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Technical Application Papers No. 25
Electromagnetic compatibility: theory and application measures in MV environments

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1. Electromagnetic compatibility

1.1 Introduction and brief history

Electromagnetic compatibility (EMC) has been playing a major role in the strategies and management of almost all industrial sectors over the past few years, following the massive deployment of electronics.
Electromagnetic compatibility refers to the fitness of a device to function satisfactorily in its electromagnetic environment without producing intolerable electromagnetic disturbances in other devices in that environment.
Problems with electromagnetic disturbance actually started when radio transmissions began, with Guglielmo Marconi. Transmitters, receivers and antennas were not very sophisticated at that time.

Figure 1: Original prototype of the radio wave detector that Guglielmo Marconi used in 1902 on board the cruiser Carlo Alberto.

The first articles about EMC began to appear in specialized journals towards the year 1920, but it was only during the Second World War, when radios and radar equipment became widespread, that researchers began to study the phenomenon owing to the problems caused by disturbance.

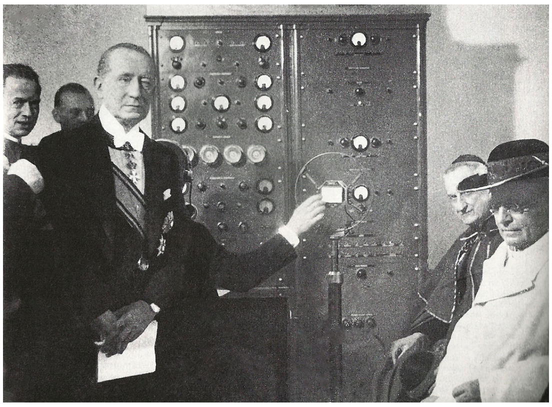
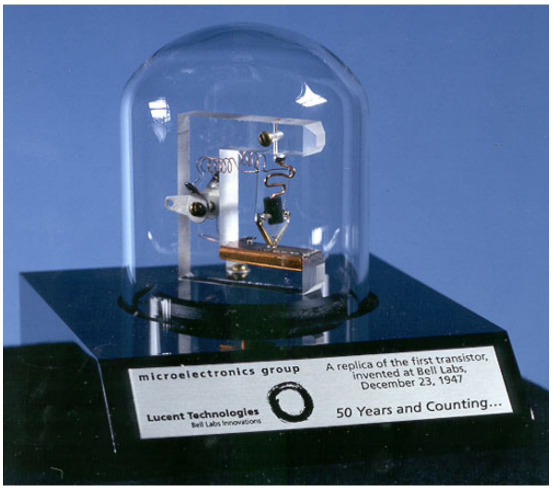


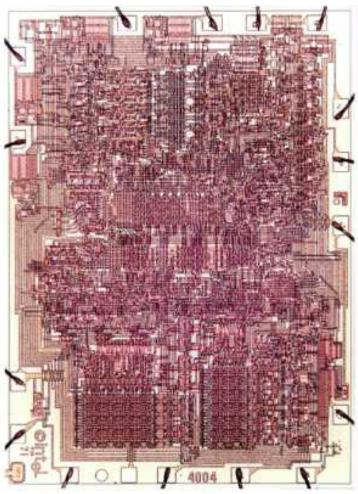
Figure 2: Marconi inaugurates Radio Vaticana in the presence of Pope Pius XI (1931)

A solution was temporarily found by allocating different frequency bands to the various systems. But just ten years later, when the first transistors appeared on the market (fig. 3a), in the sixties when integrated circuits started to become available (fig. 3b) and lastly, when microprocessors (fig. 3c) came on the scene, the problem cropped up again but was much more serious.



a)

b)



c)

Figure 3: a) The point-contact transitor invented in 1947, b) integrated circuits, c) the first monolithic microprocessor, Intel 4004 (1971)

Transition from analog to digital technology thus created a change of pace in the growing level of disturbance caused by the increasing integration of transitors into integrated circuits, as predicted by Moore's law (according to which the performance of processors and the number of transistors relating to them, double every 18 months).
If, on the one hand, enhanced calculation performance has allowed companies to develop increasingly advanced and complete products, on the other it has added to the difficulties in passing electromagnetic immunity tests.
These difficulties include:

- increasingly smaller electronic components and electronic boards that are more sensitive to disturbance (especially surges) but also higher emissions with problems concerning reciprocal interference between circuits;
- increasingly faster microprocessor clocks with bands over 10 GHz, thus high frequency disturbance making shielding more difficult to achieve;
- increasing numbers of electronic apparatus in every environment with shorter distances between them, thus more interference;
- increasingly lower energizing voltage creating more noise;
- ever-faster communication networks, even in domestic environments;
- wireless communication in almost all devices which, on the one hand, prevents single devices from being totally shielded but on the other, obliges the disturbance of other devices to be considered.

Nowadays however, training in terms of courses, books, guides, conferences and assistance from specialized research centers and laboratories helps manufacturers to overcome the growing difficulties and consumers to become more aware and safeguarded.
In view of the importance of the problem, EMC is governed world-wide by standards, directives and laws.

The terms used for defining compatibility are illustrated in figure 4:

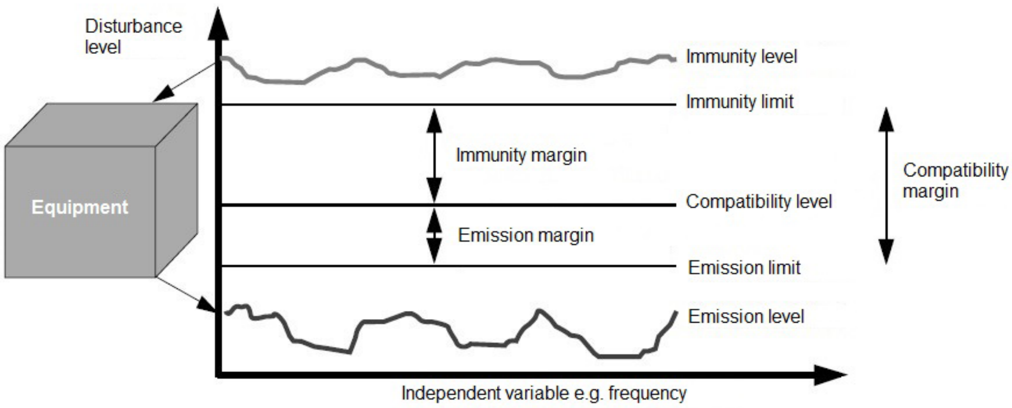


Figure 4: EMC levels

1. Electromagnetic compatibility

- apparatus: each finished device, or combination of finished devices, marketed as a functional, independent unit intended for the end user;
- electromagnetic emission or disturbance: all electromagnetic phenomena that can alter the way an apparatus operates. Electromagnetic disturbance may be electromagnetic noise, an unwanted signal or a change in the propagation medium itself;
- immunity: fitness of an apparatus to function normally without deteriorating in the presence of an electromagnetic disturbance.

This means that a system formed by at least an emitter or source device, a receiver and a coupling path must be considered.

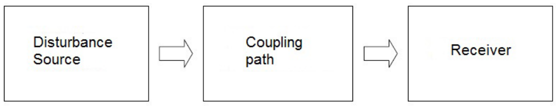


Figure 5: EMC system

In practice, if the system is to function correctly, the electromagnetic disturbance emitted by the source must be below the emission limit established by the standards and the receiver must be immune to it, with a sufficient immunity level in relation to the disturbance itself and in any case higher that the standard immunity limit established by the regulations. As regards the coupling path, high frequency emissions can propagate in different ways (fig. 6).

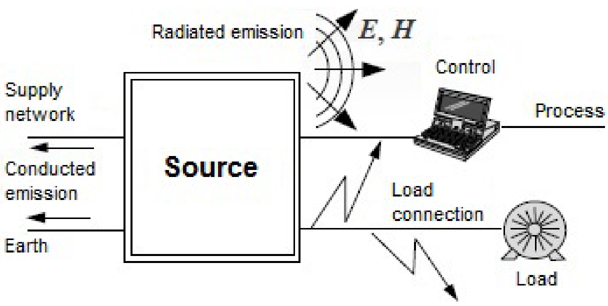


Figure 6: types of emission

- conducted coupling occurs when the source is electrically connected to the receiver, thus by cable or conductor. It can be in the common mode if the disturbance affects both the feeder wires and return circuit, or in the differential mode if the disturbance only affects the supply cabling;
- radiated coupling, which occurs through the air, includes:
  - inductive coupling, when a current source generates a magnetic field which can pair with a coil of the receiver and produce disturbance by induction;
  - capacitive coupling, when there is a source of voltage in the vicinity of the receiver **circuit.**

There is also a direct radiated coupling. In this case, the field radiated by the source travels through the air and couples to the receiver, which acts like an antenna. This occurs when the distance between source and receiver is comparable to or greater than the wavelength of the electromagnetic field.

1.2 Conducted coupling

This coupling can be of two different types:

- in the common mode: the disturbance affects both the supply cabling and return circuit by means of the parassitic capacitance to earth;

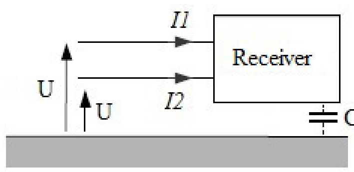


Figure 7: common mode

- in the differential mode: the disturbance only affects the supply cabling.

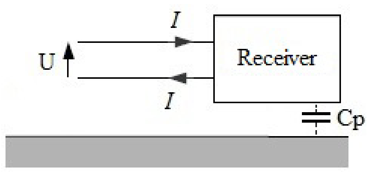


Figure 8: differential mode

Disturbances in the common mode are more difficult to identify since the circuit closes through the exposed conductive part. The earth itself can also be a source of disturbance as shown in figure 9, where the disturbance is generated by voltage Ut due a fault current that flows through the exposed conductive part.

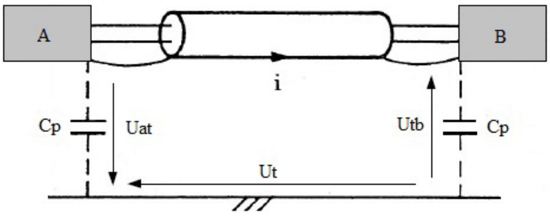


Figure 9: common mode disturbance circuit

1.3 Inductive coupling

Inductive coupling occurs when the receiver pairs with the magnetic induction flow associated with the source. In this case, any coil formed by an electric conductor with surface area S will generarte voltage U at its ends. This happens frequently in switchgear for apparatus installed near power lines with high current running through them.
Using the diagram in figure 9, this situation is illustrated in figure 10:

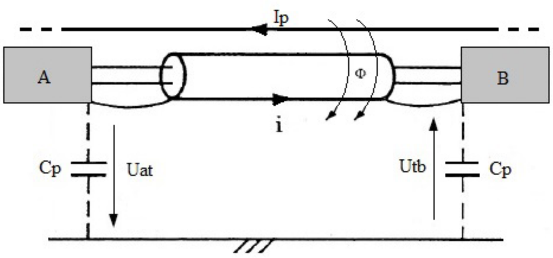


Figure 10: inductive coupling circuit

1.4 Capacitive coupling

Capacitive coupling occurs owing to the effects of interaction between the receiver and the electric field of the source due to parassitic capacitances (see figure 11). This situation is also frequent in switchgear owing to the vicinity of the energized power circuit.
It is important to note that the parassitic capacitance value is proportional to the surface area and inversely proportional to the distance between the two circuits.

The higher the voltage Up of the source and/or the parassitic capacitance Cp, the higher will be the value of the stray current.

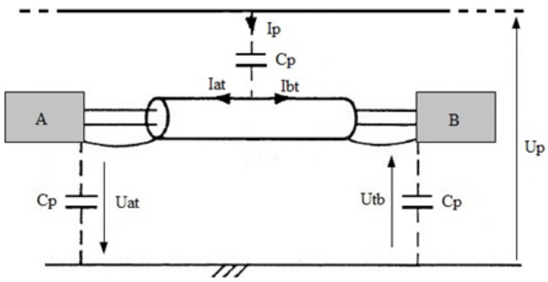


Figure 11: capacitive coupling circuit

1.5 Radiated coupling

To assess the presence of this type of coupling, wavelength λ of the disturbance must be calculated using the following formula:

$$\lambda = \frac{c}{f}$$

where c is the propagation speed and f the frequency of the disturbance. The wavelengths of certain types of signals are given below.

Type of signal	**Frequency**	**Wavelength λ**
Grid voltage	50 Hz	6000 km
Telephone	4 kHz	75 km
HF musical	20 kHz	15 km
Lightning strikes	1 MHz	300 m
Television	5.5 MHz	54 m
Data (Ethernet)	100 MHz	3 m
Modulated for GSM	900 MHz	33 cm
Data (optical fiber)	2.5 GHz	12 cm
Microprocessors	20 GHz	10.5 mm

Since this type of coupling occurs in relation to lengths comparable to the wavelength, it is not present at network frequency but affects overhead lines if lightning strikes in their vicinity and can be a serious problems for electronic boards.

2. The EMC standard

2.1 The electromagnetic compatibility directive

When facing this issue, one must start with Directive 2014/30/EU of the European Parliament and of the Council of 26 February 2014 concerning the harmonization of the laws of the Member States relating to electromagnetic compatibility. Directive 2004/108/EC was repealed with effect from 20 April 2016, without prejudice to the obligations of the Member States regarding the time-limit for transposition into their national law. Its validity is recognized by the entire enlarged single market. The directive provides for common targets, assuring that apparatus approved by one European Union Member State conforms as to intended use in all the other EU countries. The electromagnetic compatibility directive makes explicit reference to the EN technical standards issued by CENELEC (Comité Europeen de Normalisation ELECtrotechnique), which often derive from the standards issued by IEC (International Electrotechnical Commitee) and by CISPR (Comité International Spécial des Perturbations Radioélectriques), to which manufacturers of electrical products must comply. The Directive obliges manufacturers, when placing their equipment on the market, to make sure that technological progress was taken into account when such equipment was designed and manufactured so that the electromagnetic disturbance produced does not exceed the level above which radio and telecommunications equipment or other apparatus are unable to function normally. In addition, the equipment must possess a level of immunity to the electromagnetic disturbance to be expected in its intended use which allows it to operate normally without unacceptable degradation of its intended use.
The Directive also establishes that the CE mark must be mandatorily affixed to conforming products to indicate their conformity, after issue of a CE declaration of conformity, a copy of which must be kept in the technical file of the product.

Basically speaking, the Harmonized Standards can be divded into:
- basic standards which establish the characteristics of the instruments and the methods for performing tests to ensure they are repeatable. In other words, they define the characteristics of the instruments, the measuring system, measuring procedure, test environment (space, temperature, humidity, etc ...), how the documentation is organized (test report) and the choice of the sample to be tested (type tests);
- generic standards which establish the emission limits and levels of immunity relating to general characteristics of the product, such as the environment in which it is used (EN 50081-1/2/3/4);
- product standards defining the emission limits and immunity levels of specific products or product families.

The following priorities are applicable when there are several types of Standards for a particular product:
a) Dedicated product standards;
b) Standards of product families;
c) Generic standards.

The basic standards include all the EN 61000 standards relating to Part 4 – Testing and measurement techniques:
- EN 61000-4-1 Electromagnetic compatibility (EMC) Part 4-1: Testing and measurement techniques - Overview of IEC 61000-4 series
- EN 61000-4-2 Electromagnetic compatibility (EMC) Part 4-2: Testing and measurement techniques - Electrostatic discharge immunity test
- EN 61000-4-3, /A1 and /A2 Electromagnetic compatibility (EMC) Part 4-3: Testing and measurement techniques - Radiated, radio-frequency, electromagnetic field immunity test
- EN 61000-4-3/IS1 Electromagnetic compatibility (EMC) Part 4-3: Testing and measurement techniques - Radiated, radio-frequency, electromagnetic field immunity test - Interpretation sheet 1

- EN 61000-4-4 Electromagnetic compatibility (EMC) Part 4-4: Testing and measurement techniques - Electrical fast transient/burst immunity test
- EN 61000-4-5 Electromagnetic compatibility (EMC) Part 4-5: Testing and measurement techniques - Surge immunity test
- EN 61000-4-6 Electromagnetic compatibility (EMC) Part 4-6: Testing and measurement techniques - Immunity to conducted disturbances, induced by radio-frequency fields
- EN 61000-4-7 Electromagnetic compatibility (EMC) Part 4-7: Testing and measurement techniques - General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto
- EN 61000-4-7/A1 Electromagnetic compatibility (EMC) Part 4-7: Testing and measurement techniques - General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto
- EN 61000-4-8 Electromagnetic compatibility (EMC) Part 4-8: Testing and measurement techniques - Power frequency magnetic field immunity test
- EN 61000-4-9 Electromagnetic compatibility (EMC) Part 4-9: Testing and measurement techniques - Pulse magnetic field immunity test
- EN 61000-4-10 Electromagnetic compatibility (EMC) Part 4-10: Testing and measurement techniques - Damped oscillatory magnetic field immunity test
- EN 61000-4-10/A1 Electromagnetic compatibility (EMC) Part 4-10: Testing and measurement techniques - Damped oscillatory magnetic field immunity test
- EN 61000-4-11 Electromagnetic compatibility (EMC) Part 4-11: Testing and measurement techniques - Voltage dips, short interruptions and voltage variations immunity tests
- EN 61000-4-12 Electromagnetic compatibility (EMC) Part 4-12: Testing and measurement techniques - Ring wave immunity test
- EN 61000-4-13, /A1 and /A2 Electromagnetic compatibility (EMC) Part 4-13: Testing and measurement techniques - Harmonics and interharmonics including mains signaling at a.c. power port, low frequency immunity tests
- EN 61000-4-14, /A1 and /A2 Electromagnetic compatibility (EMC) Part 4-14: Testing and measurement techniques - Voltage fluctuation immunity test for equipment with input current not exceeding 16 A per phase
- EN 61000-4-15 Electromagnetic compatibility (EMC) Part 4-15: Testing and measurement techniques - Flickermeter - Functional and design specifications
- EN 61000-4-16 Electromagnetic compatibility (EMC) Part 4-16: Testing and measurement techniques - Section 16: Test for immunity to conducted, common mode disturbances in the frequency range 0 Hz to 150 kHz
- EN 61000-4-17, /A1 and /A2 Electromagnetic compatibility (EMC) Part 4-17: Testing and measurement techniques - Ripple on d.c. input power port immunity test
- EN 61000-4-18 and /A1 Electromagnetic compatibility (EMC) Part 4-18: Testing and measurement techniques - Damped oscillatory wave immunity test
- EN 61000-4-19 Electromagnetic compatibility (EMC) Part 4-19: Testing and measurement techniques - Test for immunity to conducted, differential mode disturbances and signaling in the frequency range 2 kHz to 150 kHz at a.c. power ports
- EN 61000-4-20 Electromagnetic compatibility (EMC) Part 4-20: Testing and measurement techniques - Emission and immunity testing in transverse electromagnetic (TEM) waveguides
- EN 61000-4-21 Electromagnetic compatibility (EMC) Part 4-21: Testing and measurement techniques - Reverberation chamber test methods
- EN 61000-4-22 Electromagnetic compatibility (EMC) Part 4-22: Testing and measurement techniques - Radiated emissions and immunity measurements in fully anechoic rooms (FARs)

2. The EMC standard

- EN 61000-4-23 Electromagnetic compatibility (EMC) Part 4-23: Testing and measurement techniques - Test methods for protective devices for HEMP and other radiated disturbances
- EN 61000-4-24 Electromagnetic compatibility (EMC) Part 4: Testing and measurement techniques - Section 24: Test methods for protective devices for HEMP conducted disturbance
- EN 61000-4-25 and /A1 Electromagnetic compatibility (EMC) Part 4-25: Testing and measurement techniques - HEMP immunity test methods for equipment and systems
- EN 61000-4-27 and /A1 Electromagnetic compatibility (EMC) Part 4-27: Unbalance, immunity test for equipment with input current not exceeding 16 A per phase
- EN 61000-4-28, /A1 and /A2 Electromagnetic compatibility (EMC) Part 4-28: Testing and measurement techniques - Variation of power frequency, immunity test for equipment with input current not exceeding 16 A per phase
- EN 61000-4-29 Electromagnetic compatibility (EMC) Part 4-29: Testing and measurement techniques - Voltage dips, short interruptions and voltage variations on d.c. input power port immunity tests
- EN 61000-4-30 Electromagnetic compatibility (EMC) Part 4-30: Testing and measurement techniques - Power quality measurement methods
- EN 61000-4-31 Electromagnetic compatibility (EMC) Part 4-31: Testing and measurement techniques - AC mains port broadband conducted disturbance immunity test
- EN 61000-4-34 and /A1 Electromagnetic compatibility (EMC) Part 4-34: Testing and measurement techniques - Voltage dips, short interruptions and voltage variations immunity tests for equipment with mains current more than 16 A per phase

The generic standards include:

- EN 61000-6-1 Electromagnetic compatibility (EMC) Part 6-1: Generic standards - Immunity standard for residential, commercial and light-industrial environments
- EN 61000-6-2 Electromagnetic compatibility (EMC) Part 6-2: Generic standards - Immunity standard for industrial environments
- EN 61000-6-3 and /A1 Electromagnetic compatibility (EMC) Part 6-3: Generic standards - Emission standard for residential, commercial and light-industrial environments
- EN 61000-6-4 and /A1 Electromagnetic compatibility (EMC) Part 6-4: Generic standards - Emission standard for industrial environments
- EN 61000-6-5 Electromagnetic compatibility (EMC) Part 6-5: Generic standards - Immunity for equipment used in power station and substation environment
- EN 61000-6-7 Electromagnetic compatibility (EMC) Part 6-7: Generic standards - Immunity requirements for equipment intended to perform functions in a safety-related system (functional safety) in industrial locations

Lastly, a few examples of product standards:

- EN 55011/A1 – Industrial, scientific and medical equipment (ISM) – Radio frequency disturbance characteristics – Limits and methods of measurement
- EN 55022 Information technology equipment - Radio disturbance characteristics - Limits and methods of measurement
- EN 55024 and /A1 Information technology equipment - Immunity characteristics - Limits and methods of measurement
- EN 50561-1 Power line communication apparatus used in low voltage installations - Radio disturbance characteristics - Limits and methods of measurement Part 1: Apparatus for in-home use
- IEC 62041 Transformers, power supplies, reactors and similar products - EMC requirements
- IEC 62135-2 Resistance welding equipment Part 2: Electromagnetic compatibility (EMC) requirements Information technology equipment - Radio disturbance characteristics - Limits and methods of measurement
- EN 60255-26: Measuring relays and protection equipment – Part 26: Electromagnetic compatibility requirements
- EN 62271-1: High-voltage switchgear and controlgear – part 1: Common specifications for alternating current switchgear and controlgear
- IEC 60947-2: Low-voltage switchgear and controlgear – Part 2: Circuit breakers

2.2 CE conformity and CE marking

The product Directives of the European Union establish the essential safety requirements to which products must conform in order to be freely marketed within the European Union and the procedures for certifying such conformity. In short, they define a common framework for the marketing of products.
Electromagnetic compatibility Directive 2014/30/EU obliges manufacturers, when placing equipment on the market, to ensure that such equipment has been designed and manufactured in accordance with the essential requirements, i.e. that technological progress was taken into account when such equipment was designed and manufactured. This means that:
- the electromagnetic disturbance emitted must not exceed the level above which radio and telecommunications equipment or other apparatus are unable to function normally;
- the equipment must possess a level of immunity to the electromagnetic disturbance to be expected in its intended use which allows it to operate normally without unacceptable degradation of its intended use.

The technical interpretation of the essential safety requirements is left to the Harmonized Standards. Conformity of a product to the essential requirements is accomplished by means of specific tests described in the Standards and is certified by the CE Declaration of conformity, as shown by the CE mark affixed to the product itself (fig. 12). Thus, the Declaration of Conformity and consequent CE mark are an essential requirement for placing a product on the European Union market. The CE mark must be affixed in a visible, legible and indelible way to the apparatus or its rating plate or, if this is not possible, to its packaging or its accompanying documents. The CE marking of conformity consists of the initials "CE", in accordance with the graphic symbol defined in DIRECTIVE 2006/42/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 May 2006 on machinery:

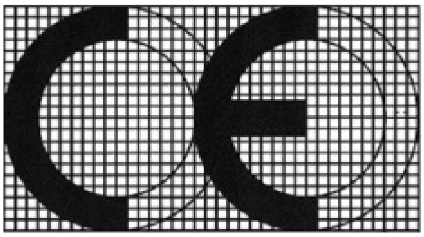


Figure 12: CE mark symbol

The CE mark is usually affixed on a self-certification basis, i.e. the manufacturer finds out which harmonized standards are applicable in the specific case, performs the relative conformity tests and then, if the equipment is judged to be compliant with those standards, makes a written declaration to this effect and takes responsibility for what is declared. Conformity tests can be certified by any technical report that provides the results of the tests performed, by the actual manufacturer in possession of the specific instruments and skills, or by an appropriate laboratory. This last requirement is not just formal but of considerable importance: electromagnetic compatibility is an extremely complex issue. It requires costly instrumentation and extensive experience as to the performance of tests and the ability to find remedies in the event of failures. A competent laboratory can therefore be an ideal solution for manufacturers that do not wish to invest resources but need to affix the CE mark to their products.
Machinery manufactured in conformity with a harmonized standard the references of which have been published in the Official Journal of the European Union, are presumed to comply with the essential safety and health requirements covered by that harmonized standard. Thus neither CE marking nor any EU declaration of conformity are required for medium voltage switchgears or the relative apparatus they contain since they must fully conform to the respective IEC standards.

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3. Types of disturbance

3.1 Classification

Depending on the type of source, electromagnetic disturbance can be classified in the following way:

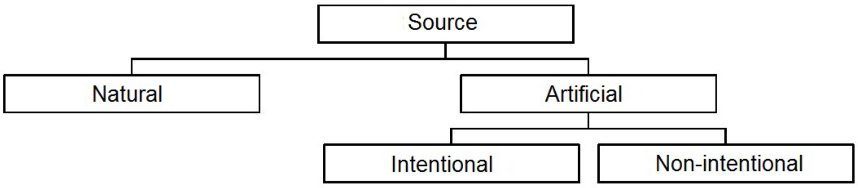

Figure 13: disturbance classification

Natural disturbance includes:
- lightning;
- Earth's electric and magnetic field;
- cosmic radiation.

Non-intentional artificial disturbance includes (for example):
- electrostatic discharges;
- continuous disturbances of varying nature due to the normal operation of certain devices, such as: fluorescent lamps, commutated motors, static converters in general;
- transient disturbances of varying nature due, for example, to faults and operations in the grid.

Lastly, intentional artificial disturbance includes:
- disturbances of varying nature, but basically of the radiated type due to sources such as radio transmission, television, radar;
- both conducted and radiated disturbances of varying nature due to sources such as arc furnaces and welding systems.

3.2 Electrostatic discharge

Electrostatic discharge is generated by the densification of electric discharges on the surface of insulating materials, which can be caused by friction, contact, ionization or photoelectric effect.

In the most frequent cases, it is the operator who, by walking on an insulating floor (e.g. carpeting) or brushing his clothes over the surface, becomes electrically charged with even high voltages of around ten kV (considering that the dielectric strength of the air is 3 kV/mm).
Figure 14 shows the charge level an operator can reach depending on the relative humidity and the different fabrics he is wearing.

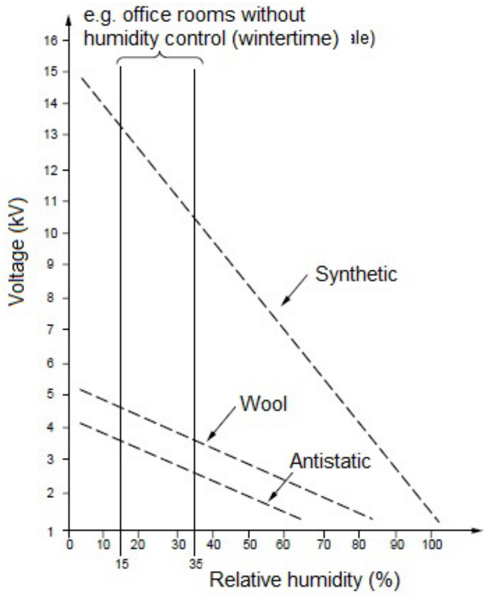

Figure 14: typical electrostatic discharge levels

The moment in which the operator approaches or touches an apparatus, a violent discharge is generated which can cause faults or even damage the electronic equipment to a serious extent. ESD (ElectroStatic Discharge) is covered by standard EN 61000-4-2. The standardized current waveform is the one illustrated in figure 15:

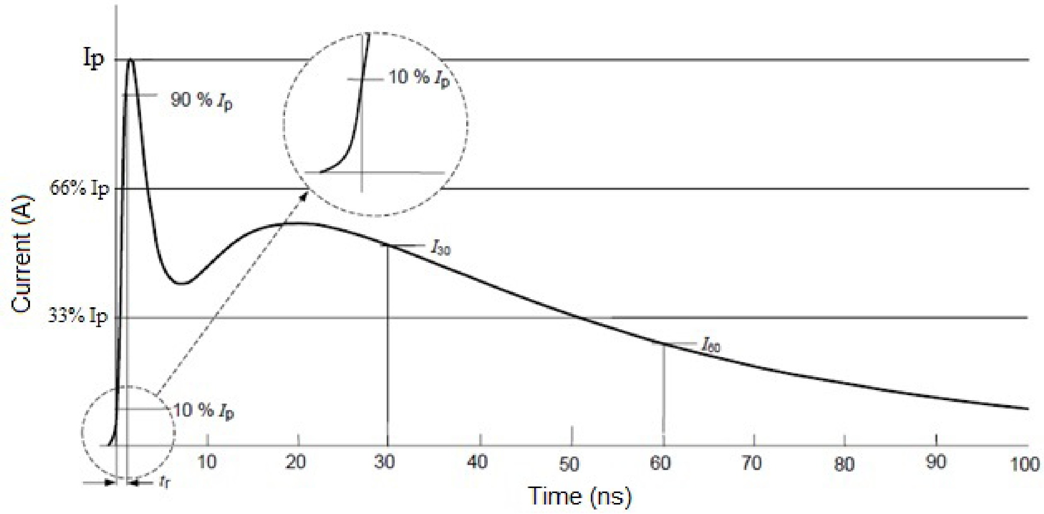

Figure 15: normalized waveform for ESD

Discharges can occur through contact, or in air near the apparatus. There are 4 increasing levels of disturbance with the following application criteria:

Level	Reference voltage for contact discharge kV	Reference voltage for air discharge kV	Relative humidity as low as %	Antistatic material	Synthetic material
1	2	2	35	√	
2	4	4	10	√	
3	6	8	50		√
4	8	15	10		√

The test should preferably occur by contact. If this is not possible, perform the test in air.

3. Types of disturbance

3.3 Radiated, radio-frequency, electromagnetic field

To get an idea of this type of disturbance, one can use the signal mentioned in standard EN 61000-4-3 to test the immunity of devices to radiated electromagnetic fields. The waveform for non modulated a) and modulated b) signals is illustrated in figure 16.

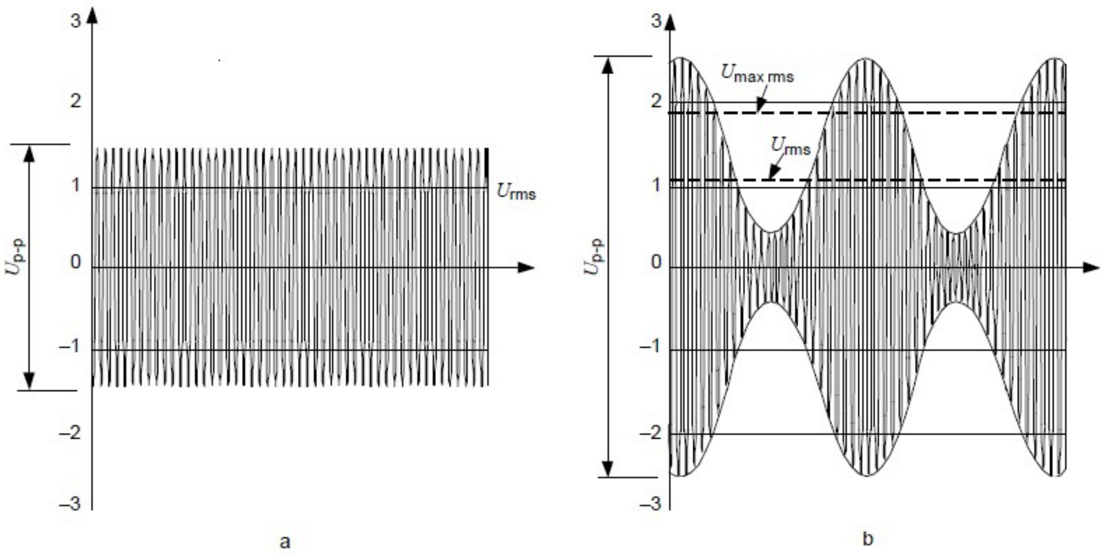

Figure 16: Waveform of severity level 1:
a) non-modulated RF signal with U_{p-p} = 2.8 V and U_{rms} = 1.0 V
b) modulated RF signal with U_{p-p} =5.1 V, U_{rms} = 1.15 V and $U_{max\ rms}$ = 1.8 V

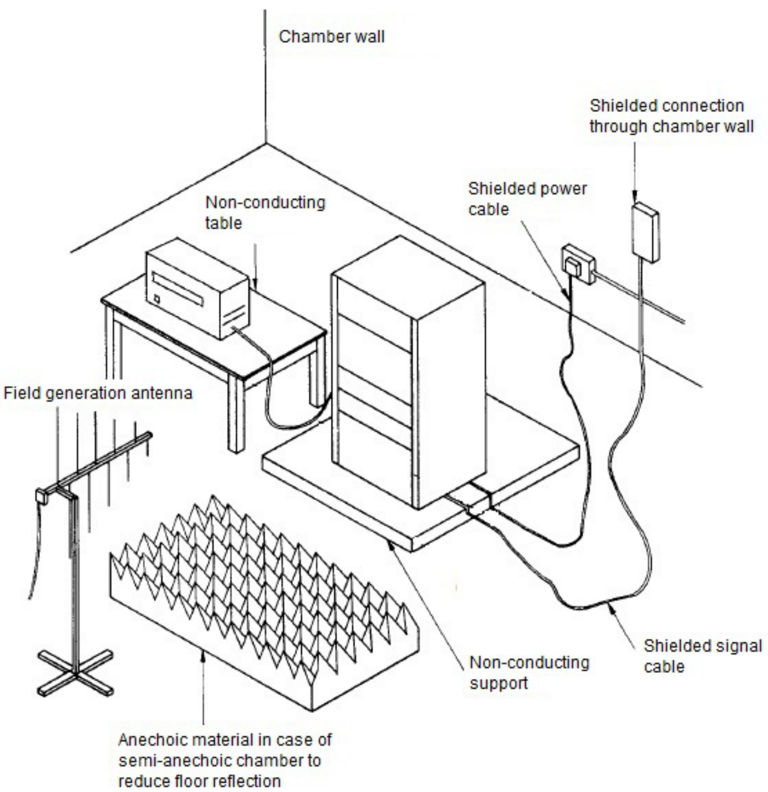

Figure 17: example with semi-anechoic chamber

In view of the amplitude of the signal, these tests must be conducted in shielded environments so as not to interfere with the radiocommunications. The laboratory measuring instruments must also be shieldeed. The tests are typically performed in anechoic or semi-anechoic chambers that are large enough to contain the tested apparatus.

There are 4 levels of increasing severity:

Level	Test field strength V/m
1	1
2	3
3	10
4	30

The specific product standards can establish the most appropriate level for each frequency range. Generally speaking, the levels can be chosen on the basis of the installation environments described in the following classes:

- Class 1 for environments with a low level of electromagnetic radiation, with radio or television broadcasting stations more than 1 km away and in the presence of low power transceivers;
- Class 2 for typically commercial environments with medium radiation, in the presence of medium-power transceivers but with restrictions as to use of apparatus;
- Class 3 for typically industrial environments with strong radiation owing to > 2 W transceivers used near equipment and/or with radio or television stations in the vicinity;
- Class 4 for environments where portable transceivers and other significantly disturbing sources are used within a distance of 1 m.

3.4 Electrical fast transient/burst

These disturbances (EFT/BURST) are formed by surge overvoltage due to conducted coupling that propagates to the electrical or electronic receiver apparatus via the feeder wires, command inputs and the signal inputs and outputs.
The reference standard is EN 61000-4-4.
The test pulse has a waveform with 5 ns rise time t_r and 50 ns pulse duration t_w.

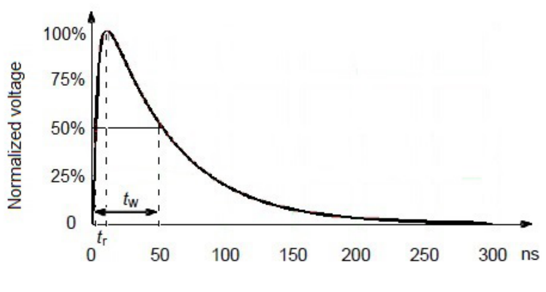

Figure 18: normalized waveform for EFT/BURST

The most widely used repetition frequency is 5 kHz, but 100 kHz is more realistic. The product standards should establish the most suitable test frequency for each product.

Frequency kHz	Pulse period T µs	Burst duration ms	Burst period ms
5	200	15	300
100	10	0.75	300

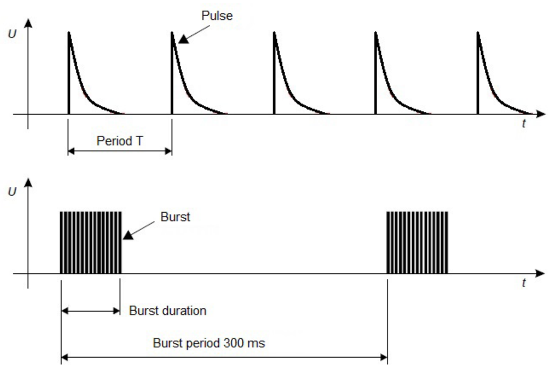

Figure 19: diagram of pulse burst

The peak voltage value depends on the test severity level. The values can be:

Level	Power supply and earthing (PE) ports kV Voltage peak	Signaling and monitoring ports kV Voltage peak
1	0.5	0.25
2	1	0.5
3	2	1
4	4	2

When choosing the severity levels, one should consider that:

- level 1 is suitable for well protected environments, such as a computer room;
- level 2 applies to equipment in protected environments, such as the control room of an industrial facility or power company;
- level 3 is suitable for industrial environments, so it applies to equipment used in industrial processes;
- level 4 applies to harsh industrial environments, typically equipment for industrial processes without specific measures having been implemented, electric power stations, the relay rooms of outdoor HV substations or gas-insulated substations with up to 500 kV operating voltage.

3. Types of disturbance

3.5 Surge

These unidirectional waves are the result of overvoltage caused by operations or discharges in the electrical installation.
Operations in the electrical installation able to cause transients include:

- switching of capacitor banks or other loads, especially when associated with switchgear or controlgear with thyristors or transistors;
- faults, such as short-circuits and earth faults.

Transients due to discharge can be caused by direct or indirect lightning able to generate overvoltage.
Lightning that directly strikes apparatus installed outdoors can produce currents which, by flowing into the earth resistance or into the impedance of the external circuit, cause overvoltages or strong electromagnetic fields and, thus overvoltages or overcurrents again.
The reference standard for this type of disturbance is EN 61000-4-5.
To give an idea of the disturbance, the waveform of the normalized voltage surge is illustrated in figure 20:

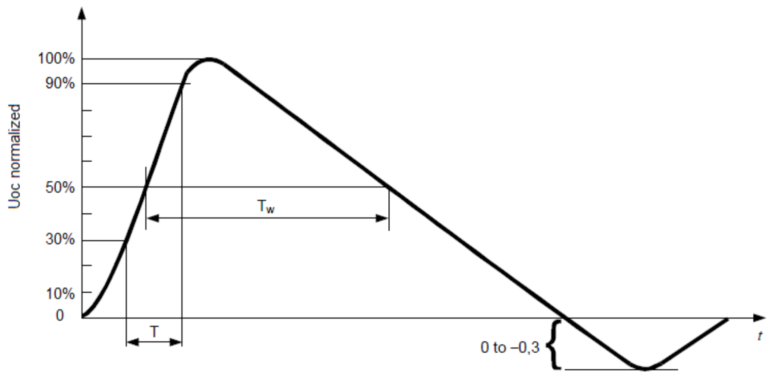

Figure 20: normalized waveform of a voltage surge

with rise time t_f = 1.67 x T = 1.2 μs and T_w = 50 μs.
The open circuit test voltage levels are:

Level	Line-to-line kV	Line-to-ground kV
1	-	0.5
2	0.5	1
3	1	2
4	2	4

The test level must be chosen with reference to the different installation environments, especially to classes 1 to 4:

- class 0, for very well protected electrical environments, with apparatus often confined to special rooms. The electronic apparatuses are all interconnected to a well-designed earthing system and have dedicated feeders. In this case, the overvoltages may not exceed 25 V.
- class 1, for partially protected electrical environments. All incoming cables are protected against overvoltage. The electronic apparatuses are all interconnected to a well-designed earthing system and are equipped with a dedicated feeder, but opening and closing operations in the grid may cause voltage disturbance. In this case the overvoltage may not exceed 500 V, thus level 1 can be applied for this class.
- class 2, for electrical environments where the cables are well separated but the earthing system is shared with the power grid, which could be affected by overvoltage generated by the electrical system itself or by lightning. The electronic components are supplied by a separate circuit, usually by a dedicated transformer, but unprotected circuits are present in the environment even though they are separate and of a limited number. In this case the overvoltage may not exceed 1 kV, thus level 2 can be applied.
- class 3, in environments where the signal and power cables are side by side. The earth connection can be affected as in the previous case. In addition, there could be voltage disturbance of an even high amplitude due to fault currents, operations or lightning. The connection cables may also be routed outdoors and inductive loads are present. In this case the overvoltage may not exceed 2 kV, thus level 3 can be applied.
- class 4, for electrical environments where the cables are routed outdoors together with the power cables and are common to electronic and electrical apparatus. The earthing system (poor) of the power grid can be subject to voltage disturbance of even high amplitude owing to faults, operations or lightning. Interconnections with HV apparatus and with a telecommunications network could also be present. In this case the overvoltage may not exceed 4 kV, thus test level 4 can be applied.

- class 5, for environments with electronic apparatuses connected to telecommunications cables and overhead power lines in thinly populated areas. All cables and primary lines are equipped with devices for protection against overvoltage, but the earthing system is not distributed thus the system is exposed to overvoltage. Voltage disturbances due to faults and lightning can be very high. In this case, the test level must be established by the product specifications.

3.6 Conducted disturbances, induced by radio-frequency fields

In this case, the radio frequency disturbances affect the entire length of the cables connected to the apparatus. If the receiver apparatus is small with respect to the wavelength of the disturbance signal (chap. 1.1.4), then the input and output cables of the apparatus act as passive receiver antennas and conduct the disturbance inside.
The reference standard is EN 61000-4-6.
Thus the apparatus can be crossed by current that flows between the system of cables, which one assumes is in the resonant mode.

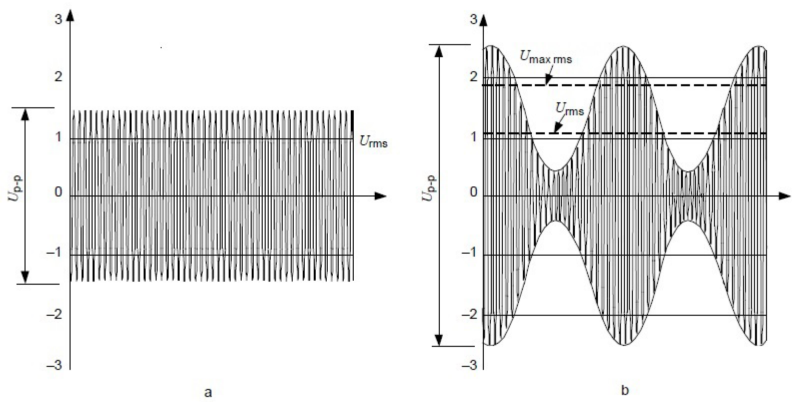

Figure 21: waveform of test level 1

The waveform used for the immunity test (fig. 21) is identical to the one mentioned in sect. 3.3 with three severity levels and 150 kHz to 80 MHz frequency range:

Level	Voltage U_0 (V)
1	1
2	3
3	10

where U_0 is the open-circuit voltage of the test generator, as shown in the circuit illustrated in figure 22
(E= electric field, H= magnetic field).

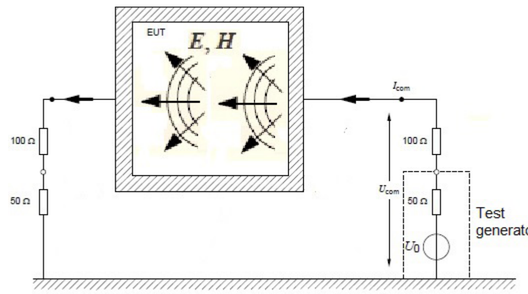

Figure 22

As described in section 3.3 concerning the choice of levels, qualitatively speaking one can consider an environment with a low level of electromagnetic radiation as being at level 1. Level 2 refers to a typically commercial environment with medium radiation, in the presence of medium-power transceivers but with restrictions as to use near apparatus. Lastly, level 3 applies to typically industrial environments with strong radiation owing to > 2 W transceivers used near equipment and/or with radio or television stations in the vicinity.

3. Types of disturbance

3.7 Voltage dips, short interruptions and voltage variations

This subject is covered by standard EN 61000-4-11 and standard EN 61000-4-34 for apparatuses with over 16 A input current.
These are other disturbances are also covered by standard EN 50160, Voltage characteristics in public distribution systems.
Voltage dips and short interruptions are caused by faults in the grid, such as short-circuits or sudden changes in important loads. Voltage dips are sometimes more than one and consecutive. Voltage variations are caused by continuous changes in the loads connected to the grid.
The three events are illustrated in figure 23:

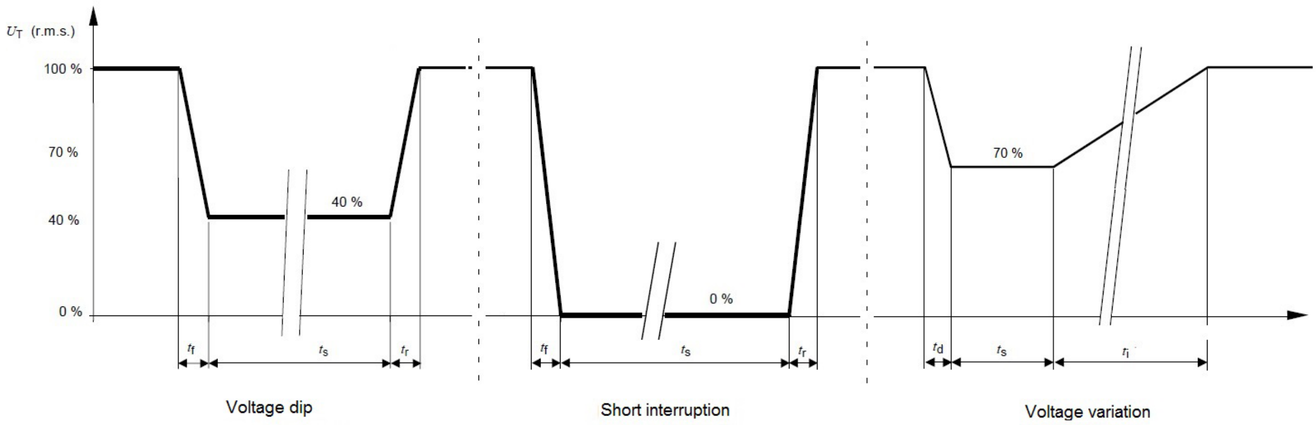

Figure 23: examples of voltage disturbance
(t_r = rise time, t_f = fall time, t_s = duratation at reduced voltage, t_d = diminution time, t_i = increase time)

As to tests with these disturbances, voltage dips are divided into 3 classes:

Class	Level and duration (t_s) of the test for voltage dips at 50/60 Hz				
Class 1	Case by case, in accordance with the requirements of the apparatus				
Class 2	0% for ½ cycle	0% for 1 cycle	70% for 25 (50 Hz) or 30 (60 Hz) cycles		
Class 3	0% for ½ cycle	0% for 1 cycle	40% for 10 (50 Hz) or 12 (60 Hz) cycles	70% for 25 (50 Hz) or 30 (60 Hz) cycles	80% for 250 (50 Hz) or 300 (60 Hz) cycles

The classes for short interruptions are defined as follows:

Class	Level and duration (t_s) of the test for short interruptions at 50/60 Hz
Class 1	Case by case, in accordance with the requirements of the apparatus
Class 2	0% for 250 (50 Hz) or 300 (60 Hz) cycles
Class 3	0% for 250 (50 Hz) or 300 (60 Hz) cycles

Lastly, there is a sole specification for the test for voltage variations which envisages a sudden diminution at 70% lasting 1 cycle and an increase time of 25 (50 Hz) or 30 (60Hz) cycles.
In all cases, the product committee can always define other levels in relation to the characteristics of the product itself.

Consult standard IEC 61000-2-4 for the choice of classes:

- class 1: for protected feeders and with compatibility levels lower than those of the public grid. It therefore refers to apparatuses that are very sensitive to these disturbances, such as laboratory instruments, special types of computers or automation systems;
- class 2: applies to the points where the load connects to the public or private grid in industrial environments in general, with the same compatibility levels as the public grid;
- class 3: applies to the points of connection to the grid in industrial environments with higher disturbance levels than class 2, e.g. in the presence of converters, welding machines, motors and strongly variable loads.

3.8 Harmonics and interharmonics

Harmonics are sine wave voltages and currents the frequencies of which are integer multiples of the fundamental frequency, i.e. of the rated frequency at which the electric grid functions, and which add to this latter, consequently causing a waveform that is no longer sinusoidal but distorted. If they are of a significant entity, harmonic currents can cause voltage dips and undesired heating in cables and apparatuses.
In the presence of particular grid impedance values (capacitance of the cables and power factor correction capacitors, line and transformer inductances, etc.), resonance events may sometimes amplify a particular harmonic voltage, which may therefore be of a significant entity even at a distance from the source.
These disturbances are normally caused by non-linear loads, typically industrial and residential loads such as:

- rectifiers, e.g. used in electronic apparatuses (e.g. televisions), frequency converters and lamps with incorporated feeders;
- phase control devices;
- certain types of calculators and uninterruptible power suppliers (UPS);
- arc welders and furnaces.

Disturbances can be at a constant or variable level, depending on how the source functions. There can sometimes be further frequencies that are not an integer multiple of the fundamental frequency and which are called interharmonics. Interharmonics are normally negligible. However, their level is on the increase owing to the growing use of frequency converters such as motor drives. The reference standard for these disturbances is EN 61000-4-13. It defines the value of the voltage harmonic as percentage of fundamental U1. The following levels are suitable for residential, commercial environments and light industry. Product committees may specify different classes with the appropriate levels for different environments, such as those in heavy industry.

Harmonics		Class 1	Class 2	Class 3
		Test levels % U1	**Test levels % U1**	**Test levels % U1**
Not multiple of 3	5	4.5	9	12
	7	4.5	7.5	10
	11	4.5	5	7
	13	4	4.5	7
	17	3	3	6
	19	2	2	6
	23	2	2	6
	25	2	2	6
	29	1.5	1.5	5
	31	1.5	1.5	3
	35	1.5	1.5	3
	37	1.5	1.5	3
Multiple of 3	3	4.5	8	9
	9	2	2.5	4
	15	/	/	3
	21	/	/	2
	27	/	/	2
	33	/	/	2
	39	/	/	2
Even	2	3	3	5
	4	1.5	1.5	2
	6	/	/	1.5
	8	/	/	1.5
	10	/	/	1.5
	12-40	/	/	1.5

3. Types of disturbance

The frequency spectrum for the three classes described above is illustrated below (fig. 24).

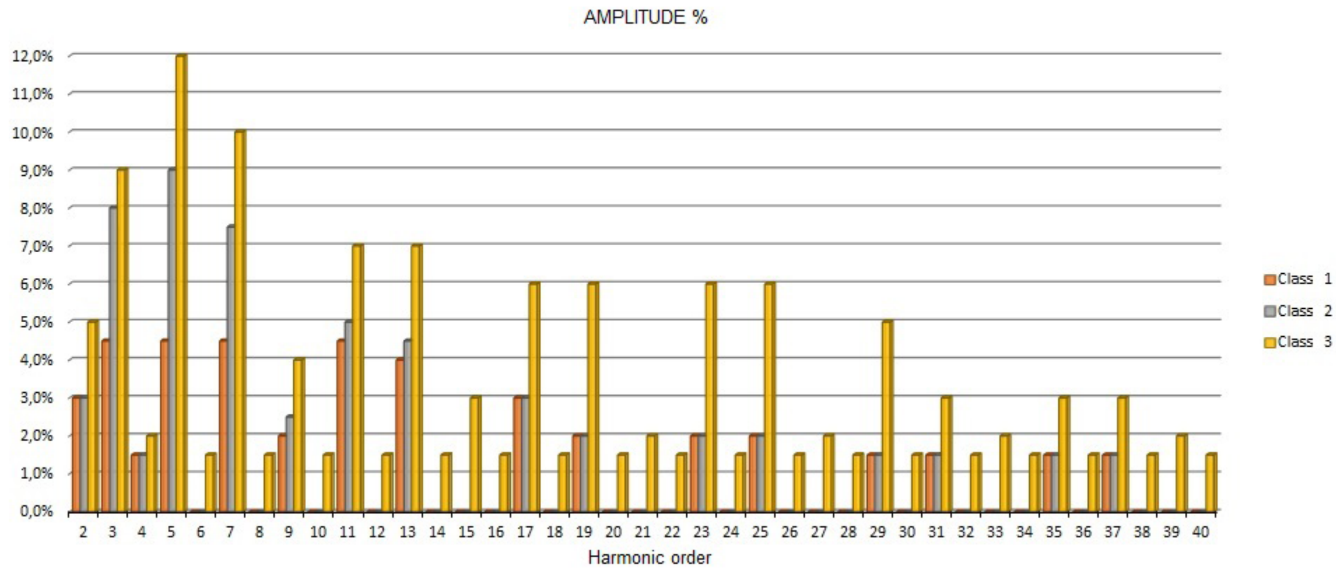

Figure 24: frequency spectrum for the three classes

Figure 25 illustrates the resulting waveform of the three classes for a 100 A rms fundamental at 50 Hz, with 0° phase shift for all the harmonics.

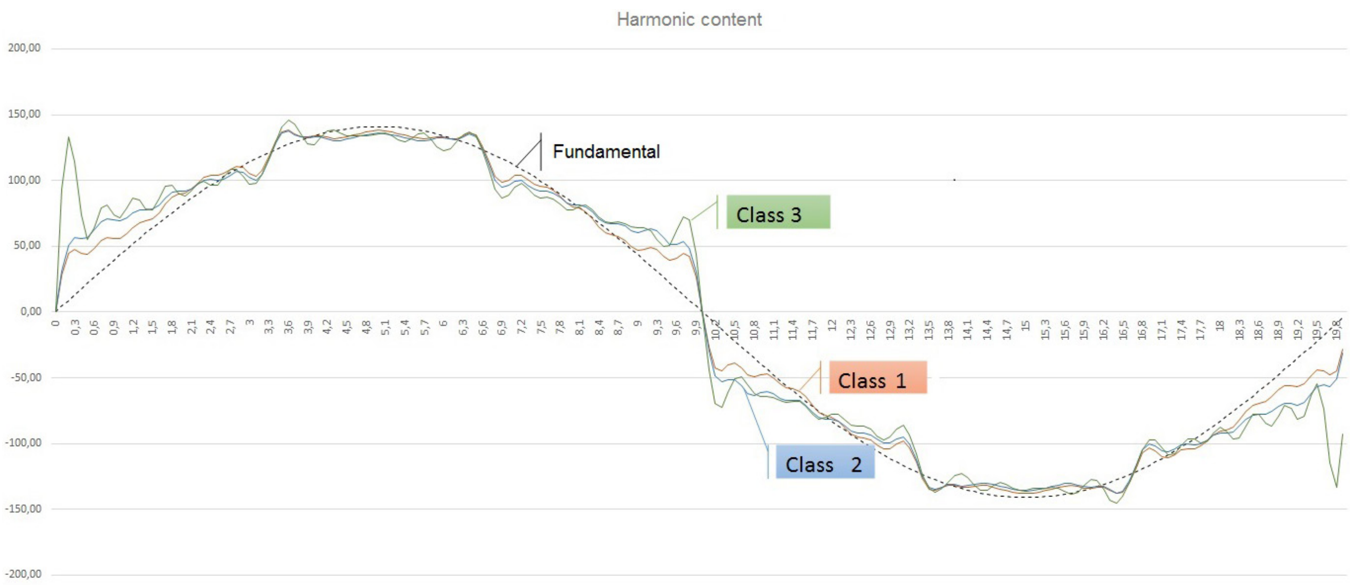

Figure 25: resulting waveform for the three classes

Regarding interharmonics, the standard defines the levels to apply to a certain frequency range, e.g. for a fundamental of 50 Hz.

Frequency ranges	Class 1	Class 2	Class 3
Hz	**Test levels % U1**	**Test levels % U1**	**Test levels % U1**
16 – 100	-	2.5	4
100 – 500	-	5	9
500 – 750	-	3.5	5
750 – 1 000	-	2	3
1 000 – 2 000	-	1.5	2

Class definition is the same as that described in section 3.7.
The compatibility and immunity levels must obviously be higher. The reference standards for this are IEC 61000-2-2 for low voltage public power supply systems and IEC 61000-2-4 for non-public industrial plants.
One of the parameters defined in the two standards mentioned above is Total Harmonic Distorsion (THD), equal to the sum of the r.m.s. values of harmonic components Q_h up to a certain order H, generally 40, divided by the r.m.s. value of fundamental Q1.

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

For example, the THD value of the three classes whose waveform is illustrated in figure 25 is 12% for class 1, 17% for class 2 and 27% for class 3.
By way of reference, standard EN 50160, which defines the characteristics of the voltage supplied by the public networks, establishes that the THD value in medium voltage must not be more than 8%.

4. Effects and control of interference

4.1 Effects of electromagnetic disturbance

The effects of electromagnetic disturbance on an apparatus due to a coupling, called interference, can range from simple functional disturbance to destruction of one of its parts resulting in total loss of its functionality.
The standard envisages three criteria regarding the performance of equipment (EUT, Equipment Under Test) subjected to an electromagnetic compatibility test (EN 61000-6-2 Part 6-2: Generic standards - Immunity standard for industrial environments.

- criterion A: The EUT continues to function as envisaged during and after the test without degradation of performance or loss of functionality below the performance level specified by the manufacturer;
- criterion B: The EUT continues to function as envisaged after the test without degradation of performance or loss of functionality below the performance level specified by the manufacturer; However, performance degradation is allowed during the test, but not changes in the actual operating status or the stored data;
- criterion C: temporary loss of functionality during the test is allowed. However, functionality is auto-recoverable or can be, by means of a manual command imparted by the user.

Generally speaking, if the EUT becomes dangerous after the tests, it is considered to have failed the actual tests themselves.
Electrical equipment must be immune to both high and low frequency phenomena. High frequency phenomena include the already described electrostatic discharge (ESD), radiated electromagnetic fields, electrical fast transients/bursts (EFT/BURST), disturbances caused by conducted electromagnetic fields and voltage pulses (SURGE).
The more typical low voltage phenomena include harmonics, voltage dips, micro-interruptions and voltage unbalance.
However, it is important to underscore that the tests do not cover all the possible combinations of negative factors present in real situations.

4.2 How to deal with electromagnetic incompatibility

The process for dealing with EMC problems can be addressed in two different ways, depending on the moment in which they are faced.
The first approach, basically to be adopted during the design stage, is to assign a level of compatibility with each disturbance, to the environment in which the equipment will be installed (fig. 26). A general suppression pattern can then be defined, after which the emission and immunity levels of all the equipment to be installed can be specified along with the relative suppression and installation methods. This approach is certainly the best if it can, in fact, be applied. A new installation with a single design engineer who has a general view of everything and who can then issue a document of EMC requirements is a typical example. The steps to be followed are illustrated below:

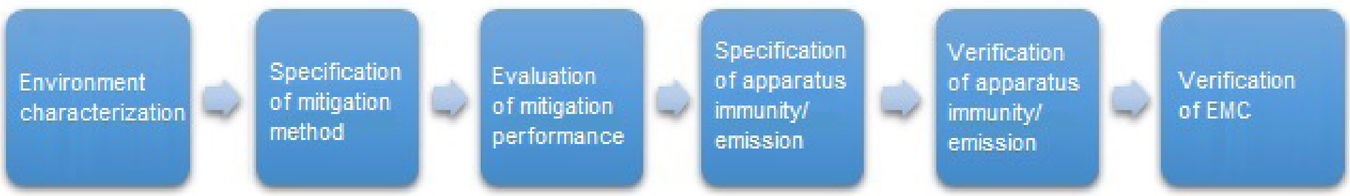

Figure 26: process to adopt beginning with design engineering

Figure 27: process to adopt for existing installations

The second approach (fig. 27) is adopted in existing installations when apparatus must be installed for which the EMC characteristics cannot be changed. In this case, an attempt must be made to match the existing compatibility level of the installation with the levels of the components that must be installed. This can only be achieved by adopting methods to mitigate the disturbances that affect the the new apparatus. This second approach is certainly more complicated and requires the assistance of an experienced EMC specialist who must be preferably called in before the apparatuses are installed but who often has to resolve problems which arise after installation. The steps to take are outlined in fig. 27.

4.3 Methods for controling interference

As explained in the previous section, the essential thing is to define disturbance mitigation methods both when new installations are designed and when existing installations are enlarged.

In a nutshell, all methods are based on reducing the degree of coupling through which disturbance interferes with the electronic receiver apparatus. This is particularly true of high frequency signals, in which the interfering signals and wanted signals are in the same frequency range.

Various different methods for mitigating interference in relation to the type of disturbance coupling are analyzed in the following pages.

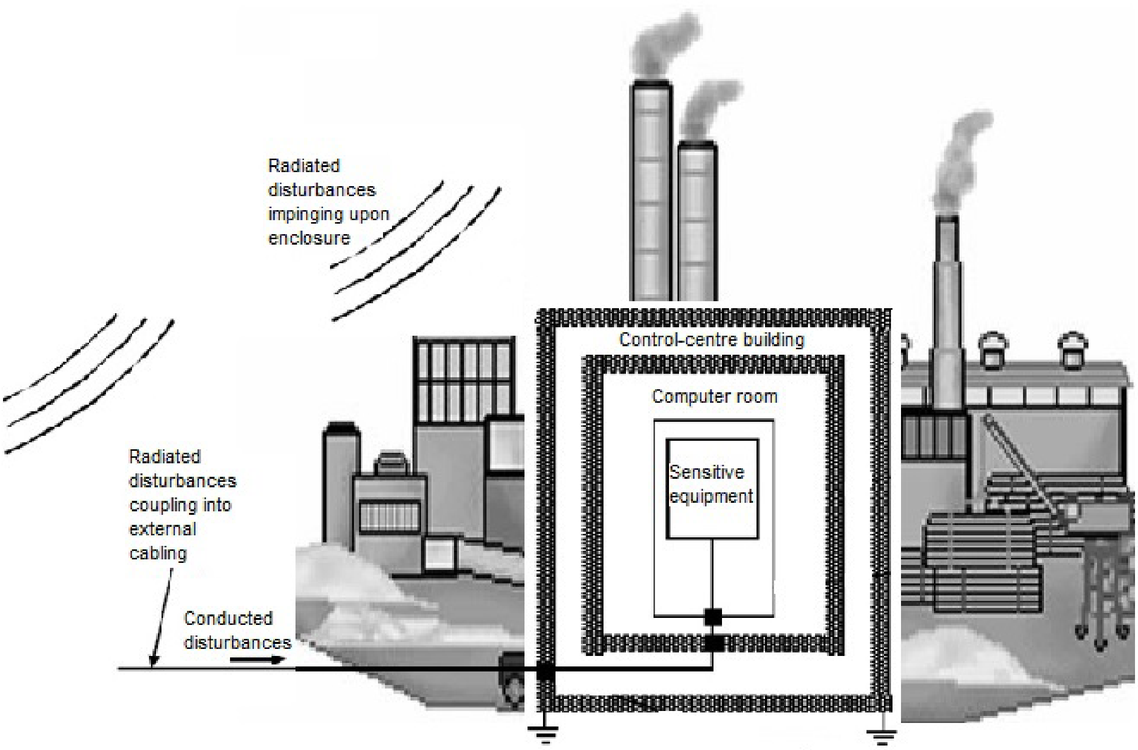

Figure 28: EMC for an industrial control center

4. Effects and control of interference

4.3.1 Methods for mitigating conducted disturbances

Conducted disturbances can propagate to other apparatuses through all conductive components, including cables, earthing systems and the metal frameworks of switchgear.

4.3.1.1 Circuit balancing

Circuit balancing is the first rule to consider. In an unbalanced circuit, the summation of the currents in the main conductors is different from zero, thus there is a common mode current that is different from zero. It can be demonstrated that, since the signal propagates by means of a residual current, it is important for the circuit to be balanced in order to be immune from conducted disturbance. In this situation, the signal associated with the residual current will be different from zero and immune to the disturbance, which propagates in the common mode.

4.3.1.2 Chokes

The second method is to wind the conductors around rings of ferromagnetic substance (nornally ferrite) with coils in phase opposition (to allow the supply currents of the device – which are in the differential mode but at much lower frequencies than those concerning EMI - to generate flows that cancel each other out) so as to create so-called chokes (fig. 29). The coil introduces an impedance, which is maximum for common mode currents and therefore limits the disturbance, and minimum for the differential mode currents pertaining to the signal.

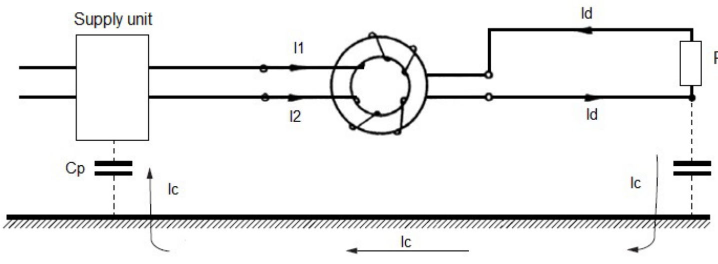

Figure 29: circuit with choke

Ferrite is normally used to prevent saturation at high frequencies.

4.3.1.3 Filters

Another method is to install filters. Low-pass, high-pass, band-pass and band-stop filters can be used.
For the purpose of preventing disturbance, the components must be installed in series with the circuit, as in the following cases (fig. 30):

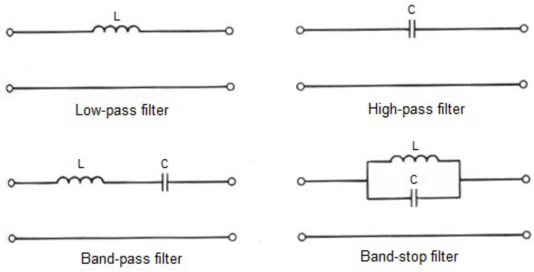

Figure 30: filters in series

The components, basically the capacitors, must be installed in parallel as in the next case (fig. 31) if the disturbances are to be discharged to earth:

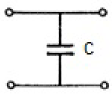

Figure 31: filters in parallel

To eliminate high frequency disturbances, the filters used normally consist of inductances in series and capacitance in parallel. There are the following types:

- feedthrough capacitor type filter (fig. 32): used when the impedances of the generator and receiver are relatively high;

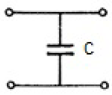

Figure 32: feedthrough capacitor type filter

- half T or L filter (fig. 33): the inductance must be positioned on the low impedance side and is used when the impedance of the generator is much different from the impedance of the receiver;

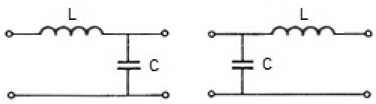

Figure 33: half T filters

- the π type filter (fig. 34) , used in high impedance circuits;

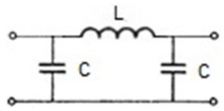

Figure 34: π type filter

- the T type filter (fig. 35) is used in circuits where the impedances of the generator and load are relatively small.

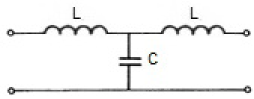

Figure 35: T filter

4.3.1.4 Varistors

Varistors belong to the family of suppression devices used as a protection against overvoltage. Variators are nonlinear resistors, the resistance of which depends on the voltage applied. This can change from MΩ to mΩ values in a few nanoseconds (typical values from 10ns ... 25ns) and can tolerate current up to 25kA and energy up to 600kJ. These devices possess 100pF to 10nF parasitic capacitance, which can limit the protected signal band but which also contributes towards filtering disturbances.

Since the performance of a varistor depends on its temperature, it is important to prevent it from being heated or, simply, to keep it away from hot spots.

Figure 36 illustrates the typical curve of a zinc oxide varistor (MOV). It is advisable to make sure that residual voltage U_{res} at I_{max} current value is never more than the withstand voltage of the apparatus being protected.

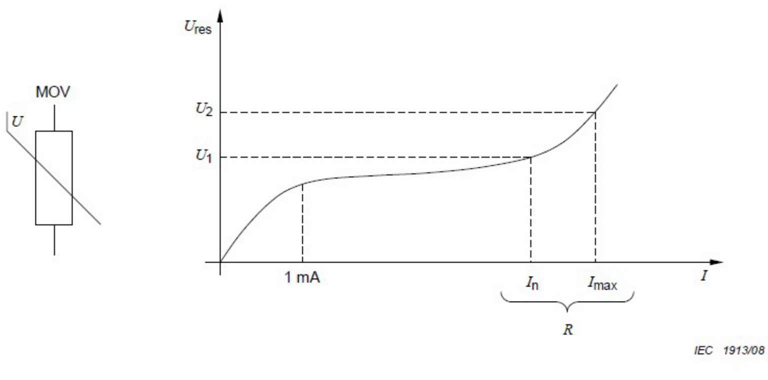

Figure 36: typical curve of a zinc oxide varistor (MOV)

In addition, figure 37 shows how the current peak associated with the pulse and that the varistor is able to support increases as pulse duration and number of pulses decrease. Thus the disturbance must be appropriately defined as to pulse number and duration, thereby allowing the component to be chosen on the basis of the maximum supportable power and energy.

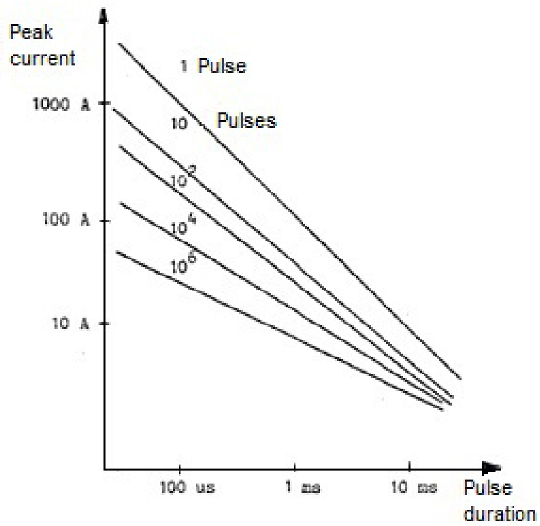

Figure 37: curves of the current peak supported by a varistor

4.3.1.5 Suppression diodes

Suppression diodes (transils) also maintain voltage at a constant level on the load in the presence of overvoltage but, compared to varistors, cannot conduct high currents and therefore support reduced amounts of energy. On the other hand, they are very fast with response times in the picosecond range.

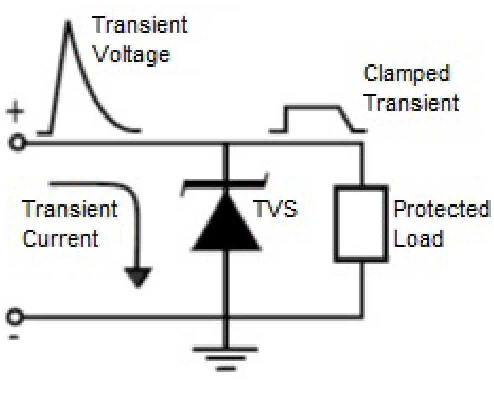

Figure 38: use pattern of a transil

4. Effects and control of interference

To select the right transil it is important to first define the rated voltage of the circuit in which the components will be installed. In addition:

- make sure that the transient peak current of the disturbance is less than the peak value of the rated current pulse corresponding to clamping voltage V_{cl};
- check Transil average power dissipation P_{AV}, especially when there is repeated disturbance. Given energy W of the individual disturbance and frequency f of the disturbances, the energy of the individual disturbance is calculated using the formula $P_{AV} = f*W$;
- make sure that the circuit can support clamping voltage V_{cl} (i.e. the voltage present when the Transil conducts its fully rated current);
- to reduce leakage current, make sure that the rated voltage is far from the clamping voltage.

4.3.1.6 Noise suppression devices

Noise suppression devices, or spike killers (fig. 39), are ferrites formed by amorphous material inserted into the terminals of the devices themselves. They function in a different way from conventional filters since their task is to reduce disturbance at its origin, when the source of disturbance is generated by rapid voltage and current changes (ringing or reverse recovery of diodes, etc.). Amorphous cores eliminate these disturbances regardless of the frequency.

Figure 39: spike killers

4.3.1.7 Positions of filters and protections

The filters and protections described in the previous sections must be installed correctly, otherwise their performance will be impaired. As established by the classification provided by standard IEC 61000-5-1, there are two types of approach to protection, global and distributed. As illustrated in figure 40, global protection is obtained with a single barrier, where the protection must protect the entire installation and must therefore be installed at the point of access to the shielded environment. It would be wrong to install the protection inside the shield since this would allow disturbances to enter the environment. There must obviously be no internal sources of disturbance.

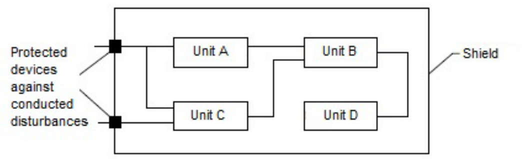

Figure 40: global protection system with single barrier

If there are apparatuses with different levels of immunity, the environment can be divided by cascaded barriers (fig. 41).

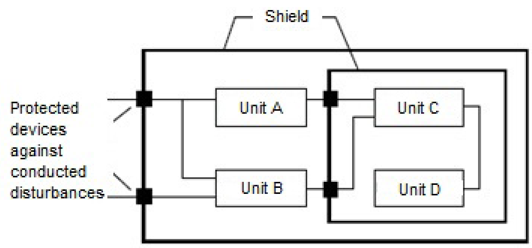

Figure 41: multiple barrier global protection system

The protections in distributed protection systems (fig. 42) are installed on each individual apparatus without a sufficient immunity level.

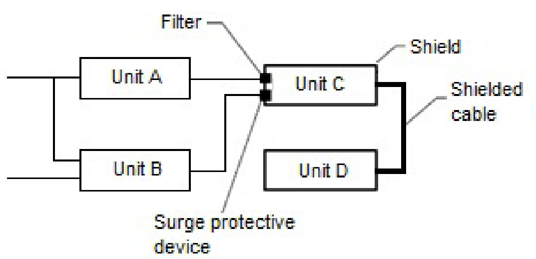

Figure 42: distributed protection system

4.3.2 Methods for mitigating radiated disturbances

4.3.2.1 Shielding

Shielding of an apparatus increases its immunity to external electromagnetic fields and reduces emissions into the outside environment.
Shielding can be extended to an entire environment containing a group of apparatuses, such as a test laboratory.
The following paragraphs describe what takes place when an incident electromagnetic field passes through a shield.

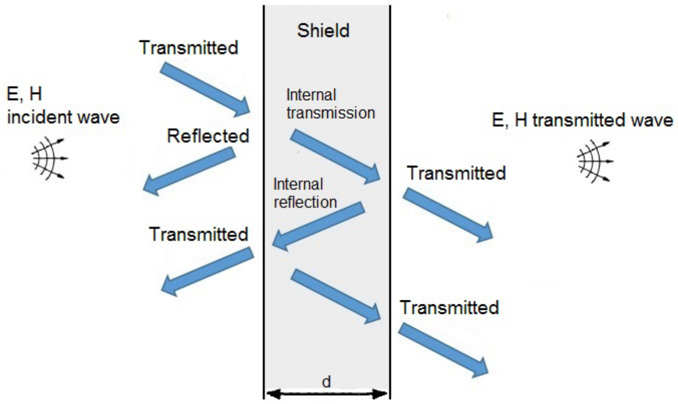

Figure 43: transmission of electromagnetic disturbances in a shield

As shown in figure 43, the electromagnetic field transmitted beyond the shield will equal the incident field minus the losses due to reflection R, absorption A and multiple reflections M.
Shielding Effectiveness (SE) is expressed as:

$$SE_E = \frac{E_{inc}}{E_{tra}} \quad \text{o} \quad SE_H = \frac{H_{inc}}{H_{tra}}$$

or in decibels as:

$$SE_E = 20\log_{10}\frac{E_{inc}}{E_{tra}} \quad \text{o} \quad SE_H = 20\log_{10}\frac{H_{inc}}{H_{tra}}$$

Based on the calculations above, the efficiency of a shield will thus be given by:

$$SE_{dB} = R_{dB} + A_{dB} + M_{dB}$$

where R_{dB} is the coefficient of reflection, A_{dB} is the absorption coefficient and M_{dB} is the coefficient of multiple reflections.

Considering δ as the depth of penetration of the electromagnetic field, this depends on the frequency f, permeability μ and conductivity σ of the material according to the following formula:

$$\delta = \frac{1}{\sqrt{\pi f \mu \sigma}}$$

Thus the depth of penetration decreases as the frequency increases and the shielding characteristics of the material (such as permeability and conductivity) improve. For example, the penetration depth of copper at 60 Hz is 8.5 mm but becomes just 0.02 mm at 10 MHz.
If the thickness of the shield d exceeds the depth of penetration, the contribution provided by loss through absorption becomes significant since absorption coefficient A is:

$$A \cong e^{\frac{d}{\delta}}$$

In addition, if d>>δ, coefficient M_{dB} (the value of which is negative since the reflections within the shield contribute towards increasing the transmitted field, therefore reducing shielding effectiveness) becomes negligible.
For the far-field, thus plane wave incident perpendicular to the shield, reflection coefficient is $\frac{\eta_0-\eta}{\eta_0+\eta}$ where η is the impedance of the shield material and η_0 = 376.7 Ω is the impedance of the air. This coefficient depends on the quality of the shield material and can range from 0 in the absence of a shield ($\eta = \eta_0$) to 1 if $\eta \ll \eta_0$, thus of a material with excellent conductivity, such as metallic materials. By way of example, the following table lists the impedance η of certain materials used for shields:

Material	η [Ω]
Aluminium	$3.8 \cdot 10^{-6}$
Mu-metal	$6.3 \cdot 10^{-3}$
Iron	$8.5 \cdot 10^{-4}$

4. Effects and control of interference

In conclusion, one can affirm that in the presence of far-field electric and magnetic sources, loss by reflection is the predominant phenomenon at low frequencies while at high frequencies it is absorption (always so long as d>>δ).
However, when it comes to near-field sources and while, in relation to the electric field, the shield behaves in exactly the same way as described above, its behaviour in relation to the magnetic field is different: loss by absorption is prevalent at all frequencies even though it is low at low frequencies. This means that alternative methods must be found to shield magnetic fields at low frequencies, such as use of low-reluctance materials. Materials which are both conductors and magnetic therefore give the best results, as shown in figure 44.

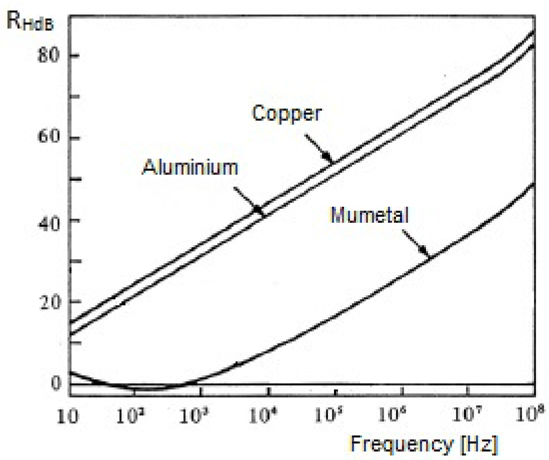

Figure 44: coefficient R_{HdB} in relation to frequency for certain materials

When the previously described notions are applied, one can affirm that all apparatuses should be completely enclosed in housings made of suitable materials, typically metallic.
Since the enclosures of electrical or electronic equipment are either made of metal or plastic, in the former case the enclosure is able to provide a shielding action while in the latter case, methods able to create characteristics that suit the materials used must be provided when necessary.
When the enclosures are made, attention must be paid:

- to the openings, sometimes indispensable when heat exchange with the outside is required;
- to routing the feeder and signal cables that supply power to the apparatus and exchange data with the outside;
- to any openable doors that might be present.

Consult standard IEC 61936-1, Power installations exceeding 1 kV AC – Part 1: Common rules if the installation falls under this category.

The following are valid general rules:

- reduce the number of openings to the minium. When they are absolutely necessary and to obtain efficient shielding, it is good practice to ensure that length L of the openings in the enclosure does not exceed one tenth of the wavelength of the incident electromagnetic radiation. For example, 300 MHz test frequency corresponds to 1.00 m wavelength λ. This means that the length of the openings must not exceed λ/10, i.e. 100 mm. This is not a problem in individual apparatuses (see figure 45), but must be carefully considered for control cubicles. Generally speaking, it is advisable to never have openings with diagonal measurements exceeding 100 mm while, in the presence of higher frequencies (e.g. 1 GHz), the openings should not exceed λ/10 = 30 mm.

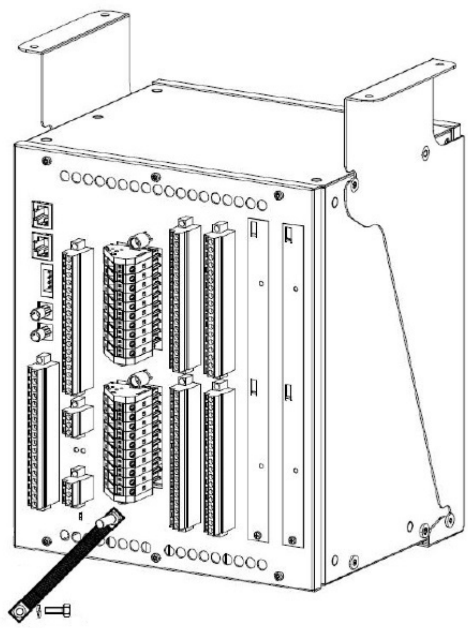

Figure 45: openings in an IED (Intelligent Electronic Device)

- when larger shielding enclosures (e.g. control cubicles) are assembled, a metal gasket must be inserted between the panels when they are joined together or in any case, they must have an unpainted anti-corrosion finish in all points of contact with other plates, etc.
- use metal gaskets for openable doors and panels or connect them to the fixed structure by means of suitable conductors (fig.46);

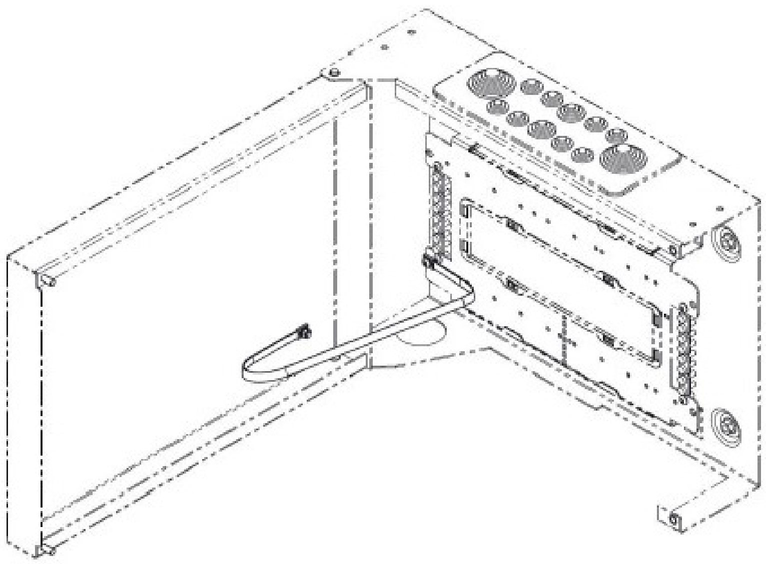

Figure 46: example of a connection between LV compartment and door

- the shields of the cables entering or leaving the enclosure must be connected to the enclosure itself and must be filtered. Analog signals from current transformers can be a strong source of disturbance in electric power panels. For this reason, these circuits must be routed in metal conduits, flexible metallic tubes or metallic braiding. These protections must reach right up to the low voltage compartment and must be earthed. The shields must must be as continuous as possible. They must also have a low resistance (a few ohms per kilometer) and a low coupling impedance in the disturbance frequency range. The earth connection of the shields must be as short as possible and must affect both ends.

A 360° connection is best. Obviously, the shields of the incoming cables must be earthed at their entrance into the panel to prevent coupling inside to unshielded circuits (fig. 47).

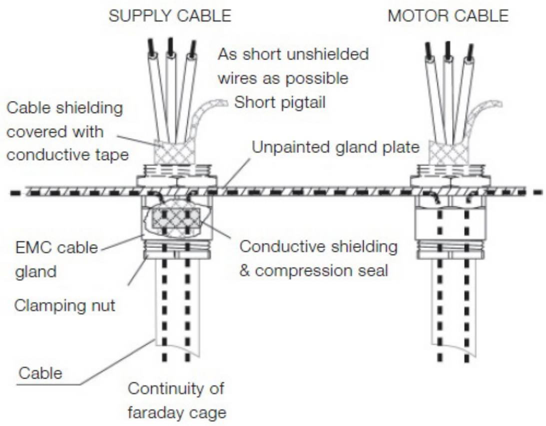

Figure 47: earthing with cable gland

Use of conductive sleeves is another method (fig. 48): the sleeve must be connected to the Faraday cage by screwing it onto a specially designed collar in the cable gland plate.

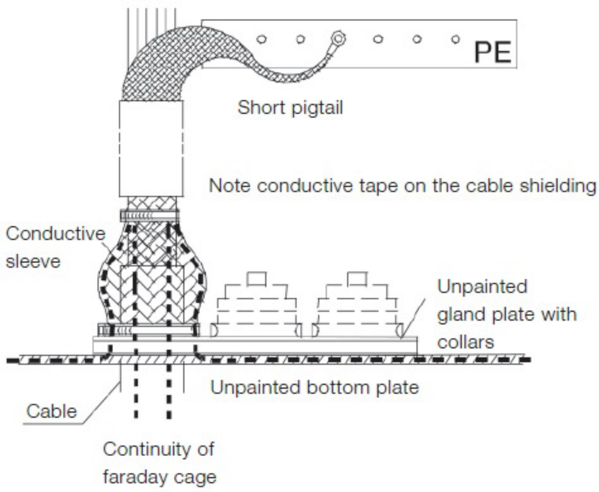

Figure 48: earthing with conductive sleeve

4. Effects and control of interference

Cable clamps can be used so long as they are earthed (fig. 49). In this case the cable glands are no longer necessary.

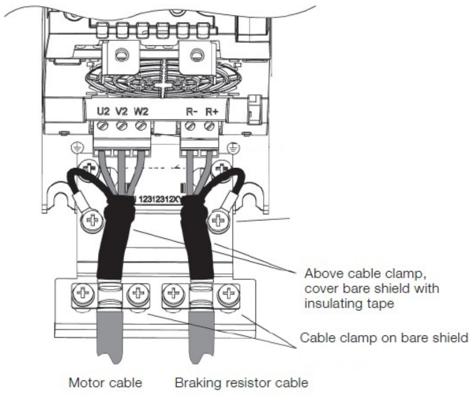

Figure 49: earthing with cable clamps

Figure 50 gives a concrete example of good practice where a shielded cable is connected in an enclosure represented by the plate:

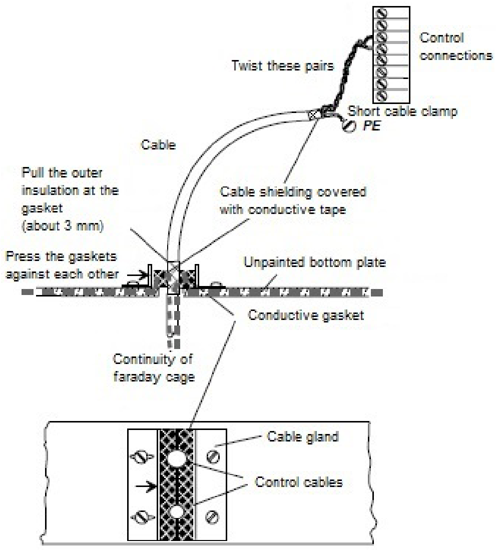

Figure 50: example of a correct connection

Lastly, the measures to apply in a control panel are outlined in figure 51.

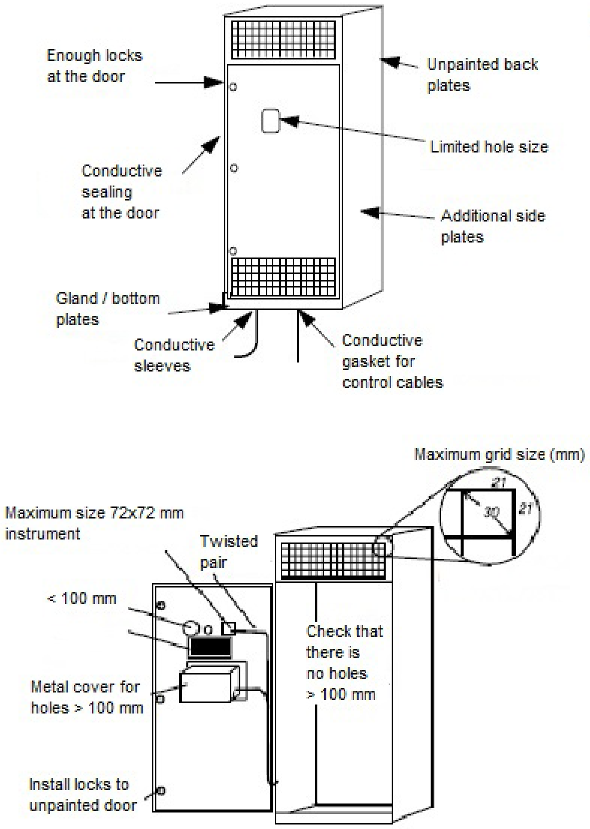

Figure 51: outline of EMC measures in a control panel

4.3.2.2 Indications concerning cables

We will now consider a piece of conductor with diameter d and finite length and represent it with constants concentrated per unit length (fig. 52):

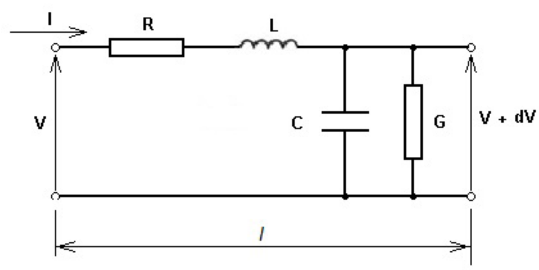

Figure 52: diagram of a conductor

Where R and L are the longitudinal resistance and inductance and C and G are the transversal capacitance and conductance for a unit length l of conductor.
Besides increasing as the temperature rises, resistance R also increases as the frequency of the signal increases. This phenomenon is caused by the tendency of the current to concentrate on the surface of the conductor and is known as skin effect. The variation is proportional to the square root of the frequency of the signal, as in the formula below:

$$R = k \cdot R_0 \cdot d \cdot \sqrt{f}$$

where k is a constant that depends on the type of conductor, with diameter d, and R_0 is the D.C. resistivity.

Inductance takes account of the effect due to the magnetic field generated by the circulation of direct current through the conductor itself, i.e. of self-inductance, which we will call L_i, and of that due to the presence of two conductors, i.e. to mutual inductance L_e. Thus overall inductance can be calculated as sum $L = L_i + L_e$.

Since Li is inversely proportional to the diameter and to the root of the frequency, according to the following formula:

$$L_i = k' \cdot L_0 \cdot \frac{1}{d} \cdot \frac{1}{\sqrt{f}}$$

with $L_0=\mu_0/8\pi$ low frequency inductance and k' a constant which depends on the type of conductor one can affirm that as the frequency increases, L_i decreases while L_e does not change since it depends on the distance between the conductors and their diameter. However, one must consider that L_i is small in relation to L_e, thus one can generally affirm that inductance varies little with frequency.

Capacitance C stands for the parassitic capacitance due to the difference in potential between the two conductors and is proportional to the dielectric constant of the insulation in between. In the case of a diameter d, distance D away from a surface (with D>1.25•d) there is:

$$C = k" \frac{\varepsilon}{\ln\left(\frac{2D}{d}\right)}$$

where k" is a constant and ε is the relative dielectric constant of the insulation. C is therefore dependant on the nature of the dielectric component and the geometry of the circuit.

Lastly, conductance G is due to the leakage current between the conductors, caused by imperfections in the insulation, and is normally negligible. Conductance is conditioned by the nature of the insulation in between, by the frequency of the signal and by the distance between conductors.

Now, considering impedance Z per unit length and given that:

$$Z = \sqrt{R^2 + (\omega L)^2}$$

one can affirm that the cable has an impedance per unit length which varies depending on the frequency, in particular with a resistance proportional to the square root of the frequency and an almost constant inductance.
The linear impedance trend in relation to frequency in certain sections of cable is illustrated in figure 53.

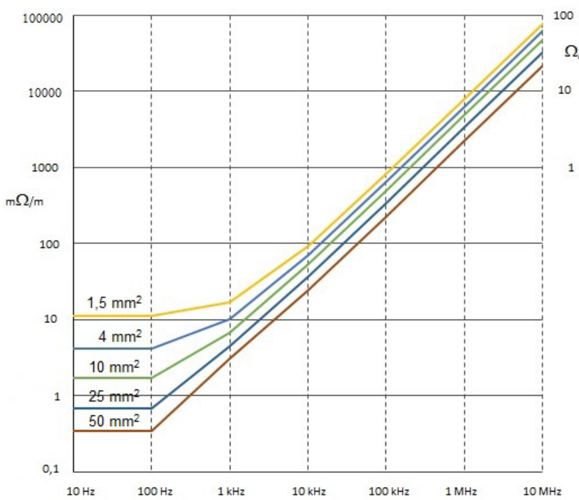

Figure 53: impedance in relation to frequency in certain cables

4. Effects and control of interference

Note that when the frequency rises, it is advisable to route several cables of smaller section in parallel rather than one single cable of a larger section.
Certain conclusions can therefore be drawn concerning the behaviour of wiring in relation to disturbances:

- the impedance of a cable increases as a function of length and frequency. Thus, in the case of high frequency disturbance, the earthing conductors must be as short as possible. Any excess length must be eliminated and the earth connection point must be as near as possible. For example, for apparatus in the low voltage compartment, it is important to connect to the nearest point of the metal structure of the switchgear (fig. 54).

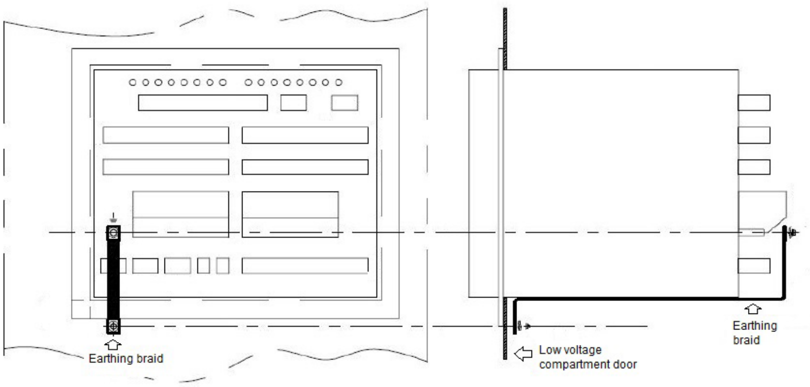

Figure 54: example of the earth connection of an IED

- since it represents possible points through which disturbance can enter, all internal wiring must be as short as possible. In addition, if the conductors are connected to apparatuses which are sources of disturbance inside the switchgear, they could act as antennas and emit radiated disturbance. There are two types of antenna: dipole (fig. 55a) and monopole (fig. 55b); the antenna effect occurs in conductor lengths l=λ/2 in the first case and l=λ/4 in the second case.

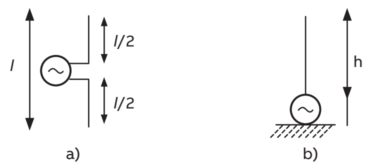

Figure 55: dipole antenna a) and monopole antenna b)

It is therefore important to avoid these two lengths as a funzione of the frequency of the disturbance emitted by the apparatus. Since the second case is the most realistic and bearing in mind that λ=c/f, the result is:

$$l = \frac{c}{4 \cdot f} = \frac{75}{f(MHz)}$$

For example, at a frequency of 80 MHz (one of the frequencies envisaged for the tests) l will equal about one meter. In such cases, it is therefore advisable to use cables of a shorter length;

- cables of different classes should be routed separately. There are two classes of signals for receivers:
  - Class 1 signals, highly susceptible (e.g. signals produced by sensors, load cells, etc.);
  - Class 2 signals, susceptible (e.g. analog signal circuits);

  and two classes of signals for sources, i.e.:
  - Class 3 signals, disturbers (e.g. diode feeders, solenoid valves, etc.)
  - Class 4 signals, highly disturbing (e.g. power converters such as inverters and switching feeders, remote control switches, brush motors, etc.).

To reduce the number of couplings, it is good practice, when possible, to route the cables near to metal parts connected to the reference potential (assembly plates, electric cabinet, etc.). It is also important to use cable trays, cable conduits or tubes made of metal (not plastic) for class 3 and 4 conductors (fig. 56).

Figure 56: examples of metal cable trays

It is advisable for cables pertaining to different signal classes to follow different routes and be suitably spaced. The minimum distances, purely indicative, could be those given below:

Minimum distance in mm	Class 1	Class 2	Class 3	Class 4
Class 1		150	300	500
Class 2			150	300
Class 3				150

Keep to a 90° angle of intersection if cables in classes 1-2 and 3-4 should cross each other.
If the distance between class 1 and class 4 cables is less than 1 m, the Standard recommends that the former be routed within closed metal conduit.

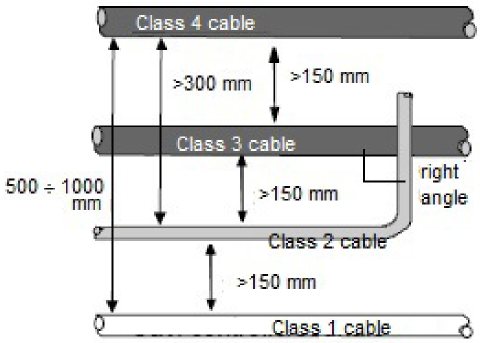

Figure 57: diagram of minimum distances between cables of different classes

- Use of twisted cable to prevent disturbance is common practice (fig. 58). Unshielded twisted pair cable (or UTP) consists of two insulated wires twisted together so as to reduce disturbance due to external electromagnetic fields. These latter induce currents in the coils that flow in opposite directions and tend to cancel themselves. This method is certainly advantageous since it is economical and flexible. However, it is unable to completely eliminate disturbance, especially at frequencies of around 1 GHz.

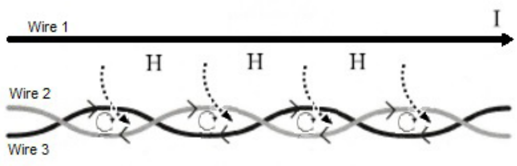

Figure 58: coupling diagram for twisted pair cable

- Use of shielded cables. Shielded cables are efficacious for high frequency transmissions, for connections between measuring instruments and, generally speaking, for transmitting signals of weak intensity. On the other hand, they are more expensive, the cables are inflexible and the connections more complex. The model of a shielded cable is illustrated in figure 59:

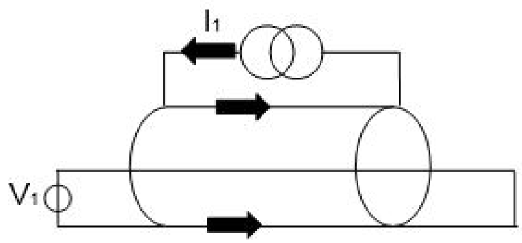

Figure 59: representative circuit for a shielded cable

A disturbance in current I_1 flowing through the shield produces, as a consequence, a disturbance in voltage V_1 given by:

$$Z_T = \frac{V_1}{I_1}$$

Since the ideal shield has a typical impedance Z_T = 1...10 mΩ , it means that the shield contributes towards diminishing the disturbance by Z_T times. The shield (fig. 60) normally consists of conductive mesh (a), a wound copper conductor (b) or aluminium foil wrapped in a helical or cigarette paper fashion (c) around the central conductors. Several mixed types of shields are used to reduce the effect of the openings in the mesh and achieve efficiency even at higher frequencies.

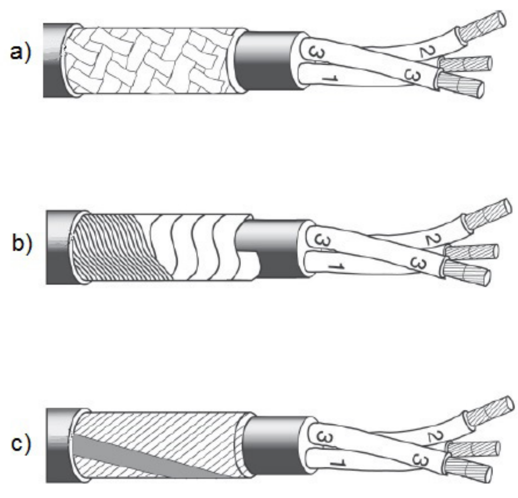

Figure 60: shield in conductive mesh a), with wound conductor b), wrapped in a helical fashion c)

4. Effects and control of interference

The disadvantage of these solutions is that they make cables more expensive and liable to be damaged by bending. In addition, oxidation could impair their continuity and, thus, their efficacy. The typical impedance in the case of continuous tubular shields depends on the geometric characteristics and material used, while admittance is null since the electric field does not penetrate through a continuous shield, which is without openings. In the case of mesh shields (fig. 61), the openings must be taken into account as well as the inevitable penetration of magnetic lines of force through the openings themselves. The typical transfer impedance can be expressed as:

$$Z_T = \sqrt{Z_d^2 + (2\pi f M)^2}$$

where Z_d is the impedance of the tubular shield while termination M represents the mutual inductance due to the magnetic field having penetrated through the openings (r1 is the internal radius of the shield, L its length, P the mesh pitch and α the tilt angle).

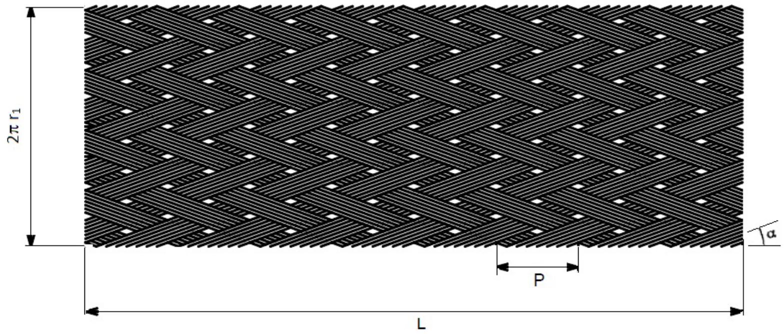

Figure 61: mesh shield

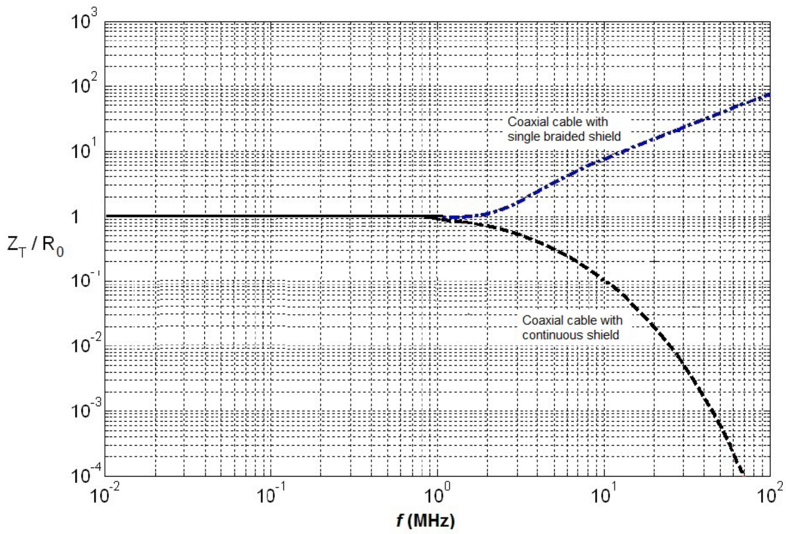

Figure 62: transfer impedance of a conductor with mesh shield and continuous shield

The graph in figure 62 shows how the impedance of a cable (with respect to DC-resistance R_0) with mesh shield coincides with that of a continuous shield until the width of the openings becomes comparable to the wavelength of the disturbance, after which the two curves diverge and the mesh shield begins to lose its efficacy. The shield must be connected at both ends, otherwise it could act as a waveguide or antenna.

One of the reasons for earthing just one of the two ends is that should there be a significant difference in the voltage between the connection points at each end of the shield, the current that would pass through could also damage the cable. This difference in voltage is not unusual in large installations or in connections between buildings. However, the best solution is to improve the earthing network, e.g. by using a meshed network with an appropriate number of ground rods in parallel, and to maintain the shield protection by earthing both ends.
In long sections, where the cable must be divided into several parts, conductive gaskets must be used for earthing the cable shields. A 360° connection is best, i.e. it must completely surround the shield in order to maintain an efficient shielding effect (fig. 63).

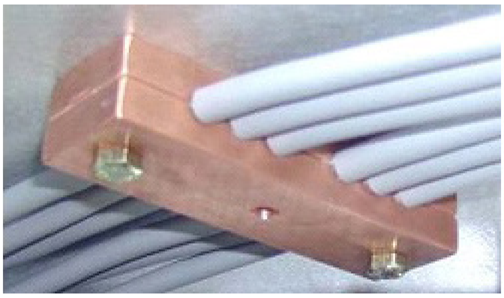

Figure 63: conductive joint

Since, as mentioned previously, the best way to shield radiated disturbances is to earth both ends of the shield, cables with double shielding can be used when it is impossible to prevent current from flowing into the shield.
In this case, just one end of each individual shield can be earthed as shown in the diagram in figure 64:

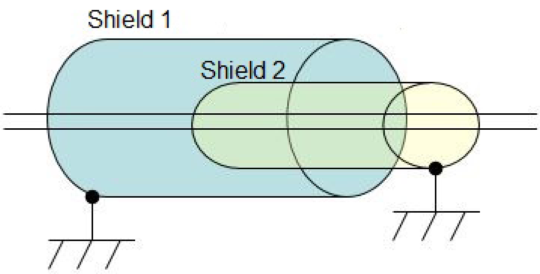

Figure 64: earthing of a cable with double shield

The model in figure 65 shows how the parassitic capacitances become distributed in the cable.

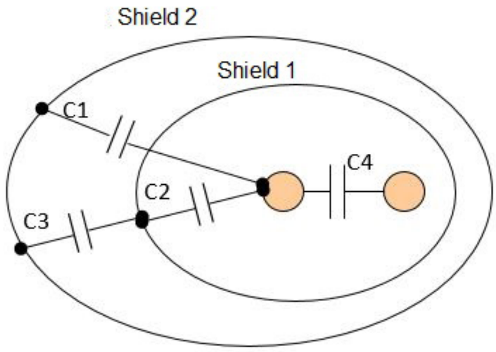

Figure 65: circuit of a cable with double shield

Capacitance C3 is actually a bridge for disturbances between shield 1 and shield 2 to earth (fig. 66)

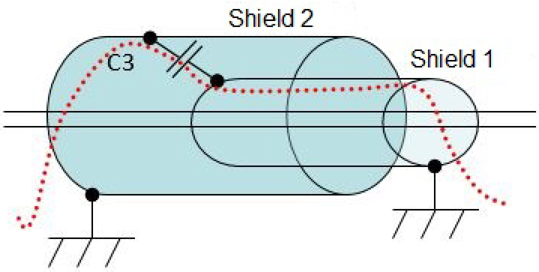

Figure 66: route taken by disturbance in a cable with double shield

The model for long cables at high frequencies is similar to that of the cable with single shield earthed at both ends.
When it comes to protection against magnetic fields, the only solution is to encapsulate the parts that need to be protected in containers made of ferromagnetic substance with a higher magnetic permeability than air.

4. Effects and control of interference

4.3.3 Protective earth and earth (functional)
First a brief outline to describe what is meant by protective earth and earth (functional). From the electrical viewpoint, earth is ground which conventionally has 0 V reference potential.
Protective earth refers to one or more points in a system or installation that are intended for electrical safety purposes while, by exclusion, functional earth refers to one or more points that are not intended for safety purposes.
The electrical symbols are illustrated in figure 67:

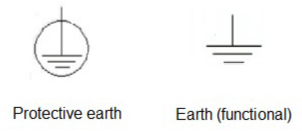

Figure 67: earth symbols

Thus earthing comprises elements able to bring a conductor to earth potential.

Earth must not be confused with a mass, frame or chassis which is a conductive point or element that constitutes the reference potential of an apparatus or a circuit and which may or may not be earthed. The reference symbol in this case is illustrated in figure 68:

Figure 68: symbol of frame or chassis

If the above mentioned conductive part is not maintained at the same potential as the earth, it is known as "floating".
The issue is widely discussed in Standard 61000-5-2. The primary objective of an earthing system is to ensure the safety of persons and protect the installations. This particularly applies to lightning strikes and faults in the power system.
By re-closing via the earth, the strong currents involved in these two phenomena can cause dangerous overvoltage. The second objective of an earthing system is to act as common reference voltage for all systems sensitive to disturbances by contributing towards their mitigation.

When it comes to EMC issues, attention should be paid to the layout when an earthing system is designed, while the type and positions of the electrodes and the section of the earth conductors are relatively important, particularly at high frequencies.
The recommended layout configuration is that with multiple electrodes connected to each other by equipotential bonding. In builidings over 20 meters high, these connections must be repeated every 20 meters of height (fig. 69).

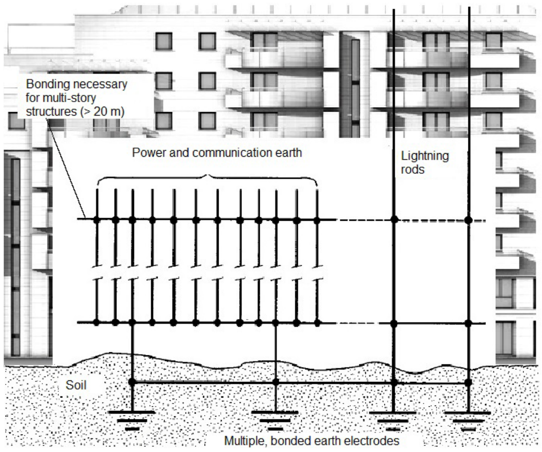

Figure 69: example of an earth connection in a building

Typically, each storey in an office block or industrial building has its own, generally, meshed network. These networks should be connected to each other with ≥2 bonding connections and with grounding rods. This means that there are a great number of routes for disturbances which depend on the frequency of the disturbances themselves. By and large one can affirm that the meshed earthing network covers a broad spectrum of disturbance frequencies (from 0 to tens of MHz) while vice versa, star connections between exposed conductive parts are to be avoided.
In the case of industrial buildings, it is especially advisable to separate the apparatuses into zones depending on their nature and to increase the distance, as far as possible, between sources of disturbance and sensitive loads. Distance is, in fact, one of the ways to mitigate disturbance. For example, in figure 70, the computer room has its own earth while the motors, typical sources of disturbance, are bonded at a certain distance.

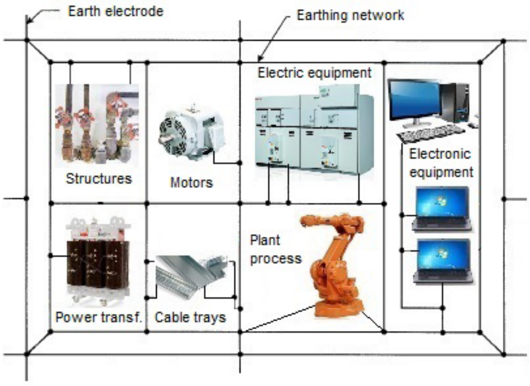

Figure 70: example of separation into zones in a building

Generally speaking, from the EMC viewpoint, it is necessary to eliminate or reduce the ground loops, i.e. those surfaces which form between the earth conductor and a functional cable (figure 71 a). This can be done by connecting the metallic enclosures of the apparatus by means of equipotential bonding that follows the route of the cable or, vice versa, have the cable follow the route of the existing equipotential bonding (figure 71 c).

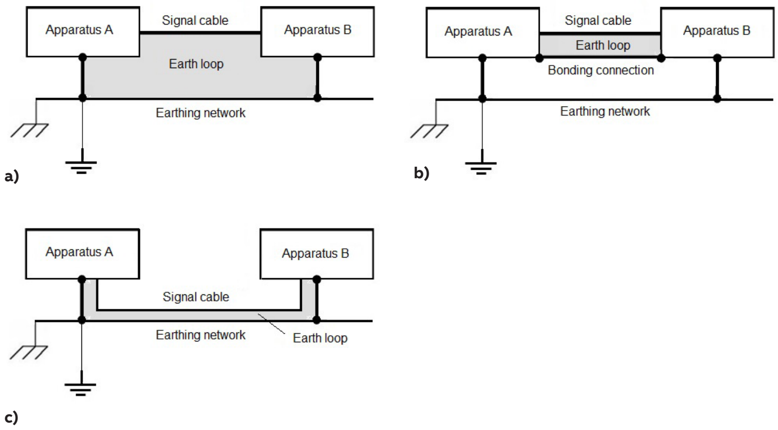

Figure 71: various ground loop configurations

The equipotential bonding mentioned in the previous paragraph is represented by the simplified circuit in figure 72:

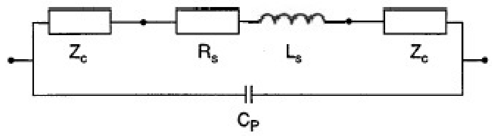

Figure 72: simplified equipotential bonding circuit

where R_s and L_s are the resistance and inductance of the connection element, Z_c is the contact impedance and C_p are the parassitic capacitances. Note how contact resistance plays an important part and how, obviously, connections on painted surfaces are to be avoided unless the paint is removed. Once the paint has been removed, it is advisable to remember to protect that point with paint or protective grease.
Different connection techniques can be used, including soldering, use of nuts and bolts, rivets, etc. The typical values of the connection substantially depend on its length and shape. Generally speaking, if high frequencies are present (> 10 MHz) it is advisable to avoid circular section conductors and to prefer flat ribbon cable or equipotential bondings leads. The typical value of the ratio between length and width of the lead must be less than 5. In any case, these connections must be as short as possible to avoid the previously mentioned ground loops.

Figure 73: connection to the busbar in an MV panel

A single connection is normally sufficient for switchgear compartments (fig. 73).

5. Outline of the measures for mitigating disturbances

The following table briefly outlines the measures described in the previous chapters. The list is not exhaustive and some of the good practices suggested may not be applicable or able to resolve the specific problems of a given context.

N°	Description	√
1	Use meshed earthing networks.	☐
2	Connect all the metallic structures of the building to the earthing network (metal structural components, concrete reinforcements, metal pipes and ducts, cable trays, metal frames, gratings ...).	☐
3	It is advisable to reinforce the earthing network in areas liable to contain materials that are sensitive to disturbances, e.g. by increasing the number of equipotential bonding connections or creating a special ground plane with tighter mesh.	☐
4	Reduce the length of the earth connections to the minimum by using flat profiles, braided or multi-braided flexible conductors to obtain a low level of impedance to radiated disturbance.	☐
5	The circuits must be balanced, possibly with incoming and outgoing wires in the same cable, better if twisted.	☐
6	Route the cables as near as possible to the earthing network or equipotential bondings so as to reduce the ground loops.	☐
7	Separate cables of different classes (power, low power, measurement and control) or at least lay them in different routes. If this is not possible, comply with the minimum distances or use metal conduits or cable trays for the control cables. Cross the cables at 90° if necessary.	☐
8	All analog and digital signal cables must be the shielded type (classes 1 and 2).	☐
9	Check the connectors at the ends of the cables. It is useless to choose an optimum cable if the connection is poor. Provide 360° grounding of connector shields for all shielded cables entering the instrument compartment.	☐
10	Earth the shields of shielded cables at both ends.	☐
11	Do not interrupt the shield. If necessary, use conductors with 360° earthing and the lowest possible impedance.	☐
12	Check whether there are telecommunications antennas in the vicinity (e.g., radar, radio/TV broadcasting, amateur radio operators, microwave appliances, etc.). Consider frequencies and distances.	☐
13	Make sure that all devices form a Faraday cage against radiated disturbances. Consider all the metallic parts of electric panels, cable trays, pipes and conduits, instrument compartments, motors, etc.	☐
14	Reduce excess cable lengths in panels to the minimum.	☐
15	If metal cable trays are used, they must be fastened straight onto the installation plates or frame. Do not leave cables hanging since they could act as antennas.	☐
16	Keep twisted pair cables as near as possible to the terminals and reduce the length of the terminal clamps to the minimum.	☐
17	Unused or spare conductors must be earthed at both ends.	☐
18	Ensure that cable trays and metal pipes are continuous by overlapping and bolting their ends. If this is not possible, connect their ends with a short bonding lead.	☐
19	Always consider the broadest range of possible frequencies when conducted disturbance is analyzed.	☐
20	Filter the supply and disturber cables towards conducted disturbances, starting from the entrance to cubicles or devices, using appropriate filters or other suitable means: ferrites in the supply cables, AC or DC choke (for harmonics, but also for high frequency disturbances).	☐
21	Electrically connect the filters to the frame or earthing busbar at the bottom of the cabinet.	
22	Electric panels must have conductive surfaces and be unpainted in all points of contact required.	☐
23	Apply conductive gaskets to doors and covers and wherever necessary.	
24	Make sure that all the metallic parts of the panel are connected to the earth network by equipotential bondings.	☐
25	Reduce the number of holes in cabinets and electric panels to the minimum.	☐
26	Make sure that the CE mark is applied to all auxiliary products inside the panel.	☐
27	Do not use fluorescent lamps for lighting in control cabinets. Use filament lamps if possible.	☐
28	Cabinets containing emitting apparatus and those containing sensitive apparatus should be separate.	☐

6. Verification and validation of electronic products

Generally speaking, when products are developed it is important to be able to use the services of laboratories with advanced equipment for conducting material, experimental, climatic, mechanical life, electromagnetic compatibility, performance and dielectric tests. Labs dedicated to electronics and electromagnetic compatibility are essential when electronic products are developed.

Figure 74: The ABB electronic lab at Dalmine

Figure 75: the ABB anechoic chamber at Dalmine

6.1 The electronic lab

The electronic lab (fig. 74) was created to assist the electronic engineering division's research and deveopment tasks. It possesses a vast array of instruments and can perform a great number of assessment and validation tasks, including:
- debugging of electronic prototypes
- design and construction of automatic test benches
- thermal analysis and climatic tests

6.2 The EMC lab

As already described, electromagnetic compatibility – EMC – includes various skills, technologies and regulations allowing electronic components to function without problems and without disturbing other devices in a given environment. Nowadays, electromagnetic compatibility is a very important issue owing to the sharp increase in the use of electronic components in electrical apparatus for industrial and civil spheres, in the field of IT and telecommunications and for the vast array of wireless communication systems now in operation. In addition, plastic enclosures are progressively replacing those made of metal, while there are changes in the types of signals, where voltages are becoming lower and frequencies increasingly higher.
Since these issues are so complex, the ability to rely on consolidated skills when electronic products are developed and validated is of fundamental importance. The Dalmine electromagnetic compatibility lab provides this opportunity by working alongside the research and development staff right from the very first stages of a project. The lab is certified and able to perform more than twenty types of different EMC tests compliant with the most recent standards and the most stringent requirements. More specifically, the lab can perform tests such as:
- conducted immunity tests at low and high frequencies, Fast transients/Burst, Surge, Ring wave, 100 kHz to 30 MHz damped oscillatory waves and all types of low frequency disturbances in single-phase apparatus (voltage fluctuation, frequency change, ripple, voltage and current drops and dips, etc.)
- radiated immunity tests of electric fields (up to 3 GHz) and magnetic fields at power frequency and pulsed;

6. Verification and validation of electronic products

Figure 76: the shielded chamber for conducted tests

Figure 77: MV circuit breaker being tested in the anechoic chamber

- electrostatic discharge immunity tests;
- measurement of conducted and radiated emission;
- numerous other tests conforming to the various requirements established by standards and specifications for different types of equipment.

The lab covers an area of some 130 m^2 and has its own earthing system formed by 50 cm copper mesh with independent earth electrodes. This system is connected to the factory earthing system in a single point.

The area is divided into four parts:
- Area where apparatus that needs to be tested is registered on receipt and checked, with storage facility for instrumentation and two 25 kVA and 70 kVA transformer panels;
- shielded chamber in aluminium for tests of the conducted type (fig. 76);
- semi-anechoic chamber for radiated tests (fig. 77);
- measurement pre-chamber with shielded walls for instrumentation (including the computers) to assist the two test chambers.

The semi-anechoic chamber (fig. 78) consists of a shielded enclosure formed by galvanized steel panels covered by ferrite bricks on the four sides and ceiling. Absorbent cones, to prevent the electromagnetic field from reflecting, are also positioned on the floor and in other sensitive internal areas.

All the electric power supplied to the chamber is filtered outside. The chamber also has a fiber-optic communication system. Inside there is a motor-operated 2 m diameter turntable (maximum load capacity 1000 kg) and an automatic antenna positioner for 1 to 4 m heights.
The chamber acceptance verifications were performed by independent external bodies. The shielding tests were performed in compliance with MIL-STD 285 and the resulting attenuation values always exceeded 100 dB. The field uniformity tests were conducted in accordance with the procedure given in the latest edition of

Figure 78: the ABB semi-anechoic chamber at Dalmine

standard IEC 61000-4-3, in 16 measurement points at test distances of (18 V / m) and 1 m (54 V / m). The values obtained differed no more than -0 dB / +6 dB from the reference field value in over 75% of the points across the entire band.
The NSA (Normalized Site Attenuation) measurements were obtained by defining a cylindrical test volume, from 30 MHz to 1 GHz. Chamber attenuation was measured by means of a horizontally and vertically polarized antenna to make sure that it differed less than 4 dB from the attenuation value in an ideal site.
These measurements confirmed that the chamber was suitable for radiated immunity tests and for measuring emissions in accordance with CISPR standards. Although pre-conformity radiated emission tests can also be performed in fully anechoic chambers that are small in size, a large chamber like the one used in the ABB Dalmine facility is best and is recommended by the standard.

Figure 79: radiated test

As described in the previous chapters, the tests for demonstrating compliance defined in the standards are numerous and vary from product to product. Figure 79 gives an example of a radiated test using a transceiver in the immediate vicinity of the apparatuses.
Quality certification is an important part of EMC lab organization. The ABB lab in Dalmine obtained certification in 1998. This was extended over the following years to include tests on specific low, medium and high voltage products. Quality certification testifes to test lab technical and management skills and is therefore very important. It Italy, the accreditation body is ACCREDIA (Italian Accreditation Body for laboratories). Operating in compliance with standard UNI CEI EN 45003, the accreditation body monitors and supervises, over time, the conformity of laboratories to its requirements and to those of standard EN ISO / IEC 17025.

7. Conclusions

As discussed in the previous chapters, electromagnetic compatibility is a very complicated issue. However, theoretical analysis of the specific phenomena can provide important indications as to how immunity problems can be resolved. Although they do not pretend to provide all the information needed in order to face such issues, these Technical Application Papers still contain useful indications concerning theory and application. Once all the precautions and good installation practices have been applied, the devices, apparatuses and systems must be tested to check that the required level of immunity has been ensured. It is advisable to have these tests performed by a competent laboratory, equipped with suitable test equipment and with staff members in possession of the necessary experience. Experience and sufficient resouces are essential for solving EMC problems, especially when radiated disturbances are involved. For example, since they are characterized by the presence of numerous auxiliary devices, by the circulation of even high primary currents and by significant voltage and current transients due to the operation of switching apparatuses, especially interruptions, medium voltage switchgears must be tested by suitable laboratories also in view of their large size.

Figure 80: MV switchgear being tested in the ABB Dalmine EMC lab

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For further details please contact:

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More product information:
abb.com/mediumvoltage
Your contact center:
abb.com/contactcenters
More service information:
abb.com/service

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