



SECTION 23 81 07 - VARIABLE FREQUENCY DRIVES

PART 1 - GENERAL

1.1 SUMMARY

- A. This section includes all variable frequency drives. All standard and optional features shall be included within the VFD panel

1.2 QUALITY REQUIREMENTS

- A. Manufacturer testing
 - 1. To ensure quality, the complete VFD shall be tested by the manufacturer. The VFD shall drive a motor connected to a dynamometer at full load and speed and shall be cycled during the automated test procedure.
 - 2. All optional features shall be functionally tested at the factory for proper operation.

1.3 SUBMITTALS

- A. Shop Drawings and Product Data.
- B. Variable Frequency Drives
 - 1. Submit complete wiring diagrams, dimensional drawings, transformer data and connection diagrams.
 - 2. Outline dimensions, conduit entry locations and weight.
 - 3. Complete technical product description include a complete list of options provided
 - 4. Customer connection and power wiring diagrams.
 - 5. Compliance to IEEE 519 B harmonic analysis for particular jobsite including total harmonic voltage distortion and total harmonic current distortion (TDD).
 - a. The VFD manufacturer shall provide calculations; specific to this installation, showing total harmonic voltage distortion is less than 5%. Input line filters shall be sized and provided as required by the VFD manufacturer to ensure compliance with IEEE standard 519. All VFDs shall include a minimum of 5% impedance reactors, no exceptions.

1.4 WARRANTY

- A. Warranty shall be 5 years from the date of certified start-up. The warranty shall include all parts, labor, travel time and expenses. There shall be support available via a toll free phone number.

PART 2 - PRODUCTS



2.1 MATERIALS

A. Variable Frequency Drives:

1. Description:

- a. Motors shall be provided with UL Listed variable frequency drive (VFD) control systems.
- b. The VFD shall be UL Type 1 or UL Type 12 for indoor applications or UL NEMA-3R for outdoor applications as required on the schedule. The VFD shall have been evaluated by UL and found acceptable for mounting in a plenum or other air handling compartment. Manufacturer shall supply a copy of the UL plenum evaluation upon request.
- c. The VFD shall be tested to UL 508C. The appropriate UL label shall be applied. VFD shall be manufactured in ISO 9001, 2000 certified facilities.
- d. The VFD and any optional panels, of any type (bypass, etc.) shall be UL listed for a short circuit current rating of 100,000 amps and labeled with this rating.

2. Manufacturers.

- a. **Danfoss.**
- b. **Yaskawa.**
- c. **ABB**

3. General

- a. The VFD shall convert incoming fixed frequency three-phase AC power into an adjustable frequency and voltage for controlling the speed of three-phase AC motors. The motor current shall closely approximate a sine wave. Motor voltage shall be varied with frequency to maintain desired motor magnetization current suitable for the driven load and to eliminate the need for motor derating. When properly sized, the VFD shall allow the motor to produce full rated power at rated motor voltage, current, and speed without using the motor's service factor. VFDs utilizing sine weighted/coded modulation (with or without 3rd harmonic injection) must provide data verifying that the motors will not draw more than full load current during full load and full speed operation.
- b. The VFD shall include an input full-wave bridge rectifier and maintain a fundamental (displacement) power factor near unity regardless of speed or load.
- c. The VFD shall have a dual 5% impedance DC link reactor on the positive and negative rails of the DC bus to minimize power line harmonics and protect the VFD from power line transients. The chokes shall be non-saturating. Swinging chokes that do not provide full harmonic filtering throughout the entire load range are not acceptable. VFDs with saturating (non-linear) DC link reactors shall require an additional 3% AC line reactor to provide acceptable harmonic performance at full load, where harmonic performance is most critical.
- d. The VFD full load output current rating shall meet or exceed NEC Table 430-150. The VFD shall be able to provide full rated output current continuously, 110% of rated current for 60 seconds and 120% of rated torque for up to 0.5 second while starting.



- e. The VFD shall provide full motor torque at any selected frequency from 20 Hz to base speed while providing a variable torque V/Hz output at reduced speed. This is to allow driving direct drive fans without high speed derating or low speed excessive magnetization, as would occur if a constant torque V/Hz curve was used at reduced speeds. Breakaway torque of 160% shall be available.
 - f. A programmable automatic energy optimization selection feature shall be provided standard in the VFD. This feature shall automatically and continuously monitor the motor's speed and load to adjust the applied voltage to maximize energy savings.
 - g. The VFD must be able to produce full torque at low speed to operate direct drive fans.
 - h. Output power circuit switching shall be able to be accomplished without interlocks or damage to the VFD.
 - i. An automatic motor adaptation algorithm shall measure motor stator resistance and reactance to optimize performance and efficiency. It shall not be necessary to run the motor or de-couple the motor from the load to perform the test.
 - j. Galvanic isolation shall be provided between the VFDs power circuitry and control circuitry to ensure operator safety and to protect connected electronic control equipment from damage caused by voltage spikes, current surges, and ground loop currents. VFDs not including either galvanic or optical isolation on both analog I/O and discrete digital I/O shall include additional isolation modules.
 - k. VFD shall minimize the audible motor noise through the use of an adjustable carrier frequency. The carrier frequency shall be automatically adjusted to optimize motor and VFD operation while reducing motor noise. VFDs with fixed carrier frequency are not acceptable.
 - l. All VFDs shall contain integral EMI filters to attenuate radio frequency interference conducted to the AC power line.
4. Protective Features
- a. A minimum of Class 20 I2t electronic motor overload protection for single motor applications shall be provided. Overload protection shall automatically compensate for changes in motor speed.
 - b. Protection against input transients, loss of AC line phase, output short circuit, output ground fault, over voltage, under voltage, VFD over temperature and motor over temperature. The VFD shall display all faults in plain language. Codes are not acceptable.
 - c. Protect VFD from input phase loss. The VFD should be able to protect itself from damage and indicate the phase loss condition. During an input phase loss condition, the VFD shall be able to be programmed to either trip off while displaying an alarm, issue a warning while running at reduced output capacity, or issue a warning while running at full commanded speed. This function is independent of which input power phase is lost.
 - d. Protect from under voltage. The VFD shall provide full rated output with an input voltage as low as 90% of the nominal. The VFD will continue to operate with



reduced output, without faulting, with an input voltage as low as 70% of the nominal voltage.

- e. Protect from over voltage. The VFD shall continue to operate without faulting with an input voltage as high as 130% of the nominal voltage.
- f. The VFD shall incorporate a programmable motor preheat feature to keep the motor warm and prevent condensation build up in the motor when it is stopped in a damp environment by providing the motor stator with a controlled level of current.
- g. VFD shall include a “signal loss detection” algorithm with adjustable time delay to sense the loss of an analog input signal. It shall also include a programmable time delay to eliminate nuisance signal loss indications. The functions after detection shall be programmable.
- h. VFD shall function normally when the keypad is removed while the VFD is running. No warnings or alarms shall be issued as a result of removing the keypad.
- i. VFD shall catch a rotating motor operating forward or reverse up to full speed without VFD fault or component damage.
- j. Selectable over-voltage control shall be provided to protect the drive from power regenerated by the motor while maintaining control of the driven load.
- k. VFD shall include current sensors on all three output phases to accurately measure motor current, protect the VFD from output short circuits, output ground faults, and act as a motor overload. If an output phase loss is detected, the VFD will trip off and identify which of the output phases is low or lost.
- l. If the temperature of the VFD’s heat sink rises to 80 degree C, the VFD shall automatically reduce its carrier frequency to reduce the heat sink temperature. It shall also be possible to program the VFD so that it reduces its output current limit value if the VFD’s temperature becomes too high.
- m. In order to ensure operation during periods of overload, it must be possible to program the VFD to periodically reduce its output current to a programmed value during periods of excessive load. This allows the VFD to continue to run the load without tripping.
- n. The VFD shall have temperature controlled cooling fan(s) for quiet operation, minimized losses, and increased fan life. At low loads or low ambient temperatures, the fan(s) may be off even when the VFD is running.
- o. The VFD shall store in memory the last 10 alarms. A description of the alarm, and the date and time of the alarm shall be recorded.
- p. When used with a pumping system, the VFD shall be able to detect no-flow situations, dry pump conditions, and operation off the end of the pump curve. It shall be programmable to take appropriate protective action when one of the above situations is detected.

5. Interface Features



- a. Hand, Off and Auto keys shall be provided to start and stop the VFD and determine the source of the speed reference. It shall be possible to either disable these keys or password protect them from undesired operation.
- b. There shall be an “Info” key on the keypad. The Info key shall include “on-line” context sensitive assistance for programming and troubleshooting.
- c. The VFD shall be programmable to provide a digital output signal to indicate whether the VFD is in Hand or Auto mode. This is to alert the Building Automation System whether the VFD is being controlled locally or by the Building Automation System.
- d. Password protected keypad with alphanumeric, graphical, backlit display can be remotely mounted. Two levels of password protection shall be provided to guard against unauthorized parameter changes.
- e. All VFDs shall have the same customer interface. The keypad and display shall be identical and interchangeable for all sizes of VFDs.
- f. To set up multiple VFDs, it shall be possible to upload all setup parameters to the VFD’s keypad, place that keypad on all other VFDs in turn and download the setup parameters to each VFD. To facilitate setting up VFDs of various sizes, it shall be possible to download from the keypad only size independent parameters. Keypad shall provide visual indication of copy status.
- g. Display shall be programmable to communicate in multiple languages including English and Spanish.
- h. A red FAULT light, a yellow WARNING light and a green POWER-ON light shall be provided. These indications shall be visible both on the keypad and on the VFD when the keypad is removed.
- i. A quick setup menu with factory preset typical HVAC parameters shall be provided on the VFD. The VFD shall also have individual Fan, Pump, and Compressor menus specifically designed to facilitate start-up of these applications.
- j. A three-feedback PID controller to control the speed of the VFD shall be standard.
 - (1) This controller shall accept up to three feedback signals. It shall be programmable to compare the feedback signals to a common setpoint or to individual setpoints and to automatically select either the maximum or the feedback signal as the controlling signal. It shall also be possible to calculate the controlling feedback signal as the average of all feedback signals or the difference between a pair of feedback signals.
 - (2) The VFD shall be able to apply individual scaling to each feedback signal.
 - (3) For fan flow tracking applications, the VFD shall be able to calculate the square root of any or all individual feedback signals so that a pressure sensor can be used to measure air flow.
 - (4) The VFD’s PID controller shall be able to actively adjust its setpoint based on flow. This allows the VFD to compensate for a pressure feedback sensor which is located near the output of the pump rather than out in the controlled system.



- k. The VFD shall have three additional PID controllers which can be used to control damper and valve positioners in the system and to provide setpoint reset.
- l. Floating point control interface shall be provided to increase/decrease speed in response to contact closures.
- m. Five simultaneous meter displays shall be available. They shall include at a minimum, frequency, motor current, motor voltage, VFD output power, VFD output energy, VFD temperature in degrees, among others.
- n. Programmable Sleep Mode shall be able to stop the VFD. When its output frequency drops below set “sleep” level for a specified time, when an external contact commands that the VFD go into Sleep Mode, or when the VFD detects a no-flow situation, the VFD may be programmed to stop. When the VFD’s speed is being controlled by its PID controller, it shall be possible to program a “wake-up” feedback value that will cause the VFD to start. To avoid excessive starting and stopping of the driven equipment, it shall be possible to program a minimum run time before sleep mode can be initiated and a minimum sleep time for the VFD.
- o. A run permissive circuit shall be provided to accept a “system ready” signal to ensure that the VFD does not start until dampers or other auxiliary equipment are in the proper state for VFD operation. The run permissive circuit shall also be capable of initiating an output “run request” signal to indicate to the external equipment that the VFD has received a request to run.
- p. VFD shall be programmable to display feedback signals in appropriate units, such as inches of water column (in-w.g.), pressure per square inch (psi) or temperature (°F).
- q. VFD shall be programmable to sense the loss of load. The VFD shall be programmable to signal this condition via a keypad warning, relay output and/or over the serial communications bus. To ensure against nuisance indications, this feature must be based on motor torque, not current, and must include a proof timer to keep brief periods of no load from falsely triggering this indication.
- r. Standard Control and Monitoring Inputs and Outputs
 - (1) Four dedicated, programmable digital inputs shall be provided for interfacing with the systems control and safety interlock circuitry.
 - (2) Two terminals shall be programmable to act as either as digital outputs or additional digital inputs.
 - (3) Two programmable relay outputs, Form C 240 V AC, 2 A, shall be provided for remote indication of VFD status.
 - (4) Two programmable analog inputs shall be provided that can be either direct-or-reverse acting.
 - i. Each shall be independently selectable to be used with either an analog voltage or current signal.
 - ii. The maximum and minimum range of each shall be able to be independently scalable from 0 to 10 V dc and 0 to 20 mA.



- iii. A programmable low-pass filter for either or both of the analog inputs must be included to compensate for noise.
 - iv. The VFD shall provide front panel meter displays programmable to show the value of each analog input signal for system set-up and troubleshooting,
- (5) One programmable analog current output (0/4 to 20 mA) shall be provided for indication of VFD status. This output shall be programmable to show the reference or feedback signal supplied to the VFD and for VFD output frequency, current and power. It shall be possible to scale the minimum and maximum values of this output.
- (6) It shall be possible through serial bus communications to read the status of all analog and digital inputs of the VFD.
- (7) It shall be possible to command all digital and analog output through the serial communication bus.
- s. **Optional Control and Monitoring Inputs and Outputs**
- (1) It shall be possible to add optional modules to the VFD in the field to expand its analog and digital inputs and outputs.
 - (2) These modules shall use rigid connectors to plug into the VFD's control card.
 - (3) The VFD shall automatically recognize the option module after it is powered up. There shall be no need to manually configure the module.
 - (4) Modules may include such items as:
 - i. Additional digital outputs, including relay outputs
 - ii. Additional digital inputs
 - iii. Additional analog outputs
 - iv. Additional analog inputs, including Ni or Pt temperature sensor inputs
 - (5) It shall be possible through serial bus communications to control the status of all optional analog and digital outputs of the VFD.
- t. Standard programmable firefighter's override mode allows a digital input to control the VFD and override all other local or remote commands. It shall be possible to program the VFD so that it will ignore most normal VFD safety circuits including motor overload. The VFD shall display FIREMODE whenever in firefighter's override mode. Firemode shall allow selection of forward or reverse operation and the selection of a speed source or preset speed, as required to accommodate local fire codes, standards and conditions.
- u. A real-time clock shall be an integral part of the VFD.
- (1) It shall be possible to use this to display the current date and time on the VFD's display.
 - (2) Ten programmable time periods, with individually selectable ON and OFF



functions shall be available. The clock shall also be programmable to control start/stop functions, constant speeds, PID parameter setpoints and output relays. It shall be possible to program unique events that occur only during normal work days, others that occur only on non-work days, and others that occur on specific days or dates. The manufacturer shall provide free PC-based software to set up the calendar for this schedule.

- (3) All VFD faults shall be time stamped to aid troubleshooting.
 - (4) It shall be possible to program maintenance reminders based on date and time, VFD running hours, or VFD operating hours.
 - (5) The real-time clock shall be able to time and date stamp all faults recorded in the VFD fault log.
- v. The VFD shall be able to store load profile data to assist in analyzing the system demand and energy consumption over time.
- w. The VFD shall include a smart logic controller to provide advanced control interface capabilities. This shall include:
- (1) Comparators for comparing VFD analog values to programmed trigger values
 - (2) Logic operators to combine up to three logic expressions using Boolean algebra
 - (3) Delay timers
 - (4) A 20-step programmable structure
 - (5) The Smart Logic controller will allow the VFD to operate in closed loop set point (PID) control mode one motor at a controlled speed and control the operation of 2 additional constant speed motor starters. (Cascade Control).
6. Serial Communications
- a. The VFD shall include a standard EIA-485 communications port and capabilities to be connected to the following serial communication protocols at no additional cost and without a need to install any additional hardware or software in the VFD:
 - (1) Johnson Controls Metasys N2
 - (2) Siemens Apogee FLN (P1)
 - (3) Modbus RTU
 - (4) LonWorks Free Topology (FTP) certified to LonMark standard 3.3
 - (5) BACnet MS/TP
 - b. VFD shall have standard USB port for direct connection of Personal Computer (PC) to the VFD. The manufacturer shall provide no-charge PC software to allow complete setup and access of the VFD and logs of VFD operation through the USB port. It shall be possible to communicate to the VFD through this USB port without interrupting VFD communications to the building management system.
 - c. The VFD shall have provisions for an optional 24 V DC back-up power interface to power the VFD's control card. This is to allow the VFD to continue to



communicate to the building automation system even if power to the VFD is lost.

7. Adjustments

- a. The VFD shall have a manually adjustable carrier frequency that can be adjusted in 0.5 kHz increments to allow the user to select the desired operating characteristics. The VFD shall also be programmable to automatically reduce its carrier frequency to avoid tripping due to thermal loading.
- b. Four independent setups shall be provided.
- c. Four preset speeds per setup shall be provided for a total of 16.
- d. Each setup shall have two programmable ramp up and ramp down times. Acceleration and deceleration ramp times shall be adjustable over the range from 1 to 3,600 seconds.
- e. Each setup shall be programmable for a unique current limit value. If the output current from the VFD reaches this value, any further attempt to increase the current produced by the VFD will cause the VFD to reduce its output frequency to reduce the load on the VFD. If desired, it shall be possible to program a timer which will cause the VFD to trip off after a programmed time period.
- f. If the VFD trips on one of the following conditions, the VFD shall be programmable for automatic or manual reset: external interlock, under-voltage, over-voltage, current limit, over temperature, and VFD overload.
- g. The number of restart attempts shall be selectable from 0 through 20 or infinitely and the time between attempts shall be adjustable from 0 through 600 seconds.
- h. An automatic “start delay” may be selected from 0 to 120 seconds. During this delay time, the VFD shall be programmable to either apply no voltage to the motor or apply a DC braking current if desired.
- i. Four programmable critical frequency lockout ranges to prevent the VFD from operating the load at a speed that causes vibration in the driven equipment shall be provided. Automated setting of lockout ranges shall simplify the set-up.

8. Optional Features

- a. All optional features shall be built and mounted by VFD manufacturer. All optional features shall be UL listed by the VFD manufacturer as a complete assembly and carry a UL label.
- b. All panels shall be marked for 100,000 AMP short circuit current rating in compliance with UL.
- c. The enclosure rating of the VFD w/options shall be consistent with the VFD rating of either NEMA/UL type 1 or NEMA/UL type 12, as required for the installation location and/or as called for on the schedule. The package shall include ALL optional devices and shipped as a complete factory tested assembly.
- d. Three-Contactor bypass shall be provided that allows operation of the motor via line power in the event of a failure of the VFD. Motor control selection shall be through either a VFD output contactor or a bypass contactor that are electrically interlocked to ensure that both contactors are not energized simultaneously. A third contactor, the drive input contactor, shall be supplied as standard. This



allows the powering of the VFD with the motor off or operating in bypass mode for testing, programming and troubleshooting purposes.

- e. The three-contactor bypass shall include the following interface and control features:
- (1) Mode selection via a four position DRIVE/OFF/BYPASS/TEST switch.
 - i. DRIVE Mode: Both the drive input and output contactors are closed and the motor is operated via VFD power
 - ii. OFF Mode: DRIVE input, drive output and bypass contactors are all open.
 - iii. BYPASS Mode: Bypass contactor is closed and motor is operating from line power. Both the drive input and drive output contactors are open for servicing of the VFD without power.
 - iv. TEST Mode: Bypass contactor is closed and the motor is operated from line power. The drive input contactor is closed but the drive output contactor is open. This allows for the testing and programming of the VFD while the motor is operated via line power.
 - (2) Contactors shall operate from a 24vdc power supply that shall function off of any two legs of the AC line and shall maintain power on the loss of any one of the AC lines.
 - (3) A bypass pilot light is supplied to indicate that the motor is operating from line power.
 - (4) Common start/stop command when operating in either bypass or VFD mode.
 - (5) Selectable Run Permissive logic shall operate in either VFD or bypass operation. When activated, any command to start the motor, in either hand bypass, remote bypass, hand VFD or remote VFD shall not start the motor, but instead close a relay contact that is used to initiate operation of another device, such as an outside air damper. A contact closure from this device shall confirm that it is appropriately actuated and the motor shall then start.
 - (6) Bypass package shall include an external safety interlock that will disable motor operation in either bypass or VFD when open.
 - (7) Firemode bypass operation shall be standard. When activated via a contact closure, the motor shall transfer to bypass (line power) regardless of the mode selected. All calls to stop the motor shall be ignored. These include the opening of the start command, an external safety trip or the tripping of the motor overload. Firemode operation will take precedence over all other commands.
 - (8) The bypass must include a selectable time delay of 0 to 60 seconds before the initiation of bypass operation. When transferring from VFD to bypass modes, the time delay starts after the motor has decelerated to zero speed. This delay allows the BAS to prepare for bypass operation. Bypass packages that do not include a time delay, or do not include a selectable delay period, will not be acceptable.



- (9) Automatic bypass shall be selectable. When active, the motor shall be transferred to line power on a VFD fault condition. The bypass time delay shall be activated prior to this transfer to line power to allow the VFD time to attempt to recover from the fault condition prior to running in bypass.
- f. Protective Features
- (1) Main input disconnect shall be provided that removes power from both the bypass and VFD.
 - (2) Main input motor rated fuses that protect the entire package.
 - (3) VFD only fast acting input fuses shall be provided. Packages that include only main input motor rated fusing or circuit breaker are not acceptable.
 - (4) Overload protection shall be supplied in bypass mode.
 - i. This overload shall supply minimum class 20 protection as well as wide adjustable current setting for complete motor protection when operating on line power. Those overloads that are not class 20 or current selectable will not be acceptable.
 - ii. Overload protection shall include phase loss and phase imbalance protection.
 - (5) Low voltage contactor operation shall be maintained to 70% of the packages nominally rated voltage. This will ensure VFD operation on low voltage conditions that would otherwise be interrupted due to contactor dropout.
 - (6) The VFD shall be able to operate the motor at a reduced load with the loss of any one of the three phases of power. Contactors shall remain closed regardless of which phase is lost. This will ensure VFD operation on single phase conditions that would otherwise be interrupted due to contactor dropout.
- g. Line/Load Conditioners
- (1) VFDs that do not include 5% DC link impedance shall include 5% AC line reactors in the operations enclosure. Lower levels of impedance will not be acceptable.
 - (2) When the installation requires additional motor dV/dT protection, it shall be via a dV/dT filter mounted in the options enclosure. Packages that include only load reactors or filters supplied separately will not be accepted.
9. Service Conditions
- a. Ambient temperature, continuous, full speed, full load operation:
 - (1) -10 to 45°C (14 to 113°F) through 125 HP @ 460 and 600 volt, through 60 HP @ 208 volt
 - b. 0 to 95% relative humidity, non-condensing.
 - c. Elevation to 3,300 feet without derating.
 - d. AC line voltage variation, -10 to +10% of nominal with full output.



- e. No side clearance shall be required for cooling.
 - f. All power and control wiring shall be done from the bottom.
 - g. All VFDs shall be plenum rated.
10. Quality Assurance
- a. To ensure quality, the complete VFD shall be tested by the manufacturer. The VFD shall drive a motor connected to a dynamometer at full load and speed and shall be cycled during the automated test procedure.
 - b. All optional features shall be functionally tested at the factory for proper operation.

PART 3 - EXECUTION

3.1 START-UP SERVICE

- A. The manufacturer shall provide start-up commissioning of the VFD and its optional circuits by a factory certified service technician who is experienced in start-up and repair services. Sales personnel and other agents who are not factory certified shall not be acceptable as commissioning agents. Start-up services shall include checking for verification of proper operation and installation for the VFD, its options and its interface wiring to the building automation system.
- B. Harmonic filtering. The VFD supplier shall, with the aid of the buyer's detailed electrical power single line diagram showing all impedances in the power path to the VFDs, perform an analysis to initially demonstrate the supplied equipment will meet the IEEE recommendations after installation. If, as a result of the analysis, it is determined that additional filter equipment is required to meet the IEEE recommendations, then the cost of such equipment shall be included in the drive supplier quotation.

3.2 TRAINING

- A. Train LAWA Maintenance personnel after the system is fully operational.
- B. Provide minimum of 12 hours (3 shifts) of classroom and hands on training to LAWA Maintenance personnel.

END OF SECTION 23 81 07