RADIO SPECTRUM MANAGEMENT

Power Drive Systems (PIB 49)

Electromagnetic Interference and Compatibility

Issue 2 | December 2014

MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT
HĪKINA WHAKATUTUKI

Contents, Disclaimer, Changes, Clarification and Corrections

Contents

Public Information Brochure 49 (PIB 49) is intended to assist all parties involved in the specification, purchase, supply and installation of Power Drive Systems (PDS). PDS are used to efficiently drive and control electric motors. This document is about the management of Electromagnetic Interference (EMI) and Electromagnetic Compatibility (EMC) issues.

Disclaimer

Ministry of Business, Innovation and Employment (the Ministry) makes no warranty, express or implied, nor assumes any liability for any loss suffered, whether arising directly or indirectly, due to sole reliance on the accuracy or contents of this Public Information Brochure (PIB 49).

This document does not provide guidance or cover electrical safety aspects. Readers must refer and comply with the appropriate regulations, codes, standards, manuals and documents. More information can be found on the Energy Safety website www.energysafety.govt.nz.

Changes

Radio Spectrum Management (RSM) may change, delete or add to, or otherwise amend information contained in the document from time to time to reflect evolving policies. Changes to this document will be notified through the 'Radio Spectrum Management Business Update' e-newsletter to those who are subscribed, and through the news sections on the RSM website www.rsm.govt.nz.

Clarification and Corrections

RSM will provide clarification of the information contained in this document when requested and would appreciate receiving suggestions for improvement or advice relating to inaccuracies or ambiguities. Such matters may be emailed to radio.spectrum@mbie.govt.nz. Correspondence received will be acknowledged, investigated and appropriate action taken.

Amendment history

Issue	Date	Amendment details
01	November 2012	First release
02	December 2014	Editorial amendment and updated format

Table of Contents

Executive Summary

This document is intended to assist all parties involved in the specification, purchase, supply and installation of Power Drive Systems (PDS). PDS are used to efficiently drive and control electric motors. This document is about the management of Electromagnetic Interference (EMI) and Electromagnetic Compatibility (EMC) issues. Where EMI and EMC may have an impact on electrical safety they are identified for information purposes. For electrical safety aspects readers must refer and comply with the appropriate regulations, codes, standards, manuals and documents. More information can be found on the Energy Safety website www.energysafety.govt.nz.

PDS use power converters and are also called Variable Frequency Drives, Variable Speed Drives and Adjustable Speed Drives. The converters operate using normal mains power to provide high frequency pulse currents to drive electric motors. When incorrectly installed they can cause:

- electromagnetic interference (EMI) to radio services;
- the injection of harmonics and common mode currents at mains point of supply, which in severe cases can result in damage to equipment connected to the same point of supply;
- stray currents that lead to voltage potentials (touch voltages) on PDS earth cables and associated earthed surfaces; and
- motor performance problems, bearing pitting, and sometimes failure.

The document identifies:

- existing EMC regulatory requirements for PDS;
- the causes and effects of PDS electromagnetic interference and related stray current issues associated with PDS;
- some EMC best practices for installing and testing PDS to mitigate these issues; and
- additional information on the installation and testing practices suitable for use in dairy sheds and rural pumping applications.

The document provides recommendations for:

- owners to ensure that their suppliers and installers are provided with correct site installation requirements;
- suppliers, to provide installation instructions that will enable PDS to be installed correctly;
- installers to implement those installation instructions; and
- operators to maintain and operate PDS without causing EMC issues.

The document does not impose new regulatory requirements. Where:

- suppliers, installers and operators have already adopted the requirements and recommendations of EN 61800-3 Adjustable speed electrical power drive systems Part 3 EMC requirements and specific test methods1; and
- PDS are operating without causing interference to radio services and other electrical equipment or safety issues, it is likely that the installation will meet the Radiocommunications Standards and Compliance notice requirements.

This document has been developed by Radio Spectrum Management after field investigations and consultation with PDS consultants, suppliers and installers.

---

[1] 1 EN 61800-3 is the standard referenced in the EMC standards notice and is identical to AS/NZS 61800-3

1. Purpose

This document is intended to identify the EMC regulatory requirements and the installation best practices for PDS that will minimise the EMI and conducted current issues that can occur with PDS. PDS are sometimes referred to as Variable Frequency Drives, Variable Speed Drives and Adjustable Speed Drives.

2. Scope

This document requires no adjustment to existing PDS installations that are compliant with the EMC regulations applicable at that time of their installation and where interference is not caused to radiocommunications services or other electrical and electronic equipment.

Where this document identifies improved supplier and installer processes, these changes should desirably be implemented at the first practicable opportunity. This document is based on the EMC standard for PDS, *EN 61800-3 Adjustable speed electrical power drive systems Part 3: EMC requirements and specific test methods,* and includes:

- the regulatory requirements applicable for PDS installations;
- an overview of Radio Spectrum Management (RSM) compliance practices associated with PDS;
- best practices for suppliers, installers and operators based on the EMC standard for PDS identified in the Radiocommunications Regulations;
- best practices for testing and site management, based on the EMC standard; and
- specific best practices for installations of PDS in dairy sheds and pump sites.

The recommendations of this document are intended to apply generally for all PDS installed in the domestic, commercial and industrial sites as identified in section 4.2.2 EMC limits for 1st and 2nd EMC environment types.

This document contains topics and principles that readers can use to locate further information in manufacturer handbooks, technical papers, text books, standards and on the web. Full details on the causes, effects and mitigation of PDS EMI and related stray current issues, installation practices and the associated test practices required are extensive and outside the scope of this document.

There are special EMC mitigation practices that may need to be implemented for particular sites used for aeronautical, chemical, hospital, laboratory, mining, petrochemical, radio broadcasting, telecommunications, scientific, veterinary and animal husbandry. While these practices are generally beyond the scope of this document, Annex B Dairy sheds installation practices identifies some recommended practices for dairy sheds.

The terms in this document are those defined in the Electricity Act 1992, Radiocommunications Act 1989 and associated regulations and standard EN 61800-3.

3. Background

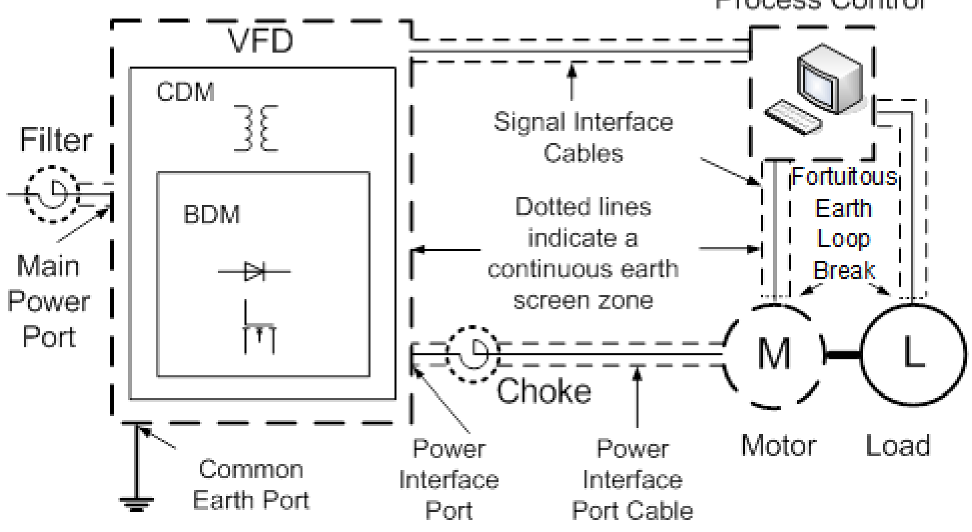
This document has been prepared by Radio Spectrum Management (RSM), in response to concerns over EMI levels around some dairy sheds, pump installations, and concerns with stray electrical currents and voltages. These concerns were often found to have the same causes and are appropriately mitigated by the same installation practices. The issues are identified to emphasise the benefits of using the 'correct' installation practices.

While practices described in this document are compatible with electrical safety, this document does not guide or provide information on meeting electrical safety requirements.

Readers must refer and comply with the appropriate regulations, codes, standards, manuals and documents for electrical safety requirements and information. More information can be found on the Energy Safety website www.energysafety.govt.nz.

PDS converter / inverter units, known as variable frequency drives (VFD), use pulse width modulated (PWM) voltages to efficiently control and drive electrical motors. The pulses in PWM have very fast rise and fall times (fast turn on / turn off times or high dv/dt) and can generate currents that comprise multiple high frequency (HF) components that can range from 50 Hz to over 100 MHz. The significant components of a typical PDS are identified in sketch 1.

Sketch 1- PDS Components



When PDS are installed using practices that do not suppress HF components generated by PWM in the VFD , the resultant stray voltages and currents, in combination with cable capacitance, motor inductance and stray capacitance, and high earth cable impedance, can cause:

- EMI to radiocommunications services; and
- HF harmonics, conducted and induced currents that interfere with the performance of adjacent sensitive electrical and electronic equipment, e.g. radio, computer, control, telecommunications, domestic, commercial and industrial equipment (EMC issues).

When those VFDs are connected to the mains without the use of mains power port HF filtering, HF currents can cause EMI to be radiated through overhead power lines and cause interference to radiocommunication services such as AM broadcast reception for several kilometres.

While beyond the scope of this document, the HF voltages and currents can include differential and common mode currents in the mains power supply and interface cables that can exceed twice the supply voltage, and may cause:

- insulation failure to PDS VFD, control, metering, transducer and cable equipment;
- failure of equipment connected to the PDS point of supply or main distribution board;
- high voltages on earth cores and touch voltages on associated surfaces that can exceed extra low voltage;
- motor failure, vibration and bearing pitting due to arcing between adjacent surfaces; and
- damage to flow meters, other transducers and other electrical equipment more than 200 m from a VFD.

The levels of the stray currents and voltages depend on the PDS installation practices, the electricity supply earth arrangement, cable HF impedances, and variations in earth impedances at each earth point. Managing these voltages requires the use of the correct PDS installation and earthing network practices.

While the potential for stray and common mode currents is increasingly more significant for higher power VFD (above a few watts), the EMI effects can be associated with all low and high power VFD.

PDS are complex devices and avoidance of these issues requires careful PDS component selection, correct installation instructions and competent suppliers, installers and operators.

Most manufacturers' installation instructions specify the use of use of screened power interface cables. However, some installers have not followed these instructions and chosen cheaper non-screened cable. This can result in operator and installer remedial and production costs that are many times the initial cost savings. Disputes between installers and operators over such issues can involve high litigation costs. RSM may also take compliance action where interference or non-compliance with regulatory requirements is established.

4. EMC requirements

4.1. General requirements

The existing EMC requirements for PDS are provided through the Radiocommunications Act 1989 (the Act) and the Radiocommunications Regulations 2001. These are intended to ensure that devices such as PDS do not cause EMI and electromagnetic induction to Radiocommunications services or adjacent electronic or electrical equipment. Any electrical, electronic or radiocommunications device must conform with the requirements of the following current Radiocommunications notices:

- Radiocommunications (Compliance) Notice;
- Radiocommunications (EMC Standards) Notice; and
- Radiocommunications (Radio Standards) Notice.

The *Compliance* notice requires suppliers to maintain product compliance folders that contain a supplier declaration of conformity, a product description and a test report or manufacturer's performance specification or other reasonable evidence of conformity, and the equipment to be labelled RCM compliance mark.

The *EMC Standards* notice classifies PDS VFD as level of conformity 2 products. Conformity 2 products must meet the requirements of the appropriate EMC standard specified in the notice.

A RCM compliance mark identifies that a VFD installed in accordance with the instructions provided by the manufacturer for the purposes of compliance testing in an approved laboratory will comply with the requirements of the EN 61800-3.

The installation or use of interfering PDS equipment in a manner that does not comply with the requirements of these regulations may result in RSM taking compliance action.

Penalties may include an infringement notice (with an associated financial penalty) or prosecution.

A *Radio Spectrum Management Compliance Guide* for users of the radio spectrum and suppliers of electrical and radio products is available from www.rsm.govt.nz.

4.2. Specific requirements

EN 61800-3 identifies EMI and terminal disturbance voltage levels that can indicate EMC performance compliance for VFD tested in approved laboratories. These levels can also be used to demonstrate compliance for VFD installed outside approved laboratories. However, because site conditions invariably do not reflect those of an approved laboratory, good installation practices are necessary to ensure that the performance of a compliant product is not degraded so as to produce practical levels which are in excess of those specified in the standard.

As a consequence, satisfactory on going operation is most likely to be achieved when:

- a PDS (the interfering equipment) is manufactured compliant with EN 61800-3 and installed in accordance with the practices outlined in this document, i.e. so that EMI, conducted current and magnetic induction interference are not caused to the operation of adjacent electrical equipment (and at more distant sites); and

- other equipment which may be affected by the PDS meets normal immunity performance standards, and is installed and operated in accordance with manufacturer requirements.

RSM, when investigating EMI interference to radio services or electrical equipment operated by other users, has due regard for installation practices used to mitigate the causes of interference.

4.2.1. EMC environment types

EN 61800-3 sections 3.2.1 and 3.2.2 identify EMC limits for the following EMC environment types:

- *First environment types:* These are environments that include domestic premises; it also includes establishments directly connected without intermediate transformers to a low voltage power supply network that supplies buildings used for domestic purposes. (Houses, apartments and commercial premises or offices in a residential building are examples of 1st environment types).
- *Second environment type*: These are environments that include all establishments other than those directly connected to a low-voltage network which supplies buildings for domestic purposes. (Industrial and technical areas of any building fed from a dedicated transformer are examples of 2nd environment type locations.)

For sites that provide for public access where radiocommunications services (such as broadcast radio or cellular mobile) usage can be expected, PDS should comply with 1st environment type EMC requirements. Such sites can include areas adjacent to cable cars, ski lifts, fly-by-wire adventure rides, sport and recreational facilities, fairgrounds and public transport locations.

The sites identified in the scope of this document as having equipment more sensitive to EMC can require lower EMI and stray current issues than those acceptable at 1st environment sites. See Annex B Dairy sheds installation practices.

4.2.2. EMC limits

EN 61800-3 sections 6.4 and 6.5 identify limits in 1st and 2nd environment types for EMI on frequencies 30 MHz and above and terminal disturbance voltages for frequencies up to 30 MHz.

4.2.3. EMI from overhead power lines

This is managed by owners of electricity lines networks (lines companies) in accordance with *NZS 6869, Limits and methods of measurement of electromagnetic interference from overhead ac. power systems in the frequency range 0.15 MHz to 1000 MHz.*

4.2.4. Conducted currents

These are managed in accordance with New Zealand Electrical Code of Practice 36 (NZECP 36).

4.2.5. Immunity

EN 61800-3 clause 5, '*Immunity requirements',* also identifies requirements for PDS. These are to ensure that a PDS is not adversely affected by a validly existing electromagnetic field (for example from a nearby broadcast transmitter). RSM does not measure immunity levels but can require the supply of the product compliance test report when investigating compliance issues.

4.3. EMC investigations

When investigating reports of interference to radiocommunications or broadcasting, RSM staff will check that the affected receiver is performing satisfactorily (other than in regard to the interference) and that the available level of the desired signal meets minimum signal level (coverage) requirements. A check will then be made of the interfering equipment installation, to establish compliance with product performance standards. This may include any installation requirements specified by the manufacturer or required by good installation practice to prevent interference.

5. Supplier obligations

EN 61800-3 clause 4.3 '*Documentation for the user*' requires that manufacturers supply documentation necessary for the correct installation of a PDS in a typical environment. That documentation, where relevant, should include:

- the maximum and minimum acceptable supply network impedances;
- the use of shielded or special cables (power and/or control);
- cables shield connection requirements;
- the maximum permitted port interface port cable length;
- cable segregation requirements;
- the use of external devices such as filters; and
- the correct bonding to a functional earth.

Where particular EMC avoidance measures are necessary to meet the required limits, the installation documentation should clearly state the requirements. If different measures are required in different EMC environments these should also be stated.

A list of auxiliary equipment, e.g. options or enhancements, that can be added to the PDS and which comply with the immunity, and/or emission requirements, should be made available.

Suppliers should also make purchasers aware of the recommendations of this document.

5.1. Non-standard installation instructions

Where the manufacturer's instructions do not apply for the intended site and the installer is unfamiliar with installations in such sites, the instructions for installation should be prepared by a person who is familiar with the:

- installation of equipment in similar locations;
- practices required to minimise the EMI and stray currents;
- electricity safety regulations;
- testing required for verifying that the performance of the PDS meets the EMC requirements; and
- site and operator requirements.

These instructions should:

- enable the correct installation of the PDS in the intended location;
- be based upon manufacturer's documentation and include any other information necessary to ensure the PDS will be compliant with EMC requirements;
- specify the requirements for installing shielded power and control cables, and their connections;
- specify requirements for installing external devices such as filters and toroids;
- specify the correct bonding to a functional earth;
- specify installation practices and testing requirements;
- specify the maximum permitted cable lengths and cable segregation requirements;
- describe the equipment, operational, and maintenance requirements, the intended EN 61800-3 environment type and category type; and
- specify the maximum and minimum acceptable supply network impedances, if applicable.

6. Installer obligations

PDS that are neither plug in devices nor moveable devices should be installed by persons that have the necessary skills and experience to install and commission a PDS in accordance with the installation instructions provided, and this document.

Installers should ensure the installation instructions are appropriate to the site requirements and provide a certificate to the operator confirming that the installation:

- is in accordance with the operator requirements and the installation instructions;
- does not cause interference to radiocommunications services; and
- does not degrade the performance of adjacent EMC-sensitive electrical equipment.

7. Operator obligations

Operators of PDS are recommended to:

- provide site access for RSM to carry out EMC investigations at a mutually agreed time;
- maintain the PDS in accordance with the EMC recommendations of this document; and
- follow RSM instructions to make adjustments to, or switch off, interfering equipment.

Operators should:

- retain PDS installation documentation for presentation to RSM when requested;
- be aware of the installation requirements of PDS and this document, or obtain the assistance of someone experienced with the requirements;
- ensure the supplier is aware of the installation site EMC environment type and any special site stray current requirements;
- obtain a written declaration from the installer that the installation is in accordance with the recommendations of this document; and
- maintain an EMC site management plan, see section 10 EMC site management.

8. Installation practices

8.1. General aspects

These practices are a summary of the key EMC installation requirements for PDS and can be used as a guide to the practices applicable to mitigate EMC issues for non VFD switch mode devices.

These practices should be read in conjunction with the installation instructions provided under section 8, the VFD manufacturer's equipment manuals, and where applicable, Annex B Dairy sheds installation practices and Annex C Pump installation practices.

In the absence of undersized earth cores, loose connections, wiring errors and equipment faults, VFD installations compliant with these practices will have minimal EMI, stray and common mode currents.

Minimising the effects of PDS EMI, electromagnetic induction and stray currents requires the use of the correct installation practices. Those practices include the use of:

- EMC screened enclosures for electrical equipment that generates, or is susceptible to, EMI and/or electromagnetic induction issues;
- screened power, control and communications cables that are correctly terminated;
- low HF impedance earth current paths between the VFD common earth point and the motor frame, i.e. the power interface port cable;
- VFD and filters designed to minimise EMI and stray currents;
- minimal cable lengths, without loops of spare cable and without sharp cable bend;
- separate routes for mains supply, power interface port, control and communications cables, and the avoidance of parallel cable runs with other similar cables;
- cable crossings of different cables being at 90 degrees, with physical separation; and
- paint and contaminant free, and physically robust connections, securely crimped with flat washers/nuts/bolts. Spring washers should not be used.

These practices are applicable both within and outside equipment enclosures, and are generally applicable for all electrical equipment that uses pulse current techniques where mitigation of EMI effects is sought, e.g. switch mode power supplies used with back-up power supplies, refrigerator power supplies, fluorescent with electronic ballasts, high intensity LED light systems, electric fence equipment, soft starters, electronic controllers and Radio Frequency Identification (RFID – such as NAIT tags) and also for radio, telecommunications and computer equipment.

8.2. EMC screened enclosures

Screened enclosures normally comprise earthed sheet metal enclosures fitted with cable gland and/or saddle mounting plates for correct termination of screened cables. High quality enclosures include metal screen mesh covers over openings and metallic door gaskets that minimise EMI radiation. VFD that are not fully screened should be installed in screened enclosures together with associated protection and control equipment. Filters, toroids, cable connections and isolation switches in the power interface port cables should be screened or installed in screened enclosures. Installation in enclosures can be simplified if screened cables with the outer insulation stripped are laid side by side and securely strapped together with stainless steel wide ties (15 mm or similar) and bonded to the enclosure earth.

8.3. Screened cables

Power interface port cables should be screened except where the:

- cable is installed in properly earthed fully enclosed steel trays or steel conduit;
- VFD manufacturer identifies that a screened cable is unnecessary; or
- cable length exceeds the maximum recommended by the VFD manufacturer.

At the time this document was first published Radio Spectrum Management was aware of one manufacturer who specifies that screened cables are not necessary with their product when installed in second environment type locations in accordance with their installation instructions; and two manufacturers who supply VFD with significantly sinusoidal waveform output voltages that do not require the use of screened power interface port cables in all EMC environments. Where unscreened power interface port cables are used, the PDS installation should use such cables, filters, toroids electromagnetic screening or other practices that will ensure the PDS complies with the EMC requirements.

PDS installed in industrial locations without the use of screened power interface port cables interference can be compliant with EN 61800-3 requirements but may still cause interference to adjacent sensitive control and communications cables and other electrical equipment. Power interface port screened cables are available in many types. EMC screened cables comprise twisted fine strand cable phase and earth cores formed inside a screen of woven fine strand tinned copper wire. EMC three phase screened cables often include three earth cores laid symmetrically between phase cores around a former within the screen. The cross sectional area of the three earth cores combined is equal to that of one phase core.

Heavy industrial screened cables can be of similar construction to that of EMC screened cables but comprise copper wire strand cores laid inside steel tape or wired armour screens.

Less effective screened cables use larger diameter wire strand cores, have no earth core, have more open screens and provide lower levels of screening. These include neutral screened power cables that have loosely wound steel tape screens that are difficult to terminate effectively. If used for power interface port cabling, such cables require a parallel low HF impedance earth strap and burial or installation in an earthed enclosed steel tray.

Separate cable mesh screening is available for use with large diameter single phase cables.

Control, monitoring and telecommunications cables should be screened. Fibre optic systems or double screened cables can be used for susceptible services in high noise environments.

The '*Power interface port cable tests*' in Annex A Installation test practices illustrates the benefits of using properly terminated screened cable and the measurement processes available to confirm those benefits.

8.3.1. Screened cable termination

The correct termination of screened cables requires purpose built panel mounted EMC metal cable glands or cable saddles that provide continuous and reliable earth contact around the screen circumference at both ends of the cables. These terminations are generally referred to as 360 degree terminations. Test results for screened cables using pigtails and those correctly terminated are noted in Annex A Installation test practices.

8.4. Earthing

Common mode currents associated with PDS tend to occur because of phase load impedance variations due to unequal motor field coil capacitance to earth, unequal field inductance and motor transformer effects. The resulting phase current imbalance can be up to 30% of phase current and can flow as earth currents between the motor and the VFD. Where the power interface port cable earth is not sized correctly the imbalance current can flow via fortuitous and lower impedance earth paths to the mains supply transformer and/or the site main distribution board to the VFD mains power port.

To reduce the potential for earth currents due to phase imbalance the power interface port cable earth cores should have an HF impedance that is less than 10% of that of other parallel protection, fortuitous and other earth paths. PDS earth busbars and earth connectors should be robust and have large surface areas. For example earth busses less than 5 mm thick and small diameter connectors can greatly increase earth impedances in low wattage PDS.

Standard earth systems and earth cores rated for 50 Hz purposes generally have high HF impedance. This will mean that HF currents between the motor and VFD common earth will tend to flow via the correctly sized low HF impedance power interface port cable earth and this should minimise the need for other ground fault protection systems to protect against common mode current issues.

The use of woven fine stranded tinned copper flat earth straps wired in parallel to power interface port cables and earth bonding systems can help minimise earth impedances.

8.5. VFD

VFD constructed to minimise EMC and stray current issues are supplied in screened enclosures that are fitted for the correct termination of screened power interface port cables and control cables. They have HF DC buss bypass capacitors, robust common earth points and fully earthed heat sinks (where appropriate and practicable). Some VFD will require the addition of these features before they can be correctly installed.

Purchasers considering the purchase of a VFD from unfamiliar sources are recommended to obtain a copy of the accredited test laboratory test report from the supplier to review prior to purchase.

The installation of multiple VFDs on a site using a common phase rotation sequence can reduce EMI, stray current and mechanical vibration issues. VFD are sensitive devices that should be installed in clean, dry, secure locations.

8.6. Filters

Mains power port filters and power interface port toroids, chokes and filters:

- should be specified in the manufacturer’s or other installation instructions;
- should be compatible with the electricity supply earth arrangement; and
- if mounted external to a VFD, should be installed as close as practicable to the VFD in screened enclosures using correctly terminated screened cables.

Special filters can be necessary for PDS installations where low levels of EMI, stray and common mode current are required. These include sites:

- using long power interface port cables (power interface port filters); and
- connected via overhead power lines (mains power port HF filters).

8.7. Motors

Motors can be designed to have a distributed winding capacitance to earth and winding inductance, and be fitted with insulated mounts and load couplings to minimise stray and common mode current issues.

9. Installation EMC testing

Installation EMC tests do not supersede or replace the requirement to test and certify an installation for electrical compliance. Readers must refer and comply with the appropriate regulations, codes, standards, manuals and documents. More information can be found on the Energy Safety website www.energysafety.govt.nz.

Specific EMC testing will depend on:

- installer experience with the equipment installed;
- the EMI and conducted and stray current requirements for the site;
- the consequences of production of failures due to EMI and conducted and stray current issues;
- level of adherence to section 8 Installation practices; and
- the results of electrical safety, harmonic current, motor performance and load tests.

Where PDS are correctly installed in accordance with section 8 Installation practices and the installer has successfully completed similar installations, EMC test requirements can be limited to:

- visual verification that the installation practices are satisfactory. (This should precede operational tests);
- operational tests to verify the PDS operation complies with the manufacturer's specifications, the installation instructions and the operator's requirements; and
- tests to ensure that when the PDS is operating, AM broadcast receivers, locally used radio equipment, line communications, computer, security, control, monitoring, transducer, other adjacent PDS and electrical systems are operating correctly.

Equipment can be introduced to test EMI and conducted and stray currents if none is installed locally.

Where the installer has little previous experience with PDS installations on similar sites and in EMC sensitive locations, the test requirements should include the:

- visual verification and operational test requirements noted above; and
- measurement of power interface port cable HF voltage drops, terminal disturbance voltage measurements and voltage potentials on conductive surfaces adjacent to the PDS as described in Annex A Installation test practices.

More comprehensive testing to avoid or resolve issues on complex and more sensitive sites can include the EMI, common mode voltages and harmonic current tests of Annex A Installation test practices.

Tests can include pre-installation and post installation tests, start-up, operational and shut down sequences, and measurements with the new PDS operating stand-alone and when operating simultaneously with other equipment, i.e. cumulative tests.

Cumulative EMC tests should include the simultaneous operation of the PDS being tested, other local PDS and local switch mode electrical equipment such as:

- standby power supplies, refrigerator power units, equipment controllers, high intensity LED and fluorescent lights, battery chargers, workshop tools and ovens; and
- remote PDS (particularly deep bore water pumps), electric fence units, power supply networks and compensation systems.

The isolation of interfering elements with intermittent EMC issues in electrical systems can be particularly difficult under production conditions and requires a systematic approach.

10. EMC site management

Sites with multiple PDS and / or special EMI and stray current requirements should maintain comprehensive installation management systems to minimise the resolution time for EMC and related production issues. These systems can include the labelling of equipment, cables, cable termination points and equipment locations, the availability of experienced staff and the maintenance of records that include details of:

- power distribution, electrical earthing and communications wiring and ducting plans;
- equipment, cable and site installation, operation and maintenance requirements;
- maintenance support contracts and processes;
- installation and maintenance test results associated with EMI and stray currents, power harmonics and other electrical performance indicators; and
- production, operations, maintenance and other related events (a diary).

EN 61800-3 Annex E EMC analysis and EMC plan includes a more comprehensive coverage of the management information activities that apply for complex PDS sites.

Annex A Installation test practices

The following describes the measurement practices identified in section 9 Installation EMC testing and other test methods that can be used to measure stray currents and voltages. Acceptable levels are included where these are available.

Oscilloscope voltage measurements

The peak to peak (ptp) HF voltage measurements identified below require use of a 100 MHz oscilloscope with differential inputs (isolated from earth) and an external sync mode. A lower bandwidth oscilloscope can be used to indicate likely levels, but may not accurately measure peak voltages of HF pulses with fast rise times. (VFD typically produce pulses of 6 to 11 kHz with rise times less than 0.1 micro second.)

Power interface port cable earth voltage drop levels

A key requirement to minimise PDS EMI and stray current issues is to provide a low HF impedance path between the motor frame and VFD common earth. It follows that where a power interface port cable has high impedance, a high voltage drop across the cable can indicate EMI and stray current issues.

Measurements completed using the oscilloscope method have provided the results described below.

a) Table 1: Voltage potentials between VDF earth and motor frame on earth cables of different types and terminations.

Cable type	Un-screened	Screened cable with a pigtail termination at one end with pigtail length in mm				Screened	Neutral screen
		500	250	100	50		
Voltage drop	92.6 v	30 v	15 v	7 v	2.9 v	0.82 v	4.8 v

Notes: Cable lengths are 10 m and voltages are peak to peak.

'Pig-tail' earth connections are formed by twisting together unravelled cable screen strands.

b) Voltage drops on 10 m power interface port cables using VFD of similar ratings from 4 suppliers / manufactures were:

- 0.6 to 2 volt ptp when the interface cable was screened and correctly terminated;
- 7 to 9 volt ptp when cable was screened and had one 100 mm pigtail termination;
- 3 to 7 volt ptp when a VFD has a plastic case and poor heat sink earthing and the interface cable was screened and correctly terminated; and
- 40 to 160 volt ptp (with an unscreened cable).

c) Field measurement of voltage drop across unscreened interface cables less than 7 m long and with earth cores sized for 50 Hz protection measured over 200 volt ptp.

Based on these measurements, expected maximum voltage drops on 10 m cables are:

- circa 1 volt (ptp) in a EMC 1st environment type location; and
- circa 10 volts (ptp) in a EMC 2nd environment type location.

Actual voltage drop limits can depend upon cable length and site and off-site equipment interference protection requirements. For example, interface cable volt drop levels close to 40 volts ptp can be acceptable in some 2nd environment type locations. However, voltage drops well below that level can cause EMI and conducted and stray currents that limit the local use of serial data and other communications systems used with site computer, control and monitoring systems.

Direct measurement of the voltage drop across power interface port cables longer than about 20 m is impractical, and the EMC performance of a PDS can require the direct measurement of common mode earth currents using HF oscilloscopes and calibrated current measurement probes, the use of the test methods identified below, and/or and other techniques.

Terminal disturbance voltage levels

These can be measured using the HF oscilloscope method described above for conducted voltages on VFD mains power port and power interface cable port terminals, power distribution boards, and adjacent equipment mains supply terminals. The voltage levels can be compared with values given for PDS equipment categories identified in Annex E in the EN 61800-3 tables. Tables 14, 16, 17, 18, 19, and 20.

Touch voltage measurements

These measurements identify surface touch voltages on earthed and other surfaces that can indicate the existence of stray current flow or electrostatic or received radio signal (EMI) levels. Acceptable levels depend upon environment type locations and operator requirements.

The voltages can be measured with an oscilloscope (as described above) with a 470 ohm burden resistor[2] across the oscilloscope input terminals, i.e. to ensure the touch voltage is based on sustained current flow rather than electrostatic and EMI signal levels. Annex B Dairy sheds installation practices provides a specific example of test requirements.

Harmonic current tests

There is increasing use of more complex power tools that can measure harmonic currents and power quality. The identification of harmonic distortion above about 5%, voltage dips, commutation notches, voltage unbalance and frequency variations may indicate the need for measurement of power interface port cable voltage drop, terminal disturbance voltages and touch voltages.

---

[2] 470 ohm is a easily available and a suitable resistance. Other resistance values close to this will give similar results.

EMC testing with standard electrical test equipment

Many 50 Hz millimetres are designed to measure 50 Hz RMS voltages and currents and do not measure PDS HF voltages above about 15 kHz, nor short duration HF peak voltages associated with EMI.

A 50 Hz clip-on ammeter can be used to measure motor transformer common mode earth RMS conductor currents and will identify the potential for associated 50 Hz common mode voltages but will not identify peak HF currents.

EMI level measurement

The accurate measurement of EMI levels requires frequency measuring receivers and calibrated antennas. Such measurements may be impractical on site due the effect of EMI reflection from other equipment and structures on measured values. The measurements can require the services of a competent radio or EMC specialist.

Where measurements are made, these can be compared with values given in EN 61800-3, Tables 15, 18, 21 and 22. These tables identify EMI levels for frequencies 30 MHz to 2 GHz. EN 61800-3 requires radiated signal levels in 1st environment type locations to be measured 10 m from the PDS boundary and, in 2nd environment type locations, 30 m from the PDS boundary.

Indications of EMI can be obtained using domestic or portable MF-AM broadcast receivers and other radio equipment that is expected to operate adjacent to a PDS VFD, motor load or associated cables.

In the event of EMI to radio services, consideration needs to be given to:

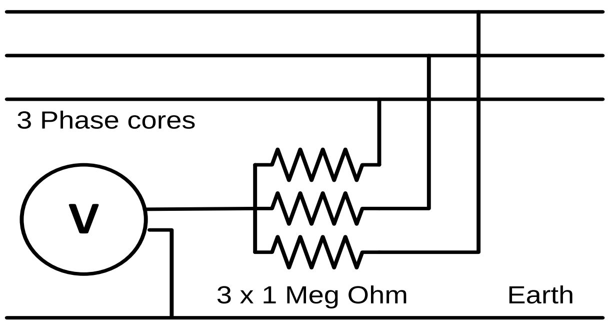
- the receive signal quality before and after PDS installation;
- the level of EMI and expected radio service coverage;
- the screening effect of local buildings and other obstructions; and
- the location and suitability of the receive antenna.

Relocation or other adjustment of an antenna or its associated feeder cable may be an option to restore the original service quality if EMI levels are low.

Common mode voltage measurement

High levels of common mode currents in conjunction with fortuitous earths or broken or inadequately sized earth conductors and high levels of HF currents due to incorrect installation practices can result in the breakdown of insulation of cables or equipment interfaces of any equipment connected to the same point of supply and any associated monitoring or control transducers. Such effects can extend for several hundred metres. 50 Hz and HF common mode voltages can be measured directly on mains supply and power interface port cables using the circuit in sketch 2 and the oscilloscope voltage measurement test described above. Use of a normal multimeter will indicate 50 Hz levels only.

Sketch 2 - Common Mode Voltage Bridge



Common mode currents of 3 phase motors can exceed 30% of phase current

Equipment EMC immunity tests

Definitive immunity measurements can be difficult to complete after equipment is installed and in use. However, equipment should work as it was intended to.

50 Hz Common mode current measurements

While EMC measurement normally requires the use of HF test methods, the transformer effect of motors can result in 50 Hz common mode currents as high as 30% of phase current levels. In less complex VFD environments, i.e., with only one VFD operating, the 50 Hz common mode currents can be directly measured using a standard 50 Hz clip-on multimeter with the current probe clipped around the neutral – earth bus link bar on the power distribution board.

Multimeters with a frequency response that exceeds 20 kHz can also give an indication of harmonic common mode current levels. However, experience gained with tests using both oscilloscope and clip-on multimeter methods in similar installations is required to enable the appropriate interpretation of measured values.

Annex B Dairy sheds installation practices

General

Exposure of livestock[3] to stray HF touch voltages (as well as other factors such as changes in weather, feed, routine, lighting, sudden movements, and the like) can make animals uncomfortable and reduce output. As a consequence, care is required to determine the cause of any cow behavioural issues.

Abnormal cow behaviour caused by 50 Hz stray currents was identified when vacuum milking was first introduced to dairy sheds. Subsequent investigations identified that the stray currents and abnormal cow behaviour could be resolved by the appropriate electrical bonding of shed metalwork.

More recently, PDS (used with water, milk, feed and effluent pumps, and gate and platform motors), switch mode power supplies (used with electric fences, milk coolers, control systems, computers, fluorescent and LED lighting equipment) and VFD have become new sources of stray currents. These new high frequency (HF) stray currents result when switch mode power supplies and VFD units are incorrectly installed, and are liable to cause both abnormal behaviour in cows and interference to local computer, control, cow monitoring, telephone and radio facilities.

The effects of stray voltages and currents on animals varies, previous exposure to stray currents, the contact points, moisture levels, and surface touch voltage levels can all have an effect. Behaviours such as fixed staring, mild flinching, foot lifting, avoidance behaviours and defecation can be indicators of cow discomfort, possibly caused by unsatisfactory levels of stray currents and voltages. The removal of the stray voltages can mean a quick return to normal behaviours.

EMC environment recommendations

Best practice requires that dairy sheds and locations connected to the same mains point of supply be EMC 1st environment type locations with surface touch voltages reduced to the levels necessary to prevent potential issues.

Installation practices

The best practices for installing VFD in dairy sheds should be aligned with the practices identified in section 8 'Installation practices' and installation instructions prepared by the manufacturer or an appropriate person for a non-standard refer to section 5 'Supplier obligations'. Best practice for instillation will typically include:

- a VFD fitted in a screened enclosure and equipped with DC bus HF bypass capacitors, properly earthed heat sinks, mounting facilities for screened cable 360 degree earth glands or saddles, a mains power port filter and power interface port filter or ferrites; and
- a screened power interface port cable comprising internal phase spaced between three earth cores and correctly terminated at the junction box and VFD.

[3] This annex relates to dairy sheds but has similar applicability to sites where other livestock such as goats and sheep are managed.

Installation acceptance

How an end user chooses to accept an instillation is their choice and it may vary depending on the circumstances. It could be appropriate for the end user to:

- ensure that the instillation is done in accordance with the manufacturer's instructions, that there has been consideration of this document and other relevant rules and procedures have been followed; and
- require a period of satisfactory operation to ensure that both the VFD and other equipment are functioning correctly for complex instillations.

Installation testing

The testing of VFD in and adjacent to dairy sheds should be based on the requirements of section 9 'Installation EMC testing' and Annex A Installation test practices. Particular requirements include:

- the verification of the installation practices of the installed VFD;
- the measurement of the new VFD power interface cable HF voltage drop levels;
- performance tests of the new VFD and adjacent equipment operating simultaneously;
- the measurement of cumulative HF touch voltages before the new VFD is installed; and
- measurement of touch voltages with the VFD standalone and during normal operation.

VFD power interface cable voltage drop tests

Minimisation of VFD power interface cable voltage drop is key to low touch voltage levels in dairy sheds. Annex A Installation test practices, identifies the purpose and method for completing these tests, and typically acceptable levels. Some installers and consultants have indicated that power interface cable HF voltage drop levels may need to be as low as 0.1 volts ptp.

Touch voltage test

Touch voltage measurements are made between any two surfaces a cow can contact simultaneously and require use of the Annex A Installation test practices HF oscilloscope method with a 470 ohm burden resistor[4]. The measurements should be made on steelwork, concrete and other surfaces at several locations representative of the cow shed and associated with:

- cow holding, feeding, milking and access areas;
- milk, water, feed, vacuum and effluent systems; and
- cow monitoring systems such as milk flow transducers and RFID readers.

In rotary sheds those locations should include cow bails adjacent to the cow platform entry and exit points and two other bails spaced equally around the platform.

[4] 470 ohm is a easily available and a suitable resistance. Other resistance values close to this will give similar results.

Touch voltage levels

Touch voltage measurements completed by experienced installers and consultants, using the Annex A Installation test practices oscilloscope method, have identified:

- touch voltage levels of 2.2 volts ptp between the fixed rump rail and mobile steelwork at several points on a 50 cow rotary platform with steel bail rails and rubber mats on a steel platform. The herd of about 400 cows indicated no abnormal behaviour during milking: and
- touch voltages of 0.6 to 0.8 volt ptp between the fixed rump rail and mobile steelwork at several points on a 60 cow rotary platform with steel bail rails and no rubber mats on a steel platform. The herd of about 500 to 600 cows indicated significant abnormal behaviour during milking. The VFD at this site was then modified by the addition of a mains power port filter and power interface port toroids. Touch voltages were reduced to a uniform 0.1 volt ptp and cow behaviour returned to normal.

Resolving touch voltage issues

When surface touch voltages exceed the level required, the installation can be adjusted by one or more of the following:

- replacing screened cable pigtail terminations with 360 degree gland or saddle terminations;
- adding toroids on the VFD power interface port and HF filters on the mains power port;
- remaking earth contacts to remove corrosion, paint and clean;
- replacing flimsy earth busses and connection bolts with more robust devices;
- adding tinned copper braided straps parallel to interface cables with high voltage drops;
- adding sliding copper straps, carbon brushes or similar to reduce the earth impedance between rotary platform metalwork and the fixed rump rail;
- screening motor isolation switches;
- screening power protection and other power cables entering the VFD and motor cases;
- relocating VFD to reduce power interface cable lengths to the motors; and
- applying the section 8 'Installation practices', 'General aspects', to switch mode power supplies, electric fence equipment, standby power supplies, refrigerator supplies, other PDS VFD, equipment controllers, Radio Frequency Identification (RFID) ear tag transmitters, radio, telecommunications and computer equipment, and other farm electrical equipment in and adjacent to the dairy shed or connected to the dairy shed mains point of supply.

Maintenance recommendations

Dairy shed VFD operation should be compliant with section 7 Operator obligations and use an EMC plan based on section 10 EMC site management. The EMC plan should include:

- periodic testing of stray currents in dairy sheds;
- regular checking of exposed earth, power, control and communications cables, and connections, to ensure to ensure a clean and contaminant free environment;
- the recording of electrical activities in and adjacent to the dairy shed - see Annex D Dairy Shed EMC Test Log – Sample for a suggested EMC Test Log.

Annex C Pump installation practices

General

Incorrectly installed PDS used with pumps (particularly pumps used in rural areas) have been identified as causing extensive EMI to AM broadcast services adjacent to overhead power lines on public roads.

EMC environment types

Pumps installed adjacent to domestic accommodation and dairy sheds should conform to 1st environment type EMC requirements. Those with dedicated point of supply transformers can conform to 2nd environment type provided EMI is not caused to radiocommunications services.

PDS installation best practices for deep bore pumps

Deep bore pumps often exceed 100 kW rating and comprise submerged motors and pumps installed in steel well casing and water risers. Motor to well head cables are normally individual unscreened phase and earth cores, and are installed within the well casing along with motor sensor cables.

Best practices for installing a VFD for a deep bore pump power include:

- a screened cable junction box mounted on, and bonded to, the well riser/casing flanges, and fitted for the interconnection of the motor power cores to the VFD power interface port cables and temperature and pressure sensor cables;
- a screened 3 phase power interface port cable with an internal earth core or alternatively three individually screened single phase cores and a separate earth core, where cores' sizes are equal to or greater than those of the motor to well head cores, and with screens terminated in 360 degree terminations in both the junction box and VFD;
- the VFD fitted in a screened enclosure and equipped with DC bus HF bypass capacitors, properly earthed heat sinks, screened 360 degree screened cable terminations mounts, a mains power port filter and power interface port filter or ferrites, i.e. as specified by the VFD manufacturer or installation instructions; and
- flow and pressure sensor cables (normally balanced single pair screened cables) where the pump pressure sensor is wired via the junction box and the flow sensor is wired directly to the control unit; and sensor cable screens are earthed in the control unit only.

PDS installation practices for surface mounted and submerged pond pumps

Surface mounted and submerged pond pumps can have a much lower power rating than deep bore pumps. Nevertheless care is required to mitigate EMI and stray current issues and the best practices for their installation are similar to those for deep well pumps. Differences can include a lack of need for the pump site junction box, i.e. the direct connection of the power interface port cable and sensor cables from the motor to the VFD and control unit.

Installation testing

PDS pump installation tests are identified in Annex A Installation test practices. As a minimum the tests should include:

- visually checking use of the correct installation practices
- ensuring the correct operation of the PDS and adjacent equipment;
- measurement of the power interface port cable earth voltage drop level. This level should not exceed circa 1 volt ptp in EMC 1st environment type locations or 10 volt ptp[5] in a EMC 2nd environment type location. Measurement requires use of the oscilloscope method noted in Annex A Installation test practices; and
- checks for EMI adjacent to the site and associated overhead power lines using a AM broadcast car or portable radio.

[5] Some transducer devices (flow meters) used with water pumps do not tolerate the levels above those suggested for 1st environment type lower levels.

Annex D Dairy Shed EMC Test Log – Sample

Below is a suggested EMC Log for a dairy shed that identifies EMC test results and outstanding issues. Individual schedules for surface touch voltages and test points can be attached on separate sheets and similar logs can be established for other locations with multiple VFD.

Dairy Shed EMC Log

Location: Smith's Farm, Muck Road   Description: Rotary shed B

New Equipment: Milk flow pump interface cable replacement

Installer/inspector Organisation: ____________________________ Date: ________

Existing Equipment	Test Conditions	Install Test		Exceptions & Actions Required
		Before	After	
		Satisfactory or Failed		
Telephone	In & out calls	s	s	
Cell phone	west entrance	s	s	
Security alarm	test alarm	s	s	
AM Radio	west entrance	issue	issue	No change
Personal computer	adj office	s	s	
Production monitor sys	normal	s	s	
Well water pump adj to road entrance **	Spraying	140 V	140V	Unsafe, 7m i/f cable. Install new screened cable/filter?
Pit pump**	wet test	0.3 V	0.3 V	
Milk vac pump**	on load	0.2 V	0.2 V	
Milk flow pump**	on load	3.1 V	0.1 V	New screened cable
Feed pump**	on load	2.2 V	2.2 V	Needs screened cable
Platform to fixed rump rail* & holding areas ground to rail* (see separate list for detail)	Set up	2.2 V	2.0 V	Cows still unsettled
	Milking	2.2 V	2.0 V	
DB 2 Harmonic THD	Milking	4.8%	8.1%	
cables/connectors	Attach list B	s	s	
Earth bonding	Attach list C	s	s	Replace earth strap bail 36

Enter Peak to Peak HF voltage drop across VDF earth to motor frame** or surface voltage difference*

Action Required: Installer to remedy outstanding items by next milking

EMC compliance with COP   Yes/No (circle one)

Signed: ________________ ________________ ______________

Installer/tester (signature) (Print name) Date

Agreed: ______________ ________________ _____________

Farmer (signature) (Print name) Date

Annex E Acronyms

AS/NZS3000	Australia/New Zealand Wiring Rules
EN 61800-3	Standard for Adjustable speed electrical power drive systems
AS/NZS 6869	Limits and methods of measurement of electromagnetic interference from overhead a.c. power systems in the frequency range 0.15 MHz to1000 MHz
AM	Amplitude Modulation, used with broadcast services in the band 521 to 1612 kHz)
BDM	Basic Drive Module of a PDS includes converter and protection
CDM	Complete Drive Module of a PDS: includes system control, converter, sequencing, protection, braking and power feed Cl. 1.2.3 (etc) Indicates EN 61800-3 clause reference
CISPR A	European standards setting group of the IEC dealing with interference to radio systems (Committee International Special Perturbations Radioelectriques, from French)
dV/dt	Rate of change of voltage over time
EMI	Electromagnetic Interference (IEC definition)
EMC	Electromagnetic Compatibility
ES	Energy Safety
ESR	Electricity (Safety) Regulations
IEC	International Electrotechnical Commission
IGBT	Insulated Gate Bipolar Transistors
HF	High frequency; for the purposes of this PIB means above 2.5 kHz. Hz, kHz, MHz, GHz Hertz, kilohertz, Megahertz, Gigahertz
Ministry	Ministry of Business, Innovation and Employment
MEN	Multiple Earthed Neutral
NZECP 36	New Zealand Electrical Code of Practice for Harmonic Levels
PDS	Power Drive Systems
PIB	Public Information Brochure
ptp	Peak To peak
PWM	Pulse Width Modulation
RFID	Radio Frequency Identification, a label method for identifying cows
RMS	Root Mean Square
RSM	Radio Spectrum Management
SCR	Silicon Controlled Rectifier

Annex F Definitions

Accrediting test laboratory test report: The report on tests completed by an accredited laboratory for the purposes of equipment compliance mark assignment.

Adjacent: In relation to testing the performance of adjacent equipment, "adjacent" can include equipment within 50 m of a PDS and at the boundary of the PDS site.

Correct practices: means installation or other practices that do suppress EMC issues.

Electromagnetic Compatibility (EMC): EMC is the branch of electrical, electronic and radio sciences that deals with the generation of unwanted electromagnetic fields (electromagnetic interference (EMI)) and the susceptibility or immunity of equipment to the effects of EMI. Both EMI and immunity have international standards.

EMC sensitive equipment: Means electrical equipment whose performance can be degraded by EMI or inducted currents, e.g. telephone, cellular, broadcast radio and TV, amateur and licensed radio, security, air conditioning controllers, garage door openers, other PDS, electronic control, telemetry, transducer, computer and similar electrical equipment.

Harmonics: Current or voltage components whose frequency is an integral number of the supply frequency.

Operator: The term "operator" includes the PDS operator, user, purchaser, owner and the owner's agent.

Power Drive Systems (PDS): PDS comprise a VFD, motor, load, filters, cables and control, see sketch 1 in section 3, Background. The VFD converts 50 Hz mains power, single or three phase, into electrical power in the form of pulse width modulated (PWM) voltage to drive electric motors, rams and similar equipment more efficiently and with increased control of motor speed and operation than can be obtained using normal 50 Hz power. VFDs use semiconductor switching components such as SCR (Silicon controller rectifiers) and IGBT (Insulated Gate Bipolar Transistors), and includes monitoring and control equipment, EMI filters, toroids and harmonic filters.

PDS categories (classes): EN 61800.3 identifies the following PFS categories:

- C1 for PDS of rated voltage less than 1000 V, intended for use in the 1st environment type
- C2 for PDS of rated voltage less than 1000 V, which is neither a plug-in device nor a movable device and, when used in a first environment, is intended to be installed and commissioned only by a professional, who has the necessary skills to install and/or commission PDS, including their EMC aspects
- C3 for PDS of rated voltage less than 1000v, intended for use in the second environment type but not intended for use the 1st environment type;
- C4 for PDS rated equal to or above 1000v, or of rated current equal to or above 400 A, or intended for use in complex systems in the 2nd environment type.

Poor practices: means installation practices that do not suppress HF EMC issues.

Section: Refers to a section of this document unless otherwise identified.