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Electromagnetic compatibility (EMC) - Part 2: Environment - Section 6: Assessment of the emission levels in the power supply of industrial plants as regards low-frequency conducted disturbances

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## Compatibilité électromagnétique (CEM) –

### Partie 2:
Environnement –
Section 6: Evaluation des niveaux d'émission dans l'alimentation des centrales industrielles tenant compte des perturbations conduites à basse fréquence

## Electromagnetic compatibility (EMC) –

### Part 2:
Environment –
Section 6: Assessment of the emission levels in the power supply of industrial plants as regards low-frequency conducted disturbances

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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# ELECTROMAGNETIC COMPATIBILITY (EMC) —

## Part 2: Environment —
## Section 6: Assessment of the emission levels in the power supply of industrial plants as regards low-frequency conducted disturbances

## FOREWORD

1) The IEC (International Electrotechnical Commission) is a world-wide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of the IEC is to promote international cooperation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, the IEC publishes International Standards. Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. The IEC collaborates closely with the International Standardization Organization (ISO) in accordance with conditions determined by agreement between the two organizations.

2) The formal decisions or agreements of the IEC on technical matters, prepared by technical committees on which all the National Committees having a special interest therein are represented, express, as nearly as possible, an international consensus of opinion on the subject dealt with.

3) They have the form of recommendations for international use published in the form of standards, technical reports or guides and they are accepted by the National Committees in that sense.

4) In order to promote international unification, IEC National Committees undertake to apply IEC International Standards transparently to the maximum extent possible in their national and regional standards. Any divergence between the IEC Standard and the corresponding national or regional standard shall be clearly indicated in the latter.

The main task of IEC technical committees is to prepare International Standards. In exceptional circumstances, a technical committee may propose the publication of a technical report of one of the following types:

- 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 1000-2-6, 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 upon the following documents:

| Committee draft | Survey of comments | Report on voting |
|---|---|---|
| 77A(Secretariat)94 | 77A(Secretariat)103 | 77A/130 |

Full information on the voting for the approval of this part can be found in the report on voting indicated in the above table.
Annexes A, B, C, D and E are for information only.

# INTRODUCTION

IEC 1000 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 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 9: Miscellaneous

Each part is further subdivided into sections which are to be published either as International Standards, or as Technical Reports.

These standards and reports will be published in chronological order and numbered accordingly.

This section is a technical report.

# ELECTROMAGNETIC COMPATIBILITY (EMC) —

## Part 2: Environment —

## Section 6: Assessment of the emission levels in the power supply of industrial plants as regards low-frequency conducted disturbances

### 1 Scope

This technical report recommends the procedures to assess the disturbance levels produced by the emission of the devices, equipment and systems installed in non-public networks in industrial environment as far as the low-frequency conducted disturbances in the power supply are concerned; on this basis, the relevant emission limits can be derived. It applies to low and medium voltage a.c. non-public supply at 50/60 Hz. Networks for ships, aircraft, off-shore platforms, and railways are out of the scope of this report.

This technical report deals with the low-frequency conducted disturbances emitted by equipment connected to the power supply. The disturbances considered are:

- harmonics and interharmonics;
- unbalances;
- voltage changes;
- voltage dips.

### 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 technical 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 146: *Semiconductor convertors*

IEC 1000-3-3: 1994, *Electromagnetic compatibility (EMC) - Part 3: Limits - Section 3: Limitation of voltage fluctuations and flicker in low-voltage supply systems for equipment with rated current* $^{2}$ *16 A*

IEC 1000-3-5: 1994, *Electromagnetic compatibility (EMC) - Part 3: Limits - Section 5: Limitation of voltage fluctuations and flicker in low-voltage power supply systems for equipment with rated current greater than 16 A*

## 3 General

To achieve electromagnetic compatibility, the total disturbance level at the different points of coupling should be limited; this implies a control of the emission of the disturbing loads connected to the power supply.

As far as the LV public networks are concerned, the control of the disturbance level is obtained by means of a strict limitation of the emission of equipment absorbing up to 16 A to be installed in the networks. These limitations are fixed on the basis of statistical consideration on:

- wide diffusion of the equipment in the network;
- type of utilization (simultaneity effect);
- characteristics of the network.

Any equipment absorbing up to 16 A can be connected, provided it satisfies the emission limits given by the relevant standard.
This approach reflects the fact that in the public network, a strict co-ordination between different users and utility is not possible.

As regards the industrial plants and non-public networks, the compliance of compatibility levels must be achieved in different locations:

**A. At the Point of Common Coupling (PCC) to the public network.** The total emission of the plant into the public networks is subject to relevant limitation on the basis of the utility's requirements, and on the network conditions of the power supply.

**B. At the Internal Point(s) of Coupling (IPC).** The total disturbance level as produced by the emission of the inplant equipment and the disturbance level of the incoming supply is to be limited to the selected compatibility levels at the concerned IPCs.

Compliance with the above stated requirements can be achieved by imposing limitations on the emission of single pieces of equipment, taking into consideration the following:

- the actual impedance of the network where the equipment is to be connected;
- the mix of equipment actually present in the plant;
- the actual utilization of the equipment in relation to the organization of the production process;
- the possible control and mitigation of the disturbances obtained by provisions such as filtering or compensating devices, distribution of the loads on different supplies, segregation of disturbing loads.

This approach reflects the fact that in the industrial plant, the co-ordination of the disturbing loads, both at the design and at the operation stage, is possible.

To achieve an overall economy, the following facts for the limitation of the emission of each piece of equipment are important:

- the actual emission of a piece of equipment can be largely dependent on the characteristics of the supply network;
- low power equipment, even if incompatible as far as the emission levels are concerned with the standards of public network, can have globally a negligible impact in industrial plants in the presence of heavily disturbing equipment;
- the pattern of summation of the disturbance caused by various sources depends widely both on the design of the equipment, and on the industrial process involved;
- the user can, to a certain extent, select the applicable electromagnetic compatibility levels at the IPC. In fact, this choice is a trade-off between the costs to limit the level of the emission, and the costs to reduce the level of the disturbance by mitigation, or to increase the immunity.

## 4 Co-ordination of the emission limits with the compatibility levels

The allowable emission limit of an equipment can be stated through a three steps procedure:

a) Information between utility and user, and between user and manufacturer.

The utility is asked to provide the user with the minimum information following:

- the total emission limit applicable to the plant;
- the expected present and future disturbance level at the PCC, neglecting the disturbance produced by the plant under consideration;
- the range of values of the source impedance at the point of coupling as necessary for the disturbance evaluation; this range is related both to the network configuration and to the frequency characteristics.

The user is asked to provide the utility with information regarding:

- the characteristics of the equipment to be installed, and its mode of operation;
- the characteristics of power factor compensation devices;
- the characteristics of possible filters for harmonic current compensation.

The user is asked to provide the manufacturer with the minimum information following:

- the plan of the installation, and the characteristics of the connected equipment;
- emission levels of the other equipment in the installation, and the disturbance conducted by the supply network;
- characteristics of the process.

The manufacturer is asked to provide the user the minimum information following:

- expected emission levels of the concerned equipment or system in the specified operating conditions;
- the sensitivity of the emission levels to changes such as the supply impedance, the operating voltage, and so on.

b) Selection of the proper summation rule to account for the presence in the plant of various disturbance sources.

c) Evaluation of the expected total emission level of the plant at the PCC, and evaluation of the expected total disturbance level at the IPCs.

If either the total emission of the installation, or the expected disturbance level, exceed the relevant compatibility level, taking into account also the future network development, and the possible increase of the number of the disturbance sources in the plant, the following provisions should be considered:

- modification to the network configuration;
- changing the characteristics of the disturbing equipment;
- applying filters or compensating devices;
- tolerating the resulting disturbance and increasing the immunity levels of the involved equipment (this provision does not apply to PCC but to IPCs only).

The process is repeated until all the requirements are satisfied.

## 5 Definitions

All terms are according to IEV 161, to IEC 146 and to IEC 1000-3.

## 6 Survey of conducted emission of industrial equipment

Table 1 presents a survey on the sources of low-frequency conducted emission and their effects on the mains.

**Table 1 — Sources of low-frequency conducted disturbances**

| Classification | Examples | Produced disturbance |
|---|---|---|
| Non-linear characteristics | Saturable magnetic devices, gas-discharge lamps | Harmonics |
| | Arc furnace, a.c. arc welders | Harmonics, interharmonics, voltage changes, unbalance |
| | Switching-on transformers | Harmonics, voltage dips |
| Electronically switched load | Convertors, a.c. controllers | Harmonics, interharmonics, voltage changes, unbalance |
| | Multicycle control devices | |
| Switched load | Switching-on capacitors, filters, and induction motors | Interharmonics, voltage dips |

## 7 Harmonics

### 7.1 *Description of the disturbing phenomena and sources*

The harmonic components in the line current are mainly generated in the ways described in the following subclauses; additional load characteristics are presented in annex A.

### 7.1.1 *Switching the line current with line frequency or its multiple by means of electronic switches such as in semiconductor convertors*

This function may be either controlled, as by thyristors, or uncontrolled as by diodes. The function in most cases is obtained by switching a series connection of impedance and voltage sources periodically either on and off, or from phase to phase. In principle, three characteristics for harmonic generation in convertors may be found:

a) The load is periodically switched on and off, for example an a.c. controller switches its load on at discrete phase angles, and switches off when the current drops to zero. Figure 1a shows the schematic arrangement. Amplitude and phase angle of the harmonic current depends on the angle at which the line voltage is connected to the load, the difference between line and load voltage, and the resulting series connection of load and line impedance.

Typical applications are:

- conductive heating, welding, melting;
- high-voltage d.c. supply for electrostatic precipitators or transmitter valves;
- high-current d.c. supply for galvanizing or metal pickling;
- static VAR compensator;
- a.c. motor starter.

b) An impressed current is cyclically switched from phase to phase (high d.c. inductance).

Figure 1b shows the schematic arrangement.

Typical devices in this category are:

- convertor feeding d.c. load (such as d.c. drive; d.c. supply for traction, for electro-chemical and electro-thermal processes; d.c. excitation for machines or magnet coils; d.c. welding convertor);
- convertor with direct current link (such as a.c. drive with current source inverter (CSI) or sub-synchronous convertor cascade; d.c. supply for medium-frequency convertor feeding metal glowing or induction furnace);
- bi-directional convertor, cycloconvertor (such as a.c. drive, low frequency supply for electrothermal melting and refining) as shown in figure A.7 of annex A.

c) A d.c. voltage is periodically switched on and off into the line via impedances. A convertor connected to a three-phase line switches the d.c. side at discrete phase angles from phase to phase with low d.c. inductance. Figure 1b shows an equivalent circuit. The harmonic current generation corresponds to that of the a.c. controller. Here the current drop to zero is either initiated at the latest by closing the switch of the following phase, or occurs previously in cases of low current or low d.c. inductance, because of current dropping voltage polarity.

Typical devices in this category are:

- convertor with direct voltage link (such as a.c. drive with voltage source inverter (VSI); uninterruptable power supply (UPS); d.c. voltage supply for resonant convertor applied to metal heating or soldering);
- self-commutated convertor (convertor type for drives and compensators that do not require reactive power or compensation for it).

### 7.1.2 *Non-linear impedances such as current dependant resistances*

(see figure 1c)

Typical devices in this category are:

- arc furnace (a.c. arc for melting and refining metal);
- a.c. welding machine (welding arc supplied via high-reactance transformer);
- fluorescent lamp, gas discharge lamp in mass applications for illumination.

### 7.1.3 *Switching on saturable inductance (for example switching on induction motor or transformer)*

The magnetic saturation may produce transient current components. Switching on a resonant circuit with inductance and capacitance oscillating transiently to the mains (for example when switching on filter or capacitor, a transient oscillations is produced between filter capacitance and inductances of filter and line).

Figure 1c shows the equivalent circuit.

## 7.2 *Typical emission data*

A range of typical emission data is presented in annex A for the most common loads generating harmonic line currents. They are given for guidance purpose only. Reliable data for the disturbance evaluation should be obtained by the manufacturer on the basis of the actual design parameters, and by his experience with similar equipment.

## 7.3 *Influence of operating and installation conditions on emission*

For the resulting emission of several loads (such as convertors), the amount and the phase angle of the harmonic current is to be estimated. The connection of the convertors and transformers (if any), as well as simultaneous and homogeneous load condition for the convertors, or their operation at random, have to be taken into consideration; this problem is dealt with in 6.4.

The disturbance in the supply system may be defined by the presence of harmonic components in the line voltage, resulting from voltage drops of the harmonic currents across the line impedance. This line impedance is determined by the parallel and series connection of all impedances to the superimposed high voltage grid, and to all loads, compensating and filter components, considering the values which apply to the respective frequencies (see figure 2a). Therefore, possible resonances must be identified and taken into consideration. Further information is given in annex B.

## 7.4 *Summation of harmonics*

When several devices producing harmonic currents are present in the same plant, the harmonic currents in the lines, and the harmonic voltage at the point of concern (IPC or PCC) depends on the superposition effect caused by the different amplitudes and phase angles of the currents emitted from different sources.

An exact calculation of the resulting harmonic voltage (vectorial sum) is restricted to a few special cases. Taking the algebraic sum of the contributions by each harmonic source may represent the worst case, but this method often leads to unrealisticly high values, especially at high harmonic orders.

An approximate evaluation is sufficient in most of the cases. Several methods exist for the approximate evaluation of the resulting harmonics; see [4],[5] and [6] in annex E for the relevant literature.

### 7.4.1 *Harmonic voltage at the point of concern*

The harmonic voltage $\underline{U}_h$ of order h at the point of concern (IPC or PCC) results from the equation (see figure 2b):

$$\underline{U}_h = \underline{U}_{ho} + \Sigma\, \underline{U}_{hi} \qquad (1)$$

where

$\underline{U}_{ho}$ is the harmonic voltage of order h of the supply network not considering the effect of the sources of concern (background disturbance);

$\underline{U}_{hi}$ is the harmonic voltage of order h produced by the injection of the source i.

Assuming that all the transfer impedances between the point of connection of the disturbing sources and the point of concern are equal for all the disturbing sources (see figure 2b); $\underline{U}_h$ results from:

$$\underline{U}_h = \underline{U}_{ho} + \underline{Z}_h \sum \underline{I}_{hi} \tag{2}$$

where
$\underline{Z}_h$ is the equivalent harmonic impedance as seen from the point of concern.

### 7.4.2 *Summation of harmonic voltages*

#### 7.4.2.1 *Principles of the evaluation*

The summation problem arises when studying the connection of a new industrial load producing harmonics, because the emission levels which may be allowed are a consequence of the pattern, the harmonics will add up to the ones generated by other existing and future loads. The lack of information, and the inherent variability concerning all the individual loads which generate harmonics, leads to the necessity of using a statistical approach for the evaluation of the resulting harmonic vectors. In such an approach, each harmonic source is represented by a randomly time-varying vector. Both magnitude and phase angle of these vectors are modelled by means of distribution laws.

In order to obtain a simple rule for practical applications, the diversity factor K is adopted:

$$K = \frac{\left| \sum \underline{U}_{hi} \right|}{\sum \left| \underline{U}_{hi} \right|} \tag{3}$$

K is defined as the ratio between the vectorial sum (actual or expected) and the arithmetic sum of the individual contribution of all harmonic sources. This contribution is caused by the emission relevant to the design operational characteristic of the equipment concerned.

With the aid of the diversity factor K, the total disturbance $\underline{U}_h$ can be evaluated as:

$$\left| \underline{U}_h \right| \approx \left| \underline{U}_{ho} \right| + K \sum \left| \underline{U}_{hi} \right| \tag{4}$$

The value of the diversity factor is influenced, among others, by:

- type of disturbing load, for example in the case of convertors
  - controlled or uncontrolled convertor;
  - inductive or capacitive smoothing;
  - type of load (ohmic, inductive, motor);
  - number of convertors operating simultaneously;
- the kind of operation of the various disturbance sources (co-ordinate duty cycles, or independently from each other);
- variability of the load;
- harmonic order under consideration.

#### 7.4.2.2 *Practical application of the evaluation*

Two methods for evaluating the diversity factor K are proposed, depending on the knowledge of the harmonic contribution of all devices in the industrial network, and the required accuracy of the resulting harmonic voltage at the point of concern. In particular, method 1 refers to special groups of equipment, while method 2 refers to overall statistical considerations.

*Method 1*

This method gives applicable diversity factors. It holds good for a first approximation, or for resulting harmonic voltages at the point of concern, with a considerable safety margin in relation to the compatibility level. It applies to low order harmonics h ≤ 7.

The diversity factor K is obtained by the following:

$$K = \frac{\sum K_i |\underline{U}_{hi}|}{\sum |\underline{U}_{hi}|} \tag{5}$$

Several different $K_i$ may be applicable in one plant.

Based on [13] of annex E, the diversity factors $K_i$ for individual loads and for different harmonic orders are given in table 2.

**Table 2 — Diversity factor $K_i$ for various values *x* and harmonic orders, *x* being the ratio between the load of the device being considered and the total disturbing load of the plant**

| h | 3 | 5 | 7 | 11 | 13 | >15 |
|---|---|---|---|---|---|---|
| *x* <0,05 | 0,6 | 0,5 | 0,3 | 0,2 | 0,2 | 0,1 |
| *x* = 0,1 | 0,7 | 0,7 | 0,6 | 0,4 | 0,4 | 0,3 |
| *x* = 0,2 | 0,9 | 0,8 | 0,7 | 0,6 | 0,6 | 0,5 |
| *x* > 0,5 | 1,0 | 1,0 | 1,0 | 1,0 | 1,0 | 1,0 |

NOTE - If the multi-unit installation is made up of several uncontrolled rectifier convertors, $K_i = 0{,}9$. In addition, if the uncontrolled rectifiers have the same load cycle, $K_i = 1{,}0$.

The diversity factors in the table take into consideration the increasing variation of the phase angle $\Delta\phi$ towards higher harmonics (see figures relevant to method 2).

*Method 2*

This method is based on a statistical approach, considering that the compatibility level has to be met with a probability of 95 % or better.

A certain knowledge concerning the variation of magnitude and phase angle of the individual harmonic contributions is required:

$$K = \frac{S\left(\underline{U}_{hi}(p)\right)}{\sum |\underline{U}_{hi}|} \tag{6}$$

where

$S(\underline{U}_{hi}(p))$ is the statistical sum vector having 95 % probability of not being exceeded.

Diversity factors K depending on the variation of magnitude and phase angle of the harmonic voltages and the number of sources N are obtained following the approach [4] of annex E:

$$K \sum | \underline{U}_{hi} | = b \left( \sum | \underline{U}_{hi} |^{a} \right)^{1/a} \qquad (7)$$

Typical relevant values for a and b are shown in the following table 3; they are applicable to values having 95 % probability of not being exceeded:

**Table 3 — Values a and b applicable to uniform statistical distribution of amplitudes and phase angles. Maximum amplitudes are all equal.**

| Range of distribution of phase angle | Range of distribution of the amplitude | N = 2 | | N > 2 | |
|---|---|---|---|---|---|
| Δφ | $\Delta U / U_{max}$ | b | a | b | a |
| 0 - 360 | 0 - 1 | 1,0 | 2,0 | 1,0 | 2,0 |
| | 0,5 - 1 | 1,3 | 2,0 | 1,3 | 2,0 |
| | 1 | 1,0 | 1,0 | 1,7 | 2,0 |
| 0 - 270 | 0 - 1 | 0,9 | 1,6 | 0,9 | 1,6 |
| | 0,5 - 1 | 1,0 | 1,4 | 1,0 | 1,4 |
| | 1 | 1,0 | 1,0 | 1,3 | 1,4 |
| 0 - 180 | 0 - 1 | 0,8 | 1,3 | 0,8 | 1,3 |
| | 0,5 - 1 | 0,9 | 1,2 | 0,9 | 1,2 |
| | 1 | 1,0 | 1,0 | 1,2 | 1,2 |
| 0 - 90 | 0 - 1 | 0,9 | 1,2 | 0,9 | 1,2 |
| | 0,5 - 1 | 0,9 | 1,1 | 0,9 | 1,1 |
| | 1 | 1,0 | 1,0 | 1,0 | 1,0 |

NOTE — The equation given above can only be used when no harmonic source provides more than 50 % of the algebraic sum of the harmonic voltage being considered. Otherwise refer to method 1.

Generally, the following applies:

| | |
|---|---|
| • harmonic orders 3, 5 and 7 | phase angle up to 90° |
| • harmonic orders 11 and 13 | phase angle up to 270° |
| • harmonic orders above 13 | phase angle up to 360° |

For vectors with different maximum magnitudes, the factors can be used with sufficient accuracy. If the result exceeds the arithmetic sum, then the arithmetic sum will be used instead. In special cases, when the result may be lower than the greatest individual components, then the latter applies.