Active Front End Drive with Line Reactor (D2D)
Air Cooled and Liquid Cooled

PART 1 GENERAL

1.1 SUMMARY

A. Section includes

1. This specification covers materials, equipment and start-up services required to place into operation an integrated medium voltage variable frequency drive (VFD) system. This specification may be applied to Induction or Synchronous AC motor applications.
2. Every VFD system shall consist of all components required to meet the performance, protection, safety, and certification criteria of this specification.
3. The following components must be integrated into the VFD System:

   - an integral line reactor
   - Active Front End [PWM converter]
   - PWM inverter
   - DC Link with common mode voltage protection
   - Input and output filters if applicable

4. Include all material and labor necessary to interconnect any VFD system elements, even if shipped separately. All cost to use alternative equipment, including redesign, will be born by the VFD manufacturer. VFD's which require phase shifting transformers will not be acceptable.

B. Related Sections

1. _____
2. _____
3. _____

1.2 QUALIFICATIONS

A. Manufacturer

1. The manufacturer shall have a minimum of 10 years experience in the manufacturer of medium voltage variable frequency drives for use in similar applications at the specified voltage and power ratings. A user list, complete with contact names and telephone numbers, shall be furnished upon request.
2. The approved manufacturers are:
   a. Rockwell Automation Allen-Bradley

B. Support

1. The manufacturer shall maintain factory trained and authorized service facilities within 100 miles of the project and shall have a demonstrated record of service for at least the previous ten years owned and operated by the VFD drive manufacturer.
2. Support personnel are to be direct employees of the manufacturer.
3. The manufacturer shall provide all required start-up and training services.
4. The approved manufacturers are:

a. Rockwell Automation Global Manufacturing Services (GMS)

C. Certification

1. The VFD shall be factory pre-wired, assembled and tested as a complete package by the VFD supplier. Customer specific drive, motor, and application data shall be pre-loaded into the operator interface and tested prior to shipment.
2. All inspection and testing procedures shall be developed and controlled under the guidelines of the Supplier's quality system. This system must be registered to ISO 9001 and regularly reviewed and audited by a third party registrar.
3. All incoming material shall be inspected and/or tested for conformance to quality assurance specifications.
4. All sub-assemblies shall be inspected and/or tested for conformance to Supplier's engineering and quality assurance specifications.
5. All printed circuit boards with active components shall be burned-in per the manufacturer's standards.
6. Third party manufacturers and brand labeling shall not be allowed.

1.3 REFERENCES

A. Variable Frequency Drive

1. Canadian Standards Association (CSA) "Industrial Control Equipment C22.2 No. 14"
2. American National Standards Institute (ANSI) "Instrument Transformers C57.13"
3. Institute of Electrical & Electronic Engineers (IEEE)
4. Electrical & Electronic Manufacturers Assoc. of Canada (EEMAC)
5. Guide for Harmonic Control and Reactive Compensation of Static Power Converters (IEEE 519-1992)
6. National Electrical Manufacturers Association (NEMA) "Medium Voltage Controllers Rated 1501 to 7200V AC ICS 3-2 (formerly ICS 2-324)"
7. Underwriters Laboratories, Inc. (UL) (High Voltage Industrial Control Equipment 347)
8. UL 347A Medium Voltage Power Conversion Equipment Preliminary Standard
9. International Electrotechnical Commission (IEC) 61800-5 AC Drives Standard
10. European Directives for Safety and EMC
11. National Electrical Code (NEC)
12. Occupational Safety & Health Act (OSHA)

B. Rectifier Duty Drive Isolation Transformer

1. IEEE C57.12.00-1993, IEEE Standard General Requirements for Liquid-Immersed Distribution and Regulating Transformers.
2. IEEE C57.12.01-1989, IEEE Standard General Requirements for Dry-Type Distribution and Power Transformers.
3. ANSI C57.12.10-1988, American National Standard for Transformers – 230 KV and Below 833/948 through 8333/10417 KVA, Single-Phase, and 750/862 Through 60000/80000 KVA with load TAP Changing – Safety Requirements.
4. ANSI C57.12.51-1981, American National Standard Requirements for Ventilated Dry-Type Power Transformers, 501 KVA and Larger, Three-Phase with High-Voltage 601 to 34500 volts, Low-Voltage 208Y/120 to 4160 Volts.
5. ANSI C57.12.70-1978, American National Standard Terminal Markings and Connections for Distribution and Power Transformers.

6. IEEE C57.12.90-1933, IEEE Standard Test Code for Liquid-Immersed Distribution, Power and Regulating Transformers and IEEE Guide for Short Circuit Testing of Distribution and Power Transformers.
7. IEEE C57.12.91-1995, IEEE Standard Test Code for Dry-Type Distribution and Power Transformers.
8. IEEE C57.18.10-1998, IEEE Standard Practices and Requirements for Semiconductor Power Rectifier Transformers.
9. IEEE C57.124-1991, IEEE Recommended Practice for the Detection of Partial Discharge and the Measurement of Apparent Charge in Dry-Type Transformers.
10. IEC 60076-1, Power Transformers: General.
11. IEC 60076-2, Power Transformers: Temperature rise.
12. IEC 60076-3, Power Transformers: Insulation levels and dielectric tests, Ammendment No.1.
13. IEC 60076-3-1, Power Transformers: Insulation levels and dielectric tests. External clearances in air.
14. IEC 60076-4, Power Transformers: Tappings and Connections.
15. IEC 60076-5, Power Transformers: Ability to withstand short circuit.
16. IEC 60616, Terminal and Tapping Markings for Power Transformers.
17. IEC 60722, Guide to the Lightning Impulse and Switching Impulse Testing of Power Transformers and Reactors.
18. IEC 60726, Dry-type Power Transformers.
19. IEC 61378-1, Converter Transformers, Part 1: Transformers for Industrial Applications.

1.4 ENVIRONMENTAL REQUIREMENTS

A. Confirm to specified service conditions during and after installation of products

B. Maintain area free of dirt and dust during and after installation of products

1.5 PRE-MANUFACTURE SUBMITTALS

A. Refer to Section _____ for submittal procedures

B. Shop Drawings
   1. Elevation drawings showing dimensional information
   2. Structure Descriptions showing
      a. Enclosure ratings
      b. Fault ratings
      c. Other information as required for approval
   3. Conduit locations
   4. Unit Descriptions including amperage ratings, frame sizes, trip settings, pilot devices, etc.
   5. Nameplate Information
   6. Schematic wiring diagrams

C. Product Data
   1. Publications on variable frequency drive
   2. Data Sheets and Publications on all major components
      a. Contactors
      b. Circuit Breaker and Fuse information including time current characteristics

c. Control Power Transformers
d. Pilot devices
e. Relays
f. Operator Interface

D. Spares
1. Recommend spare parts list and list prices shall be supplied.
2. Critical Spares - Spare parts that are identified as being associated with long lead times and/or are critical to the unit's operation. These spares should be held in reserve by the Purchaser to limit unforeseen downtime.
3. Maintenance Spares - Spare parts that are identified as being required to regularly perform scheduled maintenance on their equipment. These spares include, but are not limited to, consumable spares that are required to be exchanged during scheduled maintenance periods.

E. Specification Response
1. Detailed response to this specification showing where in the literature and drawings each requirement is satisfied.
2. All clarifications and exceptions must be clearly identified.

F. Testing and Test Reports
1. Testing shall be per manufacturer’s standard
2. A copy of the test reports shall be provided as part of the Closeout documentation

1.6 CLOSEOUT SUBMITTALS

A. Refer to Section _____ for procedure on submittal of closeout documentation

B. Contractor shall provide certification that the variable frequency drive has been installed in accordance with the manufacturer’s instructions.

C. The contractor shall provide certification that the Contractor has properly adjusted any timing devices required in the starting circuitry.

D. Final Drawings. The manufacturer shall provide final drawings reflecting the “As-Shipped” status of the motor control center. The contractor shall be responsible for making any changes to the “As-Shipped” drawings from the manufacturer to reflect any field modifications.

E. Maintenance Data
1. Variable frequency drive installation instructions and User Manual
2. Installation / Operation instructions for major components such as circuit breakers, contactors, isolation transformers, etc.
3. Drive Parameter Listing
4. Field Service report from drive start-up service
5. Variable Frequency spare parts listing and pricing
6. Include name and phone number for a local distributor for the spare parts.

1.7 DELIVERY, STORAGE AND HANDLING

A. Contractor shall coordinate the shipping of equipment with the manufacturer.

B. Contractor shall store the equipment indoors in a clean and dry space.

C. The contractor shall protect the units from dirt, water, construction debris and traffic.

D. During storage the contractor shall connect internal space heaters (if specified) with temporary power.

1.8 FIELD MEASUREMENTS

A. The Contractor shall verify all field measurements prior to the fabrication of the variable frequency drives.

1.9 SPARE MATERIALS

1.9.1 The following spare parts shall be furnished for each size drive:

A. Three of each type power and control fuse
B. Two power modules (SGCT) or 20%, whichever is greater
C. Two spare LEDs of each type used
D. Two spare control relays of each type used
E. Two sets of all replacement air filters
F. One hoisting mechanism for removal and replacement of power cells, if required
G. One set of all control printed circuit boards

1.10 WARRANTY

A. The manufacturer shall provide their standard parts warranty for eighteen (18) months from the date of shipment or twelve (12) months from the date of being energized, whichever occurs first.

B. The manufacturer shall confirm this warranty as part of the submittal.

C. This warranty applies to variable frequency drive systems.

PART 2 PRODUCTS

2.1 RATINGS

A. Voltage
   1. The VFD shall accept nominal plant power of 4160V (2400V, 3300V, 6600V, Other) at 60Hz
   2. The supply input voltage tolerance shall be ± 10% of nominal line voltage.
   3. Low voltage, 3 phase auxiliary power will be provided by customer to power the VFD cooling system and VFD control circuits. The auxiliary power voltage shall be 208V (208 – 575 V), 3 phase.

B. Displacement power factor
   1. The VFD shall be capable of maintaining a minimum true power factor (Displacement P.F. X Distortion P.F.) of .98 from 60-100% load.

2. If the VFD vendor cannot meet the true power factor requirement, then a power factor correction unit shall be quoted as an option.
3. The true power factor that can be met (with and without power factor correction unit) shall be stated clearly in the proposal.

C. Efficiency
1. VFD system efficiency shall be a minimum of 96% at 100% speed & 100% load. System efficiency shall include VFD, input transformer or line reactor, harmonic filter (if applicable) power factor correction unit (if applicable), and output filter (if applicable). (Assuming a minimum motor PF of 0.86)
2. Control power supplies, control circuits, cooling fans or pumps, shall be included in all loss calculations.

D. Environmental Ratings
1. Storage ambient temperature range: -40 degrees C to 70 degrees C.
2. Operating A. ambient temperature range: 0 degrees C to 40 degrees C without derating.
3. The relative humidity range is 0% to 95% non-condensing.
4. Operating elevation: up to 1000 Meters (3,300ft) without derating.

E. Audible Noise Level
1. The maximum audible noise from the variable frequency drive shall comply with OSHA standard 3074, Hearing Conservation, which limits noise level to 85 dB(A).
2. The variable frequency drive shall comply with the OSHA standard at a distance of one meter from the front of the equipment (with doors closed at any speed or load condition).
3. Variable frequency drives with audible noise in excess of this limit must be provided with sufficient noise abatement treatment to reduce the sound pressure level below 85dB(A).

F. Motor Compatibility
1. The variable frequency drive shall be capable of operating a standard AC squirrel cage induction motor (standard AC synchronous motor, standard AC wound rotor induction motor) of equivalent power and speed rating over the speed range specified. Drives which require motors with higher insulation values will not be acceptable.
2. The variable frequency drive shall provide near sinusoidal voltage and current waveforms to the motor at all speeds and loads. Output current THD shall be less than 5%. Standard induction or synchronous motors shall not require de-rating or upgraded turn-to-turn insulation and shall not require additional service factor.
3. The motor insulation system shall not be compromised thermally or due to dv/dt stress. Dv/dt at the motor terminals (line-to-line) shall be limited to 10 volts per microsecond. If dv/dt at the motor terminals (line-to-line) exceeds 10 volts per microsecond, the vendor must state the actual value in the attached data sheets and include steps taken to guarantee the long term life of the motor insulation system.
4. The variable frequency drive shall provide stable operation of the motor without compromising the motor insulation system, regardless of motor cable distance. The vendor shall clearly state the limitations in motor cable distance with the proposal. If an output filter is required to mitigate reflected waves, or to meet any special requirements of the application, it must be integral to the VFD controller.

5. If output filters are used in the variable frequency drive, a selective harmonic elimination (SHE) switching technique must be available to eliminate a potential harmonic resonance in the operating speed range.
6. Variable frequency drive induced torque pulsations to the output shaft of the mechanical system shall be less than 1% to minimize the possibility of exciting a resonance.

G. Sizing
1. Loads shall be as shown on the drawings.

H. Definitions
1. The Drive Unit shall refer to the actual drive that will be mounted within the specified enclosure.
2. The Drive System shall refer to the drive unit and all items specified under Drive System Options.

2.2 DRIVE UNIT DESIGN

A. Hardware
1. The VFD shall be designed for a minimum availability of 99.9%.
2. The VFD shall be designed for a Mean Time Between Failures (MTBF) of 100,000 hours.
3. The VFD shall be designed for a minimum life expectancy of 20 years.
4. In order to optimize reliability and minimize complexity, inverter power switch component count shall be minimized by utilizing high peak inverse voltage (PIV) rated devices. Preference will be given to designs exhibiting the lowest overall power component count.
5. The VFD shall have a control power monitoring system that monitors all power supply voltages and signals.
6. Fiber optic interface boards shall be used to provide gating and diagnostic feedback signals for power semiconductor devices. The diagnostic feedback system shall allow constant control of the device as well as constant monitoring of device health and temperature feedback.
7. Field programmable gate arrays (FPGA) shall be utilized on drive control boards to provide high speed handling of diagnostics and fault handling routines. High speed digital control systems shall continuously monitor all hardware and software faults including sensing of all power circuit voltage and currents as well as any internal equipment faults.
8. Power switch device diagnostics shall detect and protect against device short, over or under gate voltage, loss of gating, loss of diagnostic feedback, heat sink temperature feedback as well as overload monitoring and protection.
9. Failed power switch components shall be replaceable without removal of the entire power module. Special tools or force measuring transducers shall not be required. Failed power switch components shall be replaceable in less than 5 minutes.
10. Converter power modules shall be repairable in 5 minutes or less. If entire power module is replaced, vendor to specify mean time to repair failed power modules.

B. Control Logic
1. The VFD shall produce a variable voltage and variable frequency output to provide continuous operation over the application speed range.

2. The VFD shall be capable of operating with the output short circuited at full current.
3. The drive system shall provide controlled speed over the range specified. Speed accuracy within this range, expressed as a percent of top speed, shall be within 0.1% of base speed without encoder or pulse tachometer feedback (0.01% with encoder or pulse tachometer feedback).
4. The VFD shall have a “normal duty” rating of 100% continuous current with a short-time duty rating of 110% overload for one minute, once every 10 minutes (suitable for variable torque loads).
5. The variable frequency drive shall be capable of 100% breakaway torque without tachometer feedback.
6. For high inertia loads, a preference shall be given to variable frequency drives capable of regenerative motor braking.

2.3 DRIVE UNIT FEATURES

A. Control Mode
1. The variable frequency drive shall utilize sensorless direct vector control or full vector control, with pulse tachometer feedback, for optimum performance.

B. Auto Tuning
1. The variable frequency drive shall have a programmable auto tuning function.
2. The function shall be capable of being disabled.
3. The function shall be programmable for the following tuning options.
   a. Communtation inductance
   b. DC link time constant
   c. Motor stator resistance
   d. Motor leakage inductance
   e. Flux regulator
   f. Total Inertia

C. Starting Mode
1. The variable frequency drive shall offer two starting modes.
2. The S-Curve profile shall consist of both nonlinear and linear portions.
   a. A parameter shall exist that specifies the duration that the drive is ramping in the non-linear portion.
   b. A parameter shall define the total time to accelerate to rated speed in S-Curve.
3. The Ramp Mode shall be programmable with four ramp speed break points
   a. The Ramp Mode shall have programmable acceleration and deceleration times.
   b. The Ramp Mode shall have a parameter for Ramp Start Delay that specifies the time the speed reference remains at zero after the drive is started.

D. Stopping Mode
1. The variable frequency drive shall have three stop modes.
2. The Ramp Mode shall be programmable with four deceleration times.
3. In the Coast Mode, a programmable parameter shall be set to specify the speed at which the drive shuts off and coasts when stopping.
4. Regen Mode

E. Auto-Restart Capability

1. The VFD shall be capable of automatically restarting in the event of a momentary loss of power.
2. An automatic restart delay parameter shall be available in the drive with an adjustment range of 0 -10 seconds.

F. Flying Re-Start
1. The VFD shall be capable of restarting and taking control of a motor attached to a spinning load in the forward or reverse direction.

G. Preset Speeds
1. The variable frequency drive shall have three (3) preset speeds.
2. The preset speeds shall be programmable between 0.5 and 75.0 Hz.

H. Skip Speeds
1. The variable frequency drive shall have three (3) skip speeds.
2. The skip speeds shall be programmable between 1.0 and 75.0 Hz.
3. The skip speeds shall have a programmable band width between 0.0 and 5.0 Hz.

I. Ride Through
1. The VFD shall be capable of riding through a loss of power of 5 cycles.
2. If specified, a UPS shall be supplied inside the VFD controller for an extended ride through of up to 2 minutes.
3. The VFD system shall be capable of operating with a 30% voltage sag on the input power line. The motor shall not be allowed to reach a pull out condition.

J. Load Loss Detection
1. The drive shall have a parameter to specify the response of the drive to a loss of load condition.
2. The parameter shall have the following configuration options: disabled, warning or fault.

K. Digital I/O
1. Sixteen (16) isolated digital inputs shall be available as standard on the drive.
2. Sixteen (16) isolated digital outputs shall be available as standard on the drive.
3. Digital I/O shall be rated 12V to 260V AC or DC.

L. Fault Configuration
1. The variable frequency drive shall have fault classes that define the following.
    a. Class of drive input protection
    b. Class of rectifier magnetic protection
    c. Class of dc link protection
    d. Class of motor protection
    e. Class of isolation transformer protection
    f. Auxiliary trip class
    g. External fault class

2. Each fault class shall have the following configurations.
    a. Disable the fault input
    b. The drive will shut down immediately
    c. The drive will perform a controlled shutdown
    d. The drive will not shutdown but a warning will be displayed

3. The variable frequency drive shall have fault and warning masks.

M. Protection Features
1. Fault information shall be accessible through the Human Interface
2. The variable frequency drive shall have the following minimum line side protective features.
   a. Line current unbalance trip with programmable delay
   b. Line overcurrent trip with programmable delay
   c. Line overload warning and trip with programmable delay
   d. Line overvoltage trip with programmable delay
   e. Line undervoltage trip with programmable delay
   f. Line voltage unbalance trip with programmable delay
   g. Ground fault overvoltage trip with programmable delay
   h. Ground Fault overcurrent trip with programmable delay

3. The variable frequency drive shall have the following minimum system level protective features.
   a. DC Overcurrent trip with programmable delay
   b. DC overvoltage trip with programmable delay
   c. Rectifier heatsink temperature warning and trip
   d. Cabinet temperature warning and trip
   e. Inverter heatsink temperature warning and trip
   f. Control Power warning and fault
   g. Adapter (communication port) loss warning and fault
   h. XIO adapter loss

4. The variable frequency drive shall have the following minimum load side protective features.
   a. Ground fault overvoltage trip with programmable delay
   b. Ground fault overcurrent trip with programmable delay
   c. Machine side dc link overvoltage trip with programmable delay
   d. Motor overcurrent trip with programmable delay
   e. Motor overload warning and trip with programmable delay
   f. Motor overvoltage trip with programmable delay
   g. Motor stall delay
   h. Motor overspeed trip with programmable delay
   i. Motor flux unbalance trip with programmable delay
   j. Motor current unbalance trip with programmable delay
   k. Load loss level, speed and programmable delay

N. Metering
1. The variable frequency drive shall display metered parameters through the operator interface.
2. The variable frequency drive shall meter the following.
   a. Root Mean Square value of the motor current
   b. Root Mean Square value of the motor terminal voltage
   c. Motor output power in kilowatts
   d. Motor speed in revolutions per minute

3. The metered values shall be capable of being assigned to an analog output to drive an optional output meter.

O. Contactor Configuration
1. The variable frequency drive shall have parameters for specifying input and output contactor configurations.

2. The input contactor configuration parameter shall specify under what conditions the input contactor shall be commanded to open the drive. The parameter options shall be: open when not running, open for all faults or open for critical faults.
3. The output contactor configuration parameter shall specify under what conditions the output contactor shall be open. The parameter options shall be: open when not running or open for all faults.

4. An output contactor (if required per the data sheets) shall safely isolate the motor from the VFD when the pump is operating in the reverse direction.

2.4 DRIVE SYSTEM OPTIONS

A. Structure (Air Cooled VFD's)

1. Enclosure
   a. Air-cooled VFD enclosures shall be NEMA 1 (IP21). Door vents shall consist of louver-panel assemblies that can be removed from the front in order to replace air filters. Safety screens shall be located behind each louver panel. Cabinets and doors shall be fabricated using minimum 12 gauge (2.64 mm thick) steel for sturdy construction. All doors shall be gasketed to provide environmental protection and secure fits.
   b. Door latches shall be heavy-duty ¼-turn type units which are operated with an Allen wrench. The converter cabinet door and cabling cabinet door shall be interlocked with up-stream isolators or breakers with a key lock. Interlocking shall be fully coordinated to prevent access to all medium voltage compartments.
   c. The VFD shall be designed for front access to allow for installation with no rear access. Equipment that requires rear or side access shall not be accepted.

2. Structure Finish
   a. All variable frequency drive exterior metal parts (except for low voltage panel, external isolating switch handle assembly, lifting angles, lifting brackets and low voltage wireway cover) shall be painted with hybrid epoxy powder paint per manufacturer's standard color.
   b. Low voltage panel, external isolating switch handle assembly, lifting angles, lifting brackets and low voltage wireway cover shall be painted with hybrid epoxy powder paint using manufacturer's standard color.
   c. All metal back plates in the power cell and low voltage compartments shall be painted high gloss white for high visibility.
   d. Touch-up spray can(s), matching the enclosure color, shall be supplied.
   e. Painting shall be done on a continuous paint line through air-atomized electrostatic spray. All parts shall be painted before assembly.
   f. The preparation shall be Alkaline wash/rinse; iron phosphate rinse; iron-chrome sealer rinse; re-circulated de-ionized water rinse and virgin de-ionized water rinse
   g. Total paint thickness – 0.002" (0.051 mm) minimum
   h. Baking process shall be by Natural gas oven at 179°C (355°F) minimum.

i. All unpainted steel parts shall be plated with a zinc plate/bronze chromate process for corrosion resistance.

3. Cooling System (air cooled system)
   1. The VFD system shall be air-cooled unless otherwise specified.
   2. Air-cooled VFDs shall be provided with a single, mixed flow cooling fan, mounted integral to the VFD enclosure. The VFD shall include air flow pressure switches and temperature detectors to monitor proper operation of the air cooling system. If a fan fails, the system must generate alarm indication of the fan failure. Vane type air flow switches are not acceptable.
   3. If specified, a provision shall be made for ducting VFD exhaust air outside the control room.
   4. If specified, a spare fan will be supplied on a skid.

B. Structure & Design (Liquid Cooled System)

1. The design for cooling the converter, inverter and DC Link reactor shall utilize direct water cooling. The following features shall be incorporated in the cooling system design:
2. Heat losses from the power devices shall be removed by a closed loop system using an ethyl-glycol / de-ionized water (60/40% mixture) as the heat transfer medium.
3. The pump cubicle shall contain the water pumps, heat exchanger, de ionization tank, conductivity meter, reservoir tank, and miscellaneous valves, fitting and other plumbing.
4. Redundant water pumps shall be provided. The control scheme shall equalize use of the pumps by timing their operating periods. Water flow shall be monitored and the loss of the active pump shall automatically cause the standby pump to be started.
   1. To maintain the non-conductive nature of the cooling water, a replaceable de-ionization cartridge shall be included in the cooling system. A dual set point conductivity meter shall continuously monitor the conductivity of the water. If the water conductivity raises above the lower threshold, it shall signal a warning. Further increase in water conductivity shall cause the drive to shut down.
6. The individual chill blocks and chill plates shall be manufactured of copper. The heatsinks shall be specially shaped with bends to minimize laminar flow and insure maximum heat transfer between the heatsink and the water.
7. All heatsinks will operate at approximately the same temperature.
8. The piping and tubing for the cooling system shall consist of two different materials. The main piping in the pumping cabinet, between the cabinets, and the manifold piping shall be thick wall CPVC. The tubing from the manifold to the chill blocks and the DC link shall be silicone hose. The tubing shall be fitted on to copper hose barbs, and secured with standard stainless steel hose clamps.
9. All the small bore hoses shall be arranged to be long enough so as to provide adequate electrical resistance between water circuits at different potentials in conjunction with the use of de-ionized water.

10. The highest point of the low-pressure pipe work shall be directly connected to the reservoir tank slowing air to bleed into the tank from the low-pressure side.

The pump cubicle shall contain all the main cooling circuit components including de-ionizer cartridge, monitoring instrumentation, and two [2] 5 HP pumps.

The closed-loop liquid coolant shall be circulated continuously, so that if a fault occurs the standby pump will automatically take over the duty. All the principal components shall have isolating valves to assist in maintenance and replacement if required. The drip tray shall be arranged to collect leakage water. Strainers shall be included to filter out any suspended solids during test and commissioning.

On initial start up there shall be a 10 second delay to allow water pressure to establish itself before a pump changeover is initiated. Provided water pressure reaches rated value within 10 seconds, the changeover shall be inhibited.

A pump changeover when the drive is operating shall be initiated by reduction of water flow. A pressure switch shall monitor the pressure. When the flow rate has fallen below minimum rated value, the contactor shall de-energize the running pump and energize the standby pump. Provided the water flow increases above rated value within 10 seconds of calling for the standby pump to start, the drive shall continue to run. If the second pump fails to start within this time, then the complete drive shall be stopped.

The system shall be arranged that whenever the drive is re-energized after a shut down, the coolant pump, which is energized, is the one that was previously on standby.

C. The liquid cooled system principal components

1. Water to water heat exchanger (water to air optional):
The heat exchanger shall be tube and shell or plate construction, and shall permit 100% counter flow of both primary and secondary water so that the difference in temperature between the two water circuits participating in the heat exchange if fully utilized. The secondary coolant shall be any suitable liquid such as filtered raw water, chilled process water or chilled glycol solution.
2. Redundant coolant pumps:
The motor operated pumps shall be centrifugal close-coupled driven by three phase TEFC motors. The pump shall include mechanical seals and shall be selected for use with de-ionized water. The system shall have working pressure as required by the drive manufacture and the test pressure shall be 2 times the operating pressure. PSIG.
3. De-ionizer cartridge:
The cartridge shall consist of a mixed bed polishing tank with both caution and anion exchange resin contained in a durable transport housing complete with transport head.
4. The flow fed to the de-ionizer shall be approximately 5 US gpm. The quality of the water shall be constantly monitored and displayed within the system.
5. The monitor system shall include a conductivity cell and meter. Alarm and trips shall be capable of being set at any point between 0-99.9 µS/cm,

dependent upon the quality of water required. Once water quality falls below a predetermined level, the alarm shall be automatically activated indicating that the cartridge needs changing. Further loss of coolant quality shall activate the trip and trip the drive. The normal working range shall be 0.0 to 0.5 µS/cm. The alarm is typically set at 1.0 µS/cm and the trip at 2.0 µS/cm.
The de-ionizer cartridges shall generally be replaced at six-month intervals.

Isolation valves shall be provided so that the DI Cartridge may be replaced while the drive is running.

6. Reservoir tank (make-up water tank):
The reservoir tank shall be open to the atmosphere in the primary system helping to displace air in the system. It shall also provide some reserve capacity if there is a leak or fault in the cooling system. Level detectors shall be provided to check water evaporation or leakages.
7. Strainers and filters
8. Instrumentation:
The instrumentation shall be designed to protect against major equipment damage. Monitors for water flow and water over-temperature detection shall be provided, and shall include:
   a. Flow trip (Paddle Switch)
   b. Low level alarm (Float Switch)
   c. Temperature and pressure gauges
   d. Water over-temperature alarm and trip (Thermal Switches)
   e. Conductivity alarm and trip (Conductivity Monitor)

D. The instrumentation shall include to monitor and initiate alarms and corrective action as well as to trip the drive if necessary. The following failure modes shall be detected:

1. Loss of pump or power to pump
2. Loss of secondary water supply or secondary water over-temperature
3. Leakage of water from system
4. Obstruction in water pipe work

E. Typical materials in contact with water:

1. Copper-thyristor heatsinks
2. Stainless Steel
3. CPVC pipes, valves
4. Non-conductive silicone hose
5. EPDM rubber for flanges
6. Polypropylene
7. Bronze
8.

F. The conductivity meter continuously monitors the conductivity of the water. Since the conductivity is a measure of the soluble chemical content of the water, there is no need to carry out any chemical analysis test of the secondary water. The de-ionizer cartridges must be changed when the conductivity reaches 1 µS/cm.

Since the secondary water circuit is a re-circulating system, the quantity of insoluble impurities in the system will not increase with time provided any topping up water is free from contaminants. The only metal in contact with the primary water are stainless steel

and copper. As the maximum operating temperature for this water is 60°C, no adversely appreciable migration or corrosion will occur.

G. Cabling
   a. The VFD shall contain a power cable termination assembly designed for easy termination and access to line and load cables. The termination assembly cabinet shall allow for top and bottom entry and exit of line and load cables.
   b. A low voltage wire way shall be provided at the top front of the VFD and shall be available with a removable cover.
   c. All power and control terminations and termination strips shall be identified in accordance with all schematics and wiring diagrams.
   d. Low voltage control wire shall be TEW tinned, 600 volt AC rated.

H. Harmonic Mitigation Techniques
   1. VFDs shall comply with the latest edition of IEEE 519 Harmonic Guidelines.
   2. Preference shall be given to drive systems that meet IEEE 519 harmonic guidelines with the lowest possible design complexity. The VFD supplier shall detail the number of main power components supplied in the VFD and number of secondary windings on the isolation transformer in the vendor's proposal.
   3. The following VFD rectifier solutions are acceptable:
      a. PWM rectifier (Active Front End)

I. Auxiliary Relays
   1. Provide relays for Drive Warning, Drive Fault, Drive Run and Drive Ready.
   2. Provide (2) additional relays to be wired per custom requirements.
   3. The relays shall be Allen-Bradley 700HC24A1 relays (2 form C contacts, 2N.O. & 2N.C.).The relay contacts shall be rated for 115V AC/30V DC, 5.0 Amp resistive, 5.0 Amp inductive.

J. Communications
   1. The VFD shall be provided with digital communication capability to allow direct control and status communication with a PLC, SCADA or other control system.
   2. Provide a ControlNet (DeviceNet) adapter mounted on the customer interface board.

K. Isolated Analog Input and Output
   1. The analog interfaces shall be isolated.
   2. The analog signal interfaces (maximum of four (4)) shall be configurable for:
      a. Speed reference input (4-20 mA input signal).
      b. Speed output (4-20 mA output signal).
      c. Voltage output (4-20 mA output signal).
      d. Current output (4-20 mA output signal).
      e. Load (kW) output (4-20 mA output signal).
      f. Torque output (4-20 mA output signal).

L. Motor Heater Control
   1. Provide drive control circuitry to interface with a remote 120VAC/2700W power source to energize the motor heater whenever the motor is not running.
   2. The heater shall be interlocked with the drive run relay and shall be energized whenever the motor is not running.

3. Provide a pilot light mounted on the drive system enclosure door for indication of Motor Heater On.

M. Pilot Devices
1. Pilot devices shall be Allen-Bradley Bulletin 800E (NEMA Type 4/4X/13) and shall be mounted on the drive system enclosure door.
2. Provide an Auto/Manual selector switch for Speed Reference
3. Provide a "Hand/Off/Auto" selector switch for start-stop control and pilot lights for indication of the "Hand" and "Auto" modes.
4. Provide Start and Stop pushbuttons.
5. Provide pilot lights, mounted on the enclosure door, for indication of Ready, Run, Fault and Warning. Pilot lights shall be transformer type.
6. Provide a NEMA Type 1/4/12, single turn speed pot mounted on the drive system enclosure door.

N. Motor Run Time Meter
1. Provide a digital, non-resettable, door-mounted elapsed time meter.
2. The meter shall be electrically interlocked with the Drive Run relay and Bypass contactor (if required) to indicate actual motor operating hours.

O. Operator Interface Module
1. The VFD shall have a user-friendly operator interface terminal.
2. The interface terminal shall have the following minimum features.
   a. Large LCD display screens (minimum 16 line – 40 characters) that are easy to read and provide ‘at a glance’ indication of drive operating status
   b. User configurable bar type LCD metering for motor speed, load, torque, and voltage
   c. Elapsed time indication
   d. Extensive diagnostic functions that provide separate fault and warning queues in non-volatile memory that retain information under all conditions
   e. On-line help that provides enhanced fault text messages
   f. Trend buffers for at least 8 variables that allow one-shot or multi-shot trending
   g. Multi-level (minimum of four levels) password access to ensure that only qualified personnel have access to critical parameters but still allow easy access to other levels of personnel
   h. Extended use of plain language messages to eliminate need to look up error codes or decipher the meaning of error messages
   i. Start-up wizard, including auto tuning, that is interactive and user-friendly

P. Monitoring and Editing Software
1. Provide a Windows based application software to monitor and edit drive parameters, upload and save parameters to a file, download parameters to the drive, print parameters, and view and clear faults/alarms in the drive.

Q. Motor Protection Options
1. Interfaces shall be provided to interface with the motor protection specified in the motor specification.
2. If specified, provide a door mounted temperature monitor / controller. The module shall be TecSystem model T-538 and shall monitor up to eight (8), three

(3) wire RTD inputs. The monitor shall monitor the quantity and type of RTDs specified in the motor specification.

2.5 AC LINE REACTORS

1. An AC line reactor shall be supplied instead of an isolation transformer. The VFD system with line reactor shall include common mode voltage protection for the motor. (special motor insulation shall not be required).
2. Multi-secondary, phase shifting transformers are not acceptable
3. Line reactors shall be integral to the VFD line-up.
4. The line reactor K-factor shall be designed for rectifier service (AFE rectifier).
5. The line reactor shall be convection cooled with Class H insulation.
6. The line reactor shall include thermal protection.

2.6 OUTPUT TRANSFORMERS

A. The use of output transformers or step-up transformers is not approved for this project. Any technology utilizing such a design will be rejected.

2.7 INPUT CONTACTOR WITH ISOLATION UNITS

A. The medium voltage input contactor and isolation unit shall be Allen-Bradley bulletin 1512DM or equivalent with the following features:

1. Fixed mounted vacuum contactor

2. The 400A units shall include two [2] three-pole, gang-operated, non-load break isolating switches with one [1] single external operating handle. Both switches are mechanically interlocked with each other, the contactor and power cell doors.

3. Three [3] R-rated current-limiting power fuses.

4. Three [3] bar type current transformers.

5. Low voltage control panel complete with pilot control relays; control circuit fusing; DC economizing circuits; “Normal-Off-Test” circuit; receptacle for remote test supply; set of control circuit terminal blocks.

6. Low voltage and power cell doors with viewing windows in both power cell doors to view the position of the isolating switches.

2.8 FULL VOLTAGE NON-REVERSING, OUTPUT BY-PASS STARTER UNITS WITH VACUUM CONTACTORS [TWO (2) PER DRIVE SYSTEM]

A. Fixed mounted “Output” and “By-pass” vacuum contactors shall be Allen-Bradley Bulletin 1512M or equivalent with the following features.

1. Fixed mounted vacuum contactor

2. The 400A units shall include two [2] three-pole, gang-operated, non-load break isolating switches with one [1] single external operating handle. Both switches are mechanically interlocked with each other, the contactor and power cell doors.

3. Three [3] R-rated current-limiting power fuses.

4. Three [3] bar type current transformers.

5. Low voltage control panel complete with pilot control relays; control circuit fusing; DC economizing circuits; “Normal-Off-Test” circuit; receptacle for remote test supply; set of control circuit terminal blocks.

6. Low voltage and power cell doors with viewing windows in both power cell doors to view the position of the isolating switches.

2.9 SYNCHRONOUS TRANSFER BYPASS (IF REQUIRED)

A. Each VFD system shall capable of both “HOT” and “COLD” bumpless synchronous transfer using an Allen-Bradley ControlLogix PLC [no equal]. PLC shall be compatible with the PLC in the master control Panel.

1. The VFD PLC control system shall include a synchronizing regulator to adjust the drive speed reference as required to synchronize the motor to the line. The VFD PLC control shall include the following adjustable parameters for synchronous transfer:

- Synchronous Transfer Lead Angle
- Synchronizing Regulator Gain
- Synchronizing Regulator Error
- Synchronous Transfer Mask
- Synchronizing Time
- Synchronous Transfer Time
- Synchronous Transfer Off Delay

EXECUTION

3.0 MANUFACTURE TESTING AND INSPECTION

A. Standard Testing

1. The following tests shall be carried out in accordance with applicable requirements and/or specifications of Canadian Standards Association (CSA), Underwriters Laboratories (cULus), National Electrical Manufacturers Association (NEMA), European Standard (EN), and International Electrotechnical Commission (IEC).
2. Functional checks shall be performed wherever possible; otherwise, inspection and continuity checks shall be made.
3. A "HI-POT" dielectric withstand test shall be performed on all buswork and cables from phase-to-phase and phase-to-ground (except solid-state components, low voltage controls and instrument transformers). The voltage level used for this test depends on the product's nominal AC voltage.
4. Component devices shall be functionally operated in circuits as shown on electrical diagrams or as called for by specific test instructions.
5. Instruments, meters, protective devices and associated controls shall be functionally tested by applying the specified control signals, current and/or voltages.
6. Medium Voltage Drives shall be inspected for the following:
   a. Control Power Failure Test
   b. Rectifier Gating Checks
   c. Inverter Gating Checks
   d. Line Converter Tests
   e. Machine Converter Tests

f. Load Tests

7. Cycle Testing
   a. Drives shall be accelerated to the test motor's nominal frequency, under load on a dynamometer.
   b. Drives shall be decelerated to 10 Hz and then accelerated back to test motor's nominal frequency with a ramp time of approximately ten seconds.
   c. This cycle shall be repeated continuously for up to one hour.
8. Load Testing
   a. Drives shall be tested under load at the test motor's nominal frequency on a dynamometer. Testing on load banks not acceptable.

B. Physical Inspection
1. The product must meet all applicable engineering and workmanship standards and specifications. All components shall be verified against engineering documentation to be present and correctly installed.
2. All bus and bus connections shall be checked for proper clearance, creepage, phasing, and torque.
3. Warning plates, isolation barriers, and mechanical interlocks must provide sufficient safety/isolation for personnel and equipment.
   a. Warning labels and nameplates must be present and in their specified positions to advise personnel of possible hazards.
   b. Isolation barriers must be in place within the cabinet. Such barriers protect personnel from touching live medium voltage components in an area that otherwise does not have power supplied to it.
   c. Operation of isolation switch handle and door interlocks must be verified. The interlocking prevents the opening of any medium voltage door on a medium voltage cabinet when the isolation switch handle has been moved to the full ON position.

1. Witness Testing
   a. At the conclusion of testing, the customer will reconvene with the Application Engineer or Project Manager to discuss any concerns or issues that arose during the test. Any modifications or changes requested by the Purchaser will be documented and discussed at this meeting. The Project Manager or Applications Engineer will respond to the Purchaser at the earliest possible time with an outline of the financial and/or schedule impact of the changes.
   b. If requested, a review of the electrical and mechanical drawings for the purchased equipment shall be done with the Supplier’s Application Engineer or Project Manager prior to commencing the tests. Any questions or clarifications, prior to commencing the test, will be addressed at this time.
   c. The witness test shall include a Drive System Run Test that shall consist of operating the variable frequency drive connected to a dynamometer. During the testing of the drive, a demonstration of the operator interface and functionality will be provided as well as demonstration of the operation of the drive.
   d. The drive will be tested up to rated horsepower at both steady state and varying speeds.
   e. The drive will be tested with the facility isolation transformer, facility input contactor and facility DC link.
   f. For liquid-cooled drives, the test facility heat exchanger will be utilized.

g. The following equipment, if purchased, shall be tested at additional cost above the base cost of the standard tests:
   1.) Isolation devices
   2.) Contactors
   3.) Harmonic filters
   4.) Bypass starters
   5.) Synchronous transfer
   6.) Remote communications options

h. A Certified Test Report shall be issued to the Purchaser.

3.1 MANUFACTURE'S FIELD SERVICES

A. The service division of the variable frequency drive manufacturer shall perform all start-up services. The use of third party supplier start-up personnel is not allowed.

B. Start-up personnel shall be direct employees of the variable frequency drive manufacturer and shall be degreed engineers.

C. Provide a minimum of (__) hours of on-site start-up service for each pump station having (__) pumps. For stations having (__) pumps, provide an additional (4) hours of on-site start-up service.

D. At a minimum, the start-up service shall include:

1. Pre-Installation Meeting
   a. The start-up plan
   b. The start-up schedule
   c. The drive's installation requirements
2. Pre-Power Check
   a. Inspect the drive's mechanical and electrical devices enclosed
   b. Perform a tug test on all internal connections within the drive and verify wiring.
   c. Verify critical mechanical connections for proper torque requirements.
   d. Verify and adjust mechanical interlocks for permanent location.
   e. Confirm all sectional wiring is connected properly.
   f. Re-verify control wiring from any external control devices.
   g. Set up all drive internal power supplies and thyristor control circuits.
   h. Verify proper phasing from isolation transformer to drive.
   i. Confirm cabling of drive to motor, isolation transformer and line feed.
   j. Megger Motor Resistances.
3. Drive Power-up and Commissioning
   a. Apply medium voltage to the drive and perform operational checks.
   b. Bump motor and tune drive to the system attributes
   c. Run the drive motor system throughout the operational range to verify proper performance.
4. Record all measurements
5. Provide Drive Parameter Listing

3.2 TRAINING

A. Manufacturer to provide one (1) session of 8 hours of on-site instruction for a maximum of eight (8) participants.

B. The service engineer shall perform training.

C. The manufacturer shall outline the training session duration and content.

D. The basis of the training shall be the variable frequency drive, the engineered drawings and the user manual.

E. The instruction shall include the operational and maintenance requirements of the variable frequency drive.

F. At a minimum, the training shall:
1. Review of the engineered drawings identifying the components shown on the drawings.
2. Review starting / stopping and speed control options for the controller.
3. Review operation of the Operator Interface for programming and monitoring of the variable frequency drive.
4. Review cooling system operation.
5. Review the maintenance requirements of the variable frequency drive.
   a. Board replacement procedures
   b. Power device replacement procedures
   c. Fault analysis and troubleshooting
   d. Preventative maintenance procedures
6. Review safety concerns with operating the variable frequency drive.