

[26 29 23 Variable-Frequency Motor Controllers](#)

At Subsection .01, update the Document Table with new version as follows. Remainder of section is unchanged.

Document	Version Date	Description
OPP VFD GuideSpec	April 13, 2012 <u>August 1, 2014</u>	This guide specification is intended to provide the Design Professional with general OPP minimum requirements for Variable Frequency Drives in typical HVAC motor applications.

Editor's Note: Replace the document in the hyperlink above with the updated document attached below. Keep the same name in the hyperlink. Just swap out the documents. The attached document is saved with "track features" showing. The version with all the additions and deletions shall be posted in the Revisions Archive to show the changes. The final document posted on the Standards page shall show only the final text by selecting "Accept all changes in Document" under the Review tab, and then saving it prior to being swapped out.



OPP_VFD_GuideSpec
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END of revision

Update Commentary:

Section was updated primarily for the following reasons:

- 1) *Revised VFD cable and cable installation requirements.*
- 2) *Revised and replaced all occurrences of VFC to VFD, throughout document.*

THE PENNSYLVANIA STATE UNIVERSITY
OPP Specification Guideline
VARIABLE FREQUENCY DRIVES
File Name: OPP_VFD_GuideSpec_20140801-2
Version Date: July 30, 2014

26 29 23 Variable Frequency Drives

Directions to Design Professional

CHANGES with THIS Revision:

1. @3.2.B: Revised VFD cable and cable installation requirements.
2. Revised and replaced all occurrences of VFC to VFD, throughout document.

General Notes:

1. This guide specification is intended to provide the Design Professional with a basic guideline of minimum requirements for Variable Frequency Drives in typical fan and pump applications. The guide specification shall be carefully reviewed and edited with respect to application-specific project requirements and proposed modifications shall be reviewed with OPP Staff. Finalized version shall be included in the project contract documents.

Editing Notes

1. This OPP Guide specification must only be altered by notation (i.e. deleted text with strikethrough and additional text with underline). This shall be accomplished by using Tools /Track Changes / Highlight Changes, and select "Track changes while editing" in MS Word.
2. The Review Submittal Specification section shall be provided in electronic form for OPP Review.
3. Leave the following Note ("For Construction Document Review, Design Submittal") as part of the Review Submittal, to aid any Reviewer to understand WHY there are strikeouts and underlines. Also, leave any "DESIGNER NOTE" placed in this Guide Spec.
4. AFTER comments are received from PSU and incorporated, the strikeouts and underlines shall be removed, and the REVIEWER NOTES deleted, before the spec is issued for Bidding.

PART 1 GENERAL

1.1 SUMMARY

A. Section Includes:

1. Variable Frequency Drives (VFDs), rated 600 V and less, for speed control of three-phase, induction motors.
2. Extent of variable frequency drives (VFD's) is indicated on the Drawings and as defined by the requirements of this section.

B. Related Documents:

1. Drawings and general provisions of Contract, including General and Supplementary Conditions and Division-1 Specification sections, apply to work of this section.
2. University Design and Construction Standards
 - a. Division 21, 22, & 23.

Designer Note: The University has experienced widespread premature motor shaft bearing failures due to fluting from electrical arcing on motors equipped with Variable Frequency Drives. The Design Engineer must specify appropriate technologies and/or include provisions in the system design to prevent electrical fluting induced premature bearing failure from occurring.

- b. [Division 25 - Integrated Automation](#), BAS: comply with Sub-system integration requirements with existing campus BAS.

c. [26.05.10 Electrical Acceptance Testing](#)

1.2 DEFINITIONS

- A. BAS: Building automation system.
- B. EMI: Electromagnetic interference
- C. FLA: Full Load Amps
- D. IGBT: Insulated-gate bipolar transistor
- E. LAN: Local area network
- F. LED: Light-emitting diode
- G. PWM: Pulse-width modulated
- H. RFI: Radio-frequency interference
- I. VFD: Variable-frequency drive motor controller

1.3 COMPLIANCE WITH SPECIFICATIONS

- A. Complete compliance with all requirements of this specification is required. If any supplier takes exception to any of the requirements of this specification, the deviations from the specification requirements shall be clearly explained on the submittal documents.

1.4 REFERENCES

- A. Institute of Electrical and Electronic Engineers:
 - 1. IEEE C62.41 - Recommended Practice on Surge Voltages in Low-Voltage AC Power Circuits.
- B. National Electrical Manufacturers Association:
 - 1. NEMA 250 - Enclosures for Electrical Equipment (1000 Volts Maximum).
 - 2. NEMA FU1 - Low Voltage Cartridge Fuses.
 - 3. NEMA ICS 7 - Industrial Control and Systems: Adjustable Speed Drives.
 - 4. NEMA ICS 7.1 – Safety Standards for Construction and Guide for Selection, Installation, and Operation of Adjustable Speed Drive Systems.

1.5 SUBMITTALS

- A. Submit specific product data and shop drawings for each type and rating of Variable Frequency Drive (VFD) indicated. Include manufacturer, dimensions, weight, mounting arrangements, required clearances and service space around equipment, ratings, listings, enclosure types, conduit entry locations and sizes, schematic power and control wiring diagrams and complete list of all features and components (standard and optional). Any exceptions to the specification shall be clearly noted in the submittal.
- B. LEED Submittals:

LEED-NC Credit EA 5 requires continuous metering equipment for monitoring building energy-consumption performance over time. VFDs providing input to a BAS on energy usage can support this requirement. Coordinate with requirements in "Control Features" Article.

- 1. Product Data for Credit EA 5: For continuous metering equipment for energy consumption.

THE PENNSYLVANIA STATE UNIVERSITY
OPP Specification Guideline
VARIABLE FREQUENCY DRIVES
File Name: OPP_VFD_GuideSpec_20140801-2
Version Date: July 30, 2014

- C. Field quality-control reports. Indicate field test and inspection procedures and test results.
- D. Operation and maintenance data. Submit instructions for starting and operating controllers, and describe operating limits that may result in hazardous or unsafe conditions. Submit routine preventive maintenance schedule.

1.6 WARRANTY

- A. The VFD shall be warranted by the manufacturer for a period of 24 months from the date of certified start-up, not to exceed 30 months from date of shipment. The warranty shall include parts, labor, travel time, and expenses incurred by the manufacturer to provide factory authorized service to diagnose and repair or replace VFD's that fail within warranty period.

1.7 QUALITY ASSURANCE

- A. The drive manufacturer shall supply the drive and all necessary options as herein specified.
 - 1. The manufacturer shall have been engaged in the production of this type of equipment for a minimum of five years documented experience.
 - 2. The drive manufacturing facility shall be ISO 9001 certified.
 - 3. VFD's that are manufactured by a third party and "brand labeled" shall not be acceptable.
 - 4. All VFDs for each project shall be from the same manufacturer and a single supplier for single-source responsibility and product support.
 - a. For equipment that is specified to have VFD's factory mounted/wired, the successful single-source VFD supplier shall coordinate arrangements to ship VFD packages to equipment vendor for final factory installation.
- B. VFDs and options shall be UL listed as a complete assembly. VFD's that require the customer to supply external fuses for the VFD to be UL listed are not acceptable. VFDs with red label UL stickers, requiring additional branch circuit protection are not acceptable.
- C. The VFD and options shall comply with the applicable requirements of the latest standards of ANSI, IEEE, the National Electrical Code and NEMA.
- D. The VFD and options shall be tested to ANSI/UL Standard 508C and listed by a nationally recognized testing agency such as UL or ETL.
- E. All standard and optional features shall be functionally tested at the factory for proper operation.
- F. Product Support: Factory trained application engineering and service personnel that are thoroughly familiar with the VFD products offered shall be locally available, within approximately 100 miles, of installation locations. A toll free 24/365 technical support line shall be available.

1.8 DELIVERY, STORAGE AND HANDLING

- A. Deliver products to site with factory-installed protective skids and containers.
- B. Store in a clean, dry space. Maintain factory wrapping or provide an additional heavy canvas or heavy plastic cover to protect units from dirt, water, construction debris, and traffic.
- C. Handle in accordance with manufacturer's written instructions. Lift only with lugs provided for the purpose. Handle carefully to avoid damage to components, enclosure, and finish.

THE PENNSYLVANIA STATE UNIVERSITY
OPP Specification Guideline
VARIABLE FREQUENCY DRIVES
File Name: OPP_VFD_GuideSpec_20140801-2
Version Date: July 30, 2014

1.9 MAINTENANCE MATERIALS

- A. Furnish two of each filter.

PART 2 PRODUCTS

2.1 PACKAGED VARIABLE FREQUENCY DRIVES

- A. Manufacturers: Subject to compliance with requirements, provide products by one of the following:
1. ABB
 2. Allen Bradley
 3. Cutler-Hammer
 4. General Electric
 5. Square D
 6. Or approved equal.
- B. General: Furnish complete variable frequency drive(s) as specified herein for the equipment designated on the drawing schedules or control sequences with variable speed controls. Each VFD, with all standard and optional features, shall be factory packaged in a UL rated and listed enclosure most appropriate for each application and location, completely assembled and tested by the manufacturer in an ISO9001 facility. The variable frequency drives shall convert three-phase, 60 Hz utility power to proportionally variable voltage and frequency, three-phase, AC power using the latest isolated gate bipolar transistor (IGBT) technology for stepless motor speed control of one or more three-phase induction motors. Drives shall include integral manual disconnecting means and shall provide means of overload and overcurrent self-protection and motor protection. Input voltage shall be as specified in the schedule.
1. The VFD power input stage shall convert three-phase AC line power to a fixed DC bus voltage. This will be accomplished with a solid state three-phase full-wave diode rectifier with metal oxide varistor (MOV) three-phase protection.
 2. The VFD output power shall vary frequency to the motor from 0 to 60 Hz with resultant motor speed varying at the motor nameplate rated speed, with output voltage variation from zero to motor rated voltage for optimum volts per hertz (V/Hz) ratio for fan and pump loads. The output must be a voltage source type generating a sine coded PWM waveform utilizing an asynchronous carrier frequency (output transistor switching frequency is to be independent of drive output frequency). This carrier frequency shall be adjustable to minimize harmonically induced noise or vibration.
 3. Cooling Fan and Exhaust System: For Type 1 or Type 12; UL 508 component recognized: Cooling fan, with intake and exhaust grills **[and filters for Type 12]**. The VFD shall have cooling fans **[and filters – when applicable]** that are designed for easy replacement. The fans shall be designed for replacement without requiring removing the VFD from the wall or removal of circuit boards. The cooling fans shall be controlled by VFD to cycle on only as required to maintain safe operating temperature.
 4. The VFD shall include a door interlocked, padlockable, input power disconnect switch that will disconnect all input power from the drive and all internally mounted options.
 5. Application: Drives shall be capable of controlling and set up for either variable or constant torque loads, as follows.
 - a. Variable torque: loads such as centrifugal fans, pumps and compressors
 - b. Constant torque: loads such as positive displacement pumps and reciprocating or screw compressors.

THE PENNSYLVANIA STATE UNIVERSITY
OPP Specification Guideline
VARIABLE FREQUENCY DRIVES
File Name: OPP_VFD_GuideSpec_20140801-2
Version Date: July 30, 2014

- C. Service Conditions and Performance Ratings: All VFD's shall be designed to operate continuously within the following conditions:

Designer Note: VFDs are available that are suitable for use under environmental conditions different than those indicated in the rating subparagraphs below; however, derating or special modifications, or both, may be required. Consult manufacturers to accommodate unusual service conditions.

1. Ambient Conditions:
 - a. Ambient temperature, 0-40°C (32 to 104°F).
 - b. 0 to 95% relative humidity, non-condensing.
 - c. Elevation to 1,000 meters (3,300 feet) without derating.
2. Input Ratings:
 - a. AC line voltage variation, -10% to +10% of nominal,
 - b. AC line frequency variation: 48-63 Hz.
 - c. Input AC Voltage Unbalance: Not exceeding 3 percent.
 - d. Displacement power factor shall not be less than 0.95 throughout the speed range.
3. Output Ratings:
 - a. Minimum Efficiency: 97 percent at full load. (The input current rating of the VFD shall be no more than 3% greater than the output current rating.) VFD's with lower efficiencies (higher input current ratings) require the upstream wiring, protection devices, and source transformers to be oversized per NEC 430.120 and are not acceptable. Input and output current ratings must be shown on the VFD nameplate.
 - b. Minimum Short-Circuit Current (Withstand) Rating: The base VFD shall be UL listed for 100 KAIC without the need for input fuses.
 - c. Continuous Output Current: 100% of the nominal FLA rating
 - d. Overload Capability: minimum short term of 110% of the nominal FLA rating for 60 seconds every 10 minutes; minimum peak overload of 130% of the nominal FLA rating for 2 seconds per minute.
- D. Adjustments: The VFD shall include the following minimum adjustments inside the enclosure:
 1. Maximum speed limit: adjustable 50-200% base speed.
 2. Minimum speed limit: adjustable 0-50% base speed.
 3. Acceleration time, adjustable 0.1 to 1800 seconds.
 4. Deceleration time, adjustable 0.1 to 1800 seconds with override circuit to prevent nuisance trips if decel time is set too short.
 5. Current Regulation limit, adjustable 0-130%.
 6. Output Carrier Frequency: Field selectable between 1 to 12 kHz.in maximum increments of 4 kHz. See Start- Up Service requirements in Part 3.
- E. Protective Features: The VFD shall include the following protective features:
 1. Protection against input transient voltage spikes (phase to phase and phase to ground).
 2. Separate overload protection for each motor controlled.
 3. Protection against input power under voltage, over voltage, and phase loss (input and output).
 4. Protection against output current overload and over current.
 5. Protection against over temperature within the VFD enclosure.
 6. Protection against over voltage on the DC bus.
 7. DC bus discharge circuit for protection of service personnel.
 8. Insensitive to incoming power phase sequence.
 9. Output Ground Fault protection
 10. Output Short Circuit protection

THE PENNSYLVANIA STATE UNIVERSITY
OPP Specification Guideline
VARIABLE FREQUENCY DRIVES
File Name: OPP_VFD_GuideSpec_20140801-2
Version Date: July 30, 2014

11. Microprocessor fault
12. Motor Overtemperature
13. Motor Stall protection shall be programmable to provide a warning or stop the drive after the motor has operated above a programmed torque level for a programmed time limit.
14. Underload / loss-of-load (broken drive belt or coupling): The drive shall be programmable to signal the loss-of-load condition via a keypad warning, Form-C relay output, and / or over the serial communications bus. The loss-of-load condition sensing algorithm shall include a programmable time delay that will allow for motor acceleration from zero speed without signaling a false loss-of-load condition.
15. Critical frequency lockout ranges, with a minimum of 3 selectable, adjustable deadbands. The lockout range must be fully adjustable, from 0 to full speed.
16. Loss of control signal: Selectable response strategy, including speed default to a percent of the most recent speed, a preset speed, or stop; with alarm, or warning alarm alone to be issued. The drive shall be programmable to signal this condition via a keypad warning, Form-C relay output and / or over the serial communication bus.

- F. Line Conditioning and Filtering: Include internal mounted components to mitigate harmonic distortion, provide protection from input transients and reduce EMI/RFI emissions as required for each application. At a minimum, drives shall include the following:

Designer Note: The basic conditioning is for typical, non-critical applications. If input current distortion due to harmonic generation in VFDs is of more serious concern, consult manufacturers for options available to mitigate harmonic distortion. Other options may include active and passive harmonic filters, and 12- or 18-pulse phase-shifting input transformers.

1. The VFD shall have internal 5% impedance reactors to reduce the harmonics to the power line and to add protection from AC line transients.
 - a. The 5% impedance may be from dual (positive and negative DC bus) reactors, or 5% AC line reactors.
 - b. VFD's with only one DC reactor shall add an AC line reactor.
2. EMI / RFI filters. All VFD's shall include EMI/RFI filters. The onboard filters shall allow the VFD assembly to be CE Marked and the VFD shall meet product standard IEC/EN 61800-3 for the First Environment restricted level with up to 100 feet of motor cable. No Exceptions. Certified test reports shall be provided with the submittals confirming compliance to IEC/EN 61800-3, First Environment.

Designer Note: For more information, refer to the following:
<http://www.automation.com/resources-tools/articles-white-papers/motor-drives-control/specifying-adjustable-frequency-drives-for-electromagnetic-compatibility-emc>

- G. Control Features: The VFD shall include the following control features:
1. The control pad shall include a backlit LCD multi-line display in plain English. The display shall be in complete English words for programming and fault diagnostics (alpha-numeric codes are not acceptable). All VFD faults shall be displayed in English words.
 2. The following display/control parameters shall be located on the front of the enclosure:
 - a. Hand/Off/Auto selector to start and stop the motor. In the auto position, the drive shall start/stop from a remote contact closure. In the auto position, motor speed shall be determined by the follower signal. In the manual position, motor speed shall be determined by manual adjustment.
 - b. Power on indication that the VFD is being supplied by the power line.
 - c. Fault indication that the VFD has tripped on a fault condition.

THE PENNSYLVANIA STATE UNIVERSITY
OPP Specification Guideline
VARIABLE FREQUENCY DRIVES
File Name: OPP_VFD_GuideSpec_20140801-2
Version Date: July 30, 2014

- d. Display shall indicate load parameters such as motor speed (RPM or percent), output frequency/voltage, running load amps, motor torque, motor power (kW), DC bus voltage, motor status, fault or alarming status.
3. A set of form C, dry contacts to indicate when the VFD is in the run mode.
4. A set of form C, dry contacts to indicate when the VFD is in the fault mode. This fault output shall be hard-wired to BAS independently of Serial Communications interface so it can be monitored even network connection has failed.
5. Terminations for safety interlocks such as freeze and smoke shut-down.
6. For a fault condition other than a ground fault, short circuit or internal fault, an auto restart function shall provide up to 6 programmable restart attempts. The time delay before restart attempts shall be a minimum of 30 seconds. This function permits automatic restarting after the drive controller detects a fault, provided that the other operating functions are correct, a run command is present, and the fault has disappeared. This shall be a function that is field selectable.
7. Run permissive circuit - There shall be a run permissive circuit for damper or valve control. Regardless of the source of a run command (keypad, input contact closure, time-clock control, or serial communications), the VFD shall provide a dry contact closure that will signal the damper to open (VFD motor does not operate). When the damper is fully open (proven by damper end switch feedback), a normally open dry contact (end-switch) shall close. The closed end-switch is wired to a VFD digital input and allows VFD motor operation. Two separate safety interlock inputs shall be provided. When either safety is opened, the motor shall be commanded to coast to stop and the damper shall be commanded to close. The keypad shall display "start enable 1 (or 2) missing". The safety input status shall also be transmitted over the serial communications bus.
8. Speed Reference Input: Shall accept both a manual speed signal and a 0-10 VDC speed reference analog input signal from the Building Automation System (BAS).
9. Feedback Signal: Provide 0-5 VDC or 0-20 mA analog output signal to indicate actual operating speed of VFD. Output signal shall be fed into the BAS.

Designer Note: Typically include below in accordance with BAS subsystem integration requirements in [Division 25 - Integrated Automation](#). Requests for exceptions in certain applications (such as no existing BAS with little or no probability for having any BAS for the expected life of the drive) shall be submitted to OPP, Environmental Systems Manager for review and approval.

10. BAS Serial Communications Interface: VFD manufacturer shall include factory-installed hardware and software to enable the BAS primarily to monitor and display VFD feedback, status, alarms and energy usage, and secondarily to allow but not be fully dependent on BAS control commands. Each individual drive shall have the protocol in the base VFD. The use of third party gateways and multiplexers is not acceptable. All protocols shall be "certified" by the governing authority (i.e. BTL Listing for BACnet). Use of non-certified protocols is not allowed. Allows VFD to be used with an external system within a multidrop LAN configuration; settings retained within VFD's nonvolatile memory. The VFD BAS interface shall comply with the requirements defined in the BAS Specifications and Sequences of Operation.
 - a. Network Communications Ports: Ethernet and **RS-485**.
 - b. Embedded BAS Protocols for Network Communications: Shall include **BACnet** protocol accessible via the communications ports.

Designer Note: Requests for exceptions to use MODBUS protocol in certain applications shall be submitted to OPP, Environmental Systems Manager for review and approval.

THE PENNSYLVANIA STATE UNIVERSITY
OPP Specification Guideline
VARIABLE FREQUENCY DRIVES
File Name: OPP_VFD_GuideSpec_20140801-2
Version Date: July 30, 2014

- c. Communication capabilities shall include, but not be limited to; run-stop control, speed set adjustment, proportional/integral/derivative PID control adjustments, current limit, accel/decel time adjustments, and lock and unlock the keypad. The drive shall have the capability of allowing the BAS to monitor feedback such as process variable feedback, output speed / frequency, current (in amps), % torque, power (kW), kilowatt hours (resettable), operating hours (resettable), and drive temperature. The BAS shall also be capable of monitoring the VFD relay output status, digital input status, and all analog input and analog output values. All diagnostic warning and fault information shall be transmitted over the serial communications bus. Remote VFD fault reset shall be possible.
11. Optional Fireman's Override input: When required for smoke control mode, the VFD shall include a fireman's override input. Upon receipt of a contact closure from the fire / smoke control station, the VFD shall operate in one of two modes: 1) Operate at a programmable predetermined fixed speed. 2) Operate in a specific fireman's override PID algorithm that automatically adjusts motor speed based on override set point and feedback. The mode shall override all other inputs (analog/digital, serial communication, and all keypad commands), except customer defined safety run interlocks, and force the motor to run in one of the two modes above. "Override Mode" shall be displayed on the keypad. Upon removal of the override signal, the VFD shall resume normal operation, without the need to cycle the normal digital input run command.

2.2 BYPASS CONTROLLER:

Note to Designer: Bypass controllers require additional consideration of system parameters, BAS coordination and code requirements.

The University must maintain day to day operations in all of its facilities in the event of a drive failure and cannot be without a system while waiting to repair/replace a drive. It is not an acceptable practice to have maintenance staff resorting to temporarily jumper across drive with power cables to run the motor across the line without control safeties. General guidelines are as follows.

Bypass is required for:

- *Any VFD systems without fan or pump redundancy that provides essential heating, cooling or ventilation to maintain acceptable comfort and indoor air quality to regularly occupied areas of buildings.*
- *Any VFD systems without fan or pump redundancy that provides critical HVAC or process heating/cooling critical research areas of buildings. Normally, such applications should have redundant fans or pumps, but if there are exceptions or existing systems without redundancy, provide the bypass to give some degree of added reliability.*

Bypass is not required for:

- *VFD systems with multiple pieces of equipment arranged to provide redundancy: provide regular drives for each fan or pump.*
- *Single return/relief fan systems in which running at full speed would create unacceptable pressure relationships for occupant health and safety reasons. For example, return fans in an air handling system serving non-lab spaces that should always remain positive with respect to adjacent lab spaces. If return fan goes full speed without other means to control return airflow, non-lab spaces could go extremely negative with respect to lab areas, which would not be acceptable. In that case, spare drives kept in reserve for quick replacement are recommended.*
- *VFD pumps serving exterior snow melt systems.*

If in doubt in some unique situation, bypass selection shall be reviewed with Engineering Services.

THE PENNSYLVANIA STATE UNIVERSITY
OPP Specification Guideline
VARIABLE FREQUENCY DRIVES
File Name: OPP_VFD_GuideSpec_20140801-2
Version Date: July 30, 2014

- A. General: Bypass controller shall be a complete, factory-wired and tested system that safely transfers motor between VFD output and bypass circuit, manually, automatically, or both. User interface shall allow selection of modes and indicator lights shall indicate mode selected. Motor driven equipment shall be capable of stable operation (starting, stopping, and running) with motor completely disconnected from VFD section. The bypass system shall NOT depend on the VFD in any way for bypass operation. The bypass system shall be designed for stand alone operation and shall be completely functional in both Hand and Automatic modes even if the VFD has been removed from the system for repair / replacement.
1. The bypass enclosure door and VFD enclosure must be mechanically interlocked such that the disconnecting device must be in the "Off" position before either enclosure may be accessed.
 2. The operator shall have full control of the bypass starter by operation of the VFD/OFF/BYPASS selector switch or control keypad.
 3. In the AUTOMATIC mode of operation the isolation and bypass contactors shall be sequenced by the auto start contact provided by user.
 4. A TEST/NORMAL selector switch shall provide test operation of the power converter while operating the motor in bypass.
 5. The following indicating lights (LED type) or keypad display indications shall be provided. A test mode or push to test feature shall be provided.
 - a. Power-on (Ready)
 - b. Run enable
 - c. Drive mode selected
 - d. Bypass mode selected
 - e. Drive running
 - f. Bypass running
 - g. Drive fault
 - h. Bypass fault
 - i. Bypass H-O-A mode
 - j. Automatic transfer to bypass selected
 - k. Safety open
 - l. Damper opening
 - m. Damper end-switch made
- B. Bypass Modes:
1. 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.
 - a. There shall be a keypad adjustment to select manual or automatic transfer bypass. The user shall be able to select via keypad programming which drive faults will result in an automatic transfer to the bypass mode and which faults require a manual transfer to bypass. The user may select whether the system shall automatically transfer from drive to bypass mode on the following drive fault conditions:
 - 1) Over current
 - 2) Over voltage
 - 3) Under voltage
 - 4) Loss of analog input

***Designer Note:** The field selectable auto or manual mode is the default for typical applications for projects that will have BAS remote control capability. Normally retain paragraph above and delete below. Requests for exceptions to provide manual only in certain applications (such as no existing BAS with little or no probability for having any BAS for the expected life of the drive) shall be submitted to OPP, Environmental Systems Manager for review and approval. Call out exception for manual only in VFD schedule.*

2. **[EDIT per project requirements – see note above: Manual operation only: requires local operator selection at VFD. Transfer between power converter and bypass contactor and retransfer shall only be allowed with the motor at zero speed.]**

- C. Bypass Controller: Two-contactor-style bypass allows motor operation via the VFD or the bypass controller.

Designer Note: IEC-rated contactors are most often used for the bypass contactor in HVAC applications and for smaller motors, and they are usually smaller and less costly than equivalent NEMA-rated contactors. NEMA-rated contactors are most often used in industrial applications and for larger motors, where they must carry high motor inrush and full-load running currents. IEC-rated contactors are most often used in all applications for the isolating contactors, because they are only used to isolate the power converter and normally do not carry any current. Consult manufacturers for the types used for each.

1. Bypass Contactor: Load-break, **[IEC] [NEMA]**-rated contactor.
2. Output Isolating Contactor: Non-load-break, **[IEC] [NEMA]**-rated contactor.

Designer Note: The input isolating contactor of a three-contactor bypass, without an isolating switch and a barrier between the power converter and the bypass is not an acceptable method for safe isolation of the power converter during energized maintenance, because the contactor is not a positive, lockable disconnecting means, and lack of a barrier can lead to accidental contact with live parts in the bypass. The isolation switch is an add option and generally not required for most cases. But if application is of a unique, special or critical nature that would absolutely demand of repair, troubleshooting and testing of VFD while bypass is energized because the system cannot go down even momentarily long enough to replace drive, then retain reference for isolating switch below.

3. **[EDIT – TYPICALLY DELETE, See note above: Optional Service Switch: Non-load-break switch and barrier 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.]**

- D. Protective Features: The Bypass shall include the following protective features:

1. Drive Isolation Fuses - To ensure maximum possible bypass operation, fast acting fuses, exclusive to the VFD, shall be provided to allow the VFD to disconnect from the line prior to clearing upstream branch circuit protection. This maintains bypass operation capability in the event of a VFD failure. Bypass designs which have no such fuses, or that incorporate fuses common to both the VFD and the bypass, will not be accepted.
2. Motor overload protection (UL listed) and thermal overload protection shall be provided in both the controller mode and the bypass mode.
3. Motor protection from single phase power conditions - the bypass system must be able to detect a single phase input power condition while running in bypass, disengage the motor in a controlled fashion, and give a single phase input power indication. Bypass systems not incorporating single phase protection in bypass mode are not acceptable.
4. There shall be an adjustable motor current sensing circuit for the bypass and VFD modes to provide proof of flow (broken belt) indication. The condition shall be indicated on the keypad display, transmitted over the building automation protocol and / or via a Form-C relay output contact closure. The broken belt indication shall be programmable to be a system (drive and bypass) indication. The broken belt condition sensing algorithm shall be programmable to cause only a warning or a fault and / or system shutdown.

THE PENNSYLVANIA STATE UNIVERSITY
OPP Specification Guideline
VARIABLE FREQUENCY DRIVES
File Name: OPP_VFD_GuideSpec_20140801-2
Version Date: July 30, 2014

5. The bypass control shall monitor the status of the VFD and bypass contactors and indicate when there is a welded contactor contact or open contactor coil. This failed contactor condition shall be indicated on the bypass LCD display, programmed to fire a Form-C relay output, and over the serial communications protocol (if present).
 - E. Control Features: The Bypass shall include the following control features
 1. The bypass I/O shall be available to the BAS / DDC system even with the VFD removed.
 2. The bypass shall provide a separate terminal strip for connection of freeze, fire, smoke contacts, and external start command. All external safety interlocks shall remain fully functional whether the system is in VFD or Bypass mode. The remote start/stop contact shall operate in VFD and bypass modes. The terminal strip shall allow for independent connection of up to four (4) unique safety inputs.
 3. There shall be a run permissive circuit for damper or valve control. Regardless of the source of a run command (keypad command, time-clock control, digital input, or serial communications) the bypass shall provide a dry contact closure that will signal the damper to open (motor does not operate). When the damper is fully open, a normally open dry contact (end-switch) shall close. The closed end-switch is wired to a bypass system input and allows motor operation. Up to four separate safety interlock inputs shall be provided. When any safety is opened, the motor shall be commanded to coast to stop, and the damper shall be commanded to close. This feature will also operate in Fireman's override / smoke control mode.
 4. The bypass shall include a supervisory control mode. In this bypass mode, the bypass shall monitor the value of the VFD's analog input (feedback). This feedback value is used to control the bypass contactor on and off state. The supervisory mode shall allow the user to maintain automated cycled on-off control over applications such as cooling towers and booster pumps even with the VFD out of service.
 5. The on-board Form-C relay outputs in the bypass shall include the minimum following indications.
 - a. Bypass fault status
 - b. System started
 - c. System running
 - d. Bypass selected
 - e. Bypass H-O-A position
- Designer Note: The following might apply to fans that are part of engineered fire/smoke control systems. Include if required for Drive application. Review application specific requirements, consult with VFD manufacturer, and edit below accordingly, and/or list special features required for each application in VFD schedule.*
6. Optional Firefighter's Override Modes:
 - a. Smoke Control Override Mode (Override 1) – If scheduled, the bypass shall include a dedicated digital input that will transfer the motor from VFD mode to Bypass mode upon receipt of a dry contact closure from the Fire / Smoke Control System. The Smoke Control Override Mode action is not programmable and will always function as described in the bypass User's Manual documentation. In this mode, the system will ignore low priority safeties and acknowledge high priority safeties as required by UL 864/UUKL. All keypad control, serial communications control, and normal customer start / stop control inputs will be disregarded. This Smoke Control Mode shall be designed to meet the intent of UL864/UUKL.
 - b. Fireman's Override Mode (Override 2) – If scheduled, the bypass shall include a second, programmable override input which will allow the user to configure the unit to

THE PENNSYLVANIA STATE UNIVERSITY
OPP Specification Guideline
VARIABLE FREQUENCY DRIVES
File Name: OPP_VFD_GuideSpec_20140801-2
Version Date: July 30, 2014

acknowledge some digital inputs, all digital inputs, ignore digital inputs or any combination of the above. This programmability allows the user to program the bypass unit to react in whatever manner the local Authority Having Jurisdiction (AHJ) requires. The Override 2 action may be programmed for "Run-to-Destruction". The user may also force the unit into Override 2 via the serial communications link.

Designer Note: Coordinate control features with OPP, [Environmental Systems](#), [Building Automation System \(BAS\) Application Engineering](#). The OPP BAS group does not mandate serial communications for controlling or monitoring the [bypass](#) feature. However, if it is present in the standard bypass offered by drive manufacturers, it shall comply with BAS subsystem integration requirements in [Division 25 - Integrated Automation](#), and shall be coordinated with the Control System Contractor and functionally tested and demonstrated to perform the intended functions.

7. Serial communications (when present): Manufacturer shall include factory-installed hardware and software to enable the BAS primarily to monitor and display bypass mode selected, start/stop and run status, fault alarms, and secondarily to allow but not be fully dependent on BAS control commands.
 - a. On-board communications protocol shall be BACnet.

Designer Note: Requests for exceptions to use MODBUS protocol in certain applications shall be submitted to OPP, Environmental Systems Manager for review and approval.

- b. Serial communication in bypass shall include, but not be limited to; bypass run-stop control, the ability to force the unit to bypass, and the ability to lock and unlock the keypad. The bypass shall have the capability of allowing the BAS to monitor feedback such as, current (in amps), kilowatt hours (resettable), operating hours (resettable), and bypass logic board temperature. The BAS shall also be capable of monitoring the bypass relay output status, and all digital input status. All bypass diagnostic warning and fault information shall be transmitted over the serial communications bus. Remote bypass fault reset shall be possible. Serial communications shall remain functional even with the VFD removed.
- c. The following additional status indications and settings shall be transmitted over the serial communications bus and / or via a Form-C relay output – keypad "Hand" or "Auto" selected, bypass selected, and broken belt indication. The DDC system shall also be able to monitor if the motor is running in the VFD mode or bypass mode over serial communications. A minimum of 50 field serial communications points shall be capable of being monitored in the bypass mode.

2.3 ENCLOSURES AND OTHER ACCESSORIES:

Designer Note: Review application specific requirements, consult with VFD manufacturer, and edit below accordingly.

- A. Enclosures: Shall be selected to provide protection of all internal components for the application and environmental conditions at installed location. Enclosures shall be rated and listed UL Types. VFD's without these UL ratings are not acceptable. NEMA only type enclosures are not acceptable.

THE PENNSYLVANIA STATE UNIVERSITY
OPP Specification Guideline
VARIABLE FREQUENCY DRIVES
File Name: OPP_VFD_GuideSpec_20140801-2
Version Date: July 30, 2014

Designer Note: Coordinate subparagraphs below with Drawings by identifying the designated areas on plans or by including the required enclosure types. Enclosure materials and finishes may be added to the Section Text. Availability of some enclosure types is limited by type and rating of controller; special accommodations and accessories (e.g., powered/filtered ventilation) may be required for some enclosure types. Consult manufacturers for availability of, and limitations on, enclosures other than Type 1.

In general, it is the intent to apply Type 1 enclosures (without filters) in typical indoor mechanical/electrical spaces (which in most applications are considered "dry and clean". The exception would be for applications in which the VFD is installed in an environment that is inherently dusty or dirty such as steam power plants, wood shops, manufacturing or other processes that generate dust/dirt, animal or agricultural facilities or similar applications.

Where filters are required for the application, specifications shall require contractor to include adequate identification, documentation and owner training during project closeout to ensure the filter units get included in the Preventative Maintenance program at start-up time.

Where VFD's are located in mechanical rooms or other spaces with nearby water piping, the installation shall comply with the requirements in the NEC, "Dedicated Equipment Space". If it is unavoidable to have foreign systems running above the dedicated space, protection must be installed to avoid damage to the VFD from condensation, leaks, or breaks in such foreign systems.

1. Dry and Clean Indoor Locations: Type 1
 2. Indoor Locations Subject to Dust, Falling Dirt, and Dripping Noncorrosive Liquids: Type 12.
 3. Outdoor Locations: [Type 3R] [Type 4X]
 4. [Kitchen] [Wash-Down] Areas: [Type 4X], [stainless steel].
 5. Other Wet or Damp Indoor Locations: [Type 4]
 6. If installed in plenums (e.g., in the air stream inside an air-handling unit) or in a space used for environmental air (e.g., above a suspended ceiling used for return air) then include Plenum Rating: UL 1995; NRTL certification label on enclosure, clearly identifying VFD as "Plenum Rated."
- B. Breather and drain assemblies, to maintain interior pressure and release condensation in [Type 4] [Type 4X] [Type 12] enclosures installed outdoors or in unconditioned interior spaces subject to humidity and temperature swings outside of ambient condition ratings of VFD..
- C. Space heaters, with NC auxiliary contacts, to mitigate condensation in [Type 3R] [Type 4X] [Type 12] enclosures installed outdoors or in unconditioned interior spaces subject to humidity and temperature swings outside of ambient condition ratings of VFD.

PART 3 EXECUTION

3.1 EXAMINATION

- A. Contractor to verify that jobsite conditions for installation meet factory recommended and code required conditions for VFD installation prior to start-up. These shall include as a minimum:
1. Clearance spacing.
 2. Temperature, contamination, dust, and moisture of the environment.
 3. Separate conduit installation of the motor wiring, power wiring, and control wiring.

THE PENNSYLVANIA STATE UNIVERSITY
OPP Specification Guideline
VARIABLE FREQUENCY DRIVES
File Name: OPP_VFD_GuideSpec_20140801-2
Version Date: July 30, 2014

- B. Do not install controller until building environment can be maintained with the service conditions required by the manufacturer.

3.2 INSTALLATION

- A. The installing contractor shall install the drive in accordance with the recommendations of the VFD manufacturer as outlined in the VFD installation manual.
 - 1. Wall-Mounting Controllers: Install VFDs 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 Division 26 Section "Hangers and Supports for Electrical Systems."
 - 2. Avoid exterior installations to fullest extent possible.
 - 3. Roof-Mounting Controllers: Install VFD on roofs with tops at uniform height and with disconnect operating handles not higher than 79 inches above finished roof surface unless otherwise indicated, and by bolting units to curbs or mounting on freestanding, lightweight, structural-steel channels bolted to curbs. Seal roof penetrations after raceways are installed.
 - 4. The VFD is to be covered and protected from installation dust and contamination until the environment is cleaned and ready for operation. The VFD shall not be operated while the unit is covered.
 - 5. The installation shall comply with the working, access, and equipment protective space requirements in the NEC - Spaces About Electrical Equipment, including "Dedicated Equipment Space". If it is unavoidable to have foreign systems running above the dedicated space, adequate protection must be installed to avoid damage to the VFD from condensation, leaks, or breaks in such foreign systems.

Designer Note: Coordinate and conform subparagraphs below with requirements in 26 05 19 Low-Voltage Electrical Power Conductors and Cables and 26 05 26 Grounding and Bonding for Electrical Systems.

- B. All electrical power wiring shall be completed by the electrical contractor, to NEC wiring requirements based on the VFD input current. **The contractor shall complete all wiring in accordance with the instructions of the VFD manufacturer as outlined in the installation or user's manual.** In general, comply with the following:
 - 1. Input power, motor output and control wiring shall each be run in separate conduits.
 - 2. Use a separate conduit run for each drive.
 - 3. Motor cables require shielding using conduit, armored cable or shielded cable.
 - a. When using conduit:
 - 1) Bridge joints with a ground conductor bonded to the conduit on each side of the joint.
 - 2) Bond conduit run to the drive enclosure.
 - 3) Conduit shall have continuous continuity from VFD enclosure to motor frame. Externally mounted bonding conductor is acceptable only when Liquid-tight Flexible Metal Conduit (LFMC) or Flexible metal conduit (FMC) is used from the motor terminal box to the rigid conduit.
 - b. When using armored VFD cable:
 - 1) J-Type MC continuous corrugated cable shall still be VFD rated cable with overall shield and three symmetrical grounds.
 - 2) Armored motor cable can share a cable tray with input power cables, but not with control cables.

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THE PENNSYLVANIA STATE UNIVERSITY
OPP Specification Guideline
VARIABLE FREQUENCY DRIVES
File Name: OPP_VFD_GuideSpec_20140801-2
Version Date: July 30, 2014

- 3) Type MC VFD cable shall only be used on a case-by-case basis and must be approved by OPP Engineering Services.
- c. VFD cable installations shall adhere to the manufacturer's recommendation for the correct installation procedures.
- d. VFD cable installations shall be installed with the manufacturer's recommended cable termination and termination kits or accessories as needed.
4. For personnel safety, proper operation and to reduce electromagnetic emission/pick-up, the drive and motor shall be properly grounded.
 - a. Motor cables require extra care in grounding and routing in order to reduce parasitic capacitance current leaks that can create noise interference, damage motor bearings or other components.
5. Check motor and motor cable insulation for adequate resistance per manufacturer's recommendations.
 - a. **WARNING!** Disconnect the drive before conducting any voltage tolerance (Hi-Pot) test or insulation resistance (Megger) test on the motor or motor cables. Do not conduct these tests on the drive.

Deleted: For shielded cable details: Comply with manufacturer's instructions.

3.3 CONTROL WIRING INSTALLATION AND COORDINATION

- A. The Control Systems Contractor shall install control wiring between VFDs and remote devices and facility's central BAS per requirements in BAS specifications.
 1. Connect all hard-wired control inputs from BAS devices to VFD.
 2. Connect all hard-wired control outputs (normal/fault indication) from VFD to BAS.
 3. Connect network communication and coordinate that correct parameter values are reading to BAS.
- B. Bundle, train, and support wiring in enclosures. Control wiring shall ALWAYS be run in control pathways separated from VFD input and output power wiring.
- 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.

3.4 IDENTIFICATION

- A. Contractor shall identify VFDs, components, driven motor characteristics, and control wiring. Comply with requirements specified in Identification sections.
 1. Identify field-installed conductors, interconnecting wiring, and components; provide warning signs.
 2. Label each VFD with engraved nameplate.
 3. Label each enclosure-mounted control and pilot device.
 4. Provide neatly typed label inside each motor controller door identifying motor served, nameplate horsepower, full load amperes, code letter, service factor, and voltage/phase rating.
 5. Where specialty enclosures with air filters or other options that need routine inspection and maintenance to ensure proper operation are required for the application, the installing contractor shall provide identification labels requiring preventative maintenance for such units.

THE PENNSYLVANIA STATE UNIVERSITY
OPP Specification Guideline
VARIABLE FREQUENCY DRIVES
File Name: OPP_VFD_GuideSpec_20140801-2
Version Date: July 30, 2014

3.5 START UP SERVICE:

- A. The manufacturer shall provide certified start up service by a factory trained service technician. The service technician shall verify correct installation, start up the drive, and check for proper operation of all features, including interface to the building automation system. Sales personnel and other agents who are not factory certified technicians for drive field repair shall not be acceptable as commissioning agents. A certified start-up form shall be filled out for each drive with a copy provided to the owner, and a copy kept on file at the manufacturer. Included in this service shall be (as a minimum):
1. Verification of contractor wire terminations to the VFD and its optional circuitry.
 2. **Setting of carrier frequency: Select for lowest frequency available that provides acceptable motor audible noise for the application.** Lower carrier frequencies generate less heat in the VFD and motor and less potential for undesirable currents through motor shaft bearings.
 3. Measurements and verification for proper operation and reliability of the VFD, the motor being driven, and the building automation system.
 - a. Calibration check for the following set points (and adjustment as necessary) (1) minimum speed (optimized for each application and coordinated with TAB Agency and CSC), (2) maximum speed, (3) acceleration and deceleration rates.
 - b. Confirmation of proper installation and functioning of grounding of VFD, motor, and motor shaft.
 - c. Confirm correct settings of control input/output programmed parameters for proper building automation system interface and control calibration.
- B. 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.
- C. Compile a thorough list of all specialty enclosures with air filters or other options that need routine inspection and maintenance to ensure proper operation are required for the application. Provide written and/or electronic documentation (signed and dated) to the Owner's Preventive Maintenance (PM) representatives during start-up to ensure any and all such specialty units get input in the PM database as part of project turnover.

3.6 TESTING

- A. After check out and start up of drive(s) by manufacturer, the University will monitor the voltage and current percent Total Harmonic Distortion (THD) at the input of each drive installed. The Electrical Contractor shall provide manpower to assist the University with the operation of the drives during testing.
- B. Comply with University's testing requirements in [26 05 10 Electrical Acceptance Testing](#).

3.7 TRAINING

- A. The manufacturer shall have regularly scheduled maintenance and training schools on the equipment supplied.
- B. A computer based training CD or 8-hour professionally generated video shall be provided to the owner at the time of project closeout. The training shall include installation, programming and operation of the VFD, bypass and serial communication.

THE PENNSYLVANIA STATE UNIVERSITY
OPP Specification Guideline
VARIABLE FREQUENCY DRIVES
File Name: OPP_VFD_GuideSpec_20140801-2
Version Date: July 30, 2014

- C. Where specialty enclosures with air filters or other options that need routine inspection and maintenance to ensure proper operation are required for the application, the installing contractor shall include specific training coordinated with the Owner's O & M representatives as part of project turnover.

3.8 SCHEDULES

Note to Designer: The Professional shall include coordinated schedule of project/application specific VFD requirements on the construction documents. Schedules shall indicate at a minimum the following: VFD identification tag, equipment served (Fan or Pump ID #), location, motor horsepower/kW and FLA, electrical characteristics (volts/phase/hertz), Enclosure Type (NEMA), Optional Features, Bypass (Y/N), manufacturer and model number (basis of design), Remarks.

Professional shall follow University [Equipment Acronym List](#) and Equipment numbering policy defined in Mechanical Identification in developing equipment tags and schedules.

END OF SECTION