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SPECIFICATIONS - DETAILED PROVISIONS
Section 16160 - Variable Frequency Drives

C O N T E N T S

SECTION 16160
VARIABLE FREQUENCY DRIVES

PART 1 - GENERAL

1.01 SCOPE

A. This section specifies the requirements for the design, integration, fabrication, assembly, wiring, testing, delivery, and installation of low voltage (600 volt) variable frequency drive (VFD) units to control the speed of electric motor drivers for the driven equipment specified.

B. Contractor shall furnish and install VFDs as specified herein and shown on the Drawings, including all accessories and controls necessary for a complete and operable system.

C. All equipment specified herein shall be furnished as a complete assembly.

1.02 SPECIFIC PROJECT VFD REQUIREMENTS

Specific project requirements may be provided in Section 16160.1 attached to this Specification Section. Where provided, this section provides specific project details regarding VFDs and shall take precedence over requirements herein, in case of conflict.

1.03 RELATED SECTIONS

A. The Contract Documents are a single integrated document, and as such all Specification Sections apply. It is the responsibility of the Contractor and its subcontractors to review all sections and ensure a complete and coordinated project.

B. Related Specification Sections include, but are not limited to, the following:

1. Sections of the Specifications specifying equipment and/or systems requiring electrical power and control.

2. Division 16 – Electrical

3. Division 17 – Instrumentation and Controls

1.04 REFERENCE STANDARDS, SPECIFICATIONS, AND CODES

A. Equipment and materials shall meet or exceed the applicable requirements of the following standards, specifications, and codes (latest edition):

Institute of Electrical and Electronics Engineers (IEEE)

IEEE 519	Recommended Practice and Requirements for Harmonic Control in Electric Power Systems
IEEE C62.41.1	Guide on the Surge Environment in Low-Voltage (1000 V and Less) AC Power Circuits
IEEE C62.41.2	Recommended Practice on Characterization of Surges in Low-Voltage (1000 V and Less) AC Power Circuits

National Electrical Manufacturers Association (NEMA)

NEMA 250	Enclosures for Electrical Equipment (1000 Volts Maximum)
NEMA AB 1	Molded Case Circuit Breakers and Molded Case Switches
NEMA ICS 1	Standard for Industrial Control and Systems: General Requirements
NEMA ICS 4	Terminal Blocks
NEMA ICS 5	Industrial Control Systems, Control Circuit and Pilot Devices
NEMA ICS 6	Enclosures
NEMA ICS 7	Adjustable Speed Drives

National Fire Protection Association (NFPA)

NFPA 70	National Electrical Code

Underwriters Laboratories (UL)

UL 50	Standard for Enclosures for Electrical Equipment, Non-environmental Considerations
UL 50E	Standard for Enclosures for Electrical Equipment, Environmental Considerations
UL 489	Standard for Molded-Case Circuit Breakers, Molded-Case Switches, and Circuit-Breaker Enclosures
UL 508A	Standard for Industrial Control Equipment
UL 508C	Standard for Power Conversion Equipment
UL 1283	Standard for Electromagnetic Interference Filters
UL 61800-5-1	Standard for Adjustable Speed Electrical Power Drive Systems – Part 5-1: Safety Requirements – Electrical, Thermal and Energy

B. Equipment shall bear the appropriate labels and markings in accordance with above standards, specifications and codes. Equipment shall be designed, manufactured, and tested in certified International Organization for Standardization (ISO) 9001 facilities.

1.05 SUBMITTALS

All submittals shall be in accordance with the General Conditions and requirements specified herein.

A. Shop Drawings

Contractor shall submit complete information, drawings, and technical data for all equipment and components, including, but not limited to, the following:

1. Complete Bills of Materials for all equipment and components comprising the VFD system.

2. Manufacturer's product literature and specifications for all VFD system equipment and components including, but not limited to, the following: variable frequency drives, input filters and line reactors, output filters, isolation transformers, phase shifting transformers, circuit breakers and fuse information (including time current characteristics), bypass contactors, enclosures, control power transformers, pilot devices, relays, timers, fans, and thermostats. Product literature and specifications shall be marked to clearly identify all applicable information and crossing out all inapplicable information. Sufficient data and detail shall be provided to demonstrate compliance with these specifications.

3. Summary for each type of VFD, listing design capabilities and operating parameters, including all user selectable features and setpoints.

4. VFD efficiency and VFD unit overall operating efficiency (including power for harmonic mitigation equipment, and power for equipment cooling) at full rated load and 100 percent speed.

5. Motor manufacturer's guarantee that motor insulation and cooling is suitable for continuous operation over specified frequency range and VFD output pulse maximum peak voltage, pulse rise time, and pulse rate.

6. Drawings showing enclosure exterior elevation, interior elevation, and plan views with dimensional information, including, but not limited to: enclosure height and depth, section widths and shipping splits (if applicable), conduit stub-up/connection locations, and anchorage/mounting holes. Exterior elevation view shall show location of all door mounted components, including disconnect handle, operator interface, lights, switches, push buttons, and corresponding nameplates. Interior elevation view shall show general arrangement and identification of all major internal components.

7. Terminal size ranges for all cable connections (line and load sides).

8. Complete single line diagrams indicating all components comprising the VFD system, including, but not limited to: circuit breakers, motor circuit protectors, fuses, contactors, VFDs, control power transformers, control devices, space heaters, and fans.

9. Control ladder diagrams and interconnection diagrams (point to point wiring diagrams), including terminal blocks and identification numbers. Interconnection diagrams shall show wiring between VFD and all external field devices, and between VFD and all electrical panels, including (but not limited to) distribution panels, MCCs, PLCs, and RTUs.

10. Where the proposed enclosure is not the VFD manufacturer's standard enclosure (e.g. NEMA 1 enclosure with a NEMA 3R wrapper, or a Hoffman type enclosure), design calculations shall be provided for the enclosure cooling system addressing all heat producing VFD unit components operating at full rated capacity and with the maximum specified ambient temperature. Where building cooling systems are shown on the Drawings, calculations shall be performed with building cooling system off.

11. Harmonic distortion study per Part 1.08 herein, demonstrating compliance with specified voltage and current distortion requirements.

12. Results for VFD unit(s) from Short Circuit/Coordination and Arc Flash Hazard Studies per Specification Section 16040.

13. Design calculations and details for equipment seismic design and restraint. Calculations and anchorage details shall be prepared and stamped by a Registered Professional Civil or Structural Engineer in the State of California. Equipment seismic design and restraint calculations shall be provided for all VFD units. Calculations shall include anchor bolt type, size, locations, and embedment depth. Anchor bolt embedment depth for free standing floor mounted VFD units shall be based on the thickness of the structure floor slab only, and shall not include any portion of the raised concrete housekeeping pad beneath the equipment structures. Calculations shall be performed in accordance with the California Building Code (latest edition) for Occupancy Category IV, Essential Facilities.

14. Manufacturer's installation instructions, including:

    a. Receiving, handling, and storage instructions
    b. Installation procedures including mounting, conduit and wiring connections, and terminal torque requirements
    c. Grounding requirements
    d. Arc flash protection marking
    e. Operation of operator handles and unit interlocks
    f. Checklist before energizing
    g. Procedure for energizing equipment.

15. Manufacturer's warranty guaranteeing the operation of the VFD unit against failure due to defects for two (2) years from date of project acceptance. During this period, parts and labor shall be supplied at no cost to the District.

B. Operation and Maintenance Manuals

Operation and maintenance manuals shall be provided in accordance with the requirements of the General Conditions, and Specification Section 01430. Manuals shall be completely indexed and include step-by-step procedures for the operation and maintenance of the VFD as installed. As a minimum, operation and maintenance manuals shall include:

1. Design capabilities, operating parameters, and recommended ranges.

2. Specification packets on all components in the unit.

3. System schematic diagrams, block diagrams, interconnection diagrams, ladder diagrams, complete wiring diagrams, and enclosure drawings.

4. Safety provisions and precautions, including protective equipment and clothing.

5. Pre-energizing and energizing procedures.

6. Maintenance procedures, including: preventive measures, inspection and cleaning, servicing, and testing.

7. Troubleshooting.

8. Complete replacement parts list, and list of recommended spare parts.

9. Manufacturer warranties.

10. Contact Information, including name, address, and telephone number of manufacturer and manufacturer's local service representative.

11. Complete listing of VFD control settings and setpoints for all controller inputs.

Contractor shall provide approved operations and maintenance manuals to District at least 30 days prior to VFD startup and testing.

Final operation and maintenance manuals shall include as-built drawings of all VFD schematic diagrams, block diagrams, interconnection diagrams, ladder diagrams, and enclosure drawings. As-built drawings shall include any field modifications. Final operation and maintenance manuals shall include the complete listing of VFD control settings and setpoints for all controller inputs (factory set and field set) as established at the completion of field startup and testing.

1.06 QUALITY ASSURANCE

A. Contractor shall provide a complete, reliable, fully tested, adjustable speed drive system suitable for manned or unmanned operation. VFD units shall be as manufactured by Toshiba, ABB, Allen Bradley, or Schneider Electric (no substitutes).

Third party distributor or packager modifications to a standard product will only be permitted with written approval from the VFD manufacturer, and statement confirming that the installed VFD equipment will be fully covered by manufacturer's warranty. In addition, VFD manufacturer (factory) shall review and approve all shop drawings prepared by third party distributors prior to submittal of said shop drawings to the District.

B. The District believes that the manufacturers listed herein are capable of producing equipment and/or products that will satisfy the requirements of these specifications. The listing of specific manufacturers herein does not imply acceptance of their products that do not meet the specified ratings, features, functions, and space restrictions. Manufacturers listed herein are not relieved from meeting these specifications in their entirety; and, if necessary, they shall provide non-standard, custom equipment and/or products. Contractor shall be responsible for confirming that the proposed equipment and/or products will meet these specifications.

C. Model numbers supplied herein are provided for information purposes only, to assist Contractor in selecting equipment that conforms to the Specification and Drawing requirements. In case of any conflict between model numbers provided and the descriptive requirements specified herein, the descriptive requirements shall govern.

1.07 COORDINATION

A. Each VFD unit shall be coordinated with the requirements of the driven equipment. Contractor shall be responsible for matching the motor and the VFD. Load requirements, torque, horsepower, and speed range of VFDs shall be coordinated with and meet or exceed that of the driven equipment.

B. In addition, Contractor shall be responsible for coordinating the collection of data and manufacturer’s design efforts necessary to comply with all requirements specified herein, including harmonic distortion limits. Contractor shall submit written confirmation to the District that all specified requirements have been satisfied and the proposed VFD has been approved by the driven equipment manufacturer.

C. Contractor shall coordinate the working space allowed with the equipment to be provided, and any discrepancies shall be brought to the District's attention prior to the bid opening. Contractor shall be responsible for making the VFD manufacturer and supplier aware of project space requirements and ensuring that the proposed equipment will fit within the allowed space.

D. Where indicated on the Drawings, emergency standby power generation equipment shall be provided to operate electrical facilities in the event that normal utility power is not available. The VFD system shall be suitable to operate on a limited power generation source. Contractor shall coordinate the design and fabrication of the VFD system equipment and components with emergency power generation equipment, and ensure compatibility and performance in accordance with this Specification.

1.08 HARMONIC DISTORTION STUDY AND DISTORTION LIMITS

A. Harmonic Distortion Study

1. VFD manufacturer shall prepare a comprehensive pre-equipment selection harmonic distortion study of the system. The study shall conform to the requirements of IEEE 519, except as modified herein. The study shall include harmonics from existing equipment as well as the harmonics from equipment provided under this Section. In addition, the study shall include the electrical utility service connection, main service switchboard, distribution switchboards, motor control centers (MCCs), and all interconnecting power cables and busing. The harmonic distortion study shall demonstrate compliance with the harmonic distortion limits specified herein. The harmonic distortion study shall be submitted to the District as part of the shop drawing submittals.

2. VFDs will be provided with electrical power from a Southern California Edison Company (SCE) transformer and service. The SCE service will provide power to the service switchboard, distribution switchboards (if any), MCCs, and VFDs. Unless specified otherwise, the service switchboard shall be the point of common coupling (PCC) for calculating and measuring voltage and current distortion. Unless specified otherwise, the value of the utility short circuit current at the PCC shall be obtained from SCE by the Contractor for the project location and equipment. Contractor shall be responsible for all necessary coordination with SCE to obtain the short circuit current value, and pay all associated costs for same.

3. The harmonic distortion study shall be based on a computer aided system circuit simulation of the total actual system performed through the 50th harmonic, with information and data obtained from the utility (SCE), Construction Drawings, and equipment manufacturers. Unless indicated otherwise in the Specific Project VFD Requirements, the harmonic analyses shall be performed without any linear loads. The harmonic distortion study shall clearly describe all assumptions, computer input information, voltage and current distortion results, and comparison of results to specified limits.

4. If the harmonic distortion study indicates the need for harmonic suppression equipment, including: line reactors, passive filters, isolation transformers, 12-pulse VFDs, or 18-pulse VFDs, these shall be provided at no additional cost to the District. Harmonic suppression utilizing active front end VFDs are acceptable. Shop drawings shall indicate the location of the harmonic suppression equipment. Harmonic suppression equipment and its location shall be subject to acceptance by the District, prior to commencing fabrication of the VFDs and associated harmonic suppression equipment.

B. Harmonic Distortion Limits

The harmonic distortion values resulting from the operation of all or any combination of VFDs operating at full load and without any linear loads shall be limited to the following:

1. Maximum allowable Total Harmonic Voltage Distortion, THD Voltage shall be 8%.

2. Maximum allowable individual frequency harmonic voltage distortion shall be 5%.

3. Maximum allowable individual frequency harmonic current distortion; Total Harmonic Current Distortion, THD Current; and Total Demand Distortion, TDD shall be within the limits of IEEE 519.

Compliance with the specified limits shall be verified by onsite field measurements of the harmonic distortion at the PCC, performed with and without VFDs operating. Field measurements shall be obtained by an independent third party testing firm acceptable to the District, after satisfactory full-load operation of the equipment.

PART 2 - PRODUCTS

2.01 DESCRIPTION

A. The VFD shall be solid state with a pulse width modulated (PWM) AC to AC converter utilizing the latest isolated gate bipolar transistor (IGBT) technology. The VFD shall employ a sensorless vector inner loop torque control strategy that mathematically determines motor torque and flux. The VFD shall also provide an optional motor control operational mode for scalar of V/Hz operation.

B. The VFD shall employ a full wave rectifier to prevent input line notching and operate at a fundamental (displacement) input power factor of 0.98 at all speeds and nominal load.

C. Unless specified otherwise, each VFD unit shall include, but not be limited to, the following major components: solid state VFD (6, 12, or 18-pulse), input line power molded case circuit breaker or motor circuit protector, input current-limiting fuses, line reactor, passive filter (if necessary), motor protection output filter (if necessary), EMI/RFI filter (if necessary), enclosure with door mounted operator interface and pilot devices, control power transformer, integrated controls, enclosure cooling fans, and enclosure space heater.

2.02 RATINGS

A. VFD units shall be sized based on the maximum motor horsepower and required starting and operating torque of the selected equipment to be driven, or the minimum output as shown on the Drawings or specified herein, whichever is greater.

B. VFD units shall be rated to operate from 3-phase power at 480 VAC ±10%.

C. VFD units shall be rated to operate continuously at full load under any combination of the following environmental conditions:

1. Ambient temperature of 0 to 40°C; and where specified, up to 50°C with application of a derating factor. VFD units that can operate at 40°C intermittently (during a 24 hour period) are not acceptable and shall be sized (i.e. oversized) to operate continuously at the specified maximum ambient temperature.

2. Altitudes ranging from 0 to 3300 feet above sea level without derating.

3. Relative humidity of 95% or less (non-condensing).

D. VFD output frequency shall be adjustable between 0 Hz and 300 Hz (minimum).

E. VFDs shall be rated to operate from input power ranging from 48 Hz to 63 Hz.

F. Output voltage and current ratings shall match the adjustable frequency operating requirements of standard NEMA Design B motors.

G. Unless specified otherwise, VFDs shall have an overload current capacity for a duration of one (1) minute of at least 110% of rated motor current for variable torque units and at least 150% of rated motor current for constant torque units.

H. VFD efficiency shall be 98% or better at the full rated capability of the VFD at full speed and load. VFD unit overall efficiency, including all harmonic mitigation equipment, output reactor, sine wave filter, dV/dt filters, cooling fans, control power transformers, etc. shall be 95% or better of the full rated capability of the VFD at full speed and load.

I. VFDs shall be protected from atmospheric contamination by chemical and solid substances per IEC 60721-3-3. Chemical substances shall be classified 3C2 and solid substances shall be classified 3S2.

2.03 CONSTRUCTION

A. All VFD microprocessor and control circuitry shall be isolated by rigid non-conductive barriers providing finger-safe protection from all AC and DC power circuitry.

B. All power semiconductors shall be accessible from the front of the unit without the removal of the heat sinks upon which the devices are mounted. Each power semiconductor shall be capable of being visually inspected, electrically checked, and mechanically replaced from its heat sink assembly without removal of the entire heat sink or heat sink covers.

C. Each VFD unit shall be provided with an input molded case circuit breaker or motor circuit protector with a short circuit interrupting capacity of 65,000 RMS symmetrical amps (minimum), which shall disconnect all line power to the VFD, bypass contactors (if applicable), harmonic distortion suppression equipment, and control power transformer. The input power disconnect shall be provided with a door mounted operator that is padlockable in the Off position and mechanically interlocked with the VFD unit enclosure door.

D. Each VFD unit shall be provided with input line power fuses. Fuses shall be current limiting type with a short circuit interrupting rating of 200,000 amps, and shall be provided with blown fuse indicators.

E. Each VFD unit shall be provided with a 480V/120V control power transformer equipped with primary and secondary fuses. Unless indicated otherwise on the Drawings, the control power transformer shall be sized all control power loads, and enclosure cooling and heating loads.

F. Each VFD unit shall be equipped to function as specified herein and as indicated on the Drawings.

G. Door Mounted Components and Pilot Devices

Unless indicated otherwise on the Drawings, each VFD unit shall be provided with the following door mounted components and pilot devices.

1. Padlockable handle for VFD unit circuit breaker.

2. Power on indicator with push to test LED lamp.

3. VFD on-line indicator with push to test LED.

4. Bypass on-line indicator lamp (if bypass contactors are specified).

5. VFD malfunction indicator with push to test LED lamp.

6. VFD fault reset push button.

7. Motor thermal and motor overload reset push buttons.

8. Operator Interface (Digital Display/Keypad Unit). Unit shall control, monitor and display VFD functions, operating conditions and faults. Operating conditions shall include, but not be limited to: output frequency, output voltage, motor current, running speed (rpm), input and output power.

9. VFD Manual, VFD Auto, Off, Bypass Manual (if bypass contactors are specified) selector switch as specified. Selector switch shall be provided with auxiliary contacts for position signal to remote control panel.

10. Elapsed time meter (eight (8) digit, minimum).

11. Motor high temperature indicator lamp.

12. Motor overload indicator lamp.

13. Speed pot for VFD speed control in Hand mode.

14. Other functions and devices shown on the Drawings, or otherwise specified.

VFD shall shutdown on motor "high temperature" and "overload" conditions. External dry contacts shall be provided for each motor alarm condition and common VFD fault condition.

VFD unit pilot devices shall be in accordance with Specification Section 16480.

H. VFD Bypass

Where indicated on the Drawings or specified in the Specific Project VFD Requirements, VFD units shall be provided with bypass contactors to permit the motor to run at full speed in the event of a VFD shutdown. Unless specified otherwise, the VFD bypass shall be provided with the following components and features:

1. The bypass circuitry shall be located in a separate section of the VFD unit enclosure and shall isolate the VFD on both the line side and load side. For motors less than 100 hp, VFD units shall be provided with mechanically and electrically interlocked full-voltage bypass contactors sized for the motor full load amperage. For motors 100 hp and greater, VFD units shall be provided with solid-state reduced voltage starting (soft starter) for bypass motor starting; and the soft start shall be electrically interlocked with the VFD isolation contactors. Controls shall be provided for automatic bypass of the VFD to constant speed operation in event of VFD failure, except for condition of motor high temperature, motor overload, or motor moisture. When selector switch is in VFD Auto position, upon VFD failure the equipment shall stop and automatically restart in constant speed mode via bypass contactors with start/stop functioning as if operating on VFD. Time delay for restart in bypass mode shall be provided. Manual reset to return to VFD mode shall be required. The VFD shall be isolated on the line-side and load-side during bypass operation. The bypass motor starter shall be equipped with current overload protection and a minimum of one (1) NO and one (1) NC auxiliary contactors.

2. Full voltage contactors and soft starters shall be provided in accordance with Section 16480.

3. Indicating lights for operation in VFD mode and Bypass mode shall be provided. Selector switch shall be provided with Bypass Manual position to allow operation in bypass mode without VFD failure.

4. Dry contacts shall be provided for operation in bypass mode for connection to RTU and/or Plant SCADA system.

2.04 OPERATOR INTERFACE

A. The VFD shall be equipped with a door (front) mounted operator interface control panel consisting of a four (4) line (minimum) back-lit alphanumeric LCD display. The LCD display shall be configurable to show a bar graph or meter. The operator interface shall be provided with an integral keypad with keys for Run/Stop, Local/Remote, Increase/Decrease, Reset, Menu navigation and Parameter select/edit.

B. The operator interface control panel shall be removable, capable of remote mounting, and allow for uploading and downloading of parameter settings.

C. The display of the operator interface control panel shall have the following features:

1. All parameter names, fault messages, warnings and other information shall be displayed in complete English words or standard English abbreviations to allow the user to understand what is being displayed without the use of a manual or cross-reference table.

2. During normal operation, one (1) line of the control panel shall display the speed reference, and status of run/stop, forward/reverse, and local/remote. The remaining three (3) lines of the display shall be programmable to display the values of any three (3) operating parameters. The parameter 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.

D. The control panel shall be used for local control, for setting all parameters, and for stepping through the displays and menus.

E. 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 be provided.

2.05 PROTECTIVE FEATURES

The VFD unit shall be provided with capabilities and features to protect the VFD components and the driven motor from damage. Protective features with user adjustable setpoints shall be accessed through the operator interface for enabling and disabling. As a minimum, each VFD unit shall be provided with the following protective features:

A. A message shall be displayed on the operator interface for each programmed warning and fault protection function. The VFD shall be capable of displaying up to five (5) active faults and store the previous five (5) non-active faults and provide a time stamp of when the faults occurred. The VFD shall provide a help feature to further explain the displayed fault.

B. The VFD shall be provided with internal metal-oxide varistors (MOVs) for phase-to-phase and phase-to-ground line voltage transient protection.

C. Output short circuit and ground fault protection rated for 100,000 amps (without relying on line fuses) shall be provided per UL508A.

D. Motor phase loss protection shall be provided.

E. The VFD shall provide electronic motor overload protection qualified per UL508C.

F. Protection shall be provided for AC line or DC bus overvoltage at 130% of maximum rated voltage or undervoltage at 65% of minimum rated voltage.

G. The VFD shall be provided with protection against input phase loss.

H. 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.

I. 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.

J. Over-temperature protection shall provide a warning if the power module temperature is less than 5°C below the over-temperature trip level.

K. Desaturation circuit to drive the inverter section transistor base current to zero in the event of a controller fault.

L. Input terminals shall be provided for connecting a motor winding thermistor (PTC type) to the VFD's protective monitoring circuitry. An input shall also be programmable to monitor an external motor high temperature relay or switch contact.

2.06 CONTROL INPUTS AND OUTPUTS

A. Discrete Inputs

1. Minimum of six (6) discrete inputs shall be provided.

2. The inputs shall be independently programmable with function selections (run/stop, hand-off-auto, etc.).

3. Inputs shall be designed for use with either the VFD's internal 24 VDC supply or a customer supplied external 24 VDC supply.

B. Discrete Outputs

1. Minimum of two (2) form C relay contact outputs shall be provided.

2. 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 A at 24 VDC or 115/230 VAC.

C. Analog Inputs

1. Minimum of two (2) analog inputs shall be provided and shall be selectable for either a current or a voltage input.

2. Inputs shall be independently programmable to provide signals including speed/frequency reference, torque reference or set point, PID set point and PID feedback/actual.

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

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

5. If the input reference is lost, the VFD shall give the user the option of the following:

   a. Stopping and displaying a fault.

   b. Running at a programmable preset speed.

   c. Holding the VFD speed based on the last good reference received.

   d. Cause a warning to be issued, as selected by the user.

   The VFD shall be programmable to signal the lost input reference condition via an operator interface warning, relay output, and/or over the serial communications bus.

D. Analog Outputs

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

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

2.07 CONTROL FUNCTIONS AND ADJUSTMENTS

A. Output frequency shall be adjustable between 0 Hz and 300 Hz (minimum). Operation above motor nameplate speed shall require programming changes to prevent inadvertent high-speed operation.

B. Stop mode selections shall include coast to stop and ramp to stop.

C. 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.

D. 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 shall then 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.

E. The VFD shall have the ability to automatically restart after a protective trip caused by overcurrent, overvoltage, undervoltage, or loss of input signal. The number of restart attempts, trial time, and time between reset attempts shall be programmable.

F. Control functions shall include two (2) sets of acceleration and deceleration ramp time adjustments with linear and an s-curve ramp time selection.

G. Speed control functions shall include:

1. Adjustable minimum and maximum speed limits.

2. Selection of up to 15 preset speed settings for external speed control.

3. Three sets of critical speed lockout adjustments.

4. A built-in PID controller to control a process variable such as pressure, flow or fluid level.

H. Functions shall include motor 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.

I. The VFD shall be capable of sensing a loss of load (e.g. broken belt or broken coupling) and signal the loss of load condition. The VFD shall be programmable to signal this condition via an operator interface warning, relay output, and/or over the serial communications bus. Relay output shall include programmable time delays that shall allow for VFD acceleration from zero speed without signaling a false underload condition.

J. A minimum of two (2) programmable critical frequency lockout ranges shall be provided to prevent the VFD from operating the load continuously at an unstable or critical equipment speed.

2.08 SERIAL COMMUNICATIONS

A. The VFD shall be capable of communicating with other VFDs or controllers via a serial communications link. A variety of communications interface modules for the typical overriding control systems shall be available.

B. Interface modules shall be available for a number of communication protocols including, but not limited to: Modbus RTU and ModBus TCP.

C. Interface modules shall mount directly to the VFD control board or be connected via fiber optic cables to minimize interference and provide maximum throughput.

D. VFD I/O shall be accessible through the serial communications adapter. Serial communication capabilities shall include, but not be limited to:

1. Run-Stop control.

2. Hand-Off-Auto control.

3. Speed adjustment.

4. PID (proportional/integral/derivative) control adjustments.

5. Current limit control.

6. Acceleration and deceleration time adjustments.

E. The VFD shall have the capability of allowing the overriding controller 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.

F. A connection shall also be provided for a personal computer interface. Personal computer software shall be provided for VFD setup, diagnostic analysis, monitoring and control. The software shall provide real time graphical displays of VFD performance.

2.09 WIRING AND TERMINATIONS

A. As a minimum, interconnecting wiring and wiring to terminals for external connection shall be stranded copper with thermoplastic insulation that is moisture-resistant and flame-retardant, and rated at 600 V and 90°C.

B. Where fine stranded conductors, Class C and higher (such as DLO cable) are utilized for internal wiring, all terminations in mechanical lugs shall be provided with copper flex-cable compression adapters to properly confine the fine strands and prevent overheating of the connection and wire pullout from lugs. The flex-cable compression adapters shall fit mechanical set-screw mechanical lug type connectors and shall be sized for the full current carrying capacity of the cable. The adapters shall be provided a flared barrel-opening to allow easy cable insertion. The adapter shall be constructed of wrought copper with pin of Class B stranded copper conductor, rated for 600 V and 105ºC cable, and shall be UL listed. Pin length shall be sufficient to allow full engagement into the mechanical lug. Flex-cable copper compression adapters shall be Shoo-pin PT-FX Series, as manufactured by Greaves Corporation, or equal.

C. Wiring shall be neatly installed in wireways wherever possible, or bundled with wire tie-down straps and securely attached to mounting surfaces.

D. Terminals on door mounted components shall be provided with finger-safe protective barriers; or alternatively, a single clear plastic protective barrier shall be provided covering all terminals.

E. Terminal blocks shall be interlocking, track-mounted type, with a marking strip, covers, and pressure connectors. A terminal shall be provided for each conductor of external circuits, plus one ground for each shielded cable. Each control loop shall be individually fused and located for ease of maintenance.

F. Terminals shall be labeled to match with the identification shown on the shop drawings.

2.10 ENCLOSURES, HEATING, AND COOLING

A. VFD units shall be housed in wall mounted or floor mounted enclosures as shown on the Drawings and specified herein. Enclosures shall be of sufficient size to afford access to all parts and components, and constructed with all line, load, and control terminations fully front accessible. All control components and wiring shall be separated by rigid non-conductive barriers from all 3-phase AC and DC power components and wiring.

B. Where shown on Drawings or specified herein that the VFD shall be installed in a MCC line-up, the enclosure shall match MCC construction including height and depth.

C. Unless otherwise specified, the sheet metal surfaces of all enclosures shall be phosphetized and coated with a rust resisting primer. Over the primer a corrosion resistant baked enamel finish shall be applied on interior and exterior metal surfaces. Exterior color shall be medium light gray (unless otherwise specified) and interior color shall be white. All enclosure hardware shall have a corrosion resistant finish.

D. Unless otherwise specified, outdoor electrical equipment shall be housed in weatherproof, gasketed, NEMA Type 1 (dead front with front accessibility) enclosures with NEMA 3R wrappers, and indoor electrical equipment shall be housed in NEMA Type 12 (dead front with front accessibility) enclosures or gasketed NEMA Type 1 enclosures. Enclosures shall be provided with top and bottom entry/exit locations for conduit and power/control conductors.

E. Outdoor enclosures shall be provided with padlockable door handles and sufficient internal lighting to perform maintenance work. Lighting shall be controlled by an internal light switch. Unless otherwise specified, lighting shall be powered by the VFD control power transformer.

F. Enclosures shall be provided with 120 V, 60 Hz space heaters for condensation protection. Space heaters shall be strip or tubular type and shall be controlled by line voltage thermostats. Unless otherwise specified, heating systems shall be powered by the VFD control power transformer.

G. Where specified environmental conditions necessitate enclosures to be ventilated and/or provided with forced air cooling, all enclosures be gasketed and be equipped with gasketed air filters to prevent entry of dust. All cooling fans shall be constructed to enable regular maintenance or removal without dismantling of the VFD unit. Air filters shall be washable aluminum mesh type and shall be removable (without the use of tools) for cleaning. Refer to environmental conditions as specified herein and requirement to submit cooling calculations.

H. Where indicated on the Drawings or where specified environmental conditions necessitate VFDs to be provided with mechanical cooling, outdoor enclosures shall be gasketed NEMA Type 1 with walk-in gasketed NEMA Type 3R wrappers. The walk-in space between the NEMA Type 1 doors and NEMA Type 3R doors shall be air-conditioned with a pad mounted commercial air conditioner located adjacent to the enclosure. Supply and return ducting between the air conditioner and enclosure shall be insulated and weatherproofed. The air conditioner location shall be subject to the District's review and approval.

2.11 HARMONIC DISTORTION SUPPRESSION

The electrical system shall be provided with the necessary equipment to protect the VFDs and power system(s) on the line side of the VFDs from harmonic distortion, as specified in Part 1.08 herein. Prior to equipment selection, a harmonic distortion study shall be performed to determine the characteristics and ratings of individual line reactors, passive filters, isolation transformers, 12-pulse VFDs, 18-pulse VFDs, or other suppression equipment necessary to achieve the specified distortion limits. Unless indicated otherwise in the Specific Project VFD Requirements, active filters or active front end VFDs will not be allowed for suppression of harmonic distortion.

A. <u>Line Reactors</u>

1. Unless otherwise specified, each VFD shall be provided with a line reactor. The line reactor shall be factory mounted and wired within the VFD unit enclosure.

2. Line reactors shall be provided on the incoming power lines to the VFDs to:

   a. Minimize the effects of "line notching" due to the switching of power semiconductor devices for controlled rectifier type drives.

   b. Prevent overvoltage trips and/or damage to the drive itself due to transients (i.e. utility power capacitor switching, etc.) on the VFD incoming power lines.

   c. Reduce input harmonic currents thereby improving the total power factor of the drive system.

3. The line reactor shall provide a minimum of 3% line impedance and be designed for harmonic filtering service and for slowing the rate of rapid current changes.

4. Line reactors shall be in accordance with the requirements specified herein, and shall be as manufactured by Trans-Coil, Inc., MTE Corp., or equal.

B. Passive Filters

1. Passive filters, if selected for harmonic distortion suppression, shall be provided for each VFD unit. Passive filters shall be factory mounted and wired within the VFD unit enclosure.

2. Passive filters shall contain tuned circuits designed to remove harmonics generated within the power distribution system while improving the system power factor. Passive filters shall consist of inductive and capacitive elements configured and tuned to resonate just below the harmonic frequency for which they are designed to filter.

3. Passive filters shall be provided with 3-phase contactors, which shall disengage the filter capacitor cells when the VFD is not running and engage the filter capacitor cells when the VFD is running. As a minimum, provide an adjustable (0 to 30 second) time-delay relay, which shall energize via a run contact from the VFD and cause the capacitor cell contactors to engage at the end of the time delay. Manufacturer shall modify the control diagrams shown on the Drawings as required to perform the above function.

4. Passive filters shall be in accordance with the requirements specified herein, and shall be as manufactured by Trans-Coil, Inc., MTE Corp., or equal.

C. Components for Line Reactors and Passive Filters

Line reactor and passive filter components shall comply with the following minimum requirements:

1. Inductors

a. Both series line reactors and tuning reactors (inductors) shall be designed for harmonic filtering service and for slowing the rate of rapid current changes. The inductors shall be UL component-recognized and shall be built to comply with UL 508. Construction shall be of copper wire-wound on magnetic steel cores. Inductors shall be three-phase. Series line reactors shall be sized appropriately for the total connected load. Design maximum temperature rise for inductors shall be 115°C on bobbin wound and 155°C on form wound devices at rated current.

b. The core shall be constructed of laminated, magnetic steel (grade M36 or better). Brackets shall be ASTM structural steel or structural aluminum. Coils shall be wedged in place and the core shall be locked in place using vertical ties or rods.

c. Windings shall consist of copper wire or of copper foil. Terminations shall be copper alloy ring lugs, UL-recognized terminal blocks, or solid copper bus. Sheet insulation shall be DuPont Nomex 410, or 3M Cequin of the thickness as required for UL insulation systems.

d. Completed inductors shall be impregnated, using 100% solid epoxy resin. All insulation varnish systems shall be rated Class H (180°C) or Class R (220°C), 600 V. Inductors shall be Hi-Pot tested (2,500 V, 60 Hz, 1 minute) line-to-line and line-to-ground.

e. Inductors shall be air-gapped to avoid control point saturation. Inductance shall be measured under full load and shall be within -2% to +8% for the tuning reactor and +/- 20% for the series line reactor, of the design value.

2. Capacitor Cells

   a. Capacitor cells shall have a voltage rating capable of handling continuously the nominal system voltage plus 10% of the over voltage tolerance. Capacitor cells shall also be capable of operating under the worst case voltage gain due to the leading nature of the capacitive current. Dielectric material shall be low-loss (less than 0.25 watts per kVAR).

   b. Capacitor cells shall be standard (non-custom), high-endurance type, and shall be contained in hermetically sealed metal cans. Capacitor cells shall be rated to operate at an ambient temperature of 65°C.

   c. Capacitor cells shall be provided with a UL mandated, pressure-sensitive interrupter which, in case of a hazardous internal pressure increase, shall disconnect all three phases simultaneously. Capacitor cells shall be recognized or listed under UL810.

   d. Individual capacitor cells, or groups of cells, shall be provided with a 3-phase, discharge resistor network. The resistors shall be sized to reduce residual voltage to less than 50V within one minute of de-energization (per NEC Article 460-6).

   e. The RMS current in each capacitor cell at full load shall not exceed 150% of the current at no load to limit the stress on the capacitors.

3. Contactors

   a. Contactors shall be provided in the capacitor cell circuit. Contactors, shall be used in conjunction with the VFDs run relay, and shall remove the capacitors from the circuit when the motor is not operating; thereby, eliminating the opportunity for “leading” power factor condition.

   b. Contactors shall be designed for 3-phase capacitor cell switching applications, and shall be rated for 600 volts and be UL listed.

4. Protection

   a. Internal wiring, including wiring for the tuning reactors, shall be protected by three fuses, one for each phase. Fuses shall be current limiting type and rated for a minimum interrupting current of 200,000 symmetrical amperes at 600 VAC, 60 Hz.

   b. Fuses shall be Class T and shall be UL listed. Fuses shall be sized for a minimum of 150% of nominal capacitor cell rating. Fuses internal to capacitor cells shall not be acceptable as the primary means of protection.

   c. Protective barriers shall be furnished as necessary to provide finger-safe protection between 3-phase power components and control power circuitry.

5. Connections

   a. Unless otherwise specified, compression type, pure copper or copper alloy terminal lugs shall be provided for electrical connections of harmonic filters to 3-phase line power. An internal grounding lug shall also be provided. Lugs shall be UL listed.

   b. Distribution blocks, when necessary, shall be rated for copper wire and shall be UL listed or recognized.

6. Wire

   a. Unless specified otherwise, interconnecting wiring for inductors and capacitor cells shall be constructed of copper with thermoplastic insulation that is rated at 600 V and for a minimum of 90°C. All control wiring shall be copper wire that is rated at 600 V and 90°C.

   b. Signal wire shall be multi-conductor jacketed wire that is rated at 300 V and 80°C.

7. Enclosures

a. Unless specified otherwise, harmonic filters and reactors shall be incorporated in the VFD unit's enclosure. Wherever possible, harmonic filters and reactors shall be mounted in a separate section of the enclosure from the VFD assembly.

b. The filters and reactors shall be provided with integral mounting brackets for horizontal or vertical mounting.

2.12 MOTOR PROTECTION OUTPUT FILTERS

A. Where the conductor length between the VFD and motor exceeds 100 feet, or where specified on the Drawings or in the Specific Project VFD requirements, a motor protection output filter shall be provided within the VFD enclosure. The motor protection output filter shall be a low pass filter which protects the motor and power cables from voltage spiking. The output filter shall be sized for the motor load and shall be located immediately adjacent to the output terminals of the VFD.

B. Motor output filter components shall be in accordance with Part 2.11, C herein.

C. The motor protection output filter shall be Model V1k as manufactured by Trans-Coil, Inc., Model dV Sentry as manufactured by MTE Corp., or equal.

2.13 EMI/RFI FILTERS

A. An electromagnetic interference and radio frequency interference (EMI/RFI) filter shall be provided on the incoming power lines of the VFD if required as a result of system startup and testing to prevent conducted radio frequency noise generated by the VFD from interfering with other sensitive electronic equipment (such as lighting systems, telecommunications equipment, instrumentation, etc.).

B. The EMI/RFI filter shall be capable of handling a 400% current overload at startup and a 150% current overload for at least 1 minute (minimum once per hour) when operating.

C. The EMI/RFI filter shall be designed and fabricated to meet the requirements of UL 1283. EMI/RFI filters shall be as manufactured by Schaffner, or equal.

2.14 NAMEPLATES

Nameplates shall be provided bearing the VFD unit description as indicated on the Drawings. In addition, nameplates shall be provided for all door mounted components and devices. Nameplates shall be in accordance with Specification Section 16480, Part 2.05.

2.15 SPARE PARTS

As a minimum, Contractor shall furnish the following spare parts:

A. Two (2) spare lamp lenses of each color.

B. Five (5) pilot lamps of each type.

C. Three (3) control fuses of each type and size.

D. Three (3) power fuses of each type and size.

E. Two (2) air filters of each size.

F. One (1) fan for each VFD unit.

Spare parts shall be undamaged and packaged and labeled in original containers and supplied to the District at time of final acceptance of the work.

PART 3 - EXECUTION

3.01 INSTALLATION

A. Contractor shall install all equipment in accordance with the manufacturer's written instructions, NEC requirements, requirements and standards specified herein, and as shown on the Drawings. Each VFD unit shall be installed with clearance in front of the enclosure to satisfy all NEC requirements.

B. All equipment furnished under this Section shall be installed and adjusted under the supervision of a factory-trained service engineer, other than a sales representative.

C. Install arc flash hazard label in accordance with the Arc Flash Studies performed per Specification Section 16040, as accepted by the District.

D. Conduit stub-ups for power conductors and interconnected or remote cables shall be located and terminated in accordance with the VFD manufacturer's written recommendations which shall be subject to the District's review and approval.

E. Contractor shall anchor VFD enclosures to walls or floors in accordance with the calculations and details prepared by the manufacturer's engineer. Floor mounted enclosures shall be mounted on concrete bases, extending 3 inches above the surrounding ground or floor. Anchor bolt embedment depth shall be based on the thickness of the structure slab only, and shall not include any portion of the raised concrete housekeeping pad beneath the equipment.

F. Contractor shall require the VFD manufacturer to examine the Contract Documents as to the location and operating environment that the VFD unit will be subjected to, and advise the District prior to bidding of any potential problems, which could prevent the VFD from functioning as specified and as intended.

G. Perform all pre-energizing checks as recommended by the VFD manufacturer. Under no circumstances are any portions of the VFD unit to be energized without written authorization from the manufacturer's representative, as specified below.

3.02 TESTING AND STARTUP

A. Upon completion of manufacturing, each VFD unit shall be factory inspected and load tested. In addition, all VFD unit control logic shall be factory tested by simulating external control signals. Written certification that the factory inspections, load tests, and control logic testing have been successfully performed shall be submitted to the District prior to VFD unit shipment. All costs associated with said factory tests shall be included in the Contractor's bid.

B. Manufacturer or supplier of the equipment furnished under this Section shall furnish the services of competent factory-trained personnel to provide technical assistance during installation and startup of the VFD equipment.

C. Prior to the commencement of field testing, manufacturer’s service engineer shall perform the following:

1. Set and/or adjust all operating parameters according to the manufacturer's written instructions and District's preference for VFD features, which may be enabled or disabled through the operator interface.

2. Provide District with a complete listing of all VFD operating parameters (control settings and setpoints for all controller inputs).

3. Provide District with written certification stating that the VFD equipment, including controls, have been properly installed and adjusted, and are ready for operation.

D. Field Testing

1. VFD field testing shall be conducted concurrently with field testing of the driven equipment. All field testing shall be witnessed by the District.

2. Field testing shall demonstrate satisfactory operation of all interlocks, alarms, and normal operational sequences. The VFD manufacturer shall utilize suitable field test equipment to locate and correct all malfunctions. Repeated failure of any component will cause the test to be terminated and restarted when equipment has been repaired or replaced. VFD performance shall be documented by obtaining concurrent readings showing input and output: voltage, amperage, power factor, and power over the full speed range of driven equipment.

3. Harmonic distortion field tests shall be conducted at the PCC (service switchboard bus, unless otherwise specified) to determine the voltage distortion and current distortion, and compliance with specified limits. Measurements shall be made utilizing a Dranetz HDPQ Xplorer 400 analyzer (or equal) capable of recording current and voltage distortions. Measurements shall include phase-to-phase, phase-to-neutral, and neutral-to-ground. Measurements shall be obtained over the full range of VFD operation, and shall include individual voltage and current harmonic values up to the 50th harmonic as well as total harmonic distortion (THD) and total demand distortion (TDD). Graphs of the test results shall be submitted for speed values of 60%, 80%, and 100%. Also, testing shall be performed with no VFD units operating, then one unit, then two units, then three units, etc. operating simultaneously (no concurrent linear loads).

4. A written report covering the service engineer's inspection findings, field test readings, field test results, comparison of field test results to specified values/limits, and final listing of all VFD operating parameters (control settings and setpoints for all controller inputs) shall be submitted to the District. The report shall also include a comparison of readings from the VFD and Contractor/manufacturer furnished meters/analyzers, and an evaluation of field measured VFD efficiencies versus manufacturer's guaranteed VFD efficiencies.

3.03 INSTRUCTION

After the VFD equipment has been installed, tested, and adjusted, and placed in satisfactory operating condition, the equipment manufacturer shall provide classroom instruction to the District's personnel in the use and maintenance of the equipment. Comprehensive instruction shall be provided on the VFD controller and operator interface, including menu navigation, changing control parameters, and modifying setpoints. Equipment manufacturer shall provide and discuss the complete listing of VFD control settings and setpoints for all controller inputs (factory set and field set) as established at the completion of field startup and testing.

Four (4) hours of instruction shall be provided, unless otherwise specified. Contractor shall give the District formal written notice of the proposed instruction period at least two weeks prior to commencement of the instruction period. Scheduled training shall be at a time acceptable to the District and the manufacturer. During this instruction period, the manufacturer shall answer any questions from District personnel. The manufacturer's obligation shall be considered ended when he and the District agree that no further instruction is needed.

END OF SECTION 16160