PART 1 - GENERAL

1.1 APPLICABLE REQUIREMENTS

A. All work to be furnished and installed under this section shall comply with all the requirements of General Conditions, Supplemental Conditions, Division 01 - General Requirements, and Section 230500 - Basic HVAC Materials and Methods, and other Sections in Division 23 specified herein.

1.2 SCOPE

A. Furnish complete and operational VFD systems as shown on the plans. All work to be furnished and installed under this Section shall comply with all the requirements of Division 01, and shall include, but not necessarily be limited to, the following:
1. Variable frequency drives (VFDs), with or without bypass.
2. Controls and control connections.
3. Electrical power connections.

1.3 RELATED WORK IN OTHER SECTIONS

A. Section 230500: Basic HVAC Materials and Methods

B. Section 230593: Testing, Adjusting and Balancing

C. Section 230900: Building Automation System (BAS) Controls

D. Section 232123: Pumps and Hydronic Specialties

E. Section 237312: Custom Factory AHU

F. Section 237313: Modular Air Handler

G. Division 26: Coordination of interface items between the Mechanical equipment and controls and the Electrical Work specified in Division 26.

1.4 QUALITY ASSURANCE

A. Supplier of VFD shall be solely responsible for assuring that the VFD shall work properly with the motor(s) being controlled. VFD supplier shall provide all materials and labor required to replace motors, bearing, shafts, etc. that may be incompatible with VFD or become damaged by VFD at no additional cost to the owner. VFD supplier shall reimburse Architect and Engineer at their standard hourly rates for their involvement in resolving failures due to their VFDs.

B. Manufacturer shall have a minimum of 15 years experience building similar equipment for controlling the speed for induction motors and at least one hundred successful installations with a variety of VFD sizes and applications.

C. To reduce the known problem of bearing failures by "fluting" the VFD switching rates shall be 6-8 KHz wherever possible. Manufactured VFDs at switching rates of 12-15 KHz shall be accompanied by an additional extended warranty to cover bearings and motors to a period of ten (10) years. Should it be impossible to provide matched

motor and VFD's provide a shaft grounding system for the driven motor. Acceptable manufacturers include Shaft Grounding Systems (www.shaft-grounding-systems.com) or Aegis Shaft Grounding Ring (www.est-aegis.com).

D. To insure quality and minimize infantile failures at the job site, the VFD shall be burned in at the factory at an ambient of 104°F minimum for at least 8 hours. The VFD shall be operating a dynamometer and the load speed shall be cycled during the test. All optional and special features shall be functionally tested at the factory for proper operation.

E. Standards and Guidelines: Provide VFDs conforming to the requirements of the latest addition of the following:
1. UL508: The UL Safety Standard for Industrial Control Equipment. All VFD equipment provided under this section must be labeled as UL 508 approved.
2. ANSI/IEEE 518: Guide for the Installation of Electrical Equipment to Minimize Electrical Noise Inputs to Controllers from External Sources.
3. ANSI/IEEE 519: Recommended Practices and Requirements for Harmonic Control in Electrical power systems.
4. International Standards Organization certified 9001.
5. California Building Code (CBC) 2012 Seismic – referencing ASC 7-05 and ICC AC-156
6. International Electrotechnical Commission 60721-3c1, 2, & 3 Conformal coating
7. CEC 430.120, Adjustable-Speed Drive Systems.
8. NEMA ICS 7.0, Application Guide for AC Adjustable Speed Drives.
9. AHJ approval or proof of special seismic certification for structures requiring it.
10. RoHS (Restriction of Hazardous Substances) certified.
11. SEMI F47-0706 for voltage sag immunity.

1.5 QUALIFICATIONS:
1. VFDs and options shall be UL508 listed as a complete assembly. The base VFD shall be UL listed for 100 kA SCCR without the need for external input fuses.
2. The entire VFD assembly shall be seismically certified and labeled as such in accordance with the International Building Code (IBC):
   a. VFD manufacturer shall provide Seismic Certification and Installation requirements at time of submittal.
   b. Seismic importance factor of 1.5 rating is required, and shall be based upon actual shake test data as defined by ICC AC-156
   c. AHJ approval if needed.
3. Base VFD shall have CE Mark conforming to European Union Electromagnetic Compatibility directive, requiring VFD meet product standard EN 61800-3 for the First Environment restricted level (Category C2). Base drives that only meet the Second Environment (Category C3, C4) shall be supplied with filters to bring the drive in compliance with the First Environment levels.
4. VFD Enclosure to be UL rated: 1,12, 3R or 4X as needed. Cabinets correctly sized for airflow and heat dissipation of drive with interlocked handle. Outdoor 3R enclosures include thermostatically controlled vent fans and heater. 4X shall be stainless steel cabinet with temperature controlled air-conditioned air isolated from outside air in the VFD cabinet. Self-certified UL enclosures not accepted.
5. Factory authorized start up and owner training should be provided locally

upon request. A toll free 24/365 technical support line connected to factory support personnel located in the US shall be available

6. VFDs shall be considered as an “end device” and not specifically listed as UL 864 UUKL compliant. However, VFDs shall be provided with control and override capabilities as required for smoke control.

1.6 SUBMITTALS

A. Prior to construction submit for approval the following materials:
   1. VFD supplier shall provide reference list showing at least ten years of prior manufacturing experience in production of VFDs and a list of at least twenty successful installations with a variety of VFD sizes and applications.
   2. Manufacturer's data, installation instructions, and maintenance and operational instructions for variable frequency drives. Indicate electrical service and special requirements. Include manufacturer's descriptive literature, repair data, and parts listing.

1.7 DELIVERY, STORAGE, AND HANDLING

A. Deliver units to the site in containers with manufacturer's stamp or label affixed.

B. Protect units against dirt, water, chemical, and mechanical damage. Do not install damaged units. Remove damaged equipment from site.

1.8 WARRANTY

A. Provide two-year (24 months) warranty under provisions of Division 01 from date of Certificate of Occupancy. The warranty shall include parts, labor, travel costs, and living expenses incurred by the manufacturer to provide factory authorized service.

PART 2 - PRODUCTS

2.1 MANUFACTURERS

A. ABB ACH 550 or ULH, or equal by Danfoss, Allen-Bradley, Emerson, Schneider Electric (Square D), Toshiba, Yaskawa, or Trane. Connected motors should be by the same manufacturer whenever possible.

2.2 GENERAL

A. Furnish a complete VFD as scheduled on the plans. Refer to plans for locations of variable speed controllers. Each fan or pump motor shall have a dedicated VFD unit. All systems shall be provided with a backup VFD capable of operating with any motor. All standard and optional features shall be included within the VFD enclosure unless otherwise specified. The VFD enclosure shall be provided to match the environment requirements where the VFD will be mounted and operated. Provide NEMA/UL rated enclosure as required for environment.

B. The adjustable frequency controller shall convert three-phase, 60 Hz utility power to adjustable voltage and frequency, three-phase, AC power for stepless motor speed control from 10% to 100% of the motor's 60 Hz speed.

C. The VFD shall provide full rated output from a line of ±10% of nominal voltage. The

VFD shall continue to operate without faulting from a line of +30% to -35% of nominal voltage. Overload rating of VFD shall be 110% of normal duty current rating for 1 minute every 10 minutes, 130% overload for 2 seconds every minute. VFDs shall be capable of continuous full load operation in the following environmental conditions:

1. -15 to 40° C (5 to 104°F) ambient temperature. Operation to 50° C (122°F) shall be allowed with a 10% reduction from VFD full load current.
2. Altitude 0 to 3300 feet above sea level. Operation to 6600 shall be allowed with a 10% reduction from VFD full load current.
3. Humidity less than 95%, non-condensing.

D. The VFD shall include a converter and an inverter section. The converter section shall convert fixed frequency and voltage AC utility power to a DC voltage. Drive shall utilize a single surface mount micro-processor.

E. The VFD shall be of the pulse width modulation (PWM) type. VFDs shall be provided with an advanced flux vector frequency control to limit noise at drive and motor.

F. Drive manufacturer or sales representative shall evaluate electrical system of the project. Any additional protective equipment such as line filters, reactors or input isolation transformers required to prevent interference from drive with other electrical equipment in the building shall be included as part of the bid. No additional expense shall be incurred by Owner for provision or installation of these devices if required for electrical system operation after drive has been purchased. Units shall include factory mounted input line reactors.

G. The VFD maximum output current rating shall be 110% of the motor nameplate full load current. VFD shall be able to start into a rotating load in either direction without trip.

H. The VFD and options shall be tested to ASNI/EIA Standard 508 and listed by a nationally recognized testing agency such as UL or ETL.

I. The VFD and options shall comply with the applicable requirements of the latest standards of ANSI, IEEE, and the National Electrical Code.

J. Power line noise shall be limited to a voltage distortion factor and line notch depth as defined in ANSI/IEEE Standard 519.

K. The drive efficiency shall be 97% (minimum) and have a fundamental power factor of 0.98 at all speeds.

2.3 BASIC FEATURES

A. The VFD shall be housed in a NEMA enclosure appropriate to the mounting location.

1. NEMA 12 enclosure shall be used for dusty locations, plenum mechanical rooms, penthouses, or air stream mounting.
2. NEMA 3R is required for all locations exposed to falling rain, snow or ice or to indoor locations subject to falling water.
3. If NEMA 1 enclosure is suitable it shall be vented through cabinet and equipped with an integral cooling fan with thermostat control, and arranged so that units can be mounted back to back on a frame and/or side to side on

a wall. Venting fans shall be supplied in enclosure if required. If a different NEMA enclosure is indicated the enclosure shall provide means of maintaining the drive at temperature acceptable to the drive manufacturer in exterior ambient temperatures. Enclosure shall be complete with no requirements for low voltage wiring. Factory mounted main circuit breaker disconnect shall be included.

B. All circuit boards shall be coated to protect against corrosion. Control boards shall be conformal coated to at least IEC 60721-3c2.

C. All VFDs shall have the same HMI/keypad, with backlit digital display, regardless of horsepower rating. The keypad shall be removable, capable of remote mounting and allow for uploading and downloading of parameter settings as an aid for start-up of multiple VFDs. It shall incorporate “Bumpless transfer” of speed reference when switching between “Hand” and “Auto” modes. HMI/keypad shall include password protection against parameter changes.

D. The HMI/keypad shall include Hand-Off-Auto selections and manual speed control. There shall be fault reset and “Help” buttons on the keypad. The Help button shall include “on-line” assistance for programming and troubleshooting. The display shall be in complete English words for programming and fault diagnostics (alphanumeric codes only are not acceptable.)

E. The HMI/keypad shall utilize pre-programmed application macros or templates specifically designed to facilitate start-up. The Macros shall provide one command to reprogram all parameters and customer interfaces for a particular application to reduce programming time. The VFD shall have two user savable programs to allow the user to save custom settings.

F. HMI/keypad operating values shall be capable of being displayed in engineering units for sub-metering purposes [i.e. GPH, KW, Motor Amps, Frequency, Speed, Torque, etc.]. A minimum of three operating values shall be displayed at all times.

G. VFD shall include built in coordinated AC transient surge protection system consisting of 4 MOVs (phase to phase & phase to ground), capacitor clamp, 1600 PIV Diode Bridge and internal chokes.

H. VFDs shall have 5% impedance AC reactors or internal dual 5% DC chokes to reduce harmonics to the power line and as protection from AC line transients. VFD’s with only one DC choke shall have OEM add AC UL 508 listed and approved Chokes or line reactors.

I. VFD shall automatically mitigate harmonics throughout the effective load range using Swinging chokes or other devices designed to lower harmonics when VFD is at partial loads.

J. VFD’s shall include Ferrite Core EMI/RFI/Common mode filters. The onboard filters shall allow the VFD assembly to be CE Marked and the VFD shall meet product standard EN 61800-3 for the First Environment restricted level (Category C2).

K. The input current rating of the VFD shall not be greater than the output current rating. VFD’s with higher input current ratings require the upstream wiring, protection devices, and source transformers to be oversized per CEC 430.122

L. VFD shall have its own standardized control board that is the same for all drive sizes, with all communications and I/O terminals on it, and standard BAS communications protocols to include ModBus RTU; Johnson Controls N2; Siemens Building Technologies FLN (P1); and BACnet MS/TP. All diagnostic warning and fault information shall be transmittable over serial communications. With Remote fault reset if programmed. Options available for: Ethernet IP, BACnet IP, ControlNet, DeviceNet, Lonworks, ModBus TCP and Profibus. All protocols shall be “certified” by the governing authority.

M. Two (2) programmable analog inputs shall accept 0-10VDC or 4-20 ma signals.

N. Two (2) programmable analog outputs 0-20ma or 4-20 ma signals. Outputs proportionally programmable for: Motor Current, Power, Speed, Torque, (kW) and other data.

O. Minimum of six (6) programmable digital inputs for interfacing with external devices. All digital inputs shall be programmable to initiate upon an application or removal of 24VDC.

P. Minimum of two (2) programmable, Form-C relay outputs. The relay outputs shall include programmable on and off delay times and adjustable hysteresis. Rated for maximum switching current 8 amps at 24 VDC and 0.4 A at 250 VAC; Maximum voltage 300 VDC and 250 VAC; continuous current rating of 2 amps RMS. Outputs shall be true Form-C type contacts.

Q. The VFD shall have 250 ma of 24 VDC auxiliary power and be capable of loop powering a transmitter supplied by others.

R. The VFD shall have Pass thru I/O- to allow the BAS to monitor and control the VFD/ backup drive or its analog and digital outputs via communications. This control shall be independent of any VFD function and may be used to control or monitor any other device.

S. The VFD shall include multiple “two zone” PID algorithms that allow the VFD to maintain PID control from two separate feedback signals (4-20mA, 0-10V, and/or communications). The two zone control PID algorithm will control motor speed based on a minimum, maximum, or average of the two feedback signals. All of the VFD PID controllers shall include the ability for “two zone” control. The PID set points shall be adjustable from the VFD keypad, analog inputs, or over the communications bus.

T. The VFD shall have cooling fans that are designed for replacement without requiring removing the VFD from the wall or removal of circuit boards. The VFD cooling fans shall operate only when required, based on the temperature and run command to the drive. VFD protection shall be based on thermal sensing and not cooling fan operation.

U. There shall be a built-in time clock in the VFD keypad. The clock shall have a battery backup with 10 years minimum life span. The clock shall be used to date and time stamp faults and record operating parameters at the time of fault. VFD programming shall be held in non-volatile memory and is not dependent on battery power.

V. Drive options shall be furnished and mounted by the drive manufacturer as defined on the VFD schedule. All optional features shall be UL Listed by the drive manufacturer as a complete assembly and carry a UL508 label.

2.4 PROGRAMMABLE ADJUSTMENTS

A. Three (3) programmable critical frequency lockout ranges [aka Skip or resonant] to prevent the VFD from operating the load continuously at an unstable speed. The lockout range must be fully adjustable, from 0 to full speed.

B. The VFD shall include a programmable time delay for VFD start and a keypad indication that this time delay is active. A Form C relay output provides a contact closure to signal the VAV boxes open. This will allow VAV boxes to be driven open before the motor operates.

C. Two independent adjustable acceleration and deceleration ramp times, adjustable from 1 to 1800 seconds, initial setting at 60 seconds

D. VFD shall include a motor flux optimization and noise smoothing circuits that will automatically reduce applied motor voltage to the motor to optimize energy consumption and reduce audible motor noise.

E. VFD shall provide built in programmable loss-of-load (broken belt / broken coupling) option to signal the loss-of-load condition via a keypad warning, Form-C relay output, and / or over the serial communications bus.

F. 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.

G. VFD to have two PID controls built in for VFD or other uses. PID controllers have ability for “two zone” control. PID set points adjustable from the VFD keypad, analog inputs or BAS

H. If the input reference is lost, the VFD shall be programmable to: (1) stop and display a fault, (2) run at a programmable preset speed, (3) hold the VFD speed based on the last good reference received, or (4) go to a backup control system wired to the VFD. As well as cause a warning to be issued, as selected by the user. The drive shall be programmable to signal this condition via a keypad warning, Form-C relay output and / or over the communication bus.

I. VFD shall have the ability to automatically restart after an over-current, over-voltage, under-voltage, or loss of input signal protective trip. The number of restart attempts, trial time and time between attempts shall be programmable. VFD shall be initially set to perform at least five (5) restarts after a power outage, drive fault or external fault before requiring manual reset. After ten minutes of runtime, the restart attempts return to zero. The VFD shall display a countdown timer when auto restart is being attempted, or incorporate programming to select number of restarts, number of faults per time period, and time between restarts.

J. VFD shall be capable of starting into a coasting load (flying start or forward or reverse) up to full speed and accelerate or decelerate to set point without tripping or component damage.

K. 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 programmed predetermined fixed speed ranging from -500Hz (reverse) to 500Hz (forward). 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.

2.5 PROTECTIVE FEATURES

A. A minimum of Class 20 I^2t electronic motor overload protection for single motor applications shall be provided. Overload protection shall automatically compensate for changes in motor speed.

B. Protection against input transients, loss of AC line phase, output short circuit, output ground fault, over voltage, under voltage, VFD over temperature and motor over temperature. The VFD shall display all faults in plain language. Codes are not acceptable.

C. Protect VFD from input phase loss. The VFD should be able to protect itself from damage and indicate the phase loss condition. During an input phase loss condition, the VFD shall be able to be programmed to either trip off while displaying an alarm, issue a warning while running at reduced output capacity, or issue a warning while running at full commanded speed. This function is independent of which input power phase is lost.

D. Protect from under voltage. The VFD shall provide full rated output with an input voltage as low as 90% of the nominal. The VFD will continue to operate with reduced output, without faulting, with an input voltage as low as 70% of the nominal voltage.

E. Protect from over voltage. The VFD shall continue to operate without faulting with a momentary input voltage as high as 130% of the nominal voltage.

F. The VFD shall incorporate a programmable motor preheat feature to keep the motor warm and prevent condensation build up in the motor when it is stopped in a damp environment by providing the motor stator with a controlled level of current.

G. VFD shall include a "signal loss detection" algorithm with adjustable time delay to sense the loss of an analog input signal. It shall also include a programmable time delay to eliminate nuisance signal loss indications. The functions after detection shall be programmable.

H. VFD shall function normally when the keypad is removed while the VFD is running. No warnings or alarms shall be issued as a result of removing the keypad.

I. VFD shall catch a rotating motor operating forward or reverse up to full speed without VFD fault or component damage.

J. Selectable over-voltage control shall be provided to protect the drive from power

regenerated by the motor while maintaining control of the driven load.

K. VFD shall include current sensors on all three output phases to accurately measure motor current, protect the VFD from output short circuits, output ground faults, and act as a motor overload. If an output phase loss is detected, the VFD will trip off and identify which of the output phases is low or lost.

L. If the temperature of the VFD's heat sink rises to 80°C, the VFD shall automatically reduce its carrier frequency to reduce the heat sink temperature. It shall also be possible to program the VFD so that it reduces its output current limit value if the VFD's temperature becomes too high.

M. In order to ensure operation during periods of overload, it must be possible to program the VFD to automatically reduce its output current to a programmed value during periods of excessive load. This allows the VFD to continue to run the load without tripping.

N. The VFD shall have temperature controlled cooling fan(s) for quiet operation, minimized losses, and increased fan life. At low loads or low ambient temperatures, the fan(s) may be off even when the VFD is running.

O. The VFD shall store in memory the last 10 alarms. A description of the alarm, and the date and time of the alarm shall be recorded.

P. When used with a pumping system, the VFD shall be able to detect no-flow situations, dry pump conditions, and operation off the end of the pump curve. It shall be programmable to take appropriate protective action when one of the above situations is detected.

2.6 BACK UP VFD

A. A back up VFD shall be provided per each system or horse power denominator.

PART 3 - EXECUTION

3.1 INSTALLATION

A. Verify that mounting surface is ready to receive work. Mount the VFD(s) on the wall or at supports in locations identified on the drawings. Provide a layout drawing of VFD locations to electrical installer.

B. If the disconnect for the equipment powered by the VFD is in a location where it is probable that it will be placed in an off position prior to shutting down the VFD, the contractor is to provide electrical protection for the VFD. This may be in the form of a conduit and wire interlock between disconnect and drive or internal protection integral to the VFD.

C. Coordinate wiring and control with Control Contractor. Control installers shall install all wiring associated with control signals into the VFD and for interlock control wiring between disconnects and VFDs.

D. Electrical installer shall install all line voltage power wiring and conduit from electrical switchgear and from the VFD to the disconnect at the controlled motor. The only

exception to this is when the motor and drive are factory installed on a packaged piece of equipment. In that case the wiring from drive to motor is to be installed in the factory to meet the requirements herein. Coordinate with Division 26 work.

E. Line length between VFD and driven motor shall be as short as possible. Line length shall not exceed twenty (20) feet without prior approval from Engineer.

F. Input and output power wiring shall be installed in separate grounded conduit. In addition, control wiring shall be installed in its own separate grounded conduit.

G. Use symmetric motor cable between the VFD and motor, with low inductance shield or conduit, and with all joints joined with bonding straps. MC metal clad 3 phase type cable per CEC 330.1, UL approved, 3 phase conductors and 3 ground conductors. Sheath to be continuous corrugated aluminum. Manufacturer and type to be BICC 2 kV rated Drives Cable, Anixter series 7V, or approved equal.

H. Use cable connectors with 360 degree connections to the armor conduit at both ends of motor cable. Verify electrical path from inverter cabinet entry plate to armor / conduit to motor terminal box.

I. Install an auxiliary high frequency bonding connection for potential equalization between VFD frame and building steel.

J. Unless absolutely necessary do not install disconnect between VFD and connected motor. VFD is to be furnished with a lockable disconnect.

K. Installation in “Fan Wall “ Air Handlers: When a single VFD supplies multiple fans, assemble and prewire units at the factory, installing conduit and conductors between the fan motor, VFD, and terminal strips. Wiring from the VFD output terminals to the fan motor shall be Belden VFD Cable installed in conduit (295XX Series).

3.2 MANUFACTURER'S START-UP SERVICES

A. The manufacturer shall provide start-up service in the form of a factory trained service technician. The service technician shall verify correct installation, verify control wiring, verify power wiring, start-up the drive, and check for proper operation. The service technician shall provide final adjustments to meet the specified performance requirements. Fully staffed parts and service personnel shall be within four hours travel from the jobsite.

B. Carrier frequency setup:
   1. Set initial carrier frequency at 2 kHz.
   2. Manually raise VFD speed output from 10 Hz to 60 Hz by 10 Hz increments, allowing at least 15 seconds between each adjustment. If excessive motor noise is heard at any speed, raise carrier frequency by 2 kHz increments until motor noise is no longer excessive. Do not set carrier frequency higher than 10 kHz.
   3. If excessive motor noise continues to be heard at or below 10 kHz, inform owner. If the motor is provided by the VFD manufacturer, either repair, replace, or provide 5 year extended warranty on the effected motor.

C. Lockout of resonant frequencies:
   1. With carrier frequency set per the above specification, manually and slowly

raise VFD speed output from 10 Hz to 60 Hz by 1 Hz increments. If excessive motor, frame, or driven load noise is heard at any speed, lock out that frequency.

2. Each frequency skip shall be programmed with as narrow a bandwidth as possible, while still avoiding the most objectionable range of resonant frequencies. Each frequency skip bandwidth shall not exceed 5 Hz without approval by Engineer.

D. Training:
1. Provide one (1) hour training session to the Owner's Representative.
2. Training to include:
   a. Demonstration of operation of backup drive switch and door-mounted disconnect switches. Explain emergency operation.
   b. Demonstrate operation of operator keypads for viewing data and setting parameters.
   c. Demonstrate operation in manual mode, including setting of specific speeds.
   d. Explain the drive parameters that might require operator adjustment.
   e. Describe troubleshooting techniques and warranty procedure.

END OF SECTION