Techsys Corporation **APPLICATIONS BULLETIN**

ELECTROMAGNETIC COMPATIBILITY IN AC MOTOR CONTROLLERS

What is electromagnetic compatibility?

Electromagnetic compatibility, or **EMC**, is associated with any electronic equipment It is a measure of the equipment’s ability not to generate radio frequency interference (RFI) and also a measure of a its immunity to RFI produced by other equipment. This article discusses EMC as it relates to AC motor controllers (drives).

What causes RFI in a drive?

Most modern AC motor controllers have two stages of power conversion, as shown in Figure 1.

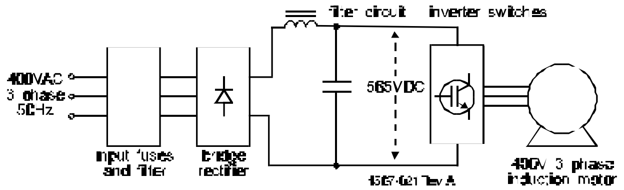

Figure 1: Block Diagram of AC Drive Power Conversion Stages

The rectifier stage consists of a bridge rectifier and filter, to generate an intermediate DC level by direct rectification of the incoming mains. This **DC bus** supplies the inverter stage, which is a three phase bridge made of six sets of power semiconductor switches. By operating the switches in a co-ordinated manner, the DC bus voltage is reconverted into three-phase AC, for connection to the motor.

The inverter stage in most modern drives uses IGBT power switching devices. The output voltage and frequency are controlled by using **pulse width modulation (PWM)** techniques at a high switching frequency (4 kHz and higher). The IGBTs have very fast turn-on and turn-off times, which minimize switching losses and provide high conversion efficiencies.

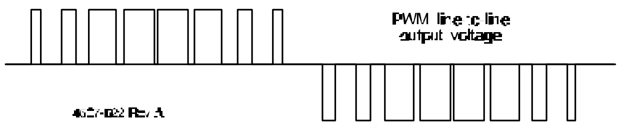

Figure 2: Output Voltage Waveform from AC Drive

A simplified illustration of the output voltage waveform is shown in Figure 2. Fourier analysis shows that such a voltage waveform consists of a fundamental frequency and a spectrum of harmonics, which will be at multiples of the switching frequency. The higher the harmonic frequency, the lower its magnitude. The fast switching rates of the IGBTs cause steep slew rates (rates of rise or fall of voltage) on this voltage waveform. This in conjunction with the high modulation frequency causes a rich spectrum of harmonics. The higher frequency harmonics - say greater than 100 kHz - can escape from the drive, couple into power and control cables, and cause interference and operational problems with other equipment.

How does RFI escape from a drive?

There are three ways in which RFI can escape from a drive and interfere with its “victim”. These are shown in Figure 3.

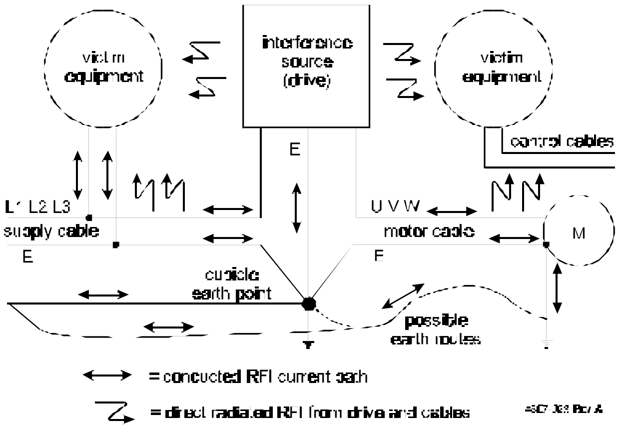

Figure 3: RFI Emission from a Drive

The RFI may be **radiated** from the drive. The RFI escapes as electromagnetic radiation. There need be no physical medium between the drive and the victim as radiation can occur through a vacuum. Radiated RFI is comparatively simple to suppress by cabinet screening techniques. The field strength of radiated RFI rapidly diminishes with increasing distance from the drive.

The RFI can also be **conducted** from the drive. This conduction can occur through **output power cables** to the motor, and through **incoming mains cables** to the drive. The RFI conducted into these cables can subsequently radiate into adjacent cables if adequate suppression measures are not taken. The output cables have a voltage waveform as shown in Figure 2. The RFI due to this waveform is difficult to prevent from entering the output cables, so these cables should be screened. The RFI on input cables is mainly generated by the inverter switches, and is conducted back along the DC bus , through the rectifier to the input cables. This input RFI can be made worse by the harmonic content of the input current waveform, which is due to the rectifier and filter design. This RFI can be suppressed relatively simply by the use of inductors.

How can RFI be suppressed?

RFI emission from a drive can be minimized by paying particular attention to the following points:

- **Drive design.** If the drive has been supplied with input filters, then the conducted RFI through incoming mains cables should be adequately suppressed. So install a drive with an RFI suppression scheme already fitted.
- **Earthing.** Effective earthing must be undertaken. Safety earthing is necessary to safely handle the fault currents in the event of an earth fault. However RFI suppression earthing requirements are different. The currents carried by such an earth are at high frequencies, thus cabling and layout must be suitable for high frequencies.
- **Screening.** Screening helps to suppress radiated RFI. The cabinet of the drive must be effectively made into a screen by proper bonding techniques between panels. Screening of the output cable to the motor is usually necessary. Proper screening of control cables is also required to prevent locally and externally produced RFI from upsetting the drive's control circuits.
- **Filtering.** Filters usually consist of series inductors (chokes) which provide a high impedance to RFI currents, and shunt capacitors to earth to provide a low impedance bypass path. Filters cause RFI to be conducted to ground and re-directed to the source. If filters are required extra to what are supplied with the drive, proprietary input and output units are available for fitting externally to the drive.

What RFI suppression measures can be supplied with a drive?

Refer to Figure 4. Input RFI suppression may be achieved in a number of ways. RFI chokes may be three low value inductors mounted in the input lines as shown, with bypass capacitors fitted to ground. Alternatively, DC bus chokes, normally fitted to all medium and high powered drives for input harmonic reduction, may be "split", with a choke of half the total inductance required in each pole of the DC bus. Alternatively no DC chokes may be used, but a high inductance line choke may be used in each of the three incoming phases.

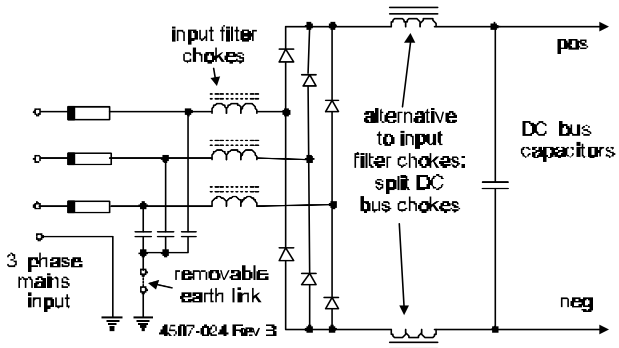

Figure 4: Input RFI Suppression Schemes in AC Drive

The input RFI suppression is most effective if the star point of the bypass capacitors is earthed. However the earth link may need removal if sensitive earth leakage detection equipment upstream of the drive is tripped by the capacitive currents flowing to earth.

What about screening?

The purpose of screening is to prevent any unwanted electromagnetic radiation entering or escaping from a system. The three main items needing screening are:

- **The drive.** Remember that the drive is the main source of interference. Normally a drive supplied in its cubicle should be well screened as supplied. However if a "baseplate" drive is mounted in a third party cabinet, then that cabinet will require proper screening precautions. These include bonding of all panels, with a low impedance at high frequencies. Paint may need to be removed to provide good conductive paths, and EMC gaskets may be needed.
- **The motor cable.** A screened cable to the motor is highly recommended, and is essential for cable lengths exceeding 1 metre. The recommended cable is three-core plus neutral screen, or steel wire armoured, with the screen earthed at both ends. This screen doubles as a safety earth. There should be no breaks in the screen between drive and motor.
- **The motor frame.** Normally the motor frame is a solid effective RFI screen, earthed to the drive via the screen on the motor cable.

The three screens - cabinet, cable screen and motor frame - must be bonded together to form one screen.

What about earthing?

In any cubicle, a single low impedance earth point should be established, to which circuits are earthed independently and to which the incoming earth is connected. However the earth return in the drive's motor cable should be connected to the drive's earth point, not to the cubicle busbar.

In general, the essential objectives of good earthing are:

- To ensure that high frequency earth current flows through defined paths only.
- To minimize the area enclosed by these paths.
- To ensure that no sensitive circuit shares a path with these earth currents.

Figure 5 shows a good earthing layout for a drive system. Note the following, with reference to the system:

1. Use screened motor cable, with the screen terminated at the drive earth and on the motor. Use a metal cable gland in the gland plate, and avoid forming the screen into a "pig tail" for earthing.
2. There is a single connection of the drive's earth to the cubicle earth busbar, with no other equipment sharing the drive's earth connection.
3. Ensure the motor frame is well earthed to the drive, via the cable screen. Failing this, the motor frame may itself become a source of RFI, coupling capacitively into the local metalwork and the earthing system.
4. No sensitive equipment is to be mounted within 300 mm of the drive and its input and output cables.
5. The "0V" connection on the control system is earthed, at one point only.

6. Note that an extra filter is shown on the input of the drive. If the drive is not supplied with adequate input filtering, this filter may be needed. Refer to the following section for recommendations for its installation.

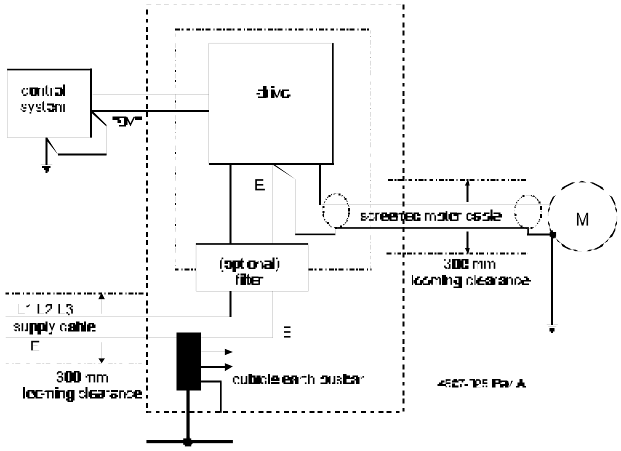

Figure 5: Earthing Layout for Drive System

Will I need extra filters?

Generally, if the drive has been supplied with input filters incorporated, extra filters will not be required.

However if radio frequency interference is causing problems despite all of the above recommendations being followed, and the RFI can be traced to the input of the drive, then an additional **input filter** may be required. It must be installed in accordance with the filter manufacturer's instructions. A summary of requirements is:

- The filter must be mounted on the same panel as the drive. It should be bonded to this panel, with paint being removed if necessary.
- The filter must be connected as close as possible to the drive input. Keep cables between drive and filter to less than 300 mm. If this is not possible, special flat cables with good high frequency characteristics must be used between drive and filter.
- Segregate all wiring from the (unfiltered) cables between the filter and the drive terminals. For example, do not combine the filter's input and output wires in the same loom.

An **output filter** between the drive and the motor may be needed for one or more of the following reasons:

- It is not possible to install screened cable. By reducing the voltage slew rate on the drive output, the level of RFI is reduced, although not eliminated.
- To reduce the effects of long cable runs. Circuit reactances associated with long cable runs can cause severe ringing (overshoot) in the motor voltage waveform. This in turn can stress the motor's insulation. Insertion of an output filter can reduce this overshoot, and also reduce the proportion of the drive's output current absorbed by the cable capacitance.

Installation recommendations for an output filter are the same as those for an input filter.

What about a drive's immunity to external radio frequency interference?

A well-designed drive should be insensitive to radiated RFI. The drive cabinet forms a screen which is the first line of defence, providing earthing recommendations are adhered to. Measures used in a drive's control circuits to provide RFI immunity include use of ground planes on PC boards, R-C or R-L filter networks on all low voltage inputs and outputs, and plenty of decoupling capacitors installed throughout the circuits.

However connections to the drive control terminals can provide ingress points for noise disturbances, so measures need to be taken to reduce this.

Control wiring screening is important to reduce noise pickup into control circuits. Most noise is induced by the control cable running through rapidly changing electric fields. To avoid capacitive pickup by this cable, use a screened cable, and earth the screen at one end only. Do not use the screen as a "0V" return.

Noise can also be induced by running the cable through rapidly changing magnetic fields. This can be countered by earthing the screen at both ends, however this does create other difficulties. Alternatively, run the control wires as balanced twisted pairs, so any induced noise is common-mode noise, which can be rejected by a well-designed input circuit.

Earthing the screen at both ends should be avoided. It can cause earth loops, i.e. low frequency circulating currents caused by small potential differences between earth points at each end of the cable. Also the screen may inadvertently carry fault currents which can cause destruction of the cable. So earth the screen at one end only, and ensure that the cable has an overall insulation sheath.

Earthing of the "0V" point needs careful consideration. Many drives provide the ability to "float" the "0V" point above ground by removal of a link. Often this point is already decoupled to earth via a suitably rated capacitor, so the point remains effectively grounded for RFI frequencies. For safety and noise suppression reasons the "0V" point should be earthed, but **at one point only.** This earth link should be removed if:

- The "0V" point is earthed elsewhere, e.g. in the external control system.
- Multiple drives are connected to the one control system. In this case, earth the "0V" at the control system or in one drive only.

The control system has another point earthed. For example, if a number of drives are operating with their reference inputs connected in series from the same 4-20mA control source, then appropriate links should be removed to avoid shorting out the reference inputs.

Routing of control cables must be done carefully. Avoid running control cables in parallel with power cables with a spacing less than 300 mm. For long runs (greater than 10 m), increase this spacing in proportion to the length of the run. Where control cables must cross power cables, this should be done as close as possible to right angles.