

1.0 Purpose and Scope:

1.1 Purpose:

This specification defines the requirements for the design, manufacture, test, quality control/quality assurance, and shipment of high performance, high efficiency Medium Voltage (MV) Variable Frequency Drive (VFD) packages.

1.2 Scope:

This specification defines the performance requirements, power quality control requirements (for both input and output power), functional and protective features of the VFD, as well as Operator interface. The VFD is one component of a larger system. The overall system specification is beyond the scope of this document. This specification is limited to the VFD and its interface with other components of the system.

2.0 Codes and Standards:

2.1 Codes and Standards:

All equipment and materials shall comply with the applicable portions of the Codes and Standards of the following organizations:

- IEEE 519
- UL 347A
- CSA
- NEMA
- NEC
- ANSI
- IEC

3.0 Power Requirements and Service Conditions:

3.0.1: Power Requirements:

3.1.1:

The VFD shall operate from 3 phase, 2400Vac or 4160Vac +10% -20%, 60Hz $\pm$ 5%.

3.1.2:

The VFD shall be provided with control power of 1 phase, 200/240V $\pm$ 10%, 50/60Hz, $\pm$ 5%, 5-15kVA, kVA rating is model specific.

3.0.2: Service Conditions:

3.2.1:

Operating Temperature: The VFD shall operate in an ambient temperature range of -5 to 40°C (+23 to +104°F) without derating, to 50 °C (122 °F) with derating. Derating not to exceed 1% / °C

3.2.2:

Storage Temperature: The VFD shall be capable of being stored in an ambient temperature range of -10 to 50 °C (+14 to +122 °F) continuously, -20 to 60 °C (-4 to +140 °F) for up to 3 months in shipping.

3.2.3:

Humidity: The VFD shall operate in a relative humidity of 95% maximum, non-condensing

3.2.4:

Altitude: The VFD shall operate without derating at an altitude range from 0 to 2000masl (0 to 6600ft). Above 2000masl, the VFD shall operate with current derate of 1%/1000m and voltage derate of 1.25%/1000m to a maximum of 4500masl (14,800ft).

3.2.5:

Environment: The VFD shall operate in general environmental conditions, free of dust, saline, and corrosive gases.

3.2.6:

Vibration: Maximum vibration 1G@ 10-20Hz, 0.2G@ 20-50Hz

3.2.7:

Maximum audible noise level: 80dBA @ 3 feet (1 Meter) from enclosure.

4.0 Performance Requirements:

4.0.1: VFD Configuration:

4.0.1.1:

The VFD shall be a digital microprocessor based modern design providing for state of the art control, operation, packaging, and sustainability in a variety of environments.

4.0.1.2:

The VFD shall be able to control either 3 phase ac induction or synchronous motors by using a Pulse Width Modulation (PWM) algorithm to provide adjustable voltage and frequency from a fixed power source.

4.0.1.3:

The VFD shall produce a 9-level (17-level, line to line) low voltage spike output waveform to provide smooth motor operation with minimal harmonics.

4.0.1.4:

The VFD shall be constructed using compact, self contained, modular power cell each containing all of the power electronic components (rectifiers, capacitors and IGBTs) in appropriate configurations to facilitate quick, easy replacement in the unlikely event of a power cell failure.

4.0.1.5:

The VFD shall be designed with utmost operational safety in mind, by using fiber optic isolation cabling between control and power cell sections.

4.0.1.6:

The Power Cells shall be accessible from the front of the unit without the need to disassemble any power bus structure.

4.0.1.7:

The Power Cells shall not need to be replaced in pairs or any other specific combination relating to rating or “gain matching” considerations.

4.0.1.8:

All power wiring to the power cells shall be with screw terminals at the front of the unit for easy access.

4.0.2 VFD Operating Modes and Performance:

4.0.2.1:

The VFD shall be capable of operating in four control modes, Open Loop Vector (OLV), Closed Loop Vector (CLV), and V/f for Induction Motors; Closed Loop Vector (CLV) for Synchronous Motor operation (exciter provided by others).

4.0.2.2:

OLV Torque Control Accuracy shall be $\pm 5\%$; CLV Torque Control Accuracy shall be $\pm 3\%$

4.0.2.3:

The Frequency Control Range shall be from 0.01 to 120Hz with accuracy of $\pm 0.5\%$.

4.0.2.4:

Acceleration / Deceleration Time shall be 0.1 to 6000 seconds.

4.0.2.5:

Torque ripple: torque perturbations at the motor shaft caused by the VFD output waveform shall be $\leq \pm 2\%$ of rated torque.

4.0.2.6:

In OLV, the VFD shall have a speed range of 100:1 and minimum speed regulation of 0.2%.

4.0.2.7:

In CLV, the VFD shall have a speed range of 1000:1 and minimum speed regulation of 0.02%.

4.0.3 Autotuning:

4.0.3.1:

The VFD shall be capable of autotuning that will run the motor and automatically calculate and set motor parameters within the VFD.

4.0.3.2:

The VFD shall be capable of static autotuning to measure line-to-line resistance.

4.1 Efficiency:

4.1.1:

The VFD shall have a minimum efficiency of 97% at rated speed and full load. This efficiency shall include effects of input transformers or reactors, input and/or output filters, and power factor correction components. Losses from control power, cooling fans etc. shall also be included in this calculation.

4.2 Overload Capability:

4.2.1

The VFD shall have a minimum overload capability of 110% for 1 minute and 120% for 15 seconds, each for 1 event every 10 minutes. Some loads present a higher overload requirement.

4.3 Power Quality:

4.3.1:

Input harmonics: The VFD input current harmonics shall be less than 2.5% measured at the VFD input terminals. These harmonic levels shall be confirmed by an independent testing agency such as TUV.

4.3.2:

Input power factor: The VFD input power factor shall be 0.95 or greater regardless of speed and for any load $> 50\%$ of full load. This input power factor shall be achieved without supplemental power factor correction components.

4.3.3:

Output waveform: The VFD shall produce a sinusoidal output waveform with minimal total harmonic distortion without supplemental filtering.

4.3.4:

Surge voltage (reflected wave phenomenon): The VFD switching voltage shall be such that it will not damage standard motor insulation, without the need for supplemental filters.

4.3.5:

Maximum cable length: For standard applications, the maximum motor lead length shall be 1,000 Meters, without supplemental filtering.

4.4 Control Features and Functions:

4.4.1: The VFD shall have, as a minimum, the following control features and functions:

4.4.1.1:

Acceleration and Deceleration (accel/decel) Control: The VFD shall have four (4) independent sets of accel/decel ramps to optimize process control. Each of the eight (8) ramps shall have a range of adjustment of 0.1 to 6000 seconds. An additional accel/decel set shall be provided for jog mode, and an additional decel ramp shall be provided for Fast Stop.

4.4.1.2:

"S curve" Acceleration and Deceleration Control: The VFD shall have an S curve function to soften the start and end of the accel and decel ramps. Four (4) independent S curve functions shall be provided, one each for accel start, accel end, decel start and decel end.

4.4.1.3:

Speed Reference: The VFD shall have the capability of setting speed from the built-in digital operator, a remote signal of either 0 to 10VDC or -10 to +10VDC, 4-20ma, or serial communication. Analog input resolution shall be 0.03Hz.

4.4.1.4:

Preset Speeds: The VFD shall be capable of operating at one of seventeen (17) internally preset speeds, selectable by contact closure or serial communication.

4.4.1.5:

Increase or Decrease Speeds by Contact Closure: The VFD shall be capable of accelerating or decelerating for the length of time a contact closure is made (digital M.O.P. function).

4.4.1.6:

Upper and Lower Speed Reference Limits: The VFD shall have internally adjustable parameters to limit the upper and lower speeds of the VFD regardless of the speed reference command.

4.4.1.7:

Jump Frequencies: The VFD shall have three (3) jump frequency settings to avoid mechanical resonance. The jump frequency bandwidth shall be adjustable.

4.4.1.8:

DC Injection Braking: The VFD shall be capable of providing an adjustable DC current to the motor at start (to stop a coasting motor and restart it under control), or at stop (to prevent coasting when the output frequency has decelerated to zero).

4.4.1.9:

Speed Search: The VFD shall be capable of starting into a spinning motor (forward or reverse direction) and continue operation without the need of pulse generator feedback.

4.4.1.10:

Slip Compensation: The VFD shall provide slip compensation in open loop modes of operation to improve speed regulation with varying load conditions.

4.4.1.11:

High Slip Braking: The VFD shall provide for high slip braking operation to limit the need for external motor energy consumption hardware (dynamic braking) during hard braking operations.

4.4.1.12:

Droop Control: The VFD shall have a droop control function to allow load sharing between two VFDs and their motors.

4.4.1.13:

PID Function: The VFD shall have an internal Proportional-Integral-Differential (PID) control function (with sleep mode) to minimize external control requirements.

4.4.1.14:

Torque Control: The VFD shall be capable of operating as a torque regulator as well as a speed regulator and be capable of switching between the modes by contact closure or logic command.

4.4.1.15:

Energy Saving Function: The VFD shall be capable of adjusting the V/f ratio applied to the motor to optimize energy consumption in lightly loaded applications.

4.4.1.16:

ASR: The VFD shall provide an Automatic Speed Regulator function for increased performance capability.

4.4.1.17:

AFR: The VFD shall provide an Automatic Frequency Regulator function for increased performance in high dynamic load operating conditions.

5.0 Protective Functions:

5.0.1: Motor and Load protection:

5.0.1.1:

The VFD shall have, as a minimum, the following motor and load protection features:

5.0.1.2:

Motor Overload Protection: The VFD shall calculate motor overload based on torque requirements and motor parameters. The motor overload detection level shall be adjustable. The motor overload protection time constant shall be adjustable. Actions taken at time of overload shall be selectable from decelerate to stop, coast to stop, Fast Stop at the Fast Stop deceleration time, or continue operation while outputting a motor overload signal.

5.0.1.3:

Torque limit: The VFD shall be provided with an adjustable torque limit function for machine protection.

5.0.1.4:

Overtorque and Undertorque Detection: The VFD shall have independently adjustable overtorque and undertorque detection levels. Action taken at time of detection shall be selectable between stopping the VFD or continuing operation while outputting an overtorque or undertorque detection signal.

5.0.1.5:

Overcurrent Detection: The VFD will detect output overcurrent and react according to selected operation settings.

5.0.1.6:

Stall Prevention: The VFD shall have a stall prevention function during acceleration. The purpose is to prevent the motor from exceeding its breakdown torque level while accelerating a high inertia load, and stalling. Stall prevention shall be selectable between two (2) implementations:

- Stopping acceleration until the output current reduces below the stall prevention setpoint, **or**
- Intelligent Acceleration, where the drive continues to accelerate at the stall prevention current level.

5.0.2 Power Transient Protections:

5.0.2.1:

Automatic Restart After Power Loss: The VFD shall be capable of restarting automatically after a loss of incoming power. The power loss time shall be adjustable to as long as 25.5 seconds, rating dependent. Upon restart, the VFD shall utilize a speed search function to capture the coasting motor and return it to set speed. Note: Requires that control power be maintained (Uninterruptible Power Supply (UPS) optional).

5.0.2.2:

Automatic Restart After a Fault: The VFD shall be capable of restarting automatically after an internal fault trip. The number of restart attempts and the maximum restart time shall be adjustable. Upon restart, the VFD shall utilize a speed search function to capture the coasting motor and return it to set speed.

5.0.2.3:

Input Overvoltage: The VFD shall trip in the event of an input overvoltage greater than 120% of nominal voltage. The overvoltage detection time shall be adjustable to as long as 2 sec.

5.0.2.4:

Input Undervoltage: The undervoltage level (AUV) shall be adjustable to prevent nuisance trips when the application can tolerate brief undervoltage conditions. The undervoltage level shall be adjustable to as low as 65% of nominal voltage.

5.0.2.5:

Momentary Power Loss: The VFD shall provide for momentary power loss recovery protection when a loss of input power occurs for a maximum of up to 2 seconds. When power is restored, the VFD shall execute a speed search function to capture the motor and smoothly accelerate to set speed. Note: Requires that control power be maintained (Uninterruptible Power Supply (UPS) optional).

5.0.2.6:

Kinetic Energy Braking (KEB): The VFD shall be capable of remaining in operation during an input power loss by absorbing stored mechanical energy from the load, decelerating as necessary to maintain operation. Requires uninterruptible Power supply (UPS) for control power (optional, or by others).

5.0.3: General Protective Functions:

5.0.3.1:

Loss of Frequency (Speed) Reference: If selected by parameter setting, the VFD shall be capable of continuing operation after loss of frequency reference. "Loss of frequency reference" is defined as a drop in frequency reference of over 90% in 400msec.

5.0.3.2:

Output Phase Loss: The VFD shall be capable of detecting the loss of one or two output phases, shut down the VFD and announce the fault.

5.0.3.3:

Output Ground fault: The VFD shall be capable of detecting an output ground fault condition. The output ground fault detection level and time shall be adjustable. Action taken at the time of ground fault detection shall be selectable among no action (detection disabled), coast to rest, or continue operation and provide a "Ground Fault" digital output.

5.0.3.4:

Control Power Loss: The VFD shall provide a digital output to announce the loss of control power.

5.0.3.5:

Overtemperature monitors: The VFD shall monitor and announce the overtemperature of the motor (if motor RTD is supplied, by others), input transformer, heat sinks, as well as cooling fan failure.

5.0.3.6:

Fault History: The Drive will capture data from up to 49 faults and provide stack retrieval to facilitate quick remedy and operation recovery.

5.0.3.7:

Fault Trace Data: The Drive will record the following data before and after a fault has occurred to facilitate advanced trouble shooting efforts and provide quick identification to the cause.

- Operational State (Run, Stop, Accelerating, Decelerating, etc.)
- Operational condition (input/output voltage, current, output speed, current, power, etc.)

6.0 Operator Interface/Communications:

6.0.1:

Digital Operator: The VFD shall be provided with a 4 line LCD Digital Operator for basic control functions and monitoring.

6.0.2:

Personal Computer (PC) Interface: The VFD shall be provided with a PC interface to monitor operating status for maintenance and control. Software shall be provided by the VFD manufacturer to expedite setup, store drive data, recover fault history, and provide a 'trace' function to display (selectable) drive operating functions in real time.

6.0.3:

Serial Communications: The VFD shall be capable of serial communication by Modbus, Ethernet, Profibus DP, DeviceNet.

7.0 Reliability:

7.0.1:

Design Considerations: The VFD shall be designed for high reliability using Insulated Gate Bipolar Transistors (IGBTs) and the high reliability, low power base driver circuitry afforded by an IGBT based design.

7.0.2:

Mean Time Between Failures (MTBF): The VFD shall have a documented MTBF of 200,000 hours or higher. MTBF shall be calculated as a two parameter exponential distribution.

7.0.3:

Mean Time To Repair (MTTR): The VFD shall be designed and constructed in such a way as to allow for power cell exchange by a skilled, trained technician in under 20 minutes.

7.0.4:

Life Expectancy: The VFD shall have a minimum designed life expectancy of 20 years with components serviced per the recommended replacement schedule.

7.0.5:

Availability: The VFD shall have a proven availability of 99.9% or greater. Inherent Availability (A_I) is defined as $MTBF/(MTBF+MTTR)$ where MTTR is "Mean Time To Repair".

8.0 Enclosure:

8.0.1:

Form: The VFD enclosure shall be free standing, frame and panel construction. NEMA 1, IP40 and NEMA 3R (IP32) configurations shall be available. All components shall be accessible from the front.

8.0.2:

Cooling: The VFD enclosure shall be air cooled with door mounted filters and roof mounted exhaust fans. The filters shall be removable and cleanable. Loss of cooling air flow detection shall be standard.

8.0.3:

Painting: The VFD enclosure shall be painted 5Y7/1 Munsell semi-gloss Beige on both interior and exterior surfaces.

8.0.4: Panels: The VFD enclosure shall be separated into compartments (panels).

8.0.4.1:

Transformer Panel: This panel shall contain the multi-phase input transformer and all MV input and output connection points.

8.0.4.2:

Power Cell Panel: This panel shall contain the VFD Power Cells. The Power Cells shall be modular, self contained, and rack mounted for simple replacement and contain all power components, including rectifier diodes, bus capacitors, IGBT modules and gate drivers etc.

8.0.4.3:

Control Panel: This panel shall contain the low voltage (LV) control components, power supplies, etc. as well as the LV Input / Output (I/O) terminal blocks. This panel shall not have any points at MV potential. Interface between control components and Power Cells shall be via fiber optic cables.

9.0 Factory Test/Witness Test:

9.0.1:

Standard Factory Test: Individual components and subassemblies shall be tested to the VFD manufacturer's standards. System test of the complete VFD shall include a load test driving a motor.

9.0.2:

Witness Test: The VFD manufacturer shall allow the customer to witness tests during the standard factory testing at no charge. A custom witness test to accommodate customer's schedule shall be available at additional charge.

10.0 Commissioning:

10.0.1:

Staff: VFD Commissioning shall be performed by Startup Engineers certified and trained by the VFD Manufacturer.

10.0.2: Commissioning Sequence:

10.0.2.1:

The manufacturer's certified commissioning sequence and procedures shall be taken for an orderly and complete commissioning process.

10.0.2.2:

Detailed procedures shall be available to customer upon request.

11.0 Training:

11.0.1:

Factory Training: The VFD Manufacturer shall offer training on the MV product at the manufacturer's location. Manuals and training/support documentation shall be provided. Factory training details and fees shall be included during the bid proposal phase.

11.0.2:

User Site Training: The VFD manufacturer shall also offer training at the end user location. This training shall be tailored to the specific application and shall be quoted separately from the bid proposal.

12.0 Service and Maintenance:

12.0.1:

The VFD Manufacturer shall maintain a team of qualified Field Service Engineers to provide field service and maintenance support.

12.0.2:

Field repair shall be limited to replacement at the subassembly level, i.e. power cell, control board, etc. Subassembly repair and retest shall be provided at the VFD manufacturer's site to ensure Quality Control.

13.0 Submittals:

13.0.1:

The VFD manufacturer's standard submittal drawings and information shall be provided at time of bid.

14.0 Deviations to this Specification:

14.0.1:

Any deviations from, or exceptions to this specification shall be defined in writing with the bid.

15.0 Spare Parts:

15.0.1:

The VFD manufacturer shall supply a list of recommended spare parts with prices as part of the bid.

16.0 Warranty:

16.0.1:

The VFD manufacturer shall warranty the design, material and workmanship of the MV drive for a period of 18 months from date of delivery or 12 months from date of commissioning, whichever occurs first, against defects of materials or manufacture – see manufacturer's complete Terms and Conditions document for additional details.

17.0 **Acceptable Manufacturers:**

- Yaskawa America, Inc.