

**SECTION 23 09 33  
VARIABLE FREQUENCY MOTOR CONTROLLERS**

**PART 1 - GENERAL**

**1.1 DESCRIPTION**

- A. Drawings and general provisions of the Contract, including General and Supplementary Conditions and Division 01 Specification Sections, apply to this Section.
- B. Section includes separately enclosed, pre-assembled, combination VFCs, rated 600 V and less, for speed control of three-phase, squirrel-cage induction motors. This section does not include panel-mounted VFC's incorporated into equipment as part of a packaged system.

**1.2 DEFINITIONS**

- A. BAS: Building automation system.
- B. CE: Conforme Europeene (European Compliance).
- C. CPT: Control power transformer.
- D. EMI: Electromagnetic interference.
- E. IGBT: Insulated-gate bipolar transistor.
- F. LAN: Local area network.
- G. LED: Light-emitting diode.
- H. MCP: Motor-circuit protector.
- I. NC: Normally closed.
- J. NO: Normally open.
- K. OCPD: Overcurrent protective device.
- L. PCC: Point of common coupling.
- M. PID: Control action, proportional plus integral plus derivative.
- N. PWM: Pulse-width modulated.
- O. RFI: Radio-frequency interference.
- P. TDD: Total demand (harmonic current) distortion.
- Q. THD(V): Total harmonic voltage demand.
- R. VFC: Variable-frequency motor controller.

**1.3 ACTION SUBMITTALS**

- A. Product Data: For each type and rating of VFC indicated. Include features, performance, electrical ratings, operating characteristics, shipping and operating weights, and furnished specialties and accessories.

- B. Shop Drawings: For each VFC indicated. Include dimensioned plans, elevations, and sections; and conduit entry locations and sizes, mounting arrangements, and details, including required clearances and service space around equipment.
  - 1. Show tabulations of installed devices, equipment features, and ratings. Include the following:
    - a. Each installed unit's type and details.
    - b. Factory-installed devices.
    - c. Enclosure types and details.
    - d. Nameplate legends.
    - e. Short-circuit current (withstand) rating of enclosed unit.
    - f. Features, characteristics, ratings, and factory settings of each VFC and installed devices.
    - g. Specified modifications.
  - 2. Schematic and Connection Wiring Diagrams: For power, signal, and control wiring.

#### **1.4 INFORMATIONAL SUBMITTALS**

- A. Field quality-control reports.
- B. Load-Current and List of Settings of Adjustable Overload Relays: Compile after motors have been installed and arrange to demonstrate that switch settings for motor-running overload protection suit actual motors to be protected.

#### **1.5 CLOSEOUT SUBMITTALS**

- A. Operation and Maintenance Data: For VFCs to include in emergency, operation, and maintenance manuals. In addition to items specified in Section 017823 "Operation and Maintenance Data," include the following:
  - 1. Manufacturer's written instructions for testing and adjusting thermal-magnetic circuit breaker and MCP trip settings.
  - 2. Manufacturer's written instructions for setting field-adjustable overload relays.
  - 3. Manufacturer's written instructions for testing, adjusting, and reprogramming microprocessor control modules.
  - 4. Manufacturer's written instructions for setting field-adjustable timers, controls, and status and alarm points.

5. Seismic qualification certificates.

**1.6 MAINTENANCE MATERIAL SUBMITTALS**

- A. Furnish extra materials described below that match products installed and that are packaged with protective covering for storage and identified with labels describing contents.
  - 1. Power Fuses: Equal to 10 percent of quantity installed for each size and type, but no fewer than three of each size and type.
  - 2. Control Power Fuses: Equal to 10 percent of quantity installed for each size and type, but no fewer than two of each size and type.
  - 3. Indicating Lights: Two of each type and color installed.
  - 4. Auxiliary Contacts: Furnish one spare(s) for each size and type of magnetic controller installed.
  - 5. Power Contacts: Furnish three spares for each size and type of magnetic contactor installed.

**1.7 QUALITY ASSURANCE**

- A. Field Quality Control Testing Agency Qualifications (if required elsewhere in these specifications): Member company of NETA or an NRTL.
  - 1. Testing Agency's Field Supervisor: Currently certified by NETA to supervise on-site testing.
- B. Electrical Components, Devices, and Accessories: Listed and labeled as defined in NFPA 70, by a qualified testing agency, and marked for intended location and application.
- C. Comply with NFPA 70.
- D. IEEE Compliance: Fabricate and test VFC according to IEEE 344 to withstand seismic forces (when required in VFD schedule).

**1.8 DELIVERY, STORAGE, AND HANDLING**

- A. Store in space that maintains temperature and humidity requirements in conformance with "Environmental Limitations" in "Project Conditions" below.

**1.9 PROJECT CONDITIONS**

- A. Environmental Limitations: Rate equipment for continuous operation, capable of driving full load without derating, under the following conditions unless otherwise indicated:

1. Ambient Temperature: Not less than 14 deg F and not exceeding 104 deg F
2. Ambient Storage Temperature: Not less than minus 4 deg F and not exceeding 140 deg F
3. Humidity: Less than 95 percent (noncondensing).
4. Altitude: Not exceeding 3300 feet

**1.10 COORDINATION**

- A. For floor mounted VFC's, coordinate sizes and locations of concrete bases with actual equipment provided. Cast anchor-bolt inserts into bases.

**1.11 WARRANTY**

- A. Special Warranty: Manufacturer's standard form in which manufacturer agrees to repair or replace VFCs that fail in materials or workmanship within specified warranty period.
  1. Warranty Period: Five years from date of Substantial Completion.

**PART 2 - PRODUCTS**

**2.1 MANUFACTURED UNITS**

- A. VFC Description: Variable-frequency power converter (rectifier, dc bus, and IGBT, PWM inverter) factory packaged in an enclosure, with integral disconnecting means and overcurrent and overload protection; listed and labeled by an NRTL as a complete unit; arranged to provide self-protection, protection, and variable-speed control of one or more three-phase induction motors by adjusting output voltage and frequency.
  1. Units suitable for operation of inverter-duty motors as defined by NEMA MG 1, Section IV, Part 31, "Definite-Purpose Inverter-Fed Polyphase Motors."
  2. Listed and labeled for integrated short-circuit current (withstand) rating by an NRTL acceptable to authorities having jurisdiction.
- B. General Requirements for VFCs: Comply with NEMA ICS 7, NEMA ICS 61800-2.
- C. Output Rating: Three-phase; 10 to 60 Hz, with voltage proportional to frequency throughout voltage range for variable-torque controllers:

10 to 66 Hz, with torque constant as speed changes for constant-torque controllers; maximum voltage equals input voltage.

D. Unit Operating Requirements:

1. Input AC Voltage Tolerance: Plus 10 and minus 10 percent of VFC input voltage rating.
2. Input AC Voltage Unbalance: Not exceeding 3 percent.
3. Input Frequency Tolerance: Plus or minus 3 percent of VFC frequency rating.
4. Minimum Efficiency: 97 percent at 60 Hz, full load.
5. Minimum Displacement Primary-Side Power Factor: 97 percent under any load or speed condition.
6. Vibration Withstand: Comply with IEC 60068-2-6.
7. Overload Capability: Minimum 1.1 times the base load current for 60 seconds for variable torque controllers; minimum of 1.5 times the base load current for three seconds for constant torque controllers.
8. Starting Torque: Minimum 100 percent of rated torque from 3 to 60 Hz.
9. Speed Regulation: Plus or minus 5 percent.
10. Output Carrier Frequency: Selectable; minimum 2kHz-10kHz for 1-40 HP at 208/240V and 1-75HP at 460V; minimum 2kHz-8kHz for 50-100HP at 208-240V and 100-200HP at 460V.
11. Stop Modes: Programmable; includes fast, free-wheel, and dc injection braking.

E. Isolated Control Interface: Allows VFCs to follow remote-control signal over a minimum 40:1 speed range.

1. Signal: Electrical.

F. Internal Adjustability Capabilities:

1. Minimum Speed: 5 to 25 percent of maximum rpm.
2. Maximum Speed: 80 to 100 percent of maximum rpm.
3. Acceleration: 0.1 to 999.9 seconds.
4. Deceleration: 0.1 to 999.9 seconds.
5. Current Limit: 30 to minimum of 150 percent of maximum rating.

G. Self-Protection and Reliability Features:

1. Input transient protection by means of surge suppressors to provide three-phase protection against damage from supply voltage surges 10 percent or more above nominal line voltage.
  2. Loss of Input Signal Protection: Selectable response strategy, including speed default to a percent of the most recent speed, a preset speed, or stop; with alarm.
  3. Under- and overvoltage trips.
  4. Inverter overcurrent trips.
  5. VFC and Motor Overload/Overtemperature Protection: VFC overtemperature and motor overload alarm and trip.
  6. Instantaneous line-to-line and line-to-ground overcurrent trips.
  7. Loss-of-phase protection.
  8. Reverse-phase protection.
  9. Short-circuit protection.
  10. Motor overtemperature fault.
  11. Fast acting VFC isolation fuses to disconnect VFC from the line prior to the clearing of upstream branch circuit protection.
- H. Automatic Reset/Restart: Attempt three restarts after drive fault or on return of power after an interruption and before shutting down for manual reset or fault correction; adjustable delay time between restart attempts.
- I. Bidirectional Autospeed Search: Capable of starting VFC into rotating loads spinning in either direction and returning motor to set speed in proper direction, without causing damage to drive, motor, or load.
- J. Integral Input Disconnecting Means and OCPD: NEMA KS 1, fusible switch with pad-lockable, door-mounted handle mechanism.

## **2.2 CONTROLS AND INDICATION**

- A. Status Lights: Door-mounted indicators displaying the following conditions:
1. Power on.
  2. Run.
  3. Overvoltage.
  4. Line fault.
  5. Overcurrent.
  6. External fault.

- B. Panel-Mounted Operator Station: Manufacturer's standard front-accessible, sealed keypad and plain-English language digital display; allows complete programming, operating, monitoring, and diagnostic capability.
- C. Historical Logging Information and Displays:
  - 1. Kilowatt-hours consumption.
  - 2. Running log of total power versus time.
  - 3. Total run time.
  - 4. Fault log, maintaining last three faults with time and date stamp for each.
- D. Indicating Devices: Digital display and additional readout devices as required, mounted flush in VFC door and connected to display VFC parameters including, but not limited to:
  - 1. Output frequency (Hz).
  - 2. Motor speed (rpm).
  - 3. Motor status (running, stop, fault).
  - 4. Motor current (amperes).
  - 5. Motor torque (percent).
  - 6. Fault or alarming status (code).
  - 7. PID feedback signal (percent).
  - 8. DC-link voltage (V dc).
  - 9. Set point frequency (Hz).
  - 10. Motor output voltage (V ac).
- E. Control Signal Interfaces:
  - 1. Electric Input Signal Interface:
    - a. A minimum of one programmable analog inputs: 0- to 10-V dc.
    - b. A minimum of one programmable analog input: 4- to 20- mA dc.
    - c. A minimum of three multifunction programmable digital inputs.
  - 2. Output Signal Interface: A minimum of one programmable analog output signal(s) 0- to 10-V dc and one programmable analog output signal 4- to 20-mA dc, which can be configured for any of the following:
    - a. Output frequency (Hz).
    - b. Output current (load).
    - c. DC-link voltage (V dc).

- d. Motor torque (percent).
  - e. Motor speed (rpm).
  - f. Set point frequency (Hz).
3. Remote Indication Interface: A minimum of two programmable dry-circuit relay outputs (120-V ac, 1 A) for remote indication of the following:
- a. Motor running.
  - b. Set point speed reached.
  - c. Fault and warning indication (overtemperature or overcurrent).
  - d. PID high- or low-speed limits reached.
- F. BAS Interface: Factory-installed hardware and software to enable the BAS to monitor, control, and display VFC status and alarms and energy usage. Allows VFC to be used with an external system within a multidrop LAN configuration; settings retained within VFC's nonvolatile memory.
- 1. Network Communications Ports: Ethernet and RS-422/485.
  - 2. Embedded BAS Protocols for Network Communications: ASHRAE 135 BACnet, Johnson Metasys N2 protocols accessible via the communications ports.

## **2.3 LINE CONDITIONING AND FILTERING**

- A. Input Line Conditioning: When indicated on the VFC schedule on the plans, provide input filtering, as required, to limit TDD at input terminals to less than 5 percent and THD(V) to 3 percent.
- B. Output Filtering: Provide output line inductors when indicated on the VFC schedule on the plans.
- C. EMI/RFI Filtering: Provide EMI/RFI filtering when indicated on the VFC schedule on the plans. CE marked; certify compliance with IEC 61800-3 for Category C2.

## **2.4 BYPASS SYSTEMS**

- A. Provide bypass system when indicated on the VFC schedule on the plans.
- B. Bypass Operation: Safely transfers motor between power converter output and bypass circuit, manually, automatically, or both. Selector switches set modes and indicator lights indicate mode selected. Unit



is capable of stable operation (starting, stopping, and running) with motor completely disconnected from power converter.

- C. Bypass Mode: Provide manual or automatic bypass as indicated on the VFC schedule on the plans:
1. Manual operation only; requires local operator selection at VFC. Transfer between power converter and bypass contactor and retransfer shall only be allowed with the motor at zero speed.
  2. Field-selectable automatic or manual, allows local and remote transfer between power converter and bypass contactor and retransfer, either via manual operator interface or automatic control system feedback.
- D. Bypass Controller: Provide bypass controller when indicated on the VFC schedule on the plans.
1. Three contactor style.
  2. Bypass allows motor operation via the power converter or the bypass controller; with input isolating switch and barrier arranged to isolate the power converter input and output and permit safe testing and troubleshooting of the power converter, both energized and de-energized, while motor is operating in bypass mode
  3. Bypass Contactor: Load-break, IEC or NEMA-rated contactor as is appropriate for the motor horsepower.
  4. Input and Output Isolating Contactors: Non-load-break, IEC or NEMA-rated contactors.
  5. Isolating Switch: Non-load-break switch arranged to isolate power converter and permit safe troubleshooting and testing of the power converter, both energized and de-energized, while motor is operating in bypass mode; pad-lockable, door-mounted handle mechanism.
  6. NORMAL/BYPASS selector switch.
  7. HAND/OFF/AUTO selector switch.
  8. Power Contacts: Totally enclosed, double break; assembled to allow inspection and replacement without disturbing line or load wiring.

9. Control Circuits: 120-V ac; obtained from integral CPT, with primary and secondary fuses, of sufficient capacity to operate all integral devices and remotely located pilot, indicating, and control devices.
10. Overload Relays: NEMA ICS 2.
  - a. Solid-State Overload Relays:
    - 1) Switch or dial selectable for motor-running overload protection.
    - 2) Sensors in each phase.
    - 3) Class 10/20 selectable tripping characteristic selected to protect motor against voltage and current unbalance and single phasing.

## **2.5 MULTIPLE-MOTOR CONTROL CAPABILITY FEATURES**

- A. Multiple-Motor Capability: When indicated on the VFC schedule on the plans provided, VFC suitable for variable-speed service to multiple motors. Overload protection shuts down VFC and motors served by it, and generates fault indications, when overload protection activates.
  1. Supply Fan Motors: Configure to allow two or more motors to operate simultaneously at the same speed; separate overload relay for each controlled motor.
  2. Return Fan Motors: Configure to allow two motors to operate separately; operator selectable via local or remote switch or contact closures; single overload relay for both motors; separate output magnetic contactors for each motor.

## **2.6 DAMPER CONTROL CIRCUIT**

- A. Provide damper control components when indicated on the VFC schedule on the drawings.
- B. VFC enabled after damper contact proves.

## **2.7 FIREFIGHTER'S OVERRIDE (SMOKE PURGE) INPUT**

- A. Provide firefighter's override input feature when indicated on the VFC schedule on the drawings.
- B. On a remote contact closure from the firefighter's control station or smoke-control fan controller, this input:
  1. Overrides all other local and external inputs (analog/digital, serial communication, and all keypad commands).

2. For VFC's with bypass system, this input forces VFC to transfer to Bypass Mode and operate motor at full speed.
3. Causes display of Override Mode on the VFC display.
4. Reset VFC to normal operation on removal of override signal automatically.

## **2.8 ENCLOSURES**

- A. VFC Enclosures: NEMA 250, of types indicated in VFC schedule on the drawings.
- B. Plenum Rating when indicated on the VFC schedule on the drawings: UL 1995; NRTL certification label on enclosure, clearly identifying VFC as "Plenum Rated."
- C. Enclosure Heater: Provide an enclosure heater when indicated on the VFC schedule on the drawings.
  1. With thermostat for control.

## **PART 3 - EXECUTION**

### **3.1 EXAMINATION**

- A. Examine areas, surfaces, and substrates to receive VFCs, with Installer present, for compliance with requirements for installation tolerances, and other conditions affecting performance.
- B. Examine VFC before installation. Reject VFCs that are wet, moisture damaged, or mold damaged.
- C. Examine roughing-in for conduit systems to verify actual locations of conduit connections before VFC installation.
- D. Proceed with installation only after unsatisfactory conditions have been corrected.

### **3.2 LABOR AND INSTALLATION**

- A. Installation and line wiring of VFC is provided by Division 26.
- B. Installation and wiring of external components (i.e.: input disconnect switch, input and output line conditioning, by-pass, etc.) shall be provided by Division 23.

### **3.3 INSTALLATION**

- A. Coordinate layout and installation of VFCs with other construction including conduit, piping, equipment, and adjacent surfaces. Maintain required workspace clearances and required clearances for equipment access doors and panels.

- B. Wall-Mounting Controllers: Install VFCs on walls with tops at uniform height and with disconnect operating handles not higher than 79 inches above finished floor unless otherwise indicated, and by bolting units to wall or mounting on lightweight structural-steel channels bolted to wall. For controllers not on walls, provide freestanding racks complying with Section 260529 "Hangers and Supports for Electrical Systems."
- C. Floor-Mounting Controllers: Install VFCs on 4-inch nominal thickness concrete base.
  - 1. Install dowel rods to connect concrete base to concrete floor. Unless otherwise indicated, install dowel rods on 18-inch centers around the full perimeter of concrete base.
  - 2. For supported equipment, install epoxy-coated anchor bolts that extend through concrete base and anchor into structural concrete floor.
  - 3. Place and secure anchorage devices. Use setting drawings, templates, diagrams, instructions, and directions furnished with items to be embedded.
  - 4. Install anchor bolts to elevations required for proper attachment to supported equipment.
- D. Seismic Bracing: Comply with requirements specified in Section 260548 "Vibration and Seismic Controls for Electrical Systems" when indicated on the VFC schedule on the drawings.
- E. Temporary Lifting Provisions: Remove temporary lifting eyes, channels, and brackets and temporary blocking of moving parts from enclosures and components.
- F. Install fuses in each fusible-switch VFC.
- G. Install fuses in control circuits if not factory installed.
- H. Install heaters in thermal-overload relays. Select heaters based on actual nameplate full-load amperes after motors have been installed.
- I. Comply with NECA 1.

### **3.4 IDENTIFICATION**

- A. Identify VFCs, components, and control wiring. Comply with requirements for identification specified in Section 260553 "Identification for Electrical Systems."

- B. Operating Instructions for VFC's used as part of emergency procedures: Frame printed operating instructions for VFCs, including control sequences and emergency procedures. Fabricate frame of finished metal, and cover instructions with clear acrylic plastic. Mount on front of VFC units.

### **3.5 CONTROL WIRING INSTALLATION**

- A. Install wiring between VFCs and remote devices and BAS system. Comply with requirements in Section 260523 "Control-Voltage Electrical Power Cables."
- B. Bundle, train, and support wiring in enclosures.
- C. Connect selector switches and other automatic control devices where applicable.
  - 1. Connect selector switches to bypass only those manual- and automatic control devices that have no safety functions when switches are in manual-control position.
  - 2. Connect selector switches with control circuit in both manual and automatic positions for safety-type control devices such as low- and high-pressure cutouts, high-temperature cutouts, and motor overload protectors.

### **3.6 FIELD QUALITY CONTROL**

- A. Testing Agency: Engage a qualified testing agency to perform tests and inspections.
- B. Manufacturer's Field Service: Engage a factory-authorized service representative to inspect components, assemblies, and equipment installations, including connections, and to assist in testing.
- C. Acceptance Testing Preparation:
  - 1. Test insulation resistance for each VFC element, bus, component, connecting supply, feeder, and control circuit.
  - 2. Test continuity of each circuit.
- D. Tests and Inspections:
  - 1. Inspect VFC, wiring, components, connections, and equipment installation. Test and adjust controllers, components, and equipment.
  - 2. Test insulation resistance for each VFC element, component, connecting motor supply, feeder, and control circuits.

3. Test continuity of each circuit.
4. Verify that voltages at VFC locations are within 10 percent of motor nameplate rated voltages. If outside this range for any motor, notify Architect before starting the motor(s).
5. Test each motor for proper phase rotation.
6. Perform each electrical test and visual and mechanical inspection stated in NETA Acceptance Testing Specification. Certify compliance with test parameters.
7. Correct malfunctioning units on-site, where possible, and retest to demonstrate compliance; otherwise, replace with new units and retest.
8. Perform the following infrared (thermographic) scan tests and inspections and prepare reports:
  - a. Initial Infrared Scanning: After Substantial Completion, but not more than 60 days after Final Acceptance, perform an infrared scan of each VFC. Remove front panels so joints and connections are accessible to portable scanner.
  - b. Follow-up Infrared Scanning: Perform an additional follow-up infrared scan of each VFC 11 months after date of Substantial Completion.
  - c. Instruments and Equipment: Use an infrared scanning device designed to measure temperature or to detect significant deviations from normal values. Provide calibration record for device.
9. Test and adjust controls, remote monitoring, and safeties. Replace damaged and malfunctioning controls and equipment.
- E. VFCs will be considered defective if they do not pass tests and inspections.
- F. Prepare test and inspection reports, including a certified report that identifies the VFC and describes scanning results. Include notation of deficiencies detected, remedial action taken, and observations made after remedial action.

### **3.7 STARTUP SERVICE**

- A. Engage a factory-authorized service representative to perform startup service.

1. Complete installation and startup checks according to manufacturer's written instructions.

### **3.8 ADJUSTING**

- A. Program microprocessors for required operational sequences, status indications, alarms, event recording, and display features. Clear events memory after final acceptance testing and prior to Substantial Completion.
- B. Set field-adjustable switches, auxiliary relays, time-delay relays, timers, and overload-relay pickup and trip ranges.
- C. Adjust the trip settings of MCPs and thermal-magnetic circuit breakers with adjustable, instantaneous trip elements. Initially adjust to six times the motor nameplate full-load amperes and attempt to start motors several times, allowing for motor cool-down between starts. If tripping occurs on motor inrush, adjust settings in increments until motors start without tripping. Do not exceed eight times the motor full-load amperes (or 11 times for NEMA Premium Efficient motors if required).

### **3.9 DEMONSTRATION**

- A. Engage a factory-authorized service representative to train Owner's maintenance personnel to adjust, operate, reprogram, and maintain VFCs.

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