whether periodic or non-periodic, is a function in the frequency domain and is referred to as the frequency spectrum of the time function, or simply spectrum. If the time function is periodic, the spectrum is constituted of discrete lines (or components). If the time function is not periodic, the spectrum is a continuous function, indicating components at all frequencies.

NOTE 2 For simplicity, the definitions given in this report refer only to (inter)harmonic components. However, these should not be interpreted as a restriction on the use of other definitions given in other IEC documents, for example IEC 61000-4-7, where the reference to (inter)harmonic groups or subgroups are more appropriate for measuring rapidly varying signals.

3.27.1
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 corresponding to the period of the function itself.

3.27.2
fundamental component
component whose frequency is the fundamental frequency

3.27.3
harmonic frequency
frequency which is an integer multiple of the fundamental frequency. The ratio of the harmonic frequency to the fundamental frequency is the harmonic order (recommended notation: “h”)

3.27.4
harmonic component
any of the components having a harmonic frequency. For brevity, such a component may be referred to simply as a harmonic

3.27.5
interharmonic frequency
any frequency which is not an integer multiple of the fundamental frequency

NOTE 1 By extension from harmonic order, the interharmonic order is the ratio of an interharmonic frequency to the fundamental frequency. This ratio is not an integer. (Recommended notation “m”).

NOTE 2 In the case where m < 1, the term subharmonic frequency may be used.

3.27.6
interharmonic component
component having an interharmonic frequency. For brevity, such a component may be referred to simply as an “interharmonic”

3.27.7
total harmonic distortion
THD
ratio of the r.m.s. value of the sum of all the harmonic components up to a specified order (H) to the r.m.s. value of the fundamental component

$$\mathrm{THD} = \sqrt{\sum_{h=2}^{H} \left(\frac{Q_h}{Q_1} \right)^2}$$

where

Q represents either current or voltage,

Q_1 is the r.m.s. value of the fundamental component,

h is the harmonic order,

Q_h is the r.m.s. value of the harmonic component of order h,

H is generally 40 or 50 depending on the application.

3.27.8
distorting installation
electrical installation as a whole (i.e. including distorting and non-distorting parts) which can cause distortion of the voltage or current into the supply system to which it is connected

NOTE For the purpose of this report, all references to distorting installations not only include linear and non-linear loads, but generating plants, and any source of non-sinusoidal current emissions such as regenerative braking systems.

3.27.9
non-linear load or equipment (see also distorting installation)
any load or equipment that draws a non-sinusoidal current when energised by a sinusoidal voltage

3.28
Phenomena related definitions – Flicker and rapid voltage changes

3.28.1
flicker
impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates with time

NOTE Flicker is the effect on the incandescent lamps while the electromagnetic phenomenon causing it is referred as voltage fluctuations.

3.28.2
rapid voltage changes
changes in fundamental frequency r.m.s. voltages over several cycles; rapid voltage changes could also be in the form of cyclic changes

NOTE Rapid voltage changes are often caused by start-ups, inrush currents or switching operation of equipment.

3.28.3
fluctuating installation
electrical installation as a whole (i.e. including fluctuating and non-fluctuating parts) which is characterized by repeated or sudden power fluctuations, or start-up or inrush currents which can produce flicker or rapid voltage changes on the supply system to which it is connected

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

3.28.4
voltage fluctuations
series of voltage changes or a cyclic variation of the voltage envelope

3.29
phenomena related definitions
unbalance

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

3.29.1
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)

[IEC 60050-161:1990, 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.

3.29.2
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 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.

3.29.3
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 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.

3.29.4
zero-sequence component of 3-phase voltages (or currents)

defined as the symmetrical vector system derived by application of the Fortescue's transformation matrix and 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.

3.29.5
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

$$u = \frac{|\underline{U}_2|}{|\underline{U}_1|}.100 = \frac{|\underline{U}_a + \mathbf{a}^2\underline{U}_b + \mathbf{a}\underline{U}_c|}{|\underline{U}_a + \mathbf{a}\underline{U}_b + \mathbf{a}^2\underline{U}_c|}.100 \qquad (\%)$$

NOTE 1 Phase-to-phase voltages may also be used instead of line to neutral voltages.

NOTE 2 For simplicity in this report u has been used to denote the voltage unbalance factor instead of u_2.

An equivalent formulation is given in IEC 61000-4-30:

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

3.29.6
current unbalance factor
IUF

defined as the ratio of the modulus of the negative-sequence to the positive-sequence components of the current at fundamental frequency, expressed as a percentage

$$i_2 = \frac{\left|\underline{I}_2\right|}{\left|\underline{I}_1\right|}.100 = \frac{\left|\underline{I}_a + \mathbf{a}^2\,\underline{I}_b + \mathbf{a}\,\underline{I}_c\right|}{\left|\underline{I}_a + \mathbf{a}\,\underline{I}_b + \mathbf{a}^2\,\underline{I}_c\right|}.100 \qquad (\%)$$

3.29.7
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

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

4 Basic EMC concepts

4.1 General

The development of emission limits (voltage or current) for individual equipment or a customer’s installation should be based on the effect that these emission limits 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 IEC 60050(161).

4.2 Compatibility levels

4.2.1 General

These are reference values 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 distributions which represent both time and space variations of disturbances. There is allowance for the fact that the system operator 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 low-frequency conducted disturbances in public LV power supply systems are given in international standard IEC 61000-2-2.

4.2.2 Harmonics

The compatibility levels in IEC 61000-2-2 for harmonic voltages in LV systems shall be understood to relate to quasi-stationary or steady-state harmonics, and are given as reference values for both long-term effects and very-short-term effects.

- The long-term effects relate mainly to thermal effects on cables, transformers, motors, capacitors, etc. They arise from harmonic levels that are sustained for 10 min or more.
- Very short-term effects relate mainly to disturbing effects on electronic devices that may be susceptible to harmonic levels sustained for 3 s or less. Transients are not included.

With reference to long-term effects, the compatibility levels for individual harmonic components of the voltage are given in Table 1. The compatibility level for the total harmonic distortion is *THD* = 8 %.

Table 1 – Compatibility levels for individual harmonic voltages in LV networks (percent of fundamental component) reproduced from IEC 61000-2-2

Odd harmonics non-multiple of 3		Odd harmonics multiple of 3		Even harmonics	
Harmonic order h	**Harmonic voltage** %	**Harmonic order** h	**Harmonic voltage** %	**Harmonic order** h	**Harmonic voltage** %
5	6	3	5	2	2
7	5	9	1,5	4	1
11	3,5	15	0,4	6	0,5
13	3	21	0,3	8	0,5
$17 \le h \le 49$	$2{,}27 \cdot \frac{17}{h} - 0{,}27$	$21 < h \le 45$	0,2	$10 \le h \le 50$	$0{,}25 \cdot \frac{10}{h} + 0{,}25$

With reference to the very-short term effects (see IEC 61000-2-2), the compatibility levels for individual harmonic components of the voltage are the values given in Table 1 multiplied by a factor k_{hvs}, where k_{hvs} is calculated as follows:

$$k_{hvs} = 1{,}3 + \frac{0{,}7}{45} \cdot (h - 5) \qquad (1)$$

With reference to the very-short term effects of harmonics, the compatibility level for the total harmonic distortion is *THD* = 11 %.

4.2.3 Interharmonics

Knowledge of the electromagnetic disturbance involved in interharmonic voltages is still developing.

In standard IEC 61000-2-2, compatibility levels are given only for the case of an interharmonic voltage occurring at a frequency close to the fundamental frequency (50 Hz or 60 Hz), resulting in amplitude modulation of the supply voltage which causes flicker. The compatibility level for a single interharmonic voltage in this case is based on a flicker level of P_{st} = 1 (see Figure 2 in IEC 61000-2-2).

Standard IEC 61000-2-2 also provides indicative values for interharmonics at other frequencies.

- It is suggested that the reference level for each interharmonic frequency be equal to the compatibility level given in Table 1 for the next higher even harmonic.
- On a network containing ripple control receivers, the reference level at the defined operational frequency of the receivers should be 0,2 % of the nominal supply voltage.
- For a discrete frequency in the range from the 50th harmonic up to 9 kHz, the suggested reference level is 0,2 % of the fundamental component.
- For a band of frequencies in the range from the 50th harmonic up to 9 kHz, the suggested reference level for any 200 Hz bandwidth is 0,3 % of the fundamental component.

4.2.4 Voltage fluctuations

The international flickermeter (see IEC 61000-4-15) provides two quantities to characterize the flicker severity: P_{st} (“st” referring to “short term”: one value is obtained for each 10 min period) and P_{lt} (“lt” referring to “long term”: one value is obtained for each 2 h period). The flicker related voltage quality criteria are generally expressed in terms of P_{st} and/or P_{lt}, with P_{lt} typically being derived from groups of 12 consecutive P_{st} values as follows:

$$P_{lt} = \sqrt[3]{\frac{1}{12} \cdot \sum_{j=1}^{12} P_{st\,j}^{3}} \tag{2}$$

For flicker in LV systems, the compatibility levels are reproduced in Table 2 from IEC 61000-2-2.

Table 2 – Compatibility levels for flicker in LV networks reproduced from IEC 61000-2-2

	Flicker
P_{st}	1,0
P_{lt}	0,8

It is also assumed in this report that the flickermeter and the associated severity factors are adapted to the type of incandescent lamps in use (e.g.: 120 V or 230 V) so that the flicker limit remains the same irrespective of the voltage of the lamps. This is important because 120 V lamps are less sensitive to voltage fluctuations than 230 V lamps and 100 V lamps are even less sensitive.

In normal circumstances, the value of rapid voltage changes is limited to 3 % of nominal supply voltage in LV systems. However step voltage changes exceeding 3 % can occur infrequently on the public supply network (see IEC 61000-2-2).

4.2.5 Unbalance

The compatibility level for voltage unbalance in LV systems given in IEC 61000-2-2 is a negative sequence component of 2 % of the positive sequence component. In some areas, especially where it is the practice to connect large single-phase loads, values up to 3 % may occur.

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).

4.3 Planning levels

4.3.1 Indicative values of planning levels

These are levels that can be used for planning purposes in evaluating the impact on the supply system of all disturbing 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.

Planning levels are equal to or lower than compatibility levels and they should allow co-ordination of disturbance levels between different voltage levels. Some margin between planning and compatibility levels might be justified to account for Voltage Characteristics (see note below), for resonance, etc. Planning levels will differ from case to case, depending on system structure and circumstances, and no definite values can be given (for compatibility levels see 4.2).

NOTE Voltage characteristics that are quasi-guaranteed levels exist in some countries. These should be coordinated with the planning levels. In considering these, the nature of the system should be taken into consideration.

The rest of this report outlines procedures for using these planning levels to establish the emission limits for individual customer disturbing installations.

4.3.2 Assessment procedure for evaluation against planning levels

The measurement methods to be used are the class A measurement methods defined in IEC 61000-4-30. The data flagged in accordance with the 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.

For rapid voltage changes, no standardized measurement method exists. For this reason, it is recommended that the assessment procedure used in this case be based on measured changes in r.m.s. voltage considering only the power frequency component with transients removed. In practice, the shortest possible multi-cycle window should be used to avoid artificially smoothing the desired r.m.s fundamental frequency voltage change.

For each type of disturbance, the minimum measurement period is one week of normal business activity. The monitoring period should include some part of the period of expected maximum disturbance levels.

One or more of the following indices may be used to compare the actual disturbance 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 shorter periods of time such as during bursts or start-up conditions.

For harmonic voltages, the indices are the following.

- The 95 % weekly value of $U_{h,sh}$ (r.m.s. value of individual harmonics over "short" 10 min periods) should not exceed the planning level.
- The greatest 99 % probability daily value of $U_{h,vs}$ (r.m.s. value of individual harmonic components over "very short" 3 s periods) should not exceed the planning level times the multiplying factor k_{hvs} given in Equation (1) with reference to very short-term effects of harmonics.

NOTE 1 Harmonics are generally measured up to order 40 or 50, depending on the application.

For Flicker, the indices for P_{st} and P_{lt} are the following.

- The 95 % probability weekly value of P_{st} should not exceed the planning level.
- The 99 % probability weekly value of P_{st} should not exceed the planning level times a multiplying factor (for example: 1 – 1,5) to be specified by the system operator or owner, depending on the system and load characteristics.
- The 95 % probability weekly value of P_{lt} should not exceed the planning level.

NOTE 2 Possible abnormal results (e.g. due to voltage dips or other transients) should be eliminated. It is also advisable that each new P_{st} value be incorporated in a revised P_{lt} calculation using a sliding window where the oldest P_{st} measurement is replaced by the newest P_{st} value at each 10 minute interval. This recommended P_{lt} calculation procedure results in 144 P_{lt} values each day. In some cases, this may require post-processing of P_{st} outputs from a flickermeter.

For rapid voltage changes, because of their low frequency of occurrence, no statistical indices are considered. Thus maximum values of rapid voltage changes should not exceed the planning levels. However, high values due to abnormal disturbances such as faults or abnormal switching operations should be removed from the assessment.

For voltage unbalance, the indices are the following.

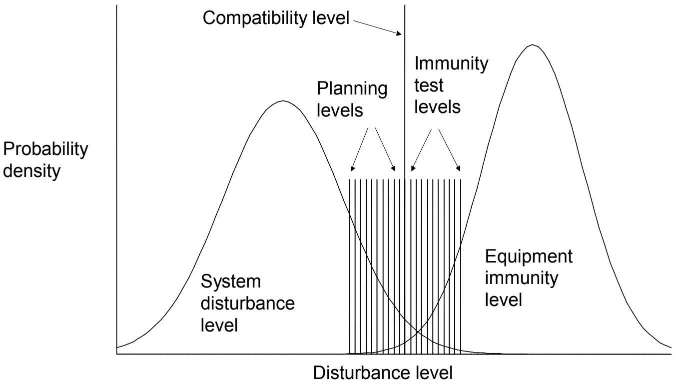
- The 95 % weekly value of u_{sh} (voltage unbalance factor at fundamental frequency over "short" 10 min periods) should not exceed the planning level.
- The greatest 99 % probability daily value of u_{vs} (voltage unbalance factor at fundamental frequency over "very short" 3 s periods) should not exceed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

NOTE 3 In accordance with IEC 61000-4-30, only the fundamental frequency positive and negative-sequence components must be used when assessing the voltage unbalance factor (harmonics should be extracted as some negative-sequence harmonics can alter the measurement results).

4.4 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). Planning levels 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.



IEC 2357/11

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

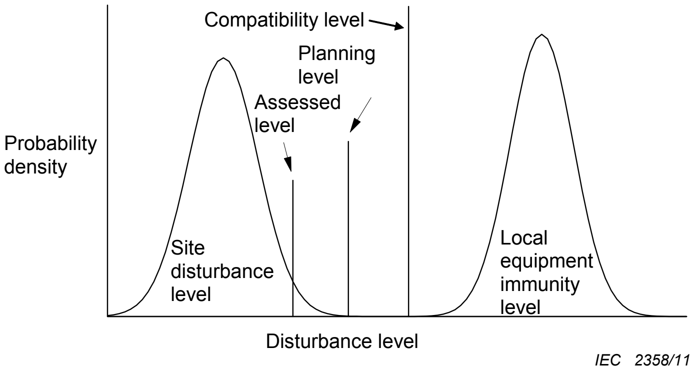


Figure 2 – Illustration of basic voltage quality concepts with time statistics relevant to one site within the whole system

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.

4.5 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.

For harmonic emissions, the indices are:

- the 95 % weekly value of $U_{h,sh}$ (or $I_{h,sh}$), the r.m.s. value of individual harmonics over "short" 10 min periods, should not exceed the emission limit E_{Uhi} (or E_{Ihi});
- the greatest 99 % probability daily value of $U_{h,vs}$ (or $I_{h,vs}$), the r.m.s. value of individual harmonic components over "very short" 3 s periods, should not exceed the emission limit multiplied by the factor k_{hvs} given in Equation 1.

For flicker emissions, the indices are:

- the 95 % probability weekly value of P_{st} should not exceed the emission limit E_{Psti};
- the 99 % probability weekly value of P_{st} should not exceed the emission limit E_{Psti} times a multiplying factor (for example: 1 – 1,5) to be specified by the system operator or owner, depending on the system and load characteristics;
- the 95 % probability weekly value of P_{lt} should not exceed the emission limit E_{Plti}.

For rapid voltage changes, because of their low frequency of occurrence, no statistical indices are considered. Thus maximum values of rapid voltage changes including frequency of occurrence should not exceed the emission limits. However, high values due to abnormal disturbances such as faults or abnormal switching operations should be removed from the assessment.

For unbalance emissions, the indices are:

- 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 $E_{u2\ i}$ (or $E_{i2\ i}$);
- 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 loads with their protection devices.

In order to compare the levels of disturbance emissions from a customer's installation with the emission limits, 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 disturbance emissions which is expected to occur. If any disturbance emission 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 emission is caused by the summation of several items of equipment, the period should be at least one operating shift.

The measurement methods to be used are the class A measurement methods defined in IEC 61000-4-30. The data flagged in accordance with the standard should be removed from the assessment. For clarity, where data is flagged, the percentile used in calculating the indices defined above is calculated using only the valid (unflagged) data.

For harmonics, when the signal to be analysed is rapidly varying (e.g. the current drawn by an electric arc), the measurement of (inter)harmonic groups and subgroups should be used as explained in IEC 61000-4-7, rather than the harmonic components.

For rapid voltage changes, no standardized measurement method exists. For this reason, it is recommended that the assessment procedure used in this case be based on measured changes in r.m.s. voltage considering only the power frequency component with transients removed. In practice, the shortest possible multi-cycle window should be used to avoid artificially smoothing the desired r.m.s fundamental frequency voltage change.

For each type of disturbance, the emission level from a disturbing installation is the disturbance level assessed according to other indications given in Clause 6.

5 General principles

5.1 General

The proposed approach for setting emission limits of disturbing installations depends on the agreed power of the customer's installation and the system characteristics. The objective is to limit the disturbance injection from the total of all disturbing installations to levels that will not result in voltage disturbance levels that exceed the planning levels. Three stages of evaluation are defined which may be used in sequence or independently.

5.2 Stage 1: simplified evaluation of disturbance emission

It is generally acceptable for a customer to install small appliances without specific evaluation of disturbance emission by the system operator or owner. Manufacturers of such appliances are generally responsible for limiting the emissions. For instance, IEC 61000-3-2 and IEC 61000-3-12 in the case of harmonics, and IEC 61000-3-3 and IEC 61000-3-11 in the case of voltage fluctuations are product family standards that define emission limits for equipment connected to LV systems. For small installations, such as residential dwellings, the system operator or owner can thus rely on these emission limits for individual pieces of equipment to comply with the planning levels.

In the case of larger installations, more care has to be taken by the system operator or owner to make sure that planning levels are not exceeded. However, it remains possible to define conservative criteria for quasi-automatic acceptance for disturbing installations on LV systems. Indeed, if the total disturbing load, or the customer’s agreed power, is small relative to the short circuit capacity at the point of evaluation, it should not be necessary to carry out detailed evaluation of the disturbance emission levels.

In Clauses 8 to 10 specific criteria are developed for applying stage 1 evaluation.

5.3 Stage 2: emission limits relative to actual system characteristics

If an installation does not meet stage 1 criteria, the specific characteristics of the disturbing installation should be evaluated together with the absorption capacity of the system. For each type of disturbance, the absorption capacity of the system is derived from the planning levels, and is apportioned to individual customers' installations according to their demand with respect to the total system capacity. The disturbance level transferred from the upstream voltage levels of the supply system to the low voltage level should also be considered when apportioning the planning levels to individual customers' installations.

The principle of this approach is that, if the system is utilized at its full designed capacity and all customers' installations are injecting up to their individual limits, the total disturbance levels will be equal to the planning levels taking into account the transfer factors between different parts of the system and the summation of various disturbing loads. A procedure for apportioning the planning levels to individual installations is outlined in Clauses 8 to 10.

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

Under some circumstances, the system operator or owner may accept a disturbing installation to emit disturbances 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. In such a situation, the customer and the system operator or owner may agree on special conditions that facilitate connection of the disturbing installation.

The following factors may leave a margin on the system for allowing higher emission limits, for example:

- Some installations do not produce significant levels of disturbances because they do not have disturbing equipment of significant magnitude. Therefore, some of this unused disturbance capacity of the system may be available for utilization on a temporary basis.
- The general summation law may be too conservative in some instance: some disturbing installations can produce disturbances with opposite phase; or phase shifting within the system may lead to partial cancellation of disturbances.
- The actual LV system characteristics may allow more emissions than hypothesized for the development of the generic emission limits in stage 2 (e.g.: shorter LV feeders).
- For unbalance, if all the pieces of equipment within LV installations are single-phase, it is possible to allow higher unbalance levels because equipment is not as much affected by unbalance.
- In some cases, higher global contribution at LV may be defined after reallocation of the planning levels between LV and MV systems, to take account of local phenomena such as special attenuation effects or absence of disturbing installations at a certain voltage 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 be carried out, taking account of the pre-existing levels of disturbances and of the expected contributions from the considered installation for different possible operating conditions. Acceptance of higher than normal emission limits may be given to customers' installations only on conditional basis and limitations may be specified by the system operator or owner. For instance, temporary stage 3 limits may apply

- 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 emissions limits,
- for the time needed for a new installation to implement additional corrective measures whenever needed.

5.5 Responsibilities

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

- The customer is responsible for maintaining his emissions at the specified point of evaluation below the limits specified by the system operator or owner.
- The system operator or owner is responsible for the overall co-ordination of disturbance levels under normal operating conditions in accordance with national requirements. For evaluation purposes, the system operator or owner should, where required, provide relevant system data, such as system impedance (see 6.4) or short-circuit power, and existing levels of disturbances. The evaluation procedure is designed in such a way that the disturbance emissions from all disturbing installations do not cause the overall system disturbance levels to exceed the planning 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, especially if the pre-existing disturbance levels are already high.
- Finally, in the case where the installation exceeds its emission limits, the system operator or owner and customer 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.

NOTE This report is mainly concerned with emissions. However, disturbance absorption may also be a problem if, for instance, filters or capacitor banks are connected without due consideration for their interaction with the harmonics normally present in the power system. Absorption of negative-sequence currents may also be a problem if equipment is connected without due consideration for their rating given the unbalance voltage normally present in the power system. Thus the problem of disturbance absorption 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 limits. This is also a point within the considered power system at which the planning levels are defined. This point could be the point of connection (POC) or the point of common coupling (PCC) of the disturbing installation or any other point specified by the system operator or owner or agreed upon.

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

NOTE 2 It should be remembered that voltage characteristics or contracted limits generally apply at the point of connection. This should be taken into consideration in discussions between the parties.

6.2 Concept of emission level

The emission level from an installation into the power system is the magnitude of the disturbing voltage (or current) vector which is caused by the considered installation at the point of evaluation. In case of harmonics or unbalance, the general concept can be illustrated in Figure 3 by the vector U_{di} and its contribution (together with the disturbance vector U_{d0} caused by all other sources of disturbances when the installation under consideration is not connected to the system) to the measured disturbance vector U_d at the point of evaluation, once the installation has been connected.

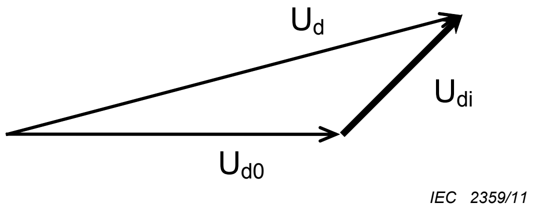


Figure 3 – Illustration of the emission vector U_{di} and its contribution to the measured disturbance vector U_d at the point of evaluation

Where the emission vector results in increased levels of disturbance on the network (i.e. $|U_d| > |U_{d0}|$), the emission level as defined above (i.e. $|U_{di}|$) needs to be less than the emission limits assessed according to the relevant clauses in this report.

For harmonics, the interaction between the supply system and customer's installation may in some cases result in amplification or in reduction of the voltage distortion level at a given harmonic order (i.e. due to the creation of a parallel or a series resonance condition, or due to a cancellation effect). An amplification is possible even where the installation itself does not generate harmonics of this order. As this report addresses the EMC co-ordination requirements, such amplification situations are taken into consideration with this definition of actual emission levels.

For voltage unbalance, the interaction between the supply system and customer's installation may result in a reduction of the voltage unbalance (i.e. due to the balancing effect of rotating machines). This situation is taken into consideration in this definition of actual emission levels. Conversely, connection of an installation to the supply system may in some cases result in increased unbalance levels at the point of evaluation, where the installation itself is a balanced load (i.e. due to the effect of un-transposed lines). In this case the contribution of balanced loading to the levels 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 installation.

For flicker however, disturbances are almost always additive and no cancellation or reduction should be expected.

6.3 Operating conditions

It is recommended that the emission levels be assessed under normal operating conditions, unless otherwise specified. The assessment of emission levels from disturbing installations should consider the worst normal operating conditions including contingencies for which the system or the customer's installation is designed to operate.

Where significant, the following factors should also be taken into account.

- Non-ideal operating conditions and asymmetries that can be present in the supply system and within the disturbing installation.
- Planned switching operations of the equipment such as filters and capacitor banks with the variation of load.

Other detail on the assessment of the emission levels in the power supply of industrial plants may be found in IEC/TR 61000-2-6. Simplified and advanced prediction methods for evaluating flicker severity indices are also given in IEC/TR 61000-3-7.

6.4 System impedance characteristics

Information on the supply system characteristics is a prerequisite both for the system operator or owner for assessing emission limits and for the customer in order to assess his emission levels.

At LV, it is customary to use the short-circuit power or the Thevenin’s impedance of the supply system (excluding the contribution of motors or other equipment connected to it) at fundamental frequency. As in 6.3, it is recommended to consider the worst normal operating conditions including contingencies for which the system is designed to operate.

The system characteristics may vary significantly with time. So when important changes are expected between the present and the future system configuration, a different set of system impedance data should be provided in order for the customer to assess his emission levels for both situations and to achieve an optimal design of his equipment.

For harmonics, the procedure given in this report does not take into account all cases of resonance at LV level. For cases where resonance might occur, more detailed assessment or simulation would be needed. It is worthwhile noting that other customer’s facilities also affect the system impedance. Special attention must be paid to their capacitor banks, which can modify resonances or create additional ones (see Robert et al.).

For flicker, it is recommended to use the short-circuit power, including power factor information, or the Thevenin equivalent impedance of the supply system at the point of evaluation.

For setting emission limits for unbalance at Stage 2, the LV system negative sequence impedance at the POE is assumed to be equal to the positive sequence impedance obtained from the short-circuit power at the POE. Three-phase motor loads in other customers' installations on the LV network may affect the actual negative sequence impedance seen at the POE.

The system operator or owner generally does not have complete information about existing customers' facilities, so he can only provide approximate information.

7 General summation law

7.1 General

The co-ordination of conducted disturbances requires the adoption of hypotheses relevant to the summation of the disturbances produced by various disturbing installations. In the case of harmonic, flicker or unbalance disturbances due to randomly disturbing loads, the actual global disturbance level at any point on a distribution system is the result of the vectorial summation of each individual source of disturbance.

On the basis of experience, a general summation law can be adopted for application at the level of a supply system:

$$\mathrm{D} = \sqrt[\alpha]{\sum_{\mathrm{i}} \mathrm{D}_{\mathrm{i}}^{\alpha}} \qquad (3)$$

where

D is the magnitude of the resulting disturbance level for the considered aggregation of sources;

D_i is the magnitude of the disturbance level produced by one of the sources of disturbances to be combined;

α is an exponent which mainly depends upon 3 factors:

- the type of disturbance;
- the chosen value of the probability for the actual value not to exceed the calculated value;
- the degree to which individual disturbances vary randomly in terms of magnitude and phase.

NOTE 1 This general summation law is a statistical approximation of the underlying vectorial summation for many random sources. It is used specifically for the allocation of emission limits to installations in order to define a reasonable increase in the disturbance level that may be allowed by the system operator or owner.

NOTE 2 It remains apparent that, when considering a specific source of disturbance, vectorial summation may in practice result in a reduction of the level of disturbance, even though the general summation law can only give an increase.

7.2 For harmonics

For the purpose of this report, the set of exponents given in Table 3 can be adopted in the absence of further specific information.

Table 3 – Summation exponent for harmonics (indicative values)

Harmonic order	α
$h < 5$	1
$5 \le h \le 10$	1,4
$h > 10$	2

NOTE 1 When it is known that the harmonics are likely to be in phase (i.e. phase angle differences less than 90°), then an exponent $\alpha = 1$ should be used for order 5 and above.

NOTE 2 Higher summation exponents can be used for low order even harmonics that are less likely to be in phase.

7.3 For flicker and rapid voltage changes

The summation law which best fits measurement results depends on both the degree of coincidence in the voltage changes and the P_{st} percentile which is used for the evaluation, as well as on the equipment technologies involved in producing the voltage fluctuations.

In general, a value of $\alpha = 3$ (“cubic summation law”) has been largely used for years and is recommended for P_{st} (or P_{lt}) summation provided that additional information is not available to justify a different value as discussed in IEC/TR 61000-3-7.

For rapid voltage changes, the coincidence of occurrence of several changes presents a very low probability. For this reason no summation law is needed.

7.4 For voltage unbalance

For voltage unbalance, on the basis of the information available to date, in the absence of further specific information (see Notes 1 to 3 below) the exponent α can be adopted for adding numerous randomly varying sources of unbalance.

Indicative value of exponent for the summation of general sources of unbalance:

$$\boxed{\alpha = 1{,}4}$$

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 phase(s) 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 in IEC/TR 61000-3-13, 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. 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-neutral, and on the power factor of the unbalance sources.

For systems where large single-phase loads can be the dominant source of voltage unbalance, the summation law should not be used to determine the total unbalance of these loads. Indeed the specific characteristics of the connection scheme and the profile of the load variations need to be considered.

8 Harmonic emission limits for distorting installations in LV systems

8.1 Stage 1: simplified evaluation of disturbance emission

For small installations, such as residential houses for example, the system operator or owner can generally rely on harmonic emission limits for individual pieces of equipment to comply with the planning levels. For instance, IEC 61000-3-2 and IEC 61000-3-12 are product family standards that define harmonic emission limits for equipment connected to public LV systems.

An installation may be connected to the supply system without further examination if all pieces of equipment in the installation comply with the relevant emission limits defined in IEC 61000-3-2 and IEC 61000-3-12, and if the following condition is fulfilled :

$$S_i < S_{\mathrm{min}} \tag{4}$$

where

- S_i is the agreed power of customer's installation i;
- S_{min} is the minimum value of the agreed power of LV installations to which the procedure to define emission limits developed in this report applies.

The minimum value of the agreed power of the LV installations (S_{min}) for the application of this report is to be specified by the system operator or owner depending on their system characteristics.

NOTE In order to take into account the specificities of each type of disturbance, different minimum values of the agreed power (S_{min}) may be specified for harmonics, voltage fluctuations and unbalance.

On the contrary, for larger installations ($S_i \geq S_{\mathrm{min}}$) or if some pieces of equipment in the installation do not comply with the relevant emission limits defined in IEC 61000-3-2 and IEC 61000-3-12, more care has to be taken by the system operator or owner to make sure that the planning levels are not exceeded.

In that case, the connection of a distorting installation can be accepted in stage 1 if the three following conditions are fulfilled:

a) the customer does not use power factor correction capacitors and/or harmonic filters;

b) the following ratio is satisfied:

$$\frac{S_i}{S_{sc}} \leq 1\% \tag{5}$$

c) for each individual harmonic order, the harmonic current emission is smaller than conservative limits defined by the network operator or owner according to the network characteristics:

$$\frac{I_{hi}}{I_i} \leq E_{Ih} \tag{6}$$

where

- S_i is the agreed apparent power of customer's installation i;
- S_{sc} is the short-circuit power at the point of evaluation;
- I_{hi} is the harmonic current of order h caused by the distorting installation i;
- I_i is the r.m.s. current (fundamental frequency) corresponding to the agreed power of customer's installation i (S_i / $U_N\sqrt{3}$, where U_N is the nominal phase-to-phase voltage of the LV system);
- E_{Ih} is the harmonic current emission limit of order h defined by the network operator or owner from conservative network characteristics for the assessment of installations at stage 1.

8.2 Stage 2: emission limits relative to actual system characteristics

8.2.1 General

Considering the actual absorption capacity of the system, due to the transfer factor between the upstream MV system and the considered LV system and the phase differences of the harmonic currents as well as the system impedance and future load, higher emissions than those according to stage 1 criteria may be granted.

In order to define harmonic current emission limits at stage 2 for the installations covered in this report (called "large installations" below), it is necessary to consider that most of the installations connected to LV public systems are small installations for which only equipment standards apply (called "small installations" below). Moreover, the proportion of small and large installations (in terms of power) is generally not known in advance and highly depends on the LV system considered.

Thus, the method proposed in this report for large LV installations takes into account the current emission from individual pieces of equipment. It is assumed here that the current limits for equipment have been defined in such a way that, if the LV system is utilized at its full designed capacity by such equipment, the overall levels of voltage disturbance will not exceed the planning levels. Given these, the procedure to set current emission limits for large LV installations in stage 2 is as follows:

- the allowable global contribution of all large and small installations connected to a given LV system to the overall level of voltage disturbance in this LV system is first determined;
- then, the contribution from an individual large LV installation is established in such a way that the overall level of voltage disturbance in the LV system is lower than or equal to the level obtained when this large installation is replaced by a group of small installations having the same total power.

This allows that the disturbance level due to the emissions of all harmonic sources connected to the system will not exceed the planning level.

8.2.2 Global emission to be shared between the customers

The aim is to set harmonic current emission limits for large LV installations (see Clause 1). As a first step, it is necessary to determine the acceptable global contribution to voltage distortion caused by the LV system under consideration.

Firstly, an application of the general summation law (Equation 3) is necessary to determine the maximum acceptable global contribution of all harmonic sources present in a particular LV system. Indeed, for each harmonic order, the actual harmonic voltage in an LV system results from the vectorial combination of the harmonic voltage propagating from the MV upstream system and of the harmonic voltage resulting from all distorting sources connected to the considered LV system. This total harmonic voltage should not exceed the planning level of the LV system. Thus the global level of harmonic voltage that can be allocated to all the installations connected to the considered LV system is given by (for more information, see Clause C.3):

$$G_{hLV} = \sqrt[\alpha]{L_{hLV}^{\alpha} - \left(T_{hML} \cdot L_{hMV}\right)^{\alpha}} \qquad (7)$$

where

- G_{hLV} is the maximum acceptable global contribution to the hth harmonic voltage anywhere in the LV system due to all LV installations that can be supplied from the considered system (expressed in percent of the fundamental voltage);
- L_{hLV} is the planning level of the hth harmonic in the LV system;
- L_{hMV} is the planning level of the hth harmonic in the upstream MV system;
- T_{hML} is the transfer coefficient of harmonic voltage distortion from the upstream MV system to the LV system under consideration at harmonic order h (if necessary, it could be determined by simulation or measurements);
- α is the summation law exponent (Table 3).

NOTE For simplicity, the transfer factor used in this equation is considered as a single value at each harmonic order.

For a simplified evaluation, the transfer coefficients T_{hML} from the MV system on an LV system can be taken as equal to 1. In practice, however, it may be less than 1 for high harmonic orders, due to the damping effect of LV loads, or higher than 1 (typically between 1 and 3) in low load condition, if resonance exists. It is the responsibility of the system operator or owner to determine the relevant values depending on the system characteristics.

8.2.3 Individual emission limits

Consider a typical LV system as illustrated on Figure 4. An MV/LV transformer supplies n feeders through an LV busbar. The aim is to define the emission limits for customer's installation i connected to one of the feeders.

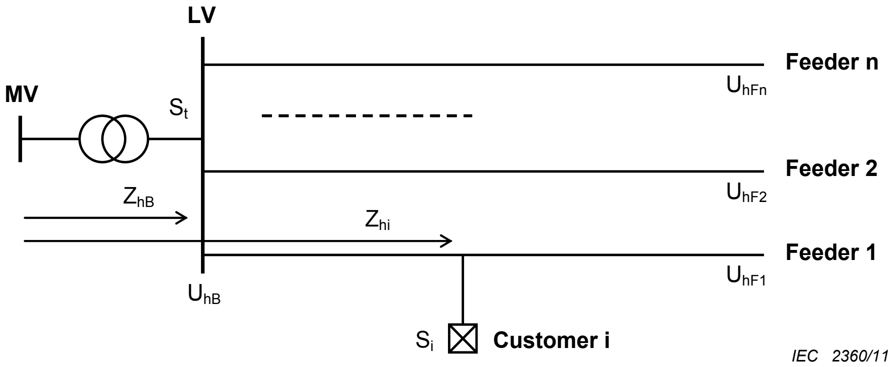


Figure 4 – Simplified scheme of an LV public system for harmonics

The proposed method to define harmonic emission limits for the large installations connected to LV public systems is described in detail in Annex C. From Figure 4, it can be shown that the considered installation (i) directly impacts the harmonic voltage on feeder 1 and also on the other feeders through the harmonic voltage it causes at the LV busbar. Thus, both of the following conditions need to be satisfied.

- The global contribution of the LV distorting installations to the harmonic voltage anywhere in the LV system is to be limited to the acceptable global contribution given by G_{hLV}.
- The global contribution of the LV distorting installations to the harmonic voltage at the LV busbar is to be limited to a portion of the acceptable global contribution G_{hB}, which relates to G_{hLV} as follows:

$$G_{hB} = K_{hB} \cdot G_{hLV} \tag{8}$$

where

- G_{hB} is the acceptable global contribution to the hth harmonic voltage at the substation LV busbar due to all LV installations that can be supplied from the considered system (expressed in percent of the fundamental voltage);
- K_{hB} is the reduction factor at harmonic order h, which corresponds to the ratio of the harmonic voltage level at the LV busbar due to all the installations connected to the considered LV system to the maximum value of the harmonic voltage level on the LV system due to these installations (this maximum level is generally reached at the far end of one of the feeders). This reduction factor does not depend on harmonic emission levels, but only on the structure of the LV system (number and length of the feeders, distribution of customers' installations, etc) and the exponent α used for the summation law. Information on the determination of K_{hB} as a function of the characteristics of the LV system is given in Annex D, as well as a simplified table giving a few typical values of K_{hB} for LV systems.

In other respects, the emission limits for equipment (see IEC 61000-3-2 and IEC 61000-3-12) are defined as current limits independently of the point where the customer is connected to the LV network. Thus, harmonic current emissions from small LV installations not subject to this report only depend on the total power of those installations. To keep in line with the same approach, emission limits for larger LV installations will also be expressed in terms of harmonic current while considering their impact in terms of the highest harmonic voltage they might cause anywhere in the LV system.

NOTE 1 Although the approach proposed hereafter for LV installations is based on emission limits being defined in terms of current instead of voltage, it remains consistent with the basic concepts given in IEC/TR 61000-3-6 as these current emission limits are based on the effect that they will have on the voltage.

Given the above considerations and those in Annex C, the harmonic emission limits for a large LV installation (i) expressed in terms of current is given by:

$$E_{Ihi} = \frac{U_N^2}{S_i} \cdot G_{hLV} \cdot \sqrt[\alpha]{\frac{S_i}{S_t}} \cdot \min\left(\frac{K_{hB}}{Z_{hB}} ; \frac{1}{Z_{hi}}\right) \tag{9}$$

where

- E_{Ihi} is the harmonic current emission limit of order h for the installation (i) connected at LV (%: expressed in percent of the installation current corresponding to its agreed power, S_i / $U_N\sqrt{3}$);
- U_N is the nominal phase-to-phase voltage of the LV system (V);
- G_{hLV} is the maximum acceptable global contribution to the hth harmonic voltage anywhere in the LV system due to all LV installations that can be supplied from the considered system (%: expressed in percent of the fundamental voltage);
- S_i is the agreed apparent power of customer's installation (i) (VA);
- S_t is the total supply capacity of the considered LV system including provision for future load growth. S_t might also include the contribution from dispersed generation (VA);

NOTE 2 In selecting S_t, the system operator or owner should consider the potential amount of dispersed generation that may be connected to the network. For example, if a 50 % penetration of dispersed generation is expected in relation to the load power (i.e. the rated power of the MV/LV transformer), S_t should be 1,5 times the rated power of the MV/LV transformer. It should be noted that, in the case of LV networks, 100 % penetration is in practice the maximum penetration given the large variations in loads in a day.

- α is the summation law exponent (Table 3);
- min (x, y) represents the minimum value of x and y;

NOTE 3 The minimum value should be taken in order to meet both conditions listed in the beginning of this clause. The first term K_{hB}/Z_{hB} is related to the condition on the harmonic voltage at the LV busbar. The second term $1/Z_{hi}$ is related to the condition on the harmonic voltage anywhere in the LV system. Also see C.4 and C.8.

- K_{hB} is the reduction factor at harmonic order h, as defined in Equation (8);
- Z_{hB} is the modulus of the harmonic impedance of the system at the LV substation busbar (Ω);
- Z_{hi} is the modulus of the harmonic impedance of the system at the point of evaluation of the installation (i) (Ω).

It may happen at some locations that the pre-existing level of harmonic voltages is higher than the normal share for the existing installations. In this case, the emission limits 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 harmonic absorption capacity could be increased.

NOTE 4 The evaluation can be made at the PCC or at the POC. However it should be noted that there might be an increase of the harmonic level between PCC and POC, especially if there is a dedicated feeder for some large installations. In that case, compatibility will be achieved on the supply system, but might not be in the customer's installation. It should also be remembered that as voltage characteristics or contracted limits apply at the point of connection, these effects should be taken into consideration in discussions between the parties.

The harmonic emission limits given by (9) depend on the reduction factors K_{hB}. In some LV systems, typical values of K_{hB} may lead to too relaxed harmonic limits. In these cases, the values of K_{hB} should be determined on the basis of the actual characteristics of the LV system. Annex D discusses a method for estimating K_{hB}.

The above approach does not take into account resonance at the LV level. For cases where resonance might occur, advanced methods possibly combining simulations would be needed for consideration in stage 3.

8.2.4 Alternative methods for stage 2

A large variety of LV systems exists worldwide, so the simplified method given above for stage 2 might be too conservative in some cases. In a given region or country, the types of LV systems are generally far less various. Therefore, it is recognized that other methods for allocating stage 2 limits might be in use in some regions or countries worldwide, and those methods may be more adapted to specific LV systems characteristics.

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

The general considerations presented in 4.3 apply to stage 3 for harmonics.

A general method which can apply to stage 3 is also described in Annex E.

8.4 Emission limits for interharmonics

With respect to the effects listed in 4.2.3, a conservative planning level for interharmonics can be set to 0,2 %.

NOTE Experience shows that higher planning levels may be accepted in some cases, for example when there is no ripple control system.

Interharmonic voltages can be added arithmetically only if frequencies and phases are equal. These conditions are met infrequently and for short periods of time. For that reason, in practice, not more than double the value of the highest interharmonic voltage can arise.

If the interharmonic voltage from a large LV installation is below 0,1 %, no disturbance will be considered.

If higher values are permitted, the interharmonic frequencies should not exceed the flicker criteria, and should not exist in an area where ripple control frequencies (and their side-band frequencies with a distance of twice the fundamental; see 4.2.3) are used.

9 Voltage fluctuation emission limits for installations in LV systems

9.1 Stage 1: simplified evaluation of disturbance emission

For small installations, such as for example residential dwellings, the system operator or owner can generally rely on voltage fluctuation emission limits for individual pieces of equipment to comply with the planning levels. For instance, IEC 61000-3-3 and IEC 61000-3-11 are product family standards that define voltage fluctuation emission limits for equipment connected to public LV systems.

The installation may be connected to the supply system without further examination if all pieces of equipment in the installation comply with the relevant emission limits defined in IEC 61000-3-3 and IEC 61000-3-11, and if the following condition is fulfilled:

$$S_i < S_{min} \tag{10}$$

where

- S_i is the agreed power of customer's installation i;
- S_{min} is the minimum value of the agreed power of LV installations to which the procedure to define emission limits developed in this report applies.

The minimum value of agreed power (S_{min}) for the application of this report is to be specified by the system operator or owner depending on their system characteristics.

NOTE 1 In order to take into account the specificities of each type of disturbance, different minimum values of the agreed power (S_{min}) may be specified for harmonics, voltage fluctuations and unbalance.

On the contrary, for larger installations ($S_i \geq S_{min}$), more care has to be taken by the system operator or owner to make sure that planning levels are not exceeded.

In that case, the connection of a fluctuating installation can be accepted in stage 1 without further analysis if both following conditions are fulfilled:

a) all pieces of equipment in the installation comply with the relevant emission limits defined in IEC 61000-3-3 and IEC 61000-3-11;

b) the percentages of apparent power variations ΔS with respect to the system short-circuit power S_{SC} are within the limits given in Table 4 at the POE. These limits depend on the number r of voltage changes per minute (a voltage drop followed by a recovery means two voltage changes).

Table 4 – Stage 1 limits for the relative power variations as a function of the number of voltage changes per minute

r min^{-1}	$K=(\Delta S/S_{sc})_{max}$ %
$r > 200$	0,1
$10 \le r \le 200$	0,2
$r < 10$	0,4

NOTE 2 The apparent power variations ΔS may be lower, equal or higher than the agreed power S_i of the considered installation (e.g. for a motor within the installation, account should be taken of its apparent power at starting and it may that $\Delta S \approx 3\text{-}8\ S_N$, where S_N is the rated power of the motor).

9.2 Stage 2: emission limits relative to actual system characteristics

9.2.1 General

Considering the actual absorption capacity of the system, higher emissions than those based on the stage 1 criteria 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 should generally ensure that the disturbance level due to the emissions of all customers' installations connected to the system will not exceed the planning level.

NOTE The limits defined in product family standards IEC 61000-3-3 and IEC 61000-3-11 aim to limit the Pst to 1,0 with a system impedance equal to the reference impedance or the maximum permissible system impedance declared by the manufacturer. In general, the pieces of equipment are connected at locations with lower values of the system impedance, so that the planning levels are not exceeded. However, when one or several pieces of equipment complying with IEC 61000-3-11 are present in the neighbourhood, it may happen that the pre-existing flicker level is higher than the normal share for existing installations. In this case, the emission limits for new installations could be reduced or the system flicker absorption capacity could be increased.

9.2.2 Global emission to be shared between the customers' installations

The aim is to set emission limits at LV. As a first step, it is necessary to determine the acceptable global contribution to flicker level caused by the LV system under consideration (G_{PstLV} or G_{PltLV}).

Firstly an application of the general summation law (Equation 3) is necessary to determine the acceptable global contribution of all flicker sources present in a particular LV system. Indeed, the actual flicker level in a LV system results from the combination of the flicker level coming from the MV upstream system with the flicker level produced by all fluctuating sources connected to the considered LV system. This total flicker level should not exceed the planning level of the LV system. Thus the global contribution to flicker level that can be allocated to the total of the installations connected to the considered LV system is given by:

$$G_{PstLV} = \sqrt[\alpha]{L_{PstLV}^{\alpha} - T_{PstML}^{\alpha} \cdot L_{PstMV}^{\alpha}} \qquad (11)$$

$$G_{PltLV} = \sqrt[\alpha]{L_{PltLV}^{\alpha} - T_{PltML}^{\alpha} \cdot L_{PltMV}^{\alpha}} \qquad (12)$$

where

- G_{PstLV} is the maximum acceptable global contribution to the flicker level anywhere in the LV system due to all LV installations that can be supplied from the considered system (expressed in terms of P_{st} or P_{lt});
- L_{PstLV} is the planning level for flicker (indices P_{st} or P_{lt}) in the LV system;

- L_{PstMV} is the planning level for flicker (indices P_{st} or P_{lt}) in the upstream MV system;
- T_{PstML} is the transfer coefficient of flicker (indices P_{st} or P_{lt}) from the upstream MV system to the LV system (this coefficient is generally very close to unity, see IEC/TR 61000-3-7);
- α is the summation law exponent (recall that a value α=3 is generally used).

9.2.3 Individual emission limits

For each customer's installation, only a fraction of the global emission limits G_{PstLV} and G_{PltLV} will be allowed. A reasonable approach is to take the ratio between the agreed power S_i and the total supply capability S_t of the LV system. Such a criterion is related to 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.

Using the recommended summation law (Equation 3), the individual emission limits (E_{Psti} and E_{Plti}) are then given by (13) and (14) where α = 3 is generally used:

$$E_{Psti} = G_{PstLV} \cdot \sqrt[\alpha]{\frac{S_i}{S_t}} \tag{13}$$

$$E_{Plti} = G_{PltLV} \cdot \sqrt[\alpha]{\frac{S_i}{S_t}} \tag{14}$$

where

- E_{Psti} is the allowed flicker emission limit (indices P_{st} or P_{lt}) for the customer's installation i directly supplied at LV;
- G_{PstLV} is the maximum acceptable global contribution to the flicker level anywhere in the LV system due to all LV installations that can be supplied from the considered system (expressed in terms of P_{st} or P_{lt});
- S_i is the agreed apparent power of customer's installation i (VA);
- S_t is the total supply capacity of the considered LV system including provision for future load growth. S_t might also include the contribution from dispersed generation (VA).

NOTE 1 In selecting S_t, the system operator or owner should consider the potential amount of dispersed generation that may be connected to the network. For example, if a 50 % penetration of dispersed generation is expected in relation to the load power (i.e. the rated power of the MV/LV transformer), S_t should be 1,5 times the rated power of the MV/LV transformer. It should be noted that, in the case of LV networks, 100 % penetration is in practice the maximum penetration given the large variations in loads in a day.

For customers having a low agreed power, this approach may yield impractically low limitations. Emission limits shall then be set at values given in Table 5.

Table 5 – Minimum emission limits at LV

E_{Psti}	E_{Plti}
0,30	0,25

It may happen at some locations that the pre-existing flicker level is higher than the normal share for existing installations. In particular, this may occur when one or several pieces of equipment complying with IEC 61000-3-11 are present in the neighbourhood. In this case, the emission limits for new installations could be reduced or the system flicker absorption capacity could be increased.

NOTE 2 For voltage fluctuations, reduction factors are not necessary because emission limits are defined in terms of voltage disturbance for large installations and for pieces of equipment. However, based on practical assumptions made long ago, the present limits for equipment given in IEC 61000-3-3 and IEC 61000-3-11 may lead to the compatibility level to be exceeded, because the contribution of each piece of equipment to the Pst level is limited to 1,0.

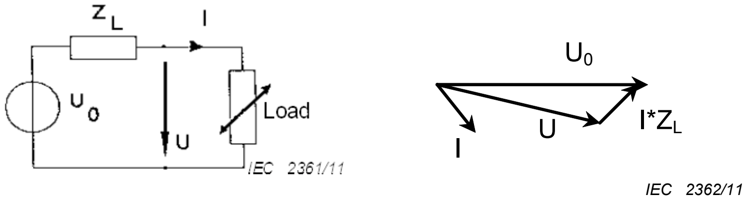
9.3 Stage 3: acceptance of higher emission levels on a conditional basis

The general considerations presented in 4.3 apply to stage 3 for voltage fluctuations.

9.4 Rapid voltage changes

9.4.1 General considerations

The visual discomfort due to light flicker is the most frequent reason to limit voltage changes due to fluctuating installations. However, system operators or owners have to maintain the voltage magnitude within narrow limits and individual customers' installations should not produce significant voltage variations even if they are tolerable from the flicker point of view. In the context of this report, rapid voltage changes are considered to be changes in fundamental frequency r.m.s. voltages over several cycles.



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IEC 2362/11

Figure 5a – Equivalent circuit **Figure 5b – Vector diagram**

Figure 5 – Equivalent circuit and vector diagram for simple assessments

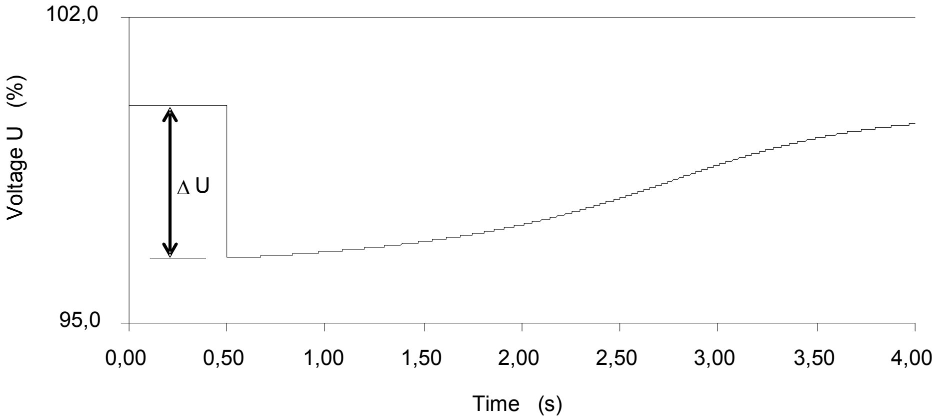

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Figure 6 – Example of rapid voltage change associated with motor starting

A simple assessment of the relative voltage change may be done as follows (see Figure 5 and Figure 6).

$$\underline{I} = I_p - jI_q \tag{15}$$

$$\underline{\underline{Z}}_L = R_L + jX_L \tag{16}$$

For single-phase and symmetrical three-phase installations:

$$\Delta U \approx \Delta I_p \cdot R_L + \Delta I_q \cdot X_L \tag{17}$$

9.4.2 Emission limits

The coordination approach recommended in this report relies on individual emission levels being derived from the planning levels so that overall EMC is maintained. Because the indicative planning levels are defined in terms of numbers of occurrences of a specific rapid voltage change permitted during a specific interval, emission limits for individual installations must be defined by the system operator or owner on a case by case basis taking into account the particular operation and impact of each installation that may cause rapid voltage changes in the system of interest. The combined effect of all installations should not result in rapid voltage changes exceeding the planning levels set by the system operator or owner.

10 Unbalance emission limits for unbalanced installations in LV systems

10.1 General

The emission limits defined in this clause only apply to three-phase installations. As the system operator or owner is responsible for the connection of all installations to LV public systems, it is his responsibility to manage with unbalance produced by single-phase installations.

NOTE The coordination approach given in this clause might also be used by the system operator or owner to manage the connection of single-phase installations to the LV power system.

10.2 Stage 1: simplified evaluation of disturbance emission

In stage 1, the connection of small customers' installations or customers' installations with only a limited amount of unbalanced load can be accepted without detailed evaluation of the emission characteristics or the supply system response.

The installation may be connected to the supply system without further examination if the following condition is fulfilled:

$$S_i < S_{min} \tag{18}$$

where

- S_i is the agreed power of customer's installation i;
- S_{min} is the minimum value of the agreed power of LV installations to which the procedure to define emission limits developed in this report applies.

The minimum value of agreed power (S_{min}) for the application of this report is to be specified by the system operator or owner depending on their system characteristics.

NOTE In order to take into account the specificities of each type of disturbance, different minimum values of the agreed power (S_{min}) may be specified for harmonics, voltage fluctuations and unbalance.

For larger installations ($S_i \geq S_{min}$), the connection of an unbalanced installation can be accepted in stage 1 without further examination if the following criterion is fulfilled:

$$\frac{S_{ui}}{S_{sc}} \leq 0{,}2\% \tag{19}$$

where

- S_{ui} is the single phase power equivalent of the load unbalance of installation i;
- S_{sc} is the short-circuit power at the point of evaluation.

10.3 Stage 2: emission limits relative to actual system characteristics

10.3.1 General

Considering the actual absorption capacity of the system, due to the simultaneity 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.

Most of the installations connected to LV public systems are small installations which are not subject to the application of the emission limits defined in this report. Moreover, the proportion of the installations subject to the application of this report is generally not known in advance and highly depends on the LV system considered. To define the unbalance emission limits for installations subject to stage 2 (called "large installations" below), it is thus necessary to take into account the unbalance emissions produced by all other unbalance sources in LV public systems. It is supposed here that, if the LV system is utilized at its full designed capacity by installations not subject to the application of this report (called "small installations" below), the overall level of unbalance will not exceed the planning level. Given these, the procedure to set emission limits for large LV installations at stage 2 is as follows:

- the allowable global contribution of all large and small installations connected to a given LV system to the overall level of unbalance in this LV system is first determined;
- then, the contribution from an individual large LV installation is established in such a way that the overall level of unbalance in the LV system is lower than or equal to the one obtained when this large installation is replaced by a group of small installations having the same total power.

This allows that the disturbance level due to the emissions of all unbalance sources connected to the system will not exceed the planning level.

10.3.2 Global emission to be shared between the sources of unbalance

The aim is to set unbalance emission limits for large LV installations (see Clause 1). As a first step, it is necessary to determine the acceptable global contribution to voltage unbalance caused by the LV system under consideration.

Firstly an application of the summation law (Equation 3) is necessary to determine the maximum acceptable global contribution of all unbalance sources present in a particular LV system. Indeed, the actual voltage unbalance in an LV system results from the vectorial combination of the voltage unbalance coming from the MV upstream system and of the voltage unbalance resulting from all unbalanced installations connected to the considered LV system. This total voltage unbalance should not exceed the planning level of the LV system. Thus the global level of voltage unbalance that can be allocated to the total of the installations connected to the considered LV system is given by:

$$G_{uLV} = \sqrt[\alpha]{L_{uLV}^{\alpha} - \left(T_{uML} \cdot L_{uMV}\right)^{\alpha}} \qquad (20)$$

where

- G_{uLV} is the maximum acceptable global contribution to the voltage unbalance anywhere in the LV system due to all LV installations that can be supplied from the considered system (expressed in terms of the voltage unbalance factor u);
- L_{uLV} is the planning level for voltage unbalance in the LV system;
- L_{uMV} is the planning level for voltage unbalance in the upstream MV system;

- T_{uML} is the transfer coefficient of voltage unbalance from the upstream MV system to the LV system under consideration (if necessary, it could be determined by simulation or measurements);
- α is the summation law exponent (see 7.4).

NOTE The voltage unbalance resulting from LV line impedance asymmetries is generally negligible compared to the voltage unbalance due to LV unbalanced loads. For simplicity, line impedance asymmetries are not considered at LV in the rest of this report. In some cases however the voltage unbalance due to LV lines might not be negligible (e.g. open-wire overhead LV lines carrying high currents for one hundred meters or more).

For an initial simplified evaluation, the transfer coefficient T_{uML} from the upstream MV system on an LV 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_{uML} are provided in IEC/TR 61000-3-13, Annex A.).

10.3.3 Individual emission limits

Consider a typical LV system as illustrated on Figure 7. An MV/LV transformer supplies n feeders through an LV busbar. The aim is to define the emission limit for customer's installation i connected to one of the feeders.

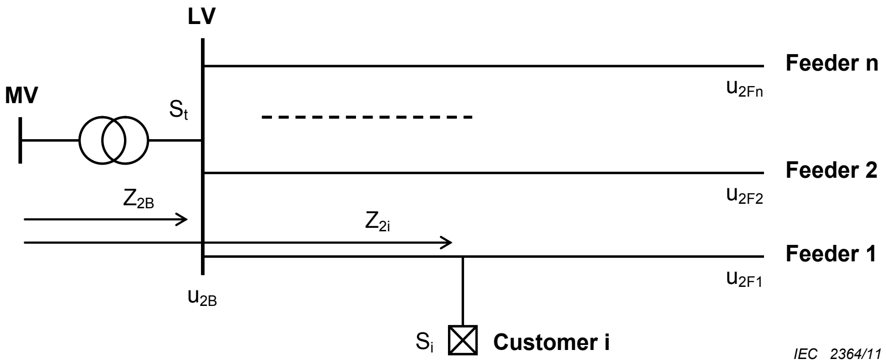


Figure 7 – Simplified scheme of an LV public system for unbalance

Single-phase installations produce unbalance currents proportional to their agreed power. Similarly, small three-phase LV installations not subject to the application of this report can produce unbalance currents that only depend on their agreed power. Consequently, these installations produce unbalance in terms of currents irrespective of their point of connection in the LV system. To take this into account, emission limits for larger LV installations will also be expressed in terms of current unbalance while considering their impact in terms of the highest voltage unbalance they might cause anywhere in the LV system.

NOTE 1 Although the approach proposed hereafter for LV installations is based on emission limits being defined in terms of current instead of voltage, it remains consistent with the basic concepts given in IEC/TR 61000-3-13 as these current emission limits are based on the effect that they will have on the voltage.

The proposed method to define unbalance emission limits for the large installations connected to LV public systems is similar to that for harmonics (see 8.2.3). From Figure 7, it can be shown that the considered installation (i) directly impacts the voltage unbalance on feeder 1 and also on the other feeders through the voltage unbalance it causes at the LV busbar. Thus, both of the following conditions need to be satisfied.

- The global contribution of the LV unbalanced installations to the voltage unbalance anywhere in the LV system is to be limited to the acceptable global contribution given by G_{uLV}.

- The global contribution of the LV unbalanced installations to the voltage unbalance at the LV busbar is to be limited to a portion of the acceptable global contribution G_{uB}, which relates to G_{uLV} as follows:

$$G_{uB} = K_{uB} \cdot G_{uLV} \tag{21}$$

where

- G_{uB} is the acceptable global contribution to the voltage unbalance at the substation LV busbar due to all LV installations that can be supplied from the considered system (expressed in terms of the voltage unbalance factor u);
- K_{uB} is the reduction factor for voltage unbalance, which corresponds to the ratio of the level of voltage unbalance at the LV busbar due to all the installations connected to the considered LV system to the maximum level of voltage unbalance on the LV system due to these installations (this maximum level is generally reached at the far end of one of the feeders). This reduction factor does not depend on unbalance emission levels, but only on the structure of the LV system (number and length of the feeders, distribution of customers' installations, etc) and the exponent α used for the summation law. Information on the determination of K_{uB} as a function of the characteristics of the LV system is given in Annex D, as well as a typical value of K_{uB} for LV systems.

Given the above considerations, the unbalance emission limits for a large LV installation (i) expressed in terms of current is given by

$$E_{I2\,i} = \frac{U_N^2}{S_i} \cdot G_{uLV} \cdot \sqrt[\alpha]{\frac{S_i}{S_t}} \cdot \min\left(\frac{K_{uB}}{Z_B} ; \frac{1}{Z_i}\right) \tag{22}$$

where

- $E_{I2\ i}$ is the current unbalance emission limit for the installation (i) connected at LV (%: expressed in percent of the installation current corresponding to its agreed power, S_i / $U_N\sqrt{3}$);
- U_N is the nominal phase-to-phase voltage of the LV system (V);
- G_{uLV} is the maximum acceptable global contribution to the voltage unbalance anywhere in the LV system due to all LV installations that can be supplied from the considered system (expressed in terms of the voltage unbalance factor u);
- S_i is the agreed apparent power of customer's installation (i) (VA);
- S_t is the total supply capacity of the considered LV system including provision for future load growth. S_t might also include the contribution from dispersed generation (VA);

NOTE 2 In selecting S_t, the system operator or owner should consider the potential amount of dispersed generation that may be connected to the network. For example, if a 50 % penetration of dispersed generation is expected in relation to the load power (i.e. the rated power of the MV/LV transformer), S_t should be 1,5 times the rated power of the MV/LV transformer. It should be noted that, in the case of LV networks, 100 % penetration is in practice the maximum penetration given the large variations in loads in a day.

- α is the summation law exponent (7.4);
- min (x, y) represents the minimum value of x and y;

NOTE 3 The minimum value should be taken in order to meet both conditions listed in the beginning of this clause. The first term K_{uB}/Z_B is related to the condition on the voltage unbalance at the LV busbar. The second term $1/Z_i$ is related to the condition on the voltage unbalance anywhere in the LV system.

- K_{uB} is the reduction factor for voltage unbalance, as defined in Equation (21);
- Z_B is the modulus of the short-circuit impedance of the system at the LV substation busbar (Ω);

- Z_i is the modulus of the short-circuit impedance of the system at the point of evaluation of installation (i) (Ω).

It may happen at some locations that the pre-existing level of voltage unbalance is higher than the normal share for the existing customers' installations. In this case, the emission limits 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 unbalance absorption capacity could be increased.

The unbalance emission limit given by Equation (22) depends on the reduction factor K_{uB}. In some LV systems, the typical value of K_{uB} may lead to too high unbalance limits. In these cases, the value of K_{uB} should be determined on the basis of the actual characteristics of the LV system. Annex D discusses a method for estimating this reduction factor.

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

The general considerations presented in 4.3 apply to stage 3 for unbalance.

11 Summary diagrams of the evaluation procedure

An overview of the evaluation procedure presented in this report is given in Figure 8 for harmonics, in Figure 9 for voltage fluctuations and in Figure 10 for unbalance. For voltage fluctuations, the evaluation procedure is equally applicable to P_{st} and P_{lt}.

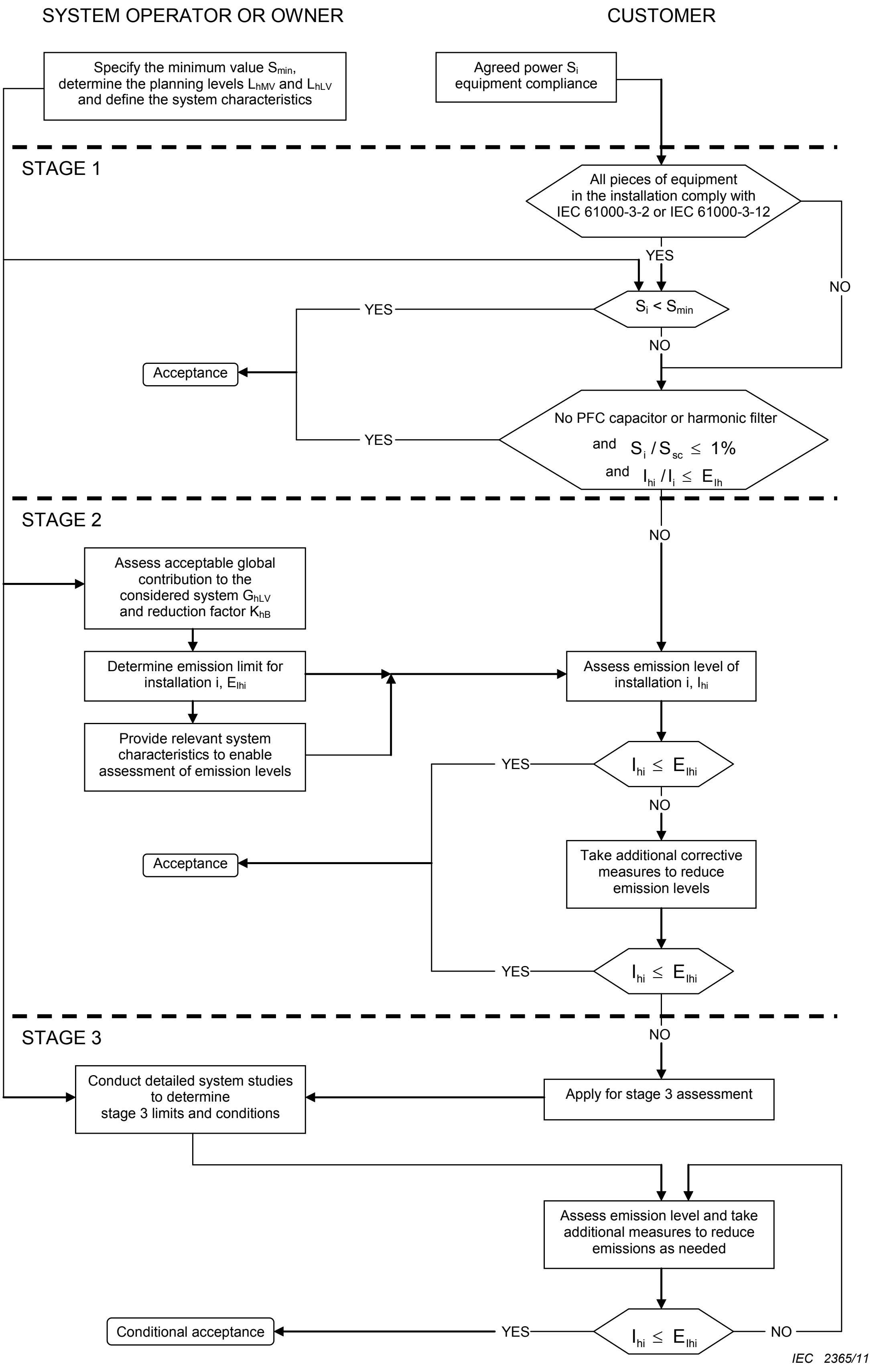


Figure 8 – Diagram of evaluation procedure for harmonics

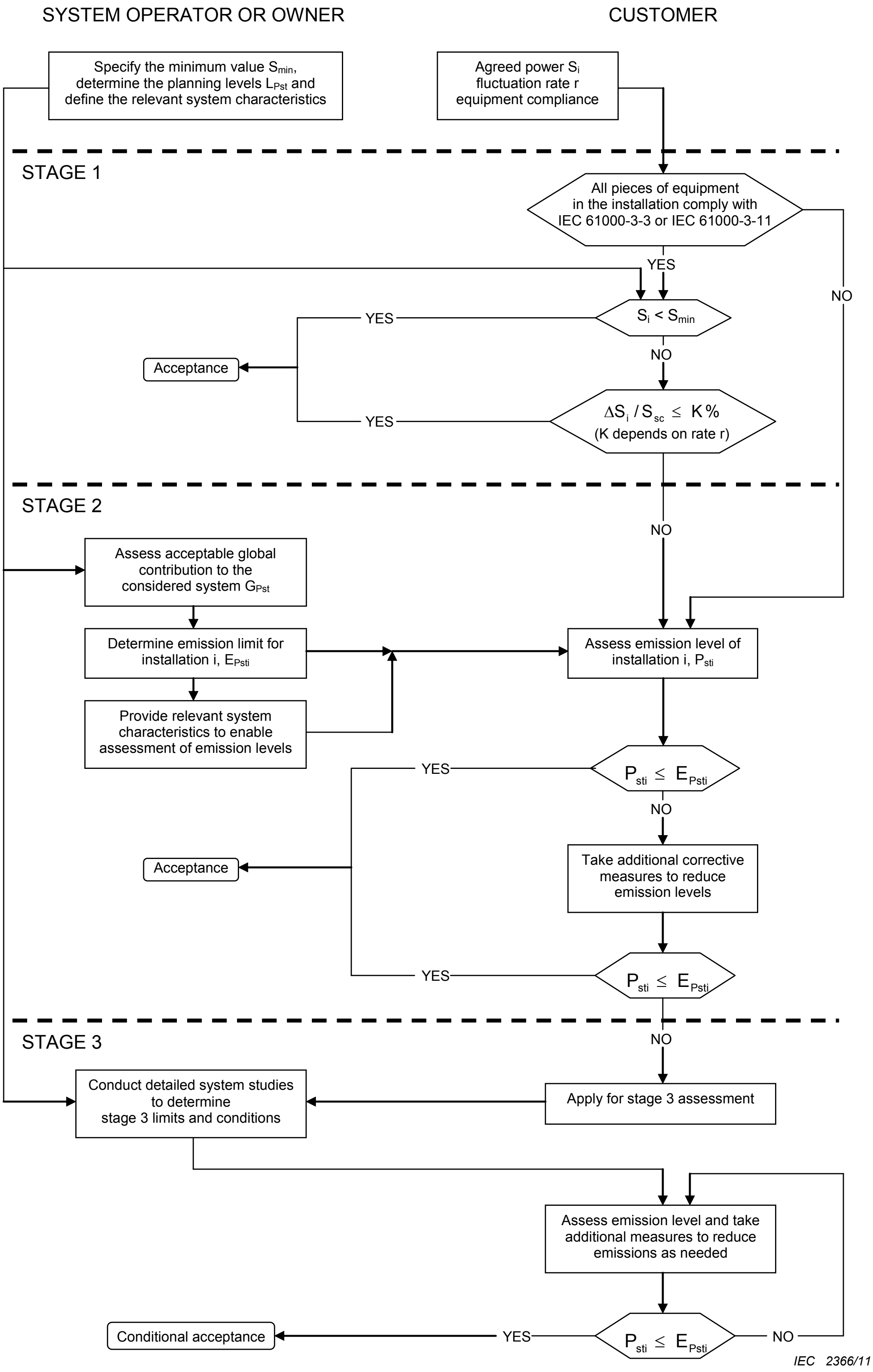


Figure 9 – Diagram of evaluation procedure for voltage fluctuations

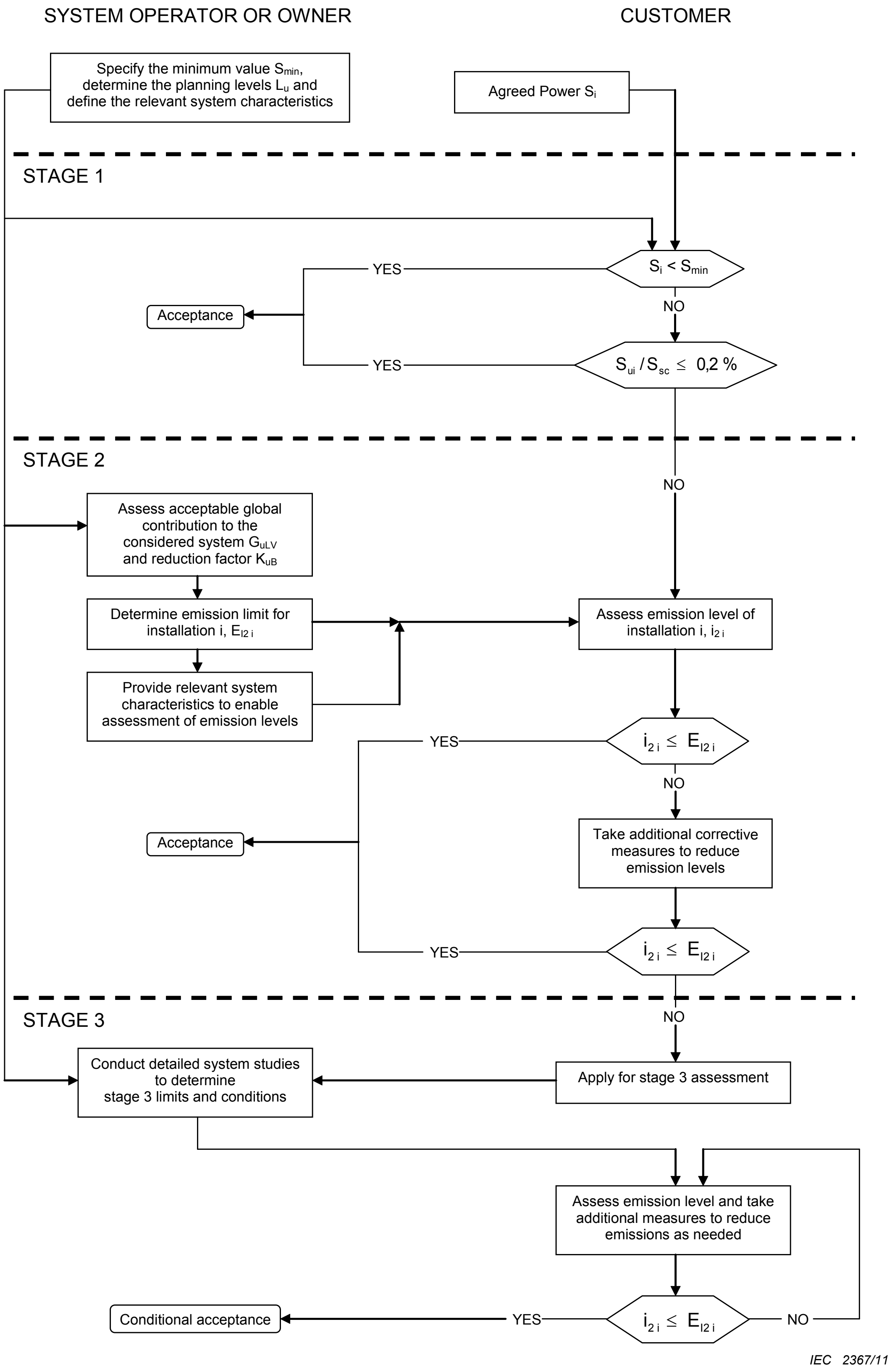


Figure 10 – Diagram of evaluation procedure for unbalance

Annex A
(informative)

Example of application of the general method for the derivation of limits for a specific type of LV networks

A.1 Overview

The general method described in this report can be applied in two steps:

a) the calculation of global parameters related to a type of LV network;
b) the calculation of individual parameters and emission limits for a given installation.

The first step should be done by a technical expert in a distribution network utility or a regulatory body. The second step should be done by a local operator of the distribution network, possibly with the help of calculation tools designed by a technical expert.

This annex gives a practical example of technical application for the first step. An example of application for the second step is described in Annex B.

A.2 Determination of S_{min}

This report only applies to large installations exceeding a minimum size. This minimum size (S_{min}) is to be specified by the system operator or owner depending on

- the total number of the installations exceeding S_{min},
- the potential impact of an installation with an agreed power equal to S_{min} on the distribution system.

On the one hand, the total number of the installations of which the agreed power exceeds a given value S dramatically decreases when S increases. In order to limit the number of installations to assess, it is in the interest of the system operator or owner to choose a value of S_{min} as high as possible.

On the other hand, for installations with an agreed power less than S_{min}, only equipment standards apply. The limits specified in these standards have been determined based on assumptions of the number, type and usage of equipment producing disturbances in a small installation connected to a supply system and based on the reference impedance given in IEC 60725 considered to be representative of the source impedance for small residential installations. The assumptions may not apply to larger LV installations. In particular, there may be higher concentrations of disturbing equipment in that case. Thus the system operator or owner should assess the potential impact of such installations on the distribution system and determine a value of S_{min} so that installations with an agreed power less than this value do not produce unacceptable disturbance levels. The value of S_{min} depends on the characteristics of the distribution system, in particular its impedances.

So, the choice of the value of S_{min} is a compromise between both requirements: to limit the number of installations of which the emissions should be assessed, to keep acceptable levels for disturbance emissions from LV installations.

A value of S_{min} between 30 kVA and 100 kVA should suit for most types of networks.

NOTE If the value chosen for S_{min} is high, a low number of large installations may be addressed by stage 1. In that case, the network operator or owner may choose to directly assess all installations at stage 2.

A.3 Global emission to be shared between the customers

A.3.1 Harmonics

The maximum global contribution to the hth harmonic voltage that can be shared among all LV installations, G_{hLV}, is determined using Equation (7):

$$G_{hLV} = \sqrt[\alpha]{L_{hLV}^{\alpha} - \left(T_{hML} \cdot L_{hMV}\right)^{\alpha}}$$

Assuming that

- the harmonic voltage planning levels for LV, specified by the system operator or owner, are equal to the compatibility levels given in Table 1,
- the harmonic voltage planning levels for MV, specified by the system operator or owner, are equal to the values given in IEC/TR 61000-3-6, Table 2,
- the harmonic voltage transfer coefficients from MV to LV are equal to 1,
- the summation law exponent is given in Table 3,

the values of the maximum acceptable global contribution G_{hLV} for the lower odd harmonic orders are given in the Table A.1.

Table A.1– Example of maximum acceptable global contribution to harmonic voltages

h	L_{hLV} %	L_{hMV} %	T_{hML}	α	G_{hLV} %
3	5	4	1	1	1,0
5	6	5	1	1,4	2,1
7	5	4	1	1,4	2,0
9	1,5	1,2	1	1,4	0,6
11	3,5	3	1	2	1,8
13	3	2,5	1	2	1,7

A.3.2 Voltage fluctuations

The maximum global contribution to the short-term or long-term flicker level that can be shared among all LV installations, G_{PstLV} or G_{PltLV}, is determined using Equation (11) or (12):

$$G_{PstLV} = \sqrt[\alpha]{L_{PstLV}^{\alpha} - T_{PstML}^{\alpha} \cdot L_{PstMV}^{\alpha}}$$

$$G_{PltLV} = \sqrt[\alpha]{L_{PltLV}^{\alpha} - T_{PltML}^{\alpha} \cdot L_{PltMV}^{\alpha}}$$

assuming that

- the flicker planning levels for LV, specified by the system operator or owner, are equal to the compatibility levels given in Table 2,
- the flicker planning levels for MV, specified by the system operator or owner, are equal to the values given in IEC/TR 61000-3-7, Table 2,
- the flicker transfer coefficients from MV to LV are equal to 1,

- the summation law exponent is equal to 3,

the values of the maximum acceptable global contribution to the flicker level are found as:

$$G_{PstLV} = \sqrt[3]{1{,}0^3 - 1{,}0^3 \cdot 0{,}9^3} = 0{,}65$$

$$G_{PltLV} = \sqrt[3]{0{,}8^3 - 1{,}0^3 \cdot 0{,}7^3} = 0{,}55$$

A.3.3 Unbalance

The maximum global contribution to the voltage unbalance that can be shared among all LV installations, G_{uLV}, is determined using Equation (20):

$$G_{uLV} = \sqrt[\alpha]{L_{uLV}^{\alpha} - \left(T_{uML} \cdot L_{uMV}\right)^{\alpha}}$$

assuming that

- the voltage unbalance planning level for LV, specified by the system operator or owner, is equal to the compatibility level given in 4.2.5,
- the voltage unbalance planning level for MV, specified by the system operator or owner, is equal to the values given in IEC/TR 61000-3-13, Table 2,
- the voltage unbalance transfer coefficient from MV to LV is equal to 1,
- the summation law exponent is equal to 1,4,

the value of the maximum acceptable global contribution to the voltage unbalance is found as

$$G_{uLV} = \sqrt[1{,}4]{2^{1{,}4} - \left(1{,}0 \cdot 1{,}8\right)^{1{,}4}} = 0{,}5 \,.$$

A.4 Reduction factors for harmonics and unbalance

A.4.1 General

According to Annex D, the reduction factor for harmonic order h is defined as follows:

$$K_{hB} = \frac{U_{hB}(S_t)}{\max\limits_{j}\left[U_{hFj}(S_t)\right]}$$

where

- U_{hB} (S_t) is the contribution of all the LV installations to the harmonic voltage of order h at the substation LV busbar;
- U_{hFj} (S_t) is the contribution of all the LV installations to the harmonic voltage of order h at the far end of feeder j.

The reduction factors for harmonics and unbalance have to be determined separately for each type of LV networks, mainly for networks with overhead lines and for networks with underground cables.

The method, which is used hereafter, consists of the following steps:

- the determination of the characteristics of the considered type of LV networks;

- the analysis of the influence of the networks parameters on ratio U_{hB}/U_{hFj};
- the calculation of the network voltages in various network configurations;
- the elimination of the non-realistic configurations;
- the determination of the reduction factor values.

Some information is also given on the method that can be used for the calculation of harmonic voltages (or voltage unbalance) at any node of an LV network.

Hereafter, this general method is applied in the case of LV networks with overhead lines for the calculation of the reduction factors for non-triplen harmonics.

A.4.2 Determination of the characteristics of the considered type of LV networks

First, the structure of the considered type of network has to be determined. According to Annex D, the general scheme of an LV network for the calculation of harmonic voltage levels may be described as illustrated in Figure A.1, where

- n is the number of LV feeders;
- m is the number of nodes between the LV busbar and the far end of feeder j, depending on the feeder considered (excluding the LV busbar and including the end of the feeder);
- N_{jk} is node k on feeder j;
- S_t is the total supply capacity of the considered LV system;
- S_{Fj} is the apparent power of all installations connected to feeder j;
- S_{jk} is the apparent power of all installations supplied by node N_{jk};
- h is the harmonic order;
- Z_{hB} is the modulus of the harmonic impedance of the system at the LV busbar;
- Z_{hjk} is the modulus of the harmonic impedance of the system at node N_{jk};
- I_{hT} is the harmonic current of order h flowing through the MV/LV transformer;
- I_{hjk} is the harmonic current emission from customer's installations connected to node N_{jk}
- I_{hFjk} is the harmonic current of order h flowing through feeder j just upstream node N_{jk};
- U_{hB} (S_t) is the contribution of all the LV installations to the harmonic voltage of order h at the substation LV busbar;
- U_{hFj} (S_t) is the contribution of all the LV installations to the harmonic voltage of order h at the far end of feeder j;
- U_{hjk} (S_t) is the contribution of all the LV installations to the harmonic voltage of order h at node N_{jk}.

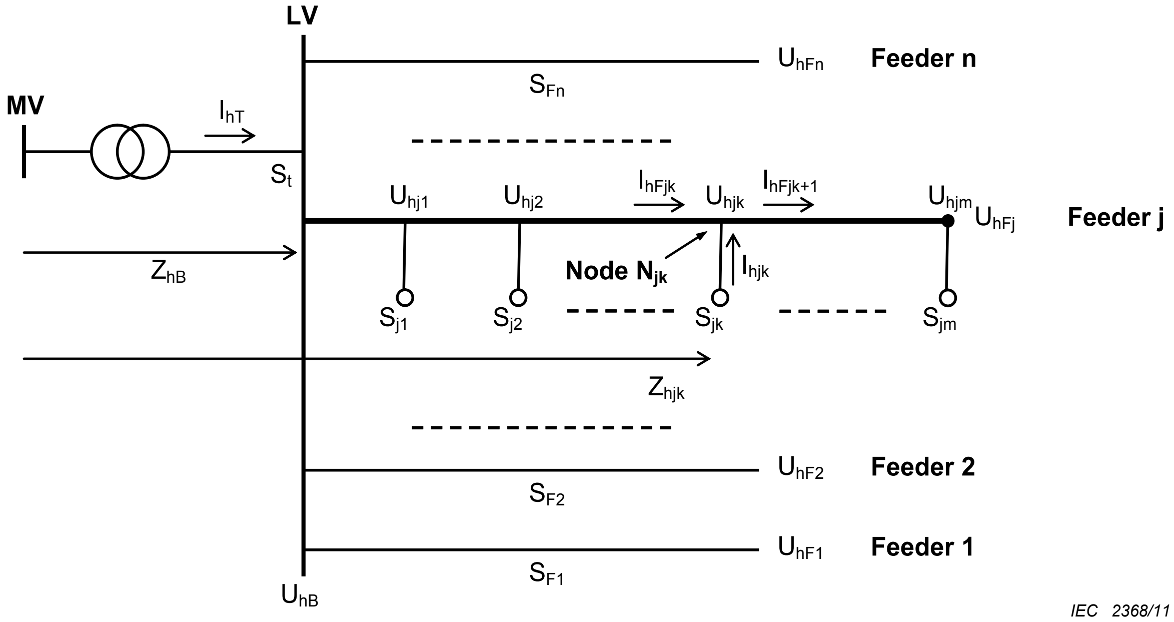


Figure A.1 – Simplified scheme of an LV public system for the calculation of harmonic voltage levels

In the example considered here, it is supposed that it is possible to adopt the following simplifications:

- the substation LV busbar supplies n identical LV feeders;
- each LV feeder is an overhead line having the same cross section over its total length without spurs;
- the customer's installations are uniformly distributed along the feeders,
- the LV system and the loads connected to it (only for the determination of the reduction factors for harmonics) are balanced.

Then, the ranges of the network parameters to be taken into account have to be determined. According to Equation (D.11), the network parameters to be considered for the calculation of the reduction factor K_{hB} are:

- S_t, the total supply capacity of the LV system;
- n, the number of LV feeders (the feeders being identical, S_{Fj} is calculated from S_t and n);
- l_F, the length of the LV feeders;
- $\underline{z}_{hF}$, the complex harmonic impedance of overhead line per unit length (the complex harmonic impedance $\underline{Z}_{hjk}$ is calculated from $\underline{Z}_{hB}$, $\underline{z}_{hF}$, l_F, m the number of nodes on each LV feeder, and k the number of node on feeder Fj);
- h, the harmonic order;
- β, the summation law exponent for small installations.

The following parameters need not be taken into account:

- m, the number of nodes on each feeder has no influence when its value is high enough (≥10);
- S_{jk}, the apparent power of all installations supplied by node N_{jk} is calculated from S_t, n and m);
- $\underline{Z}_{hB}$, the complex harmonic impedance of the system at the LV busbar mainly depends on the rated power of the MV/LV transformer supplying the LV network.

In the example considered here, it is supposed that the network parameters have the following ranges:

- S_t, from 50 kVA to 1 000 kVA;
- n, from 1 to 8 LV feeders;
- l_F, from 50 m to 1 000 m;
- $\underline{z}_F$, corresponding to a line in copper with a cross section between 12 mm^2 and 48 mm^2 or in aluminium with a cross section between 35 mm^2 and 75 mm^2;
- h, non-triplen odd orders from 5 to 37;
- β, from 1,0 to 2,0.

A.4.3 Method for the calculation of the harmonic voltages

This subclause gives the different steps to calculate the harmonic voltages at any node and the harmonic currents in any branch of the LV system described in Figure A.1 by means of a simple program.

According to Annex D, all harmonic currents and voltages due to the LV installations are proportional to a same factor (this factor is termed A_h in the theoretical development in Annex D). Thus, the calculation of harmonic quantities may be made in two stages. At the first stage, the value of one quantity is chosen and all other quantities are calculated from this value. At the second stage, the real values of harmonic currents and voltages are updated by multiplying all values obtained in the first stage by the correct factor of proportionality. This factor is worked out by choosing a constraint: the maximum value of harmonic voltages on LV feeders, the harmonic current emitted by an installation with a given apparent power, etc.

In the present case, ratios U_{hB}/U_{hjk}, which do not depend on the proportionality factor, are only needed. So, only the program used for the first stage is described in detail below.

- Step 1: Choice of the value of the harmonic voltage level at the substation LV busbar.

  The contribution of all LV installations to the harmonic voltage at the substation LV busbar is fixed at an arbitrary value, for example:

  U_{hB} (S_t) = 1 %.
- Step 2: Choice of a value for m.

  The value for m should be higher than or equal to 10. For the example described in this annex, m = 20.
- Step 3: Calculation of the modulus of harmonic impedances Z_{hB} and Z_{hjk}.

  Z_{hB} is calculated from the rated power of the MV/LV transformer.

  Z_{hjk} is calculated from the complex harmonic impedance $\underline{Z}_{hB}$, the complex harmonic impedance of the feeders per unit length $\underline{z}_{hF}$, the length of the feeders l_F, the number of nodes per feeder m and the number of node k on feeder j.
- Step 4: Calculation of the apparent power of all installations connected to feeder j.

  In general, we have:

$$S_{Fj} = \sum_{k=1}^{m} S_{jk} \tag{A.1}$$

  In the case the n LV feeders are identical, we have:

$$S_{Fj} = \frac{S_t}{n} \tag{A.2}$$

- Step 5: Calculation of the harmonic current flowing through the MV/LV transformer.

$$I_{hT} = \frac{U_{hB}(S_t)}{Z_{hB}} \tag{A.3}$$

- Step 6: Calculation of the harmonic current emission from customer's installations connected to node N_{jk}.

  From Equation (D.3), it comes:

$$\frac{I_{hjk}}{I_{hT}} = \frac{\sqrt[\beta]{S_{jk}}}{\sqrt[\beta]{S_t}} \tag{A.4}$$

So

$$I_{hjk} = I_{hT} \cdot \sqrt[\beta]{\frac{S_{jk}}{S_t}} \tag{A.5}$$

- Step 7: Calculation of the harmonic current flowing through feeder j just upstream node N_{jk}.

$$I_{hFjk} = \sqrt[\beta]{\sum_{a=k}^{m} I_{hja}^{\beta}} \tag{A.6}$$

or

$$I_{hFjk} = I_{hT} \cdot \sqrt[\beta]{\frac{\sum\limits_{a=k}^{m} S_{ja}}{S_t}} \tag{A.7}$$

- Step 8: Calculation of the contribution of all the LV installations to the harmonic voltage at first node N_{j1} of feeder j.

  From Equations (D.6) and (D.3), it comes:

$$U_{hjk}^{\beta}(S_t) = \frac{I_{hT}^{\beta}}{S_t} \cdot \left[(S_t - S_{Fj}) \cdot Z_{hB}^{\beta} + \sum_{a=1}^{k} (S_{ja} \cdot Z_{hja}^{\beta}) + Z_{hjk}^{\beta} \cdot \left(S_{Fj} - \sum_{a=1}^{k} S_{ja} \right) \right] \tag{A.8}$$

So for node N_{j1}:

$$U_{hj1}^{\beta}(S_t) = I_{hT}^{\beta} \cdot Z_{hB}^{\beta} + I_{hT}^{\beta} \cdot \frac{S_{Fj}}{S_t} \cdot \left(Z_{hj1}^{\beta} - Z_{hB}^{\beta} \right) \tag{A.9}$$

and finally

$$U_{hj1}(S_t) = \sqrt[\beta]{U_{hB}^{\beta}(S_t) + I_{hFj1}^{\beta} \cdot \left(Z_{hj1}^{\beta} - Z_{hB}^{\beta} \right)} \tag{A.10}$$

- Step 9: Calculation of the contribution of all the LV installations to the harmonic voltage at other nodes N_{ja} ($2 \le a \le m$) of feeder j.

  From Equation (A.8), it comes for ($2 \le a \le m$):

$$U_{hjk}^{\beta}(S_t) = \left(\frac{S_t - S_{Fj}}{S_t} \right) \cdot Z_{hB}^{\beta} \cdot I_{hT}^{\beta} + \sum_{a=1}^{k-1} (Z_{hja}^{\beta} \cdot I_{hja}^{\beta}) + Z_{hjk}^{\beta} \cdot I_{hFjk}^{\beta} \tag{A.11}$$

so

$$U_{hjk}^{\beta}(S_t) - U_{hjk-1}^{\beta}(S_t) = Z_{hjk-1}^{\beta} \cdot I_{hjk-1}^{\beta} + Z_{hjk}^{\beta} \cdot I_{hFjk}^{\beta} - Z_{hjk-1}^{\beta} \cdot \left(I_{hFjk}^{\beta} + I_{hjk-1}^{\beta} \right) \tag{A.12}$$

And finally, for ($2 \le a \le m$):

$$U_{hjk}(S_t) = \sqrt[\beta]{U^{\beta}_{hjk-1}(S_t) + I^{\beta}_{hFjk} \cdot \left(Z^{\beta}_{hjk} - Z^{\beta}_{hjk-1}\right)} \qquad (A.13)$$

A.4.4 Analysis of the influence of the network parameters for harmonics

In order to find the minimum value of ratio U_{hB}/U_{hFj} (see Equation D.11), it is necessary to analyse the influence of the network parameters on this ratio. This enables the expert to eliminate the parameters that have a small impact on this ratio.

The method consists of the three following steps:

- the definition of a particular case that roughly corresponds to an average case of the considered type of LV networks;
- the analysis of the influence of each of the network parameters listed in A.4.2 on ratio U_{hB}/U_{hFj};
- the determination of the network parameters that are dominating.

For the type of networks considered in this annex, the characteristics chosen for the particular case of network used to analyse the influence of the network parameters are as follows:

- S_t = 250 kVA;
- n = 5 LV feeders;
- l_F = 300 m;
- $\underline{z}_F$, corresponding to a line in aluminium with a cross section of 35 mm^2;
- h = 5;
- β = 1,4.

When varying ratio U_{hB}/U_{hFj} as a function of each parameter, the other parameters keeping the value defined just before, following Table A.2 to Table A.7 are obtained.

Table A.2 – Influence of the total supply capacity of the LV system on ratio UhB/UhFj (example)

S_t (kVA)	50	100	160	250	400	630	1 000
U_{hB}/U_{hFj}	0,89	0,81	0,74	0,63	0,51	0,38	0,33

Table A.3 – Influence of the number of LV feeders on ratio UhB/UhFj (example)

n	2	3	4	5	6	7	8
U_{hB}/U_{hFj}	0,43	0,52	0,58	0,63	0,67	0,70	0,73

Table A.4 – Influence of the length of LV feeders on ratio UhB/UhFj (example)

l_F (m)	50	100	200	300	400	500	600	800	1 000
U_{hB}/U_{hFj}	0,93	0,85	0,74	0,63	0,56	0,49	0,44	0,36	0,31

Table A.5 – Influence of the impedance of LV feeders on ratio UhB/UhFj (example)

Line characteristics	Cu 12 mm^2	Al 35 mm^2	Al 55 mm^2	Al 75 mm^2
U_{hB}/U_{hFj}	0,61	0,63	0,65	0,65

Table A.6 – Influence of the (odd non-triplen) harmonic order on ratio UhB/UhFj (example)

h	5	7	11	13	17	19	23	25
U_{hB}/U_{hFj}	0,63	0,65	0,65	0,66	0,66	0,66	0,66	0,66

Table A.7 – Influence of the summation law exponent on ratio UhB/UhFj (example)

β	1,0	1,1	1,2	1,3	1,4	1,5	1,6	1,7	1,8	1,9	2,0
U_{hB}/U_{hFj}	0,69	0,68	0,66	0,65	0,63	0,62	0,61	0,60	0,58	0,57	0,56

It can be seen from these tables that ratio U_{hB}/U_{hFj} does not depend much on the characteristics of lines, the harmonic order (in the case of non-triplen orders) and the summation law exponent. So, in this case of LV networks and non-triplen harmonic orders, the dominating network parameters are

- S_t, the total supply capacity of the LV system,
- n, the number of LV feeders,
- l_F, the length of the LV feeders.

For triplen harmonic orders in the case of LV networks with overhead lines, the results are similar except that,

- compared to non-triplen harmonic orders, ratio U_{hB}/U_{hFj} is very different for triplen orders,
- compared to other triplen harmonic orders, ratio U_{hB}/U_{hFj} is lower for order 3.

A.4.5 Calculation of the harmonic voltages in various network configurations

In this subclause, ratio U_{hB}/U_{hFj} is studied as a function of the dominating network parameters determined in A.4.4. Table A.8 to Table A.11 give the value of this ratio as a function of S_t and n, for 4 different lengths of LV feeders. It is to be noted that n ≥ 2 because there is no need to consider the reduction factor K_{hB} when there is only one LV feeder.

Table A.8 – ratio UhB/UhFj for an LV feeder length of 100 m (example)

Number of LV feeders	Total supply capacity S_t kVA						
	50	100	160	250	400	630	1 000
2	0,91	0,85	0,79	0,71	0,60	0,49	0,43
3	0,94	0,89	0,85	0,79	0,69	0,58	0,52
4	0,95	0,92	0,89	0,83	0,74	0,64	0,58
5	0,96	0,93	0,91	0,85	0,78	0,68	0,63
6	0,97	0,94	0,92	0,88	0,81	0,72	0,67
7	0,97	0,95	0,93	0,89	0,83	0,75	0,70
8	0,98	0,96	0,93	0,91	0,85	0,78	0,73

Table A.9 – ratio UhB/UhFj for an LV feeder length of 300 m (example)

Number of LV feeders	Total supply capacity S_t kVA						
	50	100	160	250	400	630	1 000
2	0,77	0,65	0,55	0,43	0,32	0,23	0,19
3	0,83	0,72	0,63	0,52	0,40	0,29	0,25
4	0,86	0,78	0,69	0,58	0,46	0,34	0,29
5	0,89	0,81	0,74	0,63	0,51	0,38	0,33
6	0,91	0,83	0,77	0,67	0,55	0,42	0,37
7	0,92	0,85	0,79	0,70	0,58	0,46	0,40
8	0,93	0,87	0,81	0,73	0,61	0,49	0,43

Table A.10 – ratio UhB/UhFj for an LV feeder length of 500 m (example)

Number of LV feeders	Total supply capacity S_t kVA						
	50	100	160	250	400	630	1 000
2	0,66	0,51	0,41	0,31	0,21	0,15	0,12
3	0,74	0,60	0,50	0,38	0,27	0,19	0,16
4	0,79	0,66	0,56	0,44	0,32	0,23	0,19
5	0,82	0,70	0,61	0,49	0,37	0,26	0,22
6	0,85	0,74	0,65	0,53	0,40	0,29	0,25
7	0,86	0,77	0,68	0,57	0,43	0,32	0,27
8	0,88	0,79	0,70	0,60	0,46	0,34	0,30

Table A.11 – ratio UhB/UhFj for an LV feeder length of 1000 m (example)

Number of LV feeders	Total supply capacity S_t kVA						
	50	100	160	250	400	630	1 000
2	0,48	0,33	0,25	0,17	0,12	0,08	0,06
3	0,57	0,41	0,31	0,23	0,15	0,10	0,08
4	0,63	0,47	0,37	0,27	0,18	0,12	0,10
5	0,68	0,52	0,41	0,31	0,21	0,14	0,12
6	0,71	0,56	0,45	0,34	0,24	0,16	0,14
7	0,74	0,60	0,49	0,37	0,26	0,18	0,15
8	0,76	0,63	0,52	0,40	0,28	0,20	0,16

A.4.6 Elimination of non-realistic configurations

Some configurations studied in A.4.5 lead to very low values for ratio U_{hB}/U_{hFj}. But these configurations are not realistic because they correspond to too high voltage drops along LV feeders. So non-realistic configurations should be eliminated before determining values of K_{hB}.

For example, in the preceding tables, Table A.8 to Table A.11, cells corresponding to voltage drops higher than 10 % were hatched, as non-realistic configurations.

NOTE In this case, according to the assumptions made in A.4.2, the conductor cross section was considered constant for all cases regardless the number of feeders.

A.4.7 Determination of the reduction factor values for harmonics

After using the preceding method, it is now possible to determine the reduction factor values.

The expert may provide

- either a simple value for K_{hB},
- or tables giving the value of K_{hB} as a function of the relevant network parameters (see Table A.8 to Table A.11).

If it is desired to have only one value of the reduction factor, it is recommended that the chosen value of K_{hB} is the minimum value of ratio U_{hB}/U_{hFj} (see Equation D.8). In the particular case considered in this annex, Table A.8 to Table A.11 give, for odd non-triplen harmonic orders:

- $K_{hB} = 0{,}34$

If the same study was conducted for odd triplen harmonic orders, it would come:

- $K_{hB} = 0{,}15$ for $h = 3$
- $K_{hB} = 0{,}12$ for $h > 3$.

So, the value of the reduction factor K_{hB} for the considered type of LV networks is given in Table A.12.

Table A.12 – Reduction factor KhB as a function of the harmonic order (example)

h	3	5	7	9	11	13	15	17	19	21	23	25
K_{hB}	0,15	0,34	0,34	0,12	0,34	0,34	0,12	0,34	0,34	0,12	0,34	0,34

Another option is to determine the value of K_{hB} as a function of the network configuration. In that case, a technical expert has to provide tables or a calculation tool giving the value of K_{hB} as a function of the relevant network parameters, so that the system operator can choose the relevant value of K_{hB} for the application of the emission limit formula when studying the connection of a particular installation to the LV system. For example, in the case of an installation to be connected to an LV network with a 250 kVA MV/LV transformer and four 200 m LV feeders, Table A.9 gives K_{hB} = 0,58 for odd non-triplen harmonic orders.

A.4.8 Determination of the reduction factor value for unbalance

As for harmonics, the same study can be done for unbalance. In that case, the analysis of the influence of the network parameters shows that the dominating network parameters are

- S_t, the total supply capacity of the LV system,
- n, the number of LV feeders,
- l_F, the length of the LV feeders,
- $\underline{z}_F$, the complex impedance of overhead line per unit length.

After calculation of the voltage unbalance in various network configurations and elimination of non-realistic configurations, the expert may provide either a single value for K_{uB} or tables giving the value of K_{uB} as a function of the relevant network parameters.

If the same study (as from A.4.2 to A.4.7) was conducted for voltage unbalance, it would come:

- K_{uB} = 0,27.

Annex B
(informative)

Example of application of the general method for the calculation of emission limits for a specific installation

B.1 Overview

The general method described in this report can be applied in two steps:

a) the calculation of global parameters related to a type of LV network;
b) the calculation of individual parameters and emission limits for a given installation.

The first step should be done by a technical expert in a distribution network utility or a regulatory body. The second step should be done by a local operator of the distribution network, possibly with the help of calculation tools designed by a technical expert.

An example of application for the first step is described in Annex A. This annex gives an example of practical application for the second step.

B.2 Description of the case considered

As an example of application of the method described in this technical report, the following particular case is considered. A new installation is to be connected to an LV network and the system operator or owner has to determine emission limits for harmonics, flicker and unbalance. In this particular case, it is supposed that:

- U_N = 400 V;
- S_t = 400 kVA (the global impedance of the upstream MV system and the MV/LV transformer is supposed to be equal to $\underline{Z}_B$ = 0,007 Ω + j 0,020 Ω);
- n = 6;
- S_i = 100 kVA (agreed apparent power of the considered installation);
- the considered installation is connected to the LV busbar by a 50 m overhead line in aluminium with a cross section of 75 mm^2 ($\underline{z}_{LF}$ = 0,44 Ω/km + j 0,35 Ω/km for the line conductors and $\underline{z}_{NF}$ = 0,60 Ω/km + j 0,35 Ω/km for the neutral conductor);
- l_F = 300 m (for the other LV feders).

B.3 Global parameters to be considered

The values of the global parameters related to the type of network considered have already been worked out by a technical expert according to Annex A. The local operator of the distribution network only has to take these values into account to calculate the emission limits for the specific installation.

In this annex, the global parameters related to the type of network considered are supposed to have the following values.

The minimum size of large installations is:

- S_{min} = 50 kVA

The limits for each individual harmonic order, E_{Ih}, defined for the assessment of the installation at stage 1 from conservative network characteristics, are given in Table B.1.

Table B.1 – Example of conservative harmonic current emission limits for stage 1 assessment

Harmonic order h	3	5	7	9	11	13	>13 and ≤ 40
Harmonic current emission limit E_{Ih} (%)	4	5	5	1	3	3	$\frac{500}{h^2}$

For harmonics, the maximum acceptable global contribution G_{hLV} and the reduction factor K_{hB} are given in Table B.2 for the lower odd harmonic orders.

NOTE In this example, it is supposed that there is no neutral conductor at MV. Therefore, the harmonic voltage planning levels for triplen orders at MV can be chosen far lower than the values given in Table A.1, which leads to higher values for the maximum acceptable global contribution for triplen harmonics.

Table B.2 – values of global parameters for harmonics

h	3	5	7	9	11	13
G_{hLV} (%)	4,0	2,1	2,0	1,2	1,8	1,7
K_{hB}	0,15	0,34	0,34	0,12	0,34	0,34

For voltage fluctuations, the maximum acceptable global contributions G_{PstLV} and G_{PltLV} are:

- G_{PstLV} = 0,65
- G_{PltLV} = 0,55

For voltage unbalance, the maximum acceptable global contribution G_{uLV} and the reduction factor K_{uB} are:

- G_{uLV} = 0,5 %
- K_{uB} = 0,27

B.4 Harmonic emission limits

The agreed apparent power of the customer's installation (S_i = 100 kVA) is higher than the value of S_{min} (50 kVA). So the procedure described in 8 has to be applied.

The calculation of the short-circuit power at the point of evaluation of the considered installation gives:

$$S_{sc} = 3\,375 \text{ kVA}, \qquad \text{so } S_i/S_{sc} = 3{,}0\ \%$$

Condition (5) is not fulfilled. The connection of the installation cannot be accepted at stage 1 and stage 2 has to be applied.

Therefore, the emission limits for harmonics are calculated according to Formula (9):

$$E_{Ihi} = \frac{U_N^2}{S_i} \cdot G_{hLV} \cdot \sqrt[\alpha]{\frac{S_i}{S_t}} \cdot \min\left(\frac{K_{hB}}{Z_{hB}}; \frac{1}{Z_{hi}}\right)$$

As a first approximation, the modulus of the harmonic impedance of the system at the LV substation busbar is calculated as follows:

$$Z_{hB} = \sqrt{(R_B)^2 + h^2 (X_B)^2}$$

where

- R_B is the resistive part of impedance $\underline{Z}_B$ at fundamental frequency (R_B = 0,007 Ω);
- X_B is the reactive part of impedance $\underline{Z}_B$ at fundamental frequency (X_B = 0,020 Ω);
- h is the harmonic order.

Assuming that the LV system and the loads connected to it are balanced, the modulus of the harmonic impedance of the supply system at the point of evaluation of the customer's installation is calculated as follows:

$$Z_{hi} = \sqrt{\left[R_B + l_i \cdot (r_{LF} + 3\delta_3 r_{NF})\right]^2 + h^2 \left[X_B + l_i \cdot (x_{LF} + 3\delta_3 x_{NF})\right]^2}$$

where

- l_i is the length of the feeder between the LV substation busbar and the considered installation (l_i = 50 m);
- r_{LF} is the resistive part of the impedance of the feeder line conductor at fundamental frequency (r_{LF} = 0,44 Ω/km);
- x_{LF} is the reactive part of the impedance of the feeder line conductor at fundamental frequency (x_{LF} = 0,35 Ω/km);
- r_{NF} is the resistive part of the impedance of the feeder neutral conductor at fundamental frequency (r_{NF} = 0,60 Ω/km);
- x_{NF} is the reactive part of the impedance of the feeder neutral conductor at fundamental frequency (x_{NF} = 0,35 Ω/km);
- δ_3 is equal to 0 for non-triplen harmonics and to 1 for triplen harmonics.

Following Table B.3 gives the emission limits derived from the application of formula (9), together with the values of the parameters used at each harmonic order.

Table B.3 – Emission limits for harmonics
(with a single value of KhB)

h	G_{hLV} %	K_{hB}	α	Z_{hB} Ω	Z_{hi} Ω	E_{Ihi} %
3	4,0	0,15	1	0,060	0,295	4,0
5	2,1	0,34	1,4	0,100	0,190	4,2
7	2,0	0,34	1,4	0,140	0,264	2,9
9	1,2	0,12	1,4	0,180	0,819	0,5
11	1,8	0,34	2	0,220	0,414	2,2
13	1,7	0,34	2	0,260	0,488	1,8

The emission limits obtained in Table B.3 are very conservative because a single value of K_{hB} was used, irrespective of the real characteristics of the LV network to which the new installation is to be connected. Looking at A.4.5, it can be seen that the real value of K_{hB} for the considered LV network (l_F = 300 m, n = 6, S_t = 400 kVA) is equal to 0,55 for non-triplen harmonics. If the technical expert provided tables or a calculation tool giving the value of K_{hB} as a function of the relevant network parameters, the local operator would obtain the emission limits in Table B.4.

Table B.4 – emission limits for harmonics (KhB value depending on real network characteristics)

h	G_{hLV} %	K_{hB}	α	Z_{hB} Ω	Z_{hi} Ω	E_{Ihi} %
3	4,0	0,26	1	0,060	0,295	5,4
5	2,1	0,55	1,4	0,100	0,190	6,6
7	2,0	0,55	1,4	0,140	0,264	4,5
9	1,2	0,22	1,4	0,180	0,819	0,9
11	1,8	0,55	2	0,220	0,414	3,5
13	1,7	0,55	2	0,260	0,488	2,8

B.5 Voltage fluctuation emission limits

The agreed apparent power of the customer's installation (S_i = 100 kVA) is higher than the value of S_{min} (50 kVA). So the procedure described in 9 has to be applied.

Here it is assumed that, in the considered installation, there are several motors with a rated power S_N = 5 kVA and their apparent power at starting is ΔS ≈ 5 S_N. The calculation of ratio $\Delta S/S_{sc}$ when one motor is starting gives:

- $\frac{\Delta S}{S_{sc}} = \frac{5 \cdot S_N}{S_{sc}} = \frac{5 \cdot 5}{3\,375} = 0{,}74\ \%$

This ratio is higher than 0,4 % and so the limits given in Table 4 are not met. The connection of the installation cannot be accepted at stage 1 and stage 2 has to be applied.

Therefore, the emission limits for flicker are calculated according to formulas (13) and (14).

- $E_{Psti} = G_{PstLV} \cdot \sqrt[\alpha]{\frac{S_i}{S_t}} = 0{,}65 \cdot \sqrt[3]{\frac{100}{400}} = 0{,}41$
- $E_{Plti} = G_{PltLV} \cdot \sqrt[\alpha]{\frac{S_i}{S_t}} = 0{,}55 \cdot \sqrt[3]{\frac{100}{400}} = 0{,}35$

Because these values are greater than the minimum values allowable for all LV installations given in Table 5, the emission limits for this LV installation are equal to the values calculated just above.

B.6 Unbalance emission limits

The agreed apparent power of the customer's installation (S_i = 100 kVA) is higher than the value of S_{min} (50 kVA). So the procedure described in 10 has to be applied.

Here it is assumed that, in the considered installation, a large load is connected between 2 phases so that condition (19) is not fulfilled. So, the connection of the installation cannot be accepted at stage 1 and stage 2 has to be applied.

Therefore, the emission limit for voltage unbalance is calculated according to formula (22):

$$E_{I2\,i} = \frac{U_N^2}{S_i} \cdot G_{uLV} \cdot \sqrt[\alpha]{\frac{S_i}{S_t}} \cdot \min\left(\frac{K_{uB}}{Z_B}\,;\,\frac{1}{Z_i}\right)$$

With the same notations as in B.4, the modulus of the short-circuit impedance of the system at the LV substation busbar, Z_B, and at the point of evaluation of the installation, Z_i, are given by

$$Z_B = \sqrt{(R_B)^2 + (X_B)^2}$$

$$Z_i = \sqrt{(R_B + l_i \cdot r_{LF})^2 + (X_B + l_i \cdot x_{LF})^2}$$

Following Table B.5 gives the emission limit derived from the application of formula (22), together with the values of the parameters used.

Table B.5 – Emission limit for voltage unbalance (with a single value of KuB)

G_{uLV} %	K_{uB}	α	Z_B Ω	Z_i Ω	$E_{I2\,i}$ %
0,5	0,27	1,4	0,021	0,047	3,8

As for harmonics, the emission limit obtained in Table B.5 is conservative because a single value of K_{uB} was used, irrespective of the real characteristics of the LV network to which the new installation is to be connected. For the considered LV network (l_F = 300 m, n = 6, S_t = 400 kVA, overhead lines in aluminium with a cross section of 75 mm^2), the real value of K_{uB} is equal to 0,51. If the technical expert provided tables or a calculation tool giving the value of K_{uB} as a function of the relevant network parameters, the local operator would obtain the following emission limit:

- $E_{I2\,i}$ = 6,3 %.

Annex C
(informative)

Harmonic emission limits at stage 2

C.1 Overview

The purpose of this annex is to explain the method and the assumptions used to define the harmonic emission limits for stage 2 given in 8.2.

The context of LV systems is different from MV system context. On the one hand, most of the installations connected to LV public systems are small installations that are not subject to the application of the emission limits defined in this report. For these small installations, only equipment standards apply. On the other hand, the emission limits for LV equipment (see IEC 61000-3-2 and IEC 61000-3-12) have been defined as current limits while the general approach given in IEC/TR 61000-3-6 is based on an allocation of harmonic voltages. For LV systems, it is thus necessary to adapt both approaches in a consistent manner.

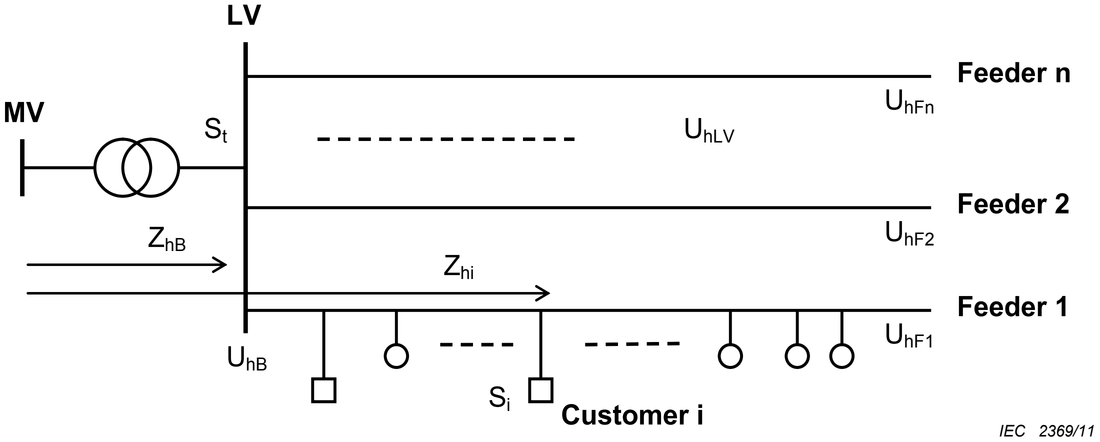
In this annex, the definition of harmonic emission limits for stage 2 is made with the following steps:

a) presentation of the assumptions,
b) definition of the global emission to be shared between the customers at LV,
c) description of the general conditions to define individual emission limits,
d) condition to be met at the LV busbar, in order not to exceed the acceptable harmonic levels at this point of the system,
e) condition to be met for the LV feeder, in order not to exceed the acceptable harmonic levels on the LV feeder to which the considered installation is connected,
f) definition of the individual emission limits for an installation connected to a LV system.

C.2 Assumptions

C.2.1 General scheme of an LV public system

In this annex, a typical LV public system is considered, as illustrated on Figure C.1. An MV/LV transformer supplies n feeders through an LV busbar. The transformer is supposed to be fully loaded. Customer's installations are connected to each feeder. The small installations, which are not subject to the application of the emission limits defined in this report, are distinguished from the large installations to which this report applies. On this figure, small installations are represented by small circles, whereas the large ones are represented by small squares. The general aim of this annex is to define the harmonic emission limits for the installation of customer i connected to feeder 1.



IEC 2369/11

Figure C.1 – Scheme of an LV public system

The notations used on Figure C.1 are the following:

- S_i is the agreed apparent power of customer's installation i;
- S_t is the total supply capacity of the considered LV system;
- U_{hB} is the harmonic voltage of order h at the substation LV busbar;
- U_{hFj} is the harmonic voltage of order h at the end of feeder j;
- Z_{hB} is the modulus of the harmonic impedance of the system at the LV busbar;
- Z_{hi} is the modulus of the harmonic impedance of the system at the point of evaluation of customer's installation i;
- n is the number of the feeders supplied by the MV/LV substation.

In order to define the contribution of each type of installations to the harmonic voltages on the LV system, the following notations will also be used:

- S_{Fj} is the apparent power of all installations connected to a particular feeder (j);
- S_{Lt} is the apparent power of all large installations connected to the considered LV system;
- S_{St} is the apparent power of all small installations connected to the considered LV system;
- S_{LFj} is the apparent power of all large installations connected to a particular feeder (j);
- S_{SFj} is the apparent power of all small installations connected to a particular feeder (j);
- U_{hB} (S_{xx}) is the contribution of all the installations corresponding to the apparent power S_{xx} to the harmonic voltage of order h at the substation LV busbar;
- U_{hFj} (S_{xx}) is the contribution of all the installations corresponding to the apparent power S_{xx} to the harmonic voltage of order h at the end of feeder j;
- U_{hLV} (S_{xx}) is the contribution of all the installations corresponding to the apparent power S_{xx} to the harmonic voltage of order h at any point of the LV system.

C.2.2 Emission limits for equipment

For small installations, only emission limits for equipment defined in IEC 61000-3-2 and IEC 61000-3-12 apply. In this annex, both of the following assumptions are made.

- The harmonic voltages are lower than or equal to the planning levels at any point on the LV system if it is fully loaded by small installations.
- The emission limits for equipment are defined as current limits independently of the short-circuit power at the PCC of the installation. This is true for IEC 61000-3-2, but not completely true for IEC 61000-3-12. However, Table 4 of IEC 61000-3-12 applies for most

types of equipment ≥16 A, and the last row of this table (R_{sce} ≥ 120) applies in most cases. That is why it is reasonable to assume that the harmonic emissions from a small installation do not depend on the point where it is connected to the LV system.

C.2.3 Small and large installations

The fundamental assumption is that the percentages of small and large installations (S_{St}/S_t and S_{Lt}/S_t) are generally not known in advance, and actually highly depend on the LV system considered. Therefore, the emission limits for large installations will be defined so that a large installation can replace a set of small installations having a same global power without increasing harmonic voltage levels.

In other respects, small installations are generally dwellings so that the behaviour of two small installations is rather similar, whereas for large installations there is much more diversity in installed equipment and in their behaviour in terms of harmonic emissions. Therefore, it is supposed in this annex that the phase angle diversity is higher for large installations or between a large and a small installation than for small installations. Thus, when using the general summation law defined in 7.2 for harmonics, two values of the exponent will be considered:

- α to add harmonic emissions from large installations;
- β to add harmonic emissions from small installations;
- α to add global harmonic emissions from a group of large installations and a group of small ones;
- $\beta \leq \alpha$.

C.3 Global emission to be shared between the customers

In order to work out the global emission that can be shared between the customers connected to a given LV system, the scheme of the LV public system derived from Figure C.1, as illustrated on Figure C.2, is considered.

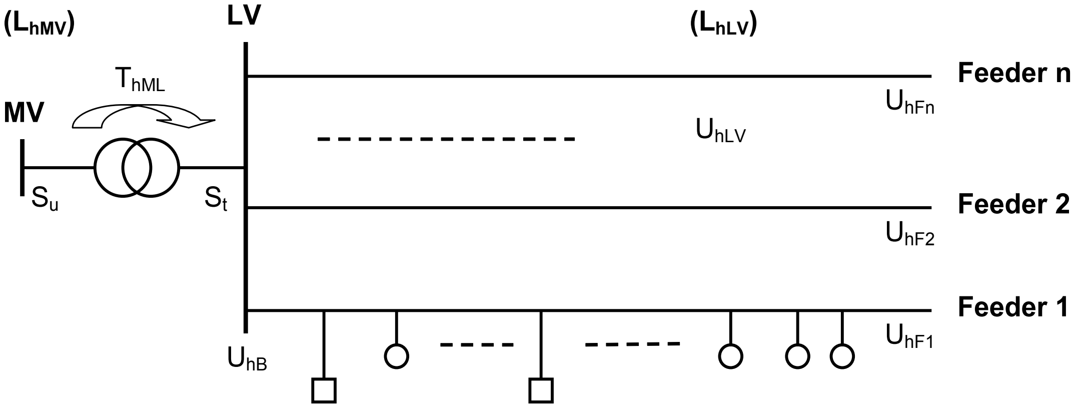


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Figure C.2 – Scheme of an LV public system in order to work out the global emission to be shared between the customers

For each harmonic order, the actual harmonic voltage in an LV system (U_{hLV}) results from the vectorial combination of the harmonic voltage coming from the upstream MV system ($U_{hLV}(S_u)$) and of the harmonic voltage resulting from all installations connected to the considered LV system($U_{hLV}(S_t)$). This total harmonic voltage should not exceed the planning level of the LV system. So:

$$U_{hLV}^{\alpha} = U_{hLV}^{\alpha}(S_u) + U_{hLV}^{\alpha}(S_t) \leq L_{hLV}^{\alpha} \tag{C.1}$$

or

$$U_{hLV}^{\alpha}(S_t) \leq L_{hLV}^{\alpha} - U_{hLV}^{\alpha}(S_u) \tag{C.2}$$

As the actual harmonic voltage in the upstream MV system should not exceed the planning level at MV, it comes, taking into account the transfer coefficient T_{hML}:

$$U_{hLV}(S_u) \leq T_{hML} \cdot L_{hMV} \tag{C.3}$$

Therefore, the global harmonic voltage emissions that can be allocated to the total of installations connected to the considered LV system is given by

$$G_{hLV} = \sqrt[\alpha]{L_{hMV}^{\alpha} - \left(T_{hML} \cdot L_{hMV}\right)} \tag{C.4}$$

where

- G_{hLV} is the maximum global contribution of the local LV installations to the hth harmonic voltage anywhere in the LV system (expressed in percent of the fundamental voltage);
- L_{hLV} is the planning level of the hth harmonic in the LV system;
- L_{hMV} is the planning level of the hth harmonic in the upstream MV system;
- T_{hML} is the transfer coefficient of harmonic voltage distortion from the upstream MV system to the LV system under consideration at harmonic order h;
- α is the summation law exponent for large installations.

Due to the general summation law used, the contribution U_{hLV} (S_t) of all installations supplied by the LV system to the harmonic voltage of order h on this system is maximum at the end of feeders. The contribution U_{hB} (S_t) of these installations to the harmonic voltage at the LV busbar is lower.

An acceptable global contribution of the local LV installations to the harmonic voltage at the LV busbar is also defined, as a fraction of the maximum global contribution G_{hLV}:

$$G_{hB} = K_{hB} \cdot G_{hLV} \tag{C.5}$$

where

- G_{hB} is the acceptable global contribution of the local LV installations to the hth harmonic voltage at the LV busbar (expressed in percent of the fundamental voltage);
- G_{hLV} is the maximum global contribution of the local LV installations to the hth harmonic voltage anywhere in the LV system (expressed in percent of the fundamental voltage);
- K_{hB} is the reduction factor at harmonic order h, corresponding to the ratio of the global contribution of the local LV installations at the LV busbar to their maximum global contribution at the end of the LV feeders, when the LV system is fully loaded by small installations.

This reduction factor is given by

$$K_{hB} = \frac{U_{hB}(S_t)}{\max(U_{hLV}(S_t))} \tag{C.6}$$

Because it is assumed that the harmonic emissions from a small installation do not depend on the point where it is connected to the LV system, the reduction factor K_{hB} does not depend on harmonic emission levels, but only on the structure of the LV system (number and length of feeders, distribution of customers, etc) and the exponent β used for the summation law. Values of K_{hB} are given for some typical LV systems in Annex D.

C.4 General conditions to define individual emission limits

The harmonic emission limits for large installations have to be defined in such a way that the planning levels are not exceeded on the LV systems. As harmonic levels are higher at the end of the LV feeders (due to the summation law used), this means that, for each feeder j and each harmonic order h, the contribution U_{hFj} (S_t) of all the installations supplied by the LV system considered to the harmonic voltage at the end of the feeder should be lower than or equal to the maximum global contribution G_{hLV}. This corresponds to the following set of n conditions to be met for each harmonic order:

$$U_{hFJ}(S_t) \le G_{hLV} \qquad \forall J \in [1,n] \tag{C.7}$$

However, when considering the connection of a particular large installation, for example the installation of customer i to be connected to feeder 1 (see Figure C.1), it can be noticed that this installation modifies the harmonic voltage levels on the other feeders only through the harmonic voltage at the LV busbar. Therefore, the contribution U_{hFj} (S_t) of all the LV installations to the harmonic voltage at the end of each other feeder will not exceed the maximum global contribution G_{hLV} if the harmonic voltage level at the LV busbar does not exceed the acceptable global contribution G_{hB} at the LV busbar level. Thus, the set of n conditions (C.7) can be replaced by simply both following conditions:

$$U_{hB}(S_t) \le K_{hB} \cdot G_{hLV} \tag{C.8}$$

$$U_{hF1}(S_t) \le G_{hLV} \tag{C.9}$$

NOTE In this annex a lot of formulae present "inequality". They are therefore referrd to as "condition".

C.5 Condition at the LV busbar

C.5.1 General condition at the LV busbar

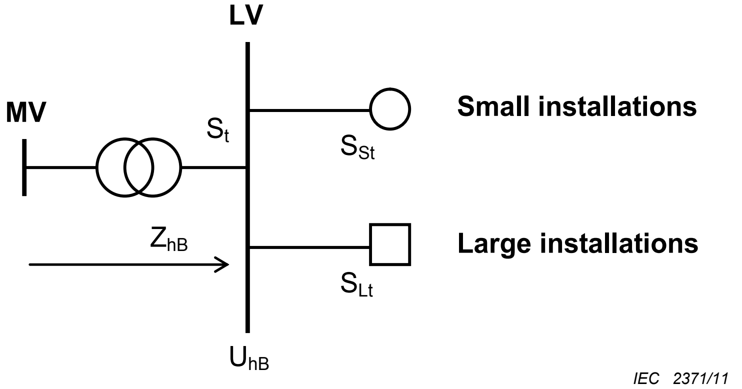


Figure C.3 – Simplified scheme of an LV public system in order to work out the condition at the LV busbar

In order to work out the condition at the LV busbar, the simplified scheme of an LV public system, illustrated on Figure C.3, is considered. This scheme is derived from Figure C.1 where all small installations were aggregated into a single equivalent load having a global apparent power equal to S_{St} and all large installations were aggregated into another single equivalent load having a global apparent power equal to S_{Lt}.

The contribution of all the LV installations to the harmonic voltage of order h at the LV busbar is the vectorial combination of the contribution from the small installations and of the contribution from the large installations. According to the assumptions on the summation law in C.2.3, it comes:

$$U_{hB}^{\alpha}(S_t) = U_{hB}^{\alpha}(S_{Lt}) + U_{hB}^{\alpha}(S_{St}) \tag{C.10}$$

This global contribution $U_{hB}(S_t)$ has to fulfil general condition (C.8) given in Clause C.4. So:

$$U_{hB}^{\alpha}(S_{Lt}) + U_{hB}^{\alpha}(S_{St}) \leq (K_{hB} \cdot G_{hLV})^{\alpha} \tag{C.11}$$

C.5.2 Global contribution of the small installations

According to the first assumption made in C.2.2 and the definition of G_{hB} in Clause C.3, the condition (C.11) is also met if only small installations are connected to the considered LV system. So, in that case, taking into account the summation law exponent for small installations, it comes:

$$U_{hB}^{\beta}(S_{St}) = \sum_k U_{hB}^{\beta}(S_k) \leq (K_{hB} \cdot G_{hLV})^{\beta} \tag{C.12}$$

or

$$\sum_k I_h^{\beta}(S_k) \leq \frac{1}{(Z_{hB})^{\beta}} \cdot (K_{hB} \cdot G_{hLV})^{\beta} \tag{C.13}$$

where $I_h(S_k)$ is the harmonic current of order h produced by small installation k.

For a single installation k, it is then supposed that:

$$I_h^{\beta}(S_k) \leq \frac{S_k}{S_t} \cdot \frac{1}{(Z_{hB})^{\beta}} \cdot (K_{hB} \cdot G_{hLV})^{\beta} \tag{C.14}$$

or

$$U_{hB}^{\beta}(S_k) \leq \frac{S_k}{S_t} \cdot (K_{hB} \cdot G_{hLV})^{\beta} \tag{C.15}$$

According to the second assumption made in C.2.2, the preceding condition is quite right when all small installations have the same agreed apparent power. It is supposed here that this condition is still right when small installations have different values of their agreed power.

If now some large installations are connected to the considered LV system, it results from condition (C.15) that the global contribution of all small LV installations to the harmonic voltage of order h at the substation LV busbar is given by

$$U_{hB}^{\beta}(S_{St}) \leq \frac{S_{St}}{S_t} \cdot (K_{hB} \cdot G_{hLV})^{\beta} \tag{C.16}$$

or

$$U_{hB}(S_{St}) \leq (K_{hB} \cdot G_{hLV}) \cdot \sqrt[\beta]{\frac{S_{St}}{S_t}} \qquad (C.17)$$

where the right part of this condition represents the acceptable global contribution of the small LV installations to the harmonic voltage of order h at the substation LV busbar.

As we supposed in C.2.3 that $\beta \leq \alpha$, we have $1/\alpha \leq 1/\beta$, and so it finally comes:

$$U_{hB}(S_{St}) \leq (K_{hB} \cdot G_{hLV}) \cdot \sqrt[\beta]{\frac{S_{St}}{S_t}} \leq (K_{hB} \cdot G_{hLV}) \cdot \sqrt[\alpha]{\frac{S_{St}}{S_t}} \qquad (C.18)$$

C.5.3 Acceptable global contribution of the large installations

According to the general condition (C.11), the global contribution of all large LV installations to the harmonic voltage of order h at the substation LV busbar shall meet the following condition:

$$U^{\alpha}_{hB}(S_{Lt}) \leq (K_{hB} \cdot G_{hLV})^{\alpha} - U^{\alpha}_{hB}(S_{St}) \qquad (C.19)$$

Condition (C.11) is still met if the global contribution of the small LV installations is replaced by a higher quantity as given in condition (C.18). So a sufficient condition for the global contribution of all large LV installations is

$$U^{\alpha}_{hB}(S_{Lt}) \leq (K_{hB} \cdot G_{hLV})^{\alpha} - \frac{S_{St}}{S_t} \cdot (K_{hB} \cdot G_{hLV})^{\alpha} \qquad (C.20)$$

After simplification, it finally comes:

$$U_{hB}(S_{Lt}) \leq (K_{hB} \cdot G_{hLV}) \cdot \sqrt[\alpha]{\frac{S_{Lt}}{S_t}} \qquad (C.21)$$

where the right part of this condition represents the acceptable global contribution of the large LV installations to the harmonic voltage of order h at the substation LV busbar.

C.5.4 Individual emission limits for a large installation with regard to the LV busbar

For each large LV installation, only a fraction of the acceptable global contribution given by condition (C.21) can be allowed. A reasonable approach is to apportion it to individual customers according to their agreed power. Such a criterion is related to the fact that the agreed power of a customer is often linked with his share in the investment costs of the power system. Thus, for customer's installation i, it comes:

$$U_{hB}(S_i) \leq (K_{hB} \cdot G_{hLV}) \cdot \sqrt[\alpha]{\frac{S_i}{S_t}} \qquad (C.22)$$

This leads to define the following harmonic current emission limits for large LV installations with regard to the LV busbar.

$$E_{IBhi} = \frac{1}{Z_{hB}} \cdot \frac{U_N^2}{S_i} \cdot K_{hB} \cdot G_{hLV} \cdot \sqrt[\alpha]{\frac{S_i}{S_t}} \qquad (C.23)$$

where

- E_{IBhi} is the harmonic current emission limit of order h with regard to the LV busbar for the installation (i) connected at LV (%: expressed in percent of the installation current corresponding to its agreed apparent power, $S_i / U_N\sqrt{3}$);
- Z_{hB} is the modulus of the harmonic impedance of the system at the LV busbar (Ω);
- U_N is the nominal phase-to-phase voltage of the LV system (V);
- S_i is the agreed apparent power of the installation (i) (VA);
- K_{hB} is the reduction factor at harmonic order h, as defined in Clause C.3;
- G_{hLV} is the maximum global contribution of the local LV installations to the h^{th} harmonic voltage in the LV system (%: expressed in percent of the fundamental voltage);
- S_t is the total supply capacity of the considered LV system (VA);
- α is the summation law exponent for large installations.

C.6 Condition for the LV feeder to which a large installation is connected

C.6.1 General condition for the LV feeder

In order to work out the condition for the LV feeder to which the considered large installation (i) is connected, the simplified scheme of an LV public system, illustrated on Figure C.4, is considered. This scheme is derived from Figure C.1 where

- all small installations connected to feeder 1 were aggregated into a single equivalent load having a global apparent power equal to S_{SF1},
- all other small installations were aggregated into another single equivalent load having a global apparent power equal to $S_{St} – S_{SF1}$,
- all large installations connected to feeder 1 were aggregated into a single equivalent load having a global apparent power equal to S_{LF1},
- all other large installations were aggregated into another single equivalent load having a global apparent power equal to $S_{Lt} – S_{LF1}$.

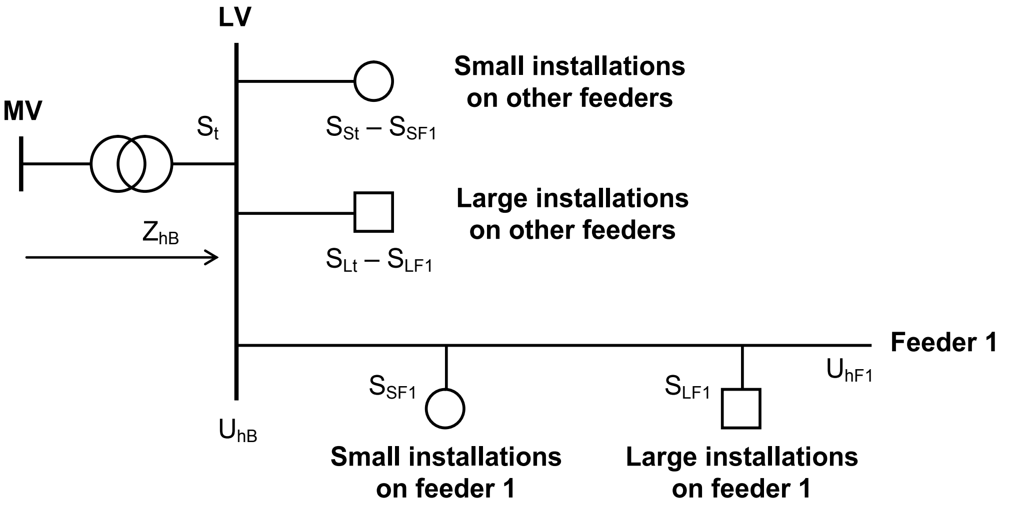


Figure C.4 – Simplified scheme of an LV public system in order to work out the condition for the LV feeder to which a large installation is connected

The contribution of all the LV installations to the harmonic voltage of order h at the end of feeder 1 is the vectorial combination of the contribution from the small installations and of the contribution from the large installations.

$$U^{\alpha}_{hF1}(S_t) = U^{\alpha}_{hF1}(S_{Lt}) + U^{\alpha}_{hF1}(S_{St}) \qquad (C.24)$$

As regards the contribution of all the large (small) LV installations to the harmonic voltage of order h at the end of feeder 1, it is the vectorial combination of the contribution of the large (small) LV installations connected to feeder 1 and of the contribution of all other large (small) installations to the harmonic level at the substation LV busbar. According to the assumptions on the summation law in C.2.3, it comes:

$$U^{\alpha}_{hF1}(S_{Lt}) = U^{\alpha}_{hB}(S_{Lt} - S_{LF1}) + U^{\alpha}_{hF1}(S_{LF1}) \qquad (C.25)$$

$$U^{\beta}_{hF1}(S_{St}) = U^{\beta}_{hB}(S_{St} - S_{SF1}) + U^{\beta}_{hF1}(S_{SF1}) \qquad (C.26)$$

The global contribution $U_{hF1}(S_t)$ has to fulfil general condition (C.9) given in Clause C.4. Combining Equations (C.24) and (C.25), it comes:

$$U^{\alpha}_{hF1}(S_{LF1}) + U^{\alpha}_{hB}(S_{Lt} - S_{LF1}) + U^{\alpha}_{hF1}(S_{St}) \le G^{\alpha}_{hLV} \qquad (C.27)$$

C.6.2 Global contribution of the large installations connected to the other feeders

From condition (C.21), it comes that the global contribution of the large LV installations connected to the other feeders to the harmonic voltage of order h at the substation LV busbar is given by

$$U_{hB}(S_{Lt} - S_{LF1}) \le (K_{hB} \cdot G_{hLV}) \cdot \sqrt[\alpha]{\frac{S_{Lt} - S_{LF1}}{S_t}} \qquad (C.28)$$

C.6.3 Global contribution of the small installations connected to the other feeders

From condition (C.17), it comes that the global contribution of the small LV installations connected to the other feeders to the harmonic voltage of order h at the substation LV busbar is given by

$$U_{hB}(S_{St} - S_{SF1}) \le (K_{hB} \cdot G_{hLV}) \cdot \sqrt[\beta]{\frac{S_{St} - S_{SF1}}{S_t}} \qquad (C.29)$$

C.6.4 Global contribution of the small installations connected to the same feeder

According to the first assumption made in C.2.2, condition (C.9) is also met if only small installations are connected to the considered LV system. So, if we supposed in a first step that all large installations were replaced by small installations having the same equivalent power, (C.26) and (C.9) would give:

$$U^{\beta}_{hB}(S_t - S_{F1}) + U^{\beta}_{hF1}(S_{F1}) \le G^{\beta}_{hLV} \qquad (C.30)$$

or

$$U^{\beta}_{hF1}(S_{F1}) \le G^{\beta}_{hLV} - U^{\beta}_{hB}(S_t - S_{F1}) \qquad (C.31)$$

Now, taking into account condition (C.29), the acceptable global contribution of the small LV installations connected to feeder 1 is given by

$$U_{hF1}^{\beta}(S_{F1}) \;\le\; G_{hLV}^{\beta} \;-\; \frac{S_t - S_{F1}}{S_t}\cdot(K_{hB}\cdot G_{hLV})^{\beta} \qquad (C.32)$$

or

$$U_{hF1}^{\beta}(S_{F1}) \;\le\; \left[1 - \left(\frac{S_t - S_{F1}}{S_t}\right)\cdot K_{hB}^{\beta}\right]\cdot G_{hLV}^{\beta} \qquad (C.33)$$

If now some large installations are also connected to feeder 1, the global contribution of all small LV installations connected to feeder 1 to the harmonic voltage of order h at the end of feeder 1 is given by

$$U_{hF1}^{\beta}(S_{SF1}) \;\le\; \frac{S_{SF1}}{S_{F1}}\cdot\left[1 - \left(\frac{S_t - S_{F1}}{S_t}\right)\cdot K_{hB}^{\beta}\right]\cdot G_{hLV}^{\beta} \qquad (C.34)$$

C.6.5 Global contribution of all the small installations connected to the LV system

According to its definition in Equation (C.26) and to both conditions (C.29) and (C.34), the global contribution of all the small installations connected to the LV system to the harmonic voltage of order h at the end of feeder 1 is given by

$$U_{hF1}^{\beta}(S_{St}) \;\le\; \left(\frac{S_{St} - S_{SF1}}{S_t}\right)\cdot(K_{hB}\cdot G_{hLV})^{\beta} \;+\; \frac{S_{SF1}}{S_{F1}}\cdot\left[1 - \left(\frac{S_t - S_{F1}}{S_t}\right)\cdot K_{hB}^{\beta}\right]\cdot G_{hLV}^{\beta} \qquad (C.35)$$

or

$$U_{hF1}^{\beta}(S_{St}) \;\le\; G_{hLV}^{\beta}\cdot\left[\frac{S_{SF1}}{S_{F1}} + K_{hB}^{\beta}\cdot\left(\frac{S_{St}}{S_t} - \frac{S_{SF1}}{S_{F1}}\right)\right]. \qquad (C.36)$$

C.6.6 Acceptable global contribution of all the large installations connected to the feeder under consideration

According to the general condition (C.27), the global contribution of all large LV installations connected to feeder 1 to the harmonic voltage of order h at the end of feeder 1 shall meet the following condition:

$$U_{hF1}^{\alpha}(S_{LF1}) \;\le\; G_{hLV}^{\alpha} - U_{hB}^{\alpha}(S_{Lt} - S_{LF1}) - U_{hF1}^{\alpha}(S_{St}) \qquad (C.37)$$

Condition (C.27) is still met if the global contribution of all the small LV installations connected to the LV system and the global contribution of all the large LV installations not connected to feeder 1 are respectively replaced by higher quantities as given in conditions (C.36) and (C.28). So a sufficient condition for the global contribution of all the large LV installations connected to feeder 1 is given by

$$U_{hF1}^{\alpha}(S_{LF1}) \;\le\; G_{hLV}^{\alpha} \;-\; \left(\frac{S_{Lt} - S_{LF1}}{S_t}\right)\cdot(K_{hB}\cdot G_{hLV})^{\alpha} \;-\; G_{hLV}^{\alpha}\cdot\left[\frac{S_{SF1}}{S_{F1}} + K_{hB}^{\beta}\cdot\left(\frac{S_{St}}{S_t} - \frac{S_{SF1}}{S_{F1}}\right)\right]^{\frac{\alpha}{\beta}} \qquad (C.38)$$

or $$U^{\alpha}_{hF1}(S_{LF1}) \le G^{\alpha}_{hLV} \cdot \left[1 - K^{\alpha}_{hB} \cdot \left(\frac{S_{Lt} - S_{LF1}}{S_t}\right)\right] - G^{\alpha}_{hLV} \cdot \left[\frac{S_{SF1}}{S_{F1}} \cdot \left(1 - K^{\beta}_{hB}\right) + \frac{S_{St}}{S_t} \cdot K^{\beta}_{hB}\right]^{\frac{\alpha}{\beta}} \quad \text{(C.39)}$$

To simplify the reasoning, the last term of condition (C.39) is now considered separately and is temporarily defined as A:

$$A = \frac{S_{SF1}}{S_{F1}} \cdot \left(1 - K^{\beta}_{hB}\right) + \frac{S_{St}}{S_t} \cdot K^{\beta}_{hB}$$

As $0 \le K_{hB} \le 1$, it comes that $A \ge 0$.

The term A can also be written as follows:

$$A = \left(\frac{S_{F1} - S_{LF1}}{S_{F1}}\right) \cdot \left(1 - K^{\beta}_{hB}\right) + \left(\frac{S_t - S_{Lt}}{S_t}\right) \cdot K^{\beta}_{hB} = 1 - \frac{S_{LF1}}{S_{F1}} \cdot \left(1 - K^{\beta}_{hB}\right) - \frac{S_{Lt}}{S_t} \cdot K^{\beta}_{hB}$$

As $0 \le K_{hB} \le 1$, it comes that $A \le 1$.

Therefore, $0 \le A \le 1$, and as $\alpha/\beta \ge 1$ according to the assumptions made in C.2.3, it finally comes:

$$A^{\frac{\alpha}{\beta}} \le A$$

Condition (C.27) is still met if the last term in condition (C.39) is replaced by a higher quantity. So a sufficient condition for the global contribution of all the large LV installations connected to feeder 1 is given by

$$U^{\alpha}_{hF1}(S_{LF1}) \le G^{\alpha}_{hLV} \cdot \left[1 - K^{\alpha}_{hB} \cdot \left(\frac{S_{Lt} - S_{LF1}}{S_t}\right)\right] - G^{\alpha}_{hLV} \cdot \left[1 - \frac{S_{LF1}}{S_{F1}} \cdot \left(1 - K^{\beta}_{hB}\right) - \frac{S_{Lt}}{S_t} \cdot K^{\beta}_{hB}\right] \text{(C.40)}$$

or $$U^{\alpha}_{hF1}(S_{LF1}) \le G^{\alpha}_{hLV} \cdot \left[-K^{\alpha}_{hB} \cdot \left(\frac{S_{Lt} - S_{LF1}}{S_t}\right) + \frac{S_{LF1}}{S_{F1}} \cdot \left(1 - K^{\beta}_{hB}\right) + \frac{S_{Lt}}{S_t} \cdot K^{\beta}_{hB}\right] \quad \text{(C.41)}$$

or $$U^{\alpha}_{hF1}(S_{LF1}) \le G^{\alpha}_{hLV} \cdot \left[\left(K^{\beta}_{hB} - K^{\alpha}_{hB}\right) \cdot \left(\frac{S_{Lt} - S_{LF1}}{S_t}\right) + \frac{S_{LF1}}{S_{F1}} - K^{\beta}_{hB} \cdot \frac{S_{LF1}}{S_{F1}} + K^{\beta}_{hB} \cdot \frac{S_{LF1}}{S_t}\right] \quad \text{(C.42)}$$

or $$U^{\alpha}_{hF1}(S_{LF1}) \le G^{\alpha}_{hLV} \cdot \left[\frac{S_{LF1}}{S_{F1}} - K^{\beta}_{hB} \cdot \frac{S_{LF1}}{S_{F1}} \cdot \left(1 - \frac{S_{F1}}{S_t}\right) + \left(K^{\beta}_{hB} - K^{\alpha}_{hB}\right) \cdot \left(\frac{S_{Lt} - S_{LF1}}{S_t}\right)\right] \quad \text{(C.43)}$$

As $0 \le K_{hB} \le 1$ and $1 \le \beta \le \alpha$, it comes:

$$K^{\beta}_{hB} \le 1 \quad \text{and} \quad K^{\beta}_{hB} - K^{\alpha}_{hB} \ge 0 .$$

So a sufficient condition to meet the general condition (C.27) is given by

$$U^{\alpha}_{hF1}(S_{LF1}) \leq G^{\alpha}_{hLV} \cdot \left[\frac{S_{LF1}}{S_{F1}} - \frac{S_{LF1}}{S_{F1}} \cdot \left(1 - \frac{S_{F1}}{S_t} \right) \right] \qquad (C.44)$$

Therefore, the acceptable global contribution of all the large LV installations connected to feeder 1 to the harmonic voltage of order h at the end of feeder 1 is given by

$$U_{hF1}(S_{LF1}) \leq G_{hLV} \cdot \sqrt[\alpha]{\frac{S_{LF1}}{S_t}} \qquad (C.45)$$

C.6.7 Individual emission limits for a large installation with regard to the LV feeder

For each large LV installation connected to feeder 1, only a fraction of the acceptable global contribution given by condition (C.45) can be allowed. As in C.5.4, a reasonable approach is to apportion it to individual customers according to their agreed power. Thus, for customer's installation i, it comes:

$$U_{hF1}(S_i) \leq G_{hLV} \cdot \sqrt[\alpha]{\frac{S_i}{S_t}} \qquad (C.46)$$

This leads to define the following harmonic current emission limits for large LV installations with regard to the LV feeders.

$$E_{IFhi} = \frac{1}{Z_{hi}} \cdot \frac{U_N^2}{S_i} \cdot G_{hLV} \cdot \sqrt[\alpha]{\frac{S_i}{S_t}} \qquad (C.47)$$

where

- E_{IFhi} is the harmonic current emission limit of order h with regard to the LV feeder for the installation (i) connected at LV (%: expressed in percent of the installation current corresponding to its agreed apparent power, $S_i / U_N\sqrt{3}$);
- Z_{hi} is the modulus of the harmonic impedance of the system at the point of evaluation of customer's installation i (Ω);
- U_N is the nominal phase-to-phase voltage of the LV system (V);
- S_i is the agreed apparent power of the installation (i) (VA);
- G_{hLV} is the maximum global contribution of the local LV installations to the h^{th} harmonic voltage in the LV system (%: expressed in percent of the fundamental voltage);
- S_t is the total supply capacity of the considered LV system (VA);
- α is the summation law exponent for large installations.

C.7 Individual emission limits for a large installation connected at LV

To fulfil the general conditions (C.8) and (C.9), it was shown that a sufficient condition for large LV installations is to meet both conditions (C.22) and (C.46). As a consequence, this leads to define the following harmonic current emission limits for the large installations connected at LV.

$$E_{Ihi} = \min\left(E_{IBhi}\,;E_{IFhi}\right) \tag{C.48}$$

That is to say finally:

$$E_{Ihi} = \frac{U_N^2}{S_i}\cdot G_{hLV}\cdot\sqrt[\alpha]{\frac{S_i}{S_t}}\cdot\min\left(\frac{K_{hB}}{Z_{hB}}\,;\frac{1}{Z_{hi}}\right) \tag{C.49}$$

C.8 Justification of the approach used

It can be noted that it is not possible to use the same approach at LV as at MV. For, in IEC/TR 61000-3-6, the harmonic emission limits for individual installations are defined in terms of harmonic voltages irrespective of their locations on the MV system, so that the installations connected near the MV busbar are allowed higher harmonic current limits than the installations connected at the far end of MV feeders. In case an MV/LV transformer is fully loaded by residential customers and only one large installation located very close to the LV busbar, using the same approach at LV as at MV for this large installation would lead to higher harmonic current limits than those obtained by application of Equation (9), by actually neglecting the reduction factor K_{hB}. In that case, the harmonic voltage level at the LV busbar would increase and it would no longer be possible to ensure that the planning levels are not exceeded at the far end of the LV feeders.

Annex D
(informative)

Calculation of the reduction factors for harmonics and unbalance

D.1 Overview

According to Clause C.3, the reduction factor at harmonic order h, K_{hB}, is defined by

$$K_{hB} = \frac{U_{hB}(S_t)}{\max\left(U_{hLV}(S_t)\right)} \quad (D.1)$$

where

- U_{hB} (S_t) is the global contribution to the harmonic voltage of order h at the substation LV busbar due to all the LV installations connected to the considered LV system,
- max (U_{hLV} (S_t)) is the maximum value of the global contribution to the harmonic voltage of order h at any point of the considered LV system due to all the LV installations connected to this LV system,

when the LV system is fully loaded by small installations.

In the same way, the reduction factor for unbalance K_{uB} is defined by

$$K_{uB} = \frac{U_{2B}(S_t)}{\max\left(U_{2LV}(S_t)\right)} \quad (D.2)$$

where

- U_{2B} (S_t) is the global contribution to the voltage unbalance at the substation LV busbar due to all the LV installations connected to the considered LV system,
- max (U_{2LV} (S_t)) is the maximum value of the global contribution to the voltage unbalance at any point of the considered LV system due to all the LV installations connected to this LV system,

when the LV system is fully loaded by small installations.

In this annex, the reduction factors are first considered in the case of harmonic disturbances, then the obtained results are extended to the case of unbalance. The calculation of the reduction factors is dealt with according to the following order:

a) General method to calculate the reduction factors for harmonics,

b) Calculation of the reduction factors for harmonics on a generic case,

c) Assessment of the reduction factors for harmonics on particular cases and recommended values,

d) Assessment of the reduction factors for unbalance on particular cases and recommended values.

D.2 General method to calculate the reduction factors for harmonics

D.2.1 General scheme of an LV public system and assumptions

In this annex, the general scheme on an LV public system is considered, as illustrated on Figure D.1. An MV/LV transformer supplies n feeders through an LV busbar. The transformer is supposed to be fully loaded. Each feeder has a tree structure with spurs, which is different from those of the other feeders. The customer's installations are not supposed to be equi-distributed along the feeders.

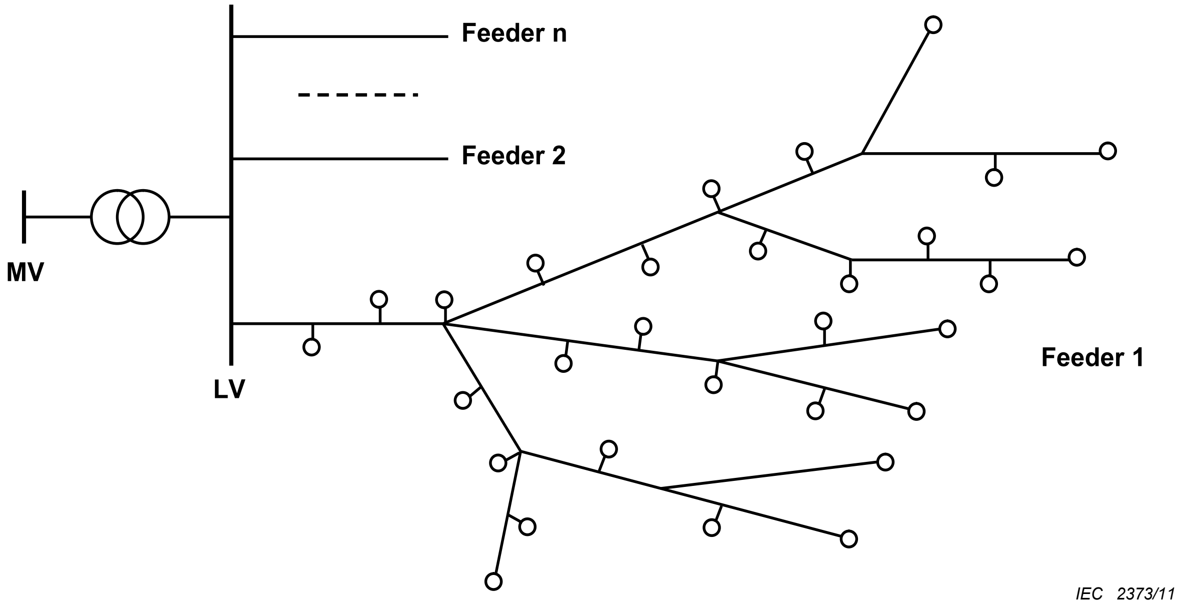


Figure D.1 – General scheme of an LV public system

In this annex, the following assumptions are made.

- Only small installations, which are not subject to the application of the emission limits defined in this report, are connected to the LV system considered (see the definition of the reduction factor in Clause D.1).
- Harmonic current emissions from any small installation do not depend on the point where it is connected to the LV system (see C.2.2). They only depend on the agreed apparent power for the considered installation.
- The summation law exponent for small installations is equal to β (see C.2.3).

From both last assumptions, it comes that the harmonic current of order h produced by installation i is given by

$$I_{hi} = A_h \cdot \sqrt[\beta]{S_i} \tag{D.3}$$

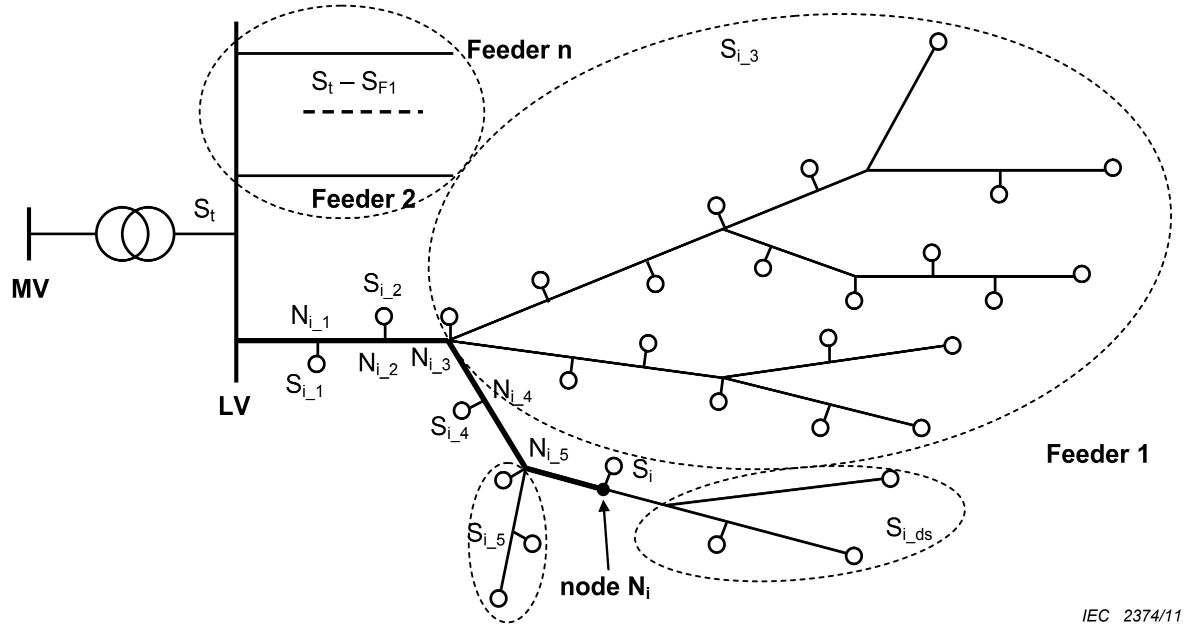
where

- h is the harmonic order;
- I_{hi} is the harmonic current emission level of installation i;
- S_i is the agreed apparent power of installation i;
- β is the summation law exponent for small installations;

- A_h is an allocation constant. This constant does not need to be determined for the calculation of the reduction factor K_{hB}, but can be calculated subsequently.

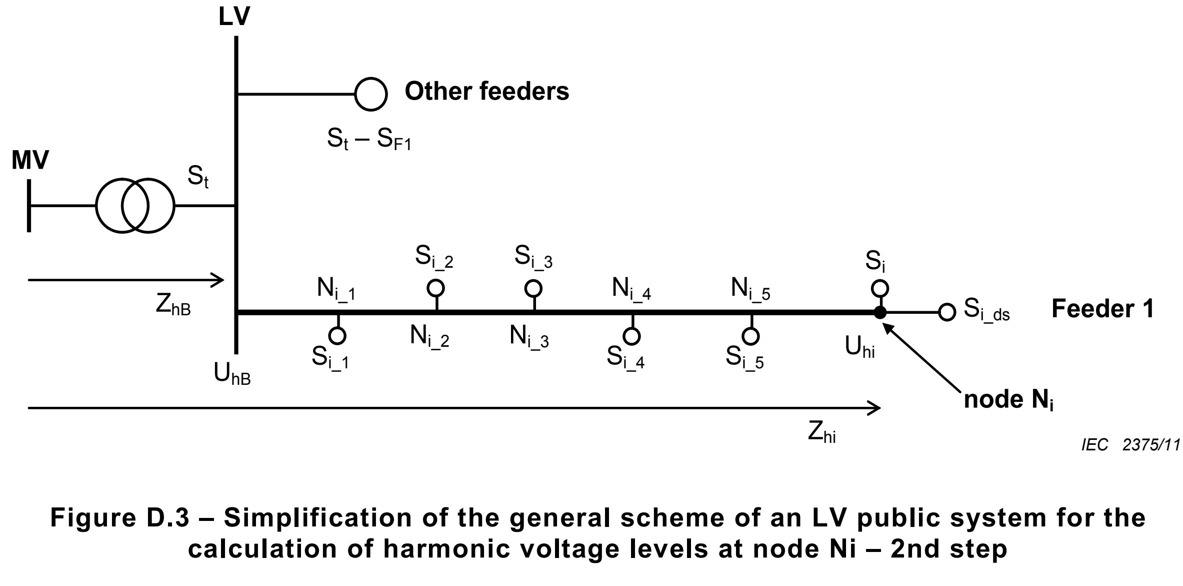
D.2.2 Simplified scheme of an LV public system for the calculation of the global contribution of all LV installations to the harmonic voltage levels at a given node

The purpose in this paragraph is to obtain a simplified equivalent scheme in order to calculate the harmonic voltage levels at any node of the LV system considered. For that, a particular node N_i on feeder 1, which could be anywhere on the LV system, is considered as illustrated in Figure D.2. On the way from the substation LV busbar to node N_i, there are several intermediate nodes, N_{i_1}, N_{i_2}, …, N_{i_s}. Each of these nodes supplies either a small installation (see nodes N_{i_1}, N_{i_2} and N_{i_4}, in the case of Figure D.2) or a set of small installations (see nodes N_{i_3} and N_{i_5}, in the case of Figure D.2).



IEC 2374/11

Figure D.2 – Simplification of the general scheme of an LV public system for the calculation of harmonic voltage levels at node Ni – 1st step



IEC 2375/11

Figure D.3 – Simplification of the general scheme of an LV public system for the calculation of harmonic voltage levels at node Ni – 2nd step

A simplified equivalent scheme of the LV system for the calculation of the harmonic voltage levels at node N_i can then be deduced from Figure D.2, as illustrated in Figure D.3, where

- N_i is the considered node where the harmonic voltage levels are calculated;
- N_{i_k} is the kth intermediate node between the substation LV busbar and node N_i;
- s is the number of intermediate nodes between the LV busbar and node N_i;
- S_t is the total supply capacity of the considered LV system;
- S_{F1} is the apparent power of all installations connected to feeder 1;
- S_i is the agreed apparent power of customer's installation i, directly connected at node N_i;
- S_{i_ds} is the apparent power of all installations downstream from node N_i;
- S_{i_k} is the apparent power of all installations supplied by node N_{i_k};
- Z_{hB} is the modulus of the harmonic impedance of the system at the LV busbar;
- Z_{hi} is the modulus of the harmonic impedance of the system at node N_i;
- Z_{hi_k} is the modulus of the harmonic impedance of order h at intermediate node N_{i_k};
- U_{hi} is the harmonic voltage of order h at node N_i.
- U_{hB} (S_{xx}) is the contribution of all the installations corresponding to the apparent power S_{xx} to the harmonic voltage of order h at the substation LV busbar;
- U_{hi} (S_{xx}) is the contribution of all the installations corresponding to the apparent power S_{xx} to the harmonic voltage of order h at node N_i.

D.2.3 Global contribution of all LV installations at a given node

The global contribution of all the LV installations to the harmonic voltage of order h at the given node N_i is the vectorial combination of the contributions of each set of installations illustrated in Figure D.3. Applying the general summation law, it comes:

$$U_{hi}^{\beta}(S_t) = U_{hi}^{\beta}(S_t - S_{F1}) + \sum_{k=1}^{s} U_{hi}^{\beta}(S_{i\_k}) + U_{hi}^{\beta}(S_i) + U_{hi}^{\beta}(S_{i\_ds}) \tag{D.4}$$

The contribution of one set of installations to the harmonic voltage of order h at node N_i is the product of its harmonic current emission at order h by the common harmonic system impedance seen by this set of installations and node N_i. Thus, taking into account the general assumption made in (D.3), the contribution of all installations supplied by node N_{i_k} is given by

$$U_{hi}(S_{i\_k}) = A_h \cdot Z_{hi\_k} \cdot \sqrt[\beta]{S_{i\_k}} \tag{D.5}$$

Therefore, the global contribution of all the LV installations to the harmonic voltage of order h at node N_i is:

$$U_{hi}^{\beta}(S_t) = A_h^{\beta} \cdot \left[(S_t - S_{F1}) \cdot Z_{hB}^{\beta} + \sum_{k=1}^{s} (S_{i\_k} \cdot Z_{hi\_k}^{\beta}) + S_i \cdot Z_{hi}^{\beta} + S_{i\_ds} \cdot Z_{hi}^{\beta} \right] \tag{D.6}$$

D.2.4 Global contribution of all LV installations at the substation LV busbar

As a particular case of the preceding paragraph, the global contribution of all the LV installations to the harmonic voltage of order h at the substation LV busbar is given by:

$$U_{hB}^{\beta}(S_t) = A_h^{\beta} \cdot S_t \cdot Z_{hB}^{\beta} \tag{D.7}$$

D.2.5 Calculation of the reduction factors for harmonics

The reduction factor for the harmonic of order h can then be calculated for the considered system from:

$$K_{hB} = \frac{U_{hB}(S_t)}{\max\limits_{i}\left[U_{hi}(S_t)\right]} \tag{D.8}$$

where

- U_{hB} (S_t) is given by Equation D.7,
- max (U_{hi} (S_t)) is the maximum value given by Equation (D.6), as a function of node N_i.

D.3 Calculation of the reduction factors for harmonics on a generic case

D.3.1 General

Because of the use of the general summation law, the maximum harmonic voltage level of order h, max (U_{hi} (S_t)), is obtained at the far end of one of the LV feeders. In this paragraph, the calculation of the reduction factor K_{hB} is directly calculated from the global contribution of all LV installations to the harmonic voltage level of order h at the far end of each LV feeder.

D.3.2 Simplified scheme of an LV public system for the calculation of the reduction factors

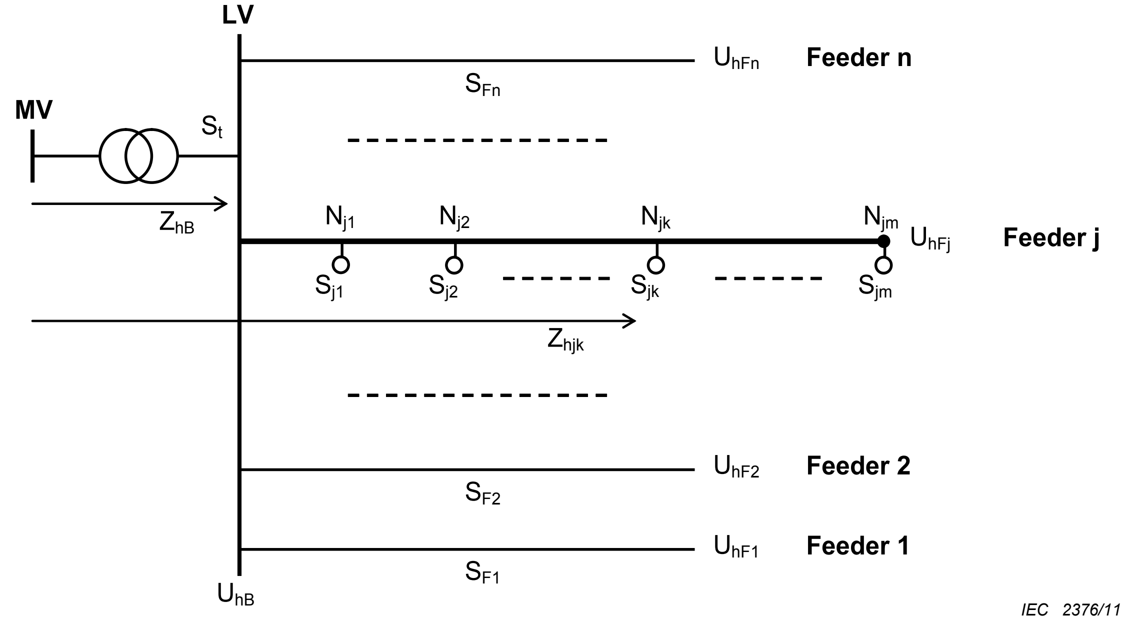


Figure D.4 – Simplified scheme of an LV public system for the calculation of harmonic voltage levels at the far end of LV feeders

For the calculation of the reduction factors for harmonics, the simplified scheme in Figure D.4 is considered. This scheme, derived from Figure D.2 and Figure D.3, allows to calculate the contribution of all LV installations to the harmonic voltage level at the far end of feeder j. On the way from the substation LV busbar to the far end of feeder j, there are m nodes (m depending on the feeder considered), N_{j1}, N_{j2}, …, N_{jk}, …, N_{jm}, N_{jm} being the node at the far end of the feeder. Each of these nodes supplies a set of small installations with a global agreed apparent power S_{jk}.

D.3.3 Global contribution of all LV installations at the far end of LV feeders

According to Equation (D.6), the global contribution of all the LV installations to the harmonic voltage of order h at the far end of feeder j is given by

$$U_{hFj}^{\beta}(S_t) = A_h^{\beta}\cdot\left[(S_t - S_{Fj})\cdot Z_{hB}^{\beta} + \sum_{k=1}^{m} S_{jk}\cdot Z_{hjk}^{\beta}\right] \qquad (D.9)$$

where

- U_{hFj} (S_t) is the contribution of all the LV installations to the harmonic voltage of order h at the far end of feeder j;
- h is the harmonic order;
- m is the number of nodes between the LV busbar and the far end of feeder j, depending on the feeder considered (excluding the LV busbar and including the end of the feeder);
- S_t is the total supply capacity of the considered LV system;
- S_{Fj} is the apparent power of all installations connected to feeder j;
- S_{jk} is the apparent power of all installations supplied by node N_{jk};
- Z_{hB} is the modulus of the harmonic impedance of the system at the LV busbar;
- Z_{hjk} is the modulus of the harmonic impedance of order h at node N_{jk};
- A_h is the allocation constant defined in Equation (D.3);
- β is the summation law exponent for small installations.

D.3.4 Reduction factors for harmonics

As the harmonic voltage level due to all installations connected to the considered LV public system is maximum at the far end of one of the LV feeders, it comes from Equations (D.8), (D.7) and (D.9) that the reduction factor at harmonic order h K_{hB} is given by

$$K_{hB} = \frac{Z_{hB}\cdot\sqrt[\beta]{S_t}}{\max\limits_{j}\left[\sqrt[\beta]{(S_t - S_{Fj})\cdot Z_{hB}^{\beta} + \sum\limits_{k=1}^{m} S_{jk}\cdot Z_{hjk}^{\beta}}\right]} \qquad (D.10)$$

or finally

$$K_{hB} = \frac{1}{\max\limits_{j}\left[\sqrt[\beta]{1 - \frac{S_{Fj}}{S_t} + \sum\limits_{k=1}^{m}\frac{S_{jk}}{S_t}\cdot\left(\frac{Z_{hjk}}{Z_{hB}}\right)^{\beta}}\right]} \qquad (D.11)$$

D.4 Assessment of the reduction factors for harmonics on particular cases and recommended values

D.4.1 Application of the general method on simplified LV systems

In this clause, the general method described in Clause D.3 for the calculation of the reduction factors for harmonics is applied on two particular cases of LV systems, a rural overhead system and an urban underground system, before proposing typical values of these reduction factors for LV systems.

The particular cases of LV systems considered here are simplified systems with the following characteristics:

- the substation LV busbar supplies n identical LV feeders;
- each LV feeder has the same cross section over its total length without spurs;
- the customer's installations are uniformly distributed along the feeders.

It is also assumed that the LV system and the loads connected to it are balanced. In that case, non-triplen harmonic components behave like positive- or negative-sequence components and the complex harmonic impedance of order h at node N_{jk} is given by

$$\underline{Z}_{hjk} = \underline{Z}_{L\,hjk} \tag{D.12}$$

whereas triplen harmonic components behave like zero-sequence components and the complex harmonic impedance at node N_{hjk} is

$$\underline{Z}_{hjk} = \underline{Z}_{L\,hjk} + 3 \cdot \underline{Z}_{Nhjk} \tag{D.13}$$

where

- $\underline{Z}_{hjk}$ is the complex harmonic impedance of order h at node N_{jk};
- $\underline{Z}_{Lhjk}$ is the complex harmonic impedance of order h at node N_{jk} for the line conductor;
- $\underline{Z}_{Nhjk}$ is the complex harmonic impedance of order h at node N_{jk} for the neutral conductor.

As explained in C.2.3, the values of the summation law exponent for small installations β are supposed to be lower than the values α considered for large installations in Table 3. The values used for β in the following cases for harmonic orders 3 to 13 are given in Table D.1.

Table D.1 – Summation law exponent values used for small installations

Harmonic order h	3	5	7	9	11	13
β	1	1,2	1,2	1,2	1,4	1,4

D.4.2 Case of a rural overhead LV system

The LV system considered in this paragraph has the following characteristics:

- S_t = 100 kVA (total supply capacity of the LV system);
- X_B = 4 % (reactance of the MV/LV transformer at fundamental frequency; the MV upstream impedance is neglected);
- n = 2 (number of LV feeders);
- l_F = 300 m (length of the LV feeders);
- $\underline{z}_{LF}$ = 0,96 + j 0,35 Ω/km (impedance of the line conductor of LV feeders at fundamental frequency);
- $\underline{z}_{NF}$ = 0,96 + j 0,35 Ω/km (impedance of the neutral conductor of LV feeders at fundamental frequency);
- U_N = 400 V (nominal voltage of the LV system).

The values of the reduction factor for harmonic orders 3 to 13 obtained with the general method described in Clause D.3 on this particular case are given in Table D.2.

Table D.2 – values of the reduction factors in the case of a particular rural overhead LV system

Harmonic order h	3	5	7	9	11	13
Reduction factor K_{hB}	0,30	0,65	0,66	0,32	0,66	0,66

D.4.3 Case of an urban underground LV system

The LV system considered in this paragraph has the following characteristics:

- S_t = 630 kVA (total supply capacity of the LV system);
- X_B = 4 % (reactance of the MV/LV transformer at fundamental frequency; the MV upstream impedance is neglected);
- n = 5 (number of LV feeders);
- l_F = 250 m (length of the LV feeders);
- $\underline{z}_{LF}$ = 0,32 + j 0,08 Ω/km (impedance of the line conductor of LV feeders at fundamental frequency);
- $\underline{z}_{NF}$ = 0,64 + j 0,08 Ω/km (impedance of the neutral conductor of LV feeders at fundamental frequency);
- U_N = 400 V (nominal voltage of the LV system).

The values of the reduction factor for harmonic orders 3 to 13 obtained with the general method described in D.3 on this particular case are given in Table D.3.

Table D.3 – values of the reduction factors in the case of a particular urban underground LV system

Harmonic order h	3	5	7	9	11	13
Reduction factor K_{hB}	0,35	0,81	0,81	0,47	0,81	0,81

D.4.4 Example of typical values of the reduction factors for harmonics on LV systems

The values of the reduction factors for harmonics mainly depend on the total supply capacity of the LV system, the length of the LV feeders and their number. They may be calculated by the system operator or owner according to the actual characteristics of the LV systems he operates, by using the general method described in this annex. In the absence of sufficiently reliable data for the assessment of the reduction factors for harmonics, typical values such as those given in Table D.4 may be used. These values, based on simulation, lead to the definition of harmonic limits that are reasonably conservative. Thus, the values in Table D.4 are generally suitable for LV systems, but in some rare cases (very long or loaded LV feeders) lower values should be chosen for the reduction factors for harmonics.

Table D.4 – Example of typical values of the reduction factors KhB for harmonics

	Triplen harmonics (h = 3 n)	Non-triplen harmonics (h ≠ 3 n)
Overhead LV systems	0,20	0,50
Underground LV systems	0,20	0,65

D.5 Assessment of the reduction factor for unbalance on particular cases and recommended values

D.5.1 Application of the method for the assessment of the reduction factor for unbalance

The same assumptions as for harmonics in D.2.1 can be made for unbalance. For a similar summation law is used for unbalance, and, as for harmonics, current unbalance produced by a small installation only depends on its agreed power irrespective of its point of connection to the LV system. Therefore, for the assessment of the reduction factor for unbalance, it is possible to use the same method as the one developed for harmonics. The only changes are the use of negative-sequence impedances instead of harmonic impedances and the use of the summation law exponent for unbalance. It will be supposed here that

- the negative-sequence system impedances can be approximated by the positive-sequence system impedances at LV,
- the summation law exponent for small installations β is equal to the summation law exponent α defined in 7.4.

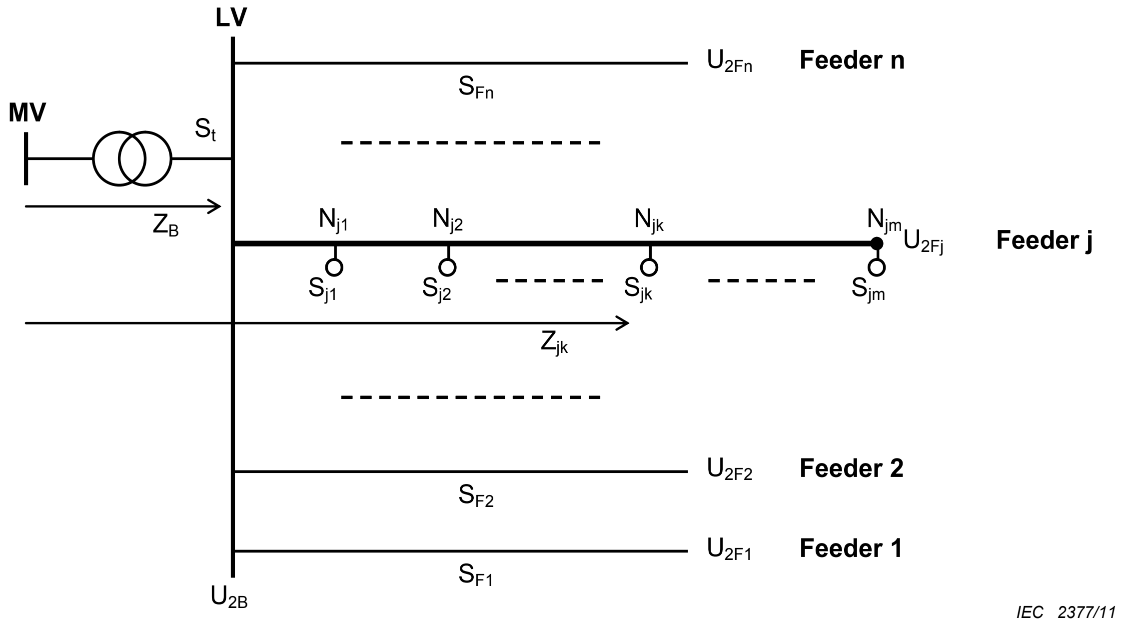


Figure D.5 – Simplified scheme of an LV public system for the calculation of voltage unbalance levels at the far end of LV feeders

For the calculation of the reduction factor for unbalance, the simplified scheme in Figure D.5 is considered. In the same way as in Equation (D.9) for harmonics, the global contribution of all the LV installations to the voltage unbalance at the far end of feeder j is given by

$$U_{2Fj}^{\alpha}(S_t) = A_u^{\alpha} \cdot \left[(S_t - S_{Fj}) \cdot Z_B^{\alpha} + \sum_{k=1}^{m} S_{jk} \cdot Z_{jk}^{\alpha} \right] \qquad \text{(D.14)}$$

where

- U_{2Fj} (S_t) is the contribution of all the LV installations to the voltage unbalance at the far end of feeder j;
- m is the number of nodes between the LV busbar and the far end of feeder j, depending on the feeder considered (excluding the LV busbar and including the end of the feeder);
- S_t is the total supply capacity of the considered LV system;

- S_{Fj} is the apparent power of all installations connected to feeder j;
- S_{jk} is the apparent power of all installations supplied by node N_{jk};
- Z_B is the modulus of the system impedance at the LV busbar (fundamental frequency);
- Z_{jk} is the modulus of the system impedance at node N_{jk} (fundamental frequency);
- A_u is the allocation constant for unbalance;
- α is the summation law exponent for unbalance.

The global contribution of all the LV installations to the voltage unbalance at the substation LV busbar is:

$$U_{2B}^{\alpha}(S_t) = A_u^{\alpha} \cdot S_t \cdot Z_B^{\alpha} \qquad \text{(D.15)}$$

So the reduction factor for unbalance K_{uB} is given by

$$K_{uB} = \frac{1}{\max\limits_{j} \left[\sqrt[\alpha]{1 - \frac{S_{Fj}}{S_t} + \sum_{k=1}^{m} \frac{S_{jk}}{S_t} \cdot \left(\frac{Z_{jk}}{Z_B} \right)^{\alpha}} \right]} \qquad \text{(D.16)}$$

In the following subclauses, this method is applied to the same particular cases of LV systems as for harmonics, a rural overhead system and an urban underground system, before proposing typical values of the reduction factor for unbalance.

D.5.2 Case of a rural overhead LV system

The considered LV system has the following characteristics:

- S_t = 100 kVA (total supply capacity of the LV system);
- X_B = 4 % (reactance of the MV/LV transformer);
- n = 2 (number of LV feeders);
- l_F = 300 m (length of the LV feeders);
- $\underline{z}_{LF}$ = 0,96 + j 0,35 Ω/km (impedance of LV feeders);
- U_N = 400 V (nominal voltage of the LV system).

The value of the reduction factor for unbalance obtained on this particular case is:

$$K_{uB} = 0{,}45.$$

D.5.3 Case of an urban underground LV system

The considered LV system has the following characteristics:

- S_t = 630 kVA (total supply capacity of the LV system);
- X_B = 4 % (reactance of the MV/LV transformer);
- n = 5 (number of LV feeders);
- l_F = 250 m (length of the LV feeders);
- $\underline{z}_{LF}$ = 0,32 + j 0,08 Ω/km (impedance of LV feeders);
- U_N = 400 V (nominal voltage of the LV system).

The value of the reduction factor for unbalance obtained on this particular case is:

$$K_{uB} = 0{,}52.$$

D.5.4 Typical value of the reduction factor for unbalance on LV systems

The value of the reduction factor for unbalance mainly depend on the total supply capacity of the LV system, the length of the LV feeders, their cross section and their number. It may be calculated by the system operator or owner according to the actual characteristics of the LV systems he operates, by using the general method described in this annex. In the absence of sufficiently reliable data for this assessment, the typical following value may be used.

$$K_{uB} = 0{,}25$$

This value leads to the definition of unbalance limits that are reasonably conservative. Thus, this value is generally suitable for LV systems, but in some rare cases (very long or loaded LV feeders) a lower value should be chosen for the reduction factor for unbalance.

Annex E
(informative)

Example of method to allocate harmonic emission limits at stage 3

E.1 Overview

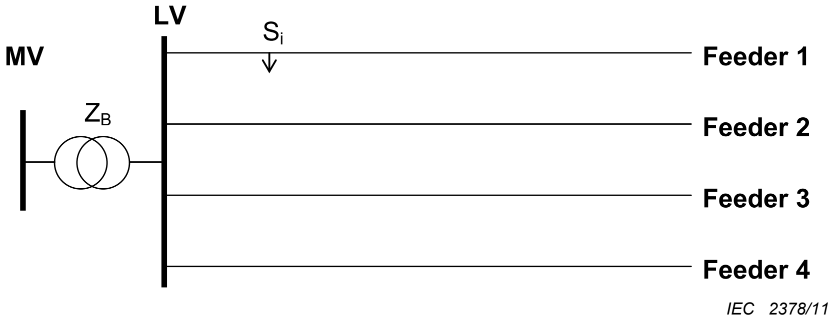


Figure E.1 – LV system under study

The theory will be discussed with reference to the 4 feeder radial LV system shown in Figure E.1 and can be simply extended to any other number of feeders. The study installation whose harmonic allocation is to be determined is a large installation of agreed power S_i. Its position is given in terms of the harmonic impedance Z_{hi} from the proposed point of connection to the MV busbar.

Steps in the application of the method are the following.

a) Estimate the harmonic voltage from all contributions other than large installation (i) of agreed power S_i and other large installations yet to be connected (See Clause E.2).

b) Determine the harmonic voltage available to all large installations (See Clause E.3).

c) Determine a harmonic allocation coefficient which can be applied to all large installations to be connected to this LV system (See Clause E.4).

d) Use the harmonic allocation coefficient to determine the harmonic allocation for the study installation (i) (see Clause E.5).

Assumptions need to be made in some of the steps regarding data which is not normally available. It is possible to fine-tune the method if improved data is obtained over time as discussed in Clause E.5.

E.2 Estimation of the harmonic voltage contributions from all sources other than large installations yet to be connected

One harmonic source is the MV supply system to which the transformer primary is connected. It is usual to assume the MV harmonic voltage will reach the corresponding planning level and that this will propagate to the LV system unchanged. The MV planning level is represented by the symbol L_{hMV}.

Other sources are the existing installations within the LV system. Their harmonic emission will be determined by the types of equipment contained, the harmonic emission standards to which the equipment conforms and the pattern of use. There is no accurate method of predicting this. An estimate of its value can be obtained by

- measurement,
- simulation.
- The allocation of a proportion of the harmonic voltage available based on the ratio of the installed VA relative to the supply capacity.

An estimate also needs to be made of the contribution made by small LV installations yet to be connected. This requires some application of engineering judgement. This might be determined by scaling the contribution found for the existing installations, described in the paragraph above, in proportion to the relative VA of the two load types.

Let the contribution made by existing and future small installations at the hth harmonic to Feeder 1, as an example, be $U_{hF1}(S_{St})$.

E.3 Determination of the harmonic voltage available to all large installations

Suppose also that the planning level for the hth harmonic voltage in the LV system is L_{hLV}. Using the summation law, the global voltage available on Feeder 1 for all large installations to be connected to the LV system can be determined as

$$G_{hF1}(S_{Lt}) = \sqrt[\alpha]{L_{hLV}^{\alpha} - L_{hMV}^{\alpha} - U_{hF1}^{\alpha}(S_{St})} \qquad \text{(E.1)}$$

where

- $G_{hF1}(S_{Lt})$ is the acceptable global contribution of all large LV installations to the hth harmonic voltage at the end of feeder 1;
- L_{hLV} is the planning level for the hth harmonic in the LV system;
- L_{hMV} is the planning level for the hth harmonic in the upstream MV system;
- $U_{hF1}(S_{St})$ is the contribution of all small LV installations to the harmonic voltage of order h at the end of feeder 1;
- α is the summation law exponent for large installations.

Similar values can be determined for each of the other feeders.

E.4 Determination of harmonic allocation constant for large installations

E.4.1 Allocation principle

Harmonic allocation should be made taking into account the installation size. Installations of a equal size can be allocated an equal quota of

(i) harmonic voltage
(ii) harmonic current
(iii) harmonic VA

These three allocation principles have been proposed and compared in other documents (originally in Annex D and E of the IEC/TR 61000-3-6:1996) where it is shown that (i) and (ii) are unsatisfactory where LV feeder impedance is significant, while (iii) gives a good compromise and is the allocation principle to be used here. However, Principle (iii) has a difficulty in its application – it is necessary to have data for both agreed power and position for all large installations before the allocation can be calculated. Although there might be advance knowledge for some large installations, there will generally be some for which nothing is known at the time when a study installation (i) is being assessed. Finding good estimates for this missing data is addressed in the next subclause.

E.4.2 Estimate of magnitude and position of large installations

The large installation load is made up of the particular study load and other large installations yet to be connected. It can be considered to be made up of three components as shown in Figure E.2.

(i) Study installation (i): agreed power S_i with known position for which a harmonic allocation is to be made.

(ii) Known large installations: it is possible in some cases that there are large installations, yet to be connected, whose agreed power and position are known. These are represented in Figure E.2 as loads of agreed power S_{kLF1} – S_{kLF4} on Feeders 1-4, with position represented by the equivalent harmonic impedance. Where there are more than one such load per feeder, they can be represented individually. Alternatively, where it is desired to reduce calculation, they can be combined into one load per feeder with an average representative position. This is the approach taken here.

(iii) Unknown large installations: the remainder of the future large installation load (symbol S_{uLt}) has a total value which can be estimated from the unused supply capacity which is ultimately desired to utilise. These are represented in Figure E.2 as loads of agreed power S_{uLF1} – S_{uLF4} on Feeders 1-4, with position represented by the equivalent harmonic impedance.

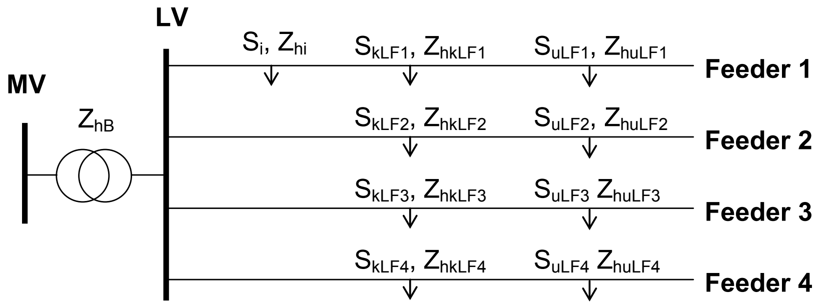


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Figure E.2 – Large installation components

A reasonable estimate of the magnitude and position of the various parts of the unknown large installation component discussed in (iii) above needs to be made so that an allocation based on harmonic VA can be determined as shown in E.4.3. One approach for making this estimate is as follows.

a) Determine the total large installation load S_{Lt}

$$S_{Lt} = S_i + (S_{kLF1} + S_{kLF2} + S_{kLF3} + S_{kLF4}) + S_{uLt} \tag{E.2}$$

b) Determine the average large installation load/feeder S_{L_av}:

$$S_{L\_av} = \frac{S_{Lt}}{n} \tag{E.3}$$

c) Find the number of feeders with a known loading (made up from S_i, S_{kLF1} – S_{kLF4}) less than S_{L_av}. Suppose this to be $n_{less\_than\_av}$. S_{uLt} is then distributed uniformly over these feeders by giving each an increment ΔS_{uL}:

$$\Delta S_{uL} = \frac{S_{uLt}}{n_{less\_than\_av}} \tag{E.4}$$

Thus, using this method, some of $S_{uLF1} - S_{uLF4}$ will be zero while the rest will equal ΔS_{uL}. Several studies have been made which suggest that an assumed position of 30 % of the feeder length from the supply will minimise errors.

E.4.3 Determination of A_h for LV installations

For a large installation of agreed power S_i, the modulus of the impedance at the point of evaluation is represented by the symbol Z_{hi}. This is made up of the harmonic impedances of the transformer and feeder (including resistance terms). The modulus of the harmonic impedance of the transformer is represented by Z_{hB}. An allocation is made on the basis of harmonic VA if the allocated current emission E_{Ihi} is taken as:

$$E_{Ihi} = \frac{A_h \cdot \sqrt[\alpha]{S_i}}{\sqrt{Z_{hi}}} \qquad \text{(E.5)}$$

The allocation constant A_h needs to be determined so that the available harmonic voltage for each feeder is not exceeded. The calculation of the harmonic voltage in a feeder must account both for those installations directly connected and for those connected in adjacent feeders.

The voltage produced at the point of evaluation by the allocated current for a large installation of agreed power S_k is:

$$U_{hk}(S_k) = Z_{hk} \cdot E_{Ihk} = A_h \cdot \sqrt[\alpha]{S_k} \cdot \sqrt{Z_{hk}} \qquad \text{(E.6)}$$

The voltage produced at the supply transformer terminals by the allocated current for a large installation of agreed power S_k is:

$$U_{hB}(S_k) = Z_{hB} \cdot E_{Ihk} = \frac{A_h \cdot Z_{hB} \cdot \sqrt[\alpha]{S_k}}{\sqrt{Z_{hk}}} \qquad \text{(E.7)}$$

For Feeder 1, by use of the summation law:

$$\begin{aligned} &\left\{ \left(A_h \cdot \sqrt[\alpha]{S_i} \cdot \sqrt{Z_{hi}}\right)^{\alpha} + \left(A_h \cdot \sqrt[\alpha]{S_{kLF1}} \cdot \sqrt{Z_{hkLF1}}\right)^{\alpha} + \left(A_h \cdot \sqrt[\alpha]{S_{uLF1}} \cdot \sqrt{Z_{huLF1}}\right)^{\alpha} \right\} \\ &+ \left\{ \sum_{j=2}^{4} \left(\frac{A_h \cdot Z_{hB} \cdot \sqrt[\alpha]{S_{kLFj}}}{\sqrt{Z_{hkLFj}}} \right)^{\alpha} + \sum_{j=2}^{4} \left(\frac{A_h \cdot Z_{hB} \cdot \sqrt[\alpha]{S_{uLFj}}}{\sqrt{Z_{huLFj}}} \right)^{\alpha} \right\} \le G_{hF1}^{\alpha}(S_{Lt}) \end{aligned} \qquad \text{(E.8)}$$

The first three terms (in the first curly bracket) represent the harmonic voltage contribution to Feeder 1 from loads connected to it. The remaining terms, also bracketed, give the harmonic voltage contribution to Feeder 1 from loads connected to other feeders.

We define the quantity A_{hF1} as the maximum allowed value of A_h giving an acceptable value for the harmonic voltage in Feeder 1. Hence

$$A_{hF1} = \frac{G_{hF1}(S_{Lt})}{\sqrt[\alpha]{\left\{S_i \cdot Z_{hi}^{\alpha/2} + S_{kLF1} \cdot Z_{hkLF1}^{\alpha/2} + S_{uLF1} \cdot Z_{huLF1}^{\alpha/2}\right\} + \left\{\sum_{j=2}^{4} \frac{S_{kLFj} \cdot Z_{hB}^{\alpha}}{Z_{hkLFj}^{\alpha/2}} + \sum_{j=2}^{4} \frac{S_{uLFj} \cdot Z_{hB}^{\alpha}}{Z_{huLFj}^{\alpha/2}}\right\}}} \tag{E.9}$$

Similar equations can be written for AhF2 – AhF4.

To ensure that the largest harmonic voltage in this LV system is less than the limit value, A_h is chosen as:

$$A_h = \mathrm{Min}\left(A_{hF1}, A_{hF2}, A_{hF3}, A_{hF4}\right) \tag{E.10}$$

The use of the value in Equation (E.10) allows that, when the system is utilized at its full designed capacity and all installations are taking their full emission allocation, the highest harmonic voltage occurring at the end of LV feeders is just at the LV planning level $L_{hLV.}$

E.5 Determination of harmonic allocation for the study installation

The harmonic current to be allocated is found using Equation (E.5) for the study installation giving

$$E_{Ihi} = \frac{A_h \cdot \sqrt[\alpha]{S_i}}{\sqrt{Z_{hi}}} \tag{E.11}$$

It is emphasised that the same value of A_h can be used for all future large installation studies for the given LV system, unless one wishes to review the data used in its calculation at some later date. For example, at some future time it might become apparent the small installation load is different to what was originally assumed. This can be used to give improved values for $U_{hFj}(S_{St})$ and hence of $G_{hFj}(S_{Lt})$ for one or more feeders, and this may lead to a better value for A_h from Equation (E.10).

Annex F
(informative)

Example of application of the approach presented in Annex E

F.1 Overview

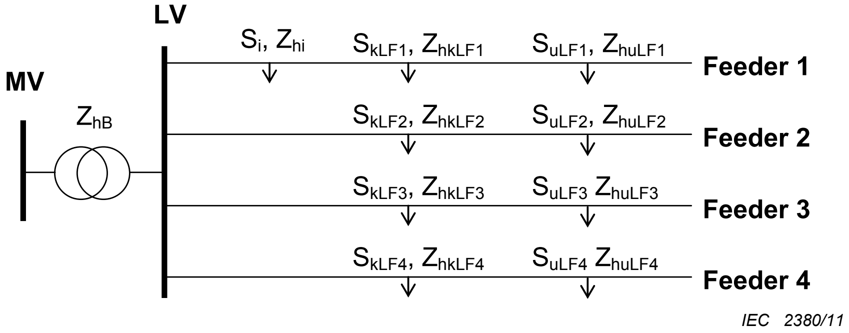

Figure F.1 – System under study

The system under study is shown in Figure F.1. The installation on Feeder 1 with an agreed power of S_i is the study installation. Known large installations are represented with agreed power S_{kLF1} – S_{kLF4}, while large installation capacity whose details are unknown are represented with agreed power S_{uLF1} – S_{uLF4}.

NOTE Small installations are not shown on this figure, however, they are included in the determination of $G_{hFj}(S_{Lt})$.

It is required to determine the 5th harmonic current allocation for a study installation (i) of 50 kVA connected 50m from the supply point. Main system data is given in Table F.1.

Table F.1 – Main system data

Number of LV feeders	4
LV feeder reactance	0,4 Ω/km
LV feeder R/X	2
Line-line voltage	415 V
Transformer rating	350 kVA
Transformer reactance	5 %

All feeders have a length of 100 m and it is assumed that, at the 5th harmonic, there is 1 % harmonic voltage to be allocated to large installations. The following data (see Table F.2) is given for other large installations yet to be connected for which size and connection details are known.

Table F.2 – Known large installation data

LV feeder ID	Installation agreed power kVA	Installation distance from transformer m
1	50	50
2	50	50
3	50	50
4	50	50

There is 60 kVA of large installation capacity which has not been allocated to particular installations at this time.

F.2 Step 1: Estimation of the harmonic voltage contributions from all sources other than large installations yet to be connected (see Clause E.2)

See Step 2.

F.3 Step 2: Determination of the harmonic voltage available to all large installations (see Clause E.3)

Steps 1 and 2 do not need to be carried out in detail for the example given, as it is stated that $G_{hFj}(S_{Lt})$, the available harmonic voltage for large installations, is 1% for each feeder.

F.4 Step 3: Estimate of magnitude and position of large installations (see Clause E.4.2)

The total LV large installation load is determined from Equation (E.2)

$$S_{Lt} = S_i + S_{kLF1} + S_{kLF2} + S_{kLF3} + S_{kLF4} + S_{uLt} = 50 + 50 + 50 + 50 + 50 + 60 = 310\,\text{kVA}$$

The average large installation load/feeder is determined from Equation (E.3)

$$S_{L\_av} = \frac{S_{Lt}}{n} = \frac{310}{4} = 77{,}5\,\text{kVA}$$

The known load on each of the LV feeders is given in Table F.2, with the addition of another 50 kVA (the study installation) on Feeder 1. Hence there are three feeders, Feeders 2-4, with less than the computed average loading. The unknown future load is allocated equally to these three feeders. From Equation (E.4)

$$\Delta S_{uL} = \frac{S_{uLt}}{n_{less\_than\_av}} = \frac{60}{3} = 20\,\text{kVA}$$

Hence $S_{uLF1} = 0$

$$S_{uLF2} = S_{uLF3} = S_{uLF4} = \Delta S_{uL} = 20\ \text{kVA}$$

The three loads of agreed power $S_{uLF2} – S_{uLF4}$ are all assumed to be connected at a position of 30% of the feeder length, that is 30 m from the supply point. Figure F.2 shows the assumed LV installations including the estimated unknown load which has been just computed.

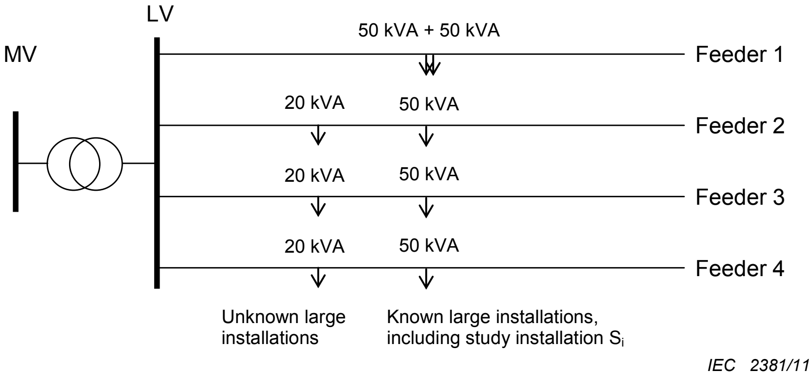

Figure F.2 – Data for large installations

F.5 Step 4: Determination of harmonic impedances

This is a standard calculation in harmonic analysis and is not referred to in Annex E.

We shall use a base of 350 kVA (the transformer rating) for calculations. For this case, it is sufficient to determine three impedances – (i) transformer, (ii) feeder impedance to the unknown installations' estimated position, (iii) feeder impedance to the known installations' estimated position. It is noted that, in this case, the study installation will have the same feeder impedance as impedance (iii).

$$Z_N = \frac{U_N^2}{S_t} = \frac{415^2}{350 \cdot 10^3} = 0{,}492\ \Omega$$

(i) Transformer:

$$Z_{hB} = h \cdot X_B = 5 \times 0{,}05 = 0{,}25\ \text{pu}$$

(ii) Unknown load:

For the feeder,

$$X_{uLFj} = \frac{0{,}4 \times 0{,}03}{0{,}492} = 0{,}0244\ \text{pu}$$

$$R_{uLFj} = 2 \cdot X_{uLFj} = 0{,}049\ \text{pu}$$

For the total impedance, including the transformer

$$Z_{huLFj} = \left| R_{uLFj} + jh\left(X_B + X_{uLFj}\right)\right| = \left|0{,}049 + j5\left(0{,}05 + 0{,}0244\right)\right| = 0{,}375\ \text{pu}$$

(iii) Known LV installations and study installation:

For the feeder,

$$X_{kLFj} = \frac{0{,}4 \times 0{,}05}{0{,}492} = 0{,}0407 \text{ pu}$$

$$R_{kLFj} = 2 \cdot X_{kLFj} = 0{,}081 \text{ pu}$$

For the total impedance, including the transformer

$$Z_{hkLFj} = \left| R_{kLFj} + jh\left(X_B + X_{kLFj}\right) \right| = \left| 0{,}081 + j5\left(0{,}05 + 0{,}0407\right) \right| = 0{,}460 \text{ pu}$$

F.6 Step 5: Determination of A_h for LV installations (see E.4.3)

To ensure allocation is made on the basis of harmonic VA, the allocated current emission E_{Ihk} for the large installation of agreed power S_k is taken as Equation (E.5)

$$E_{Ihk} = \frac{A_h \cdot \sqrt[\alpha]{S_k}}{\sqrt{Z_{hk}}}$$

For numerical calculation, it is simple to assume an initial value for A_h of 1. Next one determines the harmonic voltage produced at the end of each feeder. By comparing this voltage with the allowed feeder global voltage, one can determine a maximum value allowed for A_{hFj} for the given feeder. A value which can be used for the LV system under study is then found by taking the minimum of these different A_{hFj} values.

For the unknown loads

$$E_{Ih\,uLFj} = \frac{1 \cdot \sqrt[1{,}4]{20/350}}{\sqrt{0{,}375}} = 0{,}211 \text{ pu}$$

while for the known installations and the study installation

$$E_{Ihi} \left(\text{or } E_{Ih\,kLFj}\right) = \frac{1 \cdot \sqrt[1{,}4]{50/350}}{\sqrt{0{,}460}} = 0{,}368 \text{ pu}$$

To determine the voltage at the end of a specific feeder, two different types of contributions need to be determined:

- voltages due to installations connected to the feeder, equal to the current drawn times the impedance to the point of connection;
- voltages due to installations connected to other feeders, equal to the current drawn times the harmonic impedance of the supply transformer.

Table F.3 shows, for each installation, its key parameters and harmonic voltages (i) at the point of connection and (ii) at the transformer.

Table F.3 – Harmonic voltages due to large installations (all values are in pu, h has the value 5 and Ah is provisionally taken as 1)

Load	Agreed power	Z_h	E_{Ih}	U_h(i)	U_h(ii)
S_i, S_{kLFi}	0,143	0,460	0,368	0,169	0,092
S_{uLFi}	0,057	0,375	0,211	0,079	0,053

For Feeder 1, the voltage at the end due to the LV installations consists of contribution (i) from installations of agreed power S_i and S_{kLF1} and contribution (ii) from all other large installations. These need to be combined using the summation law giving

$$\sqrt[1,4]{2\times 0{,}169^{1,4} + 3\times 0{,}092^{1,4} + 3\times 0{,}053^{1,4}} = 0{,}445\ \text{pu}$$

Since the allowable large installation emission $G_{hF1}(S_{Lt})$ is 0,01 pu, the maximum allowed value for A_{hF1} is

$$A_{hF1} = 0{,}01/0{,}445 = 0{,}0225$$

Similarly, a harmonic voltage of 0,409 pu can be determined for Feeders 2, 3 and 4. By a similar calculation as above, this gives the maximum allowed values for feeder allocation constants of :

$$A_{hF2} = A_{hF3} = A_{hF4} = 0{,}01/0{,}409 = 0{,}0244$$

To ensure that no feeder exceeds the allowed harmonic limit, A_h is chosen as the minimum of these values giving

$$A_h = 0{,}0225$$

F.7 Step 6: Determination of harmonic allocation for the study installation (see Clause E.5)

Making use of Equation (E.11),

$$E_{Ihi} = \frac{A_h \cdot \sqrt[\alpha]{S_i}}{\sqrt{Z_{hi}}} = \frac{0{,}0225\times\sqrt[1,4]{50/350}}{\sqrt{0{,}460}} = 0{,}0083\ \text{pu}$$

on a base of 350 kVA. This can also be expressed as a percentage relative to the installation fundamental current.

$$E_{Ihi}\,(\%) = 100\cdot\frac{E_{Ihi}}{S_i} = 100\cdot\frac{0{,}0083}{50/350} = 5{,}8\ \%$$

Annex G
(informative)

List of principal letter symbols, subscripts and symbols

G.1 Letter symbols

A	Allocation constant depending on the harmonic voltage response of a given system
a	vectorial operator ($a = 1\angle 120^\circ$) used for calculating the symmetrical components of three-phase quantities
α	exponent of the summation law (general case)
β	exponent of the summation law for small installations
D	disturbance level
E	emission limit
G	acceptable global contribution of emissions in some part of a system
h	harmonic order
I	current
K, k	coefficient or ratio between two values (general meaning)
L	planning level
m	number of nodes between the substation LV busbar and the far end of a feeder
N	node on a feeder
n	number of feeders
PCC	Point of Common Coupling
POC	Point Of Connection
POE	Point Of Evaluation
R	resistance
S	apparent power
ΔS	apparent power variation of a fluctuating installation
T	transfer coefficient
U	voltage
X	reactance
Z	impedance modulus
$\underline{Z}$	*complex impedance*

G.2 List of subscripts

a, b, c	phase identifier on a 3-phase system
B	substation LV busbar
h	harmonic order
i	single customer's installation
j	single feeder
k	single node

LV	Low Voltage
ML	between MV and LV systems
MV	Medium Voltage
Plt	long-term flicker
Pst	short-term flicker
u	unbalance (negative-sequence)
1, 2, 0	positive, negative, zero-sequence component (of 3-phase voltages or currents)
2	unbalance (negative-sequence)

G.3 List of main symbols

(Self-explaining symbols are not listed)

E_{Ihi}	harmonic current emission limit of order h for the customer's installation (i)
$E_{I2\ i}$	current unbalance emission limit for the customer's installation (i)
E_{Plti}	long-term flicker emission limit for the customer's installation (i)
E_{Psti}	short-term flicker emission limit for the customer's installation (i)
G_{hB}	acceptable global contribution to the h^{th} harmonic voltage at the substation LV busbar due to all LV installations that can be supplied from the considered system (expressed in percent of the fundamental voltage)
G_{hLV}	maximum acceptable global contribution to the h^{th} harmonic voltage anywhere in the LV system due to all LV installations that can be supplied from the considered system (expressed in percent of the fundamental voltage)
G_{PstLV} (G_{PltLV})	maximum acceptable global contribution to the flicker level anywhere in the LV system due to all LV installations that can be supplied from the considered system (expressed in terms of P_{st} or P_{lt})
G_{uB}	acceptable global contribution to the voltage unbalance at the substation LV busbar due to all LV installations that can be supplied from the considered system (expressed in terms of the voltage unbalance factor u)
G_{uLV}	maximum acceptable global contribution to the voltage unbalance anywhere in the LV system due to all LV installations that can be supplied from the considered system (expressed in terms of the voltage unbalance factor u)
I_h	harmonic current of order h (generic)
I_{hFjk}	harmonic current of order h flowing through feeder j just upstream node N_{jk}
I_{hi}	harmonic current emission level of order h of customer's installation (i)
I_{hjk}	harmonic current emission from customer's installations connected to node N_{jk}
I_{hT}	harmonic current of order h flowing through the MV/LV transformer
i_2	current unbalance factor (see definition 3.29.6)
K_{hB}	reduction factor at harmonic order h, which corresponds to the ratio of the harmonic voltage level at the substation LV busbar due to all the installations connected to the considered LV system to the maximum value of the harmonic voltage level on the LV system due to these installations
K_{uB}	reduction factor for voltage unbalance, which corresponds to the ratio of the level of voltage unbalance at the substation LV busbar due to all the installations connected to the considered LV system to the maximum level of voltage unbalance on the LV system due to these installations

k_{hvs}	multiplying factor for the short-term harmonic voltage compatibility level of order h to obtain the corresponding very short-term compatibility level (as defined in 4.2.2, Equation (1))
l_F	length of an LV feeder
L_{hLV}	harmonic voltage planning level of order h for LV (%)
L_{hMV}	harmonic voltage planning level of order h for MV (%)
L_{PltLV}	long-term flicker planning level for LV (p.u.)
L_{PltMV}	long-term flicker planning level for MV (p.u.)
L_{PstLV}	short-term flicker planning level for LV (p.u.)
L_{PstMV}	short-term flicker planning level for MV (p.u.)
L_{uLV}	voltage unbalance planning level at LV
L_{uMV}	voltage unbalance planning level at MV
N_{jk}	node k on feeder j
S_{Fj}	apparent power of all installations connected to feeder j
S_i	agreed power of customer's installation (i)
S_{jk}	apparent power of all installations supplied by node N_{jk}
S_{LFj}	apparent power of all large installations connected to feeder j
S_{Lt}	apparent power of all large installations connected to the considered LV system
S_{min}	minimum value of the agreed power of LV installations to which the procedure to define emission limits developed in this report applies
S_{sc}	short-circuit power
S_{SFj}	apparent power of all small installations connected to feeder j
S_{St}	apparent power of all small installations connected to the considered LV system
S_t	total supply capacity of the considered LV system including provision for future load growth
S_{ui}	single phase power equivalent of the load unbalance of installation (i)
THD	Total Harmonic Distortion – ratio of the r.m.s. value of the sum of all the harmonic components up to a specified order (H) to the r.m.s. value of the fundamental component
T_{hML}	MV/LV harmonic voltage transfer coefficient of order h; value depending on system characteristics, load level and harmonic order
T_{PltML}	MV/LV long-term flicker transfer coefficient (value generally very close to unity)
T_{PstML}	MV/LV short-term flicker transfer coefficient (value generally very close to unity)
T_{uML}	MV/LV voltage unbalance transfer coefficient
U_h	harmonic voltage of order h (generic)
U_{hB}	harmonic voltage of order h at the substation LV busbar
U_{hFj}	harmonic voltage of order h at the far end of feeder j
U_{hLV}	harmonic voltage of order h on the LV system
U_N	nominal voltage of the LV system (phase-to-phase)
u	voltage unbalance factor (see definition 3.29.5)
Z_B	modulus of the short-circuit impedance of the system at the substation LV busbar at fundamental frequency

Z_{hB}	modulus of the harmonic impedance of the system at the substation LV busbar at harmonic frequency of order h
Z_{hi}	modulus of the harmonic impedance of the supply system at the point of evaluation (POE) of the customer's installation (i) at harmonic frequency of order h
Z_{hjk}	modulus of the harmonic impedance of the supply system at node N_{jk} at harmonic frequency of order h
Z_i	modulus of the short-circuit impedance of the supply system at the point of evaluation (POE) of customer's installation (i) at fundamental frequency
Z_{jk}	modulus of the short-circuit impedance of the supply system at node N_{jk} at fundamental frequency
$\underline{\underline{Z}}_{Lhjk}$	complex harmonic impedance of the supply system at node N_{jk} for the line conductor at harmonic frequency of order h
$\underline{\underline{Z}}_{Nhjk}$	complex harmonic impedance of the supply system at node N_{jk} for the neutral conductor at harmonic frequency of order h
$\underline{\underline{z}}_F$	complex impedance of an LV feeder per unit length at fundamental frequency
$\underline{\underline{z}}_{hF}$	complex harmonic impedance of an LV feeder per unit length at harmonic frequency of order h
$\underline{\underline{z}}_{LF}$	complex impedance of an LV feeder per unit length for the line conductor at fundamental frequency
$\underline{\underline{z}}_{NF}$	complex impedance of an LV feeder per unit length for the neutral conductor at fundamental frequency

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