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Variable Frequency Drive (VFD) Specifications for Water Pumping

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Key Concepts

VFD System

A VFD system is required to meet the specifications.

> *A VFD system is defined in this report, and the attached specifications, as "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 conductors. Cable termination filters mounted on the motor shall be considered part of the VFD system."*

In most cases, a VFD system contains devices from multiple manufacturers.

Key points:

1. The VFD unit, provided by a major manufacturer, is only one part of a VFD system.
2. The remaining components are selected and sized by VFD experts, usually employed by a VFD vendor or other special firm.
3. Each component must be considered as part of a system, with potential tradeoffs.
4. The VFD system is usually assembled by an industrial control panel shop. Professional panel shops tend to pay fees for certification by the Underwriters Laboratory (UL) or equivalent organizations. Certified panel shops are also described as "UL Listed".
5. There are a number of optional VFD system add-ons to provide additional functions or features. Some can be considered essential for the customer's application, while others are for convenience.

Common components within a VFD system are illustrated in Figure 1.

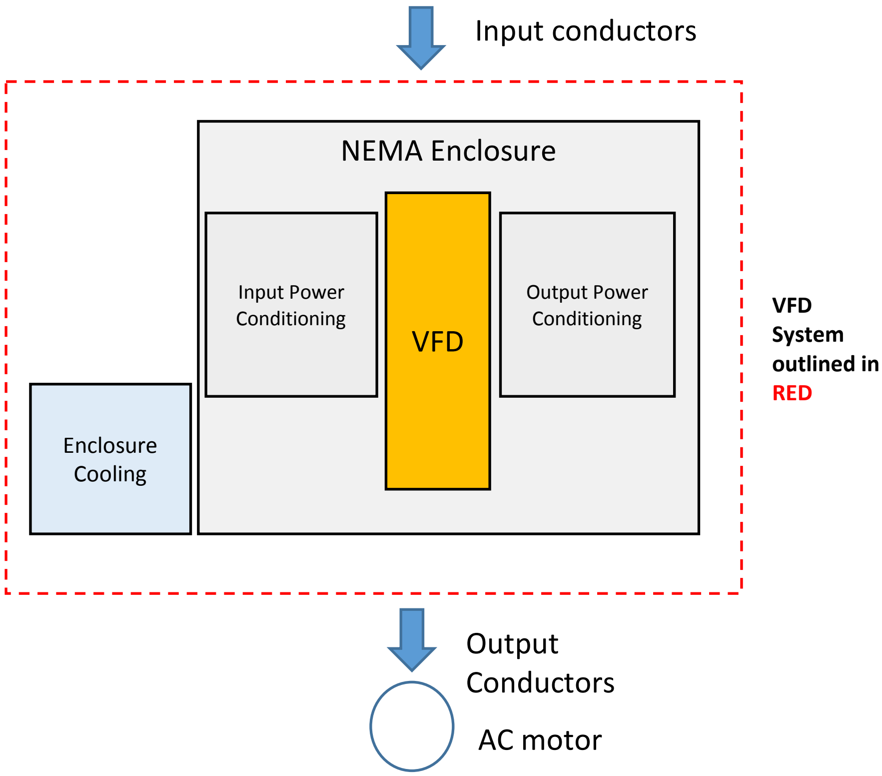

Figure 1. Typical VFD system components

Harmonic Distortion

The standard IEEE 519 is often cited as the benchmark for line side harmonic mitigation analysis and design criteria; however, IEEE 519 is generally incompatible as a prescriptive requirement for energy conservation programs for the following reasons:

1. Applying IEEE 519 requires a licensed electrical engineer and is typically considered unnecessary and overly expensive for smaller VFD systems. A common threshold for considering IEEE 519 in VFD system design varies between 60-100 HP. Under the threshold horsepower is it more cost-effective to install standard harmonic mitigation devices such as DC chokes or AC line reactors than pay for the IEEE analysis.
2. Agricultural pump motors over the threshold HP range are typically fed by an individual service drop and pole-mounted transformer. Therefore, the point of common coupling (PCC), an important reference location for IEEE 519, is on the line side of equipment installed and maintained by the utility.
3. IEEE 519 requires knowledge of the electric utility-owned equipment, which may not be readily available.

As such, the specifications provide the option for VFD systems over 75 HP to:

- Install a VFD system that meets prescribed, yet conservative harmonic performance targets, or
- Hire an electrical engineer to conduct an IEEE 519 analysis when it is likely that the engineered design will result in net monetary savings.

VFD System Cooling

VFD units as well as other components within the VFD system generate heat. To maximize the life expectancy of the components, it is prudent to maintain temperatures in and around the components within their temperature ratings, if not lower.

While there are a number of methods used to dissipate VFD system heat, most VFD vendors provide VFD systems that use filtered fans to circulate outside air within the NEMA enclosure. In most cases circulating outside air is the simplest and least expensive option. On the other hand:

- Agricultural fields are extremely dusty environments
- Fine dust can travel through the filters
- VFD system owners may neglect to, or unknowingly fail to service the filters as prescribed

The common result is early failure of the VFD or accessory components. As such, these specifications require alternative cooling systems that are less problematic for agricultural applications. It is important to note that the proposed specifications do not mandate a specific cooling method. Instead, the proposed specifications enable the VFD designer to select the most appropriate cooling method based on local conditions and experience such as:

- Closed loop heat exchangers including air-to-air and air-to-water
- Closed loop HVAC (air conditioning units)
- Passive cooling using:
    - The VFD system NEMA enclosure itself as a convective and radiant heat sink
    - Exterior, panel-mounted heat sinks usually mounted to the back of the VFD system enclosure
    - Heat pipes and heat exchanges that use conductive, convective and phase change heat transfer

Organization of the Specifications

The VFD system specifications are composed of the following major parts:

1. Applicability standards (for pumps less than or equal to 600 HP)
2. Definition of terms
3. Minimum VFD system requirements, including:
    - Minimum VFD system installation and commissioning checklist
    - Documentation requirements to the owner
    - Considerations for special cases
4. Optional additional features and equipment

VFD Specifications

Specifications	References Used in Specification
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	
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	

Specifications	Comments	More information	Link
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.	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	See NFPA website for free online access to NFPA (and NEC) codes	www.nfpa.org
3.A.1a. All of the VFD manufacturer guidelines and instructions regarding materials, components, environment, and installation must be followed. Many of those requirements are not repeated in this specification.	Extensive recommendations and guidelines are readily available online from most VFD manufacturers	See manufacturer websites	
3.A.1b. The owner shall provide proof that the Authority Having Jurisdiction (AJH) over the installation, such as a County Building Department that issues permits and conducts inspections of work done, has approved the completed work	In some cases, the AHJ might be a city or similar entity	Inquire with local city or county staff	

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.	The label provides information that may be useful for future installations if the VFD is used again in another application		
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: Indoor NEMA 1 (dry location) NEMA 12 (wet location) Outdoor NEMA 3 (dusty) NEMA 3R NEMA 4X (corrosive environment)	NEMA enclosure ratings describe protection against ingress of water and dust. Corrosion resistance is also described.	See ***NEC Article 110*** and ***NEC Table 110.28*** for more environmental protection details	www.nfpa.org
3.A.4. All internal VFD electronics shall be protected for the environment to which they are exposed.	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"	See ***Conformal Coating for Variable Speed Drives. Rockwell Automation***	http://literature.rockwellautomation.com/idc/groups/literature/documents/wp/drives-wp021_-en-p.pdf
3.A.5. The VFD system shall conform to all other applicable electric utility performance requirements, including harmonic distortion.	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.	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,	See: ***Service Factor: What is it and what does it do?***	http://www.avonmore-electrical.com/contentfiles/Service%20Factor%20-%20What%20is%20it%20and%20What%20does%20it%20do.pdf
3.B.2. New motors shall meet NEMA MG-1 Part 31 Standard.	NEMA NMG-1 Part 31 Standard outlines minimum requirements for motors designed to operate in conjunction with VFDs	See **NEMA MG-1: 2011**	www.NEMA.org
3.B.3. An automatic motor heater, intended to minimize condensation in the motor shall be provided for all new motors over 50 HP.	Motor heaters are designed to minimize condensation build-up inside the motor. Condensation inside the motor can accelerate insulation degradation and other problems	See ***Application Manual for NEMA motors*** Section 7 for further details, installation and wiring methods	https://www.industry.usa.siemens.com/drives/us/en/electric-motor/nema-motors/literature-and-technical-resources/documents/app-man-section7-rev1.pdf
3.B.4. Bearing current mitigation:	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	Discussion on the types of bearing currents, their causes and impacts, is provided in ***Dealing with Shaft and Bearing Currents*** and ***Technical Guide No. 5***	http://www.kyservice.com/wp-content/uploads/2017/03/EASA-Shaft-Bearing-Currents.pdf https://library.e.abb.com/public/8c253c2417ed0238c125788f003cca8e/ABB_Technical_guide_No5_RevC.pdf
3.B.4a. Properly installed shaft grounding rings shall be provided on the drive end of all motors over 50 HP.	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.	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.	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	A good example of extensive recommendations is provided in ***Wiring and Grounding Guidelines for Pulse-Width Modulated (PWM) AC Drives.*** Each manufacturer may have different recommendations.	http://literature.rockwellautomation.com/idc/groups/literature/documents/in/drives-in001_-en-p.pdf
3.C.2. Wiring must be specifically designed for VFD applications and include the following minimum features:			
3.C.2a. Shielding or armoring	Shielding the VFD cable helps contain EMI/FRI noise emittance and can also reduce shaft voltages/bearing currents		
3.C.2b. Grounding conductor(s)	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			

<table>
<tr><td>3.E. Technical specifications for VFD systems</td><td></td><td></td><td></td></tr>
<tr><td>3.E.1. VFD selection:</td><td></td><td></td><td></td></tr>
<tr><td>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</td><td>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.</td><td></td><td></td></tr>
<tr><td>3.E.1b. The VFD and associated equipment shall be of sufficient current or horsepower rating to meet or exceed all of the following:</td><td>Undersizing 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.</td><td></td><td></td></tr>
<tr><td>(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</td><td>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.</td><td>For details on good motor rewind practices and test results, see The Effect of Repair/Rewinding on Motor Efficiency</td><td>http://www.easa.com/sites/files/resource_library_public/EASA_AEMT_RewindStudy_1203-0115.pdf</td></tr>
<tr><td>(ii) Derating adjustments as recommended by the manufacturer of each component, for the specific application</td><td>Example reasons for derating components include low air pressure (high altitude) and expected ambient temperatures above the ambient temperature rating of each component</td><td></td><td></td></tr>
<tr><td>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:</td><td>VFD and motor efficiency decreases with partial loads, especially below 50% of the rated load</td><td></td><td></td></tr>
<tr><td>3.E.2a. The VFD output power shall be no less than 96.5% of the VFD input power.</td><td>This efficiency requirement includes only the VFD, and excludes other equipment that may be supplied with the VFD system by the vendor</td><td>A good reference for typical VFD efficiencies at full and partial loads is provided by the Department of Energy</td><td>https://www1.eere.energy.gov/manufacturing/tech_assistance/pdfs/motor_tip_sheet11.pdf</td></tr>
<tr><td>3.E.2b. The VFD system (including harmonic and surge mitigation) output power shall be no less than 93% of the VFD system input power.</td><td></td><td></td><td></td></tr>
<tr><td>3.E.3. VFD systems shall be UL508 or UL 61800-5-1 compliant, and be assembled in a UL listed facility. Unwitnessed factory acceptance testing shall be conducted and documented. A document certifying the successful test results shall be provided with the equipment during shipment.</td><td>UL508 lists standards to promote user safety for electric motor control systems. Requiring assembly in a UL-listed facility promotes a minimum standard for design and workmanship that is audited by an independent entity.</td><td></td><td></td></tr>
<tr><td>3.E.4. Line side</td><td>The VFD input side</td><td></td><td></td></tr>
<tr><td>3.E.4a. VFD systems shall meet the minimum line side requirements listed in the table below regarding harmonic distortion and mitigation</td><td>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.

NOTE: 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).</td><td></td><td></td></tr>
<tr><td>Minimum VFD system line side harmonic performance and components
<table>
<tr><th>Motor HP</th><th>Minimum line side component</th><th>Maximum THiD measured at the input terminals of the VFD system during operation under 70-100% of field load conditions, and neglecting any pre-existing, ambient harmonic distortion or voltage imbalances from other sources</th></tr>
<tr><td><= 75</td><td>3% AC line reactor or DC bus equivalent, or active front end</td><td>n/a</td></tr>
<tr><td>> 75</td><td>n/a</td><td>5% or certified by a registered electrical engineer to meet IEEE 519 at the Point of Common Coupling</td></tr>
</table></td><td>For smaller motors (≤ 75 HP), either 3% line reactors or 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.</td><td></td><td></td></tr>
<tr><td>3.E.4b. A listed UL 1449 surge protection device shall be installed on the line side of the VFD system</td><td>Surge or impulse voltage protection is important to minimize damage from lightning strikes, for example.</td><td>More details are provided in Isolation in AC Motor Drives</td><td>http://www.ti.com/lit/wp/slyy080/slyy080.pdf</td></tr>
<tr><td>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.</td><td>A lower power factor requires conductors and other equipment to be upsized to handle larger reactive power</td><td></td><td></td></tr>
</table>

3.E.5. The VFD system shall be designed to meet the conducted emissions limits published in EN/IEC 61800-3 for Class C3 (industrial) or Class C2, or Class C1 environments. An appropriately rated radio frequency interference (RFI) filter, other means to achieve equivalent maximum conducted emissions, are considered acceptable	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.		
3.E.6. Temperature rating. The VFD shall be rated for continuous full load output at 50 degrees Celsius (122 degrees Fahrenheit).	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 quite common.		
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 shall also comply with the requirements listed in 3.E.7b and 3.E.7c	Cooling loads are determined by the VFD size and other field conditions such as daily ambient temperatures, indoor/outdoor locations, etc.		
3.E.7b. VFD systems installed outdoors shall be provided with one of the following	Outdoor installations must be designed to operate in all expected environmental conditions, such as extremely hot days in peak summer.	A good reference for heat dissipation methods is by Hoffman and probably other enclosure manufacturers.	http://www.hoffmanonline.com/stream_document.aspx?rRID=233309&pRID=162533
(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.	Shading, and painting enclosures white are simple methods to significantly reduce heat buildup in outdoor installations		
(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.	Agricultural installations 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.		
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.	User interfaces provide for the initial configuration and ongoing operation/adjustment of VFD parameters without an external device such as a laptop 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	Basic VFD configuration parameters for every VFD installation		
(ii) Carrier frequency from 2 kHz to 8 kHz at minimum	Extremely <u>low</u> carrier frequencies increase VFD system efficiency but can create larger harmonics and audible motor noise. Extremely <u>high</u> 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.	A good reference for optimizing carrier frequency is provided by Allen Bradley	https://library.e.abb.com/public/a05e87eeb064df20c12571b600587bff/SOUND.pdf
(iii) Maximum rate of motor speed change, including acceleration and deceleration of the motor	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		
(iv) The number of restart attempts and restart delay. The system shall be capable of automatically restarting as configured by the parameters listed.	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		
3.E.8b. A user display shall be provided with visual indication for the items listed above.			
3.E.9. Load side.			
3.E.9.a 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 to resolve the peak voltage and dv/dt problems.	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.	Good discussions of voltage overshoot and mitigation techniques by ABB (see link to the right)	https://library.e.abb.com/public/fec1a7b62d273351c12571b60056a0fd/voltstress.pdf and **Application Paper AP043001EN** "Applying dV/dT filters with AFDs" (2014)
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.	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	See ABB white paper for details and compliant disconnect switch options	https://www.logic-control.com/datasheets/45/Control%20Products/Brochure/NFPA79%20and%20UL508A;%20Industrial%20Machinery%20Operating%20Handle%20Requirements.pdf

3.F.2. Across-the-line bypass starting capabilities shall not be provided unless across-the-line starting is approved by PG&E for the application	The equipment used to bypass the VFD shall be provided and labeled.		
3.G. Installation and commissioning			
3.G.1. VFD and VFD control panel anchoring requirements shall be compliant with the California Building Code.			
3.G.2. The VFD system owner shall be given a minimum of 3 hours of training covering basic operations and maintenance activities			
3.G.3. A trained VFD installer shall inspect and certify that the installation is compliant with the items listed in Table 3.G.3	The long-term success of the VFD system is dependent on a quality installation, configuration and good documentation		

Table 3.G.3. Installation and Commissioning Checklist

Item Description	***Notes***
Sensors used for automatic control have been installed per manufacturer's recommendations	Sensors may include flow meters or pressure transmitters or transducers
Conduits, conductors and earth grounds have been installed per manufacturer and/or engineer recommendations	
Motor parameters have been configured within the VFD that match motor nameplate or designer's parameters	Example parameters include name plate: RPM, voltage, full load amperage, frequency, etc.
Sensor calibration within the VFD has been completed and verified	
Motor acceleration and deceleration ramp speeds have been configured	"Optimum" values for these parameters may depend on the system supplied by the water pump rather than electrical or motor constraints. The designer of the irrigation system should be consulted for a recommendation if possible.
The VFD system, including cooling systems, have been function tested in all designed operating modes (manual and automatic as applicable) without faults under normal operating conditions	
Automatic restart after trip functions have been configured and tested	
The carrier frequency has been adjusted as recommended by the system designer	Adjustment of the carrier frequency shall consider all of the following: achieving acceptable audible motor noise, maintaining voltage overshoot and dv/dt ratings of the motor, dv/dt filter requirements, as well as maintaining minimum VFD system and motor efficiencies
All space heaters have been adjusted to maintain temperatures above the maximum dew point temperature, or minimum VFD temperature ratings, based on the space heater purpose, and have been function tested	
Wiring diagrams have been verified to as-built conditions	
A complete documentation package and field training has been provided to the owner per Specification 3.G.2	Documentation includes wiring diagrams, user manual, warranty information, maintenance activities, and step-by-step instructions for adjusting set points
The VFD system is fully shaded, or the enclosure(s) are painted white	
The installation has met all requirements of electric utility and the authority having jurisdiction (AHJ)	
A oil-filled pressure gauge has been installed just downstream of the VFD-controlled pump discharge	

3.H. Documentation to the owner.			
3.H.1 Provide a standalone documentation package to the customer. All information shall be complete and reflect as-built conditions. Include the following at minimum:	A good documentation package is useful for future operation and maintenance		
3.H.1.a. Single line diagram showing all major devices located between the branch circuit and the VFD-controlled motor.	The single line diagram is a schematic used to easily identify major components and their relative location in the circuit		
3.H.1.b. An as-built configuration sheet has been developed listing the as-built programming parameters configured for the project	A record of the configuration parameters is critical for record-keeping		
3.H.1.c. Maintenance program. Provide a written description of the recommended maintenance tasks and schedule based on operating hours and/or calendar year.			
3.H.1.d. A wiring diagram showing all of the following at minimum:	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.H.1.e. Unwitnessed factory acceptance testing results covering successful testing of all circuits, control loops and wiring workmanship			
3.I. Considerations for Special Cases			

3.I.1. The owner shall consider implementing the recommendations in the table below on a case-by-case basis is listed in **Table 3.I.**

Item	**Reasons, beyond the specifications to purchase the item**	**Minimum specifications**
Megger and surge testing	Existing motors should be evaluated for insulation degradation prior to being reused in VFD systems.	Megger testing procedures and result interpretation is listed in IEEE 43-2000 Surge testing procedures and result interpretation is listed in IEEE 522
Automatic space heater for VFD system enclosure	Manufacturers also provide a minimum VFD temperature rating for operating and storage conditions.	VFD applications in areas that can experience winter freezes shall install a heater to maintain enclosure temperatures within the VFD temperature rating.

Section 4 - Optional Additional Features and Equipment			
NOTE: The minimum specifications listed above do not cover automatic control of external devices, or automatic flow rate/pressure control of the water pump. These capabilities are considered optional "add-ons". Refer to the list below for common "add-ons" that facilitate additional VFD capabilities. It is recommended that these items be discussed with the VFD designer on a case-by-case basis.			

4.1. Equipment/items that may be necessary for control of external equipment such as well pump oilers, filter backflush controllers, or fertigation systems/pumps

Optional Items Specific to Automatic Actuation of External Equipment	Descriptions and Notes
Externally mounted, outdoor rated GFCI duplex receptacle(s) or branch circuits	120VAC, 15 amp or as needed, and energized only when the pump motor is running – commonly used for fertigation systems/pumps or backflush controllers. A transformer and subpanel may be required if single phase AC is not already available at the location.
Programmable digital input/output terminals for external monitoring and control	AC or DC, low amperage. Useful for oiler solenoid control or other capabilities

4.2. Equipment/items that may be necessary for automatic, closed loop control, such as automatically maintaining a relatively constant target flow rate or downstream pressure

Optional Items Specific to Automatic, Closed Loop VFD control	Descriptions and Notes
Analog input terminals or a supplemental analog input card (a printed circuit board with multiple analog input terminals)	Analog input terminals (0-5VDC or 4-20mA) are a basic requirement for closed loop automatic control, which enables the VFD to interface with standard industrial sensors. Sometimes the analog input terminals come standard with the VFD. In other cases, an additional analog input card needs to be purchased as an add-on.
Pulse signal input terminals or supplemental printed circuit board (card) for flow meters	High or low frequency pulses are common output signals to many agricultural flow meters used in automatic pump flow control applications
Sensors. Examples include: (a) Pressure transmitter with cable, or (b) flow meter with electronic output	At minimum, one sensor is required to provide automatic closed loop control. The type of control target (flow rate or pressure) will determine what type of sensor is needed. Sensors are usually add-on items. Ask the VFD designer about sensor accuracy and resolution and how that affects the automatic control performance.
Serial or Ethernet communication port	Communication ports are necessary to pass VFD, integrated sensor or other data to other devices. An example application is remote monitoring or control of the VFD and/or pump parameters

4.3. Equipment/items that may be necessary for general or specific uses

Optional Items Specific to Automatic, Closed Loop VFD control	Descriptions and Notes
A panel mounted 3-position Hand-Off-Auto (HOA) switch and speed potentiometer. a. When in "Hand", the VFD will be manually started, and the speed will be controlled from a panel-mounted speed potentiometer. b. When in "OFF", the VFD will be stopped. c. When in "Auto", the VFD will start and adjust its speed automatically to maintain a target set point (flow or pressure)	The combination of these devices provides the user with a very simple method of manually starting a pump and setting a desired speed, downstream pressure or flow rate - all without using the keypad. Sometimes, the keypad overloads the user with complexity, or grants the user too much access to unauthorized modification to VFD parameters.
A panel mounted multi-position switch to select between various automatic VFD closed loop control programs	This option is useful for simplifying operations that have multiple target pressure or flow set points. An example use case is explained below. Example: A vineyard irrigation system with frost protection sprinklers. When the VFD is turned ON and in AUTO mode, operators use a physical switch to select program "A" to configure the VFD to automatically maintain a low discharge pressure (e.g., 35 psi) for drip irrigation events. Then during frost events, operators simply switch to program "B" to configure the VFD to automatically maintain a higher discharge pressure (e.g., 55 psi) to operate the frost protection sprinkler system. Combining this multi-position switch with other physical switches, and the necessary VFD programming (completed by the installer) could eliminate the need for operators to use the manufacturer's keypad. Learning to use the VFD keypad is unnecessarily complicated for some users who prefer to keep it simple.
Externally mounted, outdoor rated GFCI duplex receptacle(s)	120VAC, 15 amp for convenience (mobile device chargers, work lights, etc.). A transformer and subpanel may be required if single phase AC is not already available at the location.
Automatic space heater for VFD system enclosure	Automatically maintains the inside of the enclosure to prevent condensation on electronics
VFD interface language switchable to other languages such as Spanish	The capability to switch languages on the VFD keypad can be useful for some operations and users
Pilot lights	Door mounted pilot lights provide a fast and easy-to-understand indication of pump status (e.g., running) or problems such as faults or alarms. Controlling the pilot light circuit requires digital (on/off) output terminals integrated into the VFD or add-on printed circuit boards
Lockable shade cover over VFD keypad and/or door-mounted switches	Provides some resistance to UV damage of the keypad and door-mounted switches/labels as well as provides some level of protection against unauthorized control of the VFD system (and vandalism protection)
Extended warranty	For example: 5-year parts and workmanship
Enclosure access door lock	Provides additional protection against unauthorized access to VFD system internal components. There is both a safety and vandalism-resistance component. Many users prefer to use door handles that accept padlocks
Vandalism enclosure for VFD system	Additional vandalism protection is common in rural areas to help prevent wire theft and system damage. Some vandalism enclosures enclose the VFD system inside of 1/4" or thicker mild steel plate. Plates of AR500 steel are used to stop most bullets. Vandalism enclosures should be discussed with the VFD system designer and accounted for in the cooling system design
VFD display has been programmed to display the following instantaneous values	Motor speed (RPM, %, or engineering units)
	Motor current (Amps)
	Output voltage
	Input voltage
	For VFDs used in closed loop control applications, provide both the instantaneous (or averaged) reference measurement and target set point
Internal, door-mounted document holder	Provides the ability to keep an organized set of documents inside the VFD for future reference

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