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		Date: 2/21/20
		Author: Office of Facilities
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## Change History


Date	Description of Change	Pages / Sections Modified	Change Approver Initials
2/21/20	Added requirement that allows the use of 6 pulse PWM drives with an Ultra-Low Harmonic design.	B.4-7	JR
8/23/17	Updated sections on System Design and Performance Requirements; Submittals; Equipment; Accessories or Special Features; Quality Control Testing; and Startup and Training.	1>2 - B.#s4, 5, 6, 7, 10 & 15; 3>4 - C. 2. b. (1); 5>8 - H.#1, #8, #19.d.(removed); 8 - I. 2. & 3.; 9 - K. 3. (added); 10 - M. 1. c.(removed)	SO
6/15/16	Updated division section from 16269 to 26 29 23, removed references to other section numbers	all	mgl44
10/17/14	Add text to paragraphs B. #4 and B. #5 for clarity. Repair numbering ills.	2 – 16269, B, #4 & #5 (Variable Frequency Drives; System Design and Performance Requirements)	SO
10/17/14	Add text to paragraph #2. Add new paragraph #3 between current #2 and #3, with renumbering.	4 – 16269, C, 2.b. #2 & #3 (Variable Frequency Drives; Submittals)	SO
10/17/14	Add Eaton/ Cutler-Hammer to the list of acceptable Manufacturers.	5 - 16269, F. #2 (Variable-Frequency Drives; Manufacturers)	SO
4/19/13	Remove all from the Manufacturers List except ABB & Yaskawa.	5 - 16269, F. #2 (Variable-Frequency Drives; Manufacturers)	SO
4/19/13	Amend text for present group name	6 - 16269, F. #3 (Variable-Frequency Drives; Manufacturers)	SO

### A. Summary

This section contains design criteria for variable-frequency drives (VFDs).


### B. System Design and Performance Requirements

- At a minimum, VFD performance must comply with IEEE 519-1992, or the latest standard, and with Yale University design standards, Section 15950: Energy Management and Controls Systems. (Refer to Section 01420: Consolidated Reference List.)
- All VFDs must include pulse width modulated (PWM) technology, with diode bridge front ends and insulated gate bipolar transistors in the output sections that use soft switching.
- Assign overall responsibility for coordinating compatibility in the specifications with either the VFD vendor or driven load motor vendor.
- All VFD for loads 10 to 50 HP (and lower) shall use 6 pulse design with isolation contactor to keep capacitors off line when drive is powered but not running.
- All VFD 10 to 50 HP (and lower) must prove from harmonic calculation whether line reactors,

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filters, etc. should be used or not used based on:

- The total harmonics voltage distortion is less than 3 percent.
  - The total harmonics current distortion is less than 7 percent at the point of common coupling.
6. All VFDs for loads of 50 HP or higher shall use line reactors and be equipped with a VFD that uses a 18 pulse PWM drive design, or a 6 pulse PWM drive with Ultra Low Harmonic design.
  7. Harmonics calculations for 50 HP and larger VFDs must prove that:
    - The total harmonics voltage distortion is less than 3 percent.
    - 
    - The total harmonics current distortion is less than 5 percent at the point of common coupling.
  8. All installations must include a line reactor. In areas that are sensitive to radiated energy, installed VFDs must be equipped with RFI filters. If the distance between motor and VFD exceeds 200 feet the VFD shall have a DV/DT filter on the drive.
  9. For variable-torque applications, the VFD overload capability must be 110 percent, for one minute in every 10 minutes, of the inverter current rating. For constant-torque applications, the VFD overload capability must be 150 percent, for one minute, of the inverter current rating. VFDs shall have an adjustable current limit capability of up to 120% during acceleration, for accelerating high initial loads.
  10. Provide a condensation space heater, ventilation fan, and supplemental cooling with automatic temperature control for outdoor and conditioned space applications.
  11. All VFDs must have an adjustable carrier frequency range of 750 Hz to 15 kHz.
  12. All VFDs must be equipped with AUTO restart for instances in which the power system returns to normal after a power line transient (overcurrent, overvoltage, or undervoltage) or outage. Their current limit set to motor nameplate amps during run, for automatic speed reduction to operate at, or less than, motor FLA to allow for trip-free operation.
  13. All VFDs must have a minimum efficiency of 95 percent and a minimum power factor of 95 percent at full load.
  14. All motors that are connected to VFD drives shall contain winding thermistors.
  15. VFDs must have short-circuit capability to meet the highest short-circuit rating in its voltage class in the system. VFDs must have a minimum stand-alone SCCR short circuit rating of 100K without additional input fusing. The VFD assembly must have a SCCR rating of 65K. All bypasses must include UL-listed short-circuit protection and separate UL-listed motor

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overload devices. DC bus as a supply to the VFD output section shall maintain a fixed voltage with filtering and short circuit protection utilizing a DC bus fuse for protection of VFD components in the event of any output failure.

16. The VFDs shall be capable of starting into a rotating load (forward or reverse) and accelerating or decelerating to setpoint without safety tripping or component damage (flying start).
17. The VFDs shall be equipped with an automatic extended control power loss ride through circuit, which shall utilize the inertia of the load to keep the drive powered.
18. The VFD shall be capable of sensing a loss of load (examples: broken belt, no water in pump) and signal the loss of load condition.
19. The VFD shall have programmable "Sleep" and "Wake up" functions to allow the drive to be started and stopped from the level of a process feedback signal.

## C. Submittals

### 1. Designer Submittals

Submit calculations for VFD sizing. Size all VFDs based on the rated voltage at full-load amps. If the vendor requires de-rating of the VFD when running at maximum carrier frequency, then compensate by increasing the drive size.


### 2. Construction Documents

#### a. Product Data

- (1) Provide shop drawings including a power three-line drawing, a complete logic/controls diagram, and product data under provisions of the Contract Documents that apply to the work in this section.
- (2) Provide a list of all factory and field setpoint values.
- (3) Submit manufacturer's installation instructions under provisions of the Contract Documents that apply to the work in this section.

#### b. Product Certificates Signed by Manufacturer

- (1) The VFD manufacturer is responsible for the cost of all equipment required to meet IEEE-519-1992, at no additional costs to the user. Equipment that can be provided

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includes AC input line reactors, DC bus reactors and/or harmonic trap filters.

- (2) For 50 HP or larger VFDs, provide harmonics analysis calculations based on system configuration, short-circuit availability, and full load application.
- (3) Vendor shall provide harmonic analysis calculations if the total HP of all VFDs exceeds 40 HP. These calculations shall be based on full load applications.
- (4) Harmonic analysis shall be required for VFD submittal review.

**c. Test Reports**

- (1) Provide a copy of the factory check and test report.
- (2) Provide a copy of the field check and test report with parameters setting values.
- (3) Provide total harmonic current distortion and total harmonic voltage and current distortion test results.

**d. Operations and Maintenance Data**

Provide complete operation, troubleshooting, and maintenance information in the operation and maintenance manual.

- (1) Submit operation and maintenance data under provisions of the Contract Documents that apply to the work in this section.
- (2) Include assembly views and replacement parts lists.

**D. Quality Assurance**


1. Manufacturer’s specializing in manufacture, assembly, and field performance of VFDs must have at least ten (10) years experience.

**E. Product Standards**

1. VFDs, with all options, must be UL listed as a complete assembly.
2. Products must conform to IEEE 519-1992, NEMA, or the latest standard, and IEC 16800 Parts 1 & 2.

**F. Manufacturers**

1. VFDs must be ISO 9001 certified, furnished in accordance with Yale University design standards, Section 15950: Energy Management and Controls Systems, and installed by the electrical contractor.

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2. Subject to compliance with the design requirements, provide products by one of the following manufacturers:
  - ABB
  - Eaton/Cutler-Hammer
  - Yaskawa
3. Other models must be approved by Utilities / Engineering.

## G. Materials


All VFDs and VFD accessories must be contained in a single metal enclosure. Refer to standards section 16130 – Raceways and Boxes for NEMA enclosure requirements. As a minimum, use a NEMA 12 enclosure for mounting VFDs in a supply air or humid equipment room.

## H. Equipment


1. VFDs must be capable of being isolated for maintenance during bypass mode operations. Use magnetic transfer contactors to control the bypass remotely and locally. Provide three (3) contactor bypass (input, output and bypass with isolation) switch.
2. Provide at least two critical frequency lockout ranges to prevent the VFD from operating the load continuously at an unstable speed.
3. Provide at least two programmable digital contact relay outputs for status and alarms. Relays shall be capable of programmable on and off delay times.
4. Provide five programmable digital inputs for interfacing with external devices.
5. Provide at least two programmable preset digital inputs for preset speed selection.
6. Provide two independently adjustable acceleration and deceleration ramps. The VFD shall Ramp or Coast to a stop, as selected by the user.
7. Provide a communication protocol that is compatible to Yale such as Johnson Control on ALS building automation system; programmed to interface the driver to the Johnson Controls Metasys and/or automatic logic control design. Use the latest manufacturer's communication protocol.
8. Provide a manual speed control potentiometer and Hand/Off/Auto selector. Via keypad is acceptable.
9. Two (2) programmable analog inputs shall accept a current or voltage signal for speed reference, or for reference and actual (feedback) signals for PID controller.

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10. One (1) programmable analog output proportional to frequency, motor speed, output voltage, output current, motor torque, motor power (kW), DC bus voltage, active reference, and other data.
11. Seven (7) programmable presetspeeds.
12. All VFDs shall have the same customer interface, including digital display, and keypad, regardless of horsepower rating.
13. The VFDs shall utilize pre-programmed application macros specifically designed to facilitate start-up.
14. All VFD installations must be equipped with a micro-processor PID controller that will allow a pressure or flow signal to be connected to the VFD.
15. If the input reference (4-20mA or 2-10V) is lost, the AFD shall give the user the option of either (1) stopping and displaying a fault, (2) running at a programmable preset speed, (3) hold the VFD speed based on the last good reference received, or (4) cause a warning to be issued, as selected by the user.
16. The customer terminal strip shall be isolated from the line and ground.
17. VFDs must provide the following minimum protections:
  - DC bus under-voltage
  - Over-current
  - Ground fault
  - DC bus over-voltage
  - Controller over-temperature
  - Overload
  - Motor stall
  - Over-frequency
  - Single phase
18. VFDs must provide the following minimum operator controls and digital displays:
  - a. Door mounted control panel with pilot lights (LED) for “Control Power”, “Drive Ready”, “Drive Run”, “Drive Selected”, “Drive Fault”, “Drive Test”, “Bypass Selected”, “Bypass Run”, “Motor OL”, “Safety Open”, “Damper Closed”, “Auto Run”, “Auto Transfer”, “Smoke Purge”, “Hand Mode”, “Off Mode”, and “Auto Mode”.
  - b. Switch selectable Auto Transfer to bypass, Safety Interlock circuit and BAS Interlock circuit functions.

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- c. Normal/Test selector keys, shall allow testing and adjustment of the VFD, while the motor is running in the bypass mode.
- d. Hand/Off/Auto selector keys shall provide the following operation common to both VFD and bypass modes of operation:
  - Hand Position – The drive is given a start command, operation is via the local speed input (digital operator/keypad). If in bypass mode, the motor is running.
  - Off Position – The start command is removed, all speed inputs are ignored, power is still applied to the drive. If in bypass mode, the motor is stopped.
  - Auto Position – The drive is enabled to receive a start command and speed input from a building automation system. If in bypass mode, the motor start/stop is controlled by the building automation system.
- e. Annunciation contacts; 3 Programmable Form C contacts (120 VAC, 5 Amp) for: “Motor Run”, “Damper Actuator”, “Auto Transfer”, “Drive Run”, “Hand Mode”, “Auto Mode”, “System Fault”, “Bypass Run”, “or “Serial Com Run”.
  - Damper control circuit with end of travel feedback capability
  - Run/Stop selection with LED indication
  - Speed control setting with LED indication
  - Frequency meter
  - Motor RPM
  - Ammeter
  - DC Output voltage
  - Elapse time meter (resettable)
  - Calculated Motor Torque
  - Output Voltage
  - Heatsink Temperature
  - Analog Input Values
  - Analog Output Value
  - Keypad Reference Values
  - kWh meter (resettable)
  - Digital input status

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- Digital output status

## 19. Serial Communications

- The VFD shall be able to communicate with PLC's, DCS's, and DDC's. VFDs shall have embedded Building Automation System (BAS) protocols for network communications; Johnson Metasys N2, Siemens System 600 APOGEE, and Modbus/Memobus. These protocols shall be accessible via a RS-422/485 communication port.
- Serial communications capabilities shall include, but not be limited to, run-stop control; speed set adjustment, proportional/integral/derivative PID control adjustments, current limit, and accel/decel time adjustments. The drive shall have the capability of allowing the DDC 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. Additionally, remote (LAN) VFD fault reset shall be possible. A minimum of 15 field parameters shall be capable of being monitored.
- The VFD's shall allow the DDC to control the drive's digital and analog outputs via the serial interface. The serial communications interface shall allow for DO (relay) control and AO (analog) control. In addition, all drive digital and analog inputs shall be capable of being monitored by the DDC system.
- The VFD shall be connectable to a PC based software tool capable of operating, programming, and monitoring the drive as well as diagnosing faults.


## I. Accessories or Special Features

- Customer Interlock Terminal Strip.
- Door interlocked disconnect or circuit breaker, padlockable in off position, rated at 65k AIC.
- Manual Transfer to line power via contactors and including class 20 bimetal motor thermal overload relays and fuse or circuit breaker protection while in bypass operation complete with automatic bypass capability (3 contactor bypass).
- For VFD's on air systems using smoke isolation dampers and/or on 100 % Outside Air Systems, provide auxiliary contacts so when the fan motor is commanded on in either the normal (hand or auto) or bypass positions, the VFD shall not ramp or bypass contactor pull in until a permissive contact closure (from a damper end switch) is supplied to the VFD proving the smoke isolation dampers and/or the Outside Air dampers are open.

## J. Special Requirements

- Deliver products to site under provisions of the Contract Documents that apply to the work in this section.
- Store and protect products under provisions of the Contract Documents that apply to the work in



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this section.


## K. Quality Control Testing

1. All printed circuit boards shall be completely tested and burned-in before being assembled into the completed VFD. The VFD shall then be subjected to a computerized systems test (cold), burn-in, and computerized systems test (hot). The burn-in shall be at 104°F (40°C), at full rated load.
2. All testing and manufacturing procedures shall be ISO 9001 certified.
3. Provide conformal coating on printed circuit boards.

## L. Installation Guidelines

1. Install Variable Frequency Drives in accordance with manufacturer's instructions. VFD installation and power wiring shall be the responsibility of the Electrical Contractor. VFD LV instrument, control wiring and piping shall be the responsibility of the Mechanical Contractor.
2. Provide four-inch concrete mounting pads for outdoor or mechanical room floor installations. The distance between the VFD and the load must be as close as practicable. If the distance is more than 50 feet, consult with the VFD and electric motor vendors to determine whether an output filter is required.
3. Use a metallic conduit for all power wiring.
4. Provide a dedicated ground conductor from the power source to the VFD and from the VFD to the motor.
5. Do not install VFDs in a plenum or on air handlers, unless the drives are equipped with vibration isolators. Do not install VFDs near corrosive areas.
6. Maintain the minimum clearance between VFD cabinets recommended by the manufacturer.
7. Use twisted-pair and shielded control cables for all analog and serial communication wiring.
8. Use dedicated conduit for power wirings.
9. Use dedicated conduit for all control/communication signal inputs.
10. Use dedicated conduit for all control/communication signal outputs.
11. On installations that require a disconnecting means a motor disconnect switch shall be furnished with a "pre-break" auxiliary contact on the disconnect switch to disable the run permissive circuit.

## M. Startup and Training

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## 1. Warranty and Startup Services

- a. The VFD manufacturer shall provide a start up service package for all VFDs provided. Service shall include inspection, final adjustment, operational checks, and a final report for record purpose. Start Up service shall be performed by a factory approved and certified technician.
- b. To be included with start up service, for a period of 36 months after initial start up, the VFD manufacturer shall include a full parts and labor on-site warranty at no additional costs.

## 2. Harmonic Testing

After the factory service engineer has properly tested and started the VFD (see Startup and Training), the contractor must provide an independent testing contractor to conduct harmonic testing. The testing contractor must furnish readings with printouts of the total harmonic current distortion at each harmonic, as well as the total voltage and current distortion. These readings must be taken as described in subparagraphs 1 and 2 below.

- a. At each point of common coupling:
  - With VFDs running at full load
  - With all VFDs off
- b. At each VFD power connection:
  - With the VFD running at full load
  - With the VFD off

## 3. Training

Provide Yale University's operations personnel with one day of on-site training delivered by a factory-certified representative.

**End of Section**