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TECHNICAL NEWS

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VSD INSTALLATION TECHNIQUES

1.0 INTRODUCTION

This is the second installment in a series of Technical News articles detailing design and installation considerations when using Variable Speed Drives (VSD's). In Part 1 of the VSD Technical News series (issue 47), we concentrated on common installation issues faced between the VSD and motor. We found that voltage and current transients, motor temperature rise and audible motor operating noise could all be rectified by the use of output chokes on the VSD.

In this issue, we will be looking at potential issues faced on the input or supply side of the VSD, what causes these issues and detailing simple and cost effective ways of dealing with them.

2.0 WHAT ARE THE POTENTIAL ISSUES?

First, let's have a look at two examples:

a) Imagine you are sitting in your lounge room after work one night watching the nightly news on your television. The carpenters working on your new outdoor entertainment area are finishing up for the day, but before they go the decking needs to be trimmed before the handrails can be installed. You hear the circular power saw start-up and the carpenters begin trimming the wooden decking ends. Glancing back at your television, you see 'snow' appear on the television screen with every start of the power saw. The 'snow' on the television screen disappears when the power saw stops.

b) At around the same time later in the week, you are back at home watching a corporate DVD presentation which you are going to present to your staff the next day at work. The builders have again been working on your outdoor decking using an arc welder to weld the posts and supports for the balustrading. They are just completing the final welds when suddenly your DVD player stops working, power is lost to the unit and you can smell ozone in the air. Taking the DVD player to an electrical repair shop, they tell you that electrical components in the power supply have failed.

FEATURES

PLEASE CIRCULATE TO:

Sound familiar? Both of these examples illustrate what can happen on a small scale when electrical interference occurs within a power distribution system. Let's now explore these two scenarios in more detail.

Electro Magnetic Interference (EMI) & Radio Frequency Interference (RFI):

In example a) above, we saw what happens when Electro Magnetic Interference (EMI) is transmitted from a device - in this case the electric power saw. EMI is caused when an external force such as an electric motor or electrical transformer varies the surrounding magnetic field of the electrical power installation which incidentally, distorts the normal 50 Hz mains power waveform.

In addition to EMI, Radio Frequency Interference (RFI) also contributes to electrical noise. RFI is often confused with EMI when in fact they have two distinct differences - EMI is a modification of the surrounding magnetic field whereas RFI is the superposition of another unwanted frequency signal over the fundamental mains power waveform. RFI usually emanates from wireless telephones, mobile phones, radios, television signals and sometimes from inside equipment itself.

The influence of EMI and RFI on electrical equipment, collectively referred to as 'noise', can cause major issues which can include (but are not limited to) electronic data corruption, computer processor crashes and ultimately complete breakdown of electrical devices of surrounding equipment. Incidentally, this noise has the ability to damage the electronic components of the VSD and hence affect the overall reliability of the VSD. In most cases, the electronic componentry within a VSD will actually generate noise interference.

Most countries of the world have specific regulations which relate to the amount of noise that a VSD installation or individual product can safely generate and withstand. These regulations are generally referred to as 'Electo Magnetic Compatibility' (EMC) and in Australia, are governed by the AS/NZS 61000 - Electro Magnetic Capability (EMC) series. These EMC standards provide guidelines designed to minimise noise from electrical or electronic equipment that can cause interference to individual pieces of equipment or entire electrical installations.

Harmonics:

In example b) given above, we saw what can happen to electrical devices when the power supply itself becomes polluted with a phenomenon called 'Harmonics'. Harmonics are primarily produced by the use of non-linear loads - such as transformers (i.e. using an arc welder), fluorescent lighting, AC/DC power supplies and VSD's.

A general definition of harmonics is 'a sinusoidal component of a periodic wave or quantity, having a frequency that is an integer multiple of the fundamental frequency'. When harmonics are present, they will occur in both voltage and current waveforms.

In Australia, the fundamental frequency of our alternating current (AC) electrical system is 50 Hz which means that fifty times a second, the voltage waveform starts at zero, increases to a maximum value, decreases to a maximum negative value and then returns to zero. The resulting waveform of this action is the trigometric function called a sine wave. Consequently, the polluted electrical currents (containing the harmonics) that appear on the electrical systems pure sine wave are odd integers of the fundamental frequency. These harmonics are then summed together with the fundamental waveform to give a resulting distorted sine wave - i.e. the 3rd harmonic is 3 x 50 Hz or 150 Hz, the 5th harmonic is 5 x 50 Hz or 250 Hz and so forth.

You may be wondering why only the odd integers make up the harmonic content in the electrical currents waveform. A simple explanation is that even-type integer harmonics are less common in symmetrical, AC-type electrical systems because they indicate an asymmetry (DC offset) in the voltage and current waveforms. In the real world of AC power, the even integer harmonics are very rare.

Theoretically, the resultant waveform (made up of the fundamental and harmonic content) is derived by a complex mathematical model known as the 'Fourier Series'. The analysis of this transform is too detailed to go into here; however the resulting wave of a pure sinusoid plus harmonic content of the nth order is given as the function:

$$f(x) \approx 2\left[\sin(x)+\frac{1}{n}\sin(x)+\ldots+\frac{1}{2n-1}\sin(x),\text{where} n \geq 1\right]$$

In figures 1 to 3, you can see visual representations of superimposing odd integer harmonics onto the fundamental waveform. The amplitudes of the various harmonics (in these examples the 3rd, & 7th harmonics) generally reduce as the order of the harmonics increase. However, this is not always the case as the type of load which is causing the harmonics in the first place dictates the amplitude of the harmonic.

Looking at figure 4, the summation of the three harmonic waveforms and the fundamental waveform produces the resulting distorted output waveform shown in blue. Even with only three harmonic frequencies added to the power system, the resulting output waveform is heavily distorted. In reality, there are generally detectable amplitudes of up to the 63rd harmonic within a 'dirty' power system hence further reducing the quality of the output voltage and current waveforms.

VSD's have the unfortunate ability to generate high levels of harmonics (mainly the 5th and 7th harmonics) into the power system due to their characteristic Pulse Width Modulation (PWM) operation which is controlled by the high frequency switching of the IGBT transistors.

The harmonic currents produced by the VSD travel along the surface of the conductors reducing the available cross-sectional area required for current flow and therefore effectively increase the resistance along the conductor. As the resistance has increased, this causes power dissipation within the conductor to increase which leads to failure of conductors or electrical components themselves.

The generation of harmonics by the VSD can cause a variety of issues in the motor and in other electrical equipment within an installation. Potential issues faced by the motor connected to the VSD include:

- excessive heating in the motor coils leading to premature failure,
- excessive motor operating noise; and
- damage to motor windings from increased motor vibration.

Issues faced by harmonics on other pieces of equipment include:

- increased temperature rise in transformer windings,
- necessity to derate transformer VA ratings due to increased current caused by the distorted output waveform,
- failure of capacitors as they will cause a resonant circuit (in response to the increased harmonic content) which in turn magnifies the harmonic current, leads to increased voltage and hence overheating and failure of the capacitors,

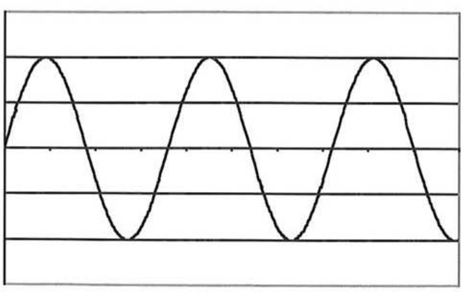

Figure 1 - Fundamental Frequency

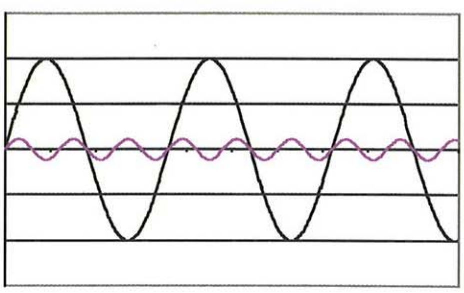

Figure 2 - 3rd Harmonic Added

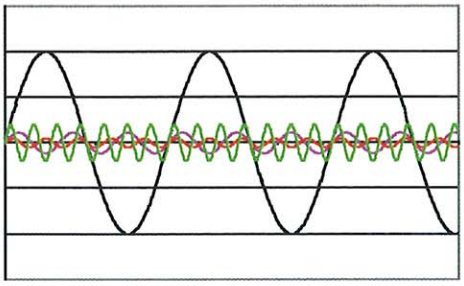

Figure 3 - 7th Harmonic Added

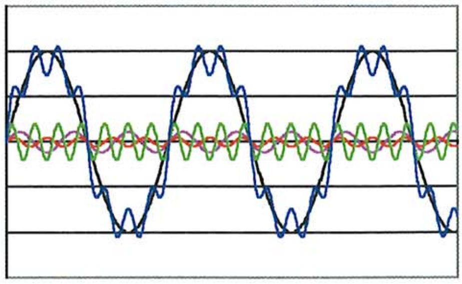

Figure 4 - Resulting Distorted Output Waveform

- Tendency for meters to under-read,
- Communication circuits being damaged through induction; and
- Failure of sensitive electronic equipment that relies on a sinusoidal waveform -e.g. Power supplies that use the supply voltage waveform for switching.

As described in the last section, the Australian Standards series AS/NZS 61000 - Electro Magnetic Capability (EMC), defines acceptable levels of harmonic content that can be generated by electrical equipment and is the reference point for many electricity distributors around Australia.

3.0 WHAT CAN I DO TO REDUCE THESE EFFECTS?

There are two simple ways to reduce or in some cases to completely remove the occurrences of noise and harmonics from the electrical power system as described above:

- install an EMC filter on the supply side of the VSD to restrict EMI/RFI or noise and
- install line reactors on the supply side of the VSD to remove unwanted harmonics

Let's now look at each solution in more detail - how they work, selecting the correct components and installation techniques.

EMC protection

EMC filters are low pass filters (LPF) which allow the transfer of mains frequency components (50 Hz) with very little attenuation. The filters work by reflecting unwanted frequencies back to their source by creating an impedance 'mismatch' or discontinuity by ensuring that the impedances of the load noise and the source noise differ from that of the filter hence reducing the effects of the unwanted noise.

The LPF are made up of numerous components - mainly inductors and capacitors. The capacitors oppose the AC flow of electrons at lower frequencies and less so at higher frequencies. Inductors on the other hand oppose the flow of AC electrons at higher frequencies and less so at lower frequencies. Each component within the filter will absorb a certain amount of power from the circuit and they have to be correctly rated to ensure efficient power dissipation.

The load and the source present to the EMC filter two different types of noise:

- Common Mode (CM) noise - Asymmetrical Interference and
- Differential Mode (DM) noise - Symmetrical Interference

CM noise appears on **all conductors** simultaneously with respect to a certain earth point. The voltages and current associated with CM noise are all in phase in the live and neutral conductors and returns via the earth. CM noise is the most common of noises in a power distribution network operating at high frequencies (≤ 1 MHz), has high impedance and is caused by stray capacitance, common impedances and coupled cabling.

CM noise can be reduced by the use of suitably sized capacitors and inductors (usually small wire wound toroids, commonly called 'chokes', where two coils share the same core). The capacitors must be type 'Y' and should have small values to limit the 50 Hz leakage current to ground. Typical values of 'Y' type capacitors for EMC filter design are approximately 4700 pF.

As described above, CM noise flows in-phase (or in the same direction) in the live and neutral conductors. When this noise enters a dual winding choke, magnetic flux is induced in the core of the toroid which results in the choke presenting high impedance to the CM signal and therefore passes through the choke highly attenuated. The actual attenuation of the CM signal depends upon the relative magnitudes of the choke impedance and the load impedance.

The above description for CM noise attenuation using a choke is for an 'ideal' case. In reality, this will never occur as a transformer (or choke) will never transfer all the electrical energy between primary and secondary windings, as the magnetic coupling will not always be equal. Any 'real' transformer or choke will have a small, but non-zero capacitance linking the primary and secondary windings.

In contrast, DM noise appears **between conductors** with current flowing in one direction through one conductor and returning via the other, hence the voltage and currents associated with DM noise are all out of phase. DM noise is the most common type of noise in a power distribution network operating at low frequencies (≤ 1 MHz), has low impedance and is caused by components that rapidly change the power current - i.e. VSD's.

DM noise can be reduced by using type 'X' capacitors which can typically have any value within the range 0.1 uF to 1.0 uF. Higher values are sometimes used depending on the interference frequencies being produced.

The use of chokes to reduce the effects of DM noise is practically non-existent due to the nature of how DM noise propagates through the electrical systems i.e. currents are equal in magnitude and travel in one direction through one core and returns via another. Therefore, the DM noise will flow in opposite directions through the choke windings and creates equal and opposite magnetic fields which cancel each other out. The result is the choke presents zero impedance to the differential mode signal, which passes through the choke unattended.

A typical circuit diagram for a single stage, single phase filter is shown in figure 5.

When installing EMC filters into existing installations, there are numerous techniques required for successful attenuation of circuit noise.

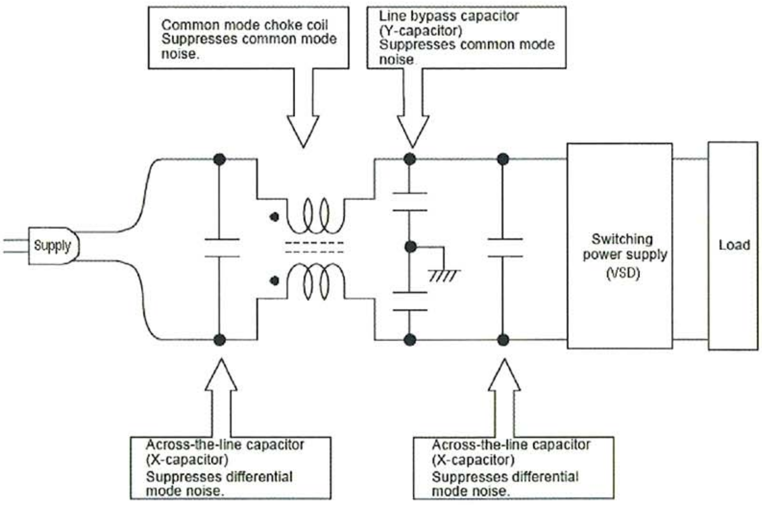

Figure 5 - Typical EMC Filter Design

The first installation technique which should be practiced is the physical location and routing of cables. The cable location and routing is the main source of noise and care should be taken to try and minimise these effects as much as possible. Noise will generally enter the cables through inductive and capacitive coupling. Inductive coupling occurs when a magnetic field caused by one current flow will cause a voltage to be induced in another circuit, causing an accidental transformer effect. Capacitive coupling occurs when an AC potential difference between two areas of the circuit cause current to flow due to stray capacitance in the cable. Both of these effects can be reduced by ensuring that mains power cable, control cable and signal cable are kept physically independent of each other and by utilising shielded cable for both control and signal transmissions.

All earthing points must be secure within the installation and be connected directly metal-to-metal at multiple points. If the filter itself cannot be connected directly to ground using direct connection (metal-to-metal) then a braided conductor should be used. The braided conductors have very low impedance at high frequencies and as they are wider than a typical cylindrical conductor, they also have a lower inductance.

It may be possible to economise by having a common filter covering several loads. This can save money and space within a distribution board. There can be several downfalls of doing this however. These include:

- Making it difficult to introduce extra components at a later date
- Ensuring rated currents of the filters are not exceeded by adding loads later on
- Connection cables must be screened as the cabling lengths will be longer between the filter and associated equipment

For these reasons and if possible, it is best practice to install individual filters on each separate load. Individual EMC filters should be installed as close as possible to the VSD and the main power supply cables should have the shortest possible length within the electrical installation before being connected to the EMC filter (see Figure 6).

The last installation point in regard to EMC filtering when used with VSD's, is the potential for leakage current to flow through the protective earth conductor to ground, creating a possible shock hazard should there not be adequate earthing installed. Leakage current is caused by the impedance produced by a parallel combination of capacitance between a voltage source and ground - in the case of an EMC filter, this capacitance is produced by the 'Y' class capacitors as shown in figure 5.

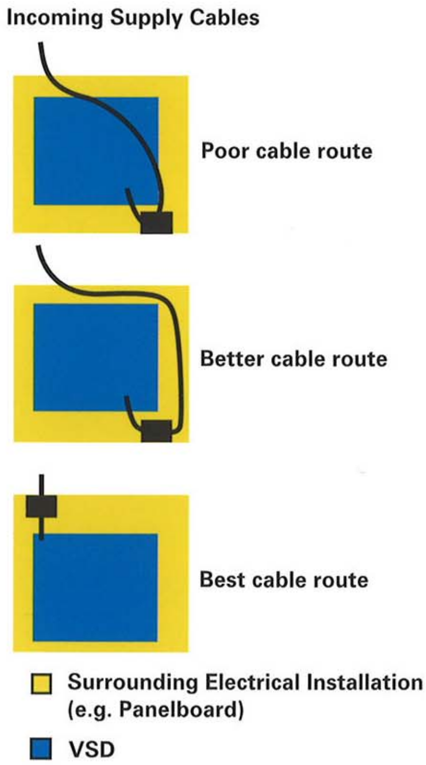

Figure 6 - Correct Cable Routing

Grounding systems are provided on most pieces of equipment to provide a suitable flow to earth in the event of an insulation failure. This resulting current flow will generally cause a circuit breaker or fuse to go open circuit removing the hazard. Should the grounding system become unstable (e.g. earth straps become loose, etc) then these leakage currents can create a potential shock hazard should someone touch the exposed conductive parts (i.e. the metal enclosure) of the EMC filter.

Harmonic protection:

Harmonic filters (otherwise known as line reactors) are devices which introduce an impedance to reduce the peak currents and voltages as well as RMS currents and voltages of the 50 Hz input waveform. In most cases, harmonic filters also improve the power factor of the system.

Looking from the supply into the VSD system, let's say that the electricity supplier switches power factor correction (PFC) capacitors into the grid which produce severe voltage spikes. The harmonic filter installed between the supply and VSD is able to virtually remove the effects of these voltage spikes and reduce the effects of nuisance tripping on the VSD circuit protection.

The harmonic filter can also reduce the severity of voltage drops which seems bizarre as adding a harmonic filter in the first place adds impedance, which therefore causes a voltage drop anyway. The reason for this is as follows: Due to the harmonic filters larger inductance, it opposes any rapid change in current. Most voltage drops are the result of current surges; hence by stabilizing the current waveform (using the harmonic filter) we can solve both undervoltage and overvoltage tripping situations.

Most importantly, looking from the VSD back into the supply, the line reactor can remove the effects of harmonics generated by the VSD and sending these signals back into the supply grid causing greater operating costs, increased temperatures and decreased equipment life. In addition to this, distortion can be filtered out by the harmonic filter which reduces EMI & RFI interference with other sensitive equipment.

In addition to the benefits discussed above, motor operating noise is reduced between 3 dB to 5 dB and greatly reduced motor operating temperatures, anywhere between 20 °C to 40 °C.

4.0 SUMMARY

In most circumstances, it is possible to combine in a single housing both the EMC filter circuitry and the harmonic filter hence saving valuable panelboard/switchboard space and minimising wiring.

In conjunction with output chokes as discussed in Part 1 of this Technical News series on VSD installations, the addition of EMC filters and harmonic filters as discussed above will ensure that the VSD installation operates at its maximum efficiency.

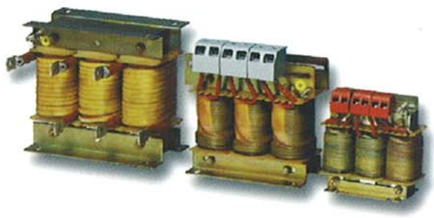

Figure 7 - Harmonic filters

In conclusion, the EMC filters will ensure that:

- electronic components within the VSD are not damaged
- electronic data corruption is reduced in surrounding equipment,
- computer processor crashes are reduced; and
- complete breakdown of electrical devices of surrounding equipment does not occur.

The harmonic filters will ensure that:

- heating in the motor's coils leading to premature failure is non-existent,
- motor operating noise is attenuated; and
- potential damage to motor windings from vibration is heavily reduced.

More importantly, the use of the EMC and harmonic filters will ensure that your VSD installation complies with all the necessary standards and regulations as described in the AS/NZS 61000 - Electro Magnetic Capability (EMC) series of standards.

In the third and final installment of Technical News' VSD Installation Techniques, we will look at considerations faced by an installer or end user of VSD's in regard to issues caused by the operation of the motor itself when driven by a VSD.

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