Complying with IEC/EN 61800-3 Good EMC Engineering Practices in the Installation of Power Drive Syst
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REO UK LTD
Complying with IEC/EN 61800-3

Good EMC Engineering Practices in the Installation of Power Drive Systems

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1. Introduction

This Guide is for what EN/IEC 61800-3 [1] calls “Power Drive Systems” (PDSs), which are AC or DC motor speed control units more usually called variable speed drives (VSDs) or adjustable speed drives (ASDs). VSDs for AC motors only are often called variable frequency drives (VFDs), adjustable frequency drives (AFDs), or just inverter drives.

EN 61800-3 is listed under the EMC Directive [2], and so may be used for declaring PDSs in conformity with it.

At the time of writing, the EMC Directive has been applying its 2004 version [1] since the 1st October 2007, which means that all PDSs supplied in the EU since then should list EN 61800-3:2004 on their EU Declarations of Conformity, and provide the appropriate test evidence in their “Technical Documentation File” – if they are following the “standards route to conformity” (see [3]).

EN 61800-3:2004 is identical to IEC 61800-3:2004, so this Guide is equally applicable outside of the European Union (EU) where the IEC version – or some national standard based upon it – is applied.

Even where there are no legal EMC requirements, complying with EN/IEC 61800-3 is good engineering practice that will help improve profits overall, over the medium and long term, and will also help increase customer confidence and market share.

1.1. The definition of a PDS

According to EN/IEC 61800-3 [1], a PDS is an adjustable speed AC or DC motor drive, consisting of a basic drive module (BDM), which is part of the complete drive module (CDM), which – when connected to its motor – becomes a PDS, which in turn is part of a system or installation, as shown in Figure 1.

IEC 61800-1, IEC 61800-2 and IEC 61800-4 provide the details for the definitions used in Figures 1 and 2. If the PDS has its own dedicated transformer, this transformer is included as a part of its CDM.

A non-exhaustive list of PDS applications includes:

- Machine tools, robots, test equipment in production, test benches;
- Paper machines, textile production machine, calenders in the rubber industry;
- Process lines in plastic industries or in metal industries, rolling mills;
- Cement crushing machines, cement kilns, mixers, centrifuges, extrusion machines;
- Drilling machines;
- Conveyors, material handling machines, hoisting equipment (cranes, gantries, etc.);
- Propulsion of ships, etc. (but not traction drives or electric vehicles);
- Pumps, fans, etc.

The PDSs may be connected to either industrial or public mains power distribution networks. An “industrial network” is considered to be one that is supplied by a dedicated high voltage (HV) distribution transformer, or its own generator, which supplies only industrial customers or, for example a ship or offshore drilling rig.

A public power distribution network is one that operates at low voltages (e.g. 115/230/400V) and supplies domestic premises. These networks usually have an earthed (grounded) neutral. Where an industrial site is powered from a low voltage mains power distribution, as sometimes happens, the mains distribution network on that site is treated as a public network.

As Figure 1 shows, a PDS may drive some equipment (e.g. a winch, pump, pump, 

Figure 1: Definitions of PDS, CDM and BDM

Figure 2 shows another view of a PDS, this time identifying the various “ports” that are tested by [1].
1.2. The requirements of EN/IEC 61800-3

[1] includes requirements for PDSs with BDM input and/or output voltages (line-to-line) of up to 35 kV AC rms, rated from a few hundred watts to hundreds of MW, installed in residential, commercial or industrial locations.

It claims to achieve EMC for such applications (but see 1.3) but warns that it cannot cover extreme cases that could occur (but which are assumed to have an extremely low probability). It also warns that it does not cover the EMC performance in the case of faults occurring, which is very relevant for section 2.4 later in this Guide.

[1] specifies emissions limits, immunity levels, and test methods for a PDS according to its intended application and the competency of its installer. It does this by defining two different electromagnetic “environments” or locations, and four different “Categories” of installer competency, as discussed below.

1.2.1. The First Environment

This environment includes domestic premises, and establishments directly connected without intermediate transformers to a low-voltage power supply network which supplies buildings used for domestic purposes.

Houses, apartments, commercial premises or offices in a residential building are examples of First Environment locations.

1.2.2. The Second Environment

This environment includes all establishments other than those directly connected to a low voltage mains power supply network which supplies buildings used for domestic purposes.

Industrial areas, and technical areas of any building that are fed from their own dedicated transformer are examples of Second Environment locations.

1.2.3. Category C1

This category is for PDSs with rated voltage less than 1,000 V, intended for use in the First Environment, permitted to be installed by anyone.

1.2.4. Category C2

This category is for PDSs with rated voltage less than 1,000 V, which is neither a plug-in device nor a movable device and, when used in the First Environment, is intended to be installed and commissioned only by a “professional”.

A professional is defined as a person or an organisation having necessary skills in installing and/or commissioning PDSs, including their EMC aspects.

1.2.5. Category C3

This applies to PDSs of rated voltage less than 1,000 V, intended for use in the Second Environment and not intended for use in the First Environment, permitted to be installed by anyone.

1.2.6. Category C4

This applies to PDSs of rated voltage equal to or above 1,000 V, or rated current equal to or above 400 A, or intended for use in complex systems in the Second Environment, permitted to be installed by anyone.

1.3. Emissions and immunity of PDSs as part of systems or installations

As mentioned above, a PDS may be a part of a system, or part of an installation, but EN/IEC 61800-3 [1] only covers the PDS itself.

However, for compliance with the EMC Directive, customer specifications, or just good EMC engineering practices, the entire system or part of an installation may be covered by other EMC standards – most likely the generic standards:

- EN/IEC 61000-6-1, immunity requirements for residential, commercial and light industrial environments
- EN/IEC 61000-6-2, immunity requirements for the industrial environment
- EN/IEC 61000-6-3, emissions requirements for residential, commercial and light industrial environments
- EN/IEC 61000-6-4, emissions requirements for the industrial environment

In this case, it is possible for a PDS that is compliant with [1] to cause the system or installation that it is part of to fail to comply with the EMC standards that apply to it. There are two reasons why this could occur:

a) The emissions permitted by [1] for the PDS might exceed the emissions limits permitted by other standards for the system or installation containing the PDS. For example, some limits that are permitted by [1] for some PDS Categories exceed the limits permitted by the appropriate generic standard for the same type of environment by more than 20 dB.

b) There may be several PDSs in one system (e.g. the sausage machine in
2. What is not covered in this Guide

2.1. Testing to EN/IEC 61800-3

This Guide is only concerned with the use of good EMC engineering installation practices to help PDSs comply with EN/IEC 61800-3 [1], it does not cover the actual testing techniques that are used by [1]. REO have seventeen Guides [4] that detail how to actually perform the various tests required by [1], including the situation where the test cannot be carried out at a “controlled EMC site”, such as inside a test laboratory’s anechoic chamber. [1] also includes guidance on what to do when testing has to be done on-site, or when the mains current required by a PDS exceeds 100A. If further guidance is required on on-site testing, [5] may prove useful.

2.2. Complying with the EMC Directive

It is not the aim of this Guide to discuss how a manufacturer should go about legally complying with the EMC Directive [2] [6], as implemented in the various national laws of the European Union’s (EU’s) Member States, such as [7] [8] for the United Kingdom (UK). The compliance methods that are available are discussed in [3].

2.3. Human Health and Safety

The very high voltages and currents associated with high-power PDSs can cause a variety of problems for health and safety. EN 61800-5-1 [l] covers electrical, thermal and energy hazards of PDSs, but does not cover human health effects due to exposure to electric and/or magnetic fields (EMFs).

All PDSs that declare compliance with the Low Voltage Directive [9] must also now declare compliance with the EMF Regulations [10]. While there are no EMF standards specifically for PDSs, it will probably be best to apply the “generic EMF standard” EN 62311 [11].

A workplace Health and Safety Directive on EMF also exists [12], but at the time of writing is not fully in force. Like all Health and Safety directives, it applies to the owners/users of a site or the equipment on it, and not to manufacturers who supply them with equipment. Neither of these issues are discussed further in this Guide.

Figure 3: Example of a machine with a number of PDSs
Part of a complex installation...
The control cubicle for the sausage machine installed at Stork Townsend B.V., The Netherlands, in 2006. 10 metres long; 60 variable speed drives 18 multi-axis servo drives...
2.4. Functional Safety

It is also not the aim of this Guide to discuss the Functional Safety issues of PDSs, other than to say that since electromagnetic interference (EMI) can cause PDSs to suffer errors or malfunctions (e.g. uncommanded changes in speed, torque, direction, etc.) – where these could have consequences for safety risks, complying with EN 61800-3 or any other EMC test standards, even military or aerospace ones, is insufficient for establishing a defence of due diligence.

EN 61800-5-2 [13] applies the basic standard on Functional Safety EN 61508 [14] to PDSs, but – like [14] – does not prescribe what to do about the possibility of EMI. EMI can cause a variety of problems for motor drives, which might be costly (e.g. downtime) or have safety risks, as shown by some of the real-life anecdotes in [15].

To cover EMI it is necessary to apply the basic standard on EMC for Functional Safety [16], for which the IET have produced a helpful series of standards is not a machine as defined by the Machinery Safety Directive [18], and so this directive does not apply to PDSs.

Of course, system integrators and owners of fixed installations (using the definition in [2] and [7]) will often use a PDS to provide the motive power for a machine that comes under the Machinery Directive, or one of the Health and Safety at Work Directives, in which case it is important that they understand the points made in 2.3 and 2.4. They will find helpful information on EMC in [19] [20] and [17].

2.5. Machinery Safety

A PDS as defined by the EN 61800 series of standards is not a machine as defined by the Machinery Safety Directive [18], and so this directive does not apply to PDSs.

2.6. Electronic and mechanical design of basic drive modules (BDMs)

This Guide does not cover the electronic and mechanical design and assembly of the BDM section of PDSs, or its cabinet or other enclosure. But well-proven techniques do exist for these EMC aspects of BDMs, see [21] [22] and [20].

3. Cost implications

3.1. The EMC of PDSs, financial risks, and the perils of short-termism

It is quite practical to design a BDM (see 2.6) so that any PDS using it is guaranteed to comply with EN/IEC 61800-3 (and the EMC Directive) regardless of how it is installed and how the PDS that employs it is configured. However, such BDMs will almost certainly cost more.

When using such a BDM, a manufacturer who integrates it into a PDS that he sells to an end-user (or their main contractor) will be able to demonstrate compliance with the EMC Directive [2] [7] without having to test to EN/IEC 61800-3. All they will need to do is to include a few verified EMC documents from the BDM manufacturer, in their Technical Documentation File [3].

Such good EMC design increases the bill-of-materials (BOM) cost of the BDM, and most manufacturers would assume that they must therefore sell it for a higher price. But this is not necessarily the case, because (for example) their product could have lower warranty costs, and/or might win a much larger market share because of its ease of use [23]. So they might make as much or more profit even when selling it for the same price as a more typical BDM that does not control EMC so well and so requires any PDS it is used in to go through costly tests to EN/IEC 61800-3, to be able to show due diligence in complying with the EMC Directive.

This all sounds good, but it rarely happens in real life because of short-termism – managers usually only look ahead as far as the next quarter’s financial figures – so even very significant possibilities for medium and long-term financial gains, improving profitability and return-on-investment (ROI) are ignored. Sometimes the benefits of investing in good EMC engineering are discounted because of a lack of appreciation of EMC issues.

Short-termism means that buyers are looking for the cheapest BDM, and often decide solely on the basis of crude “kW versus £” comparisons.

For this reason, and others, most BDM manufacturers’ salesmen feel...
reckon that as many as one-third of all PC software “crashes” are caused by EMI. We have all experienced these ...

Another issue is that there is a rapid increase in electronic instrumentation, including safety-related systems, all brought about by the continual reduction in the costs of semiconductors (transistors). Also, the reduction in costs of semiconductors is brought about by making them physically smaller and more complex, plus the worsening of industrial PDSs.

For example, some computer experts reckon that as many as one-third of all PC software “crashes” are caused by EMI. We have all experienced these crashes as an EM incident and brought it to the attention of the people who own our systems or installations don’t have EMI problems, actually don’t understand how to identify an EMI problem anyway (if they have even heard of it). They may have suffered from problems that are not serious but unavoidable that make EMI hard to reproduce at will, often an element of (bad) luck in many people who wrote [1]. Also, there is often an element of (bad) luck in many arguments for improved profitability can be understood by the people who argue that we ignore EMC issues, we have to make the cheapest products on the basis of no complaints (because of no complaints), but unavoidable that these trends inevitably make them more susceptible to EMI.

The inevitable result of this is that, if there is no evidence of an EMI incident, we have to declare compliance to the EMC Directive. This increases their overall costs and so significantly increases the price that they have to charge if they could make. Many people who claim to their customers that they have solved an EMI problem anyway (if they have even heard of it) are decreasing yields or increasing downtime – but they never recognised them as being caused by EMI. For example, some computer experts would have to charge if they could buy BDMs that had been designed appropriately.
So filtering a VSD’s motor output can be an excellent financial investment! For example, the majority of electrical submersible pumps (ESPs) rated up to around 900-1100kW serving the oil industry offshore, would not function unless output filters were installed.

3.4 An example of the financial risks of inadequate EMC engineering

[15] has many examples of costly problems caused by EMI from, or to, PDSs, including industrial ones, and I must say that over the last 20 years, almost all of my work as an independent EMC consultant in solving EMI problems in industrial sites has been caused by two electronic technologies – variable speed motor drives (i.e. PDSs) and personal wireless communications (e.g. private mobile radio, Walkie-talkies, cellphones). Here and in 3.5 are just two examples of costly EMI concerning PDSs, which do not appear in [15]. [37] is another case study of solving a high-power VSD EMI problem that had been very costly for the drive user.

This first example also shows that actual compliance with the test limits and levels in EN/IEC 61800-3 does not automatically ensure compliance with the EMC Directive [2] [7], or ensure low financial risks.

It concerns a UK factory that had a new (and very large and costly) programmable machining centre installed. This used a 50kW PDS (actually a VFD) that complied with EN/IEC 61800-3, so was assumed to comply with the EMC Directive [2] [7]. But when it was operated it put about 15V peak-to-peak at between 10 and 30kHz on the factory’s mains supply, causing some packaging machines to malfunction elsewhere on the site. Figures 4 and 5 show the mains voltage I measured on the site when the machining centre was running. When it was not running, the mains supply was a nice clean 50Hz sinewave.

EN/IEC 61800-3 only specifies limits for conducted emissions over the frequency range 150kHz to 30MHz, and the machining centre met these limits, but since its drive’s switching frequency was 2kHz it emitted significant levels of switching harmonic noise into its mains supply from 2kHz at 2kHz intervals all the way up to 150kHz and beyond. At 150kHz and above the mains filter fitted to the PDS attenuated the noise emissions to meet the specification, but it did not provide significant attenuation below 150kHz.

All mains filters resonate at some frequency (see 3.2.9 of [21], 8.1.3.1 of [26] or 5.10 of [19]) and so do all mains distribution networks, due to the combination of predominantly inductive wiring with predominantly capacitive electronic loads (e.g. due to the capacitors in their EMI filters of power factor correction banks, see C.1.3.4 of [1]). Noise currents flowing in them will cause amplified voltages at these resonant frequencies, sometimes as much as ten times higher than would normally be expected. [15] includes some examples of serious problems that occurred because noise was amplified in mains filters or mains distribution networks.

It can come as a big surprise to find that a mains filter is giving gain instead of attenuation, often in contradiction to the suppliers attenuation versus frequency curves! This is due to the fact that mains filters are not tested in situations that correspond to real-life operation. However, in this example, if the mains filter was resonating and giving amplification, it was below 150kHz.

The solution was very simple – the machining centre manufacturer replaced the original mains filter on their PDS with one that provided reliable attenuation down to below 10kHz. This filter was much the same size as the original, but weighed a lot more and was more costly. It was also less efficient, dropped a few more
safety standards. The site could not be operated until the problem was fixed, which took several months with the cost of lost production running at about £100,000 per week.

Figure 6 shows some of the noises created by these powerful drives, before their mains emissions were suppressed.

Figure 6: Voltage noises on the site’s 3-phase mains supply, due to one PDS
4. Emissions

4.1. The basic structure of a BDM

Figure 7 shows the basic “block diagram” of the BDM for a VFD for an AC motor. It is basically just a mains rectifier that produces a DC supply (often called a “DC-Link”), followed by a pulse-width-modulated (PWM) power switching circuit (often called a chopper, switcher or inverter). Sometimes the terms chopper, switcher or inverter are applied to the whole BDM including the rectifier. In a low-power VFD (<10kW), the chopper might use “PowerFET” devices, but almost all higher power choppers use IGBTs (Insulated Gate Bipolar Transistors) instead.

Any DC or AC waveform can be synthesised by chopping at a higher frequency (must be at least twice the wanted frequency) by varying its mark:space (i.e. on:off) ratio. Chopping doesn't waste much energy as heat, which is why PWM drives are much smaller and less costly, and more efficient, than previous motor speed control technologies, and why it is so popular.

It turned out that the cost of the lost production on this one new site was many times larger than the company would have incurred if it had always installed PDSs using good EMC engineering practices (which means using mains filters, see later). This is still true even when using a discounted cash-flow analysis that takes the cost of borrowing the extra money for the earlier, apparently trouble-free installations into account.

This just goes to show that we can’t beat Murphy’s Law – “If a thing can go wrong, it will”. We might think we are getting away with poor engineering and saving money as a result, but (just like gambling) our luck cannot hold for ever. In the end we will be worse off than if we had always done good engineering. For more on why Murphy’s Law is actually true (at least in part), see [27].

The only situation where this “rule” doesn’t apply, is if your company has no brand image and is happy to supply people with rubbish and then “disappear” (e.g. by changing names) so as not to have to deal with the resulting high warranty costs. There is always someone willing to buy from an unknown manufacturer, if they have the lowest price, so there is always a market for such manufacturers. I’m sure it will come as no surprise that this Guide is not intended for use by such companies.
The sharper the edges of the PWM, the higher the frequency range of the emissions. Figure 10 shows an example of the waveform and frequency spectrum of a 16kHz squarewave (i.e. a very simple, 1:1 mark-space ratio PWM) with 2μs rise and fall times. The analysis of the squarewave in terms of frequency shows that most of its energy is at the 16kHz switching rate, and that it also has significant energy at all the odd-numbered harmonics, for example at:

- 48kHz (3rd harmonic)
- 80kHz (5th harmonic)
- 112kHz (7th harmonic)
- 144kHz (9th harmonic)
- 176kHz (11th harmonic)
- ...etc., all the way to at least 1.616MHz (the 101st harmonic) and beyond.

A squarewave is a special case of a chopper output waveform, and typical PWM waveforms are generally rectangular (i.e. their mark:space ratios are usually not 1:1). This means that their frequency spectra also contain even-order harmonics of their chopping frequency (e.g. 2nd, 4th, 6th, etc.). It also means that the levels of the various harmonics do not show the simple gradual fall-off with increasing frequency that we see in Figure 10. Some high frequency harmonics may have higher
amplitudes than lower frequency ones.

A DC motor drive can use PWM just like a VFD, it only requires the PWM waveform to be such that the motor current averages to a DC current instead of to an AC one.

But some types of powerful AC and DC motor drives use thyristor or triac devices switched on and off at the frequency of the mains power, instead of plain rectifiers. They don't need to use a DC-Link or a chopper. Phase-angle-controlled triacs are used to generate a variable DC voltage, and appropriate on/off switching of thyristors can generate AC at frequencies at up to 50% of the mains supply frequency (these are called cycloconverters).

Rectifiers, whether plain or phase-angle controlled, or cycloconverters, generate harmonics of their switching frequency – which is the mains – and so they generate what we call “mains harmonics” to distinguish them from other switching harmonics.

Figure 11 shows the first few harmonics of the current in a single-phase bridge rectifier, whilst Figure 12 shows those for a phase-angle-controlled single-phase rectifier (which could be a VSD for a DC motor).

In three-phase (often called 6-pulse) rectifiers and phase-angle controlled triacs supplied from a good quality sinewave voltage, the “triplen” harmonics (3rd, 9th, 15th, etc.) cancel out almost entirely in the circuit. However, if there is any imbalance in the supply voltages, triplens are produced. Similarly, for multi-pulse systems (e.g. 12 pulse) any imbalances in the paralleled 6 pulse rectifiers, phase shift transformer secondary windings results in triplens and other unwanted noise emissions being produced.

4.2. The unwanted noise sources in a BDM

The above discussion has shown that, in a BDM, rectifiers generate currents at the mains frequency and its harmonics, and choppers generate voltages at kHz frequencies plus their harmonics – even up to tens of MHz.
The generators used to provide mains power only generate at 50Hz (or 60Hz), so mains harmonic currents are a nuisance. They circulate widely in the mains distribution network causing excess heating of the cables, induction motors, transformers, fuses and circuit-breakers, and as they flow in the impedances of the supply network they cause voltage drops that distort the mains waveform so that it is not a clean sinewave anymore. We say that it is harmonically distorted, and when voltage distortion levels rise too high, many kinds of electronic equipment can malfunction. For more on the problems of mains harmonics, see [29] and [30], and also the REO Guides on EN 61000-3-2 and EN 61000-4-13, from the list at [4].

Since mains harmonics do not contribute to delivered power (they are called “wattless power”, worsening the True Power Factor – combination of the displacement power factor and the distortion factor of harmonics), and since they cause many problems, we consider them to be an unwanted noise emission. EN/IEC 61800-3 [1] defines tests and sets limits for the emissions of mains harmonics from a PDS, as do EN/IEC 61000-3-2 (for ratings up to 15A/phase) and EN/IEC 61000-3-12 (for ratings up to 75A/phase).

Motors have too much mechanical inertia and electrical inductance to respond to kHz chopping frequencies, never mind their harmonics – but they can suffer increased downtime due to their insulation failure, motor bearing problems and cables being degraded by the high frequencies. In addition, induction motors with deep bar or double cage design can overheat significantly on heavily distorted supplies. On explosion proof (EEExd) motors with these types of rotor design, the flameproof seals on the shaft, which are designed to contain any internal explosion, can become degraded, possibly allowing any internal explosion to be transmitted outside the motor carcass with possibly disastrous consequences.

If the chopping frequencies and/or their harmonics couple with other equipment (via conduction, induction or radiation) they can interfere with its operation. So it is good engineering practice to treat the chopping frequency and its harmonics as potential source of noise or degradation that should be controlled. [1] specifies tests and sets limits for the amount of conducted and radiated emissions, in common with many other EMC standards, such as the generic emissions standards EN/IEC 61000-6-3 and EN/IEC 61000-6-4. So, we have to limit our PDS's emissions of mains harmonics, and chopper frequencies and their harmonics. But this is not all. In a VFD, the motor draws its electrical power at the AC frequency that is synthesised by the PWM of its chopper, and as a result the current in the DC-Link and the mains current demand both follow this frequency. For example, if a VFD is set to 39Hz, then when driving its loaded motor it draws current from the mains at 39Hz. And because mains rectifiers are switching circuits and not linear ones, they generate harmonics of this frequency too.

These low-frequency non-fundamental-related (50Hz in Europe) mains currents are called mains “interharmonics”, and just like mains harmonics they circulate widely in the mains distribution network, causing excess heating and distorting the voltage waveform. DC drives can also generate interharmonics to some degree, when the load on their motors, or their motor speed, fluctuates repetitively and rapidly.

Just as for mains harmonics, [1] and other standards specify tests and limits for interharmonic emissions. Interharmonic emissions are made more complex by intermodulation within the mains rectifier. The mains voltage frequency and its harmonics (distorted waveform) intermodulates with the AC motor drive frequency and its harmonics, to create a huge number of “Intermodulation Products”. Figure 13 shows a measurement that was made on the current spectrum of a 700kW VFD, and shows significant current levels at, for instance 24A at 103.75Hz, which is six times the mains frequency (near to 50Hz) minus five times the motor frequency of 39.4Hz.
and voltage fluctuations due to load current changes; so this Guide will describe the techniques that are used to control noise emissions for VFDs that use PWM. The same techniques also work for thyristor and triac drives, which will probably need more attention paying to suppressing noise emissions in the lower frequency range (i.e. below 150kHz).

Variable speed motor drives are also used to drive various kinds of motors in servo systems, and to drive stepper motors. These use the same DC or AC PWM motor drive technologies described above, so their EMC should be treated the same way.

Figure 14 shows how the noise currents flow in the BDM example previously used in Figure 7.

The remainder of this Guide will focus on VFDs and VSDs that use PWM, because these are the worst for creating high-frequency noise emissions. This is because their choppers use very fast-switching PowerFETS or IGBTs, which are operated at kHz switching rates – as low as 1kHz for MW power ratings; as high as 50kHz for ratings around 1kW. We can expect to have to control noise at frequencies of up to 1,000 times the switching rate (e.g. 1MHz for a 1kHz chopper, 50MHz for 50kHz).

Thyristors and triacs switch much more slowly than PowerFETS and IGBTs, and their switching rate is no higher than the mains frequency. As a result they produce significantly lower levels of high-frequency noise emissions than a PWM drive of the same power rating. However, since they are often used at very high powers, their high-frequency noise emissions can be significant and should not be ignored.

All types of VSDs create low frequency emissions at harmonics of the mains supply, interharmonics, and voltage fluctuations due to load current changes; so this Guide will describe the techniques that are used to control noise emissions for VFDs that use PWM. The same techniques also work for thyristor and triac drives, which will probably need more attention paying to suppressing noise emissions in the lower frequency range (i.e. below 150kHz).

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All types of VSDs create low frequency emissions at harmonics of the mains supply, interharmonics,
13) The ratios of currents between the loops is frequency-dependent. Simply put, we should expect the CM noise – consisting of mains harmonics and currents associated with the rectifier and mains – to flow in a loop that comprises the motor noise and DC-Link, and that chopper noise also flows in a loop that comprises the motor noise and DC-Link, and that chopper noise also flows in a loop that comprises the motor noise and DC-Link.

Figure 14 shows – as red ellipses – the CM noise current loop associated with the rectifier and mains supply, and the loop associated with the chopper and the motor. It also shows a larger ellipse indicating that there are many alternative loops encompassing a whole site or vessel, which travel in very large loops, or six (or more) phase rectifiers.

I'm sure the reader will appreciate that the CM noise currents associated with the rectifier and mains supply, and the loop associated with the chopper and the motor. It also shows a larger ellipse indicating that there are many alternative loops encompassing a whole site or vessel, which travel in very large loops, or six (or more) phase rectifiers.

Figure 15 shows the use of filters at the BDM’s rectifier’s input, and at its output, to suppress the DM and CM noise emissions. The best way to understand how a filter suppresses CM noise is to regard it as a means of providing a return path for the noise current along which the noise current flows. Figure 15 shows the use of filters at the BDM’s rectifier’s input, and at its output, to suppress the DM and CM noise emissions.

Most filters also add inductors and chokes to increase the impedance of the mains or motor cables on the other side, after the provision of the low-impedance return path, to help suppress noise emissions from the rectifier being suppressed by a three-phase inductor, or by the filter and not out into the installation’s cables where it might cause interference. The best way to understand how a filter suppresses DM and CM noise emissions is to regard it as a means of providing a return path for the noise current along which the noise current flows. Figure 15 shows the use of filters at the BDM’s rectifier’s input, and at its output, to suppress the DM and CM noise emissions.

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Figure 16 shows an example of a 50kW VFD assembled in an industrial cabinet with its mains filter. Note how close the mains filter is to the VFD’s rectifier, and also how both the conductively-plated metal bodies of the filter, rectifier and chopper units are all multi-point bonded to the cabinet’s conductively-plated backplate, to provide good RF-bonding up to several 10s of MHz.

Figure 16: Example of a 50kW drive with filtered mains and screened motor cable

- RF-bond the metal bodies of the inductors or filters to the metal body of the unit whose noise it is to suppress.

(Even though an inductor has no intentional path to earth/ground, like the capacitors in a filter, its windings have significant stray capacitance which will help control CM currents, providing the inductor is RF-bonded.)

“RF-bonding” means providing a conductive path that has a very low impedance, <<100mΩ, at the frequency concerned. Ideally, the conductive path should have an impedance of 1mΩ or less at the highest frequency that it is desired to control. Remember that this is the impedance of a bond, not simply its resistance.

Wires or braid straps are ineffective for RF-bonding purposes, because their impedance is too great. The inductive impedance of a straight wire is \(2\mu fL\), where \(f\) is the frequency to be suppressed in Hertz (Hz) and \(L\) is the inductance of the wire in Henries (H). We can assume about 1\(\mu\)H/metre for a long wire and about 0.3\(\mu\)H/metre for a wide braid strap, so, for example, at 1 MHz a 25mm wide braid strap just 100mm long that might have a resistance of 1mΩ has an impedance of nearly 0.2Ω at 1MHz — 20 to 200 times too high to be a good RF-bond.

Figure 15 shows how this approach reduces PDS emissions, by showing that the double-headed arrows of the DM noise currents, and the red ellipses of the CM noise currents, are all now contained within the assembly comprising the mains filter, VFD and output filter. They are not showing as flowing in either the mains supply or motor cables.

See 4.4.4 for using an isolating transformer to improve the CM performance of mains filters, and – where CM noise is the only significant problem – possibly replacing the mains filter entirely.
of high-frequency noises.
Even where the chopper does not cause interference problems, there is
the problem of bearing life, and of the
degradation of the insulation in motor
cables and windings when long motor
cables are used (see 3.3). Figure 18
shows an alternative to the output
filter shown in Figure 15 – a screened
motor cable. As this figure shows,
if the screened motor cable has its
screen correctly RF-bonded at both
ends, the CM current loops associated
with the VFD’s motor output prefer
to flow inside the cable screen. This
is because the impedance of the CM
loop path down the inside of the cable
screen is so much lower than the
alternative CM loops that exist in
the earth/ground structure.
For example, when a number of
resistors are connected in parallel,
it is the one(s) with the lowest value
that carry the bulk of the current.
The impedance of the CM loops at
frequencies above a kHz or so are
dominated by inductive and capacitive
reactances, rather than resistance,
but the same principle applies – the
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Figure 17 shows some real-life
measurements on a VFD fitted with
series inductors to limit emissions
of mains harmonics, then with an
additional filter to suppress emissions
of high-frequency noises.

I don’t have a real-life photograph of
an output filter installed on a VFD, but
the principles are exactly the same
as for the mains filter in Figure 16.
The output filter should be one that,
like the mains filter, redirects both the
DM and CM noise currents that would
otherwise flow in the motor cable and
motor, such as the REO “Sinus ++”,
otherwise known as filter type CNW
961. Figure 15 does not show it, but
CM + DM output filters like the CNW
961 generally require a connection to
the DC-Link as well.

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measurements on a VFD fitted with
series inductors to limit emissions
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Figure 19:
Detail of the motor cable connection to the chopper in Figure 16
Braid-screened motor cable's screen ... that the cable's braid is clamped to a flange protruding from the chopper's chassis, using a metal saddleclamp.

Cable screen RF-bonding is sometimes called 360° termination or 360° bonding, because it should ideally make electrical connection all around the circumference or periphery of the braid screen. Alternatives, such as multi-point bonding, may be used providing the bonding points surround the cable.

Figure 19 shows an amplified detail of Figure 16, where the motor cable connects to the 50kW VFD's chopper unit. It shows that the cable's braid is clamped to a flange protruding from the chopper's chassis, using a metal saddleclamp.

A good way to prevent noise from the chopper which is causing EMC problems, is to make the motor cable very short indeed – less than one-tenth of the wavelength at the highest significant chopper harmonic frequency (e.g. 1m for 30MHz, 10m for 3MHz, 100m for 300kHz). The very best is to combine the BDM with the motor, with their metal frames multi-point RF-bonded together, or combined in a common casting, so there is no external motor cable at all. This technique has been very successfully used by some manufacturers, including Danfoss.

All VFD and VSD manufacturers should provide detailed EMC instructions for their products. I do not recommend using any manufacturer who does not (or will not) provide them. They will often be different for different models and ratings of drives, and for example, higher rated drives will generally require different filter specifications.

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Figure 20 shows the other end of the motor cable in the system driven by the VFD in Figure 16. Here the motor cable’s braid uses an “EMC Gland” to 360° bond to the motor’s terminal box. Figure 21 shows a variety of types of EMC gland, the top left-hand one being the preferred type. Where connectors are used instead, they should terminate the cable screen in 360° just like an EMC gland.

Figure 20: Detail of the cable connection to the motor driven by the VFD of Figure 16
Figures 15 and 18 show the DM and CM currents flowing entirely within the VSD assembly, which includes any mains chokes or filters, and any output filters and/or motor cable screen bonds (at the chopper end). However, electrical installers often seem to be of the opinion that all earths or grounds are equivalent, and also that it does not matter exactly where the various components associated with a VSD are installed ([37] records some difficulties with this). So, in practice, the electrical installation of a VSD and/or its associated components (chokes, filters, isolating transformers, motor cable screen bonds, etc.) might not be compact, and its earth/ground conductors may connect all over the place.

Where it is difficult to source high-current cables with good quality screens, or when suppressing the noise from a legacy system that used an unscreened motor cable, overbraid or shielded flexible conduit can be used, as shown in Figure 22. When choosing either, make sure that appropriate 360° glands or connectors are available for it.

Solid conduit makes the best screen for a motor cable, but the usual “banjo” washers are useless for suppression purposes because they rely on lengths of wire to bond them to an earth/ground terminal, and so have too high an impedance at RF. Figure 23 shows one manufacturer’s solution – a conduit nut that makes a multi-point 360° bond between the solid conduit and a metal enclosure at the point of penetration of the enclosure.

Figures 22:
Examples of screened flexible conduit and overbraid

Figure 23:
Example of a suitable 360° bond for solid conduit

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It is however very important indeed that the following two general installation rules are followed:

a) All of the component parts of a VSD, plus its associated suppression components (chokes, filters, isolating transformers, motor cable screen bonds, etc.) must be in very close proximity, ideally all contained within one metal enclosure.

b) All of the earth/ground conductors associated with the component parts in a) above must connect to one point, ideally the chassis, frame, backplate or surface of the metal cabinet they are all contained within. This one point must then connect to the site’s or vessel’s safety earth/ground structure via one conductor – following all the necessary safety codes taking the earth/ground leakage current into account (it could be several amps, due to the mains filtering).

I make no apology for repeating some of the points already emphasised in the earlier text. Electrical installers must be controlled very carefully to ensure that these rules are met in full – otherwise all the time and cost of determining how to suppress the drives will be wasted, and the EMC engineers involved will be blamed for getting it wrong, when the problem is incorrect installation.

I strongly recommend to all EMC engineers associated with such projects, that they write down mandatory requirements for the installation of their suppression devices, using as much detail as needed to communicate with the electrical installers in terms that they will clearly understand – and insisting that the contract with the customer includes an item covering their inspection and approval of the final electrical installation.

Some readers might contrast point b) above with other REO Guides, books and articles I have written (e.g. [19] [26]) in which the virtues of meshed common-bonding networks (MESH-CBNs) are extolled at length. Note that these also allow the possibility of combining single-point bonded systems with mesh-bonded ones, so there is no conflict. However, if a MESH-CBN or MESH-IBN (see [19] or [26] for definitions) that can control up to 30MHz, at least, exists in the area where the VSD and its suppression components are located, then b) can be modified to read as follows:

b*) All of the earth/ground conductors associated with the component parts in a) above must connect to their local meshed CBN or IBN structure, using very short electrical bonds. Follow all the necessary safety codes taking the earth/ground leakage current from each into account (could be several amps, due to the mains filtering).

4.4. More details on suppressing PDS emissions

A little Guide like this cannot be a textbook and provide everything one might need to know, but at least it can provide the basics, and this has been done above. This section provides a few additional notes, and many references, on suppressing PDS emissions.

4.4.1. Obtain manufacturer’s EMC instructions and follow them

VFD and VSD manufacturers EMC design/installation guides should always be obtained, and their advice followed accurately. However, they may not aim to achieve the degree of noise suppression that is needed (for example when installing many PDSs in one system, such as the example of Figure 3). There are many general guides and textbooks on suppressing emissions from motor drives, including [31], [32], [33], [34], [35] and [36], and these might provide sufficient information to overcome any shortcomings in the drive manufacturer’s EMC installation instructions. If even more information is required, see the following subsections.
40.4.2 Filtering

The specifications for the filters should be obtained from the VFD or VSD manufacturer, whose manuals are generally adequate, but often leave room for interpretation.

When trying to specify your own mains filter, start by deciding on what level of performance is required. For even better performance from a ferrite CM filter at low frequencies, wound single-phase and three-phase filters are better for retrofitting (all EMC standards specify mains filters for the same frequency range).

For more information on EMC filtering, see section 5.10.1 of [19], 4.7.1 of [20] and Chapter 8.1.3.1 of [26]. These are basically recommendations and should be treated with great caution; you should check them against specifications in other sources.

Resonance is generally a bad idea. Resonances can occur at any frequency, and their effects can be quite severe. They are often the result of mismatches between the input impedance of the filter and the load impedance of the system.

Where RF interference is suspected, filters should be used to stop the interference, and is usually the CM currents that are to blame. Clamping a ferrite toroid around all of the phase and neutral conductors in the phase and neutral conductors can sometimes be enough to stop the interference, and is especially effective at frequencies below 30MHz.

At frequencies below 30MHz, two or more ferrite toroids may be needed in series on the cable. In some cases, a 5-stage mains filter to the incoming power conductor should include a CM choke (or ferrite toroid). Always check that the filter is designed to handle the power levels involved.

The results of “matched” tests (i.e. 50Ω input and output) are better for retrofitting than those with “mismatched” input and output, or without including their associated impedances – i.e. they are not both the same. All of the above cases will have higher stray capacitance than ordinary cables to the motor, without ordinary cables to the motor, without ordinary cables to the motor.

This is important to understand, that information proves inadequate for most distributors, who rely on the VFD manufacturer's detailed EMC specifications. When operated mismatched, mains filters resonate and provide gain rather than attenuation. So when operated mismatched, mains filters resonate and provide gain rather than attenuation.

In real life, mains filters operate with mismatched input and output impedances, and the resonance is generally a bad idea. The resonance is generally a bad idea. It is important to understand that, because they only show the worst-case scenario of any performance, and some manufacturers do not show any performance at all.

For more information on EMC filtering, see section 5.10.1 of [19], 4.7.1 of [20] and Chapter 8.1.3.1 of [26]. These are basically recommendations and should be treated with great caution; you should check them against specifications in other sources.

Cascading mains filters is generally a bad idea. Resonances can occur at any frequency, and their effects can be quite severe. They are often the result of mismatches between the input impedance of the filter and the load impedance of the system.

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causing interference problems – incidentally improving cable and motor life as mentioned earlier. But because they are costly, such output filters will probably not even be mentioned in most drive manufacturers’ EMC instructions.

Where using screened motor cables is impractical for some reason, CM+, DM filters like REO’s Sinus ++ series may be the only solution. The manufacturers of the filters should be able to tell you which VFDs or VSDs they are suitable for.

In between low-cost ferrite toroids and expensive CM + DM motor output filters, there are various medium-cost alternatives. So-called dV/dt filters “round off” the edges of the motor output PWM waveforms, which – in the frequency domain – attenuates the higher frequency noise spectrum. Figure 24 shows the effect of applying a REO dV/dt output filter to a VFD.

Ships and other vessels generally use mains supplies that do not have their neutral directly bonded to their earth/ground structure [35], and some land-based installations also use this practice. This situation is discussed in Section 4.5.

4.4.3. Safety issues with filtering

Filters contain capacitors from the phase conductors (mains or motor) to the earth/ground, and these increase the current in the protective earthing conductor (the green/yellow striped wire in the mains supply). Safety standards and electrical wiring codes set quite low limits on this current, to help prevent electric shock hazards, but they will allow any amount of earth/ground leakage current when high-integrity earthing/grounding systems are used with a fixed VSD installation (i.e. one that does not have a flexible mains lead or mains plug, sometimes called “non-pluggable” equipment).

The high earth/ground leakage currents caused by filters can also make it impossible to use residual-current circuit breakers (RCCBs), earth leakage circuit breakers (ELCBs) or ground-fault interrupters (GFIs).

Where the mains system is isolated from the safety earth/ground (see 4.5), or when it is “corner-grounded” (one phase connected to earth/ground, rather than the neutral), all capacitors connected to the earth/ground (e.g. in a filter) should be safety-rated for the full phase-to-phase voltage, rather than phase-to-neutral.

4.4.4. Benefits of isolating transformers

Where a BDM is not powered from a co-located dedicated step-down isolating mains transformer, and where the mains power supply that feeds it is shared with other electronic equipment (which may include other BDMs) that are not co-located with the BDM concerned – then a number of EMC issues arise that may be best dealt with by fitting the BDM with a dedicated co-located isolating transformer.

Isolating transformers are large and costly components, especially for high-power BDMs, but omitting them or trying to use less costly alternatives can prove to be more costly overall (see section 3).

In situations where a mains power supply feeds two or more items of equipment spread over a site or vessel, the DM impedances of the phases can become different from each other due to unequal loading, and the CM impedance between the phases and the earth/ground can
become quite low due to the stray capacitances of the long cables and the CM filters in other equipment. These impedance effects negatively affect the performance of a BDM’s mains filter (see [36]). Fitting an isolating transformer restores the balance to the DM impedances, and also restores a high CM impedance, helping the mains filter achieve its designed potential.

Earlier, I discussed how a BDM’s CM return currents were ‘steered’ by capacitors in its input and/or output filters and their low-impedance bonding to the BDM’s chassis/frame, so that they flowed mostly in the BDM’s assembly. But when the CM impedance of the mains supply is low the ratio between the path impedances provided by the mains filter and that provided by the mains supply might not be as high as we would like. For example, where there are two or more equipments fitted with mains filters connected to a mains supply, their low CM impedances encourage the CM currents of each item of equipment to flow widely, which is not what we want.

Where a BDM’s mains filter does not include a CM choke on the supply side of its CM capacitors, this problem can be reduced by fitting a CM choke in that position, co-located with the mains filter. But all chokes cause some voltage drop and so this might cause an increased rate of tripping due to sags or dips in the supply. Another possibility is to fit an earth/ground choke to the BDM, which of course will only work if it is fitted to the single conductor that connects the BDM’s earth/ground to the earth/ground structure of the site or vessel (see item b in Section 4.3).

But an isolating transformer dedicated to the BDM and co-located with it (see item a in section 4.3) will provide much better control of CM currents than any chokes.

A mains isolating transformer might also prove to be sufficient, on its own without a mains filter, for preventing the CM noise from a BDM’s mains input from circulating widely. It would do little or nothing for the BDM’s DM noise emissions, or the resulting waveform distortion, but this is often not as much of a problem as the CM noise emissions anyway.

Where a BDM is fitted with a mains filter that deals with CM noise as well as DM, the majority of problems with widely-circulating CM currents occur at lower frequencies, below 150kHz. In this case experience seems to show that the normal type of construction for an isolating transformer is adequate for controlling CM currents in this frequency range.

However, there are techniques available for decreasing the stray primary-secondary interwinding capacitance, and for adding interwinding screens. These can be used to provide better isolation performance and higher CM source impedance, from DC to radio frequencies, which may be needed on occasion, for example when a mains filter is not fitted at all.

4.4.5. More detail on RF-bonding techniques

Figure 25 shows the basics of the ideal method of RF-bonding two metal items together (e.g. RF-bonding the metal bodies of the mains filter, rectifier and chopper to the backplate in Figure 16).

But there are many more details that could be important, and in some cases alternatives might be appropriate, so the information in

![Figure 25: RF-bonding two metal surfaces](image-url)
EN/IEC 61800-3 is rather dismissive of the potential of PDSs to interfere with radio reception through radiated emissions. However, VFDs – especially low-power ones switching at over 20kHz – have been known to interfere with radiocommunications, as some items in [15] show (e.g. No. 24).

As long ago as the early 1990s I have had to improve the shielding of industrial control cabinets that contained several VFDs, to pass the radiated emission tests to the generic emissions standard for the industrial environment (which was EN 50082-1, but is now EN/IEC 61000-6-4). Each VFD complied on its own, but when all the drives in the cabinet were running, their aggregate emissions were significantly above the limit line.

As PowerFETs and IGBTs develop, they are designed to switch faster to reduce heat losses and increase efficiency, so the prospects for radiated interference can only worsen. And as mentioned in section 3, more radiocommunications are being used everywhere, which also increases the potential for radiated interference from PDSs.

Designing and/or installing shielded enclosures requires a lot of attention to detail, but the basic principles are outlined in Figure 27, which shows the DIY screen-bonding technique of Figure 26.

However, where a screened enclosure (e.g. cabinet, room, etc.) is used (see 4.4.5), “proper” glands like the top left-hand side on in Figure 21 should always be used (or connectors with similar screened braid terminations).

4.4.6. More detail on cable screening (shielding) techniques

This will be found in sections 5.7.6 through 5.7.10 and 5.11 of [19], 3.7 of [20] and Chapter 7.2 of [26].

Screen bonding need not be costly, especially where there are number of cables screens to be bonded (e.g. to a cabinet backplate) as shown by the DIY screen-bonding technique of Figure 26.

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**Figure 26:**
A low-cost way to RF-bond multiple cable screens

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**Figure 27:**
The basic principles of employing a screened enclosure
that no conductor of any type (even wires and whiskers if routed too close to cables associated with a drive, and are a matter of some concern to EN/IEC 61800-3 [see 6.2.5 in [1]]. For a real-life example of serious telephone drive, interference is covered in section 4.8 [19] and Chapter 5 of [20].) For screening, will be found in the following: 5.12 of [19], section 5 of [20] and Chapter 7.4 of [26].

A great deal of detail on the design and installation of shielded enclosures, of all sizes from just large enough for one small VFD, up to screening an entire room or even an entire building, will be found in the following: 4.4.8. Other EMC techniques

section 5.12 of [19], section 5 of [20] and Chapter 7.4 of [26].

The above discussion has not addressed all the EMC techniques that will probably be required, for example, most (if not all) VFD manufacturers' EMC installation instructions, as well as [33] and [34] and [30] will include the requirement to classify the cables associated with a PDS according to some rules, and then to route these "cable classes" separately from each other, with certain minimum spacings to be maintained between cable classes according to some rules. However, sometimes the problem has been that the system integrator has simply cut a large hole in the wall or door of the screened enclosure, or has not mounted their human-machine interface, control cables, etc., has been allowed to enter/exit the enclosure without any reason. I am often asked to solve real-life problems with localised power quality issues, using those phases. However, when carrying its full rated current, its impedance even further is not managed to reduce the harmonic suppression. This acknowledges the fact that no conductor of any type (even "decoupling reactance" and requires its size be specified. A "3% inductor" such as is often fitted to reduce emissions of mains triplens as mentioned earlier. On [1] calls this series inductor a "triplen" harmonics, of which the most important are the 3rd and 9th. Losing triplens add arithmetically in the four wire systems (i.e. 3 phase + N) and equipment operation. However, sometimes the problem has been that the system integrator has simply cut a large hole in the wall or door of the screened enclosure, or has not mounted their human-machine interface, control cables, etc., has been allowed to enter/exit the enclosure without any reason. I am often asked to solve real-life problems with localised power quality issues, using those phases. However, when carrying its full rated current, its impedance even further is not managed to reduce the harmonic suppression. This acknowledges the fact that no conductor of any type (even "decoupling reactance" and requires its size be specified. A "3% inductor" such as is often fitted to reduce emissions of mains triplens as mentioned earlier. On
is really a chopper that is controlled to source or sink mains currents in antiphase to those that are causing problems, and - despite its name - is not a filtering technique at all. Passive and active harmonic filters are often used where it is desired to deal with the harmonics of a building, or even an entire building, site or vessel, instead of dealing with them at the level of individual items of equipment.

Active filters, introduced some 10 years ago, are expensive but widely used. These electronic filters provide a low harmonic source, therefore, if rated correctly, the load draws for the harmonic currents. Consequently, the power factor of the load is improved, which has the effect of causing the 5th harmonic (often called 12-pulse) rectifiers, which is very popular is worldwide production platforms, see [35] for details.

These and other "installation level" harmonic suppression techniques that are not commonly used in land-based installations, see [36] for details. A reasonably new design technique, active filters, being series (active) so that they do not cause too much distortion of the mains waveform. AFE rectifiers, being series connected in the supply at the switching zero-crossings of the mains voltage.

Where high-powered drives have a rapidly fluctuating load, the fluctuating emissions to below 5%. One manufacturer supplies these filters up to almost 100kW for both AC and DC drives. Being passive and linear, they do not cause EMI emissions.

Cost-effectiveness calculations may show that it costs less to allow all the PDSs on a site or vessel to emit their harmonics, and to clean them up with a single filter (passive or active) so that they do not cause too much distortion of the mains waveform. Where high-powered drives have a rapidly fluctuating load, the fluctuating emissions to below 5%. One manufacturer supplies these filters up to almost 100kW for both AC and DC drives. Being passive and linear, they do not cause EMI emissions.
necessary) either filtered or screened. When filtering techniques are used, filters may be needed at both ends, because the DC-Link carries noise generated by both the rectifier and the inverter.

4.4.14. Neutral shift can stress motor insulation

Section 4.12 of [36] discusses the problems of increasing neutral voltages caused by VSDs with Wye-connected inputs. It also discusses solutions that can be used when a Delta connected mains input cannot be used. These include using an isolation transformer at the mains input and floating the neutral connection to the VSD. The DC-Link conductors can carry as much noise as the output cables. When using cable screens and/or armour instead of output filters, a screen-bonding capacitor should be used at one end of the motor cable, either at the BDM or in the motor’s terminal box. This will not be as effective as a proper RF-bond, but may be good enough if their lead lengths are kept very short. For safety, such screen-bonding capacitors should be kept separate from the mains power system.

4.4.13. Emissions from the DC-Link

DC-Link conductors can carry as much noise as the output cables. When using cable screens and/or armour instead of output filters, a screen-bonding capacitor should be used at one end of the motor cable, either at the BDM or in the motor’s terminal box. This will not be as effective as a proper RF-bond, but may be good enough if their lead lengths are kept very short. For safety, such screen-bonding capacitors should be kept separate from the mains power system.
leakage current must be taken into account.

Another technique for reducing the earth/ground leakage of filters and cable screen/armour bonds, is to fit a co-located isolating transformer to the PDS so that it can be bonded directly to the earth/ground without compromising the rest of the system. Of course, if the PDS is powered from a dedicated and co-located step-down isolating mains transformer, a separate isolating transformer is not required – its EMI suppression function is provided by the step-down transformer.

5. **Immunity**

As well as dealing with emissions, EN/IEC 61800-3 [1] specifies test methods and test levels for immunity. The issues it is concerned with are:

- Power quality issues, including:
  - Distorted mains supplies (including harmonic distortion and commutation notches)
  - Supply voltage deviations, variations, changes, fluctuations, dips, dropouts and short interruptions
  - Three-phase voltage unbalance
  - Mains frequency variations
- Magnetic fields
- Conducted continuous EM disturbances (150kHz to 80MHz)
- Fast transients
- Radiated continuous EM disturbances (80MHz to 1GHz)
- Surge transients
- Electrostatic discharge

Most of these are best dealt with by the design of the equipment, as described in [21] and [22], and so not in the scope of this Guide.

To discuss what can be done to improve the immunity of a PDS by using installation techniques, the immunity problems can be broken down into four groups, see below.

5.1. **Power quality issues**

Section 5 of [30] is the most relevant reference for installation-level methods for dealing with poor power quality, and 4.2 of [19] will also be useful.

Part 6.5 of [21] describes a number of ways of designing equipment to improve its immunity to power quality issues, and some of those techniques can also be applied “stand-alone” to a PDS, system or installation.

And the techniques for dealing with commutation notching and other low-frequency emissions such as harmonics and interharmonics described in section 4 above, may also be able to be used to improve immunity to those electromagnetic disturbances.

5.2. **Magnetic fields, conducted/radiated disturbances, fast transients**

Where a PDS has problems complying with the tests for immunity to magnetic fields; conducted continuous EM disturbances (150kHz to 80MHz); fast transients, and/or radiated continuous EM disturbances (80MHz to 1GHz) – the usual solutions are to use the filtering and screening techniques discussed in section 4 above for suppressing emissions of low and high frequencies.

A technique that attenuates an equipment’s emissions of a particular electromagnetic disturbance, generally provides a similar level of attenuation when protecting equipment from interference by that same type of disturbance.

5.3. **Surge transients**

Series inductors used for suppressing emissions of harmonics or commutation notches also help increase a drive’s immunity to surge transients. Other techniques are galvanic isolation and surge protection devices (SPDs), which are discussed in sections 4.3 and 5.13 of [19], respectively.

These techniques can be used individually, or together in any combination.

5.4. **Electrostatic discharge (ESD)**

ESD techniques for equipment are covered in part 6.1 of [21], and they can be applied to a complete BDM by enclosing it in either a plastic enclosure (to prevent ESD from occurring at all) or in a shielded enclosure (to divert ESD disturbances away from the BDM’s electronics within).

Plastic enclosures do not protect
7. References and further reading


The Directive’s official EU homepage includes a downloadable version of the current EMC Directive and its successor; a table of all the EN standards listed under the Directive; a guidance document on how to apply the Directive; lists of appointed EMC Competent Bodies; etc., all at: http://eurropa.eu.int/comm/enterprise/electr_equipment/emc/index.htm.


[4] Seventeen EMC Guides on EM phenomena, legal compliance and EMC testing have been written by Keith Armstrong and published by REO (UK) Ltd. They are very readable and practical, and can be downloaded from www.reo.co.uk/knowledgebase.

They are also available from REO (UK) Ltd and Cherry Clough Consultants as a CD-ROM that contains all 17 of them plus two other REO EMC Guides and a great deal of other useful information on EMC.


6. EMC suppression products from REO

Figure 28 shows the range of products that REO provides for suppressing and/or protecting motor drives.

Figure 28: REO’s motor drive products


[31] REO Guide on “Power Quality for Variable Speed Drives”, free download from: www.reo.co.uk/knowledgebase


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EN and IEC standards may be purchased from British Standards Institution (BSI) at: orders@bsi-global.com. To enquire about a product or service call BSI Customer Services on +44 (0)20 8996 9001 or e-mail them at cservices@bsi-global.com. IEC standards can also be purchased with a credit card, in English and many other languages, from http://webstore@iec.ch.
Keith Armstrong graduated in electrical engineering with a B.Sc (Hons.) from Imperial College London in 1972, majoring in analogue circuit design and electromagnetic field theory, with a Upper Second Class Honours (Cum Laude). Much of his life since then has involved controlling real-life interference problems in high-technology products, systems, and installations, for a variety of companies and organisations in a range of industries.

Keith has been a Chartered Electrical Engineer (UK) since 1978, a Group 1 European Engineer since 1988, and has written and presented a great many papers and articles on EMC. He is a past chairman of the IEE’s Professional Group (E2) on Electromagnetic Compatibility, is a member of the IEEE’s EMC Society, the EMC Test Labs Association [59], the EMC Industries Association (www.emcia.org), and chairs the IEE’s Working Group on ‘EMC and Functional Safety’.

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