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Variable Frequency Drive (VFD) Specifications for Agricultural Irrigation Pumping

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Variable Frequency Drive (VFD) controllers require variety of auxiliary equipment and are installed as a system (including installation details) on agricultural pumps to increase pumping plant efficiencies across a variety of pumping conditions. There are tremendous variations in quality, life, and cost of VFD systems – and customers receive limited or no information on details such as efficiency, heat disposal, special motor requirements, and negative impacts to the electrical grid and neighbors.

The VFD specifications are designed to provide VFD owners with a minimum quality level, without adding extras that are not absolutely necessary, and without the customer needing to be an expert on the topic. Specification-compliant VFD systems should be relatively safe, reliable, energy efficient, and have a reasonable cost.

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Section 1 - Applicability

1.A. This document applies to Variable Frequency Drive (VFD) system installations meeting all of the following criteria:

1.A.1. The project owner or authorized representative is applying to participate in the "PG&E Agricultural Pumping VFD Incentive Program", which involves a rebate for a complete VFD system, rather than components

1.A.2. The project involves a VFD system designed to control the speed of a 60 Hz alternating current motor that is rated for:

1.A.2a. 480VAC or less

1.A.2b. 600 HP or less

1.A.3. The VFD-controlled motor will be used specifically for pumping agricultural irrigation water into a pressurized irrigation system.

Section 2 - Definitions

References Used in Specification

AC – Alternating current

AHJ – Authority having jurisdiction, such as the local county building department

CEC – California Electric Code

dv/dt – the rate of voltage change over time

FLA – Full load amps. The current (in amperes) required to deliver the rated horsepower at the rated voltage, speed, and frequency. The value is found on the motor nameplate.

GFCI – Ground Fault Circuit Interruptor

HP – Horsepower

IEC – International Electrotechnical Commission

IEC 61800-5-1:2007 IEC 60721-3-3

IEEE – Institute of Electrical and Electronics Engineers

IEEE 519

NEC – National Electric Code, published by the National Fire Protection Agency (NFPA)

NEMA - National Electric Manufacturers Association

NEMA MG-1 : 2011

NFPA – National Fire Protection Agency

NFPA 70

RPM – Revolutions per minute

SF – Service factor

Terminal – A mechanical device used to make secure wire connections using a screw or other means to put pressure on the connection

THiD – Total harmonic current distortion (also called "TDD")

UL – Underwriters Laboratories

UL 508

VAC – Volts alternating current

VFD – Variable frequency drive, which is a system of electronic components assembled by a manufacturer for sale as the most basic unit used in practice to adjust the rotational speed of alternating current motors.

VFD System – The VFD plus all peripheral equipment typically contained in (or attached to) the enclosure (such as filters, reactors, and cooling), but not including the motor and motor leads. Cable termination filters shall be included in the VFD system

Section 3 - Minimum Requirements

3.A. General

3.A.1. The design and installation shall conform to the latest editions of the National Electric Code (NFPA 70), the California Electric Code (CEC) and any local codes, including manufacturer guidelines and instructions.

Note. References used in this specification are from the 2014 NEC. It may be necessary to refer back to the 2014 publication or modify the reference number if the references are renumbered in future versions.

Manufacturer guidelines and instructions regarding materials, components, environment, and installation shall be followed. Many of those requirements are not repeated in this specification.

3.A.2. The VFD shall be permanently marked with the manufacturer's name or identification, the voltage, current (or HP) rating, the short circuit (Isc) rating, and other necessary information to properly indicate the applications for which the VFD is suitable for. For VFDs that are an integral part of equipment approved as a unit, the above markings shall be permitted on the equipment nameplate.

3.A.3. The VFD and all associated equipment shall be contained in (an) enclosure(s) rated per the NEC for the environment in which the enclosure(s) will be located. Typical enclosure ratings are listed in the table below.

Note. NEMA enclosure ratings describe protection against ingress of water and dust. Corrosion resistance is also described.

Environment	NEMA Rating Options
Indoor	1 (dry location), 12 (wet location)
Outdoor	3 (dust), 3R, 4X (corrosive environment)

3.A.4. All internal VFD electronics shall be protected for the environment to which they are exposed.

Note. Some manufacturers can provide additional protection to electronics through coatings to minimize corrosion and shorting of printed circuit boards (PCB), connectors and other sensitive equipment. Levels of PCB protection are standardized into classes in IEC 60721-3-3 (Operation Environmental Conditions). For example, a VFD manufacturer may state: "Protection to IEC 60721-3-3 class 3C2"

3.A.5. The VFD system shall conform to all other applicable electric utility performance requirements, including harmonic distortion.

Note. These specifications do not supersede other electric utility requirements, which are subject to change over time

3.B. Motors

3.B.1. Sizing. New motors shall be sized to provide the required load at a service factor (SF) of no more than 1.0.

Note. Designing a motor to run at a service factor of less than or equal to 1 provides a buffer against overloading or overheating the motor due to intermittent increases in ambient temperatures, loads, and low or unbalanced voltages,

3.B.2. New motors shall meet NEMA MG-1 Part 31 Standard.

Note. NEMA NMG-1 Part 31 Standard outlines minimum requirements for motors designed to operate in conjunction with VFDs

3.B.3. A silicon rubber, flexible motor heater shall be provided for all new motors larger than 50 HP. The motor heater shall be controlled by an automatic thermal switch or relay and switch on at temperatures below the dew point.

Note. Motor heaters are designed to minimize condensation build-up inside the motor. Condensation inside the motor can accelerate insulation degradation and other problems

3.B.4. Bearing current mitigation:

Note. Driving a motor with a VFD generates shaft voltages for various reasons. Motor bearings act as a conductor between the higher shaft voltage and the grounded motor frame. Bearing material is removed (i.e., corrosion occurs) and the bearing is damaged if current passes through it

3.B.4a. Properly installed shaft grounding rings shall be provided on the drive end of all motors over 50 HP.

Note. Shaft grounding rings provide a lower resistance path to ground, to bypass the motor bearings

3.B.4b. An insulated bearing carrier at the upper bearing shall be provided for all vertical hollow shaft motors over 100 HP.

Note. Insulated bearings provide additional protection against voltage arcs across the motor bearings

3.C. Wiring between the motor and the VFD

3.C.1 Motor leads shall be selected based on the VFD manufacturer's recommendations, applicable codes and standards. Voltage rating, motor type, amperage, and length must be considered.

Note. Many VFD manufacturers provide extensive guidelines that cover selecting conductor or cable assembly types, sizing, shielding, etc. Selecting good conductors or cable assemblies help minimize EMI/RFI noise, motor bearing currents, and motor efficiency

3.C.2. Wiring must be specifically designed for VFD applications and include the following minimum features:

3.C.2a. Shielding or armoring

Note. Shielding the VFD cable helps contain EMI/FRI noise emittance and can also reduce shaft voltages/bearing currents

3.C.2b. Grounding conductor(s)

Note. Good grounding systems help reduce noise emittance and ground currents from common mode voltage

3.C.2c. XLP or similar insulation rather than thermoplastic

3.D. Transformer

3.D.1 If there is an ungrounded system (Delta-Delta transformer), provisions must be made to avoid shorting out various components such as Metal Oxide Varistors

3.E. Technical specifications for VFD systems

3.E.1. VFD selection

3.E.1a. The VFD shall be rated to provide 110% of the nominal output rating of the drive for 1 minute every 10 minutes

Note. A common criterion for variable torque applications such as agricultural water pumping. VFDs are rated differently for constant torque applications, such as conveyor and fixed displacement pump applications.

3.E.1b. The VFD and associated equipment shall be of sufficient current or horsepower rating to meet or exceed all of the following:

Note. Under sizing VFDs shall be avoided. For existing motor applications, there are some cases in which the VFD must be sized greater than the motor nameplate current or HP rating.

(i) the motor nameplate FLA or the maximum current required by the motor at full load when supplied by the VFD system, whichever is greater

Note. Designers shall consider and account for differences between actual motor current and nameplate current. Existing motors can experience a loss in efficiency over time, or as a direct result of poor quality motor rewinds.

(ii) Derating adjustments as recommended by the manufacturer of each component, for the specific application

Note. Example reasons for derating components include low air pressure (high altitude) and expected ambient temperatures above the ambient temperature rating of each component

3.E.2. Operating efficiency at full load. The following shall apply for VFDs driving motors with a nameplate rating greater than or equal to 20 HP:

Note. VFD and motor efficiency decreases with partial loads, especially below 50% of the rated load

3.E.2a. The VFD output power shall be no less than 96.5% of the VFD input power.

Note. This efficiency requirement includes only the VFD, and excludes other equipment that may be supplied with the VFD system by the vendor

3.E.2b. The VFD system (including harmonic and surge mitigation devices) output power shall be no less than 93% of the VFD system input power.

3.E.3. VFD systems shall be UL508 compliant, and be assembled in a UL listed facility. Unwitnessed

Note. UL508 lists standards to promote user safety for electric motor control systems. Requiring assembly in a UL-listed facility promotes

factory acceptance testing shall be conducted & documented. A document certifying the successful test results shall be provided with the equipment during shipment.

3.E.4. Line side

3.E.4a. VFD systems shall meet the minimum line side requirements listed in the table below regarding harmonic distortion and mitigation

Minimum VFD system line side harmonic performance and components

Motor HP	Minimum line side component	Maximum THID measured at the input terminals of the VFD system
<= 75	3% AC line reactor or DC bus equivalent, or active front end	n/a
> 75	n/a	5% or certified by a registered electrical engineer to meet IEEE 519 at the Point of Common Coupling

3.E.4b. Transient voltage protection must be compliant with IEC 61800-5-1:2007

3.E.4c. Displacement power factor shall be between 1.0 - 0.95 lagging at all speeds and loads down to 50% of rated load.

3.E.5. The VFD system shall have EMI/RFI emittance compliant to IEC 61800-3

3.E.6. Temperature rating. The VFD shall be rated for continuous full load output at 50 degrees Celsius (122 degrees Fahrenheit).

3.E.7. Cooling

3.E.7a. Cooling shall be designed to maintain VFD operating conditions below the temperature rating of the VFD systems, under continuous full load and under all expected environmental conditions. The cooling system

a minimum standard for design and workmanship that is audited by an independent entity.

Note. The VFD input side

Note. In general, the negative impacts affecting adjacent utility customers for line side harmonic distortion are relative to: (a) the magnitude of the distortion, and (b) the ratio of distorted current/voltage to non-distorted current/voltage at the point of common coupling as defined in IEEE 519.

Comment: Harmonic distortion just downstream of agricultural transformers is also important but is usually mitigated if the requirements in the Table are followed.

The magnitude of the distortion can be mitigated by various technologies. In agricultural applications, electric motor driven pumps are typically the largest loads on transformers. However, agricultural pumping loads are usually small relative to the capacity of medium voltage line at the point of common coupling (which in most cases is just upstream of the transformer for a pump).

For smaller motors (≤ 75 HP), 3% line reactors and DC bus equivalents, are considered acceptable because they decrease harmonic distortion by about 40%, are relatively inexpensive, and do not have a significant impact on VFD system efficiency. Active front ends are more expensive but provide excellent reductions to harmonic distortion.

For larger motors, the impact of harmonic distortion has a greater potential to affect others; therefore, additional requirements are listed.

Note. Surge or impulse voltage protection is important to minimize damage from lightning strikes, for example.

Note. A lower power factor requires conductors and other equipment to be upsized to handle larger reactive power

Note. EMI/RFI noise can create interference for sensitive electronic and wireless radio signals, including AM/FM radio, data radios and televisions. Panels can be shielded internally with a variety of materials to block emittance.

Note. To achieve a 50 deg C (122 deg F) temperature rating, most manufacturers will take a larger HP VFD and derate its output accordingly. In other words, a 100 HP VFD rated at 40 deg C (104 deg F) may only be rated at 75 HP for operations in 50 deg C. This is common.

Note. Cooling loads are determined by the VFD size and other field conditions such as daily ambient temperatures, indoor/outdoor locations, etc.

shall also comply with the requirements listed in 3.E.7b and 3.E.7c

3.E.7b. VFD systems installed outdoors shall be provided with one of the following

(i) Fully shaded by an additional structure, or shielded with sheet metal attached (with an air gap) to the VFD system enclosure. The air gap in any location shall be no less than 1 inch or otherwise designed to provide passive venting of the air gap space.

(ii) All exterior enclosures shall be white in color if exposed to the sun

3.E.7c. Outside air shall not come into contact with VFD electronics under normal operations for cooling purposes.

3.E.8. User configuration. A user interface device with a display and input keys shall be provided to enable the configuration of the VFD without the use of a computer.

3.E.8a. The user interface shall provide a user with the capability of adjusting the following configuration parameters:

(i) Motor data, such as voltage, RPM, FLA and frequency

(ii) Carrier frequency from 2 kHz to 8 kHz at minimum

(iii) Maximum rate of motor speed change, including acceleration and deceleration of the motor

(iv) The number of restart attempts and restart delay. The system shall be capable of automatically restarting as configured by the parameters listed.

3.E.8b. A user display shall be provided with visual indication for the items listed above.

3.E.9. Load side: The VFD system outputs shall not exceed the motor ratings for peak voltage and dv/dt at the motor terminals. Motor efficiency must not have more than a negligible drop due to hardware that is added.

Note. Outdoor installations must be designed to operate in all expected environmental conditions, such as extremely hot days in peak summer.

Note. Shading, and painting enclosures white are simple methods to significantly reduce heat buildup in outdoor installations

Note. Agricultural environments are very dusty. Dust buildup on electrical devices can cause problems such as shorts/faults and increased heat buildup. VFDs shall not utilize outside air, even if filtered, for cooling. Filters can quickly accumulate dust which decreases or can completely block the flow of air flow for cooling. Additionally, filters are rarely cleaned as often as they should be.

Note. User interfaces provide for the initial configuration and ongoing operation/adjustment of VFD parameters without an external device such as a laptop computer.

Note. Basic VFD configuration parameters for every VFD installation

Note. Extremely low carrier frequencies increase VFD system efficiency but can create larger harmonics and audible motor noise. Extremely high carrier frequencies will decrease VFD system efficiency but reduce audible motor noise and harmonics. There is an optimum range of carrier frequencies that is a balance between efficiency, noise and harmonics.

Note. Fast motor speed changes can cause problems such as water hammer with wells and piped water systems, and should therefore be avoided. The designer of the irrigation system or another qualified individual should be consulted to determine acceptable acceleration/deceleration rates for the pump

Note. The VFD shall have the capacity to automatically restart after tripping so that pumping can continue without user input if the problem has been resolved

Note. Motors are usually manufactured with a peak voltage and dv/dt rating (provided by NEMA) that could be exceeded when using a VFD, if precautions are not taken. Various devices can be added to the VFD system (or at the motor end of the cables) to mitigate problems with voltage characteristics at the motor - each with advantages and disadvantages.

3.F. VFD system enclosures

3.F.1. A door-mounted disconnect switch shall be provided that is capable of being padlocked in the "off" position.

Note. While NFPA79 requires the disconnect to be capable of accepting a padlock, UL508A does not specifically require a padlock for the "locking mechanism". This requirement is used to clarify that the locking mechanism must accept a padlock, which is a typical in agricultural operations

3.F.2. A door-mounted 3-position "VFD-Off-Bypass" switch shall be provided along with a panel-mounted, momentary "Start/Stop" switch, unless equivalent capabilities are provided by other external components. These components shall provide the capability of starting the motor across-the-line in emergencies.

Note. The equipment used to bypass the VFD shall be provided and labeled.

3.G. Documentation to the owner

3.G.1 Provide a standalone documentation package to the customer. All information shall be complete and reflect as-built conditions. Include the following at minimum:

Note. A good documentation package is useful for future operation and maintenance

3.G.1.a. Maintenance program. Provide a written description of the recommended maintenance tasks and schedule based on operating hours and/or calendar year.

3.G.1.b. A wiring diagram showing all of the following at minimum:

Note. A VFD system wiring diagram will be more detailed than the single line diagram

- (i) All power and control conductors terminated by the panel builder
- (ii) All field wiring connections
- (iii) Labeled wires and terminal blocks
- (iv) Identification of all major unique components not including terminal blocks or DIN rail
- (v) A bill of materials table listing the brand, part number and a description for all components

3.G.1.c. Unwitnessed factory acceptance testing results covering successful testing of all circuits, control loops and wiring workmanship