



Variable Frequency Drives (VFD)

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A brief explanation of variable frequency drives and how to apply them for irrigation pumping plants.

What Is a Variable Frequency Drive?

A variable frequency drive, known as a VFD, is an electronic drive system used to control electric motors. Its purpose is varying motor speed by controlling input frequency and voltage.

Variable frequency drives convert AC voltage to DC current and can be thought of as “pulsing” this DC current to the motor to vary the motor speed. Variable frequency drives are energy saving and load management devices that belong to a group of devices sometimes known also as adjustable speed drives. VFDs save energy by varying the input energy required for a corresponding load.

Variable frequency drives are an alternative to soft starts and are useful when slower motor speeds can provide energy savings. They allow for automation, as well as for large motor applications on single phase service applications, and serve as a load management tool. When a VFD is used to start a motor, the motor starts slowly before coming up to full speed. A VFD can be thought of as putting a “throttle” on an electric motor.

Why Use a VFD for Irrigation?

Variable frequency drives have several advantages that are useful for irrigation systems:

- Variable frequency drives provide for a gradual increase in speed to full motor load. Full motor torque is available with a

VFD even at slow speeds. This is important for mixed flow and axial pump applications where there is significant startup load on the motor at zero speed. From a power utility perspective, this long time for startup reduces startup load, or initial line loading, that is often several times the full motor load. For across the line motors, the utility must be able to accommodate the voltage drop and the inrush current necessary for motor startup. A VFD reduces this inrush current by spreading the voltage drop across a longer period of time.

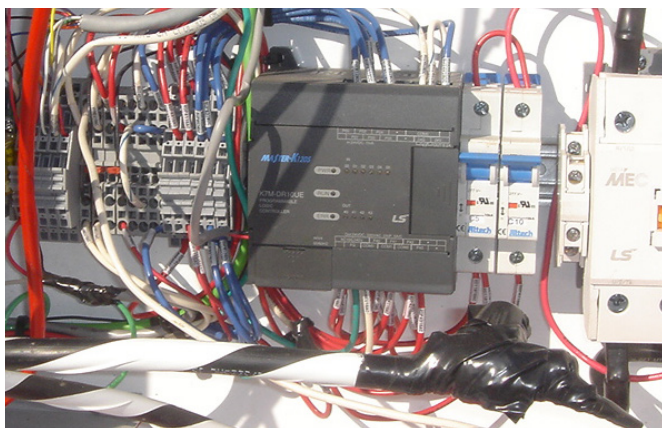


VFD pump panel controls. Auto (sensor driven) or manual mode (upper left), start/stop (top center), variable speed dial (upper right), power to panel indication (lower left), VFD operational indication (bottom middle) and fault indication (lower right).

- Variable frequency drives may overcome the 10-15 horsepower motor limitation for single-phase service. Because the VFD converts AC to DC for the motor, the phase of the input source does not matter. This allows for larger motors to be used where only single-phase service is available. Transformers must be sized

to provide the required current, but where there is a high-three-phase service installation cost, VFDs can be more cost-effective.

- Variable frequency drives allow for constant pressure and automation. VFDs include microcomputers or microcontrollers and can accept instructions from programmable logic controllers. Some VFDs have industrial controller capability. Programmable logic controllers are industrial controllers that provide the ability to accept inputs from sensors and outputs to control motors. For example, in irrigation systems, a pressure sensor can be used to report pressures to the drive to maintain constant system pressure. This is especially useful for center pivots and microirrigation systems, where flow rates may vary but constant pressure is desired. On a center pivot, end guns, corner systems and variable rate irrigation alter the flow demand. A VFD can maintain constant pressure by varying motor speed (flow) when these components are cycled.



Programmable logic controllers can be used to control variable frequency drives and other processes, such as maintaining constant pressure in an irrigation system.

- Variable frequency drives reduce the thermal and mechanical stress on motors and pumps and reduce water hammer in irrigation systems. The slow start, compared to the rapid start of an across the line motor, reduces wear on motors, pumps and irrigation systems. Especially with older irrigation systems, the reduction of water hammer can extend the life and reduce the potential for leaks and failures.

How Variable Frequency Drives Work

The rotation speed of an induction motor is fixed and determined by the frequency of the supply voltage. Alternating the current supplied to the stator windings of the motor produces a magnetic field that rotates. Within the winding of the motor are pairs of magnetic poles. Dividing 60 hertz by the number of magnetic pole pairs in the motor will give the revolutions per second and thus the revolutions per minute of the motor.

An eight-pole motor, for example, has four pole pairs and the magnetic field therefore will rotate at 15 revolutions per second. This is equivalent to 900 revolutions per minute (assuming an electrical signal of 60 hertz where 60 hertz divided by 4 equals 15 revolutions per second). When the rotating magnetic field is induced, the rotor of the motor will attempt to follow. The load on the motor, however, causes the rotor speed to slip slightly behind the rotating field speed.

Induction motors rotate close to synchronous speed. The most effective and energy efficient way to alter the speed of the motor is to change the frequency of the applied voltage. Variable frequency drives change the fixed frequency supply voltage to a continuously variable frequency. This allows for adjustable motor speeds.

The conversion is accomplished using rectifier and inverter stages. In the rectifying stage, the rectifier converts three-phase (or single-phase) 60 hertz power from the given utility supply to direct current voltage (standard industrial motors are 208, 230, 380, 415, 460 and 575 volts). Voltage, and thus motor speed, is varied by altering the firing pattern of electronic switches or insulated gate power transistors. In the inverter stage, the insulated gate power transistors, sometimes referred to as power transistors, or thyristors, switch the rectified DC voltage on and off to produce an alternating current at the desired new frequency. A control system with an electronic circuit receives continuous feedback from the driven motor and adjusts the output voltage to frequency conversion.

As electronics continue to advance, the AC-DC-AC conversion process of a variable frequency drive is likely to become more efficient while costs decline. Current efficiencies exceed 97.5 percent.

Applications of VFDs

Applying variable frequency drives to centrifugal pumps results in significant energy reduction – if slowing the motor down for the purpose of flow or pressure regulation will have a benefit. Motor-driven equipment often is operated at reduced loads or restricted flows, and the opportunity to decrease energy consumption becomes much greater compared to equipment operating at maximum throttle or flow. Centrifugal pumps consume energy proportionate to the cube of the flow rate, and a small reduction in speed or flow can lead to a great reduction in energy consumption. When lower flow rates are required, decreasing the speed can lead to large energy savings.

The variable frequency drive and the motor must be compatible. Generally, existing motors in good condition can be used with a VFD. Motor windings are the primary concern, since the VFD will cause more electrical distortion than an across-the-line application.

An insulation test called a “Meggar test” can be used to determine the resistance between motor windings and ground. A resistance of 300,000 ohms or greater is acceptable. The test should be performed just after the motor has been operated, since dust and moisture can affect the test results. Do not perform an insulation test with a VFD connected to the test unit, because the high voltage used in an insulation test can damage a VFD.

In some cases, a motor should be rebuilt before being put into service with a variable frequency drive. In addition, the manufacturers of the motor and the VFD must be contacted to determine the compatibility of the equipment. High- or premium-efficiency induction style cast iron motors are preferable to lower-efficiency motors because of the windings and components.

Slowing a motor can create additional heat the fan motor may not be able to dissipate as well as it would at full speed. If upgrading a pumping plant or considering rewinding a motor, consult the VFD provider about compatibility. Most submersible motors are compatible with VFDs. Because these motors are liquid-cooled, slower operation does not hamper heat removal. (Special VFD parameters are required for submersible pump motors, so consult with your VFD provider).

Considerations for Variable Frequency Drives

Consult your utility provider for any discounts or credits that can be given for installing a variable frequency drive as a load management device, and ask if there are any known issues with VFDs in the service area. In some rare situations, power supply quality (interruptions, voltage dips, voltage swells and harmonic generation) can be a concern that would limit the effectiveness of, or require filters for, a VFD installation. In most cases, a VFD will be a welcomed solution by the utility to reduce the effects of startup motor loads on the utility grid.

Find a reputable dealer and service provider who are knowledgeable about VFDs for your irrigation application. Service providers are not always associated with irrigation companies, although some irrigation manufacturers now offer VFDs as original equipment (center pivots, for example).

A VFD for irrigation should have manual, automatic and off modes. The manual mode is used to test the motor and drive for operation, without any automation or sensor input. There should be an emergency kill switch or lockout somewhere on the panel that stops all movement or shuts down all power.



Safety shutoff/lockout for VFD panel.

Motor speed can be altered manually, such as with a rheostat or dial control, as shown on page 1. It can be determined from motor load, such as a pressure sensor or flow meter. It is advisable to control the

VFD using a programmable logic controller or PLC. PLCs are inexpensive (a few hundred dollars) and greatly expand the ability and control possibilities of the VFD.

If a centrifugal pump surges, or has lost prime, or a part has broken, the system should be able to shut down without causing further damage. Centrifugal pumps that run dry can boil the water in the volute, so incorporating this safety feature into a VFD is an added safety option. A high-pressure and low-pressure shut-off should be incorporated into the logic of the PLC or VFD control system. If a pump cavitates, some VFDs can sense changes or irregularities in motor loading (or rapid pressure changes through the PLC) and may be able to shut a pump down before pump damage occurs. Depending upon the application, these safety features could offset the cost of a VFD by avoiding potential pump repairs.

VFDs involve electronic equipment that generates significant amounts of heat during operation. VFDs should be mounted in white NEMA-3R (outdoor, falling or driven rain) enclosures with ventilation for most irrigation applications. These cabinets have been used in agricultural settings and operate well as long as the filters are properly maintained and cleaned. Inadequate airflow will cause excessive heat, leading to early failure of a VFD. The filters are easy to clean by simply removing them, washing them with water and reinstalling them.



White panels and ventilation are used to reduce heat loads for VFDs. Air is drawn from the bottom of the cabinet (right) and exhausted through the top. Fans are thermostatically controlled, but the filters need to be periodically cleaned for everything to work properly.

As with any electrical installation in the agricultural environment, install proper safety shut-off and lightning protection. Lightning arresters or surge protection

devices are designed to protect against stray voltage and current from direct or nearby lightning strikes. These devices (often disposable) are designed to absorb or limit the voltage spike before it passes through the motor and other electronics in a panel.

Cost Savings Using VFDs

Savings of a variable frequency drive system can be illustrated by the following example. If a 40-horsepower motor is operated below its maximum capacity for about 40 percent of the pumping season, a VFD could save as much as \$6,000 during six months of operation per year. If the estimated cost for the VFD for this example is about \$5,000 and another \$3,000-\$4,000 is required for installation costs, the payback time would be less than two years.

Sources

"Electric choice." Electricity Prices by State – National Electric Rate Information. Electric Choice, 2011-01-02. Web. 9 Apr 2012.

Irrigation Training and Research Center. 2004. VFD (Variable Frequency Drive) Specifications for Irrigation District Applications. ITRC Report No. R 04-004. California Polytechnic State University, San Luis Obispo, Calif.

Kohler, Brian, 2012. President of Powercom Motor Controls. Personal Communication.

Maura, Ryan, and Richard Okrasa. Adjustable Speed Drive Reference Guide. 2. 1. Ontario: Ontario Hydro, 1991.

NEMA Standards Publication (2007). Application Guide for AC Adjustable Speed Drive Systems. Rosslyn, Va.

"Variable Frequency Drives." Natural Resources Canada., 2009-11-17. Web. 4 April 2012.



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