

Solution of EMI Problems from Operation of Variable-Frequency Drives

Background

Abrupt voltage transitions on the output terminals of a variable-frequency drive (VFD) are an inherent source of radiated and conducted Electromagnetic Interference (EMI). These voltage transition times are essentially determined by the rise and fall time of the semiconductor devices used in the inverter section of VFDs. The present tendency among drive manufacturers is to use Insulated-Gate-Bipolar-Transistor (IGBTs) devices which have a much lower power loss and higher switching speed than their predecessors Bipolar Junction Transistors (BJTs).

However, these improvements result in voltage transition times that can now be as fast as 100 ns and this high dv/dt produces higher magnitude of common-mode (CM) noise currents in the stray line-to-ground capacitance of motor and cables. These CM noise currents can cause electromagnetic interference and affect control signals, encoder feedback, communication links for programmable logic controllers, including RS-232, RS 485, Remote I/O, and different types of sensors including, ultrasonic sensors, bar code/vision systems, weight and temperature sensors. Conducted ground current also leads to radiated emissions, with the drive cables acting as antennas. AM radio reception, radio-controlled operator devices, and television are the most susceptible equipment to this radiated interference from VFDs. The purpose of this Tech Note is to explain the issues related to EMI problems associated with VFD operation, and to provide recommended guidelines for end-users toward mitigating EMI problems related to VFD operation.

Problem Description

EMI-related problems involve a source of noise, coupling of this noise by conduction or radiation, and circuits/equipment that are susceptible to this noise. The source of noise from VFD operation is the high dv/dt of pulse-width modulated (PWM) output voltage waveforms. As can be seen from Figure 1, the stray capacitance to ground of cables and motors results in high frequency ground currents, the magnitude of which is determined by the equation $I = C dv/dt$.

The high ground impedance at high frequency results in instantaneous voltage differences between two points reputed to be “ground potential.” This voltage appears as a common-mode noise voltage that can interfere with control signals and other communication devices. CM noise may also be capacitively coupled onto control signal cables that are in close proximity of unshielded VFD power leads. Conducted ground currents also lead to radiated interference, with the unshielded phase conductor, the stray capacitance, and the ground return path acting as a loop antenna. With the increasing use of VFDs in commercial and residential applications, the possibility of radio interference from VFDs is an issue

of concern for end-users. Sometimes this radio interference can affect other customers in the neighborhood of the VFD application.

The rise time of the VFD output waveform and the switching frequency of the inverter determine the frequency of the radiated and conducted noise. The switching frequency, which is typically in the range of 1 kHz to 16 kHz, determines the low-frequency conducted noise spectrum. The rise time of modern IGBT inverters can be in the range of 50 ns to 500 ns. This results in a noise frequency $fn = 0.318/T_{rise}$, respectively 6 MHz to 600 kHz.

Preventive Measures to Minimize EMI Problems

EMI problems can be minimized to a great degree by adopting preventive measures during the installation phase of VFDs. The most successful preventive measure is to use a shielded power cable to connect the VFD to the motor. This forces the noise current to flow through the shield back to the inverter, before it gets out into the system grid and takes multiple high frequency paths which are difficult to track down in an installation.

The use of shielded power cables also reduces the area of the loop antenna that is responsible for radiated interference. The shield should be connected to ground at both ends. It is important to ensure good electrical contact from the installation plate through the installation screws to the metal cabinet of the VFD. Cable clamps should be used instead of twisted shield ends (pigtailed, see Figure 2), since this ruins the shielding effect at high frequencies.

If a shielded cable is not used, avoid random lay of unshielded cables in cable troughs. Using 3-wire plus ground conductor (“green wire”) in a conduit ensures some degree of noise abatement as the conduit and the green wire carry most of the return current. However, accidental contact with grid ground structure due to strap supports, etc. is still a possibility. In contrast, with a shielded cable, this situation can be avoided by using a PVC outer coating.

In addition to the use of shielded power cable, the following noise reduction practices are usually employed for control signal wiring practice:

- Twist the leads to provide a balanced capacitive coupling
- Use shielded cable to return the noise current flowing in the shield back to the source, instead of through the signal leads
- Maintain at least 8-inch separation between control and power wires in open air, conduit or cable trays.
- Use a common-mode choke wound with multiple turns of both signal and shield.
- Use optical isolation modules for control signal communications

EMI Mitigating Devices

Common mode chokes (CMCs) and EMI filters are the two principal mitigating devices commonly used in VFD application for reducing EMI interference. A common-mode choke is an inductor with the three-phase conductors wound in the same direction through a common magnetic core, typically toroidal in shape (Figure 3). The CMC, when used on VFD output leads provides a high impedance to any line-to-ground capacitive noise current generated during the fast transition time of the output voltage waveform. The CMC does not affect the line-to-line power circuit and takes up less physical space, in contrast with an output line reactor. The phase-conductor inductance of a line reactor reduces motor phase voltage, lowering the available motor output torque.

EMI filters for VFD applications are typically structured as low-pass filters with series inductance and bypass capacitors connected in line-to-ground mode. These filters are usually installed on the input leads of the VFD. The line-to-ground by-pass capacitors in the filter provide a low impedance path for the CM noise currents (I_{cm} in Figure 3) to flow back to the VFD input out of the ground. The CM and phase inductors or the EMI filter provide high impedance to the high-frequency noise current. Drive-based equipment that must meet the European CE conformity must use an EMI/RFI filter connected to the drive input.

European Union Basic EMC Standard Applicable for VFDs

For new installations, end-users can require the VFD vendor to meet applicable European Union (EU) standards for drives in order to avoid potential EMI problems. These standards set the allowable emission limits for conducted and radiated disturbances. Table 1 presents a summary of these emission limits.

- Standard EN50081-1, *Electromagnetic Compatibility Generic Emission Standard - Part 1: Residential, Commercial and Light Industrial.*
- Standard EN50081-2, *Electromagnetic Compatibility Generic Emission Standard - Part 2: Industry.*

Table 1 – Conducted and Radiated Disturbances Limits

Frequency Range	Conducted Emissions 50 kHz - 30 MHz	
	Residential, Commercial, and Light Industry EN 50081-1 and CISPR 22, Class B	Industry EN 50081-2 and CISPR 11, Class A
150 - 500 kHz	56-46 dB μ V (Average) 66-56 dB μ V (Quasi-Peak)	66 dB μ V (Average) 79 dB μ V (Quasi-Peak)
0.5 - 5 MHz	46 dB μ V (Average) 56 dB μ V (Quasi-Peak)	60 dB μ V (Average) 73 dB μ V (Quasi-Peak)
5 MHz - 30 MHz	50 dB μ V (Average) 60 dB μ V (Quasi-Peak)	60 dB μ V (Average) 73 dB μ V (Quasi-Peak)

Frequency Range	Radiated Emissions 30 MHz - 1 GHz	
	30 dB μ V/m @ 10m	30 dB μ V/m @ 10m
30 - 230 MHz	30 dB μ V/m @ 10m	30 dB μ V/m @ 10m
230 MHz - 1 GHz	37 dB μ V/m @ 10m	37 dB μ V/m @ 10m

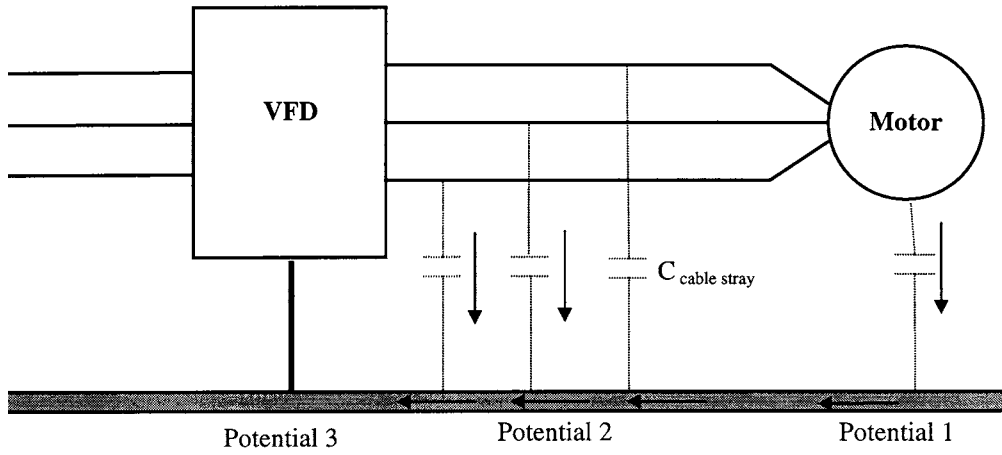


Figure 1 - Capacitive Coupled Noise Current from Unshielded Phase Conductor of VFD

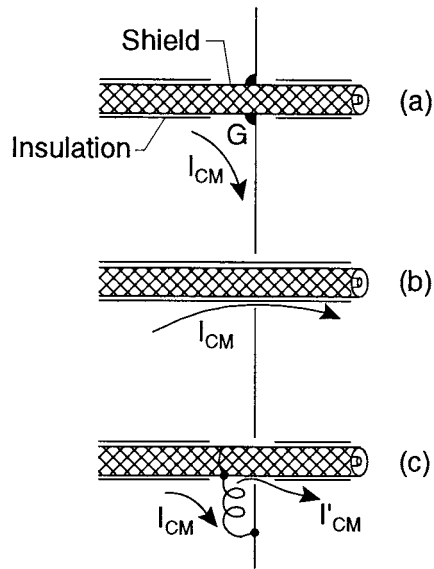


Figure 2 – Cable shield bonding: Incorrect (a) and (b) – Correct (c)

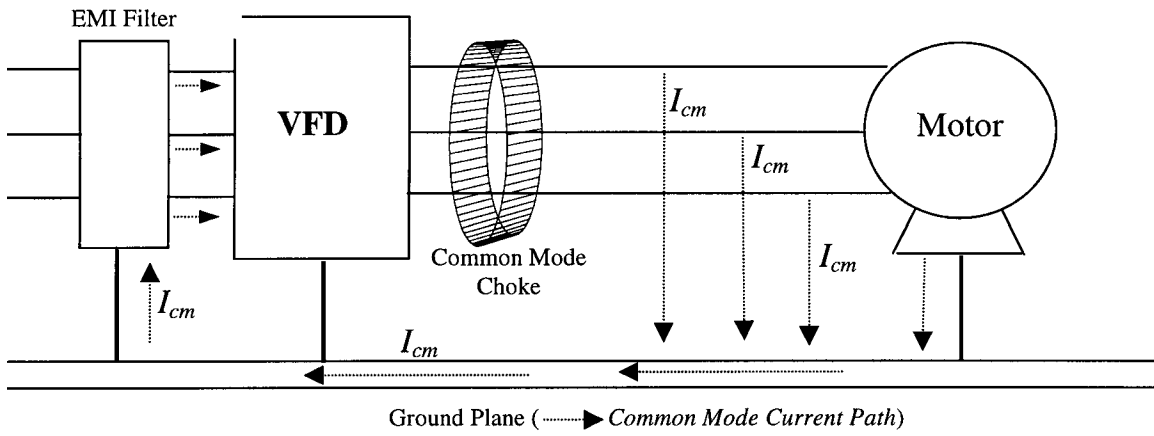


Figure 3 – Mitigating common mode effects by impeding flow of common mode currents with a Common Mode Choke or by providing low-impedance path with an EMI Filter.