Power Quality Application Guide

LEONARDO POWER QUALITY INITIATIVE

Harmonics

Understanding Compatibility Levels

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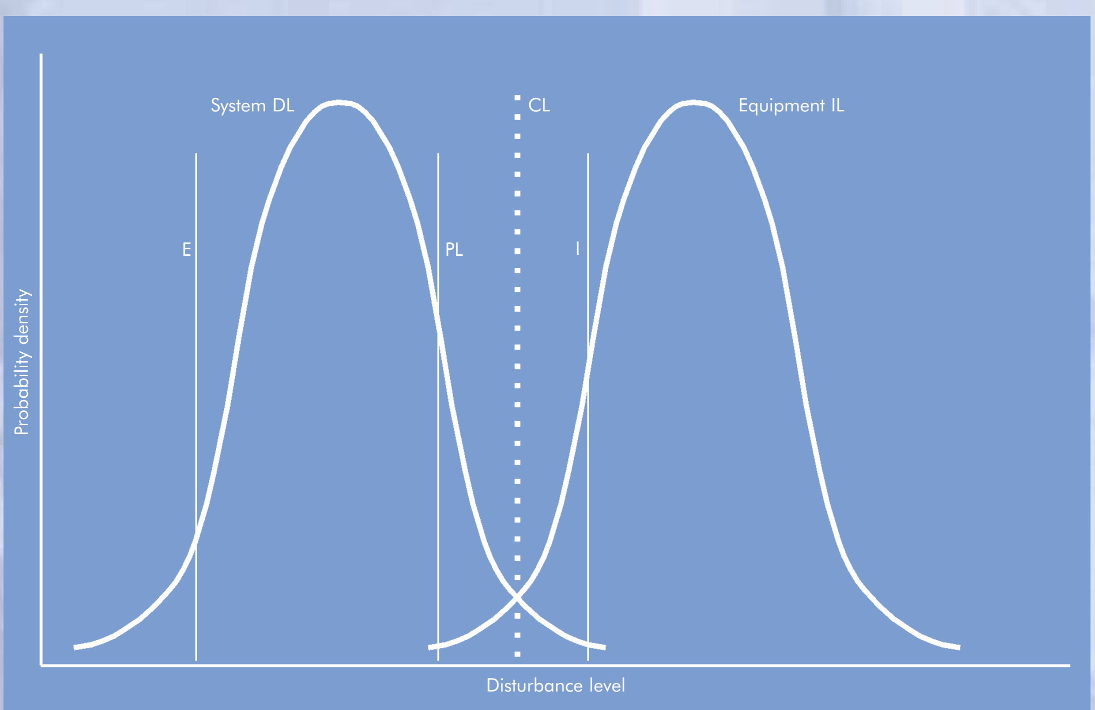

Harmonics

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Harmonics

Understanding Compatibility Levels

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Understanding Compatibility Levels

Introduction

In theory, the currents and voltages in a three-phase electricity distribution system have a perfect sinusoidal waveform, have unity power factor, are balanced (i.e. the voltages and currents in each phase have identical magnitudes) and the phases are displaced by exactly 120 degrees.

In practice, the nature of the consumers' loads (primarily) causes distortion of current and voltages and poor balance between the phases [1]. Over the last two decades the situation has become worse and today's networks have distorted voltages and currents and, even in their steady state, cannot be considered as a 'balanced, sinusoidal regime'. Among the causes of this situation are:

- harmonic currents introduced by non-linear loads such as single- and three-phase rectifiers, arc furnaces, static-var compensators, etc.
- interharmonic currents produced by ac and dc arc furnaces, ac motor drives, etc.
- unbalance created by single-phase loads connected to the three-phase system
- flicker produced by fluctuating loads
- voltage variations (dips, interruptions) caused by faults on the grid, lightning strikes, etc.

In a deregulated market, where many companies compete for customers on the same network, power quality is a major concern, because responsibility for providing 'clean power' is divided. In order to preserve good quality of power on the network, it is essential to have a set of standards that clearly specifies the limits that must be imposed on loads and networks.

The objective is to provide an environment in which electromagnetic compatibility (EMC) is achieved, defined in an IEC Standard [2] as:

> *"The ability of an item of equipment or a system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment".*

The electromagnetic compatibility problem

There are two sides to the compatibility problem. Consumers' equipment operating on the network causes disturbances on the network and the resulting disturbances on the network affect the proper operation of other equipment on the network. To ensure compatibility it is necessary to control the maximum level of disturbance that may be present at any point on the network and establish a level of disturbance to which every item of equipment will be immune.

The network is very large and is far from homogeneous; for example, the impedance at the point of common coupling depends on the structure and 'strength' of the local network and the density of equipment varies enormously. Each item of equipment produces some disturbance that aggregates in some way with that from other equipment. Equipment standards are designed to ensure that:

- the emission levels from each class of equipment are such that the connection of the equipment to the network will not unduly raise the overall level of disturbance
- the equipment will not be susceptible to the levels of disturbance that can be expected on the network.

There are several parameters that need to be specified and controlled:

- emission level (EL)
- immunity level (IL)
- compatibility level (CL)
- emission limit (E)
- immunity limit (I)

and, on MV and HV networks,

- planning level (PL).

These limits and levels are described in the following sections.

Emission level (EL)

The emission level is the disturbance level (DL) produced by a particular load at a particular location. Its value depends mainly on two factors:

- the characteristics of the equipment, including variations inherent in mass-produced equipment and
- the characteristics of the supply network at the point of connection.

Although equipment is designed and manufactured to meet a standard (which will include the level of emissions permitted), individual items of mass produced equipment will inevitably have small differences in their emission of disturbances. Equipment is 'type tested' to ensure that it meets the requirements of standards but variations in components and exact assembly details will result in small variations in emission level. This implies that the disturbance level produced by different examples of the same equipment in the same network would be different.

Because many disturbances are manifested as variations or distortions in the current drawn by equipment the resulting disturbance, measured as a voltage disturbance, will depend on the supply network impedance, sometimes expressed in terms of short circuit power.

Statistical aspects of the emission level

The network has a very large number of loads connected to it, each with an emission level. Because of differences in network impedance (short circuit level), the spatial density of loads and their operating conditions, the emission level measured at various points on the network will be different. In other words, the measured value of emission level is distributed statistically, as shown in Figure 1.

The graph shows the probability (p) of obtaining a particular value of emission level of a particular disturbance. As some value ranges of emission level are more frequent, their probability of occurrence is higher.

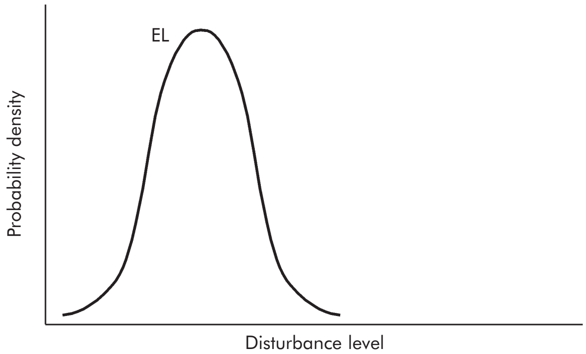

Figure 1 - Distribution of emission level

The background disturbance is made up of contributions from very many items of equipment. Some disturbances are essentially random in nature in that they are not related in phase or magnitude to the disturbance produced by other items of equipment. As a result, for these disturbances, the effect of adding another item of equipment to a system is not simply additive. However, there are some important disturbances, such as third harmonic currents and the voltage drops derived from them, which are locally additive.

Immunity level (IL)

Each piece of equipment is designed and manufactured to a standard that requires it to be immune to disturbances below a certain level. The immunity level (IL) is the maximum value of a disturbance, present in the network, that does not degrade the behaviour of a particular item of equipment under test conditions. In practice, the immunity of the equipment to disturbance is also affected by other factors. For example, component tolerances and precise assembly details will affect the immunity level relative to the type-tested samples, and installation conditions, such as cable lengths and earthing arrangements, are also likely to introduce variations.

As a result, the immunity level of equipment is also distributed statistically in the same way as emission level (Figure 1).

Compatibility level (CL)

The disturbances produced by individual loads combine to create a level of disturbance in all the buses of the network. The level of disturbance will be higher for some buses than for others, depending on their impedance and loading, and will vary according to the time of day, day of the week and time of year.

The compatibility level is defined as the disturbance level that must not be exceeded for 95% of the measurements in the entire network [2]. Note that compatibility level is a statistical value that characterises the state of the whole network - it cannot be used to describe the situation on a particular bus. See Figure 2, which shows successive measurements of the disturbance level (DL) of a particular disturbance in all buses of a network during a week.

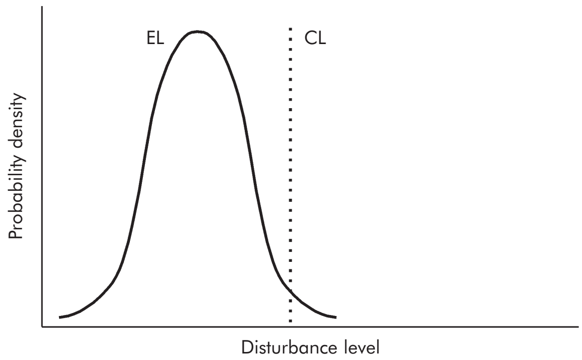

Figure 2 - Compatibility level

The compatibility level is defined absolutely, for example, the compatibility levels for some harmonic voltages in LV networks, shown in Table 1 (see [2]), are expressed as a percentage of fundamental component of voltage. However, the disturbance levels to which they are related (at the 95% level) are statistical, being the result of the effect of a large number of variables.

Harmonic	CL [%]
5	6
7	5
11	3.5
13	3

Table 1 - Compatibility levels of LV harmonic voltages

While specifying the magnitude of the compatibility level is simple, defining the equipment design standards and network planning rules that will enable it to be met is a rather more complex task relying heavily on operating experience. The emission limit described in the next section is one component of this.

Emission limit (E)

The emission limit is the maximum permitted value of emission level generated by a particular item of equipment. Note that the emission limit applies to a single piece of equipment, while compatibility level applies to the whole network. Emission limits can be confirmed by testing and non-compliant equipment designs eliminated. In practice, control of this process is left to the market, relying on manufacturers to test their designs properly and on users to report offending equipment.

The emission limit is a disturbance level set somewhat lower than the compatibility level. The reason for this is that the disturbances produced by all the loads in the system aggregate in a complex fashion to become the 'global' disturbance level. Some disturbances, such as third harmonic currents, simply add arithmetically locally but are then mitigated by, for example, passing through the delta windings of transformers. Other harmonic currents tend to aggregate as rms sums, but are also mitigated by mixing with those from other sources, assisted by the phase changes that occur as the harmonics pass through transformers and the effects of inductance and capacitance on the network. However, locally, there may be unexpected increases due to resonance effects.

Emission levels are defined in absolute terms, e.g. an absolute limit on the current at a particular harmonic frequency, unlike the network disturbance levels, which are described in statistical terms. The correspondence between the two depends on the characteristics of networks and has been derived from many years of operating experience. Regulators and standards bodies have specified equipment emission limits that may be expected to lead to disturbance levels that will not exceed the required compatibility levels.

As an example, Table 2 shows the emission limits of some harmonic currents in LV networks (EN 61000-3-2) [3]. Currents are in Amperes.

Harmonic	Limit [A]	
	Class A	Class B
5	1.14	1.710
7	0.77	1.155
11	0.33	0.495
13	0.21	0.315

Table 2 - Emission limits of LV harmonic currents

Because different types of equipment affect the system differently, several classes have been defined in EN 61000-3-2. Two examples are given here for illustration. Class A contains equipment such as three-phase balanced systems or home appliances, Class B equipment is portable tools (low duty factor equipment).

Immunity limit (I)

The immunity limit (I) is the disturbance level that equipment must withstand without loss of performance. The immunity limit is determined by design and is assured by type testing, so there will be small variations between individual items of the same nominal design. Since installation conditions vary, there will be a much wider spread of performance among similar items in different installations. There will therefore be a distribution of immunity levels of equipment on the network.

If true EMC is to be achieved, 95% of the distribution of immunity levels of equipment as installed must lie above the compatibility level, as shown in Figure 3.

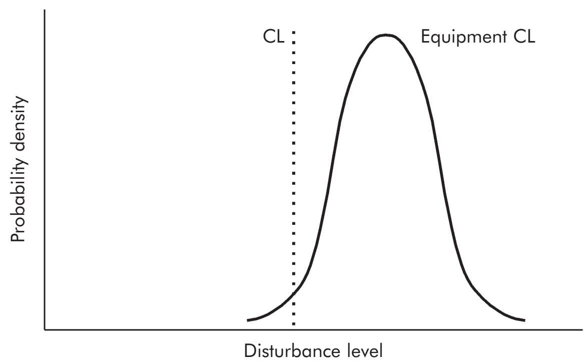

Figure 3 - Distribution of immunity level

This ideal situation can only be achieved, given a reasonable choice of compatibility level, by setting proper standards of equipment immunity limits and by the use of good installation practice.

Planning level (PL)

Planning levels are used in MV and HV networks and represent internal objectives of the electrical utilities. They are used in network design, for example in deciding how to connect new loads. In many regulatory regimes, planning levels are applied to industrial and commercial consumers to limit the harmonic currents that can be imposed on the network by a consumer. Planning levels are lower than compatibility levels, partly because there are many unknown loads on the system (e.g. domestic loads) that can only be estimated and partly because the problem is a statistical one and regulators err on the side of caution.

The relationship between these parameters

Figure 4 shows the inter-relationship of these limits.

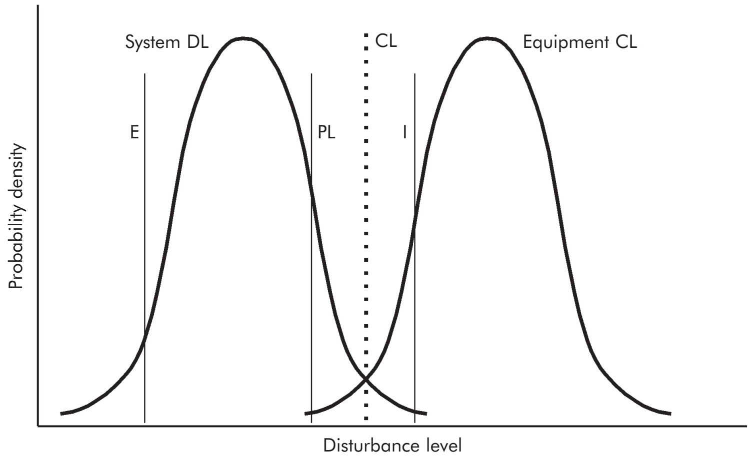

Figure 4 - Relationship between emission limit, immunity limit, compatibility level and planning level

The compatibility level is set at a disturbance level that is greater than 95% of the measured values in the whole system over time. As a result, in only 5% of cases will the ambient disturbance level exceed compatibility level.

The distribution of disturbance level is controlled such that only 5% of values are below the compatibility level. The compatibility level can be seen as a level of disturbance that is exceeded in only 5% of network measurements and to which only 5% of equipment will be sensitive. Only where problem equipment is connected at a problem location is there likely to be a problem - in other words, the EMC requirement will be met for the vast majority of cases.

In reality, the situation is that *de facto* compatibility levels were established by the design standards used by electricity distribution companies and by the fact that manufacturers' equipment would only gain acceptance in the market if it was sufficiently immune and well behaved to co-exist with other equipment. These issues are now formalised as described above.

Conclusions

The main limits used in the standards to regulate the emission and immunity of equipment connected to the mains are described, and the relationships between them explained.

Setting these limits is a compromise. A very low emission limit will result in a very low disturbance level, allowing a low compatibility level to be set. Lower immunity levels will be tolerable, but the cost of manufacturing low emission equipment will be higher. On the other hand, allowing higher levels of emission will require an increase in the stated compatibility level and would require an increase in immunity levels, again increasing manufacturing costs.

References and Bibliography

[1] Bollen, Math H J, Understanding Power Quality Problems: Voltage Sags and Interruptions, IEEE Press Marketing, 2000.

[2] IEC 61000-2-12. Electromagnetic Compatibility (EMC) - Part 2-12: Environment - Compatibility levels for low frequency conducted disturbances and signalling in public medium voltage power supply systems.

[3] IEC 61000-3-2. Electromagnetic Compatibility (EMC) - Part 3-2: Limits - Limits for harmonic current emissions (equipment input current $\leq$ 16A per phase).

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