

Electromagnetic compatibility (EMC) —

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

ICS 33.100.10

National foreword

This Published Document is the UK implementation of IEC/TR 61000-3-13:2008.

The UK participation in its preparation was entrusted by Technical Committee GEL/210, EMC — Policy committee, to Subcommittee GEL/210/12, EMC basic, generic and low frequency phenomena standardization.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

This Published Document was published under the authority of the Standards Policy and Strategy Committee on 30 April 2008

© BSI 2008

ISBN 978 0 580 56998 2

Amendments/corrigenda issued since publication

Date	Comments

TECHNICAL REPORT

BASIC EMC PUBLICATION

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

CONTENTS

INTRODUCTION.....	4
ACKNOWLEDGMENT	5
1 Scope.....	6
2 Normative references	7
3 Terms and definitions	7
4 Basic EMC concepts related to voltage unbalance.....	12
4.1 Compatibility levels	12
4.2 Planning levels.....	13
4.2.1 Indicative values of planning levels.....	13
4.2.2 Assessment procedure for evaluation against planning levels.....	13
4.3 Illustration of EMC concepts.....	14
4.4 Emission levels	15
5 General principles	16
5.1 Stage 1: simplified evaluation of disturbance emission	17
5.2 Stage 2: emission limits relative to actual system characteristics.....	17
5.3 Stage 3: acceptance of higher emission levels on a conditional basis.....	17
5.4 Responsibilities	17
6 General guidelines for the assessment of emission levels	18
6.1 Point of evaluation.....	18
6.2 Definition of unbalance emission level.....	18
6.3 Assessment of emission levels from unbalanced installations.....	19
7 General summation law	19
8 Emission limits for unbalanced installations in MV systems	20
8.1 Stage 1: simplified evaluation of disturbance emission	20
8.2 Stage 2: emission limits relative to actual system characteristics.....	21
8.2.1 Global emission to be shared between the sources of unbalance	21
8.2.2 Individual emission limits.....	22
8.3 Stage 3: acceptance of higher emission levels on a conditional basis.....	24
8.4 Summary diagram of the evaluation procedure.....	25
9 Emission limits for unbalanced installations in HV or EHV systems.....	27
9.1 Stage 1: simplified evaluation of disturbance emission	27
9.2 Stage 2: emission limits relative to actual system characteristics.....	27
9.2.1 Assessment of the total available power	27
9.2.2 Individual emission limits.....	28
9.3 Stage 3: acceptance of higher emission levels on a conditional basis.....	30
Annex A (informative) Guidance for setting planning levels and emission limits	31
Annex B (informative) Calculation examples for determining emission limits	36
Annex C (informative) List of principal letter symbols, subscripts and symbols.....	37
Bibliography.....	39

Figure 1 – Illustration of basic voltage quality concepts with time/ location statistics covering the whole system.....	15
Figure 2 – Illustration of basic voltage quality concepts with time statistics relevant to one site within the whole system.....	15
Figure 3 – Illustration of the emission vector $\underline{U}_{2i}/\underline{U}_1$ and its contribution to the measured unbalance at the point of evaluation.	18
Figure 4 – Example of a system for sharing global contribution at MV.....	21
Figure 5 – Diagram of evaluation procedure.....	26
Figure 6 – Determination of S_i for a simple HV or EHV system.....	27
Figure 7 – Determination of S_i for a meshed HV or EHV system	28
Figure A.1 – The reduction factor T_{uML} as a function of the factors k_m , k_s , and k_{sc}	34
Figure A.2 – Example of unbalance ratio measurement for a remote mine with largely motor loading.....	34
Table 1 – Compatibility levels for voltage unbalance in low and medium voltage systems reproduced from references IEC 61000-2-2 and IEC 61000-2-12	12
Table 2 – Indicative values of planning levels for voltage unbalance (negative-sequence component) in MV, HV and EHV power systems	13
Table 3 – Indicative value of exponent for the summation of general unbalanced installations	20
Table A.1 – Portion of unbalance for accounting for the system inherent asymmetries	32
Table A.2 – Summation of unbalance from different sources	33
Table A.3 – Range of values of planning levels given different parameters	35

INTRODUCTION

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

Part 1: General

General considerations (introduction, fundamental principles)

Definitions, terminology

Part 2: Environment

Description of the environment

Classification of the environment

Compatibility levels

Part 3: Limits

Emission limits

Immunity limits

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

Part 4: Testing and measurement techniques

Measurement techniques

Testing techniques

Part 5: Installation and mitigation guidelines

Installation guidelines

Mitigation methods and devices

Part 6: Generic standards

Part 9: Miscellaneous

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

ACKNOWLEDGMENT

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

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

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

ELECTROMAGNETIC COMPATIBILITY (EMC) –**Part 3-13: Limits –****Assessment of emission limits for the connection of unbalanced installations to MV, HV and EHV power systems****1 Scope**

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

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

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

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

Problems related to unbalance fall into two basic categories.

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

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

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

- low voltage (LV) refers to $Un \leq 1 \text{ kV}$;
- medium voltage (MV) refers to $1 \text{ kV} < Un \leq 35 \text{ kV}$;
- high voltage (HV) refers to $35 \text{ kV} < Un \leq 230 \text{ kV}$;
- extra high voltage (EHV) refers to $230 \text{ kV} < Un$.

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

2 Normative references

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

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

3 Terms and definitions

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

3.1

agreed power

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

3.2

customer

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

3.3

(electromagnetic) disturbance

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

3.4

disturbance level

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

3.5

electromagnetic compatibility (EMC)

ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment

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

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

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

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

3.6

(electromagnetic) compatibility level

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

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

3.7

emission

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

[IEV 161-01-08 modified]

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

3.8

emission level

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

3.9

emission limit

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

3.10

generating plant

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

3.11

immunity (to a disturbance)

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

3.12

immunity level

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

3.13

normal operating conditions

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

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

3.14

planning level

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

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

3.15

point of common coupling (PCC)

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

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

3.16

point of connection (POC)

point on a public power supply system where the installation under consideration is, or can be connected

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

3.17

point of evaluation (POE)

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

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

3.18

short circuit power

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

3.19**spur**

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

3.20**supply system**

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

3.21**system operator or owner**

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

3.22**transfer coefficient (influence coefficient)**

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

3.23**transposition**

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

3.24**unbalanced installation**

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

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

3.25**voltage unbalance (imbalance)**

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

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

3.26**phenomena related definitions**

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

3.26.1**fundamental frequency**

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

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

3.26.2

fundamental component

component whose frequency is the fundamental frequency

3.26.3

positive-sequence component of 3-phase voltages (or currents)

defined as the symmetrical vector system derived by application of the Fortescue's transformation matrix, and that rotates in the same direction as the power frequency voltage (or current). This is given mathematically by:

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

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

3.26.4

negative-sequence component of 3-phase voltages (or currents)

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

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

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

3.26.5

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

defined as the in-phase symmetrical vector system derived by application of the Fortescue's transformation matrix. This is given mathematically by:

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

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

3.26.6

voltage unbalance factor (u)

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

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

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

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

An equivalent formulation is given by [3]:

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