Power Quality

Application Guide – Adjustable Speed Drive

Introduction

Advances in technology deserve much of the credit for the new forward-looking approach of the mainstream adjustable speed drive (ASD) suppliers. The once firmly entrenched analog AC and DC drives have almost entirely been replaced by second- and third-generation digital drives. Incorporation of incremental features and functions in microprocessor-based drives will continue as suppliers attempt to further exploit the potential of technology. This situation is increasing the number of new ASD configurations hitting the market, which are boosting the price/performance of drives. Although the fast pace of both AC and DC drive technologies makes it difficult to stay abreast, it is becoming increasingly important to consider the many alternatives in order to maximize business investments. Choosing the wrong drive technology, or ignoring evaluation of the drive's interaction with the electric service source, the motor-driven process, and other facility loads, can cost companies millions of dollars in losses.

What is a ***power quality (PQ) problem****? It is any deviation of electricity applied to the equipment that results in damage or misoperation of electronic equipment or other electrical devices. Some common symptoms of power quality problems in ASD/motor-driven systems in facilities are:

- ASD frequently trips or shuts down
- motor operated by ASD requires frequent repairs or replacements
- erratic control of process parameters
- unexplained fuse blowing and/or component failures
- misoperation or damage to other electronic equipment

ASD power quality problems can be complicated, involving the facility wiring, natural phenomena such as lightning, interacting facility equipment, and equipment connections to the electric power system. ASDs are typically designed to operate with flawless electricity from the electric utility; however, many things interfere with electricity as it travels from the utility to the ASD/motor-driven system.

This brochure was created to provide commercial/ industrial facility personnel with a straightforward guide for the specification, purchase, installation and operation of power electronic-based ASDs to minimize power quality-related operating problems. When used properly, it can help you avoid the costs of such problems, as well as ensure the safety and reliability of your electronic-based production equipment. The guidelines given in this brochure will aid you in evaluating potential power quality problems in an existing facility. This brochure does not provide information necessary to design and install an electrical wiring system, nor does it describe all specialty devices, mechanical protection and special requirements for

* Words and phrases in italics are included in the glossary.

ASD/motor-driven processes and other control systems. For these you should consult a company with qualified engineering services in electrical, mechanical and process control disciplines, and an electrician having training, experience and knowledge of the Canadian Electrical Code, as well as an understanding of the importance of following accepted proper wiring practices as they relate to electric power quality.

Power quality problems

At the time you connect any electronic equipment, or ASD/motor system, into an electrical service supply, it becomes part of the electric power system – a network of wires and equipment. By plugging in electrically operated facility equipment, you are not only accessing electricity but also connecting your commercial/ industrial machinery to other electronic equipment, other buildings, and even BC Hydro's distribution system. This is why power quality problems can be so complex.

Types of ASDs

In the past, conventional process flow control for liquids and gases utilized valves, vanes, dampers or registers. In these systems the pumps, compressors or fans were driven with constant speed electric motors, engines or turbines, and flow control was accomplished by modulating the inlet or outlet devices. While the concept of motor speed control has been around for over 100 years, in recent decades it has been brought to practical, reliable, commercialized products by advances in power electronics technology and components. There now exist a number of AC and DC motor types found in commercial and industrial applications that include: squirrel cage induction, wound-rotor induction, and synchronous and direct current motors. All of these motors are today being used with power electronic control topologies.

Following are brief summaries of the operating principles for today's three most common adjustable speed drives employed in low-voltage (750 VAC or less) applications up to 1,000 horse-power, with motor speeds between 1,200 and 3,600 RPM. Figure 1 illustrates the basic principles of the pulse-width modulated (PWM) voltage source inverter (VSI) drive, which represents over 95% of today's AC drive applications. The rectifier converts input line power, which has a fixed voltage and frequency, to fixed-voltage DC power. The fixed-voltage DC power is then filtered to reduce the ripple voltage passed through the rectifier from the AC line. The inverter then changes the fixed-voltage DC power to AC output power with adjustable voltage and frequency. The output waveform consists of a series of rectangular pulses with a fixed height and adjustable width. The overall pattern of positive versus negative pulses is adjusted to control the output frequency. The width of individual pulses is modulated so that the effective voltage is regulated in proportion to the frequency.

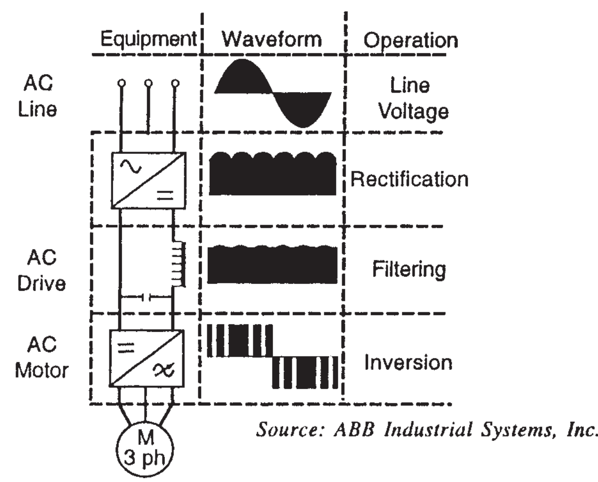

Figure 1. Typical adjustable frequency PWM-VSI AC drive

Figure 2 (next page) illustrates the basic principles of DC drives. The converter is a three-phase controlled rectifier that converts fixed-voltage input line power to adjustable-voltage DC power. This is the most common converter configuration, called a six-pulse converter. Regulating the armature current controls the torque developed by the motor. Motor speed is regulated by controlling the armature voltage. A small DC power supply provides a fixed or regulated current for motor field excitation.

In the DC motor, current flows through brushes and a commutator to the armature windings in the motor's rotor. Field excitation current flows through windings in the motor's stator. The commutator in the DC motor allows the magnetic field in the motor's armature to remain stationary while the armature rotates.

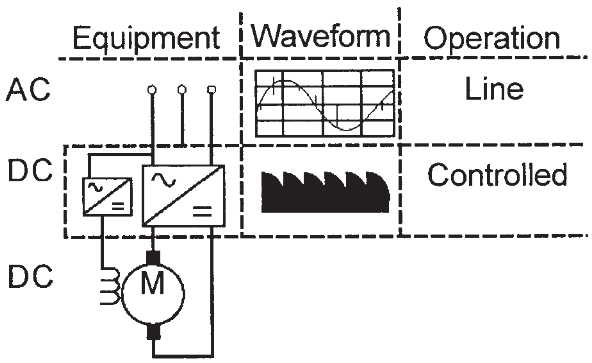

Figure 2. Typical 6-pulse non-regenerative DC drive

Figure 3 shows the basic principles of current source inverter (CSI) AC drives. The converter is a three-phase controlled rectifier that converts fixed-voltage input line power to adjustable DC power (this input converter configuration is similar to the DC drive input converter). The DC power circuit is primarily made up of a DC inductor that smooths the DC current supplied to the output inverter. The inverter section usually has six power switching devices that are switched on and off in a predetermined sequence to produce the three-phase current waveform for the motor circuit. Like the PWM-VSI drive, the distorted current wave contains harmonics that are usually not detrimental when the inverter and motor are correctly applied. The motor voltage wave, however, contains voltage spikes caused by operation of the inverter switching devices.

To change the frequency to the motor, the conducting time of the inverter switching devices is either increased or decreased, which results in a cycle time that is either longer or shorter. Depending on the motor load requirements, the DC voltage is changed accordingly, to maintain the constant volts-per-hertz ratio to the motor as the output frequency is varied.

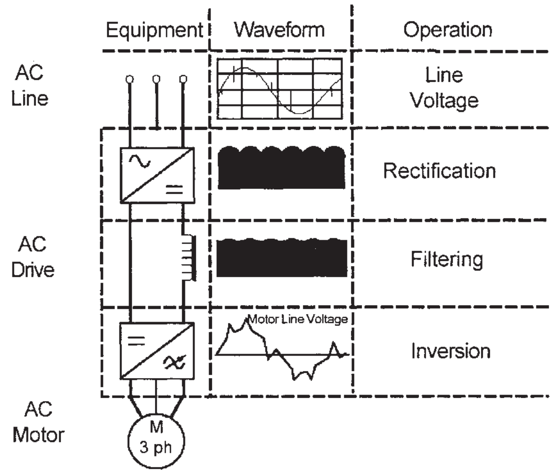

Figure 3. Typical adjustable frequency CSI AC drive

While beyond the scope of this brochure, it is noteworthy to mention that the other ASD/motor types that may be encountered in applications greater than 600 VAC and up to 60,000 horsepower are load commutated inverter (LCI), cycloconverters and slip recovery drives using the wound rotor motor.

How ASDs cause PQ problems

When properly rated, installed, operated and maintained, an ASD will provide a lifetime of service. Assuming the applications engineer has specified an ASD/motor combination compatible with the mechanical-driven process, installing the ASD in accordance with the manufacturer's installation instructions is important to achieve proper performance and normal operating life.

Physical installation – ASD manufacturers go through extensive measures to document each step to be followed for the physical installation of their equipment. They recognize that the performance of the ASD/motor system is highly influenced by the electrical environment and whether the required installation procedures have been implemented. Occasionally ASD users can cause operating problems by not protecting the unit from direct sunlight, rain or moisture, corrosive gases or liquids, vibration, and airborne dust or metallic particles. As well, free-standing ASD enclosures need to be installed with enough clearance for opening panels or doors, and to ensure sufficient air space for cooling.

Electrical installation – All basic wiring interconnection recommendations for the main power circuits are stated in the ASD manufacturer's installation manual, with suggested wire sizing relevant to the ASD's terminal functions and voltages. General caution statements are included such as:

(✔) ASDs are designed for use with conventional three-phase supplies that are symmetrical with respect to earth. Surge suppression devices are included to protect the drive from lightning-induced overvoltages between lines and earth. For this reason, the drive must not be used directly with supplies where one phase is grounded, i.e., the voltage between the other phases and ground is equal to the line voltage (the arrangement sometimes referred to as "grounded delta" in the U.S.A.). In such cases, an isolation transformer must be used to provide a supply balanced with respect to earth.

(✔) Use 600 VAC vinyl-sheathed wire, or equivalent, for input power and output motor connections. Wire size should be determined considering voltage drop of leads.

(✔) Never run ASD input and output wiring in the same conduit.

(✔) Never connect AC main power to the ASD's output terminals.

(✔) Never allow wire leads to contact the ASD enclosure (short circuit may result).

(✔) Never connect power factor correction capacitors or noise filters to the ASD's output.

(✔) In some instances, the cable to the motor carries rapidly switched voltages and should be routed well away from sensitive equipment. Screened, shielded or armoured cable may be used to contain emissions from the motor cables. The screen or armour should be connected in the same way as for standard cable, that is, to both the motor ground terminal and the ASD earth terminal. The ground core of the motor cable should be connected directly to the ASD earth terminal. It should not be connected to the ASD indirectly, for example, through a cubicle-earth busbar; this will cause high-frequency current to circulate in the earth system of the cubicle. At the motor end, the earth core should be connected to the motor ground terminal in the normal manner.

(✔) Mount all power option devices, i.e., input isolation transformer, input reactors, input filters or output reactors, close to the drive, and keep electrical connections as short as possible.

(✔) For control and signal circuit leads, use twisted shielded or twisted-pair shielded wire with the standard AWG size recommended by the ASD manufacturer. Run in a separate conduit. When using shielded wire, the shield sheath *must* be connected at the ASD terminal designated for this connection. The other end of the shield sheath should be dressed neatly and left unconnected. See Figure 4.

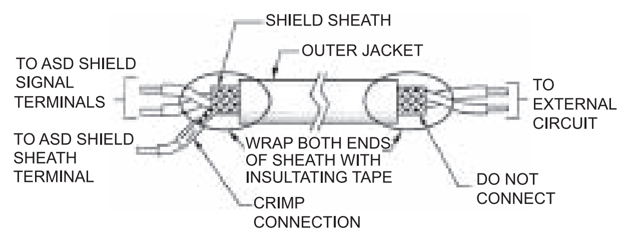

Figure 4. Control and signal circuit leads and shield sheath terminations

Before starting up the ASD, inspect the mechanical and electrical installation for compliance with the ASD manufacturer's installation guidelines, and with the prevailing electrical regulations and codes. As a minimum, inspect and verify the following:

(✔) Grounding of the ASD and the motor

(✔) Electric supply and motor wires (selection of wire size, routed in separate conduits, shielding, connections, etc.)

(✔) Control and signal cables (connections, wire shields grounding, separate conduit, location as far as possible from the ASD electric supply wires and motor cables)

(✔) Quantity and quality of cooling air for the ASD

(✔) Confirm it is safe to run the motor

After completing the ASD/motor installation inspection, the ASD manufacturer's start-up data parameters and procedures need to be initiated (this will vary from manufacturer to manufacturer and is best accomplished by utilizing the installation and start-up manual for the specific ASD). Parameters are the means by which the operating characteristics of the ASD/motor system are controlled and monitored. Operating parameters have a real-value range and take the place of variable potentiometer settings. The response of the ASD and the motor depends fundamentally on the set-up of the ASD parameters. With many ASDs, these values are accessible through a control panel keypad, and additionally by signals through the serial communications link from a host computer, a terminal, a programmable logic controller or other communicating device.

It is obvious from the previous discussion that the keys to a successful ASD/motor installation are: (1) having a properly rated ASD/motor matched to the type of mechanical process load being controlled, (2) following all of the equipment supplier's physical and electrical installation recommendations and (3) implementing the ASD's set-up parameters for the intended application. Accomplishing these steps will contribute to an installation that works reliably.

Assuming you have followed the above steps, the ASD may still cause operating problems that may have been overlooked and are related to power quality events. Based on the three most common types of ASDs, the following sections discuss power quality-initiated ASD operating problems for each type of ASD, with suggested solutions.

Measuring ASD PQ problems

Electronic-based ASDs, when functioning as intended, can increase productivity and through-put. However, ASDs can become plagued with performance issues and subjected to power variations that ultimately affect overall industry's production and profitability. One major issue that exacerbates ASD power quality performance is that each of the over fifty manufacturers who supply electronic ASDs uses different internal circuitry and control schemes for the same horsepower ratings. Different ASDs from different ASD manufacturers usually have different power quality immunity and emissions characteristics. These critical ASD application issues frequently confuse prospective ASD users when developing procurement specifications. Therefore, there is a growing need to ensure compatibility between the ASD equipment, the end-user's operating mechanical process system and BC Hydro's service power quality envelope. The following figures are simple representative graphics using measurement devices to illustrate the most common power quality problems that can be analyzed at selected points in the ASD system of interest.

ASD response to switching voltage transients

PWM-VSI AC drives – Since the DC capacitor in PWM-VSI drives is connected alternately across each of the three phases, drives of this type can be extremely sensitive to overvoltages on the AC service supply side. One event of particular concern is capacitor switching on the utility system. Utility voltage switching transients result in a surge of current into the DC-link capacitor at a relatively low frequency (300 to 800 Hz). This current surge charges the DC-link capacitor, causing an overvoltage to occur (through Ohm's law).

Figure 5 (next page) illustrates voltage and current waveforms during a capacitor switching event. The most effective (and inexpensive) way to eliminate nuisance tripping of small PWM-VSI drives is to isolate them from the power system with series inductors (chokes). With a concomitant voltage drop across the inductor, the series inductance of the choke(s) reduces the current surge into the ASD, thereby limiting the DC overvoltage. Determining the precise inductor size for a particular application requires a detailed transient simulation that takes into account utility capacitor size, transformer rating, etc. Chokes for PWM-VSI applications are commercially available, and an impedance of 3% (based on ASD horsepower rating) is usually sufficient to avoid nuisance tripping due to capacitor switching operations. Standard isolation transformers serve the same purpose.

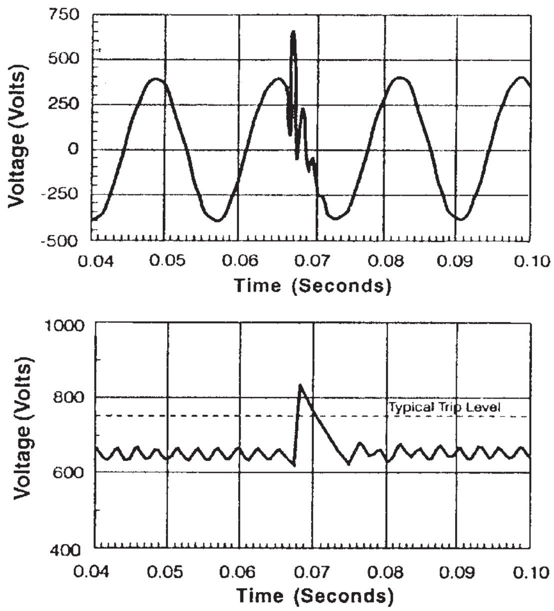

Figure 5. Typical PWM-VSI AC drive example low-voltage AC bus and resultant DC bus voltage during capacitor switching event

DC drives and CSI AC drives – Figure 6 shows the switching responses for these two drive technologies for an input line-to-line transient

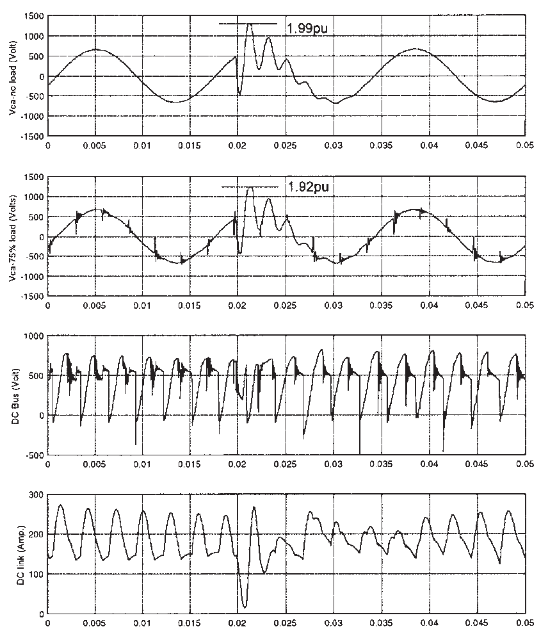

Figure 6. Typical CD drive or CSI AC drive low-voltage AC bus and DC link voltage/current during capacitor switching event

event. These ASDs have similar input silicon controlled rectifier (SCR) circuits, and Figure 6 displays the voltage transient magnitude at 1.99 per unit (with the ASDs at no-load) and 1.92 per unit (with the ASDs supplying 75% load). The ASD's DC bus voltage and DC current are also displayed in Figure 6, and in this case it is clear that the DC bus voltage and current do not rise enough to exceed these drives' protection shutdown limits.

ASD response to voltage sags

Typically, voltage sag is a momentary (i.e., 0.5 to 30 cycles) decrease in the ***RMS*** voltage magnitude, usually caused by a remote fault somewhere on the power system. Voltage sags are the most important power quality problems facing many commercial and industrial customers. Figure 7 shows the response of one brand of PWM-VSI drive that was able to ride through a 50% Phase A to neutral voltage sag for 15 cycles while maintaining motor speed (see reference 2 at end). Notice how this particular ASD's DC bus voltage dropped only 13% (i.e., 660 VDC to 575 VDC) during the voltage sag event.

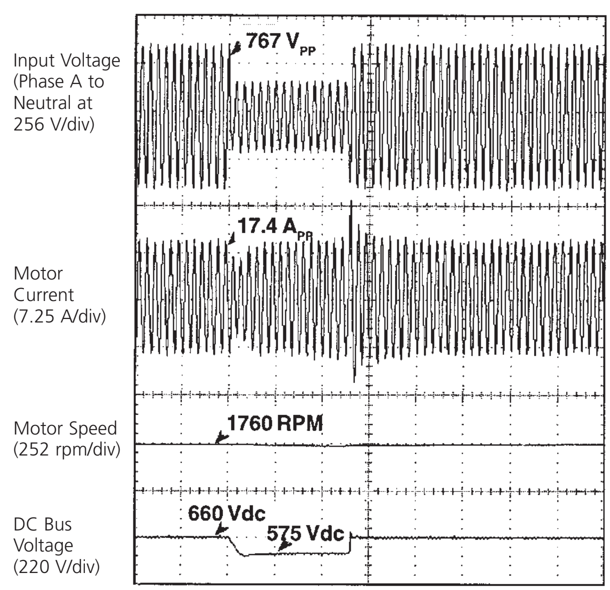

Figure 7. A PWM-VSI AC drive with high-voltage sag ride-through capability

Figure 8 depicts the response of another brand of PWM-VSI drive that "trips" as a result of the same 50% Phase A to neutral voltage sag for the 15-cycle event shown in Figure 7. As a result of the drive tripping, the motor current falls to zero and the motor speed begins to gradually decrease. This is the type of ASD response that will stop a process – no matter what the torque-speed profile of the load – and will result in the drive requiring a manual restart. This is the most common response exhibited by drives used in industrial processes (see reference 3 and 4 at end). Clearly, this explains why drives affected by voltage sags are one of the most important power quality problems experienced by industrial customers.

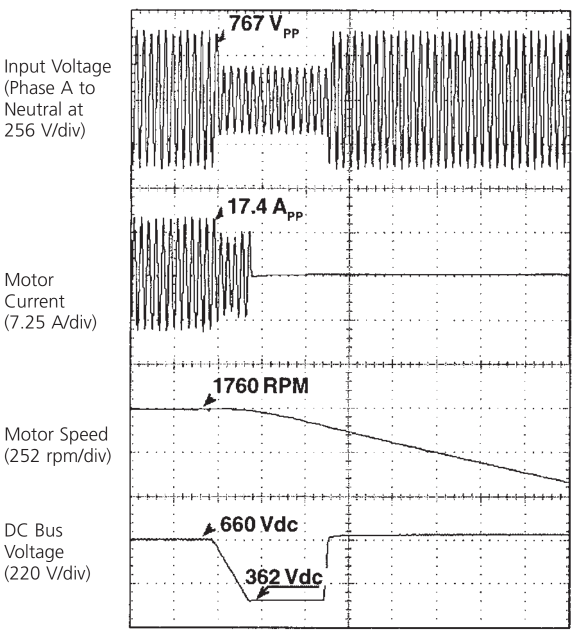

Figure 8. A PWM-VSI AC drive with low-voltage sag ride-through capacity

ASD input line current harmonics

The table below shows the input line current total harmonic distortion (THD) of one PWM-VSI ASD model for two different electric service source strengths. The data shown confirms the significance of source strength on harmonic current emissions, i.e., "soft source" with I_{THD} at 66.9% and "stiff source" with I_{THD} at 127.8%. If the source strength is not specified, then the level of harmonic current injection can vary for the same manufacturer's equipment. In general, the harmonic issues related to ASDs are more of a site-specific problem. IEEE-519 (1992), *Recommended Practice and Requirements for Harmonic Control in Electrical Power Systems*, has raised the awareness of harmonic issues among end-users and manufacturers. System integrators, consultants and end-users need to evaluate the potential impact of harmonics on facility equipment performance.

Figure 9 (on page 8) illustrates the variations in ASD input current waveshapes and harmonic current spectra for the three most common drive configurations. Notice the difference in I_{THD} percentage for the two PWM-VSI drives, i.e., with 3% AC line reactance at I_{THD} of 48.2%, and without 3% AC line reactance at I_{THD} of 126%.

Source Strength	V-THD avg %	IA – THD %	IB – THD %	IC – THD %	ITHD avg %
Soft Source	4.7	72.1	62.5	66.1	66.9
Stiff Source	2.3	128.1	128.8	127.8	127.8

ASD input line voltage distortion

Generally, with PWM-VSI drives, electric service voltage distortion levels can be met by following the guidelines established in IEEE 519. But with CSI AC drives and large DC drives that utilize SCR controlled input rectifiers, interference with other electronic loads connected to the same distribution service can occur. The cause of the problem is voltage notching created by the way CSI and DC drives operate. The voltage notches can create multiple zero crossings, which can interfere with equipment controls that utilize zero cross timing circuits, e.g., clocks, phase-angle control welders, and other less sophisticated drives. The repetitive overshoots can shorten the life of surge protection devices such as MOVs. Figure 10 (next page) is an oscilloscope snapshot taken of the input AC supply voltage notching created by a typical DC drive or CSI AC drive system under light-load conditions.

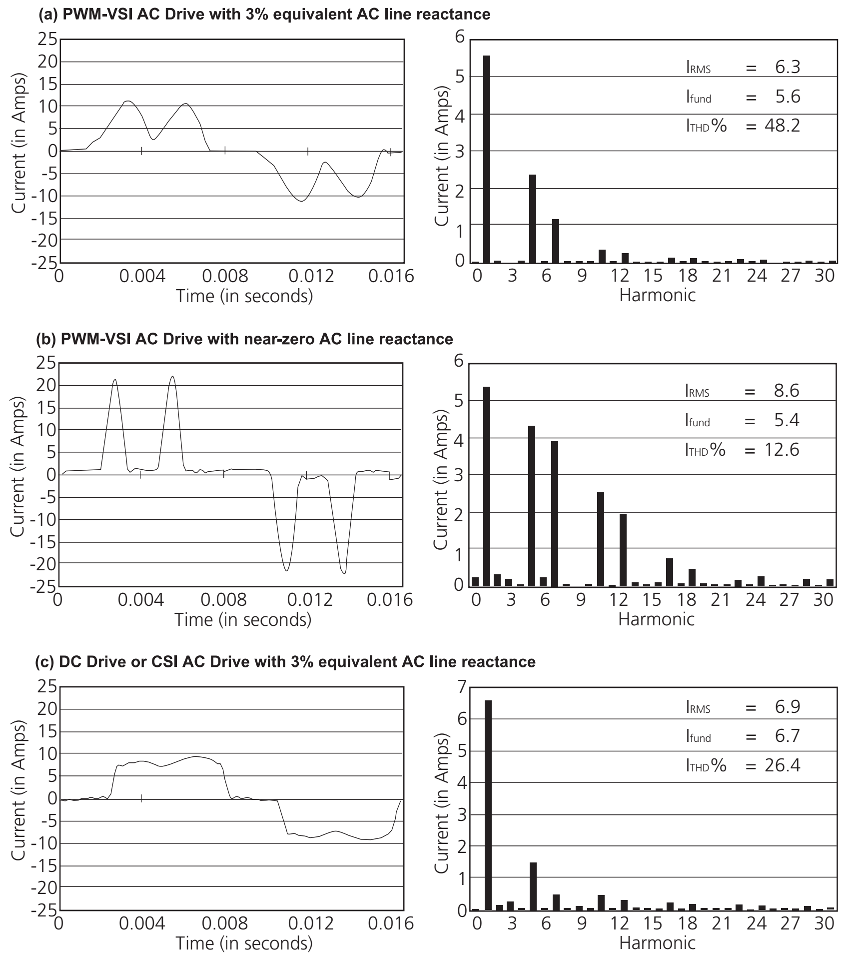

Figure 9. Typical input current waveshapes and harmonic spectra for the three most common drive configurations

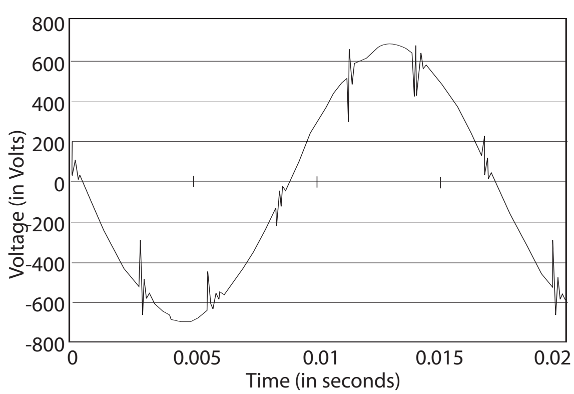

Figure 10. Typical input AC supply voltage notching of DC and CSI drives

ASD responses to steady-state voltage unbalances

Steady-state voltage unbalance has a dramatic effect on current unbalance and harmonics of PWM-VSI ASDs. Research to determine the power quality characteristics of ASDs demonstrates that, given a small voltage unbalance, the input current unbalance of the ASD can be high. Generally, findings indicate that as the electric service supply voltage unbalance increased, the ASD input current unbalance increased from a nominal 10% to 50%, depending on the ASD's internal reactance and the electric service impedance. Moreover, the third harmonic component of the line current, which is an uncharacteristic harmonic of these drives, increased greatly. Figure 11 depicts a typical ASD input phase-current waveform during virtually balanced and two unbalanced phase-voltage conditions.

High current unbalance can trip overload protection and shut down critical processes. Many motor control centres are designed to trip for a current unbalance of only 5%. Also, the generation of different levels of harmonic components in each phase with the presence of triplen harmonics makes it difficult to design tuned harmonic traps for ASD-generated harmonics. Applications of AC line reactors or DC link reactors can mitigate the adverse effects of phase-voltage unbalance on ASDs.

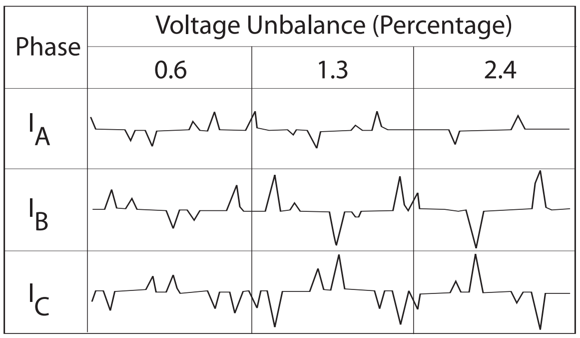

Figure 11. Typical PWM-VSI ASD phase-current waveforms during virtually balanced and two unbalanced phase-voltage conditions

Mitigating the effect of long motor leads on motors powered by PWM-VSI ASDs

Advances in semiconductor devices have made ASDs more affordable and thus more prevalent in industrial processes. To drive small- and medium-sized induction motors, most ASDs use PWM inverters with switching frequencies from 2 kHz to 20 kHz. As shown in Figure 12, the waveform of the inverter output voltage is composed of step-like functions, which are, in effect, voltage pulses with extremely quick changes in voltage magnitude (as fast as from 0 to 600 volts in 0.1 second). In many industrial applications, an ASD and the motor it drives are separated by tens or even hundreds of feet, which requires long cables, called motor leads, to connect the two together. Fast-changing PWM voltage pulses can interact with the distributed inductance and capacitance of the motor leads, which can result in an amplified peak voltage as high as 1,600 volts at the motor terminals. This phenomenon, known as the long-lead effect, can stress and, consequently, degrade the insulation around the stator windings of the motor. The magnitude of peak voltage at the motor terminals depends upon the characteristics of the motor leads and the surge impedance of the motor. The smaller the motor and the longer the leads, the greater the peak voltage.

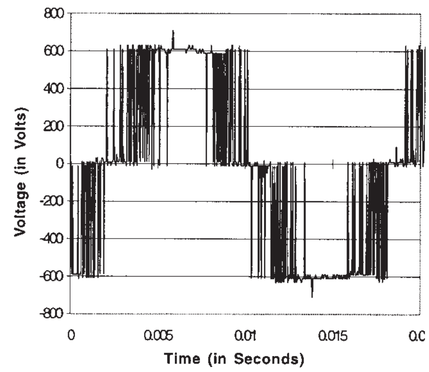

Figure 12. Typical output voltage of a PWM-VSI ASD

The most obvious symptom of the long-lead effect is the premature failure of a motor caused by degraded insulation. Damage to the insulation of the stator windings can progress gradually over a period of days or even months. Industry experience indicates that amplified voltage pulses usually do not damage winding insulation unless the motor leads are longer than 16 metres.

Preventing premature failure of bearings in motors driven by PWM-VSI ASDs

ASDs that use insulated-gate bipolar transistors (IGBTs) as high-frequency switches are most likely to cause bearing-discharge current. The high switching frequency and fast rise times of an IGBT inverter output can cause induced voltage in the rotor to be capacitively coupled to the motor shaft. This shaft voltage can exceed the dielectric strength of the lubricant in the shaft bearings. A shaft voltage as low as six volts can cause arcing through the bearing lubricant, depending upon the type of bearing lubricant and the clearing between the race and the ball bearings. The resulting current flows from the shaft, through the bearing lubricant, and to the grounded motor frame, causing pitting or fluting of the bearing races. The resulting high rolling resistance leads to premature failure of the shaft bearings. Excessive shaft voltage can be verified by measuring the shaft-to-ground voltage, which requires a specialized shaft-monitoring device.

Selecting an AC or DC drive to use in a given application can present unique challenges to the application engineer. A detailed understanding of the ASD's operation, motor performance, mechanical load characteristics, and potential application and installation technical requirements is essential to project success. Although it is not the intent of this brochure to cover in detail the non-power quality ASD specification parameters, it is important to understand that the first critical consideration in an ASD application is the type of mechanical load to be controlled and its characteristics.

Specifying ASDs to minimize PQ problems

Process loads may generally be grouped into four categories: (1) variable torque loads, (2) constant torque loads, (3) constant horsepower loads, and (4) impact loads. Also, the vast majority of motors in use today are designed to run at constant speed. NEMA publication MG-1 defines four designs (NEMA A, B, C and D) for polyphase induction motors, with each having different requirements for breakaway torque, pull-up torque, breakdown torque and maximum allowed starting current when rated frequency and voltage are applied. References 5 and 6 are excellent resources for developing technical insights into drive systems, mechanical load process characteristics and control requirements.

The most important steps in specifying ASDs to minimize power quality problems include:

Step One – Specify the ASD's response to switching voltage transients as follows: *The ASD shall not trip with transient overvoltages that can be as high as 2.0 per unit (of normal input voltage) at a damped frequency in the range of 300 to 800 Hz for 1 cycle. These transients may have significant energy associated with them but should not cause failure of ASD protective devices and other electronic components that make up the ASD.*

Step Two – Specify the ASD's response to voltage sags as follows:

- ***Single-phase sags*** *– at 75% load, the ASD shall be able to ride through single-phase voltage sags down to 0% input voltage for 30 cycles duration without causing any disruption to the connected motor-driven load.*
- ***Line-line sags*** *– at 75% load, the ASD shall be able to ride through line-line voltage sags down to 50% input voltage for 30 cycles duration without causing any disruption to the connected motor-driven load.*
- ***Three-phase sags*** *– at 75% load, the ASD shall be able to ride through three-phase voltage sags down to 0% input voltage for 5 cycles duration and voltage sags down to 75% input voltage for 30 cycles duration without causing any disruption to the connected motor-driven load.*

Step Three – Specify the ASD's input line current total harmonic distortion requirements as follows: *The ASD shall have appropriately sized AC line reactors, DC-link choke, or equivalent impedance input isolation transformer to limit the ASD's input current total harmonic distortion (I_{THD}) to under 40% at full load.*

Step Four – Specify the ASD's input line voltage total harmonic distortion (V_{THD}) level to meet the guidelines of IEEE 519-1992 as follows:

- *PWM-VSI AC drives for special applications including hospitals and airports at V_{THD} = 3% and for general commercial/industrial applications at V_{THD} = 5%.*
- *DC drives and CSI AC drives for special applications including hospitals and airports at V_{THD} = 3% with limits on notching and ringing at 10% notch depth, and for general commercial/industrial applications at V_{THD} = 5% with limits on notching and ringing at 20% notch depth.*

Step Five – Specify the ASD's response to steady-state input voltage unbalance as follows: *The ASD shall be capable of handling high-input AC current unbalance associated with up to 3% input AC voltage unbalance without causing failure of ASD protective devices and other electronic components that make up the ASD. Also, under worst-case input unbalance conditions, the ASD's impact on external trip overload protection, motor control centre protection devices, and generation of non-characteristic harmonics shall be evaluated for any detrimental performance of the electric service supply and motor-driven system.*

Step Six – Specify the need to evaluate the ASD/motor installation with regard to possible long-lead effects as follows:

- ***New ASD/motor installations*** – *When installing new ASDs with existing motors, the durability of the motor winding insulation should be addressed during the initial specification. To ensure compatibility between ASDs and the motors they are intended to drive, inform the ASD manufacturer and system integrator about the anticipated length of the motor leads. When installing new ASDs and new motors, specify a motor that complies with NEMA MG1 Part 31, "Definite Purpose Inverter-Fed Motors." The winding insulation of these motors, which are designed to be driven by PWM-VSI ASDs, is designed to withstand the stress of 1,600 volts peak with 0.1 second rise time. Although a motor manufacturer may claim "inverter duty" or "suitable for inverter power," only those motors that specify compliance with NEMA MG1 Part 31 assure compatibility with PWM-VSI ASDs.*
- ***ASD retrofit installations*** – *When reducing the lead length or switching frequency is impractical or even impossible, certain filters can mitigate the long-lead effect by matching the terminating impedance of the existing motor to the lead impedance. Installed at the motor terminals, these filters are offered as an add-on feature by some ASD manufacturers or can be purchased separately and retrofitted to an existing ASD/motor system. When installing a new ASD with an existing motor, also install a matching filter according to the recommendations of the ASD manufacturer.*

Step Seven – Specify the need to evaluate the ASD/motor installation with regard to possible EMI/RFI interferences with other sensitive loads or other EMI/RFI loads interfering with the ASD controller. Ask about any special ASD input power line separation and shielding and/or motor cable separation and shielding, and grounding requirements. Also review any special cabling recommendations for all ASD control and signal wires. Initiate your discussion with the ASD manufacturers as follows: *EMI/RFI is a common source of concern in ASD applications. The concerns are created by the fast transition of the AC drive output voltage and/or internal solid-state switching devices. The fast transitions are sources of radiated and conducted noise. These interfere with other sensitive equipment, which is connected to the same distribution bus. EMI, both radiated and conducted, can interfere with communication links, encoder feedback, ultra-sonic sensors, temperature sensors, computers, AM radio, TV, CAT scanners, security alarms and many other sensitive electronic devices. Ask how the proposed ASD EMI/RFI performance will be compatible with the intended application.*

Step Eight – Specify the need to evaluate the ASD/motor-driven system bearings to prevent premature bearing failures. Initiate your discussion with the ASD manufacturers as follows:

- ***Should a shaft grounding system be installed?*** – *Minimizing the magnitude of the shaft voltage reduces the chance of electrical arcing through bearing lubricant. Grounding the motor shaft with a system of brushes creates a low-impedance path to ground for otherwise damaging discharge currents. A number of brush systems are commercially available. Soft carbon brushes are usually not suitable, because they may create a nonconductive film that prevents electrical contact between the brushes and shaft. Brushes made of special materials, such as brass and stainless steel, do not create this film. Also, a sealed grounding system is recommended for a clean-room environment, which may be contaminated by airborne particles from a standard grounding-brush system. During every routine maintenance, ensure that the brushes are in electrical contact with the shaft, regardless of the type of grounding system you select.*
- ***Should insulated motor bearings be installed?*** – *Although insulated motor bearings stop the flow of discharge current through the motor bearings, they do not prevent damage to the bearings of other shaft-connected equipment, such as tachometers and fans. Also, the voltage on the shaft of a*

motor with insulated bearings and without shaft-connected equipment may pose a risk of a mild shock to anyone who touches the rotating shaft.

- ***Should the ASD PWM switching frequency be decreased?*** *– The switching frequency of most PWM-VSI ASDs can be set by the operator. By decreasing the switching frequency of an existing ASD, you can prevent the premature failure of motor bearings. Although shaft voltages will be present at lower switching frequencies, industry experience to date indicates that problems caused by the discharge current begin mostly when the ASD switching frequency is greater than 10 kHz. Therefore, if shaft grounding systems or insulated bearings are impractical options, then avoid using switching frequencies above 10 kHz. If a higher switching frequency must be used, then purchase motors with warranties against bearing failure caused by discharge current.*

PQ interactions/ASD problems

There are many different ways to troubleshoot an ASD, and a good troubleshooter will always find the problem, eventually. Troubleshooting begins with a good technique and the procedure set forth here suggests looking at the ASD/motor system voltages and currents. Previous Figures 1, 2 and 3 provide initial starting points with representative voltage waveforms at crucial ASD/motor system interfaces for the three ASD technologies of most interest. For each ASD the voltage snapshots depict the ideal motor voltages, DC link, rectification and AC line voltage waveforms for a properly working ASD/motor system. Measuring and confirming these voltages provides key information on a simple ASD's operating status and any interactions.

Because the voltages and currents throughout the ASD/motor system are non-sinusoidal, the type of instrument used to make measurements is important. Use a true-RMS digital multimeter because it will give accurate readings in electronics-based equipment situations. In addition to the referenced voltage readings, utilize the ASD input line current waveforms and harmonic spectra for each ASD type (see page 10). These current waveforms provide each ASD's "normal performance signature." Any departure from the referenced voltage and current signatures suggests a possible interaction with the electric service system, or other electronics-based loads.

The following table (on page 13) includes the most common power quality interactions causing ASD operating problems with suggested solutions. *Note: While collecting system voltage and current data, make sure all electrical/mechanical connections are good. Visually inspect all connection points for looseness, corrosion or conductive paths to ground. If you are uncertain about the quality of any connection, you may want to check the connection by resistance measurement, voltage drop or temperature level.*

ASD manufacturers typically divide the diagnosis and correction of problems in ASDs into several categories. The categories are described in significant detail in the ASD's operations manual for a qualified individual who is familiar with the ASD's construction, operation of the equipment, and the hazards involved. While most ASD operations manuals do not specifically address how to diagnose PQ problems with ASDs, implementing the following "diagnostic steps," combined with the power quality information provided in previous sections, can help isolate power quality symptoms that can lead to the root causes of the ASD's PQ problems.

- **Preventive maintenance actions** – required to keep the ASD working reliably and at peak efficiency, e.g., cleaning inside and outside of the enclosure, inspecting electrical connections for tightness, replacing ventilation fan filters.
- **Using diagnostic indicators** – simplified to assist the troubleshooting process with indicators that identify power, fault and running system conditions; front panel message display with messages to diagnose fault conditions and take corrective actions as necessary; and display codes that communicate functions such as memory test sequence, hardware faults or communication errors, and ASD operating modes.

- **Troubleshooting by equipment inspection** for physical signs of damage such as:
  - *Equipment damage* – burned or charred components or wires, loose or disconnected wires, swelled capacitors, signs of arcing, damage to the walls or bottom of the ASD enclosure. If one or more of these signs are encountered, the user should contact the ASD manufacturer immediately.
  - *Checking fuses* – this includes power fuses and control fuses. Frequently the ASD operations manual will contain a table listing some common fuse-related symptoms and possible causes of failure.
  - *Use of spare parts* – replacement of component parts may be the most expedient method of troubleshooting, when spare parts are available. When any sub-assembly is to be replaced, the operator must verify that the part number of the new unit matches that of the old unit, including the "dash" number. It is recommended that individual modules be kept on hand as spare parts for inverters that contain transistors, SCRs and diodes, in order to reduce the amount of downtime. Although the power electronic devices used by most ASD inverters are conventional devices that are available from any distributor, the installation and mounting of devices to a heat sink requires some skill and care. If there is any doubt about the competency

PQ interactions causing problems

Type of ASD	Symptom	AC supply disturbance	Contributing factors
PWM-VSI AC drives	• Random tripping	• Transients (impulsive) • Transients (oscillatory) • Sags • Interruptions • Voltage/current Unbalance	• Faulty or no transient Protection • Harmonic resonances • Undervoltage trip level • Faulty or no ride-through • Little or no ASD reactance
	• Frequent motor repairs - Overheating - Spike damage to motor windings - Premature nearing failures	N/A	• Inadequate PWM harmonic cancellation • Rapid PWM voltage changes • Faulty grounding and/or insufficient insulation system • High rrequency induced shaft voltages
	• Low frequency (< 3 kHz) interferences with other loads	• High line-line harmonic voltage distortion	• Service impedances too high for application
	• High frequency (> 3 kHz) interfer-ences with other loads • Resets/lockups/ control errors	• Noise (radiated and/or conducted)	• Faulty shielding and/or grounding, loose wiring, defective cables
SCR DC drives	• Random tripping	• Transients (impulsive) • Transients (oscillatory) • Sags • Interruptions • Voltage/current Unbalance	• Faulty or no transient protection • Harmonic resonances • Undervoltage trip level • Faulty or no ride-through • Inoperative SCR gate firing control circuit
	• Low frequency (< 3 kHz) interference with other loads	• High line-line harmonic voltage distortion	• Service impedances too high for application
	• High frequency (> 3 kHz) interferences with other loads • Resets/lockups/ control errors	• "Ringing/notching" • Noise (radiated and/or conducted)	• Faulty shielding and/or grounding, loose wiring, defective cables

Operating problems/solutions table

Cause of disturbance	Solutions (Arranged by cost from lowest to highest)
• Lightning, routine utility activities • Distribution system frequency response • Faulted electric service power lines • Tripped MCC, blown fuses • Uneven distribution of single-phase loads	• Reprogram ASD Parameters based on requirements • Retrofit ASD with AC or DC reactors • Install harmonic filters • Retrofit with ride-through devices
N/A	• Retrofit with inverter duty motor • Install shaft grounding device • Retrofit ASD with motor-side low-pass filter • Install ASD and motor close together (< 16m)
• Electric service system Frequency response	• Relocate ASD to different MCC • Retrofit with AC or DC reactors • Install harmonic filters
• Inadequate installation of ASD input Power leads and/or motor cables • Inadequate installation of control and signal wires	• Retrofit ASD input leads and motor cables with appropriate separation and shielding • Retrofit control and signal wires with appropriate separation and shielding • Retrofit ASD input leads with EMI/RFI filter that has the required insertion loss characteristics
• Lightning, routine utility activities • Distribution system frequency response • Faulted electric service power lines • Tripped MCC, blown fuses • Line-line phase unbalances due to uneven load distribution	• Install surge protector at ASD • Replace SCR gate firing control circuit • Install harmonic filters • Retrofit with ride-through devices
• Electric service system Frequency response	• Relocate ASD to different MCC • Install harmonic filters
• Inadequate installation of ASD input power leads • Inadequate installation of control and signal wires	• Retrofit ASD input leads with appropriate separation and shielding • Retrofit control and signal wires with appropriate separation and shielding • Retrofit ASD input leads with EMI/RFI filter that has the required insertion loss characteristics

PQ interactions causing problems

Type of ASD	Symptom	AC supply disturbance	Contributing factors
CSI AC drives	• Random tripping	• Transients (impulsive) • Transients (oscillatory) • Sags • Interruptions • Voltage/current unbalance	• Faulty or no transient protection • Harmonic resonances • Undervoltage trip level • Faulty or no ride-through • Inoperative SCR input converter gate firing control circuit
	• Frequent motor repairs • Overheating • Spike damage to motor windings	N/A	• Inadequate harmonic cancellation • High dv/dt from inverter circuit • Faulty grounding and/ or insufficient insulation system
	• Low frequency (< 3 kHz) Interferences with other loads	• High line-line harmonic voltage distortion	• Service impedances too high for application
	• High frequency (> 3 kHz) interferences with other loads • Resets/lockups/ control errors	• "Ringing/notching" • Noise (radiated and/or conducted)	• Faulty shielding and/or grounding, loose wiring defective cables

Operating problems/solutions table

Cause of disturbance	Solutions (Arranged by cost from lowest to highest)
• Lightning, routine utility activities • Distribution system frequency response • Faulted electric service power lines • Tripped MCC, blown fuses • Line-line phase unbalances due to uneven load distribution	• Install surge protector at ASD • Replace SCR gate firing control circuit • Install harmonic filters • Retrofit with ride-through devices
N/A	• Retrofit with inverter-duty motor • Retrofit ASD with motor-side low pass filter
• Electric service system frequency response	• Install harmonic filters
• Inadequate installation of ASD input power leads and/or motor cables • Inadequate installation of control and signal wires	• Retrofit ASD input leads and motor cables with appropriate separation and shielding • Retrofit control and signal wires with appropriate separation and shielding • Retrofit ASD input leads with EMI/RFI filter that has the required insertion loss characteristics

of maintenance personnel to remount devices satisfactorily, it is suggested that modules with unserviceable devices be returned to the factory for repair. However, if it is elected to keep spare devices on hand, the manufacturer's data on mounting practices, clamping forces and torques must be followed to preserve the reliability of the devices.

- ***Troubleshooting: no power*** – usually the first sign of a power-up problem is that the Power On LED (on the front of the ASD) is off. To determine the source of the problem, take the following steps:
  - Verify that the incoming power is correct and within the appropriate tolerance.
  - Turn on the unit's power and verify that the gate driver/interface board has control power. If control power is confirmed and the ASD is still inoperative, consult the factory for further assistance.
  - Turn off the unit's power. Using an ohmmeter, check the ASD line fuses for continuity. If no problems are found and the unit still will not power up, consult the factory for further assistance.
- ***Troubleshooting: faults*** – if the ASD powers up correctly, the Power On LED will be on, the display will show the identification screen, and the meter display will be shown. If a fault condition occurs during startup (or during normal operation), the Fault LED will be on, and a fault message will be shown on the front panel display. A sample fault message might show: "Overvoltage 01/15/99 9:13:21."

If a fault occurs during operation, a fault message will appear on the front panel display and the ASD will be commanded to stop in a manner similar to an emergency stop. If multiple faults have occurred, the word "more" may appear on the front panel display. This indicates that additional fault messages can be viewed using the up and down arrow keys. This type of fault message might show: "Phase Loss Fault 01/15/99 9:13:21 more." Explanations of various fault conditions are included in each ASD manufacturer's operations manual.

For further assistance

If, after following the procedures recommended in this brochure, power quality problems persist in your ASD/motor-driven system, contact your equipment supplier or a qualified electrician.

Glossary

building (or service) transformer – an electrical device for changing the voltage from a high level to a low level.

electrical disturbance – electricity distorted by electronics-based equipment connected to the electrical system or by events outside the facility.

harmonic distortion – distorted electricity caused by the power supplies of certain electronic equipment.

interruption – (also called *power outage or momentary*) – a complete stop in the flow of electricity, lasting from a fraction of a second to hours.

momentary – see *interruption*.

motor control centre (MCC) – a floor-mounted assembly of one or more enclosed vertical sections having a common horizontal power bus and principally containing combination motor starting units.

noise – non-damaging distortion of electricity, which interferes primarily with communication devices and other sensitive electronic loads, caused by electronic power supplies and electronic lighting. *Radiated noise*, sometimes referred to as *EMI or RFI noise* by technicians, is emitted through the air instead of the electrical system (*conducted noise*) and is received by televisions, hearing aids, computer monitors, security systems, sensitive equipment control and signal circuits, and other communication devices.

overvoltage (undervoltage) – an increase (decrease) in the normal voltage level lasting for seconds or minutes.

power quality (PQ) problem – the difference between the quality of electricity at an electrical point of utilization and the quality of the electricity required to reliably operate electronics-based equipment, resulting in mis-operation or damage.

RMS (root means squared) – refers to the most common mathematical method of defining the effective voltage or current of an AC wave.

sag – a decrease of the normal voltage level lasting less than a second.

service panel – a cabinet that houses all circuit breakers or fuses for a facility, office, suite or building.

swell – an increase in the normal voltage level lasting less than a second.

transients – sharp changes in voltage caused by lightning, motors starting, utility operations, and other electronics-based loads, that last a fraction of a second.

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