



EMC

for Power Cables

Lazhar Kebabbi
Ph.D NEXANS



El uso de variadores de frecuencia con motores genera pulsos tensión/corriente indeseados. La propagación de estos pulsos, así como las perturbaciones de radio frecuencia dan origen a estrés térmico y eléctrico en el aislamiento del cable. Por lo tanto, para prevenir el envejecimiento y falla del cable, se debe tener en cuenta la compatibilidad electromagnética del sistema. El propósito de este artículo es dar una visión general a los mecanismos de acoplamiento electromagnético de los convertidores de frecuencia variable (VFD) que afectan los cables, así como el dimensionamiento de parámetros que deberían ser tenidos en cuenta para reducir las perturbaciones electromagnéticas.

Palabras Clave: variadores de frecuencia, interferencia electromagnética,

Abstract-- Generalization of frequency converters used for motor drives generate unwanted high frequency voltage/current pulses. The propagation of these pulses gives rise to supplementary thermal and electrical strain in the cable insulation, as well as radio frequency disturbances. Hence, the electromagnetic compatibility of the system should be taken into consideration to prevent from insulation ageing and cable failure. The purpose of this paper is to give an overview of the electromagnetic coupling mechanisms whereby the variable frequency converters (VFD) affects the cables as well as the dimensioning parameters that should be taken into consideration to reduce the electromagnetic disturbances.

Keywords: Words—variable frequency drive, electromagnetic interference, electromagnetic compatibility

I. Introducción

Power cables and electronic systems in general, act simultaneously as an Electromagnetic Interference (EMI) source and receptor, and both of these properties affect the coexistence between systems, see figure 1 [4,5]. System electromagnetic compatibility (EMC) can be defined as the ability of a system to function satisfactorily in its electromagnetic environment without introducing intolerable disturbance to that environment. EMC has for object to take into account the disturbances generated by the electric devices to insure a correct functioning of other devices at the same time. Standards were established to specify the maximal level which the device shall emit and also define the minimum levels that the device shall be able to support without being disturbed during its functioning. These standards concern a large category of devices. For example, the maximum level of emission is much lower for devices with medical use than for the industrial domain. Up to date, no regulations or standards concern specifically cabling. Indeed, cables are considered as a part of whole electric system. Thus, power cables should comply with the electromagnetic emission standards for industrial application. According to the European standard EN 55022, the interference field strength is limited to 30 dB μ V/m for frequency ranging from 30 MHz to 230 MHz and 37 dB μ V/m for high frequencies up to 1 GHz [1- 3].

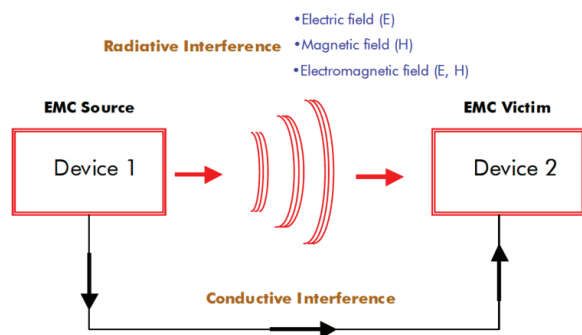


Figure 1. EMC Phenomena: conducted and radiated emission and susceptibility [4, 5].

According to the definition of EMC, there are two main identifiable electromagnetic issues:

- **Emission:** the electromagnetic emission is inherent to the functionality of the electrical systems. Indeed, whenever an electrical current or voltage is transmitted in a cable, an electromagnetic field is generated in the surrounding space, see figure 2 [2]. This field induces currents and electromotive forces in the neighboring electric circuits and causes disturbances within the victim circuit. Radiated emissions are measured as the electric field E, or magnetic field H generated by the system. The radiated emissions are specified at a certain distance D from the EMI source. The unit usually used for radiated emission evaluation is the electric field strength unit expressed by μ V/m or dB μ V/m.

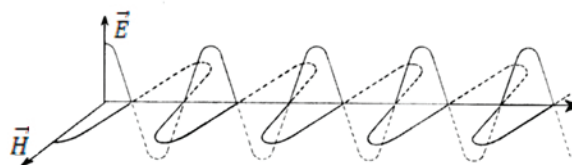


Figure 2. Electromagnetic wave propagation in the free space [5].

- **Immunity:** the term susceptibility is usually used instead of immunity as a measure of the system vulnerability to electromagnetic interference. It defines the ability of the system to meet specified performances in its electromagnetic environment. When electric, magnetic or electromagnetic fields impinge upon an electric device, it couples to the conductor, travels along it, and induces an electric current on the conductor. The electromagnetic interferences occur according three different coupling ways: inductive, capacitive and electromagnetic.

II. Variable frequency drive (vfd) as a perturbation source

A frequency converter is an electronic device that converts alternating voltage waveform (AC) of constant frequency (50 or 60 Hz) to variable waveform of another frequency and amplitude. This device is used in VFD for controlling the rotational speed of an alternating current electric motor by controlling the frequency of the electrical power supplied to the motor in order to reach specific operating characteristics such as variable speed and torque.

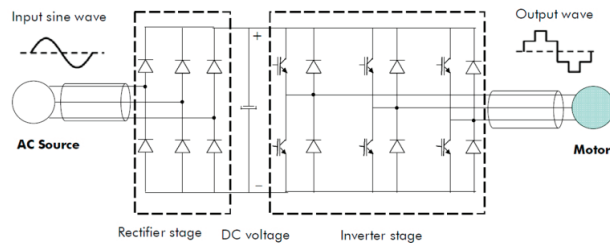


Figure 3. Diagram of variable frequency drive (VFD) [4].

The VFD usually consists of a rectifier stage (producing direct current) which is then inverted to produce AC of the desired frequency. The inverter may use thyristors, IGCTs or IGBTs. If voltage conversion is desired, a transformer will usually be included in either the AC input or output circuitry and this transformer may also provide galvanic isolation between the input and output AC circuits, see figure 3 [6].

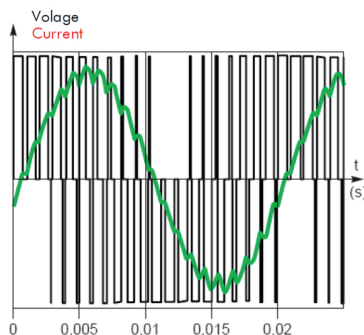


Figure 4. VFD output voltage and current waveform [6].

The output voltage waveform of the VFD consists in a train of pulses. The pulses amplitude is equal to the DC rectified voltage while their duration is modulated in order to create an alternating voltage of variable frequency and amplitude. figure 4 shows the output voltage and current of the VFD applied to the motor. Due to the rapid rise time of these pulses (for the latest generation of IGBT's, the switching time varies from 100 to 300 nanoseconds), the rate of change of voltage with respect to time (dV/dt) can exceed 4000 volts per millisecond. Furthermore, VFD generates harmonics of high frequency up to several MHz. The analysis of waves of Fourier of the output signal shown in figure 5 [6], gives an example of the signal spectrum produced by the VFD.

III. Voltage wave reflection

Often, transmission-line impedance of the cable and motor are different. As a consequence, pulses generated by the VFD tend to reflect back from the motor terminal into the power cable. The, voltage wave reflection is a function of the voltage rise time () and of the length of the motor cables. Indeed, if the transmission line is long enough i.e. cable length longer than the pulse wavelength, the resulting voltages can produce up to twice the rated line voltage and then increases the electric field on the cable insulation. This can lead to premature ageing of the insulation and eventually to partial discharges and dielectric breakdown. Consequently, the insulation thickness of the cable is dimensioned to withstand the electric field strength resulting from the reflected voltage pulses, which are higher than the sinusoidal rated voltage.

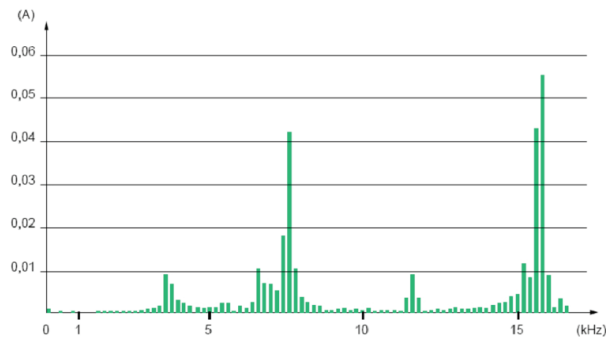


Figure 5. Current spectrum [6]

IV. Capacitive leakage current

Capacitive coupling represents the transfer of electric energy between neighboring circuits through the shared electric field, see figure 6. A parasitic capacitance exists always between two conductive wires. In the presence of variable electric potential in the perturbing wire, the electric field generates a leakage current within the victim circuit through the parasitic capacitances. The capacitive leakage current increases significantly as a consequence of pulses generated by the VFD. Hence, careful consideration should be given to the dimensioning of the shield to avoid additional Joule heating on the insulation.

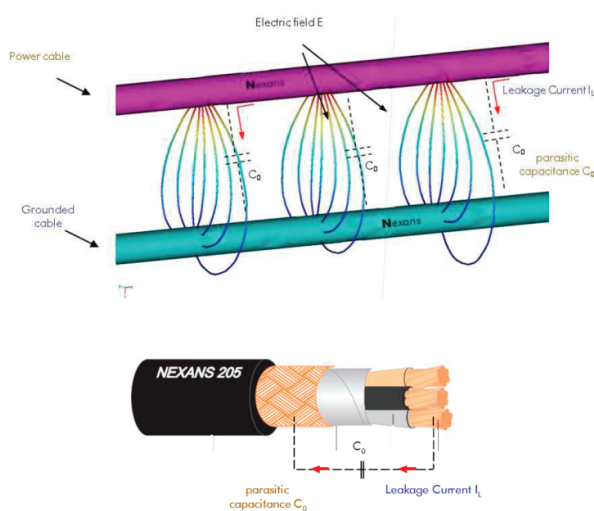


Figure 6. Capacitive coupling and leakage current

V. Inductive current

Inductive coupling as well as the capacitive coupling occurs where the distance between the EMI source and receiver is shorter than the electromagnetic wavelength, see figure 7. It represents the transfer of energy from one circuit to another by means of shared magnetic field. Indeed, the current in the disturbing circuit generates a magnetic field around the conductor. The variation of magnetic field generates an EMF within the neighboring circuits and induces disturbing current within the victim circuits.

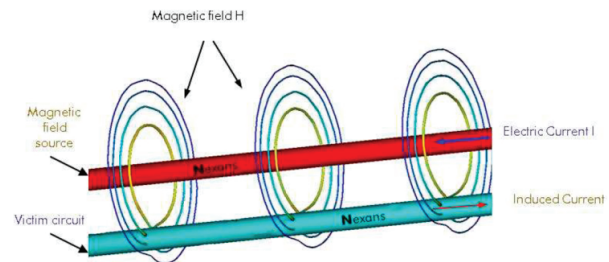


Figure 7. Inductive coupling

VI. Radio-frequency interference

Often, an EMI source emits at the same time electric fields (due to the electric potential) and magnetic fields (due to the currents). However, even if an EMI source emits at first only an electric field, the equations of Maxwell show that at a certain distance from this source, a magnetic field will also appear, to form an electromagnetic plane wave, see figure 8. This transformation takes place at a distance depending on the wavelength. The distance is long for the low frequencies, but short for the high frequencies. It is one of the reasons for which the measures of EMC are not the same for the low frequencies and for the high frequencies. When this electromagnetic plane

When an electromagnetic wave reaches a non-shielded wire, it generates a displacement current within the victim circuit. The current is then transmitted to the electric device through the conductor.

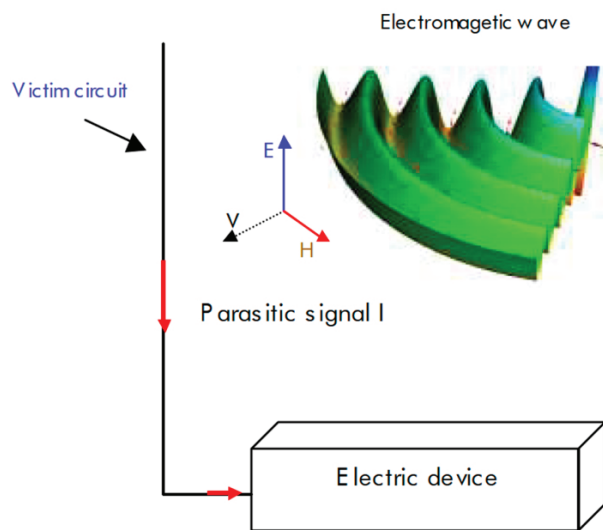


Figure 8. Electromagnetic coupling

VII. Example of dimensioning cable shield against rfi

To avoid the problems linked to the electromagnetic disturbances, the interference sources should be shielded using a conductive barrier. The electromagnetic shielding consists in separating the free space into two different areas using a conductive material, see figure 9. The first area contains the electromagnetic interference source and the second represents the shielded space. The aim of the shielding is to reduce the electromagnetic radiations generated by the cable (emission) and to protect the electric power cable against external disturbances (immunity).

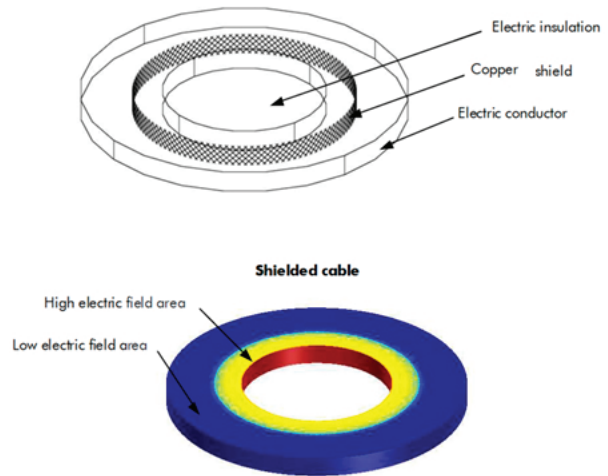


Figure 9. EMI Copper shield.

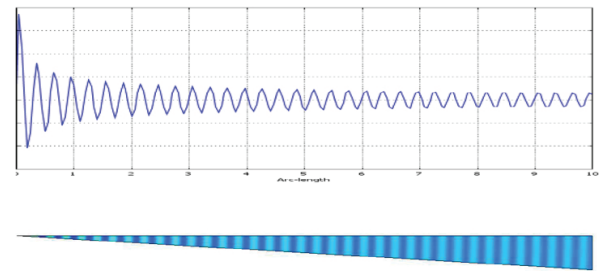


Figure 10. Example of electromagnetic wave radiated by an unshielded cable. Results are obtained using finite element method simulation.

The shielding efficiency of the power cable is evaluated using a commercial software for electromagnetic modeling. The goal is to determine the shielding efficiency of a given cable at rated voltage and current, with regard to different shielding design in broadband of frequencies, typically from 1 Hz to several GHz. The electromagnetic field emitted is then calculated in the free space at a given distance from the cable. Figure 10 shows the electromagnetic wave propagation emitted by an unshielded cable. The electric field strength

radiated by the cable should comply with the limits of the standards. Table 1 summarizes the results obtained by simulation of shielded and unshielded cables.

Frequency Hz	Electric field dB uV/m		
	Non shielded cable	Shielded cable	Limits
30 MHz	85	2	30
230 MHz	94	14	30
1 GHz	100	24	37

Table 1. Comparison of electric field strength obtained by simulation between shielded and unshielded cables.

VIII. Conclusion and recommendations

Three main issues, listed below, should be taken into consideration to comply with EMC rules:

- High frequency current pulses generate electromagnetic waves propagation in the free space. These radio frequencies induce disturbances in neighbor circuits. Thus, an electromagnetic screen is necessary to attenuate the electromagnetic radiations.
- Capacitive leakage current arises in the cable screen due to the voltage harmonics. The cable screen is then heated by joule effect. Careful attention to the dimension of the screen equivalent cross section is mandatory to avoid cable overheating.

$$dV/dt$$

- Rapid voltage rise time () generates high frequency voltage pulses up to several megahertz. If the cable length is longer than the pulse wavelength, the resulting voltages can produce up to twice the rated line voltage. The cable insulation is then subjected to rapid ageing and appearance of partial discharges leading to dielectric breakdown. The insulation thickness should be dimensioned to withstand up to two times the rated voltage.

IX. References

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X. Author

Lazhar Kebbabi, was born in 1975 in Constantine, Algeria. He received his Ph.D. degree in electrical engineering in 2006 from Ecole Centrale de Lyon, France. He presently works as a R&D Project manager in Nexans Research Center in Lyon in the field of electromagnetic modelling, high voltage engineering and dielectric materials.



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