SECTION 23 05 14

**VARIABLE FREQUENCY DRIVES**

**BASED ON DFD MASTER ELECTRICAL SPEC DATED 9/8/22**

This section has been written to cover most (but not all) situations that you will encounter. Depending on the requirements of your specific project, you may have to add material, delete items, or modify what is currently written. The Division of Facilities Development expects changes and comments from you.

The consultant shall carefully edit this section and coordinate the variable frequency drive (VFD) and line reactors to the equipment being specified in the Div. 23 specifications. The VFD will be furnished by the Div. 23 contractor(s) and be installed by the Div. 26 contractor. Coordinate VFD Div. 26 requirements with the Div. 26 consultant.

**PART 1 GENERAL**

Applicable provisions of Division 1 shall govern all work under this Section

**SCOPE**

This section includes variable frequency drives, bypass starters, and line reactors. Included are the following topics:

PART 1 - GENERAL

Scope

Related Work

Reference

Standards

Submittals

Operating and Maintenance Data

Equipment Startup

Warranty

PART 2 - PRODUCTS

Manufacturers

Design and Construction

Performance Requirements

Control Features

Protection Features

Diagnostics

Quality Assurance Tests

Bypass Equipment

AC Input Line Reactors

Output Line Filters

PART 3 - EXECUTION

Variable Frequency Drives (VFD)

Construction Verification Items

Functional Performance Testing

Agency Training

**RELATED WORK**

Section 01 91 01 or 01 91 02 – Commissioning Process

Section 23 08 00 – Commissioning of HVAC

Section 22 30 00 – Plumbing Equipment

Section 23 12 13 - Facility Fuel-Oil PumpsSection 23 21 23 - Hydronic Pumps

Section 23 34 00 - HVAC Fans

Section 23 64 15 - Water Cooled Chillers

Section 23 65 00 - Cooling Towers

Section 23 73 13 - Modular Indoor Central-Station Air-Handling Units

Section 26 05 26 - Grounding and Bonding for Electrical Systems

Section 26 05 29 - Hangers and Supports for Electrical Systems

Section 26 05 53 - Identification for Electrical Systems

Section 26 27 02 – Equipment Wiring Systems

**REFERENCE**

Applicable provisions of Division 1 govern work under this section.

**STANDARDS**

ANSI/IEEE 519-2014 Guide for Harmonic Control and Reactive Compensation of Static Power Converters

**SUBMITTALS**

Submit shop drawings and product data under provisions of Division 1, General Conditions of the Contract.

Include physical, electrical, and performance characteristics of each variable frequency drive and associated components, including dimensions; weight; input and output performance; voltage, phase, current and overcurrent characteristics; installation instructions; protective features; wiring and block diagrams indicating specified options; electrical noise attenuation equipment where required to meet the criteria specified; line side voltage notch wave form and line side current harmonics; certified efficiency versus load and speed curves; and required operating environment.

# **OPERATION AND MAINTENANCE DATA**

All operations and maintenance data shall comply with the submission and content requirements specified under section GENERAL REQUIREMENTS.

***Delete the following if there are no additional requirements.***

In addition to the general content specified under GENERAL REQUIREMENTS supply the following additional documentation:

1. ***[A/E and commissioning provider to define detailed operation and maintenance data requirements for equipment specifications added to this section.]***

**EQUIPMENT STARTUP AND AGENCY TRAINING**

Provide the services of a factory trained and certified technician to approve the installation; start-up, test, and adjust for proper operation of the unit(s). Upon completion of the equipment startup, submit a complete manufacturer’s field report, including startup and test log, signed by the factory trained technician. Coordinate with the Temperature Control Contractor and the Balancing Contractor. The startup shall be coordinated with Division 26. Electrical and shall be completed within ten (10) working days from the startup date as set by the DFD representative.

**WARRANTY**

The warranty shall be for a period of twenty-four (24) months from the date of project Substantial Completion. Further, the warranty shall include all parts, labor, travel time, administrative costs, overhead, travel expenses, technical support and any and all other costs to provide the warranty service.

**PART 2 PRODUCTS**

**MANUFACTURERS**

ABB, Toshiba, Danfoss, Trane/Danfoss, GE, Emerson, Yaskawa, Eaton/Cutler Hammer, Mitsubishi, Allen Bradley

# ***The consultant shall identify any VFDs to be installed in plenum areas and specify plenum rated devices in those areas.***

**DESIGN AND CONSTRUCTION**

The unit shall be variable torque, modular design for control of the motors as specified in Division 23 and rated at the motor full load nameplate amps.

The unit shall be U.L. listed, solid state, microprocessor based with a pulse width modulated (PWM) output wave form (none others are acceptable).

***Mechanical designer should coordinate this requirement with the electrical designer.***

The VFD package shall have a short circuit current rating (SCCR) of [XX] [65] [100] kA.

The VFD shall employ a full wave bridge rectifier and capacitors to minimize the ripple of the rectified voltage to maintain near constant DC voltage. Insulated gate bipolar transistors (IGBT’s) shall be employed as the output switching device.

The VFD package shall contain the equivalent of 5% impedance to reduce harmonic distortion. The 5% equivalent impedance shall be provided in the form of a DC choke, an input AC line reactor in each phase, or a combination of the two methods.

Control circuitry shall be plug-in, plug-out modular basis with a corrosion resistant coating on printed circuit boards.

Units to be suitable for an operating environment from 0°C to 40°C temperature and humidity up to 90% non-condensing.

Electrically and physically isolate control circuitry and conductors from power circuitry and power conductors. Control conductors and power conductors shall not be run in the same pathway.

The unit enclosure shall be NEMA[1, 12] as required for the application minimum and all components shall be fully factory assembled and tested prior to leaving the manufacturing facility.

***A manual bypass is required on VFD installations where adequate redundancy of mechanical systems does not exist, and a bypass is required to make the building functional on VFD failure. This determination should be made based on evaluating the mechanical system, what it is serving, the consequences of a failure, and economic impact on the project. There may be some cases when a manual bypass is not economical (such as in very small motor applications). If a bypass is provided, it is the AE’s responsibility to design the mechanical system it is serving with proper sizing, mechanical components, etc. to operate under full speed without damage or failure of the mechanical system. The AE shall schedule the VFD and bypass requirements on the mechanical plans.***

Include the following operating and monitoring devices mounted on the front cover:

A fused disconnect switch to de-energize the drive [and bypass circuit] with door interlocked handle and lock-open padlocking provisions.

Operating mode selector switch marked "hand-off-auto".

Manual speed adjustment via keypad, mounted on the door.

Manual bypass selector switch to select power through drive or bypass (if a bypass is provided).

[Provide a manual bypass circuit and bypass starter to transfer from variable frequency drive operation to bypass operation (if a bypass is provided).]

**PERFORMANCE REQUIREMENTS**

Units shall be suitable for input power of electrical system as scheduled on the drawings ±10%, 3 phase, 60 Hertz nominal.

Use a current limiting control device to limit output current to 110% continuous for one minute; also refer to Protection Features in this section. Full load output current available from drive shall not be less than motor nameplate amperage. The full load amp rating of the VFD shall not be less than the values indicated in the NEC Table 430-150.

Output power shall be suitable for driving standard NEMA B design, three phase alternating current induction motors at full rated speed with capability of 6:1 turndown.

Additional performance capabilities to include the following:

Ride through a momentary power outage of 15 cycles,

Start into a rotating load without damage to drive components or motor,

Capable of automatic restart into a rotating load after a preset, adjustable time delay following a power outage

Input power factor: Min 0.95 throughout the speed range

Minimum efficiency: 95% at 100% speed, 85% at 50% speed

# ***The consultant shall insert the following Harmonic Analysis requirement for projects where total motor horsepower/ KVA utilizing VFD’s is equal to or greater than 1/3 of building transformer KVA rating. This shall include fans, pumps, chillers, elevators packaged equipment, etc. The consultant shall utilize the following: For Science/ Laboratory buildings, 3% THD-v and 8% TDD Harmonic Distortion requirements shall be specified. For all other building projects, 8% THD-v and 8% TDD Harmonic Distortion requirements shall be specified. Consult with DFD if there are questions if a building is considered a Science/Laboratory building.***

**HARMONIC ANALYSIS**

VFD manufacturer shall perform harmonic analysis at building Main Switchboard, to demonstrate that the limits specified in IEEE-519-2014 are satisfied. [VFD manufacturer shall perform harmonic analysis at generator supply terminals to demonstrate that harmonic current and voltage distortion limits indicated are not exceeded while system is supplied with generator power.]

VFDs provided under other specification sections (chillers, elevators, packaged equipment, etc.) shall also be included in analysis. Contractor shall be responsible for gathering VFD information from other specification sections and providing it to VFD manufacturer performing analysis.

Analysis shall be computer generated and perform Fourier analysis of system. Results shall list current and voltage amplitudes of all harmonics up to 50th level at secondary of service transformer. A summary shall detail percent total harmonic distortion for voltage and total demand distortion for current.

Analysis shall assume maximum transformer loading of 75% of nameplate value. Analysis shall assume maximum generator loading of 75% of nameplate value.

Analysis shall assume motor loading of 75% of nameplate full load amps.

Analysis shall assume 5.75% impedance at service transformer for the purposes of calculating available fault current. Assume infinite utility fault capacity for the purposes of this study only.

Successful contractor must provide required data for VFD manufacturer to complete harmonic analysis. Information shall include short circuit amperes capability; distribution transformer kVA and impedance; length, size and number of wires per phase to distribution equipment feeding VFDs; wire data to VFDs from distribution equipment; wire data to motor from VFD; and motor nameplate data.

VFD manufacturer is responsible for cost of all equipment required to meet harmonic limits identified below, based on IEEE-519 standards. Equipment, which can be provided, includes input line reactors, DC bus reactors, harmonic filters, passive filters, and active filters.

The Total Harmonic Voltage Distortion at the building switchboard shall be limited to [3][8] % THD-v, and the Total Harmonic Current Distortion shall be limited to 8 % TDD.

**CONTROL FEATURES**

Use control circuits compatible with input signal from temperature control system in the automatic mode and from manual speed control in the manual mode. Vary motor speed in response to the input control signal. Include components necessary to accept the signal from the temperature control system in the form that it is sent. Refer to Division 23 00 00.

Include the following additional control features:

* Hand-Off-Automatic (HOA) selector switch to select local or remote start/stop and speed control
* Analog input, selectable 0-10v or 4-20 mA, for automatic control from the temperature control system
* Local speed control at the VFD
* Adjustable acceleration and deceleration rate so that the time period from start to full speed and from full speed to stop can be field adjusted
* Adjustable minimum and maximum speed settings for both automatic and manual modes of operation
* Manual transfer bypass circuit
* Field adjustment of minimum and maximum output frequency
* Two (2) sets of programmable form “C” contacts for remote indication of variable frequency drive condition. Note: default programming to be set for “Drive Run & Fault”.
* Illuminated display keypad.
* External Fault indicator
* One (1) input for a N.O. dry contact type input for a 2-wire remote start/stop
* One (1) input for a N.C. dry contact type input for external faults: (freezestats, fire alarm, smokes, etc). This input shall be factory wired to prevent both the VFD and bypass starter operation when external fault is present.
* One (1) N.O. dry contact output for proving motor status. This output shall be programmed to detect belt or coupling break that would remove the load from the motor by using sensed torque of the motor. The dry contact will open on loss of load or VFD being off.
* PID control loop capable of VFD control from an external device connected to a VFD analog input.
* When specified in the 23 09 93 sequence of operations, provide a VFD input and output for shutoff damper control that shall operate as follows: When the fan is remotely or locally commanded to start, VFD contact shall energize the shutoff damper to open the damper. The damper position end switch shall be wired to a run permissive input on the VFD and enable the VFD to start when the damper end switch provides the damper is open. This feature shall be provided for both inverter and bypass operation (if bypass option is provided).

***For VFD’s that are to be integrated into the building automation system the following paragraph should be used. Determine by discussing with Agency staff and DFD, if this type of interface is currently being utilized on the Agencies existing buildings/campus. If so, it should be provided. Determine if the system the VFD is integrated into requires a different protocol such as LonWorks FTT-10, Modbus RTU, or Modbus TCP. If so, modify the protocol from BACnet MSTP to the appropriate protocol.***

The VFD controller shall convert VFD information into the BACnet MSTP protocol that will be compatible with the building direct digital energy management system (EMS) supplied on the project. This output shall be through a serial interface port capable of two-way communication with the building EMS provided on this project. Final connection shall not require any additional intermediate gateway devices to provide throughput of data. The following data shall be provided at a minimum:

* Fault condition
* Speed
* Amperage
* Frequency
* Voltage
* Bypass status (if supplied)

**PROTECTION FEATURES**

Use electronic protection circuitry in the power circuits to provide an orderly shutdown of the drive without blowing fuses and prevent component loss under the following abnormal conditions:

Activation of any safety device;

Instantaneous overcurrent and/or over voltage of output;

Power line overvoltage and undervoltage protection;

Phase loss;

Single and three phase short circuiting;

Ground faults;

Control circuit malfunction;

Overtemperature; and

Output current over limit.

Provide the following additional protective features:

* Input transient overvoltage protection up to 3000 volts per ANSI 37.90A;
* DC bus fusing which limit the rate of rise of the DC bus current and de-energizes the drive at a predetermined current level;
* Fusing for the control circuit transformer;
* Grounded control chassis; and
* Devices and/or control circuitry to ensure that the variable frequency drive and bypass starter are not both energized and driving motor simultaneously.

**DIAGNOSTICS**

Provide an English character display (no error codes) with indicators for the following:

Phase loss

Ground fault

Overcurrent

Overvoltage

Undervoltage

Over temperature

Overload

DC bus status

**QUALITY ASSURANCE TESTS**

Use a factory heat stress test to verify proper operation of all functions and components under full load.

Field performance test of variable frequency drives to determine compliance with this specification will be performed at the DFD's discretion and may include any specified feature, including operation of protective devices through a simulated fault. Contractor will pay for initial testing. Should drive be found deficient by this testing, drive manufacturer will be required to make any and all changes necessary to bring unit(s) into compliance with the specified performance and demonstrate this performance by retesting. Cost of changes and retest will be by this contractor.

Variable frequency drive manufacturer or designated representative to perform a field test of each drive, in the presence of the DFD's representative, for the following items:

* Provide general inspection to verify proper installation;
* Demonstrate drive reaction to simulated power interruptions of two seconds and sixty seconds;
* Demonstrate adequate protection during switching from variable frequency drive operation to bypass starter operation and back again;

## BYPASS EQUIPMENT

Bypass Starters:

The bypass starters for 208 volt motors, 20 HP and less; and 480 volt motors, 40 HP and less, shall be NEMA rated across-the-line magnetic starter type.

The bypass starters for 208 volt motors, 25 HP and more; and 480 volt motors, 50 HP and more, shall be NEMA rated solid state reduced voltage starting type.

Bypass Configuration:

Provide one main fused disconnect switch to de-energize both the drive and bypass circuit. Provide a drive input disconnect switch to allow the drive to be isolated while the bypass circuit is energized. Provide one output drive contactor and one output bypass contactor. The two output contactors shall be electrically interlocked to allow only one contactor to be closed at any one time.

Provide motor overload protection in the bypass circuit.

Provide bypass equipment in a common enclosure with the VFD or, if not available, in a separate enclosure.

**AC INPUT LINE REACTORS**

When needed to comply with the requirement for 5% equivalent impedance, furnish and factory install AC input line reactors.

Line reactors shall be installed in each phase of the AC input side of the VFD and mounted within a common enclosure with the VFD.

Line reactor shall be a three phase inductor, iron core, 600V, Class H insulation, 115 degree C rise, copper windings with screw type terminal blocks.

***Include the following section if 460VAC drives on the project have output line lengths over 120 feet. It is not desirable to locate VFD’s outside and we would prefer adding an output line filter and locating the VFD inside. As a rule, do not exceed line lengths of 300 feet for 460VAC motors. Specifically call out what drives will require output filters to eliminate confusion if line lengths are indeterminate.***

**OUTPUT LINE FILTER**

Provide a three phase dV/dT output filter for any 460VAC drive with output line length of over 120 feet or as specified.

**PART 3 EXECUTION**

**VARIABLE FREQUENCY DRIVES**

Install where indicated on drawings and in accordance with approved submittals and manufacturer's published recommendations. Installation to be by the Division 26 00 00 - Electrical contractor.

Input power wiring shall be installed in a separate conduit, output power wiring shall be installed in a separate conduit and control wiring shall be installed in a separate conduit. Do not mix input power, output power, or control wiring in a common conduit. Separate conduits for input and output power wiring shall be provided for each motor. Input and output power wiring for more than one motor shall not share a common conduit. Power wiring shall be furnished and installed by the Div. 26 contractor. If provided, do not mount output line filter above the drive.

Motor status relay shall be programmed to detect belt or coupling loss for fans and pumps. This shall use motor torque to determine when the load is lost and shall be set to show status loss whenever the VFD is at the lowest programmed speed and the belt or coupling loss occurs. This shall be tested by the VFD setup technician in conjunction with the Division 23 control contractor and commissioning agent.

***The consultant is to coordinate with the Division 26 00 00 - Electrical consultant to ensure that VFD requirements, characteristics, and locations are correctly shown on the mechanical and electrical plans.***

Control signal for drive will be provided under Division 23.

Temperature Control Contractor will furnish and install the required temperature control wiring in metal conduit and in accordance with Division 26 00 00 - Electrical of this specification.

# **CONSTRUCTION VERIFICATION ITEMS**

Contractor is responsible for utilizing the construction verification checklists supplied under specification Section 23 08 00 in accordance with the procedures defined for construction verification in Section 01 91 01 or 01 91 02.

# **FUNCTIONAL PERFORMANCE TESTING**

Contractor is responsible for utilizing the functional performance test procedures supplied under specification Section 23 08 00 in accordance with the procedures defined for functional performance testing in Section 01 91 01 or 01 91 02.

# **AGENCY TRAINING**

All training provided for agency shall comply with the format, general content requirements and submission guidelines specified under Section 01 91 01 or 01 91 02.

Contractor to provide factory authorized representative and/or field personnel knowledgeable with the operations, maintenance and troubleshooting of the system and/or components defined within this section for a minimum period of [XX] hours.

END OF SECTION