SECTION 11033 - VARIABLE FREQUENCY DRIVES

City of San Diego, CWP Guidelines

PART 1 GENERAL

1.1 WORK OF THIS SECTION

A. The WORK of this Section includes providing multi pulse width modulated (PWM) variable frequency drive (VFD) units with motors, controls, and accessories. Current source type drives shall not be acceptable.

B. Where VFDs are required as part of an individual equipment specification, the VFDs and motors shall be provided by the equipment manufacturer under the provisions of unit responsibility, to assure compatibility of all equipment components. The WORK of this Section requires that the CONTRACTOR furnish a Certificate of Unit Responsibility Assignment, as provided in Section 11000, as a part of the submittal requirements under the individual equipment specifications, whenever VFDs are specified in the individual equipment specifications.

1.2 RELATED SECTIONS

A. The WORK of the following Sections applies to the WORK of this Section. Other Sections of the Specifications, not referenced below, shall also apply to the extent required for proper performance of this WORK.

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NTS: Insert applicable equipment specifications in the following list.

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1. Section 11030 Variable Speed Drives, General
2. Section 16040 Electric Motors
3. Section 16050 Basic Electrical Materials and Methods
4. Section 16431 Short Circuit and Coordination Report

1.3 CODES

A. The WORK of this Section shall comply with the current editions of the following codes as adopted by the City of San Diego Municipal Code:

1. NFPA 70, National Electrical Code (NEC)

1.4 SPECIFICATIONS AND STANDARDS

A. Except as otherwise indicated, the current editions of the following apply to the WORK of this Section:

1. IEEE Standard 519	IEEE Recommended Practice and Requirements for Harmonic Control in Electrical Power Systems
2. NEMA ICS 7	Industrial Control and Systems - Adjustable Speed Drives

3. NEMA MG1 Motors and Generators

1.5 SHOP DRAWINGS AND SAMPLES

A. In addition to the requirements of Section 11030, the following shall be submitted in compliance with Section 01300:

1. Calculation of VFD/motor efficiencies at minimum, 1/3, 2/3, and 100 percent of the speeds required to meet the specified operating conditions. The system efficiency shall include power losses from the cooling system (if any), controls, contactors, isolation transformers (if required), line reactors, and filters.
2. Control schematic showing external wiring interfaces.
3. Continuous and fault ratings of drive and disconnecting means.
4. Description of proposed factory test procedure and sketch of test setup.
5. Manufacturer's statement that motor conforms to NEMA MG1, Part 31.
6. Output reactor analysis per paragraph 2.4D.

1.6 SERVICES OF MANUFACTURER

A. Services of the manufacturer shall be provided in accordance with Section 11030 and as follows:

1. **Inspection, Startup and Field Adjustment:** An authorized service representative of the manufacturer shall visit the site for not less than [ ] days per drive system to check the installation, supervise start-up, and supervise testing and adjustment of VFDs.

2. **Instruction of OWNER'S Personnel**: The authorized service representative shall instruct the OWNER'S personnel in the skills required for each Trade Group indicated and the duration indicated. This includes all aspects of drive operation and maintenance, including step-by-step troubleshooting procedures with necessary test equipment. Instruction of the OWNER'S personnel shall be conducted separate from the start-up and testing activities. Each of the OWNER'S Trade Groups will be instructed individually, and no more than six hours will be scheduled in one day. Durations of instruction are:

Trade Group	Class Hours	Field Hours
Electricians	[3]	[3]
Electronics Technicians	[3]	[3]
Operations	[2]	[1]
Plant Maintenance Technicians	[1]	[1]

1.7 FACTORY TESTING

A. **Component Tests:** All components shall be 100 percent tested. Components shall be burned-in for 168 hours at 125 degrees C and retested to detect any drift. All printed circuit boards shall be burned-in continuously for 168 hours at 65 degrees C. The printed circuit boards shall be tested after burn-in to insure they are functioning within specification. Every transistor shall have the following critical parameters tested at rated current: gating, turn-on, turn-off, high temperature, forward blocking, reverse blocking and waveform characteristics. All assembled phase cells shall

be tested for cell balance at rated voltage, maximum current, maximum dV/dT and maximum dI/dT.

Control power shall be applied to microprocessors, printed circuit boards, diagnostic boards and similar devices including software to test for proper operation, sequencing, logic and diagnostics.

All wiring shall be checked for continuity and for compliance with the wiring diagrams.

All terminations and devices in the VFD unit shall be scanned with an infrared sensor while the VFD is energized at 100 percent power, to assure proper connections and satisfactory devices. A copy of the infrared scan results shall be furnished to the CONSTRUCTION MANAGER.

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NTS: The system tests specified below for combined motors and drives apply only to units rated from 200 to 500 horsepower. The DESIGN CONSULTANT shall modify these specifications as required for larger horsepower variable frequency drive installations.

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B. **System Tests:** Testing shall proceed in the order given below. For the motor test and the combined drive and motor test, the CONTRACTOR shall submit a sketch of the proposed test setup, along with a description of the proposed testing procedure to the CONSTRUCTION MANAGER for acceptance at least 10 weeks in advance of the proposed testing date. No tests shall be performed until the test procedure meets with the CONSTRUCTION MANAGER's approval. In addition, the CONTRACTOR shall furnish the CONSTRUCTION MANAGER with at least 4 weeks advance written notice of the date and location of the system tests. The OWNER and the CONSTRUCTION MANAGER (at the option of either or both) reserve the right to witness the system tests.

1. Horizontal Motor Test: Each variable frequency drive, along with the actual AC horizontal motor to be provided, shall be tested with the system logic and a dynamometer load coupled to simulate field operation conditions and be given complete factory tests at 25, 50, and 100 percent full load current.

   After dynamometer tests are complete, the VFD shall be load-tested in a heat room maintained at 40 degrees C for 24 hours. The motor shall be cyclically loaded via the dynamometer as follows:

   100 percent full load current for 6 hours
   75 percent full load current for 6 hours
   50 percent full load current for 6 hours
   100 percent full load current for 6 hours

   Failure of any major components during this test requires repair and commencement of a new test. Motor and dynamometer need not be in the elevated temperature room with the VFD.

2. Vertical Motor Test: In the case of vertical motors, tests shall be identical to the ones required for horizontal motor except an electrically similar horizontal motor shall be substituted for the actual vertical drive motor.

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NTS: Harmonic filtering is required in all drives to limit the harmonic content to 5 percent of fundamental. If there are generators in the system this value should be reduced to 3 percent. To provide the correct amount of filtering, the drive manufacturer needs to know the power supply impedance at the drive terminals. A convenient way of obtaining this information is from the short circuit study of the system. The short circuit amperes at the drive terminals should be the power source contribution only. Noncontributing sources such as motor loads should not be included as they are representative of the true source impedance.

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C. **Harmonic Analysis:** Harmonic analysis shall be calculated at unit full load in accordance with Section 8 of IEEE 519. Computer model shall be based on single line diagram shown with source impedance delineated in terms of noncontributing short circuit amperes as tabulated below. Analysis shall be performed at the point of common coupling (PCC), determined from the plant single line diagram and accessible for field verification (see paragraph 11033-3.2A). Analysis shall show that sufficient filtering has been provided to limit the total harmonic distortion (THD) to limits set by IEEE 519. Results shall be either in table or graphic form.

Driven Equipment Name	Short Circuit Amps
[Raw Sewage Pumps] [1 through 4]	[35,000]

1.8 VFD FEATURES:

A. The VFDs shall be provided with the following features:

1. Fused control circuit transformer and microprocessor for system logic sequencing and fault annunciation functions.
2. 4 to 20 mA process follower for input speed reference signal.

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NTS: The DESIGN CONSULTANT may utilize up to 10 percent overspeed, which corresponds to 66 hertz, if conditions warrant for the selected driven equipment. Otherwise, the maximum frequency shall be 60 hertz. Also see paragraph 11033-1.9E.

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3. Adjustable minimum/maximum frequency limits. The minimum and maximum frequency limits shall be selected to match the entire operating speed range for each specific type of driven equipment. The minimum and maximum frequency limits shall be independently adjustable within the ranges selected. The maximum frequency shall be [60] hertz.
4. Independent timed linear acceleration and deceleration functions, adjustable as indicated.
5. Adjustable motor slip compensation based on motor current.
6. Terminal blocks for control and signal wires entering and leaving the controller.

7. All fuses shall be provided with blown fuse indicator lamps.
8. Current limit adjustable from 50 to [110] percent of motor rating.
9. Automatic re-start with defeat selector.
10. Capability of picking up a spinning load.
11. 4 to 20 mA isolated output signal for VFD speed.

1.9 FUNCTIONAL REQUIREMENTS:

A. Supply Power: The VFD shall remain on line and operate without damage to either the VFD or its connected load during a supply power variation of plus 50 percent lasting for a period of up to 0.01 seconds and minus 100 percent lasting for a period of up to 0.5 seconds.

B. Load: The VFD system shall be capable of continuously driving the specified maximum motor load under the conditions specified herein. Variable-torque (VT) units shall be capable of delivering 115 percent of the specified load for up to 60 seconds in any one incident and up to 240 seconds per hour. [Constant-torque (CT) units shall be capable of delivering 150 percent of the specified load for up to 60 seconds in any one incident and up to 240 seconds per hour.]

C. Power Factor: VFDs shall have a power factor (kW/kVA), at rated base speed and full load, of not less than 0.95 for 18 pulse systems, and of not less than 0.90 for systems with less than 18 pulses.

D. Frequency and Voltage Regulation: VFD inverter output frequency shall be regulated to within 0.6 hertz of the specified instrumentation signal/output frequency relationship. VFD inverter output voltage shall be regulated to within 1.0 percent of that value which will produce minimum motor heating at any operating frequency within the specified range.

E. Frequency Range: VFD shall be capable of satisfactory continuous operation with the specified load at any frequency between the frequency corresponding to minimum speed and [60] hertz.

F. Ambient Noise: Free field noise generated by the VFD shall not exceed 85 dBA at 3 feet out from any point on the VFD cabinet under any normal operating condition.

G. dV/dt: The peak voltage at the motor terminals shall be # 1.6 kV, and the rise time shall be $0.1 Fs. Contractor shall be responsible for providing any filtering required to conform to this criteria. Filter losses shall be included in the efficiency calculation specified in paragraph 11033-2.1C.

1.10 PROTECTION:

A. Overcurrent Protection: The VFD system shall provide adjustable electronic current limit. Current limit shall be accurate to within 1.0 percent and shall smoothly limit motor speed at whatever value is necessary to limit motor current to that value.

The VFD shall also provide motor running overcurrent protection in compliance with NFPA 70. This function may be included in the electronic overload circuitry if suitably UL labeled.

B. Short Circuit Protection: The VFD shall be fully protected against load faults. Bolted, phase to phase, or phase to ground faults shall not damage the unit. Fault protection shall be based on a power source short circuit capacity of [42,000] amperes RMS symmetrical at the VFD power input terminals. Any impedance or other current limiting necessary to meet this requirement shall

be provided as part of the VFD system, and any losses caused by current limiting devices shall be included in efficiency calculation for the VFD system.

C. Line Voltage: The VFD shall be protected against high and low line voltage on one or more phases.

D. Internal Faults: The VFD shall incorporate an internal fault monitoring system to detect malfunctions. This system shall be designed to protect the VFD from transient and sustained faults and to limit damage that may be caused by these faults.

E. Motor Over-Temperature: The VFD shall interface to the motor temperature switches and shall shut down if the motor becomes overheated. The VFD shall include all components necessary to sense a contact opening and disconnect the affected motor if the motor winding temperature exceeds maximum rated operating temperature.

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NTS: The DESIGN CONSULTANT shall design, or separately specify the design and construction, of a ***harmonic filtration system*** for the ***complete*** project to be constructed. These types of systems cannot be designed on a component-by-component basis, and must be designed as a plant-wide system.

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PART 2 PRODUCTS

2.1 DRIVE NAME [RAW SEWAGE PUMP]- (VFD-[1] through VFD-[4])

A. **General:**

1.	Number of drive units	-	[4]
2.	Driven equipment	-	[Centrifugal Pump]
3.	Driven equipment Specifications reference	-	[11220]
4.	Drive voltage	-	[480][2400][4160] volts

B. **Service Conditions:**

The VFD shall be designed and constructed to operate continuously within the following service conditions:

1.	Elevation	-	to 3300 feet
2.	Ambient Temperature Range	-	5°C to 45°C
3.	Atmosphere	-	Non-condensing relative humidity to 95%
4.	AC Line Voltage Variation	-	[460][2300][4000] volts plus or minus 10%
5.	AC Line Frequency Variation	-	60 hertz plus or minus 3 Hz

C. **Operating Conditions:**

1. Efficiency of VFD systems shall be not less than 95 percent at 60 hertz output driving the specified maximum load at 100 percent speed and 100 percent torque. Efficiency shall be defined as follows:

$$Efficiency = \frac{POWER\ IN(watts) - LOSSES(watts)}{POWER\ IN(watts)} 100\% \qquad (1)$$

where losses include input line reactor, rectifier, intermediate circuit, inverter, and output filter.

2. Distribution voltage shall be [480][2400][4160] volts, three phase, three wire, 60 Hz as indicated.
3. Rectifier input line current harmonics shall not exceed the values tabulated in IEEE 519.
4. The VFD shall be specifically designed for use with variable torque equipment or pumping loads, fully capable of at least a 10:1 infinitely adjustable speed range.

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NTS: This VFD specification applies to variable torque applications such as centrifugal and bladed pumps, compressors and fans. The DESIGN CONSULTANT shall modify this specification as required to include any constant torque applications such as positive displacement pumps or conveyors. Generally, constant torque applications require 90 hertz instead of 66 hertz (150 percent instead of 110 percent of the motor rating) as the upper current limit, and constant torque (CT) units shall be capable of delivering 150 percent of the specified load for up to 60 seconds in any one incident and up to 240 seconds per hour. Affected values are indicated in the text in [brackets].

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5. The control shall vary the output frequency between the frequency corresponding to minimum speed and [60] Hz. Soft-start control circuitry shall limit inrush current, not to exceed [110] percent of motor full load current, under all manual and automatic operating conditions. When power outage occurs, the drive system shall shut down in an orderly manner. Upon restoration of ac power, the motor shall restart automatically and run at a rate depending upon the reference requirements, by the sequencing logic controller.

2.2 GENERAL

A. **Basic Description:**

1. The VFD shall consist of three (3) sections: Converter, DC link filter, and Inverter. These sections shall be grouped into separate sections with each section modularized for ease of troubleshooting. The input and output reactors as well as the phase shift transformers shall be included as an integral part of the equipment within the three sections in a single enclosure line-up.

2. The converter section shall be a full wave three-phase converter to change the input AC power to DC power.

3. The DC link filter section shall include capacitive components and optional inductive components.

4. The inverter section shall convert the DC power of the PWM to adjustable frequency power to the motor. The VFD shall not induce excessive power losses in the motor. The worst case RMS motor line current measured at rated speed, torque and voltage shall not exceed 1.05 times the rated RMS motor current for pure sine wave operation.

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NTS: The DESIGN CONSULTANT shall determine the impedance required for the line reactor.

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5. The drive shall contain an input AC reactor to allow the VFD to operate properly without an isolation transformer. The line reactor shall be [3] [5] percent impedance. The line reactor shall be mounted and wired within the drive enclosure.

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NTS: MWWD requires 18 pulse converters when competitively available, then 12 pulse, and lastly 6 pulse. Eighteen pulse converters may be appropriate down to 50 horsepower at isolated pumping stations; the DESIGN CONSULTANT shall confer with the power utility regarding this issue. The DESIGN CONSULTANT shall review the cost and harmonics impacts of selecting 18 pulse converters for applications less than 100 horsepower, and consult with MWWD for a final decision.

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6. The power bridge shall utilize a rectifier configuration to provide an 18 pulse converter [for 100 horsepower and larger motors,] to minimize harmonics on the main AC power line. [For motors smaller than 100 horsepower, the power bridge shall provide a [6], [12] or [18] pulse converter as specified in the equipment schedule.] Combinations of 6 pulse drives connected to external phase shift transformers shall not be acceptable as [12 or 18] pulse drives.

7. The controller(s) shall be suitable for use with squirrel-cage induction motor(s) having an inverter duty rating and a 1.15 Service Factor.

B. **Motor:** The motor shall be squirrel cage inverter duty type in accordance with Section 16040.

C. **Basic Features:** The VFD controller shall have the following basic features:

1. The door of each power unit shall include:

   a. Input circuit breaker handle integrally interlocked with power unit door.
   b. One manual speed control potentiometer.
   c. [One 3-position mode selector switch marked "HAND-OFF-AUTOMATIC".] [2-position mode selector switches marked ”LOCAL-REMOTE” and “START-STOP”.]
   d. A " Power On" light.
   e. A speed indicating meter with a range of 0 to 110 percent of full speed.
   f. One elapsed time meter with five digits, without reset.
   g. One VFD fault reset push-button.

h. One ammeter with a range of 0 to 125 percent of drive current rating.
i. One output voltmeter with a range of [0 - 600 volt] [0 - 3 kV].

j. VFD fault diagnostics.
k. Indicating lights to show running and ready status.

2. Switches in the door shall control the drive as follows:

   a. With the ["HAND-OFF-AUTOMATIC"] [“LOCAL-REMOTE”] switch in the ["HAND"] [“LOCAL”] position, the [drive shall be manually started and stopped by the “START-STOP” switch and the] drive output speed shall be controlled by the manual potentiometer.

   b. With the ["HAND-OFF-AUTOMATIC"] [“LOCAL-REMOTE”] switch in the ["AUTOMATIC"] [“REMOTE”] position, the drive shall start when an external isolated contact closes and its speed shall be controlled by a 4-20 mA external reference signal.

3. The VFD shall be selectable to provide automatic restart after a trip condition resulting from overcurrent, overvoltage, undervoltage, or over-temperature. For safety, the drive shall shut down and require manual reset and restart if the automatic reset/restart function is not successful within a maximum of three attempts within a short time period.

4. Speed Profile: Individual adjustable settings for start, stop, entry, slope, and minimum and maximum speed points. Speed reference shall be from an external 4 - 20 mA DC signal.

5. Control Circuit: Fused 120 VAC control transformer and control relays for system logic functions. For system logic, see electrical drawings.

6. Provision for an external 4 to 20 mA DC speed reference input signal. VFD manufacturer shall provide a signal current isolator to ensure signal and galvanic isolation of the grounded or ungrounded input speed reference signal. Where indicated, a frequency proportional 4-20 mA powered output signal shall be provided for external use and wired out to terminals.

7. Status and alarm outputs, each consisting of SPDT electrically isolated auxiliary contacts rated 5 amp at 120 VAC. Status and alarm outputs shall include the following:
   a. Drive ready
   b. Motor at speed (running above minimum speed setting)
   c. Fault
   d. Warning (fault imminent)
   e. [“HAND-OFF-AUTOMATIC”][“LOCAL-REMOTE”] switch in the [“AUTOMATIC”][“REMOTE”] position

   The VFD shall be provided with a fault annunciation system which shall indicate the cause of any shutdown. Annunciator shall identify the first fault in those cases where multiple faults occur between manual or automatic resets and shall be visible without opening the VFD cabinet. If an English language annunciator is not provided, an engraved nameplate

shall be provided on the cabinet face with explanations of each fault code. As a minimum, the following faults shall be annunciated:

a. External fault
b. Input power loss
c. DC bus undervoltage
d. DC bus overvoltage
e. Motor stalled
f. Motor overload
g. Drive overtemperature
h. Drive overcurrent
I. Ground fault
j. Output short
k. Transistor short
l. Drive controller hardware fault
m. Drive controller software fault
n. Drive configuration error

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NTS: VFD faults can be internal or external. Latching in the trip mode conflicts with automatic re-start features. The DESIGN CONSULTANT shall modify the following specification if necessary to specify which faults will cause latch out, and which faults will allow re-start. For example, an internal VFD fault, motor over-temperature or failure, and high discharge pressure should always cause latch out. However, external faults such as input undervoltage should not necessarily cause latch out.

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VFD internal faults and motor over-temperature or failure shall latch in the trip mode and shall require operator intervention to reset the drive. External VFD faults such as input power loss shall allow for automatic re-start.

Status outputs shall consist of three separate unpowered outputs; two run status outputs, and a VFD enable output. VFD enable status contacts shall monitor the emergency (coast to a stop) circuit. Wiring shall be as required by the electrical control diagrams.

8. Automatic and safety inputs, each consisting of a remote contact closure rated 5 amp at 120 VAC maximum, complying with Section [ ].

   Opening of the automatic input remote contact shall cause the motor speed to ramp down to zero speed by controlled deceleration. Opening of the safety input remote contact shall cause the motor speed to coast to a complete stop. Wiring shall be as required by the electrical control diagrams.

9. For VFDs larger than 200 horsepower, a critical frequency avoidance circuit shall be provided to allow up to three selectable bands of operating frequencies (with programmable band widths) at which the VFD will not operate continuously in order to avoid system resonant vibrations.

10. Independent timed linear acceleration and deceleration functions, adjustable from 4 to 300 seconds.

11. Terminal blocks for wires entering and leaving the VFD unit. Terminals shall be identified with alpha- numeric characters identical to the terminal identifiers indicated on the schematic and connection diagrams.

12. Frequency regulator to operate within the following tolerances:

    a. Frequency regulator span shall be 4 mA at minimum speed and 20 mA at maximum speed.

    b. Frequency regulator accuracy shall be within 1.0 percent of span.

    c. Frequency regulator deadband shall be within 0.5 percent of span.

    d. Frequency regulator repeatability shall be within 0.5 percent of span.

    e. Frequency reference signal input resistance shall not exceed 250 ohms.

13. All integrated circuit boards shall be coated for corrosion protection. All components shall be solid state controls. All circuit boards shall be arranged for ease of removal in case of repair.

D. **Warranty:** Warranty period shall cover 24 months from date of startup, not to exceed 30 months from date of shipment. During this period repairs, including parts and labor, shall be provided at no cost to the OWNER.

2.3 ENCLOSURE

A. The enclosure shall be a dead-front, freestanding assembly with cabinet base and maximum dimensions as indicated. Working height shall be not greater than 74 inches for VFDs less than 100 horsepower. Doors shall be 12 gauge sheet steel with full length piano hinges. Removable lifting angles shall be provided.

Unless otherwise indicated the enclosure shall have gasketed doors and door openings. Enclosure shall be front or side access only, as indicated. No rear access shall be provided. Enclosure shall be suitable for either top or bottom cable entry as indicated.

Enclosure shall be painted ANSI 61. Inside shall be white. The exterior of stainless steel enclosures shall not be painted.

2.4 PROTECTIVE FEATURES AND CIRCUITS

A. The controller shall include the following protective features:

1. Static instantaneous overcurrent and overvoltage trip.
2. Undervoltage protection.
3. Power unit over-temperature protection.
4. Electronic motor inverse time overload protection.

5. Responsive action to motor winding and bearing temperature detectors and any bearing vibration switches indicated. All analog temperature signals shall be converted to contacts by the use of RTD relays or similar devices. Contacts shall open on fault condition or loss

of relay power. RTD relays or similar devices shall be selected and provided by VFD manufacturer in coordination with the motor manufacturer. RTD relays or similar devices shall be mounted within the VFD cabinet.

6. The VFD shall be capable of transient operation with a line voltage dip of 15 percent of normal operating voltage on a variable torque load. During line dip, the VFD shall automatically provide a speed droop limiting maximum capable speed for the duration of the input voltage dip.

7. When power is restored after a complete power outage, the VFD shall be capable of catching the motor while it is still spinning and restoring it to proper operating speed.

B. The power circuit design shall be such that the following fault conditions can occur without damage to the power circuit components:

1. Single phase fault or three phase short circuit on VFD output terminals.

2. Failure to commutate inverter transistors due to severe overload or other conditions.

3. Opening of VFD output contactor or motor disconnect switch during VFD operation.

4. Loss of input power due to opening of VFD input disconnect device or utility power failure during VFD operation.

5. Loss of one phase of input power.

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NTS: The short-circuit rating should be inserted by the DESIGN CONSULTANT after an analysis of the requirements of the installation.

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C. Drive shall be provided with a main circuit breaker or input fused disconnect switch, mechanically interlocked with the drive cabinet door. Interlock shall be provided with defeater. Unless otherwise indicated, circuit breaker or fuse shall have a minimum short circuit interrupting capacity of [30,000] RMS symmetrical amps.

D. Output reactor shall be provided as required to limit **dv/dt** damage to motor windings. Acceptable analysis proving reactor is not necessary, because of length of feeder cable run and switching frequency, is an acceptable alternative.

2.5 CONTROL DEVICES

A. Pilot devices and instruments shall be flush mounted on a VFD unit door. Pilot devices shall be heavy duty with contacts rated 10 amp minimum at 600 VAC. Indicating lights shall be "push-to-test" type. Lens colors shall be in accordance with Section [ ]. Door-mounted indicating lights shall be removable without removing related wiring. The control units of a given type and size shall be made interchangeable. Relays shall be hermetically sealed.

2.6 DIAGNOSTICS

A. The VFD shall be provided with the following diagnostics:

1. Lights to indicate failure of converter or invertor
2. Lights to indicate presence of gate pulses on converter and invertor
3. Indication of the following fault conditions:

    a. No fault
    b. Blown power fuse
    c. Control power failure
    d. Under-voltage
    e. Instantaneous overcurrent
    f. Sustained overload
    g. Over-temperature
    h. Output over-voltage

4. Meter with switch to test the following control signals:

    a. Frequency command
    b. Voltage command
    c. Motor voltage feedback
    d. Invertor bus voltage
    e. Current command
    f. Current feedback
    g. Converter command
    h. Filtered invertor bus voltage

5. Circuitry for the following test modes:

    a. Manual operation of the invertor through each firing sequence to test power circuit and logic.
    b. Operation of the drive open circuit.

2.7 NAMEPLATES, TOOLS AND SPARE PARTS

A. **Nameplates**: Nameplates of stainless steel shall be engraved or stamped and fastened to the equipment in accessible locations. Nameplates shall contain the manufacturer's name, model, serial number, size, characteristics, and appropriate data describing the equipment performance ratings.

B. **Tools**: The WORK includes special tools necessary for maintenance and repair; tools shall be stored in tool boxes, and identified with the equipment number by means of stainless steel or solid plastic name tags attached to the box.

C. **Spare Parts:** The WORK includes the following spare parts for each VFD:

1. 1 printed circuit board of each type used
2. 1 complete inverter bridge phase cell with snubbers
3. 1 complete converter bridge phase cell
4. 5 spare light bulbs of each type used
5. 3 spare fuses of each type used
6. 2 cans of aerosol spray touch-up paint

2.8 MANUFACTURERS

A. VFDs larger than 200 horsepower shall be manufactured by one of the following (or equal), but shall be modified by the manufacturer as required to meet the indicated features and conditions:

1. Robicon Corporation, Clean Power Series
2. Ross Hill Controls Corporation
3. ABB
4. Toshiba

B. VFDs equal to or less than 200 horsepower shall be manufactured by one of the following (or equal), but shall be modified by the manufacturer as required to meet the indicated features and conditions:

1. Robicon Corporation, Clean Power Series
2. Allen-Bradley
3. ABB
4. Toshiba

PART 3 EXECUTION

3.1 INSTALLATION

A. Drives shall be installed in accordance with approved procedures submitted with the shop drawings, manufacturer's recommendations, and as indicated.

B. General installation requirements shall comply with Sections 11030 and 16030.

C. **Schedule:**

Variable Frequency Drives

Driven Equipment		Motor Control Center		Horse-Power	Converter Pulses
Tag No.	Name	Tag No.	Circuit No.		

3.2 FIELD TEST

A. Field measurement of the harmonic indices shall be performed at unit full load using a harmonic analyzer (Hewlett Packard, or equal) with CTs with rated accuracy at 400 hertz. Harmonic indices shall be measured at the PCC. Tests shall prove that sufficient filtering has been provided to limit the harmonic distortion to limits set by IEEE 519. Results shall be tabulated and included with test results required in accordance with paragraph 11000-1.6A5.

** END OF SECTION **