Variable Speed Drive Specification

Part 1 – General

A. Description

1. This specification describes an AC variable speed Direct Torque Control or sensorless vector equivalent drive (VFD) used to control the speed of a centrifugal pump power with an AC induction motor

Part 2 – Product

B. Adjustable Frequency Drives

1. The VFD shall be a solid state AC to AC inverter controlled device utilizing the latest isolated gate bipolar transistor (IGBT) technology. The VFD shall utilize Direct Torque Control (DTC) as the primary motor control, employing an inner loop torque control strategy that mathematically determines the optimal motor torque and flux every 25 microseconds. The VFD shall also provide an optional motor control operational mode for scalar of V/Hz operation.
2. The benefits that the motor control DTC shall make available for the operation of a NEMA design B induction motor shall be:
    a. Steady state speed accuracy within 1/10th the slip without an encoder, for process repeatability.
    b. 100% motor torque from zero speed available for acceleration with the VFD continuous current rating equal to or greater than the motor full load amp rating.
    c. At and below 90% speed, 100% torque is achievable even with 10% low line voltage.
    d. Ability to limit torque to protect the mechanical system with a common single torque setting above and below field weakening.
    e. Ability to provide torque in % of motor shaft torque (within +/- 4% linearity) on the VFD control panel, analog output or via field bus of actual.
    f. Quiet motor operation for audibly friendly working environment in comparison to other low voltage PWM solutions utilizing a carrier frequency.
    g. Have available the ability to operate in open loop torque control, with an ability to switch between speed and torque control on the fly with the change of state to a digital input.
    h. Have an ability to share load or speed between two or more induction AC motors connected to the same system, when those motors are controlled by separate drives.
3. The VFD shall be manufactured by a company with at least twenty (20) years' experience in the production of this type of equipment

4. The VFD shall meet the following specifications:
    a. UL 508A and/or 508C - Underwriter's Laboratory. The drive shall be UL listed and carry the UL mark.
    b. CAN/CSA-C22 No. 14-M91 - Canadian Standards Association. The drive shall be C-UL or CSA listed and carry the appropriate mark.
    c. The drive shall comply with the following European Union's CE directives and shall carry the CE mark:
        a) EMC Low Voltage Directive 73/23 EEC
        b) EMC Directive 89/336 EEC
        c) Machinery Directive 98/37 EC
5. The VFD shall utilize the same communications architecture, utilizing plug-in communications cards, for high-speed noise immune connectivity throughout the entire Drive manufacturer's Power range.

C. Ratings

1. The VFD shall be rated to operate from 3-phase power at 208 to 690 VAC +10/-10%. The overvoltage trip level shall be a minimum of 30% over nominal, and the under voltage trip level shall be a minimum 35% under the nominal voltage.
2. The VFD shall be rated to operate at the following environmental operating conditions:
    a. Ambient temperature 0 to 40°C continuous and up to 50°C continuous with a derating factor.
    b. Altitude 0 to 3300 feet above sea level without derating, less than 95% humidity, non-condensing.
3. The VFD shall be offered from 3 to 4250 HP in similar construction and operation, using the same technology.
4. The VFD shall be rated to operate from input power from 48Hz to 63Hz.
5. Output voltage and current ratings shall match the adjustable frequency operating requirements of standard NEMA design A or NEMA design B motors.
6. The Light Duty overload current capacity shall be 110% of rated current for one (1) minute out of five (5) minutes.
7. The Heavy Duty overload current capacity shall be 150% of rated current for one (1) minute out of five (5) minutes.
8. The VFD efficiency shall be 98% or better of the full rated capability of the VFD at full speed and load.

D. Construction

1. All models shall provide a complete, ready-to-install solution.
2. The latest, most efficient IGBT power technology shall be used. This technology shall be used for all power and voltage ranges offered by the manufacturer.
3. The VFD shall offer microprocessor based control logic that is isolated from power circuitry.

4. Control connections shall remain consistent for all power ratings.
5. Cabinet VFDs shall be available from 75 to 4250 HP and have the following features:
    a. Offered in UL Type 1 and UL Type 12 with filter and forced air enclosures.
    b. Include a control panel mounted on the front of the VFD enclosure door.
    c. Single point power connections per each electrical phase.
    d. Include integrated internal AC line reactor or DC choke.
    e. Include input disconnect or Molded Case Circuit Breaker (MCCB) with through the door interlock lockable in the off position.
    f. Include high speed input AC line fuses for protection of the input bridge.
    g. Offer option internally mounted braking chopper for use in dynamic braking.
    h. Common mode filter standard above 200 HP, optional below 200 HP.
6. Desired optional features shall be furnished and mounted by the VFD manufacturer and shall also be available as field installable kits as an alternative. All optional features shall carry all of the necessary certifications as described in Section 1.03. Field installed kits shall not affect the VFD's certification.

E. Operator Interface (Keypad)

1. The VFD shall be equipped with a front mounted operator control panel consisting of:
    a. A four- (4) line back-lit alphanumeric LCD display that is 240x160 pixels.
    b. Configurable displays showing, bar graph and meter.
    c. Keypad with keys for Run/Stop, Local/Remote, Increase/Decrease, Reset, Menu navigation and Parameter select/edit.
2. The control panel shall be removable, capable of remote mounting and allow for uploading and downloading of parameter settings as an aid for start-up of multiple VFDs.
3. The display of the control panel shall have the following features:
    a. All parameter names, fault messages, warnings and other information shall be displayed in complete American English words or standard American English abbreviations to allow the user to understand what is being displayed without the use of a manual or cross-reference table.
    b. During normal operation, one (1) line of the control panel shall display the speed reference, and run/stop forward/reverse and local/remote status. The remaining three (3) lines of the display shall be programmable to display the values of any three (3) operating parameters. The selection shall include at least the following values:
        a) Speed/torque in percent (%), RPM or user-scaled units.
        b) Output frequency, voltage, current and torque.
        c) Power and kilowatt hours.
        d) Heatsink temperature and DC bus voltage.
        e) Status of discrete inputs and outputs.
        f) Values of analog input and output signals.

g) Values of PID controller reference, feedback and error signals.

4. The control panel shall be used for local control, for setting all parameters, and for stepping through the displays and menus.
5. A copy function to upload and store parameter settings from a VFD and download stored parameter settings to the same VFD or to another VFD shall exist.
6. Intelligent configuration wizards shall be provided as standard, and are used automatically set up the VFD for most common applications. By answering a few application questions the wizard will parameterize the VFD for that operation. A minimum of the following wizards are required.
    a) Basic Start Up (speed control)
    b) Process Control
    c) SmartFlow
    d) Pump Protection
    e) Multipump
    f) Water/Wastewater Functions
    g) Multivariable Setup
    h) I/O Configuration
    i) Parameter Restore
7. The display shall have a real time clock and calendar for the purpose of displaying time and date stamped faults and warnings.
8. Additional keypad features shall include the following;
    a) A mini USB connection port shall be located on the keypad for the purpose of capturing various screens to a standard computer.
    b) Up to 21 home screens enabling the user to predefine personalized screens for multiple specific operations.
    c) Trend capability
    d) Status LED (faults and warnings)
    e) Multifunction softkeys

F. Protective Features

1. For each programmed warning and fault protection function, the VFD shall display a message in complete English words or Standard English abbreviations. The VFD shall be capable of displaying up to thirty-two (32) active faults and warnings and store the previous five (5) non-active faults and warnings, all with a real time stamp as to when they occurred. The VFD shall provide a help feature to further explain the displayed fault.
2. The VFD shall include internal MOV's for phase to phase and phase to ground line voltage transient protection.
3. Output short circuit and ground fault protection rated for 100,000 amps shall be provided per UL508A when protected with fusing specified in the hardware manual.
4. Motor phase loss protection shall be provided.
5. The VFD shall provide electronic motor overload protection qualified per UL508C.
6. Protection shall be provided for AC line or DC bus overvoltage at 130% of maximum rated voltage or undervoltage at 65% of min. rated voltage.

7. The VFD shall protect itself against input phase loss.
8. Power loss ride through feature shall allow the VFD to remain fully operational after losing power as long as kinetic energy can be recovered from the rotating mass of the motor and load.
9. Stall protection shall be programmable to provide a warning or stop the VFD after the motor has operated above a programmed torque level for a programmed time limit.
10. Underload protection shall be programmable to provide a warning or stop the VFD after the motor has operated below a selected underload curve for a programmed time limit.
11. Over-temperature protection shall provide a warning if the power module temperature is less than 5°C below the over-temperature trip level.
12. Input terminals shall be provided for connecting a motor thermistor (PTC type) to the VFD's protective monitoring circuitry. An input shall also be programmable to monitor an external relay or switch contact.

G. Control Inputs & Outputs

1. Discrete Inputs
    a. Minimum of six (6) discrete inputs shall be provided.
    b. Minimum of six (6) shall be independently programmable with function selections (run/stop, hand-off-auto, etc.).
    c. Inputs shall be designed for use with either the VFD's internal 24 VDC supply or a customer supplied external 24 VDC supply.
2. Discrete outputs
    a. Minimum of two (2) form C relay contact outputs shall be provided
    b. All outputs shall be independently programmable to activate with at least 30 function selections including;
        a) Operating conditions such as drive ready, drive running, reversed and at set speed
        b) General warning and fault conditions.
        c) Adjustable supervision limit indications based on programmed values of operating speed, speed reference, current, torque, and PID feedback.
        d) Relay contacts shall be rated to switch 2 Amps at 24 VDC or 115/230 VAC.
3. Analog Inputs
    a. Minimum of two (2) analog inputs shall be provided:
        a) Two (2) shall be selectable for either a current or a voltage input.
        b) Resolution of analog inputs shall be at least 11bit total resolution.
    b. Inputs shall be independently programmable to provide signals including speed / frequency reference, torque reference or set point, PID set point and PID feedback / actual.

c. A differential input isolation amplifier shall be provided for each input.

d. Analog input signal processing functions shall include scaling adjustments, adjustable filtering and signal inversion.

e. If the input reference is lost, the VFD shall give the user the option of the following (the VFD shall be programmable to signal this condition via a keypad warning, relay output and/or over the serial communications bus):
   a) Stopping and displaying a fault.
   b) Running at a programmable preset speed.
   c) Hold the VFD speed based on the last good reference received.
   d) Cause a warning to be issued, as selected by the user.

f. When inputs are used as speed references, reference signal processing shall include increase/decrease floating point control.

4. Analog Outputs

   a. Minimum of two (2) 0 / 4-20 mA analog outputs shall be provided.

   b. Outputs shall be independently programmable to provide signals proportional to output function selections including output speed, frequency, voltage, current and power.

5. Digital Inputs/Outputs

   a. Minimum of two (2) digital inputs/outputs shall be provided.

   b. Minimum of one (1) can be programmed as a frequency input.

   c. Minimum of one (1) can be programmed as a frequency output.

6. Safety Inputs

   a. A Safe Torque Off (STO) terminal shall be integrated in the drive as a standard.

   b. The STO function shall meet a Safety Integrity Level (SIL) 3 and a Performance Level (PL) e.

   c. The STO function shall be certified by a third party approval agency e.g. TUV Nord.

7. The VFD shall have the capability to receive an I/O option module for the purpose of adding two bidirectional digital I/O points, one analog output, and three analog inputs.

H. Serial communications

1. Serial communication interface modules shall be available for a wide selection of communication protocols. Available adapters are as follows: Modbus RTU, Modbus TCP, Profibus, ProfiNet, DeviceNet, ControlNet, Ethernet and Ethernet IP.

2. Serial communication capabilities shall include, but not be limited to, run-stop control; setpoint adjustment, current limit, and accel/decel time adjustments. The drive shall have the capability of allowing the Distributed Drive Controller (DDC) to monitor feedback such as process variable feedback, output speed/frequency,

current (in amps), % torque, power (kW), kilowatt hours (resettable), operating hours (resettable), relay outputs, and diagnostic warning and fault information. Additionally, remote Local Area Network (LAN) VFD fault reset shall be possible.

3. An integrated mini USB port shall be provided for access to the VFD when using a personal computer. Microsoft Windows®-based software shall be available for drive setup, diagnostic analysis, monitoring and control. The software shall provide real time graphical displays of drive performance.

I. Basic VFD Control Functions & Adjustments

1. Output frequency shall be adjustable from 0 to 500 Hz. Operation above motor nameplate shall require programming changes to prevent inadvertent high-speed operation.
2. Stop mode selections shall include coast to stop and ramp to stop.
3. The VFD shall be capable of controlling deceleration of a load without generating an overvoltage fault caused by excessive regenerated energy. Overvoltage control on deceleration shall extend the ramp time beyond the programmed value to keep the amount of regenerated energy below the point that causes overvoltage trip.
4. The VFD shall be capable of controlling a rotating motor regardless of the motor direction. From the time the start signal is given to the VFD to the time the VFD has control of the motor shall not exceed two (2) seconds. Once the VFD has control of the motor it will than accelerate or decelerate the motor to the active reference speed without tripping or faulting or causing component damage to the VFD. The VFD shall also be capable of flux braking at start to stop a reverse spinning motor prior to ramp.
5. The VFD shall have the ability to automatically restart after an overcurrent, overvoltage, undervoltage, or loss of input signal protective trip. The number of restart attempts, trial time, and time between reset attempts shall be programmable.
6. Control functions shall include one (1) set of acceleration and deceleration ramp time adjustments with linear ramp time selection.
7. Speed control functions shall include:
    a. Adjustable min/max speed limits.
    b. Two sets of critical speed lockout adjustments.
    c. A built-in PID controller to control a process variable such as pressure, flow, temperature, or level.
8. Functions shall include flux optimization for optimizing energy efficiency and limit the audible noise produced by the motor by providing the optimum magnetic flux for any given speed / load operating point.
9. The VFD shall be capable of sensing a loss of load (broken belt / broken coupling) and signal the loss of load condition. The VFD shall be programmable to signal this condition via a keypad warning, relay output and/or over the serial communications bus. Relay output shall include programmable time delays that will allow for VFD acceleration from zero speed without signaling a false underload condition.

10. Two (2) programmable critical frequency lockout ranges shall be provided to prevent the VFD from operating the load continuously at an unstable speed.
11. The VFD shall offer software to select the VFD's action in the event of a loss of the primary speed reference.

Part 3 – Controls and Programming

A. General Application Program

1. All logic set forth in this specification must reside internal to the VFD's internal microprocessor. If an external controller is required it must be clearly stated and included in the base bid.
2. VFD shall be preprogrammed with a pump specific application macros.
3. The VFD shall use pump specific wizards to guide the user through the process of setting up most common pump functions. At the completion of a wizard the VFD must automatically configure itself for that specific functionality. At a minimum the VFD must contain the following wizards:
    a. Basic Start Up (speed control)
    b. Process Control
    c. SmartFlow
    d. Pump Protection
    e. Multipump
    f. Water/Wastewater Functions
    g. Multivariable Setup
    h. I/O Configuration
    i. Parameter Restore
4. The Control Panel (keypad) should have the ability to display pump nomenclature (PSIG, GPM, IP/s, mm/s, etc.) to allow the operator to have a better understanding of the current pump and system status.
5. VFD shall have an internal Proportional/Integral/Derivative (PID) control algorithm to control a process variable such as pressure, flow, level, temperature, etc. The PID controller should be able to regulate speed or torque to accurately control the process variable.
    a. The VFD shall recognize system low demand and have the option to automatically shut down in a suspended sleep mode until the process demand requires the pump to turn back on.
6. The VFD system shall have the ability to perform process control (PID) using either motor speed, or motor torque, as the manipulated variable.
7. The VFD shall have the ability to follow a speed reference through the VFD's keypad, an analog input or serial bus command.
8. A second PID control algorithm is to be available for the purpose of enabling the drive to conduct two different PID functions.

B. Multipump Operation

1. The VFD shall include a Multipump Macro, set up by using a wizard, which will permit up to 6 VFDs to communicate on a peer-to-peer (drive to drive) network for the purpose of staging on and off up to 6 pumps. One drive will operate one pump.
2. Multipump operation shall be functional for any PID control operation.
3. Drive to drive communication shall be over a dedicated industrialized RS485 serial communications network. This network must be integrated into the base VFD and not require a separate communications module.
4. The VFD shall control to a single process variable and automatically stage and de-stage pumps on and off depending on the process demand. The settings at which the pumps are staged and de-staged shall be field adjustable through the VFD's standard keypad.
5. Staging can be operator set to be dependent on pump speed and error, or on process value.
6. In the event of a VFD, motor, or pump fault the Multipump system will recognize this failure and shall automatically start the next available pump when required.
7. When multipump pumps are running the VFDs shall synchronize in speed to ensure the pumps share the load evenly.
8. In the event a pump is demonstrating wear and is not able to share the load equally a synchronous torque option will be available. This option will synchronize the torques of all the running pumps to help evenly distribute the load over all the running pumps. The motors shall be identical on all the pumps running in synchronous torque mode.
9. The VFDs shall alternative the operation of the pumps based on one or both of the following criteria.
    a. Operating hours
    b. Number of sleeps
10. The VFD shall have a pressure boost function to compensate for additional system friction losses at higher flow rates. This function shall automatically increase the pressure setpoint when additional pumps are staged on. Alternatively the pressure setpoint will decrease as pumps are de-staged off.
11. The Multipump operations must permit the user to limit the maximum number of pumps that may run at any one time or the minimum number of pumps that may run at any one time.
12. The Multipump operation must offer the security of a roaming lead where if the designated lead pump fails a subsequent VFD will become the lead for the purpose of maintaining Multipump operation.

C. Flow Estimation

1. The VFD shall have the ability to estimate the pump flow to an accuracy of ≤ ±5% of the total rated pump flow through a variable speed range of 50%-100% of the motor synchronous speed and without external process transmitters for pumps with a specific speed under 3000. For pumps with a specific speed greater than 3000 then it is permitted to add a differential transmitter across the pump to assist in calculating flow.
2. When flow estimation is used in conjunction with Multipump operation the total estimated flow must be available to the lead VFD for proper PID operation.
3. The flow calculation algorithm shall be operational using commonly available pump performance curves. Factory performance tests shall not be required to attain the flow accuracy.
4. The flow calculation algorithm shall have the ability to be field calibrated without requiring field instrumentation.
5. ( ) When checked; the flow calculation logic shall be capable of correcting for a changing specific gravity via a 4-20 mA signal, serial buss communication, or corrected via temperature transmitter input.
6. ( ) When checked; The flow calculation logic shall be capable of calculating pump flow on a magnetic drive pump with a metal containment shell.
7. ( ) When checked; sensorless flow calculation is required for a pump specific speed (Ns) above 3000. This additional capability shall require only the use of a differential pressure transmitter across the pump or the use of a suction and discharge side pressure transmitter.

D. Flow Based Features

1. The VFD shall include an integrated flow totalizer which may totalize based on the sensorless flow estimator value or the input of a flow transmitter.
2. The VFD shall have the ability to use an external flow transmitter or the sensorless calculated flow value for the purpose of batch operations, where at a preset value the VFD will take action to shut down the pump.
3. The VFD shall have the ability to calculate real time percent of Best Efficiency Point (BEP) and display this value on the display.
4. The VFD shall have the ability to estimate the Total Dynamic Head (TDH) of the pump and display this value on the keypad display.
5. The VFD shall have a minimum flow rate bypass capability for when the flow rate is less than the pump's min flow value. When below minimum flow is detected a digital output of the VFD shall turn on to operate a flow bypass valve. The bypass valve should turn off when the flow rate exceeds a preset flow value above the pump's minimum flow rate.

E. Pump Protection

1. Pump Protection – The VFD shall have the ability to warn and/or protect the pump against process upset conditions of dry-running (severe cavitation), operation

below recommended minimum flow, and operation past recommended maximum flow throughout the anticipated variable speed range and without the need for external process transmitters.

a. The pump protection feature shall be easily set-up using values of flow (GPM or M3/hr).

b. The pump protection feature shall have the ability to offer control reactions specific to the condition:

c. Dry-Run: Warn only, Warn & Stop

d. Min-Flow: Warn only, Warn & Control to Min Speed

e. Max-Flow: Warn only

f. The protection logic shall account for changing load profiles due to changes in speed, including mechanical and hydraulic losses

g. The protection logic shall not false trip when the drive is reducing speed in normal control modes.

h. ( ) When checked; The protection logic shall be capable of calculating pump flow on a magnetic drive pump with a metal containment shell.

F. Flow Economy

1. Flow Economy – The VFD shall have the ability to calculate the Flow Economy ratio of pump flow divided by electrical input power.

    a. The pump flow shall be calculated using a sensorless flow function integral to the VFD.

    b. The electrical power input shall be the true electrical power consumption which includes all VFD and motor losses.

    c. The Flow Economy Ratio shall be a selectable parameter on the VFD's keypad and shall be available through a 4-20mA output or through a serial bus register.

G. Condition Monitoring

1. VFD shall have the capability to monitor up to two (2) channels of information. These channels shall be either an external 4-20mA / 0-10VDC analog inputs or a minimum of 13 internal VFD and pump signals.

    a. The keypad display should clearly indicate the units of the condition monitored such as Amps, Hz, IP/s or mm/s etc.

    b. The VFD will have two programmable levels for a high condition and two programmable levels for low levels to signal a warning and alarm.

    c. In the event the event the alarm level is reached VFD shall have the option to signal an alarm, go to a safe predetermined minimum speed, fault the pump or go into a suspended sleep mode until the level is restored above normal.

H. Cavitation Control

1. The VFD shall have the ability to monitor the suction conditions of a pump and react to prevent the onset of pump cavitation.
2. The VFD shall have the ability to monitor an external analog signal from either a suction pressure or level transmitter.
    a. When the suction conditions of the pump reach a critical low level the VFD will slow down to reduce the NPSH requirement of the pump.
    b. The intensity at which the VFD reduces the pump speed shall be configurable to the specific application.
3. The VFD shall resume normal operation above the low level limit threshold.

I. Water & Waste Water Functions

1. The VFD shall have a Pump Cleaning sequence with the following features.
    a. Initiation of the sequence is based on the ability to detect a blockage in the pump using sensorless speed and torque measurements.
    b. On detection of this blockage the pump shall enter into a Pump Cleaning Sequence. This sequence includes running the pump in a programmed designed to clear blockages. This program includes running the pump in forward and reverse directions until the blockage is cleared.
    c. If the blockage can not be cleared the drive shall fault the pump and clearly identify the pump has faulted dues to blockage.
    d. The VFD supplier shall verify with the pump manufacturer the pump is suitable to run in reverse rotation.
2. The VFD shall have a Pipe Fill sequence for the purpose of preventing run out due to the lack of back pressure.
    a. Initiation of the pipe fill sequence shall cause the pump to run at a safe user set speed prior to the VFD returning to its normal operation (PID or speed control).
3. The VFD shall include a Snore sequence for the purpose of removing floating debris.
    a. The Snore sequence will cause the pump to drain the sump at periodic intervals for the purpose of removing floating debris.
4. The VFD shall have a Pipe Cleaning sequence for the purpose of flushing the pipe system in an effort to reduce sedimentation buildup in the pipe.

Part 4 - WARRANTY

A. VFD Warranty

1. VFDs shall be warrantied against any and all defects in craftsmanship and materials for a time of 18 months from date of shipment. Faulty VFDs may be repaired on site or may be sent back to the factory for repair based on the supplier's recommendation.

B. Reliability Guarantee

1. The pump, motor, and VFD are required to be warrantied for a period of 36 months from the date of commissioning not to exceed 42 months from the date of shipment for new pump installations and at least 18 month for existing pump installations.
    a. The pump is to be warrantied against damage due to process related upset conditions (dry run, minimum flow, and run out) and shall cover parts only. Labor, shipping, and in/out costs are not part of this warranty.
    b. The VFD warranty shall be 36 months from date of shipment, and shall cover parts and repair labor only. In/out costs are not covered under this extended warranty. Faulty VFDs may be repaired on site or may be sent back to the factory for repair based on the supplier's recommendation.