Electrical Tech Note — 320

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Variable Frequency Drives

A variable frequency drive (VFD) is powered with 60 Hz alternating current and provides a 3-phase alternating current output with a frequency that can be varied. A VFD can be operated from a single-phase 60 Hz supply or from a 3-phase 60 Hz supply. The input alternating current supply is rectified and filtered to produce direct current. The direct current is then inverted to form a 3-phase alternating current at the desired frequency that can be the same or different than the 60 Hz input power. The power circuit contains a rectifier and filter to convert alternating current to direct current, and an inverter to convert direct current back into alternating current at the desired frequency. An electronic controller receives feedback from the system being powered as well as monitors and controls the power to the 3-phase induction motor being driven. Figure 320.1 is a block diagram of the basic components of a variable frequency drive unit.

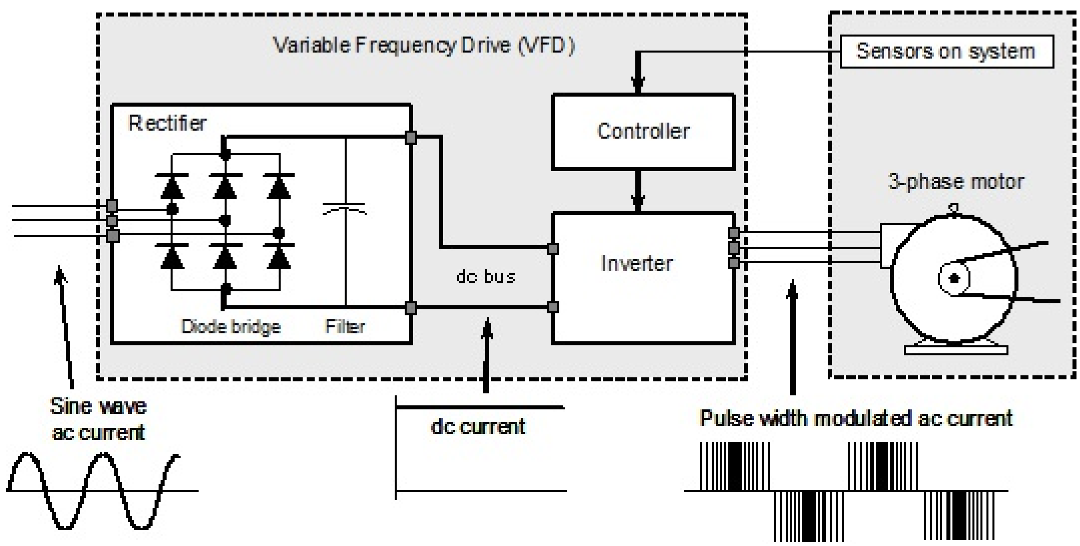


Figure 320.1 A variable frequency drive (VFD) rectifies the input 60 Hz alternating current into direct current, and using a device called an inverter, produces an alternating current output at the desired frequency to supply a 3-phase induction motor.

Induction Motors: The most common electric motors in use are induction motors that have a basically constant shaft rotation. Powered from a 60 Hz supply, a common 4-pole induction motor will have a full-load shaft rotation of from 1725 rpm to 1740 rpm. The shaft speed will decrease somewhat when the motor is heavily loaded and it will speed up when the motor is lightly loaded. With a 60 Hz supply, a magnetic field is produced by the windings in the outer frame (stator) of the motor that turns exactly at 1800 rpm for a 4-pole motor. This rotating magnetic field induces a current to flow in an aluminum structure within the rotor often referred to as a squirrel cage because of it's appearance. The induction motor derives it's torque by the strength of the rotating magnetic filed in the stator and the magnetic field induced into the rotor squirrel cage. For this to occur the rotor must turn at from 3% to 4% slower than the stator magnetic field when operating at full load. An induction motor is considered to be basically a constant speed motor with the shaft speed dependent upon the frequency of the alternating current supply.

Why Vary Frequency to a Motor: Many electric motors are used to power loads where the power required is highly variable. The motor must be sized to supply the maximum power demand, and much of the time it is operating at less than it's power rating. The efficiency of an electric motor to convert electrical power to mechanical power decreases rapidly when the motor is not working at nearly full load. For many applications, the motor is operating at full load, but the system being powered has a way of releasing excess power that is not needed. An example is a pneumatic system where the need for air-flow is highly variable, but the pump must be continually operating and maintaining a constant pressure. A pressure release valve in the system regulates the pressure when the pump and motor are applying more power than is needed. Systems of this type are common and waste huge amounts of energy. If the induction motor is powered by a variable frequency drive (VFD), the motor shaft rotation can be constantly adjusted to the speed required for optimum operation of the system. Sensors on the system control the speed of the motor and thus the power supplied to the system. The power output of a motor is directly proportional to the shaft speed (rpm) of the motor. Equation 320.1 can be used to determine the horsepower required when the torque (τ) is in pound-feet (lb-ft).

$$horsepower = \frac{2 \times \pi \times \tau \times rpm}{33{,}000}$$ **Equation 320.1**

A 3-phase induction motor is relatively inexpensive and maintenance free compared with most other types of motors. They are basically constant speed motors based upon the frequency of the input alternating current. However, if the supply frequency is increased the motor shaft rotation (rpm) will increase and will decrease as the supply frequency is decreased. The variable frequency drive (VFD) is a device that converts the 60 Hz supply to some other frequency for the purpose of varying the shaft rotational speed of an induction motor.

Output Waveform: The output voltage supplied to the induction motor by the variable frequency drive (VFD) is an alternating waveform at a desired frequency, but it is usually not a sine wave which is the case with the input voltage to the drive unit. Three-phase induction motors when designed for the purpose do not require a supply that is a sine wave. These motors can operate effectively from alternating waveforms of other types. This simplifies the design of drive units and helps control cost. A popular variable frequency drive provides an output by the method of pulse width modulation (PWM). The output on each phase is a repetitive pattern of positive and negative pulses with varying width with the pattern repeated at the desired frequency. Older motors not designed to operate with these waveforms may be subject to premature failure. Use only motors specifically rated for operation with variable frequency drives. Figure 320.2 is a representation of appearance of the output waveform of one of the phases from a pulse width modulation type variable frequency drive.

Motor Overheating: Electric motors are designed with internal fans and sometimes external fans to remove heat from the windings and rotor. When the rotor slows, cooling is reduced and the motor may be prone to overheating. This is less of a problem for 3- phase induction motors specifically designed for operation from a variable frequency drive. The *National Electrical Code* in *Article 430* requires some method be provided either in the motor or in the drive unit to detect motor overheating.

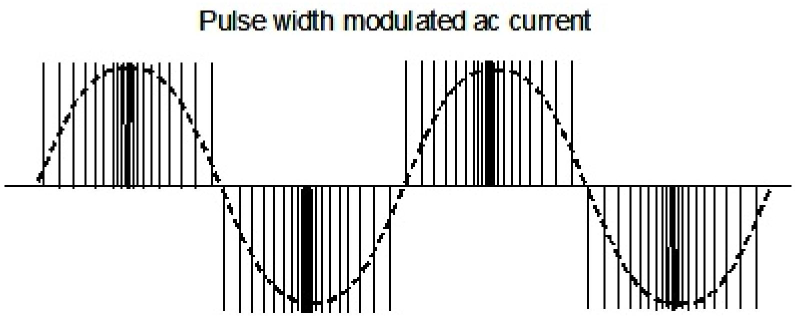
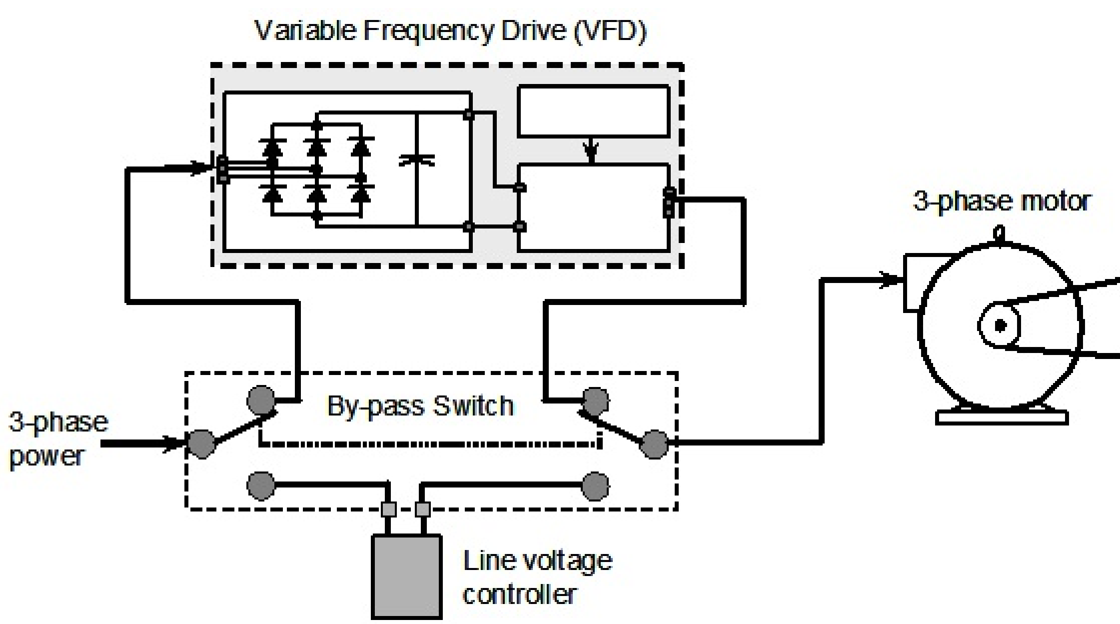


Figure 320.2 A common variable frequency drive (VFD) produces an output waveform that consists of a repetitive pattern of positive and negative pulses with varying pulse width. This method is known as pulse width modulation (PWM).

Back-up protection: The variable frequency drive unit contains electronic circuitry that is more prone to failure than an ordinary line-voltage mechanical motor starter. When used to power a system where high reliability is necessary, some means of back-up, or drive unit by-pass is recommended. If the power supply to the variable frequency drive (VFD) is 3-phase, then a by-pass switch can be installed so that the motor can be operated at normal speed directly from the 3-phase supply. A one-line diagram showing the arrangement of a by-pass switch is shown in Figure 320.3. Please note that a single line represents all three phase wires of the electrical system.

Figure 320.3 A by-pass switch can be installed that allows the motor to be operated directly form the 3-phase supply while completely isolating the drive unit from power so that it can be services with the system remaining completely operational.



Single-phase applications: Variable frequency drives are intended to supply power to 3-phase induction motors. The input supply can be single-phase, but the output to the motor is always 3-phase. For a single-phase application, the equipment that will be supplied must be converted to 3-phase. The existing single-phase equipment must be replaced. The existing single-phase equipment can sometimes be retained as a back-up system in case of failure of the variable frequency drive unit. Most variable frequency drive units are capable of being operated from a single-phase supply except that the rectifier section of the drive unit must work harder to supply the same output power derived from a 3-phase supply. When operating a motor with a variable frequency drive supplied from a single-phase power supply, check with the drive unit manufacturer for the proper rating. When operating from a single-phase supply, the drive unit will usually not be able to supply a load greater than 65% of the 3-phase rating of the unit.

Energy Savings: The energy required to operate some systems can be cut to less than half by operating the motor with a variable frequency drive rather than running the motor at full speed from a conventional line-voltage controller. The amount of savings depends upon the sytem and hours of operation. An analysis conducted by a qualified energy auditor can determine the potential energy savings, the estimated conversion cost, and the investment pay-back period. There may even be tax incentives and rebate payments available to help offset the conversion costs. Start by contacting the electric utility or an agency providing energy audit services.