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# Saving Money with Variable Frequency Drives

## Key Points

- Variable frequency drives (VFDs) allow motors to adjust their speed to better match the actual load.
- They change the speed of the motor by using semi-conductor switching devices.
- VFDs are ideal for motors driving variable torque loads often found in variable flow applications.

Source: Dekker Vacuum Technologies

There are a variety of methods to vary the speed of a motor to track its load more closely. Direct current (dc) motors are inherently variable speed devices, but are more typically thought of as specialty devices, compared to the more popular and less expensive alternating current (ac) induction motors. AC induction motors are single-speed devices that can be modified with variable frequency drives (VFDs) to achieve variable speeds. Other methods include multi-speed ac motors that rely on pole switching to change motor speeds for three-phase applications, though the speed changes are limited to step-wise increments.

Additionally, motors incorporating more than one set of windings can be made to run at more than one speed, depending on how the windings are connected. A similar technique is to use two or more motors to drive a single piece of equipment. Variable speeds are dependent on how the motors are connected.

## Variable Frequency Drives

VFDs eliminate the need for mechanical or hydraulic drives (clutches, gears, pulleys, valves, and vanes). The term adjustable speed drive (ASD) is often used interchangeably with VFDs, though this is not quite accurate. ASDs include VFDs, but also include methods to control the speed of dc motors, technology that has been around since the early 1960s. During the 1980s, VFDs became the preferred method of driving many types of loads at continuously variable speeds. VFDs are used with ordinary types of ac induction motors or synchronous motors.

## How It Works

The three main parts of a VFD are as follows:

- Regulator—Controls the rectifier and inverter to produce the desired ac frequency and voltage.
- Rectifier—Converts the fixed 60 Hz ac voltage input to dc.
- Inverter—Switches the rectified dc voltage to ac, creating variable ac frequency (and controlling current flow, if desired).

VFDs are totally electronic devices that convert alternating current to direct current by a rectifier. The direct current is converted back to alternating current by an inverter, at a frequency that will drive the motor at the desired speed. VFDs change the speed of the motor by using high-power semi-conductor switching devices (silicon controlled rectifiers, thyristors, or power transistors). These devices change the frequency of the current that is supplied to the motor, but do so only in an on/off manner. As a result, the alternating current that is provided to the motor is not a smooth sine wave. Although this makes the motor itself less efficient, the ability of the motor to respond to load variations increases the overall energy efficiency. Without a VFD, a motor might run efficiently at a single speed, but it may likely be the wrong speed as the motor's load varies.

## VFD Types/Designs

There are three major VFD designs. There are also several hybrids and less common types of VFDs. Most manufacturers are now concentrating their developmental efforts in Pulse Width Modulated (PWM) drives, since these are the only drives with a design capable of accurately simulating a sine wave current in the motor.

- Variable Voltage Input (VVI)—This is the simplest type of VFD. The output switching devices approximate a sine wave voltage for the motor by a series of square waves at different voltages. VVI drives use a large capacitor in the DC link to provide a relatively constant DC voltage to the inverter.
- Current Source Input (CSI)—Similar to a VVI, the main difference with CSI is that the CSI drive is able to force a square wave of current, rather than voltage, through the motor. CSI drives use a large inductor to keep the DC current relatively constant.
- Pulse Width Modulated (PWM)—This is the most complex VFD design, but also offers the most potential for increasing motor efficiency. The PWM inverter uses transistors to switch the direct current at high frequency to deliver a series of voltage pulses to the motor. The width of each pulse is tailored so that the voltage pulses interact with the reactance of the motor windings to produce current flow in the motor that approximates a sine wave.

## Applications

ASD/VFD products are ideal for motors driving variable torque loads often found in variable flow applications. VFDs offer the greatest opportunity for energy savings when driving these loads, because horsepower varies as the cube of speed, and torque varies as the square of speed for these loads. For example, if the motor speed is reduced 20%, motor horsepower is theoretically reduced by a cubic relationship (.8 X .8 X .8), or 51%. Actually, energy savings may be less due to drive conversion losses.

Constant torque and horsepower loads are also candidates for ASD/VFD, but the advantages are not as great. Constant torque loads represent 90% of all general industrial machines (other than pumps and fans). Constant horsepower loads are most often found in the machine-tool industry. If a motor is run constantly at full load, an induction motor with a VFD drive is about 4%–6% less efficient at full load than an induction motor with a standard drive. Be sure to look at the motor operating curve to determine the number of hours that the motor is expected to operate at full load. VFDs are used on pumps in commercial HVAC installations and waste water treatment plants, industrial motors for conveyance systems, paper mills, induced draft fans, and a variety of applications that can be served more efficiently with systems that respond to fluctuating motor loads.

| Industry | Application |
|---|---|
| Automotive and Transport Equipment | Conveyors, Marine, Pumps |
| Chemicals and Pharmaceuticals | Centrifuges, Agitators, Pumps, Fans, Filling Machines, Labeling Machines |
| Electronics, Electric, and Cables | Conveyors, Vacuum Pumps, Extruders, Winders |
| Food and Beverage | Centrifuges, Agitators, Pumps, Conveyors, Filling Machines, Bottle Washing Machines, Labeling Machines, Dryers, Ovens, Compressors |
| Metal Working | Saws, Lathes, Drills, Grinders, Presses, Flying Tools, Indexers, Punchers, Cranes |
| Material Handling, Lifts, and Cranes | Conveyors, Hoists, Screw Feeders, Cranes, Lifts |
| Metals, Minerals, and Mining | Dredgers, Conveyors, Crushers, Ovens, Smelters, Rolling Mills |
| Oil, Gas, and Energy | Separators, Conveyors, Fans, Pumps |
| Packaging Machinery | Palletizers, High Rise Stores, Foil Wrappers |
| Paper and Printing | Pumps, Wood Chippers, Washers, Winders, Printers, Paper and Cardboard Lines |
| Plastics and Rubber | Plastics and Rubber Extruders, Stretchers, Injection Molding Machines, Cutting Machines, Winders |
| Stone, Clay, and Glass | Conveyors, Grinders, Crushers, Ovens, Palletizers |
| Textile and Fiber | Man-Made Fiber Lines, Cards, Spinning Frames, Winders, Weaving and Knitting Machines, Cutting Machines |
| Woodworking | Sawmills, Lathes, Plywood Lines, Conveyors, Indexers |

## Benefits

- Efficient means of modulating the output of conventional induction motors and synchronous motors.
- Make it practical to use precise motor speed in a wide variety of applications.
- VFDs offer the best turndown ratio.
- Some of the new models approach the near-zero-speed capability of DC drives.

- Low maintenance—no moving parts other than push-buttons.
- Ease of installation and retrofit.

Limitations

- VFDs waste more energy as heat, particularly when there is significant speed reduction.
- The VFD does not deliver a true sine wave voltage to the motor. Harmonics may be an issue.
- VFDs increase losses in the transformers that feed them because of distortion of the input waveform.
- Some VFDs may cause existing motors to run substantially hotter.
- Not usable with conventional ac motors in applications where the motor must maintain high torque as the speed is reduced.
- Conventional motors lose their ability to get rid of heat as speed is reduced (limitation of the motor rather than a limitation of the drive.)
- Motors need to have cooling independent of motor speed, which is typically a special requirement.
- Overall system efficiency of modern dc drive systems and variable-pulley drives can be higher than the system efficiency of VFDs on induction or synchronous motors.

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