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**Electromagnetic compatibility (EMC) - Part 3: Limits - Section 6: Assessment of emission limits for distorting loads in MV and HV power systems - Basic EMC publication**

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



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# RAPPORT TECHNIQUE – TYPE 3

# TECHNICAL REPORT – TYPE 3

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**IEC**
**1000-3-6**

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First edition
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## Compatibilité électromagnétique (CEM) –

## Partie 3: Limites – Section 6: Evaluation des limites d'émission pour les charges déformantes raccordées aux réseaux MT et HT – Publication fondamentale en CEM



## Electromagnetic compatibility (EMC) –

## Part 3: Limits – Section 6: Assessment of emission limits for distorting loads in MV and HV power systems – Basic EMC publication



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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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# ELECTROMAGNETIC COMPATIBILITY (EMC) –

## Part 3: Limits –

## Section 6: Assessment of emission limits for distorting loads in MV and HV power systems

Basic EMC publication

## FOREWORD

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- type 1, when the required support cannot be obtained for the publication of an International Standard, despite repeated efforts;
- type 2, when the subject is still under technical development or where for any other reason there is the future but not immediate possibility of an agreement on an International Standard;
- type 3, when a technical committee has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

Technical reports of types 1 and 2 are subject to review within three years of publication to decide whether they can be transformed into International Standards. Technical reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

IEC 1000-3-6, which is a technical report of type 3, has been prepared by subcommittee 77A: Low frequency phenomena, of IEC technical committee 77: Electromagnetic compatibility.

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

| Committee draft | Report on voting |
|---|---|
| 77A/135/CDV | 77A/153/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.

Annexes A, B, C, D, E, F, G and H are for information only.

# INTRODUCTION

This technical report is part of the IEC 1000 series, 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 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: Miscellaneous

Each part is further subdivided into sections which are to be published either as international standards or as technical reports.

This section is a technical report.

# ELECTROMAGNETIC COMPATIBILITY (EMC) –

## Part 3: Limits –

## Section 6: Assessment of emission limits for distorting loads in MV and HV power systems

Basic EMC publication

## 1 Scope

This technical report outlines principles which are intended to be used as the basis for determining the requirements for connecting large distorting loads (producing harmonics and/or interharmonics) to public power systems. The primary objective is to provide guidance for engineering practices which will ensure adequate service quality for all connected consumers.

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 harmonic problems. 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 final decision regarding the connection of distorting installations will always rest with the utility.



Problems related to harmonics fall into two basic categories:

– The harmonic currents are injected into the supply network by converters and other harmonic sources. Both harmonic currents and resulting voltages can be considered as conducted phenomena. The objective of this report is to limit actual harmonic voltages on supply systems to levels (compatibility levels) that will not result in adverse effects on sensitive equipment. Since the harmonic voltages result from harmonic currents and impedances, this involves limiting the harmonic currents injected into the system.



– The harmonic currents in the range 50 Hz to 5 kHz may induce interference into communication systems. This phenomenon is more pronounced at higher order harmonic frequencies because of increased coupling between the circuits and because of the higher sensitivity of the communication circuits in the audible range.

This report primarily focuses on controlling or limiting harmonic voltages and their effects, but a clause is included to address communication interference.

NOTES

1 The load is to be understood as the complete consumer's installation.

2 This report uses the following terms for system voltage:

– low voltage (LV) refers to $U_n \leq 1$ kV;

– medium voltage (MV) refers to 1 kV $< U_n \leq 35$ kV;

– high voltage (HV) refers to 35 kV $< U_n \leq 230$ kV;

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

In the context of this report, the function of the network is more important than its nominal voltage. For example, a HV system used for distribution may be given a "planning level" (see clause 3) which is situated between those of MV and HV systems.

## 2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this technical report. At the time of publication, the editions indicated were valid. All normative documents are subject to revision, and parties to agreements based on this report are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

IEV 50 (161): 1990, *International Electrotechnical Vocabulary (IEV) – Chapter 161: Electromagnetic compatibility*

IEC 1000-2-2: 1990, *Electromagnetic compatibility (EMC) – Part 2: Environment – Section 2: Compatibility levels for low-frequency conducted disturbances and signalling in public low-voltage power supply systems*

IEC 1000-3-2: 1995, *Electromagnetic compatibility (EMC) – Part 3: Limits – Section 2: Limits for harmonic current emissions (equipment with rated current ≤ 16 A per phase).*

IEC 1000-4-7: 1991, *Electromagnetic compatibility (EMC) – Part 4: Testing and measurement techniques – Section 7: General guide on harmonics and interharmonics measurements and instrumentation for power supply systems and equipment connected thereto*



## 3 Basic concepts

Emission limits for individual equipments or a consumer's total load should be developed on the basis of voltage quality criteria. Some basic concepts are used to evaluate voltage quality. In order for these concepts to be useful in meaningful evaluation, they are defined in terms of where they apply (locations), and how they are measured (measurement duration, sample times, averaging durations, statistics), and calculated. These concepts are described here and illustrated in figures 1 and 2. Definitions may be found in IEC 50 (161).



### Compatibility levels

These are reference values (see table 1) for co-ordinating the emission and immunity of equipment which is part of, or supplied by, a supply network in order to ensure the EMC in the whole system (including network 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 utility cannot control all points of a network 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 harmonic voltages in LV and MV systems are given in table 1.

**Table 1 – Compatibility levels for harmonic voltages (in percent of the nominal voltage) in LV and MV power systems**

| Odd harmonics non multiple of 3 | | Odd harmonics multiple of | | Even harmonics | |
|---|---|---|---|---|---|
| Order h | Harmonic voltage % | Order h | Harmonic voltage % | Order h | Harmonic voltage % |
| 5 | 6 | 3 | 5 | 2 | 2 |
| 7 | 5 | 9 | 1,5 | 4 | 1 |
| 11 | 3,5 | 15 | 0,3 | 6 | 0,5 |
| 13 | 3 | 21 | 0,2 | 8 | 0,5 |
| 17 | 2 | >21 | 0,2 | 10 | 0,5 |
| 19 | 1,5 | | | 12 | 0,2 |
| 23 | 1,5 | | | >12 | 0,2 |
| 25 | 1,5 | | | | |
| >25 | 0,2 + 1,3 · (25 / h) | | | | |
| NOTE – Total harmonic distortion (THD): 8 %. | | | | | |

**Planning levels**

These are levels that can be used for planning purposes in evaluating the impact on the supply system of all consumer loads. Planning levels are specified by the utility for all voltage levels of the system and can be considered as internal quality objectives of the utility. Planning levels are equal to or lower than compatibility levels. Only indicative values may be given because planning levels will differ from case to case, depending on network structure and circumstances. As an example, see the planning levels for harmonic voltages presented in table 2.



**Table 2 – Indicative values of planning levels for harmonic voltage (in percent of the nominal voltage) in MV, HV and EHV power systems** [1)]

| Odd harmonics non multiple of 3 | | | Odd harmonics multiple of 3 | | | Even harmonics | | |
|---|---|---|---|---|---|---|---|---|
| Order h | Harmonic voltage % | | Order h | Harmonic voltage % | | Order h | Harmonic voltage % | |
| | MV | HV-EHV | | MV | HV-EHV | | MV | HV-EHV |
| 5 | 5 | 2 | 3 | 4 | 2 | 2 | 1,6 | 1,5 |
| 7 | 4 | 2 | 9 | 1,2 | 1 | 4 | 1 | 1 |
| 11 | 3 | 1,5 | 15 | 0,3 | 0,3 | 6 | 0,5 | 0,5 |
| 13 | 2,5 | 1,5 | 21 | 0,2 | 0,2 | 8 | 0,4 | 0,4 |
| 17 | 1,6 | 1 | >21 | 0,2 | 0,2 | 10 | 0,4 | 0,4 |
| 19 | 1,2 | 1 | | | | 12 | 0,2 | 0,2 |
| 23 | 1,2 | 0,7 | | | | >12 | 0,2 | 0,2 |
| 25 | 1,2 | 0,7 | | | | | | |
| >25 | $0{,}2 + 0{,}5 \frac{25}{h}$ | $0{,}2 + 0{,}5 \frac{25}{h}$ | | | | | | |
| NOTE – Total harmonic distortion (THD): 6,5 % in MV networks 3 % in HV networks. | | | | | | | | |

The planning levels in table 2 are not intended to control harmonics arising from uncontrollable events such as geomagnetic storms, etc.

1) A value of 1,5 % for $U_2$ may seem rather high for HV systems, but such values may be encountered and it is worth noting that the 2nd harmonic is not always associated with a d.c. component.

The rest of this report outlines procedures for using these planning levels to evaluate connection requirements for individual consumers.

**Assessment procedure**

The basic standard to be used for harmonic and interharmonic measurements is IEC 1000-4-7. In order to compare the actual harmonic levels with the planning levels, the minimum measurement period should be one week.

– The greatest 95 % 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.

– The maximum 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 maximum weekly value of $U_{h,vs}$ should not exceed 1,5 to 2 times the planning level.

NOTE – Harmonics are generally measured up to h = 40. In most cases, this is adequate for the evaluation of distortion effects of power disturbances. However, higher order harmonics up to the 100th order can be an important concern in some cases. Examples include:

– large converters with voltage notching;
– large installations with converters of high pulse numbers (e.g. aluminium plants);
– newer types of power electronics equipment with PWM converters interfacing with the power system.

Such cases can result in induced noise interference in neighbouring sensitive appliances (e.g. sensors, communication systems, etc.). It is generally found that higher order harmonics vary more with location and with time than lower order harmonics. In many cases, high order harmonics are produced by a single consumer, often in combination with power system resonance. (There may be a need for more extensive evaluations when higher order harmonics are a concern).



Figures 1 and 2 illustrate the basic concepts described above. They are intended to emphasize the most important relationships between the basic variables.

In the whole power system (see figure 1), interference inevitably occurs on some occasions, and therefore there is significant overlapping between the distributions of disturbance and immunity levels. Planning levels are generally equal to or lower than the compatibility level; they are specified by the owner of the network. Immunity test levels are specified by relevant standards or agreed upon between manufacturers and users.

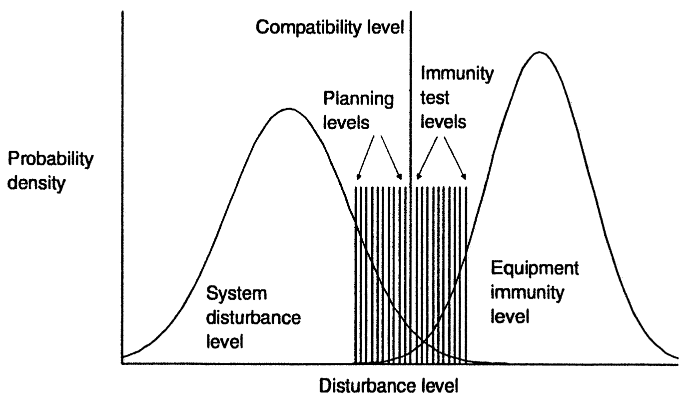


**Figure 1 – Illustration of basic voltage quality concepts with time/location statistics covering the whole system**

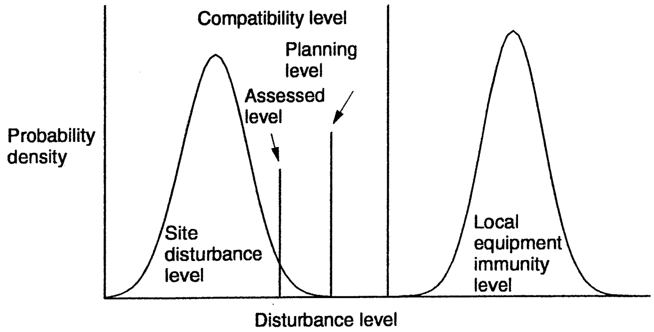


**Figure 2 – Illustration of basic voltage quality concepts with time statistics relevant to one site within the whole system**

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 of a minor nature, and equipment functions satisfactorily, that is EMC is more probable than figure 1 appears to suggest.

**Emission levels**

At each (inter)harmonic frequency, the emission level from a distorting load is the (inter) harmonic voltage (or current) which would be caused by the load into the power system if no other distorting load was present.



In order to compare a consumer's total load harmonic current emission with the emission limits, the minimum measurement period should be one week.



– The greatest 95 % daily value of $I_{h,vs}$ (r.m.s. value of individual harmonic components over "very short" 3 s periods) should not exceed the emission limit.

– The maximum weekly value of $I_{h,sh}$ (r.m.s. value of individual harmonics over "short" 10 min periods) should not exceed the emission limit.

– The maximum weekly value of $I_{h,vs}$ should not exceed 1,5 to 2 times the emission limit.

– Short duration bursts of harmonics (duration < 3 s) should also be limited, for example with respect to mains signalling systems. This problem is under consideration.

In practice, these levels are generally assessed from the available data concerning the load and the system; their direct measurement (For basic harmonic measurement principles, see IEC 1000-4-7) is made difficult by the presence of numerous other distorting loads (another technical report on this subject is under consideration).

## 4 General principles

The proposed approach for evaluating the acceptability of distorting loads depends on the agreed power of the consumer, the power of the harmonic-generating equipment, and the system characteristics. The objective is to limit the injection from the total load of individual consumers to levels that will not result in voltage distortion levels that exceed the planning levels. Three stages of evaluation are defined, which may be used in sequence or independently (see figure 3).

**Stage 1: simplified evaluation of disturbance emission**

It is generally acceptable for consumers to install small appliances without specific evaluation of harmonic emission by the supply company. Manufacturers of such appliances are generally responsible for limiting the emissions. For instance, IEC 1000-3-2 is a product family standard which defines emission limits of harmonics for equipment connected to LV systems. There are currently no emission standards for MV equipment for the following reasons:

– medium voltage varies between 1 kV and 35 kV;

– no reference impedance has been internationally defined for medium voltage systems.

In some countries, supply companies are able to declare national reference impedances for MV and HV systems which enable them to define emission limits in terms of harmonic current, and connect consumers' loads as a stage 1 connection without detailed evaluation.

Even without a reference impedance, it is possible to define criteria for quasi-automatic acceptance of consumers on the MV system (and even HV system). For example, it may be convenient to use a "weighted distorting power" (see 7.1.1) as an estimate of the total amount of distorting load within the consumer facility. If the total distorting load, or the consumer's agreed power, is small relative to the short circuit capacity at the PCC, it should not be necessary to carry on detailed evaluation.

In clause 7, specific criteria are developed for applying stage 1 evaluation.



**Stage 2: emission limits relative to actual network characteristics**

If a load does not meet stage 1 criteria, the specific characteristics of the harmonic generating equipment should be evaluated together with the absorption capacity of the system. The absorption capacity of the system is derived from the planning levels, and is apportioned to individual consumers according to their demand with respect to the total system capacity. At medium voltage, the disturbance level derived from higher voltage systems should also be considered when apportioning the planning levels to individual consumers.



The principle of this approach is that, if the system is fully loaded and all consumers are injecting up to their individual limits, the total disturbance levels will be equal to the planning levels. A procedure for apportioning the planning levels to individual consumers is outlined in clause 7.

**Stage 3: acceptance of higher emission levels on an exceptional and precarious basis**

Under special circumstances, a consumer may require acceptance to emit disturbances beyond the basic limits allowed in stage 2. In such a situation, the consumer and the utililty may agree on special conditions which facilitate connection of the distorting load. A careful study of the actual and future system characteristics has to be carried out in order to determine these special conditions.

NOTE – Emission limits obtained from the application of the methods recommended in clauses 7, 8 and 9 are intended to keep harmonic levels below the planning levels. The application of other methods mentioned in clause 10 is intended to limit communication interference.

**Responsibilities**

The consumer is responsible for maintaining his emissions at the PCC below the limits specified by the utility.

NOTE – This report is mainly concerned with emissions. However, harmonic absorption may also be a problem if filters or capacitor banks are connected without due consideration for their interaction with the harmonics normally present in the power system. The problem of harmonic absorption is thus also part of the consumer's responsibility.

The utililty is responsible for the overall control of disturbance levels under normal operating conditions in accordance with national requirements.

It has to provide network data for evaluation purposes. The evaluation procedure (see figure 3) is designed in such a way that the harmonic emissions from the consumers do not cause the overall system harmonic voltage levels to exceed the planning and compatibility levels. However, there is no guarantee that the recommended approach will always avoid exceeding the levels.

Finally, the utililty and consumer 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 consumer.

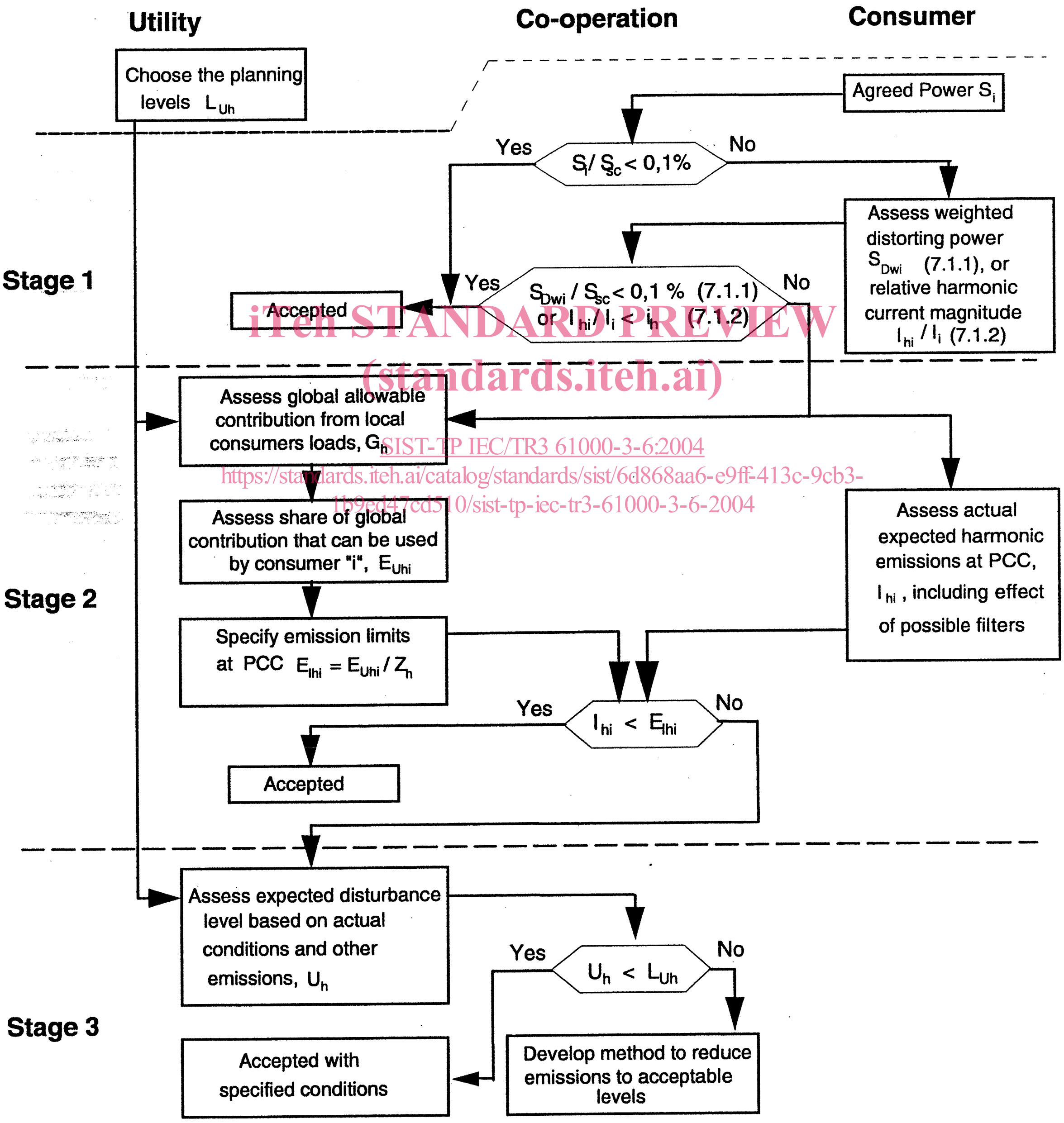




**Figure 3 – Diagram of evaluation procedure**

## 5 General guidelines for the assessment of emission levels

### 5.1 *Assessment of harmonic injection from distorting loads*

This clause is intended to provide general guidance on the assessment of harmonic injections from distorting loads, taking account of various operating and non-ideal conditions that may exist on power systems and consumer installations. More details on the assessment of the emission levels in the power supply of industrial plants may be found in another IEC publication [1].[1)]

**Operating conditions of the distorting loads**

The assessment of harmonic injection from distorting loads should consider the worst normal operating conditions including those with outages that may apply for a substantial fraction of the time (for example the outage of one 6-pulse rectifier unit in a large multiphase rectifier plant).

For simple cases, the harmonic injection from a given distorting consumer's load may be assessed by using the maximum current at each harmonic and interharmonic frequency that can be produced over the possible range of operation of each piece of equipment. For large loads, this approach may lead to excessively conservative results. Instead, a set of harmonic and interharmonic currents consistent with the worst possible simultaneous operating modes of all pieces of equipment can be considered for assessing the maximum harmonic injection from such a distorting load.



**Non-ideal operating conditions**

In practical situations, it is inevitable that some degree of asymmetry will be present in the supply network and in the consumer equipment, which will result in the generation of non-characteristic harmonics. These non-characteristic harmonics may be small relative to the characteristic harmonics, but for certain types of loads such as constantly varying loads, and large rectifier plants using high pulse number rectifiers, they need to be included in the prediction of disturbance levels.



The following non-ideal conditions have to be considered:

– Supply voltage unbalance:

  The presence of a negative sequence component of fundamental frequency on a three-phase supply voltage will usually produce odd-triple harmonics of positive and/or negative sequence. A voltage unbalance factor (up to 2 %) should be considered for the non-ideal steady state operation of the power system.

– Converter transformers and commutating impedance unbalance:

  Manufacturing tolerances on the turns ratio (turns ratio not exactly equal to $\sqrt{3}$) and on the reactance between two transformers of a 12-pulse converter produces non-characteristic harmonics normally only associated with a 6-pulse converter. Asymmetry of the commutating impedance between phases produces non-characteristic harmonics which also depend on the transformer winding connections.

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1) Figures in square brackets refer to the bibliography given in annex H.

– Firing angles asymmetries:

The variations of the valve firing instants give rise to harmonics of all orders. The deviation in firing angles between valves depends on the particular design of the firing circuits.

– Filter detuning:

When harmonic filters are required in order to comply with emission limits, the assessment of harmonic disturbances should also consider detuning effects, namely due to:

– the variation of the power frequency that may occur in steady state operation;

– the initial mistuning due to manufacturing tolerances and changes in filter component values due to ambient temperature variations;

– ageing of filter components;

– planned switching operation of the filters and capacitor banks with the variation of load.

## 5.2 *Harmonic impedance*

Most distorting loads behave as sources of harmonic currents. A knowledge of the harmonic impedance of the network, as seen from the PCC, is necessary to predict harmonic voltages that will appear at the PCC when the load is connected. Computations are also required to evaluate voltages in other parts of the supply network due to the harmonic currents in the load.

The assessment of the harmonic impedance, however, can be a very complex problem. Several measurement and calculation methods are available, but none is entirely satisfactory. Not even the best computer program or network analyzer is able to compensate for the lack of reliable data. Furthermore, the harmonic impedance of the network may vary significantly with time.



An international "Guide for assessing the network harmonic impedance" is available [2]. The following text gives guidelines for carrying out manual calculations which are sufficiently accurate to be applied in most cases, especially for problems related to MV networks.

### 5.2.1 *Simplified assessment methods*

For discussing several basic cases, reference is made to the simplified network of figure 4.

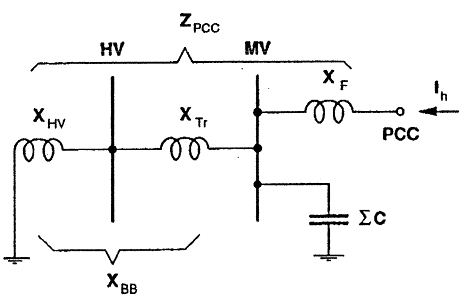


**Figure 4 – Diagram of network for assessing the "envelope impedance curve"**

**$Z_h$ directly proportional to frequency**

In simple installations, with no large capacitors for power factor correction and no large cable networks (ΣC negligible in figure 4), resonance conditions are not likely to occur for frequencies up to 13th harmonic. In such cases, $Z_h$ can be considered to be mainly inductive, and approximated as:

$$Z_h = h \cdot X_{1PCC} = h \cdot (X_{1HV} + X_{1Tr} + X_{1F}) \qquad (1)$$