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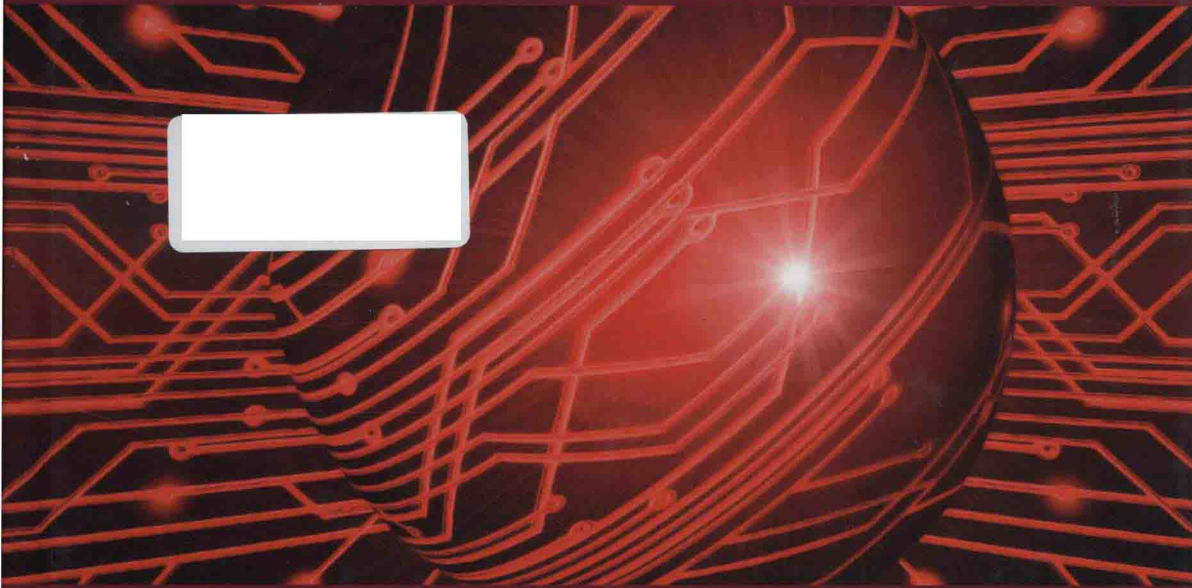

Electromagnetic Compatibility in Power Electronics

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Electromagnetic Compatibility in Power Electronics

Table of Contents

Chapter 1

Phenomena of Perturbation in Electrical Systems

1.1. Electromagnetic perturbations in energy systems

1.1.1. *Introduction*

Power electronic systems are increasingly being used in every field; initially, they were used in the industrial sector and then used increasingly in transportation, services and housing sectors. The flexibility in the control of electrical energy explains this evolution well.

For the purposes of illustration, we estimate that the electrification of service or control functions in an aircraft offers the following gains[1]:

– 10% on the mass;

– 9% on fuel consumption;

– 13% on thrust from the engines;

– 15% on maintenance costs;

– 10% on the buying price.

1 According to SAFRAN company, symposium SPEC 2007.

The field of automobiles is also subject to this evolution: the development of hybrid vehicles over the last 10 years and, more recently, the re-emergence of the fully electric car (while waiting for fuel cells vehicles) are evidence of this. Already, a large number of services have been electrified in thermal engine automobiles because of the flexibility of controls (speed variation) and high yield of the electrical systems: power steering, anti-blocking system (ABS), various pumps, window winders, air conditioning (to come).

The introduction of this technology, as a consequence, must take into consideration its implementation constraints; electromagnetic compatibility (EMC) in particular. Indeed, static converters based on power electronics are important sources of electromagnetic perturbations that can occasionally cause malfunctions in their local or distant electronic environment: avionics, navigation systems, reception antennae, etc. Thus, it is important to understand the origin of these phenomena, their mode of propagation and the effects on their potential "victims" in order to optimize the essential reduction or protection devices necessary to conform to the standards of EMC.

A chain of management of the electrical energy is generally organized according to the diagram in Figure 1.1: a primary electrical source powers the energy conversion system (distributed control), which itself powers one or more passive loads or actuators. The link between these components is achieved through conductors or power cables. The converter can itself be a complex device with different levels of conversion and have auxiliary supplies.

The converters carrying out the *processing of electrical energy* (conditioning, control) are based on the use of power electronics in the same manner as microelectronics and *signal processing*. It is noteworthy to observe that these two fields are based on the switching of semiconductors. In the first case, this involves power components (insulated grid bipolar transistor (IGBT), metal oxide silicon field effect transistor (MOSFET, diodes, etc.)) operating with vertical conduction which, in a switching system, confer a very high efficiency to the static converters where they are used; in the other case, this involves heavily integrated lateral components that enable the increase in speed of information processing. In each case, the high-frequency operation of these systems causes electromagnetic perturbations, the disturbance frequencies of which get closer and closer.

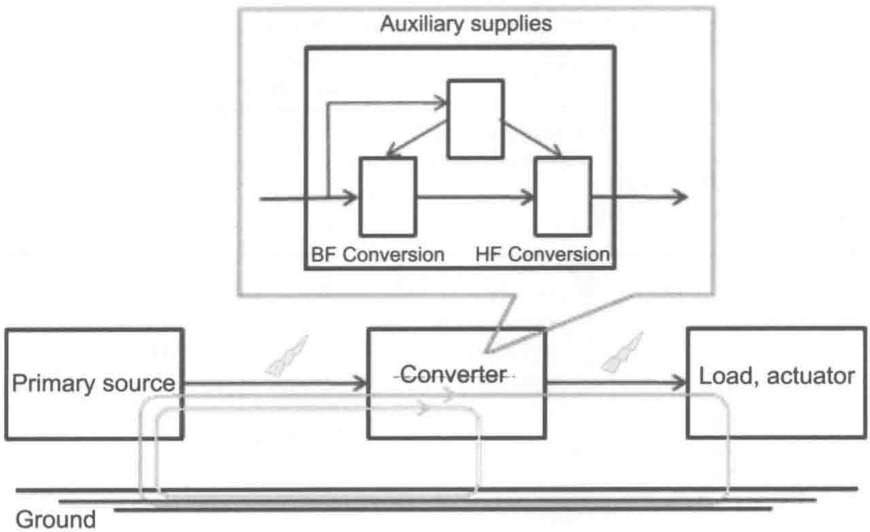

Figure 1.1. *Organization of an power electronics management system*

The consequences of the perturbations emitted by the power devices can be very serious in terms of the reliability and/or security of systems: in an airplane where security depends on electronic localization, communication and flight control systems, the introduction of electrical energy control systems based on power electronics must not threaten the current level of security; a good knowledge of these phenomena is therefore essential in this field.

Near-field or radiative couplings are proportional to the temporal derivative of the electrical quantities: Mdi/dt, CdV/dt; therefore, as their importance increases, these quantities are naturally bigger and the harmonics of the commuted electrical quantities are of a higher frequency.

Thus, the switching of power semiconductors can cause conducted and emitted electromagnetic perturbations that cover a very large frequency range as shown in Figure 1.2.

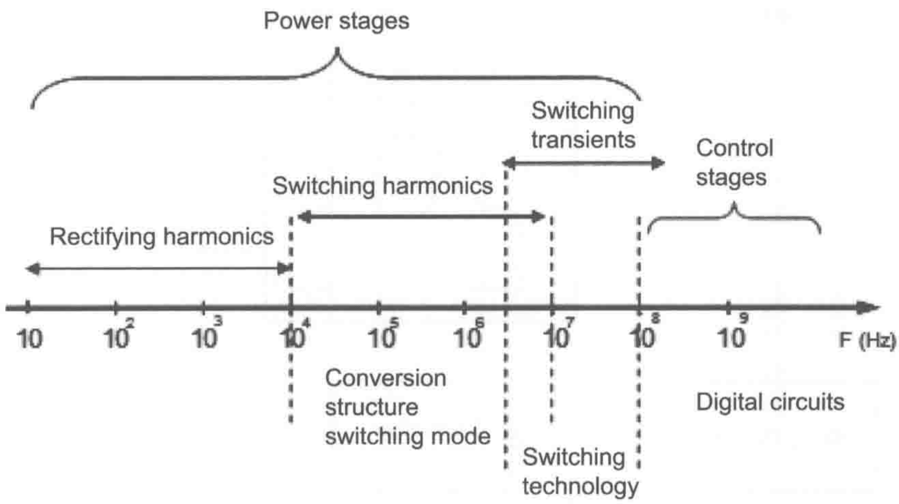

Figure 1.2. *Frequency range of power electronics perturbations*

– At low frequency from the network frequency of 50 Hz: the direct switching of diode or thyristor rectifiers, of triac dimmers, in synchronization with the network frequency, generates perturbations observable up to a few tens of kilohertz. This range is known as the "power grid harmonics".

– At medium frequency (ranging from 10 kHz to 10 MHz): the switching of controlled semiconductors (MOSFET, IGBT) is performed in this range for switched-mode power supplies, choppers and power inverters. The commuted quantities show very quick temporal variations (of the order of a few 10 kV/µs and a few 100 A/µs) with extremely large spectral contents observed over at least four frequency decades: from 10^4 to 10^8 Hz.

– At high frequency: the transients in switching of semiconductors excite the normal modes of very low resistance electrical circuits (necessary for small losses). Thus, very high frequency resonances appear (10 MHz–1 GHz) during each switching between the parasitic inductances of connections (or of magnetic components) and the structural capacitances of the semiconductors.

The reality is more complex than this first classification because in an electronic power device, there are generally several stages of conversion operating at different frequencies (rectifier, high frequency (HF) switch-mode for auxiliary power supplies, medium frequency (MF) switch-mode for power, etc.) that interfere or intermodulate. For illustrative purposes, Figure 1.3 shows the spectrum of the current measured at the input of an upstream switch-mode power supply (black curve) and at the input of a downstream rectifier (gray curve). We can clearly see the contribution of the rectifier starting from 50 Hz and the multiple harmonic peaks that it generates until approximately 10 kHz. Beyond that, we observe (black curve) multiple 15 kHz peaks (switch-mode frequency) that are modulated by the operation of the rectifier and are not modulated on the gray line: the effect of modulation is represented by a certain level of noise at the bottom of the switch-mode harmonic peaks (area circled in dotted line).

These observations show that the electromagnetic perturbations caused by the static converters are not only conducted in the electrical networks and in the cables linking the loads, but are also very easily transmitted by direct radiation, taking into account the amplitudes of the currents and voltages that are in play as well as their frequencies (see Figure 1.1).

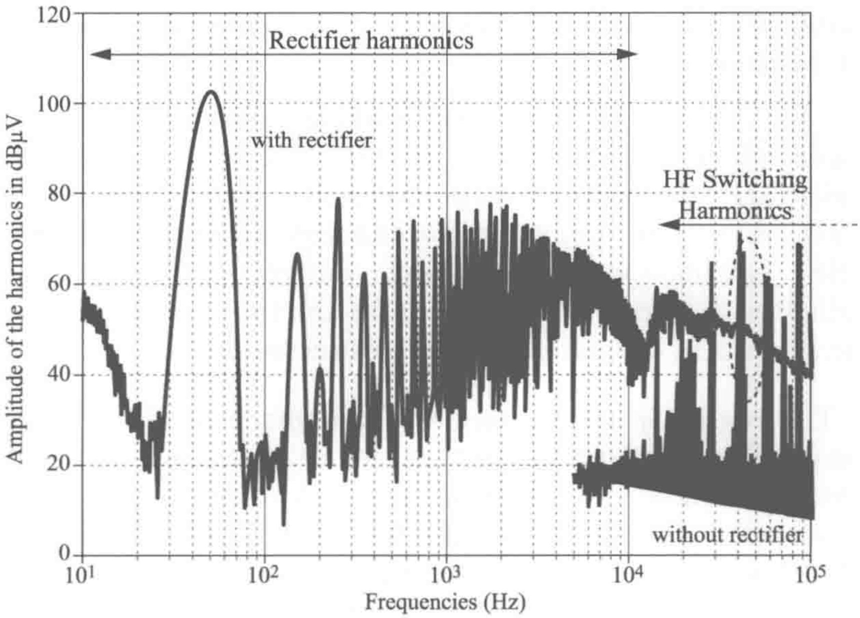

Figure 1.3. *Spectrum of parasite input current of a power supply modulated or not by the input rectifier*

1.2. Power grid harmonics

1.2.1 *Presentation*

In land-based or on-board (aircraft, vessels, etc.) electrical networks, the real shape of the current or voltage wave is never perfectly sinusoidal; real waves include harmonics caused by connected devices and present nonlinear features: diode rectifiers, inductive loads whose magnetic material is saturated over the course of its operation cycle (ballast of fluorescent tubes for example). They therefore summon non-sinusoidal currents which create deformations in the voltage which will, all the while remaining periodic, be deformed by harmonics, generally of odd order.

Figure 1.4 illustrates the propagation mechanism of harmonics in a grid: a nonlinear load creates harmonic currents that, while they travel through the branches of an impedant network, create harmonic voltage drops. The voltage wave is therefore deformed at the observed points. This deformation is evidently bigger as the impedance of the network is also bigger.

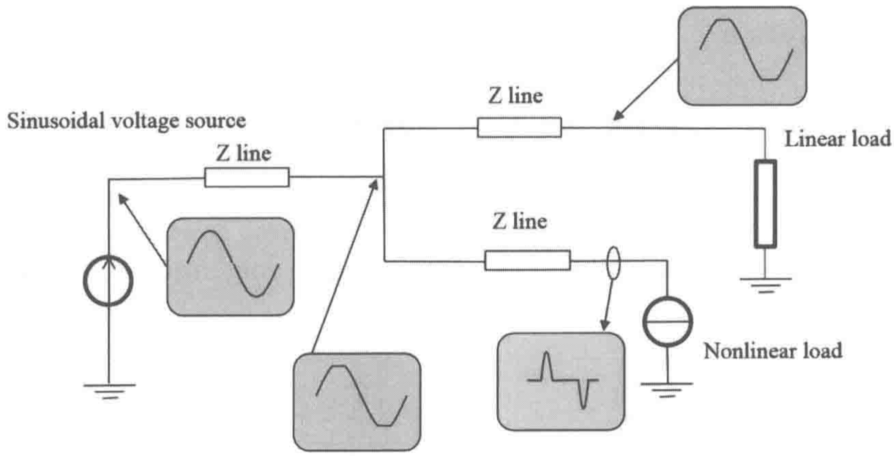

Figure 1.4. *Propagation of harmonics in a network and its consequences on the voltage waveforms*

In addition to the effects resulting from the flow of harmonic currents in the lines of non-zero impedance, the voltage harmonics originate from small imperfections of construction (asymmetries) in the winding of equipment, in other words, rotating machines (motors and alternators) and transformers. These third-order harmonic voltages play a small part, and with low rates, in the origin of the overall harmonic distortions.

For household appliances, it is the accumulation of devices, all in phase and connected to an insufficiently small line impedance, that creates a major harmonic pollution of the network. We can cite, for example, the simultaneous operation of multimedia devices (and of their switch-mode power supply), the constant connection of computers as well as the general use of fluorescent lamps.

The harmonics, being caused by nonlinear loads, are therefore preferentially propagated between phase and neutral on a single-phase network or between the phases of a three-phase network (supposing the load does not have a neutral connection). This is called differential-mode propagation.

1.2.2. *Characterization of the quality of electrical energy*

This pollution is characterized by the *total harmonic distortion* defined either by its relation to the voltage fundamental or by its relation to its root mean square (RMS), as such:

$$\mathrm{TDH}_{\mathrm{fund}} = \frac{\sqrt{\sum_{n=2}^{\infty} \mathrm{U_n}^2}}{\mathrm{U_1}} \qquad \mathrm{TDH}_{\mathrm{RMS}} = \frac{\sqrt{\sum_{n=2}^{\infty} \mathrm{U_{n_{eff}}}^2}}{\mathrm{U_{eff}}} \qquad [1.1]$$

Thus, it is appropriate to be vigilant with the adopted definition when we want to quantify these effects.

Currently in France, the distortion rate, except in certain rare cases, is between:

– 5% and 8% in the low-voltage grid;

– 5% and 7% in the medium-voltage grid;

– 2% and 3% in the high-voltage grid.

The current absorbed by a nonlinear load is defined in the same way by its current distortion rate (we can also find the definition relative to the total RMS value):

$$TDH_{fund} = \frac{\sqrt{I_2^{\,2} + I_3^{\,2} + \ldots}}{I_1} \qquad [1.2]$$

Therefore, we acknowledge that the presence of harmonics contributes to the augmentation of the RMS current, which