Variable Frequency Drives (VFDs)

Course No: M02-031

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APPENDIX D

VARIABLE SPEED DRIVES (VFD)

D-1.00 Introduction

D-1.01 Scope and Criteria.

This appendix is intended to provide basic information on the principles of operation of VFD's, description of different types of VFD's, guidance on the proper application of VFD's, and installation guidelines to ensure successful operation of VFD's. Over the last few years, the VFD has become one of the most effective motor controllers available for varying the speed of squirrel-cage induction motors. VFD's save energy, reduce electrical consumption, enhance equipment performance, are highly reliable, and have become affordable. Much of the material presented in this Appendix was developed by Mr. Solomon S. Turkel, Senior Instructor and Course Author for Advanced Technologies Marketing and Service (ATMS) Inc., Baltimore, MD.

D-1.02 Terminology.

VFD's drives are sometimes called adjustable frequency controllers (AFC's). It is incorrect to call them inverters or even adjustable speed drives (ASD's). The term "ASD" refers to many types of adjustable speed drives, including belt or gear drives, eddy-current clutches, variablepitch sheave drives, and DC systems, as well as VFD's. The VFD is the only type of motor drive that controls the speed of an AC induction motor by changing the frequency and voltage appropriately. The VFD microprocessor-based motor controller incorporates an electronic control section, an electromagnetic and semiconductor power section, and typical components used with standard motor controllers. Currently, available sizes range from 1/3 horsepower (hp) to thousands of hp.

D-1.03 Operation.

The principles of operation of VFD's are closely related to basic motor theory. During operation, the stator's rotating magnetic field, which is created by the AC line power to the motor, induces a voltage in the rotor. This induced voltage causes a current to flow in the rotor, which creates magnetic fields with north and south poles. The synchronous speed of an AC induction motor is dependent upon the number of poles in the stator and the frequency of the line power applied. The basic equation is as follows:

Speed = (120 times frequency) divided by number of poles

From this equation , a four-pole motor operating at 60 Hz will have synchronous speed of 1800 rpm. When a VFD supplies power to an AC motor, it has the capability to provide a voltage at a frequency from less than 1 Hz to about 120 Hz. This means that the motor may run extremely slow or very fast, depending on the frequency supplied; and the amplitude of the voltage supplied must be proportional to the frequency to ensure the proper volts/hertz ratio for the specific motor. The output torque for a motor is determined by the ratio of voltage applied to the motor at a given frequency. Failure to maintain the proper volts-per-hertz ratio will affect motor torque, temperature, speed, noise, and current draw. Thus, for a motor to produce its rated torque at variable speeds, it is also necessary to control the voltage as well as the frequency supplied to the motor. For example, a 460 volt motor operating at 60 Hz will have a volts/hertz ratio of 7.67 to 1. For a VFD to operate this motor at 30 Hz (half speed), the motor voltage must be reduced to 230 volts to maintain the same torque characteristics for the motor. Motors are designed with specific torque characteristics and are classified accordingly. While two motors may have the same horsepower rating, their actual torque capability in the areas of breakaway torque, pull-up torque, peak torque, and full-load torque may be different, depending on their NEMA classifications. Typical designs are Type A, B, C, and D. Refer to National Electrical Manufacturers Association (NEMA) MG-1, Motors and Generators, for a detailed explanation of these NEMA designs and of motor torque capabilities. Although the motor is sized by horsepower, the required torque at all speeds is the key to successful, efficient operation of the VFD and its motor.

D-1.04 Types of VFD's.

Although VFD's control the speed of an AC induction motor by varying the motor's supplied voltage and frequency of power, they do not all use the same designs in doing so. The major VFD designs commonly used at the time of publication of this handbook are:

a) Pulse Width Modulated (PWM)

b) Current Source Inverter (CSI)

c) Voltage Source Inverter (VSI)

d) Flux Vector Drive

An understanding of these different designs, along with their advantages and disadvantages will be beneficial to correctly match the VFD with the motor in a specific application.

D-1.04.1 PWM Design

a) The PWM drive has become the most commonly used drive controller because it works well with motors ranging in size from about 1/2 hp to 500 hp. A significant reason for its popularity is that it's highly reliable, affordable, and reflects the least amount of harmonics back into its power source. Most units are rated either 230 volts or 460 volts, three-phase, and provide output frequencies from about 2 Hz to 400 Hz. Nearly 100 manufacturers market the PWM controller.

b) In the PWM drive, an AC line supply voltage is brought into the input section. From here, the AC voltage passes into a converter section that uses a diode bridge converter and large

DC capacitors to create and maintain a stable, fixed DC bus voltage. The DC voltage passes into the inverter section usually furnished with insulated gate bipolar transistors (IGBT's), which regulate both voltage and frequency to the motor to produce a near sine wave like output.

c) The term "pulse width modulation" explains how each transition of the alternating voltage output is actually a series of short pulses of varying widths. By varying the width of the pulses in each half cycle, the average power produced has a sinelike output. The number of transitions from positive to negative per second determines the actual frequency to the motor.

d) Switching speeds of the IGBT's in a PWM drive can range from 2 kHz to 15 kHz. Today's newer PWM designs use power IGBT's, which operate at these higher frequencies. By having more pulses in every half cycle, the motor whine associated with VFD applications is reduced because the motor windings are now oscillating at a frequency beyond the spectrum of human hearing. Also, the current wave shape to the motor is smoothed out as current spikes are removed.

e) PWM's have the following advantages:

(1) Excellent input power factor due to fixed DC bus voltage.

(2) No motor cogging normally found with six-step inverters.

(3) Highest efficiencies: 92 percent to 96 percent.

(4) Compatibility with multimotor applications.

(5) Ability to ride through a 3 to 5 Hz power loss.

(6) Lower initial cost.

f) The following disadvantages, however, should also be considered:

(1) Motor heating and insulation breakdown in some applications due to high frequency switching of transistors.

(2) Non-regenerative operation.

(3) Line-side power harmonics (depending on the application and size of the drive).

D-1.04.2 <u>CSI Design</u>.

In the CSI drive design, the incoming power source is converted to DC voltage in an SCR converter section, which regulates the incoming power and produces a variable DC bus voltage. This voltage is regulated by the firing of the SCR's as needed to maintain the proper volt/hertz ratio. SCR's are also used in the inverter section to produce the variabe frequency output to the motor. CSI drives are inherently current regulating and require a large internal inductor to operate, as well as a motor load.

a) CSI's have the following advantages:

(1) Reliability due to inherent current limiting operation.
(2) Regenerative power capability.
(3) Simple circuitry.

b) The following are disadvantages which should be considered in the use of CSI technology:

(1) Large power harmonic generation back into the power source.
(2) Cogging below 6 Hz due to square wave output.
(3) Use of large and costly inductor.
(4) High voltage spikes to motor windings.
(5) Load dependent; poor for multimotor applications.
(6) (6) Poor input power factor due to SCR converter section.

D-1.04.3 VSI Design.

The VSI drive is very similar to a CSI drive in that it also uses an SCR converter section to regulate DC bus voltage. Its inverter section produces a six-step output, but is not a current regulator like the CSI drive. This drive is considered a voltage regulator and uses transistors, SCR's, or gate turn off thyristors (GTO's) to generate an adjustable frequency output to the motor.

a) VSI's have the following advantages:

(1) Basic simplicity in design.
(2) Applicable to multimotor operations.
(3) Operation not load dependent.

b) As with other types of drives, there are disadvantages:

(1) Large power harmonic generation back into the power source.
(2) Poor input power factor due to SCR converter section.
(3) Cogging below 6 Hz due to square wave output.
(4) Non-regenerative operation.

D-1.04-4 **<u>Flux Vector PWM Drives</u>**

a) PWM drive technology is still considered new and is continuously being refined with new power switching devices and smart 32-bit microprocessors. AC drives have always been limited to normal torque applications while high torque, low rpm applications have been the domain of DC drives. This has changed recently with the introduction of a new breed of PWM drive, the flux vector drive.

b) Flux vector drives use a method of controlling torque similar to that of DC drive systems, including wide speed control range with quick response. Flux vector drives have the same power section as PWM drives, but use a sophisticated closed loop control from the motor to the drive's microprocessor. The motor's rotor position and speed is monitored in real time via a resolver or digital encoder to determine and control the motor's actual speed, torque, and power produced.

c) By controlling the inverter section in response to actual load conditions at the motor in a real time mode, superior torque control can be obtained. The personality of the motor must be programmed into or learned by the drive in order for it to run the vector control algorithms. In most cases, special motors are required due to the torque demands expected of the motor.

d) The following are advantages of this new drive technology:

(1) Excellent control of motor speed, torque, and power.

(2) Quick response to changes in load, speed, and torque commands.

(3) Ability to provide 100 percent rated torque at zero speed.

(4) Lower maintenance cost as compared to DC motors and drives.

e) The following are disadvantages:

(1) Higher initial cost as compared to standard PWM drives.

(2) Requires special motor in most cases.

(3) Drive setup parameters are complex.

While flux vector technology offers superior performance for certain special applications, it would be considered "overkill" for most applications well served by standard PWM drives.

D-1.05 Application of VFD's to Specific Loads.

VFD's are the most effective energy savers in pump and fan applications, and they enhance process operations, particularly where flow control is involved. VFD's soft start capabilities decrease electrical stresses and line voltage sags associated with full voltage motor start-ups, especially when driving high-enertia loads. For the motor to produce the required torque for the load, the VFD must have ample current capability to drive the motor. It is important to note that machine torque is independent of motor speed and that load horsepower increases linearly with rpm. Individual load types are as follows:

a) Constant torque loads. Constant torque loads represent 90 percent of general industrial machines (other than pumps and fans). Examples of these load types include general machinery, hoists, conveyors, printing presses, positive displacement pumps, some mixers and extruders, reciprocating compressors, as well as rotary compressors.

b) Constant horsepower loads. Constant horsepower loads are most often found in the machine tool industry and center driven winder applications. Examples of constant horsepower loads include winders, core-driven reels, wheel grinders, large driller machines, lathes, planers, boring machines, and core extruders. Traditionally, these loads were considered DC drive applications only. With high performance flux vector VFD's now available, many DC drive applications of this type can be now handled by VFD's.

c) Variable torque loads. Variable torque loads are most often found in variable flow applications, such as fans and pumps. Examples of applications include fans, centrifugal blowers, centrifugal pumps, propeller pumps, turbine pumps, agitators, and axial compressors. VFD's offer the greatest opportunity for energy savings when driving these loads because horsepower varies as the cube of speed and torque varies as square of speed for these loads. For example, if the motor speed is reduced 20 percent, motor horsepower is reduced by a cubic relationship (.8 x .8 x .8), or 51 percent. As such, utilities often offer subsidies to customers investing in VFD technology for their applications. Many VFD manufacturers have free software programs available for customers to calculate and document potential energy savings by using VFD's.

D-1.06 **<u>Special Applications of VFD's</u>.**

If any of the following operations apply, use extra care in selecting a VFD and its setup parameters.

a) VFD operating more than one motor. The total peak currents of motor loads under worst operating conditions must be calculated. The VFD must be sized based on this maximum current requirement. Additionally, individual motor protection must be provided here for each motor.

b) Load is spinning or coasting when the VFD is started. This is very often the case with fan applications. When a VFD is first started, it begins to operate at a low frequency and voltage and gradually ramps up to a preset speed. If the load is already in motion, it will be out of sync with the VFD. The VFD will attempt to pull the motor down to the lower frequency, which may require high current levels, usually causing an overcurrent trip. Because of this, VFD manufacturers offer drives with an option for synchronization with a spinning load; this VFD ramps at a different frequency.

c) Power supply source is switched while the VFD is running. This occurs in many buildings, such as hospitals, where loads are switched to standby generators in the event of a power outage. Some drives will ride through a brief power outage while others may not. If your application is of this type, it must be reviewed with the drive manufacturer for a final determination of drive capability.

d) Hard to start load. These are the motors that dim the lights in the building when you hit the start button. Remember, the VFD is limited in the amount of overcurrent it can produce for a given period of time. These applications may require oversizing of the VFD for higher current demands.

e) Critical starting or stopping times. Some applications may require quick starting or emergency stopping of the load. In either case, high currents will be required of the drive. Again, oversizing of the VFD may be required.

f) External motor disconnects required between the motor and the VFD. Service disconnects at motor loads are very often used for maintenance purposes. Normally, removing a load from a VFD while operating does not pose a problem for the VFD. On the other hand, introducing a load to a VFD by closing a motor disconnect while the VFD is operational can be fatal to the VFD. When a motor is started at full voltage, as would happen in this case, high currents are generated, usually about six times the full load amperes of the motor current. The VFD would see these high currents as being well beyond its capabilities and would go into a protective trip or fail altogether. A simple solution for this condition is to interlock the VFD run permissive circuit with the service disconnects via an auxiliary contact at the service disconnect. When the disconnect is closed, a permissive run signal restarts the VFD at low voltage and frequency.

g) Power factor correction capacitors being switched or existing on the intended motor loads. Switching of power factor capacitors usually generates power disturbances in the distribution system. Many VFD's can and will be affected by this. Isolation transformers or line reactors may be required for these applications.

Power factor correction at VFD-powered motor loads is not necessary as the VFD itself does this by using DC internally and then inverting it into an AC output to the motor. VFD manufacturers warn against installing capacitors at the VFD output.

D-1.07 Sizing VFD's for the Load.

To properly size a VFD for an application, you must understand the requirements of the load. The torque ratings are as important as the horsepower ratings. Every load has distinct torque requirements that vary with the load's operation; these torques must be supplied by the motor via the VFD. You must have a clear understanding of these torques.

a) Breakaway torque: torque required to start a load in motion (typically greater than the torque required to maintain motion).

b) Accelerating torque: torque required to bring the load to operating speed within a given time.

c) Running torque: torque required to keep the load moving at all speeds.

d) Peak torque: occasional peak torque required by the load, such as a load being dropped on a conveyor.

e) Holding torque: torque required by the motor when operating as a brake, such as down hill loads and high inertia machines.

D-1.08 Guidelines for Matching VFD to Motor.

The following guidelines will help ensure a correct match of VFD and motor:

a) Define the operating profile of the load to which the VFD is to be applied. Include any or all of the torques listed in par. D-1.07. Using a recording true rms ammeter to record the motor's current draw under all operating conditions will help in doing this. Obtain the highest "peak" current readings under the worst conditions. Also, see if the motor has been working in an overloaded condition by checking the motor full-load amperes (FLA). An overloaded motor operating at reduced speeds may not survive the increased temperatures as a result of the reduced cooling effects of the motor at these lower speeds.

b) Determine why the load operation needs to be changed. Very often VFD's have been applied to applications where all that was required was a "soft start" reduced voltage controller. The need for the VFD should be based on the ability to change the load's speed as required. In those applications where only one speed change is required, a VFD may not be necessary or practical.

c) Size the VFD to the motor based on the maximum current requirements under peak torque demands. Do not size the VFD based on horsepower ratings. Many applications have failed because of this. Remember, the maximum demands placed on the motor by the load must also be met by the VFD.

d) Evaluate the possibility of required oversizing of the VFD. Be aware that motor performance (breakaway torque, for example) is based upon the capability of the VFD used and the amount of current it can produce. Depending on the type of load and duty cycle expected, oversizing of the VFD may be required.

D-1.09 Key VFD Specification Parameters.

The most important information to be included in a VFD specification are continuous current rating, overload current rating, and line voltage of operation.

a) Continuous run current rating. This is the maximum rms current the VFD can safely handle under all operating conditions at a fixed ambient temperature (usually 40 degrees C). Motor full load sine wave currents must be equal to or less than this rating.

b) Overload current rating. This is an inverse time/current rating that is the maximum current the VFD can produce for a given time frame. Typical ratings are 110 percent to 150 percent overcurrent for 1 minute, depending on the manufacturer. Higher current ratings can be obtained by oversizing the VFD. This rating is very important when sizing the VFD for the currents needed by the motor for breakaway torque.

c) Line voltage. As with any motor controller, an operating voltage must be specified. VFD's are designed to operate at some nominal voltage such as 240 volts AC or 480 volts AC, with an allowable voltage variation of plus or minus 10 percent. Most motor starters will operate beyond this 10 percent variation, but VFD's will not and will go into a protective trip. A recorded voltage reading of line power deviations is highly recommended for each application.

d) Additional considerations. The following information is helpful when applying drives and should be included and verified prior to selection of a drive:

(1) Starting torque currents
(2) Running torque currents
(3) Peak loading currents
(4) Duty cycle
(5) Load type
(6) Speed precision required
(7) Performance (response)
(8) Line voltages (deviations)
(9) Altitude
(10) Ambient temperature
(11) Environment
(12) Motoring/regenerating load
(13) Stopping requirements
(14) Motor nameplate data
(15) Input signals required
(16) Output signals required

D-1.10 VFD Installation and Start-Up.

Over half of drive failures are a result of improper installation and start-up. Careful planning of your VFD installation will help avoid many problems. Be sure the VFD specification requires furnishing of the drive's operation and maintenance manual. Important considerations include temperature and line power quality requirements, along with electrical connections, grounding, fault protection, motor protection, and environmental parameters.

a) Temperature. Equipment should be located in areas which are well within manufacturer's specified temperature limits and are well ventilated to remove generated heat. Avoid installing units in mezzanines, direct sunlight, or near external heat sources to avoid unpredictable temperature rises. Provide supplemental cooling if these areas cannot be avoided.

b) Supply Line Power Quality. The line voltage to the drive input should vary no more than plus or minus 10 percent to avoid tripping the unit via a protective fault. Voltage drop calculations must take this into account when running conductors long distances from the power source.

c) Electrical Connections. Size VFD line and load conductors to conform to NFPA 70.

d) Grounding. In addition to running a grounding conductor back to the electrical service entrance, bring a grounding conductor back from the motor to the VFD's internal grounding terminal. This direct motor ground to the VFD is required to minimize interference and for proper operation of the ground-fault protection function.

e) Fault Protection. Many VFD's have short-circuit protection (usually in the form of fuses) already installed by the manufacturer. This is usually the case on larger horsepower units. Smaller units (1/3 to 5 hp) normally require external fuse protection. In either case, the selection and sizing of these fuses is critical for semiconductor protection in the event of a fault. The manufacturer's recommendations must be followed when installing or replacing fuses for the VFD. Be sure to torque-bolt fuses in place according to the manufacturer's specification to ensure fast operation of fuses in case of a fault.

f) Motor Protection. Motors require overload protection. The most common practice is the use of a motor overcurrent relay system that will protect all three phases and protect against single-phasing. This type of protection will respond to motor overcurrent conditions of an overloaded motor, but will not detect overtemperature conditions.

A motor operating at reduced speeds will have reduced cooling; as a result, it may fail due to thermal breakdown of the motor windings insulation. Thus, the optimum protection for a motor is thermal sensing of the motor windings. This sensing is then interlocked with the VFD's control circuit. This is highly recommended for any motor that is to be operated for extended periods of time at low speeds.

g) Environment

(1) Humidity and Moisture. As is the case with all electrical and electronic equipment, high humidity and corrosive atmospheres are a concern. Drive units should be installed in a noncorrosive location whenever possible, with ambient humidity ranging between 0 to 95 percent noncondensing. Avoid locations subject to rain, dust, corrosive fumes, or vapors, and salt water. In some cases, appropriate NEMA enclosures may be specified where some of these locations cannot be avoided. Consult VFD manufacturers about the location and application before doing so.

(2) Vibration. Do not locate VFD's near vibrating equipment unless appropriate vibration isolation methods are employed.

(3) Line Transmitted Transients. The VFD is a solid-state electronic device, therefore, surge and transient protection (from lightning strikes, circuit switching, large motor starting, etc.) should be specified, either integral to the VFD or external, as appropriate.

D-1.11 Start-Up Procedures

a) Successful installation of VFD's, as with nearly all electrical equipment, is derived from an orderly, well planned start-up procedure. After reading the entire VFD manual and before energizing the VFD, make a physical inspection of the VFD and look for the following:

(1) Any moisture or debris (metal shavings for example) inside the equipment.

(2) Damage or dents to the enclosure, damaged or loose components and wires, and disconnected terminal conectors.

(3) Possible restrictions to airflow at the cooling fans or heat sink.

(4) Unremoved shipping blocks or tapes at power contactors, relays, etc.

b) In addition to the VFD itself, you should also make a visual inspection of the entire system, including motors, disconnect switches, circuit breakers, controls, load components, control devices (limit, float, pressure switches, etc.).

c) Finally, you should make an intense and thorough check of the following items:

(1) Connections (line, load, and ground).

(2) Motor (horsepower, full-load amperes, voltage, and rotation).

(3) VFD (input/output voltages, maximum output current).

(4) Protective devices (circuit breaker, fuses, overloads, thermal devices).

(5) Disconnects (are they in place and sized correctly?).

(6) Incoming line power voltage measurements tothe VFD (A-B phase, B-C phase, C-A phase).

d) It is recommended that you use a VFD start-up guide sheet/report in your start-up procedure. Make the report part of the project's contractual requirements within the specification section covering the VFD. The benefits of using such a report includes verifying key parameters prior to start-up, documenting the installation for warranty claims, and aiding in troubleshooting for future problems. The following instruments should be available at the VFD location for start-up:

(1) True rms multimeter capable of reading AC/DC voltages up to 750 volts.

(2) True rms clamp-on ammeter capable of reading the VFD's maximum current output.

(3) Photo tachometer to verify shaft output speed at load.

(4) Current/voltage signal generator to generate a reference analog signal to VFD (4 to 20 milliamperes or 0 to 5 volts). (This is extremely useful on HVAC applications where the building automation system designed to control the VFD is not ready at time of start-up.)

(5) Oscilloscope to check wave shapes of VFD output to motor. These wave shapes can be compared to those provided in the start-up manual, or recorded (via Polaroid camera) for future comparison during troubleshooting or maintenance. The scope also can be used to check volts/hertz ratio.

e) Make up a complete final check, via a check-off list, of electrical and mechanical components to be sure that they are set correctly. This includes valves, dampers, limit switches, steady-state voltage, and current valves.

f) Station people at key locations (motor, controller panel, load(s), etc.).

g) A proper start-up can be considered complete only when the VFD is operated at full load. This is important because you then can make meaningful drive adjustments. You can verify this by actually checking the FLA and comparing the value to that on the motor nameplate.

h) When the start-up command is given, watch, listen, and smell for anything unusual. Once start-up has been accomplished, allow the system to run a few hours before taking test readings for future comparison.

D-1.12 VFD Generated EMI and Harmonic Distortion Concerns.

Harmonics are generated by nonlinear devices which rectify the incoming AC voltage to DC and then invert it back to AC, as is the case with a VFD running a motor. Harmonics from nonlinear devices are odd multiples of the fundamental frequency (third, fifth, seventh, etc.). Some parts of the electrical distribution system designed for 60 Hz can have significant losses at harmonic frequencies, which causes higher operating temperatures and shortened component life. The harmonics generated by a VFD affect not only the load it serves (the motor), but are also reflected back into the power distribution system, thus affecting other devices connected to the distribution system. Reference 13 addresses the motor heating and life expectancy concerns. The physical location of the VFD and its interface point with the power system within the facility are important. Do not locate the VFD near other electronic equipment, including radar equipment, radio equipment, computers, hospital diagnostic and life support equipment, or telecommunications equipment. Minimize the length of line and load power leads as much as possible. Always run line and load conductors in a grounded continuous metallic conduit system. Since most mechanical systems and controls now include solid-state electronics, take precautions to prevent their damage or malfunction due to VFD generated harmonics. Filters can be added to the VFD input circuit when the VFD does not include adequate filtering internally for the specific application. Consult the electrical design engineer for help with resolving interference and harmonic distortion concerns.

D-1.13 VFD-Driven Premium Efficiency Motor Concerns.

Although beyond the scope of this handbook, it should be noted that not all premium efficiency motors are suitable for control by VFD's. During the design stage, contact both VFD manufacturers and premium efficiency motor manufacturers to ensure compatibility for the application at hand.

D-1.14 Troubleshooting VFD Problems.

Although important in ensuring long-term successful VFD operation, it is beyond the scope of this handbook to cover troubleshooting of VFD problems. The subject of troubleshooting VFD's during their operating lifetime is well covered in References 6 and 7.

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VFD START-UP REPORT

Report No.: ____________

Report Date: ___________

Customer: ____

Contact Name: ________________________________ Phone Number: ________________________

Address: ____

City/Base: ______________________ State/Country: _________________________ Zip: _________

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Equipment Manufacturer: _____________________________ Model No.: ______________________

Equipment Location: _________________________________ Serial No.: ______________________

List of Options: ____

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Installation Notes: ____

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Type of Load: _______________________________ Load Location: __________________________

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Motor Manufacturer: ______________ Horsepower: ____________ Service Factor: ______________

Voltage: ______________ RPM: ________________ Frequency: __________ Frame: _____________

Current: ______________ Insulation Class: ___________________ NEMA Class: ________________

Load Rotation: ________________________ Overload Heater Size: ___________________________

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<u>Installation Inspection</u>

Clearances - Front: _______ Back: ________ Left: ________ Right: __________ Bottom: _________

Grounding Method: ________________________ Ground Wire Size: _________________________

Isolation Transformer (Y/N): ____________ Motor Disconnects (Y/N): ____________

Details for Yes Answers: ____

____

Ambient Temperature: __________________________ Exposure: ____________________________

ELECTRICAL INSPECTION

Incoming Voltages - A-B Phase: ________ B-C Phase: ____________ C-A Phase: ______________

A-Neutral: ________ B-Neutral: ____________ C-Neutral: ________________

External Control Voltages (source): _______________________ Fused: _________________________

External Process Signals (4-20 mA, 3-15 psi, 0-10 vdc, 0-250 ohm): ___________________________

Process Signal Sources: ____

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Set Up Parameters

Accel Time (sec): ______________ Decel Time (sec): __________ Second Accel/Decel:___________

Auto Restart (Y/N): _______________ Multiple Attempt Restart (Y/N): ________________________

Maximum Speed: __________ Minimum Speed: ____________ Extended Freq. (Y/N): ___________

Torque Boost (level): _________________ Gain: __________________ Offset: _________________

Set Up Notes: ____

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Operational Parameters

		Inverter	Bypass
Line Current		A Phase: ____________________	A Phase: ____________________
		B Phase: ____________________	B Phase:_____________________
		C Phase: ____________________	C Phase: ____________________
Load Current		A Phase: ____________________	A Phase: ____________________
		B Phase: ____________________	B Phase:_____________________
		C Phase: ____________________	C Phase: ____________________

DC Bus Voltage: ______________ Heat Sink Temperature (1 hr run time): _____________________

Frequency Output at 0 % Reference Signal: ____

Frequency Output at 100% Reference Signal: ____

Start Up Complete (Y/N): ___ Completion Date: ____

Start Up Completed By: ____

Remarks: ____