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EMC REQUIREMENTS FOR POWER DRIVE SYSTEMS

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Abstract: Electromagnetic compatibility requirements for immunity tests have been presented and the emission levels of electromagnetic disturbances in adjustable speed power drive systems have been determined. The disturbances are divided into two groups: low-frequency (up to 50 harmonics of the power supply system) and high-frequency (above 150 kHz). The lack of legal regulations on permissible disturbance level in the frequency range from 2.5 kHz to 150 kHz has also been mentioned. This range is considered high frequency by the authors. Standarized compatibility levels and sample measured parameters of the electromagnetic environment have also been shown. An exemplary reaction of the drive to the most common disturbances in the power supply system has been presented.

Keywords: *power drive system, electromagnetic compatibility, immunity on disturbances, emission level*

1. INTRODUCTION

Electromagnetic compatibility (EMC) is the ability of electrical equipment to operate correctly at its destination (environment) without causing any interference in the operation of other equipment, systems or installations. To meet the above requirement, it is indicated that the equipment must be immune to disturbances occurring in the electromagnetic environment in which it operates and does not cause the degradation of parameters influencing the operation of other devices. In the case of power drive systems, the requirements related to emission limits, the levels of immunity to disturbances as well as testing methods are stated in EN 61800-3:2004 standard (new edition of IEC 61800-3:2017 standard is not harmonised with the EMC Directive yet). The requirements related to disturbance emission measurements presented in EN 61800-3 standard do not specify the requirements for the frequency range 2–150 kHz. This frequency

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range can be used for wired transmission of control signals and data in the system. (e.g., changing tariffs in electricity meters, data transfer between meters and concentrators).

2. CLASSES OF DRIVE SYSTEMS AND THEIR OPERATING ENVIRONMENT

The operating environment of the propulsion systems (PDS) is divided into two categories according to the purpose of the equipment [1]:

- The first environment includes domestic premises. It also includes establishments directly connected without intermediate transformer to a low-voltage power supply network which supplies buildings used for domestic purposes. Houses, apartments, commercial premises or offices in residential buildings are examples of this kind of locations.
- The second environment includes all establishments other than those directly connected to a low-voltage power supply network which supplies buildings used for domestic purpose.

In terms of the emission of electromagnetic disturbances, devices are divided into four categories C1–C4. Classification into a particular category is determined by supply voltage or the current of the main power supply connection and operation environment. With regard to the requirements of the EMC Directive (typically two equipment operating environments are distinguished: domestic and industrial, additionally there are special requirements for some products), the division is as follows:

- equipment of category C1 meets the requirements of the domestic environment;
- equipment of category C2 meets the requirements of the industrial environment;
- equipment of category C3 (connected to power supply systems with voltage higher than 1000 V) have increased permissible emission levels in relation to typical industrial environments, while their immunity requirements are identical with equipment of category C2;
- equipment of category C4 (usually equipment operating in high-power and high-voltage supply systems, frequently these are unique pieces of equipment) – no regulations (requirements are determined by so-called engineering practice”).

Due to various ways of the emission and penetration of electromagnetic disturbances as well as various ways in which disturbances interfere with one another, the tested object is typically presented as an enclosure (contour) and its connected interfaces (wiring). Figure 1 presents the connections and internal interfaces of the PDS. The abbreviations used in this figure are explained in the next diagram which shows the border between installation and the PDS.

The basic drive module (BDM) is understood as a converter with control connected between the power supply a motor. The complete drive module (CDM) is BDM extended by protection systems, filters and auxiliary systems. PDS can be composed of many CDMs or BDMs and motors.

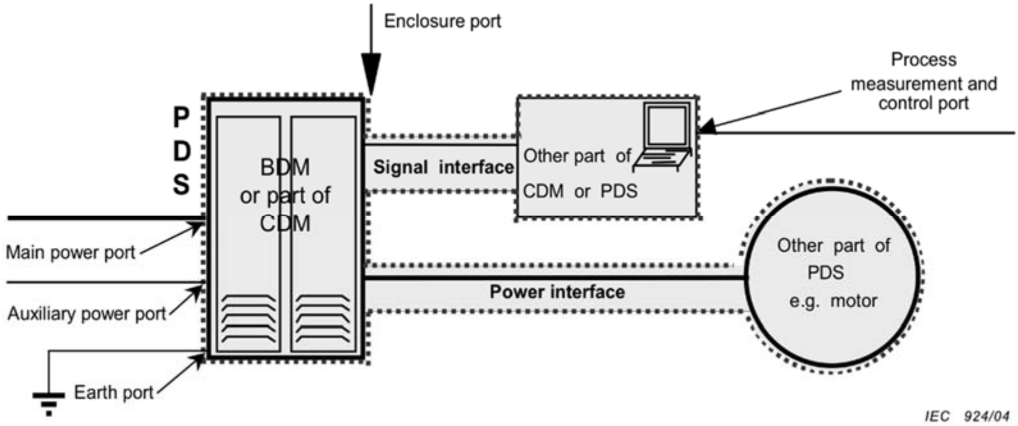

Fig. 1. Internal interfaces of the PDS and examples of ports according to standard [1]

From the perspective of EMC, the BDM enclosure (the surface surrounding the BDM) is also treated as one of the ports which can be the source of disturbances (emission of radiated disturbances – electromagnetic field), and through which disturbances can penetrate into a BDM. The immunity or emission tests are recommended or required depending on the working environment (electromagnetic field immunity test [5], magnetic field immunity test [9], electrostatic discharge immunity test [4], electromagnetic radiation [16]).

The main power port is the port through which power is fed to the motor. The main power port voltage may have a higher value than the voltage of the auxiliary power port feeding auxiliary, control systems. The power interface is the connection necessary to distribute power inside PDS.

3. SELECTED REQUIREMENTS FOR LOW-FREQUENCY DISTURBANCES

Electromagnetic compatibility issues should be taken into consideration even at the design level of a drive system. At later stages, design changes are more expensive. A manufacturer can check the compatibility with requirements through testing, calculations and simulations. In practice, the best and the most credible solution selected in the submission of a compatibility declaration is conducting complete EMC tests.

According to the classification presented by International Electrotechnical Commission (IEC), the high frequency range include signals above 150 kHz. Pursuant to EN 61800-3 [1], the limit is 9 kHz. However, in the paper it was assumed that the limit would be the 50th frequency harmonic of the supply system, which corresponds with 2.5 kHz of a power system 50 Hz and 3 kHz for 60 Hz.

3.1. PDS IMMUNITY TO LOW-FREQUENCY DISTURBANCES

The disturbances which can influence drive system operation involve:

- voltage deformation – harmonic, interharmonic, commutation notches,
- oscillation, notches and short-term voltage drops,
- voltage asymmetry increase,
- power frequency variation.

The levels of disturbances during testing result from the values of compatibility level describing the environment [2, 3]. They are 1.5- or 2-fold higher (e.g., harmonics, supply voltage asymmetry). Examples of compatibility levels for harmonics are presented in Fig. 2.

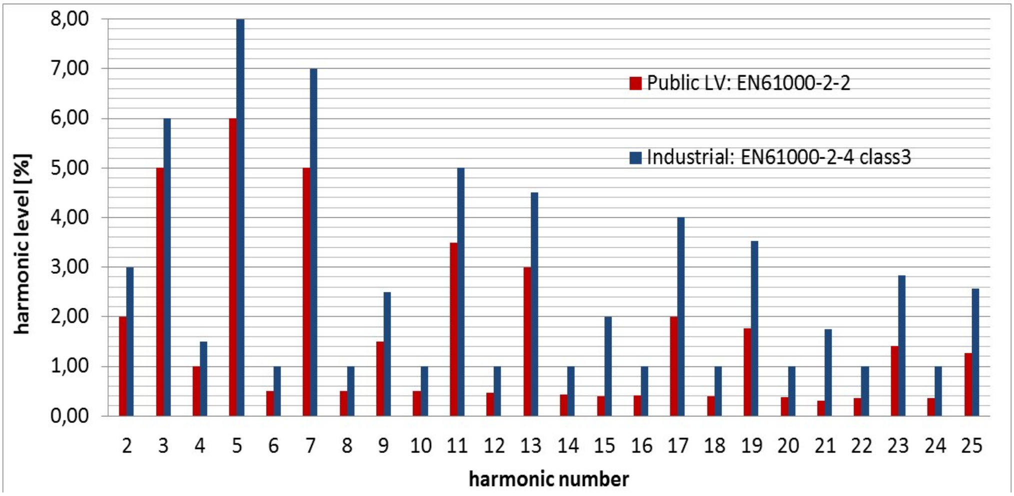

Fig. 2. Minimum requirements for harmonic immunity – compatibility levels

The compatibility level is a statistical value and defined as the disturbance level that must not be exceeded for 95% of the measurements in the whole network for given environment. For a specific bus, the level of the disturbances may be different. In the case of public low- and medium-voltage power supply networks, the compatibility levels are congruent with the power quality requirements [15] that must be assured by the power system operator.

The methods of conducting tests are specified in EN 61000-4-X basic standards [4–10]. The emission limit value and test levels are defined in the standard PN-EN 61800-3. The criterion – operation compatibility referring to a particular disturbance can be different for particular PDS components. Standards include guidelines (Table 1 in [1]), however, the responsibility for correct operation assessment is the responsibility of the manufacturer.

3.2. LOW-FREQUENCY DISTURBANCE EMISSION

The general rule applied in emission measurements indicates choosing a normal (typical) operation mode in the highest emission state. This may not be a transition or safe mode. In the low frequency range, emission measurements include basic harmonic and voltage fluctuations caused by the connected PDS. The influence of the PDS on the supply system is related to the network impedance. For the PDS working in environment 1, harmonic emission limits are determined in [11, 12] while for voltage fluctuations in [13, 14]. In the case of industrial environment, a rational approach is recommended (limits are not obligatory) taking into consideration the whole installation. The recommended levels of current harmonic emissions are presented in Table B2 in [1]. Standard EN 61800-3 does not include any requirements related to immunity and emission tests in the frequency range between 2.5 kHz and 150 kHz in the supply system. The elements of the power system limit disturbance propagation in this frequency range and for this reason the authors treat it as high frequency.

4. LOW-FREQUENCY DISTURBANCE LEVEL IN INDUSTRIAL ENVIRONMENT

4.1. QUALITY OF SUPPLY VOLTAGE

The main coupling path of low-frequency disturbances is conduction through the supply system. The compatibility levels of a given network can be determined based on voltage quality tests. Supply voltage quality parameters are key to maintain manufacturing processes. Based on the results of research conducted over more than a decade on the request of plants connected to medium or high voltage supply systems (industrial environment), it can be stated that the dominant disturbance – identifiable and negatively influencing a manufacturing process – are voltage dips. Harmonics (even when voltage THD approximates the compatibility level of 10%) and voltage asymmetry occurring in industrial power networks do not result in undertaking any significant actions.

The principal reason for ordering supply voltage quality tests is the incorrect operation of equipment, usually occurring for random reasons. The research confirms a correlation between some disturbances and dips. The recording of current does not allow to determine the source of a dip, whether it is external or caused by reception below the coupling point of measurement equipment.

4.2. SAMPLE DISTURBANCES IN A CONVERTER OPERATING IN INDUSTRIAL ENVIRONMENT

Figures 3 and 4 present current and voltage waveforms during a 15% dip at the point of coupling the fun power drive to a three-winding transformer (6 kV/0.69 kV/0.69 kV) with 1500 kW power. The parameters of the power drive system are as follows: 12-pulse rectifier, converter with 900 kW output power. DC voltage settings: inverter under voltage disable 553 V, under voltage warning: 585 V, inrush circuit enabled 585V, inrush circuit disabled 600 V. The consequence of dip was switching off the converter.

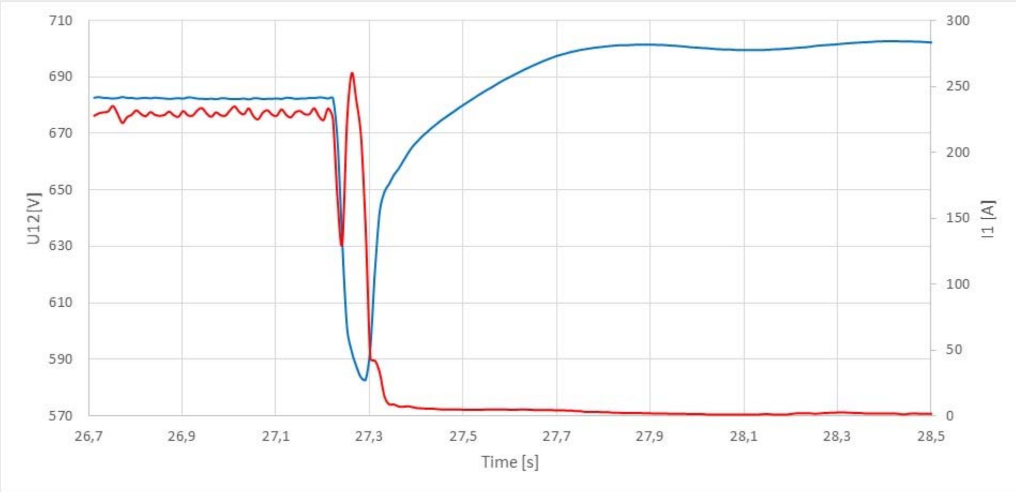

Fig. 3. Waveform of root-mean-square current and voltage
at the terminals of the converter point of common coupling during a dip

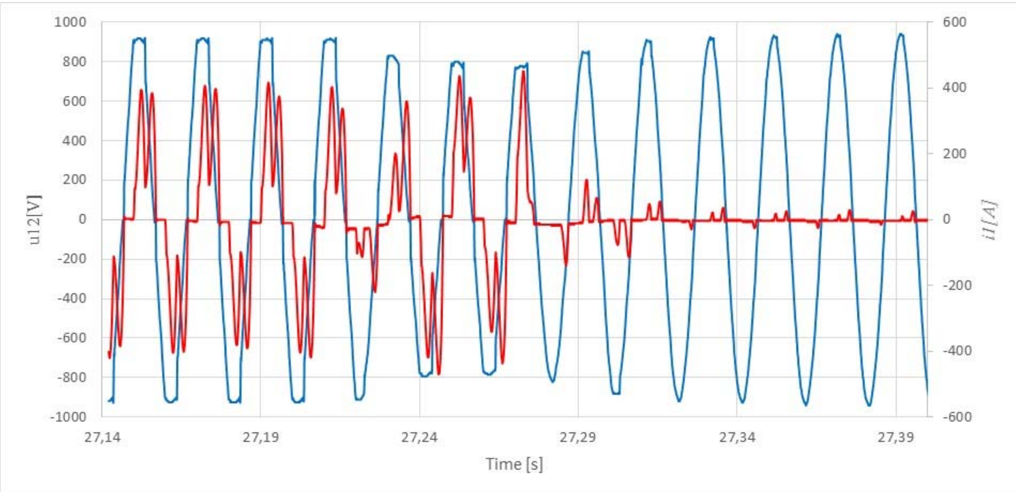

Fig. 4. Waveforms of the instantaneous value of current and voltage
at the terminals of the converter point of common coupling during a dip

The control system of the PDS is responsible for numerous parameters, including speed, torque, voltage and the current of the constant-current part, etc. The suitable parametrization of the control system can prevent switching off if operation is acceptable with given changes of characteristics. In order to increase immunity of the drive, the under voltage parameter has been reduced by 50 V. Additionally, a high power loads switching procedures have been introduced to reduce the voltage dips in supply network.

5. SELECTED REQUIREMENTS FOR HIGH-FREQUENCY DISTURBANCES

5.1. IMMUNITY TO HIGH-FREQUENCY DISTURBANCES

The recommendations of standard [1] include detailed requirements related to the immunity tests of the equipment of category C1 (the same as the requirements for the domestic environment) and category C2 and C3 (the same as the requirements for the industrial environment). With respect to the place where products are mounted, especially the equipment of class C3, the requirements on immunity levels can be insufficient. This is why a common practice among PDS equipment manufacturers is ordering tests for disturbance levels higher than the ones presented in the standard or other EMC related tests, e.g., disturbances in the frequency range below 150 kHz. The EMC tests contain both tests related to disturbances introduce to equipment by connecting wires and also couplings resulting from the impact of electromagnetic and magnetic fields.

5.2. MEASUREMENT OF HIGH-FREQUENCY DISTURBANCE EMISSION

The measurements of conducted disturbance emissions are performed using typical methods employing artificial networks or voltage and current probes (due to the limitations of the operational currents of the artificial network, the emission tests of high power equipment are performed using probes). In practice, the equipment of category C3 and C4 is tested with probes because of the size of equipment, motor power and the parameters of the power supply network at the connection point. Similar problems occur in the measurements of radiated disturbances. One of the problems experienced by many laboratories are power and voltage requirements for the terminal inside a chamber. Further difficulties are related to the connection between the loading system of this type of equipment and the heat released from the load during operation. A common practice, especially in the case of the equipment of category C3 and C4, is in-situ testing (most frequently at the place of installation or in a production hall). It is also important in what frequency range the tests of radiated disturbance emissions are conducted. The use of control systems with processors and displays, as well as remote data transmission systems (offering, e.g. the possibility to connect equipment to an external LAN or control it using radio interfaces) in contemporary PDS in many cases requires the measurements of radiated emissions up to 6 GHz.

6. CONCLUSIONS

The selected standard measurements of disturbance immunity and emission limits for PDS show challenges which have to be responded to by manufacturers of this type of equipment. The problem with this kind of products is the connection between high power equipment (converters, inverters, VFDs) and the elements of control and measurement electronics operating at high frequencies with low levels of useful signals. Another challenge faced by manufacturers are the EMC tests themselves. This type of tests are conducted in a limited number of laboratories and require extensive knowledge and experience from both the laboratory and the manufacturer.

The use of PDS is so extensive that it is difficult to pinpoint the uniform way of design, testing and installation, taking into account EMC. At the design, production and installation stage, The following factors should be consider:

- working environment,
- compliance with regulatory requirements for the environment,
- carrying out tests of the entire system or key components at higher than standard levels of disturbances that reflect actual operating conditions,
- occurrence of multiple disturbances simultaneously,
- occurrence of disturbances not specified in the standards that appear in the PDS installation location. For example, radio disturbances with frequencies of GSM, LTE, TETRA, Bluetooth, WLAN,
- human factor, for example, the installation of wires other than the design, incorrect installation of filters or electromagnetic seals.

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