WWW.CHEMICALPROCESSING.COM

CHEMICAL PROCESSING

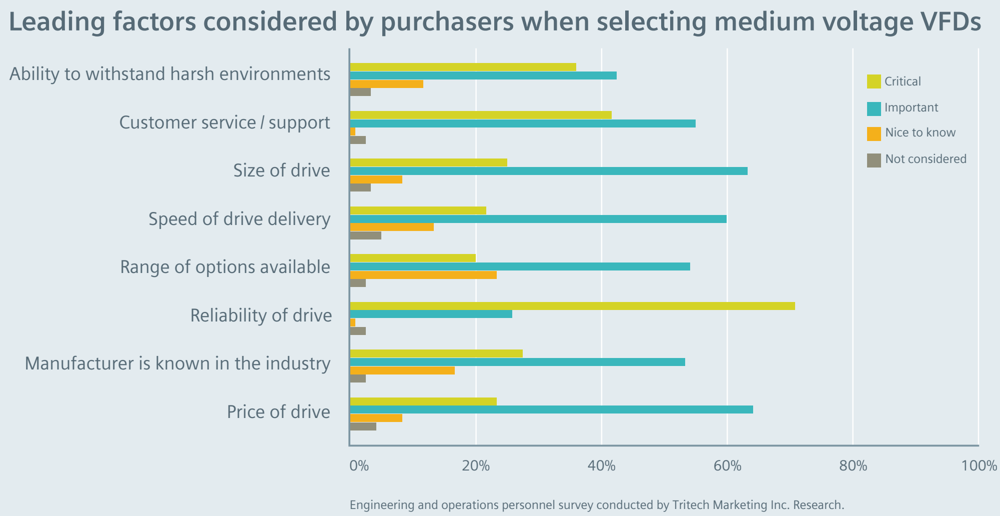
LEADERSHIP | EXPERTISE | INNOVATION

Special Report

Change Your Speed

Start ▶

PutmanMedia®



Know Your TCO

Siemens' new white paper helps manufacturers determine the total cost of ownership (TCO) of medium voltage VFDs.

In today's manufacturing sector, engineers increasingly incorporate medium voltage variable frequency drives (MV VFDs) into the manufacturing process. These high-consideration, high-cost assets deliver a range of benefits, including energy efficiency and improved process control.

However, not all drives are created equal. The MV VFDs available in today's market vary wildly in price, efficiency, lifecycle and reliability. In order to select the best drive for their needs, engineers take a bottom-line approach. They look for the drive that's most affordable and reaps the greatest rewards—the one that meets both their project budget and corporate initiative goals.

To help today's engineers with the drive selection process, Siemens has developed a new white paper, *Know Your TCO: A Look at Medium Voltage VFDs*. Inside, you'll learn the following:

- Which factors contribute to a drive's TCO
- How to calculate the net present value (NPV)
- The inverse relationship between reliability and TCO
- How product longevity, customer service and support affect TCO

It is vital to your success and your company's profitability that you know your TCO.

A Glimpse at TCO's Contributing Factors

The figure above shows the leading factors that purchasers consider when selecting an MV VFD. As you can see, the drive's purchase price is only one of the factors, all of which contribute to TCO. Anyone looking to purchase an MV VFD should explore these factors, as explained in the white paper.

Download the white paper now at usa.siemens.com/TCO

Make the Most of Variable Frequency Drives

Optimum performance depends upon proper installation and control.

By Robert Heider, Washington University, and Clay Lynch, French Gerleman Electric Co.

A VARIABLE frequency drive (VFD), sometimes also called an adjustable speed drive (ASD), is an electronic device that allows users to change the speed at which a motors runs. The combination of a VFD with a motor is becoming increasingly popular as a final control element because it consumes less power than a motor running at full speed and a control valve. Indeed, the U.S. Department of Energy (DOE) is encouraging the use of VFD for motor control to reduce power consumption [1]. However, obtaining good control depends upon proper selection and installation of the drive as well as understanding how control may differ with a VFD.

The VFD is one part of a total system that includes a motor and a load. The motor acts as a power transducer, converting electrical power to rotational mechanical power. AC induction motors, 600 V and below, often are paired with a VFD. (We'll discuss DC motors later.) These AC motors fall into classes with different torque speed curves (Figure 1). Most drive manufacturers assume use of a Class A motor and that the torque speed curve will be almost linear at the operating point (Figure 2). The VFD will shift the whole curve left or right to change the operating point. Note the "slip" in the figure. Every motor suffers from some slip or difference between rotor and stator fields. This is quite different than stiction, the term used with control valves for the needed stem force to overcome static friction. The load — mechanical conveyor, pump, fan, compressor or the like — has inertia, rotational friction and stiction. The process also has dynamic characteristics that may change when using a VFD instead of a control valve. It takes time to accelerate the load to operating speed and this is proportional to the inertia and the motor torque.

VFD BASICS

Today VFDs use a technique called pulse width modulation (PWM). First AC power is rectified to DC and filtered. Next, a solid-state semiconductor called an insulated gate bipolar transistor (IGBT) creates a voltage waveform to the motor that is a series of pulses of varying widths. The result is a varying frequency AC sine wave. The switching frequency determines the shaft rotational speed. Because the power waveform from a VFD isn't purely sinusoidal, it's important to only

AC MOTOR CLASSES

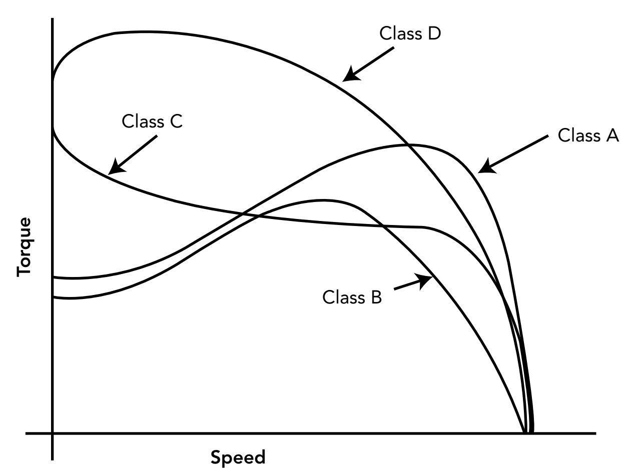


Figure 1. Each class features a distinct torque speed curve.

use motors specially designed to run with PWM VFDs — these are "inverter duty" motors, Class F winding. If a conventional motor is used, it may burn out.

A VFD also has other control electronics; these may include current, voltage and speed sensors.

The VFD electronics has limitations that affect control performance. One limitation is current. The inrush peak starting current of an "across the line" starter, one without a VFD, is eight times the full load current. Such a current would damage a VFD's rectifiers and semiconductors. Another constraint: the drive electronics is designed to prevent the motor flux from saturating the core.

The process transmitter sending its output signal to the proportional-integral-derivative (PID) controller that acts as the outer loop senses the process dynamics; its output is cascaded to the VFD.

Within the drive electronics are algorithms that control the electrical motor power, frequency, voltage and current. The current and speed set the motor torque. So the drive doesn't control just the speed, it also regulates the torque delivered to the rotor shaft. This torque produces the rotational force applied to the load (pump, etc.) that powers the process.

Properly understanding the dynamics of a VFD control loop requires considering all elements of the system and how they interact.

DRIVE CONTROL STRATEGIES

A computer program connected to the drive or a human machine interface (HMI) front panel enables inputting data about the load and the motor as well as setting the drive control strategy, which usually takes advantage of proprietary functionality. This strategy together with the load dynamic behavior determines performance. Loops within the drive electronics can be configured to control speed (through an external encoder), voltage, current and, in some cases, motor flux. These are the inner loops of the process control cascade. When

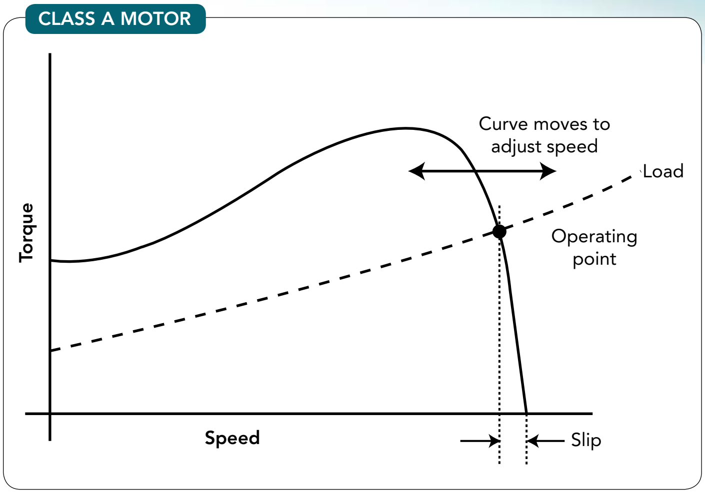


Figure 2. The curve with load is almost linear at the operating point.

tuning, remember that the inner loops must be at least five times more responsive than the outer loop. Another term to describe performance is bandwidth; it's inversely proportional to the time constant of the controller/motor with no load.

VFD manufacturers offer models with varying performance and cost. So, assess which is the best drive for the particular application.

Most drives have a defined, configured startup sequence that is to be run with the load disconnected. During this sequence the drive powers the stator and makes measurements that determine the characteristics of the motor. These motor constants then are used to tune the internal electronic program.

Drive control strategies generally fall into three categories [2]:

Volts per Hertz control. This is the simplest method. As seen in the torque speed curve (Figure 2), the region to the right of the peak can be considered linear — therefore controlling the frequency will regulate the shaft speed. The supplied voltage is $v = ir + d\lambda/dt$, where λ is the flux linkage. The derivative term is directly related to the rotation; so the rotational speed is proportional to voltage, thereby volts per hertz. At high speeds the ir term is negligible. The speed error is large at less than 10% of the rated rpm. Some configurations can compensate for this. This strategy is recommended for fan and pump applications. The resolution is about 0.5% base speed over a 40:1 range.

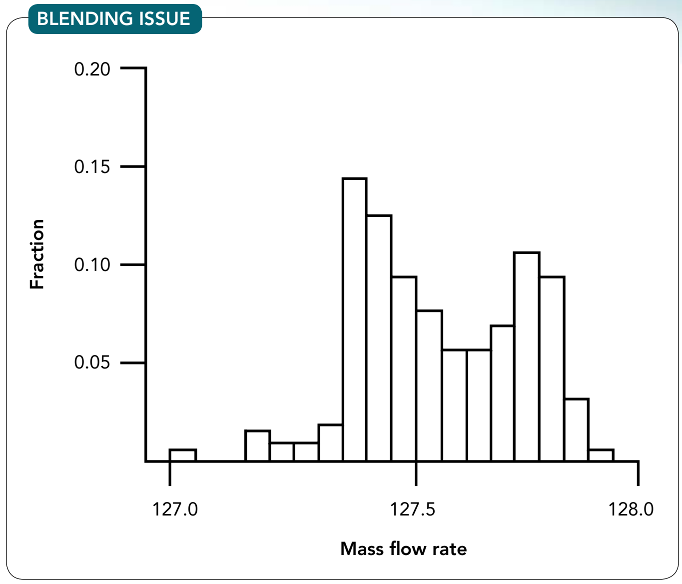


Figure 3. Original VFD led to inaccuracies in component addition.

Another problem with this strategy is the reduced motor torque at low speeds. This can be a serious problem conveying sticky solids or slurries. The torque decreases because the motor and wire *ir* drop is a larger percentage of the supplied power. Using a larger wire size can help solve this problem.

Constant-slip current control. This strategy regulates the slip or difference between the electrical speed and the actual speed. This is configured two ways, either optimum torque (maximum torque per amp) or maximum efficiency. Based on the motor constants found during configuration or testing, the drive electronics will calculate the flux linkages to avoid saturation. Two inner loops are used for this strategy. The speed command, usually the output from the outer process controller, is cascaded to a proportional-integral (PI) controller in the drive electronics. This PI controller compares the shaft speed to the set point and provides an output signal to a torque controller. This controller converts the torque set point to a current required to achieve that torque. A current sensor then corrects this current.

This strategy relies on three cascaded controllers. To obtain stable behavior each inner control loop must be several times faster than the loop it's fed from. Anti-reset windup should be used for each loop. To accommodate the sluggish torque response, the drive performs more slowly than with the volts per hertz strategy. The stator current is controlled at or just slightly above its rated peak value during start up. This strategy has 0.1% of base speed regulation across an 80:1 range.

Field-oriented control. The basis of this strategy is that the maximum torque between the rotor and stator magnetic fields occurs when the rotor current vector is perpendicular to the stator field (per Lorenz's force equation). The current control is calculated from the torque command and an estimate of flux. The strategy can be implemented two ways: direct and rotor-oriented where Hall effect transducers measure the flux, and indirect where the flux is estimated. Industrial applications don't employ flux sensors. This method offers improved transient performance. A 50-hp motor with load reaches full speed in 2 sec. and peak current remains at a steady-state value. High performance drives using this strategy have 0.001% base speed regulation across a 120:1 speed range. Because this method uses estimated machine constants, performance will deteriorate if the constants are incorrectly entered. The problem is most severe at low speeds. If the online machine parameter estimates aren't correct, the drive will experience "hunting."

Regardless of control strategy, as already noted, the drive changes the voltage or current to the motor via modulation. The IGBT is a switch either on or off. PWM produces a change in value by alternating the switching sequence. In this manner the output stator current will resemble a sine wave with steps inserted. The switching frequency, usually a configured entry, will determine how well the waveform will track. It's preferable that phases are sequenced, not all switched at once. This reduces the effective switching speed and results in an offset between the actual and desired current, therefore necessitating some closed-loop strategy.

The resulting waveform produces a quantized output. The root-mean-square value actually will vary in discrete intervals. From a closed-loop perspective this injects a non-linear term in the analysis that will create limit cycles, especially at high process gains.

DC MOTORS

These motors are classified according to how they are wound. Motor performance, usually shown as a torque speed curve, differs with winding design.

In the case of a shunt wound or separately excited motor, a constant DC voltage is applied to the stator winding while a variable voltage is applied to the rotor winding. A permanent magnet DC motor behaves similarly to a separately excited one. A shunt wound DC motor has a single voltage source that powers both the rotor and stator. The shunt wound, permanent magnet and separately excited motors have a linear torque speed curve and, thus, can provide better speed regulation with varying loads. They come in several winding variations, such as compound windings.

In a series motor, the stator is wired in series with the rotor. The torque speed curve for this motor has a parabolic relationship. This motor frequently is used for high mechanical inertia loads, elevators, cranes, etc.

PROCEED WITH CAUTION

There's a misconception that a VFD provides better resolution than a control valve. This isn't always the case. Virtually every modern electronic control system today features some sort of digital or microprocessor control. There has to be an interface between the analog domain and the digital one. Both AC and DC drives use digital-to-analog (D/A) converters. These converters don't provide infinite resolution — rather they quantize the signal. This produces a so-called quantization error. The number of digital bits is inversely proportional to the error. Process applications frequently use a "10 bit" D/A converter. This breaks up the output signal into 2^{10} or 1,024 discrete levels from the zero point to the maximum.

For example, consider a DC motor speed control powering a gear pump. In a simulated flow control problem, with 10-bit output resolution for a 22-gpm maximum pumping system, this error amounts to 0.03 gpm for a separately excited motor and 0.2 gpm for a series wound motor.

In another case, a continuous process employed a positive displacement pump powered by a VFD-controlled AC motor. Several fluids were blended and the final product quality depended on an exact ratio of all fluids. The precision of this process can be compared to that of in-line pH control — a very small deviation in reagent ratio may result in very large pH changes. This process suffered quality problems. Mass-meter flow rate data at the same set point were archived in an historian and gave the histogram in Figure 3. The positive displacement pump curve has a slope of 0.1 gal/rpm flow. The motor synchronous speed is 1,800 rpm. The adjustable frequency AC drive specification has 514 frequency divisions for the published resolution. The flow controller was trying to find the right

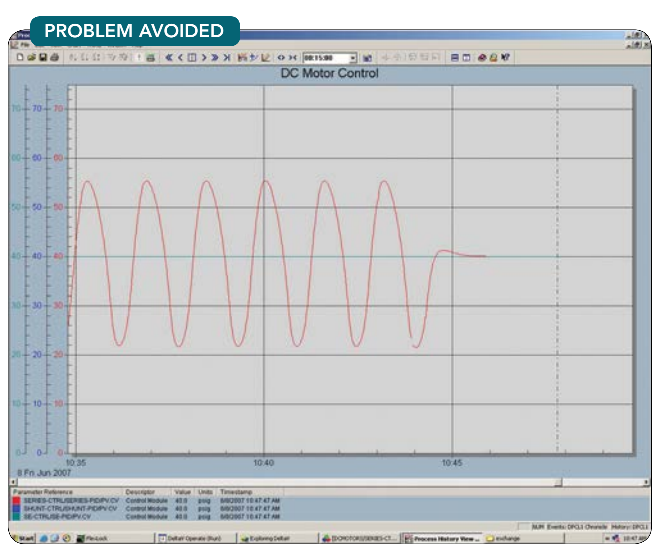


Figure 4. Reset inhibiting of controller eliminated limit cycle.

REFERENCES

1. "Variable Speed Pumping: A Guide to Successful Applications," Executive Summary, DOE/GO-102004-1913, U. S. Dept. of Energy, Washington, D. C. (May 2004). Downloadable via www1.eere.energy.gov/industry/bestpractices/pdfs/variable_speed_pumping.pdf
2. Krause, P. C. et al., "Analysis of Electric Machinery and Drive Systems," 2 ed., Wiley Interscience, Hoboken, N.J. (2004).
3. Spear, Mike, "Get a Fix on ASD Problems," p. 25, *Chemical Processing*, Dec. 2005, www.ChemicalProcessing.com/articles/2005/597.html

output, midway between these peaks, but couldn't. This caused the process signal to hunt around the set point. Always suspect a quantization problem if a bi-nodal process variable histogram distribution occurs with a continuous steady-state output signal. The plant replaced the VFD with one that had better output resolution and solved the problem. This example is extreme; however it demonstrates that the problem can occur. Drives available today have much better resolution, 0.01%.

As the above illustrates, a VFD can affect the plant. Startup and shutdown operations differ from those with a full-speed pump and control valve. Remember with a VFD you're controlling the power applied to the load while with a control valve you're introducing a controlled restriction to the power already applied to the load.

Variable speed pumps offer a linear response within a given inlet and discharge pressure range. However, you must limit the minimum speed to ensure that the pump's discharge pressure never drops below the static pressure downstream — otherwise, a disastrous flow reversal can occur. Also, you must add an on-off valve and coordinate it with the variable speed pump to provide positive flow shutoff.

LOOP CONSIDERATIONS

Just as we have acceleration and deceleration lanes on and off highways, drives have acceleration and deceleration ramps. These ramps are used to limit the motor starting current. They act as integrators in the loop dynamics. The default setting usually is 5 sec. to 10 sec., a typical flow loop reset value. If the integrator in the PI or PID controller is set faster than the VFD ramp, the resulting closed-loop performance will exhibit a limit cycle. This cycle isn't due to reset windup or saturation but, rather, occurs because the controller integrator is acting faster than the load can respond. Many controllers offer a feature that allows the reset action to be changed based on actual valve travel. Configure an auxiliary VFD output signal proportional to the actual load to the controller function block to eliminate the limit cycle.

Another factor is the process time constant. For drive-powered liquid flow control loops, the process time constant is larger during start up; in contrast, flow control loops with control valves have a smaller time constant. The loop will perform sluggishly during start up compared to a flow loop with a control valve and pump powered by an induction motor without a drive.

Always check the drive's deadband setting, which is used to reduce the reaction to noise. If not carefully adjusted, it can add deadtime and cycling.

AN ATTRACTIVE OPTION

A VFD can provide much needed power reduction and good operation. Torque and amps developed by an AC motor will determine the size of VFD needed for an application. Always size a VFD based on the load, which is expressed in amps, never on horsepower alone.

As with any instrument or control device, making the most of a VFD requires care and knowledge, including an appreciation of how control with a VFD differs from that with a control valve. ●

[Further details on installation and staff training appear in the online version of this article, www.ChemicalProcessing.com/articles/2009/043/.]

ROBERT HEIDER is an adjunct professor in the Department of Energy, Environmental and Chemical Engineering at Washington University, St. Louis. **CLAY LYNCH** is VFD and MCC product manager at French Gerleman Electric Co., Maryland Heights, Mo. E-mail them at rlheid@seas.wustl.edu and clynch@frenchgerleman.com.

To Succeed, Control Your Speed

Medium-voltage variable frequency drives can help eliminate waste and promote efficiency, reliability and quality

By Mark Harshman, Siemens Industry

MEDIUM VOLTAGE variable frequency drives (VFDs) are often the best choice to capitalize on opportunities to significantly reduce the operating and maintenance costs associated with relatively large rotating equipment. And because even a seemingly modest energy savings of a few percent of the operating load can translate into significant energy savings, there are many potential applications for medium voltage VFDs.

Medium voltage VFDs are applied to relatively large motors that can range in size from 200 to 100,000 hp. Such medium-voltage motors typically operate between 10 and 15,000 rpm, at voltages between 2.3 kV and 13.8 kV. Locating potential medium voltage VFD applications is relatively straightforward because every medium-voltage motor should be considered a potential application — if only because of the significant energy savings associated with large motors.

Medium voltage drives are used for new installations or retrofit installations. In a new installation, the saved cost of not having to install alternative solutions such as dampers, valves and mechanical transmissions can be applied to purchasing the medium voltage VFD. In some new applications, the installed cost of a medium voltage VFD can be less expensive than utilizing alternative solutions — especially when the alternative solution is expensive and requires additional plant modifications. In these applications, medium voltage VFDs not only reduce the overall cost of installation, but also provide the additional benefit of reducing the total cost of operation.

In retrofit applications, the full costs of purchasing and installing the medium voltage VFD — plus the cost of removing or disabling the existing alternative device — makes justification more challenging. Nonetheless, there are still many viable retrofit applications, especially when averted maintenance, repair and replacement costs for mechanical systems can be applied to purchasing the medium voltage VFD — along with much lower energy consumption. In many cases, the VFD will provide a payback in less than two years due to these energy savings; this does not include the reduced cost of ownership when compare to some mechanical systems.

For both new and retrofit applications, the utility serving the plant will often offer financial incentives for installing a VFD, which can greatly reduce costs as well as payback time.

Motors in which the hydraulic energy or mechanical energy generated by the motor is throttled are prime applications for medium voltage VFDs because matching the motor speed to the load conserves the electrical energy associated with generating the throttled energy. For example, it is not uncommon to throttle equipment down to as low as 70% of its full load capacity. By matching the motor speed to the reduced capacity of 70%, a 50% reduction of energy costs is achieved. The affinity laws allow for significant energy savings for even minor reductions in speed, which are realized and saved by using a VFD.

MORE POWER

Figure 1. Medium voltage VFDs accommodate larger motors than their low-voltage equivalents, operating at higher voltages to drive larger equipment.

APPLICATIONS FOR MV VFDS

Building automation	Cooling tower pumps, cooling tower fans, chiller fans, chilled water pumps, refrigeration compressors
Cement	Conveyors, kiln drives and fans
Chemical and petrochemical	Utility pumps, process pumps, fans, blowers, air compressors, process compressors, coolers, cooling tower pumps, cooling tower fans
Food and beverage	Utility pumps, fans, blowers
Marine	Long cable, offloading pumps, topside compressor
Mining	Conveyors, ball mills, grinders, crushers, mobile equipment (haul trucks, draglines, shovels)
Oil and gas	Utility pumps, process pumps, fans, process compressors, air compressors
Power	Induced draft fans, forced draft fans, cooling tower pumps, cooling tower fans, atomization air compressors
Pulp and paper	Chippers, conveyors, debarking, fans, paper machine line shafts, pumps, refiners, shredders
Water / wastewater	Process pumps, fans, blowers, air compressors

Table 1. Medium voltage variable frequency drives are commonly applied in a variety of industries and applications.

BIG MOTORS, BIGGER SAVINGS

A VFD is an electronic device that electronically alters the frequency and voltage fed to a motor to change its speed, and consequently the speed of the attached equipment. Most plant engineers are comfortable with low voltage VFDs and may use them extensively in their processes to control motor (and equipment) speed where necessary or desirable to improve product quality, increase productivity and reduce maintenance. Creative plant engineers are constantly finding new VFD applications in their plants.

Medium voltage VFDs accommodate larger motors than their low-voltage equivalents, operating at higher voltages to drive larger equipment. Their applications are often similar in nature to low voltage VFDs — just with bigger sizes and higher voltages and costs. Importantly, the energy savings associated with medium voltage VFDs are typically much higher than for low voltage VFDs because medium-voltage motors use much more electrical power.

For example, the savings associated with a 40% energy use reduction in a motor consuming 50 kW is 20 kW. The savings associated with a 20% energy use reduction in a motor consuming 1,000 kW is 200 kW — 10 times more energy savings. This illustrates how the energy savings associated with one medium-voltage motor can dwarf the energy savings associated with many smaller low-voltage motors.

To put these savings in numerical terms, if power is purchased from the utility at $0.10 per kWh and if the motor operates for 8,000 hours per year, the annual energy savings is approximately $800 per year per kW. In the above example, applying a VFD to this medium-voltage motor will reduce electrical energy costs by approximately $160,000 per year.

However, many plant engineers are not aware that medium voltage VFDs are available at reasonable costs, relative to their potential energy savings. They may also not know that they have been using throttle control for their large mechanical equipment in industrial plants and other facilities for decades — often for months or years without being shut down — and sometimes in applications that require precise speed control. Further, they are often not aware of the magnitude of the potential energy savings associated with medium voltage VFD applications.

Table 1 lists some industries where medium voltage VFDs are commonly applied, along with their typical applications. Naturally, plants with more medium-voltage motors tend to have more potential medium voltage VFD applications. However, having only a few medium-voltage motors should not discourage consideration; the application of just one or two medium voltage VFDs — even in plants dominated by low-voltage motors — can have important economic implications. In the cement industry, for example, a single plant typically has almost 30 medium voltage drives, ranging in power from 500 Hp to 2,000 Hp in pump, kiln and fan application.

In some plants, even as few as one or two medium voltage VFD applications can reduce overall electrical energy consumption significantly more than dozens of low voltage VFD applications. Therefore, the large economic impact of applying medium voltage VFDs in these plants typically results in considering the largest motors first, as this is where savings are greatest.

MEDIUM VOLTAGE VFDS VS. ALTERNATIVE SOLUTIONS

In many applications, medium voltage VFDs are superior to alternative solutions for controlling motor speed such as direct current drives, soft-starters, two- and three-speed motors, and single-speed motors coupled to various transmission components.

In other applications, medium voltage VFDs can replace mechanically based solutions used to control process parameters, such as the flow of a gas or liquid. For example, the flow of air into a large furnace or boiler can be regulated using a singlespeed motor and air vanes. However, controlling the mechanical equipment by using a medium voltage VFD to vary motor speed usually results in a superior process control, increased reliability and improved operational costs.

In either case, medium voltage VFDs offer many advantages over alternative solutions. Some of the advantages are listed in Table 2. Note that these advantages apply to specific applications in varying degrees. This will become evident when the advantages and expected results from various medium voltage VFD applications are discussed below.

ADVANTAGES OF MV VFDS
1. Decreased electrical energy consumption
2. Lower electrical demand charges from utilities
3. Decreased capital cost due to rebates from electric utilities
4. Decreased net electrical energy costs from power regeneration
5. Improved operating efficiency
6. Improved process control due to superior speed control
7. Increased product quality
8. Increased process reliability
9. Increased process throughput
10. Reduced downtime
11. Reduced maintenance
12. Reduced mechanical stress on associated equipment
13. Reduced motor stress through inherent soft-starting

Table 2. Medium voltage VFDs offer many advantages over alternative solutions.

MEDIUM VOLTAGE VFDS VS. DIRECT CURRENT DRIVES

Direct current (DC) drives vary motor speed by fluctuating the direct current voltage to the motor. VFDs, however, vary motor speed by fluctuating the frequency to the motor. Some of their advantages are similar because both control motor speed electronically.

DC motors are not as common and are typically more expensive than the corresponding alternating current (AC) motors used with VFDs. DC motors also have internal brushes that require periodic maintenance, thus compromising reliability.

As a result, the industry trend has been towards the application of AC motors. The large population of AC motors and numerous variable speed applications has tended to reduce the cost of VFDs as compared to DC drives.

VFDs are not recommended in applications where precisely controlling motor speed does not provide economic or operational benefit. In these applications, soft-starters may be required to address electrical problems associated with high inrush current, and will be a more economical solution than a VFD.

MEDIUM VOLTAGE VFDS VS. TWO-SPEED MOTORS

Starters that electrically alter the motor winding connections can allow the same motor to operate at two speeds — typically full speed and 50% speed. Operation at the reduced speed when the motor is lightly loaded can reduce the electrical energy consumption of the motor. This can represent significant energy savings under low load conditions. However, when the process load increases, the motor will be switched to full-speed operation and consume much more energy.

In contrast, VFDs can vary the motor speed continuously from zero to full speed, allowing the motor to operate at the precise speed needed to match the load and process requirements. The VFD strategy of matching the speed to the load is much more energy efficient, resulting in significant savings.

SOFT STARTER ALTERNATIVE

Figure 2. Variable frequency drives are inherently soft-starters. They ramp the voltage to the motor and limit inrush currents, prolonging motor life.

To illustrate, consider this VFD application: A medium voltage motor connected to a centrifugal fan consumes 600 kW of electrical energy while operating at 60% speed using a VFD.

In contrast, a two-speed motor would have to operate at full speed because 50 percent speed will not satisfy the load. Increasing the motor speed in this manner will increase energy consumption to 1,000 kW at full speed.

If power is purchased from the utility at $0.10 per kWh and if the motor operates for 8,000 hours per year, the annual energy savings saved is approximately $800 per year per kW. If this motor can be operated at 60% speed, applying a VFD to this motor will reduce electrical energy consumption by approximately 400 kW — or $320,000 per year. DC drives have historically been used for applications that require precise speed and torque control, but due to improved AC VFD technology and declining costs, few applications still require DC drives and motors with their higher upfront and maintenance costs.

MEDIUM VOLTAGE VFDS VS. SOFT-STARTERS

Motors generally exhibit high inrush currents when started. The current falls to normal levels after the motor reaches full speed a few seconds later. Inrush currents can play havoc with plant electrical distribution systems, and can also result in very high demand charges from the electric utility.

Demand charges are typically assessed based on the greatest instantaneous power usage — a figure that can be quite high if a large motor is started at full speed. One method of reducing the magnitude of inrush currents and the resultant stress on the motor is to use a soft-starter that electrically reduces voltage to the motor for a few seconds before switching to line voltage. Soft-starters cannot vary motor speed, so they are not an alternative to a VFD in most applications.

VFDs are inherently soft-starters because VFDs ramp the voltage to the motor and limit inrush currents. In this regard, VFDs provide even softer starts than traditional soft-starters.

VFDs can almost always start a motor and will draw significantly less starting current (usually less-than-100%-rated FLA) than soft-starters that still draw up to 300% inrush current.

MEDIUM VOLTAGE VFDS VS. MECHANICAL DEVICES

The common thread of medium voltage VFDs versus mechanical device applications is that with a VFD the motor is operated at the exact speed required to satisfy the actual process flows and load on the motor, and no greater. This is in contrast to solutions that use transmissions, valves or dampers to throttle excess mechanical or hydraulic energy that is generated by the equipment operating at full speed or a fixed reduced speed.

VFDs inherently generate only the mechanical or hydraulic energy necessary to operate the actual load; therefore, medium voltage VFDs will use less energy in almost any given application. With proper design, operating the motor at slower speeds also tends to reduce motor and equipment maintenance requirements. It can also extend operating life, often by years. Additionally, using a VFD eliminated the starting mechanical stress on the motor, which also increases the motor life. In new applications, a motor designed to operate exclusively with a VFD can be less expensive than a motor designed to allow an across-the-line start, because of the benign nature of VFD starting characteristics. In effect, the additional

FAN SPEED APPLICATIONS

Figure 3. Using a reducing coupling and a variable frequency drive can simplify fan speed adjustments.

costs of a VFD are partially offset by the opportunity to use a less-expensive motor.

The electronic nature of medium voltage VFDs can also allow more precise speed control than with mechanical throttling components that can stick or fail. Controlling speed closer to its set point can improve operations by enabling production of better quality products and by increasing plant capacity and reliability.

For example, control valve and fan damper movement can become sluggish over time, moving control further from the set point for longer periods. Installing a medium voltage VFD will move control much closer to the set point, improving operations as well as reliability by eliminating the throttling devices and all of their associated problems and maintenance.

MEDIUM VOLTAGE VFDS VS. MECHANICAL TRANSMISSION METHODS

Mechanical transmissions often are installed between a fullspeed motor and its associated drive equipment. Adjusting the transmission allows the speed of the outlet shaft of the transmission to vary to match load, but the motor will still operate at full speed, with its effective speed throttled by the transmission to match the load. This causes the motor to expend more electrical energy than if operated at the speed required by the load. The extra energy is dissipated in the transmission, and thus wasted.

Approximately 10% energy savings are typically associated when a mechanical transmission is replaced with a VFD. The electrical energy savings associated with a 2,000 kW load is therefore $800 per year per kW, or approximately $160,000 per year.

In addition, VFD operation generally reduces the complexity and sophistication of the mechanical transmission, and can actually eliminate the need for a transmission in some applications. Although most applications require operation at lower-than-rated motor speed, some VFDs are capable or operating at frequencies up to 450 Hz, or a motor speed of up to 22,000 rpm. In these cases, the complex transmission can be completely eliminated; the maintenance costs associated with these devices are also eliminated.

For example, a fan can be throttled between 100 and 400 rpm by using an 1,800 rpm motor with a hydraulic coupling that can adjust the speed of its outlet shaft speed and, hence, fan speed. This mechanical configuration could be simplified by using a reducing coupling and a VFD. In some instances, elimination of the coupling would be possible by directly coupling a motor operated by a VFD.

There are many such pump, blower and fan applications that use mechanical transmissions to vary equipment speed. However, many major pieces of equipment in the mining industry (see Table 1) deserve special scrutiny because (depending upon application) medium voltage VFDs can improve speed control, allow implementation of torque control, improve product quality, reduce inrush current and smooth motor starts, lengthen maintenance intervals and lower the energy costs associated with operating the equipment.

In new applications, the cost savings associated with eliminating engineering, purchasing, installation and maintenance of the mechanical transmission can offset much — or even all — of the cost of the medium voltage VFD, in addition to occupying less space in the plant.

In existing applications, energy savings and operational improvements should be evaluated to justify replacing the existing motor starter and mechanical transmission with a medium voltage VFD.

MEDIUM VOLTAGE VFDS VS. MECHANICAL THROTTLING DEVICES

Perhaps the most common alternative solution to medium voltage VFDs is where mechanical equipment is directly connected to an electric motor operating at full speed, and the load is varied using a throttling device (such as a control valve or damper) to control air or fluid flow in order to satisfy the process demand. Pump, blower and fan installations are often configured in this manner.

Operating a motor at full speed and then dissipating a portion of that energy across a throttling device is inherently wasteful. Nonetheless, this scenario is common practice in industry. In many cases, this is due to a continuation of past practices that may have made sense many decades ago when medium voltage VFDs were relatively expensive and power was cheap.

But in today's world, using a medium voltage VFD to operate the same equipment at a lower speed such that its energy output exactly matches the load offers a very quick and reasonable payback in nearly all cases.

Because the discharge of pumps, blowers and fans powered by medium-voltage motors is typically throttled, this equipment and associated motors are routinely oversized to account for maximum operating conditions, plus some contingency for abnormally high loads. Oversizing increases initial and operating costs, often by substantial amounts, particularly as the equipment and the motor are often quite large.

For example, a single-speed medium-voltage motor with mechanical throttling may need to be sized at 1,200 kW to handle a nominal 1,000 kW load. The motor will, of course, operate at full speed, with the throttling device matching the load to the process requirements and dissipating energy.

Applying a VFD in this case could reduce the required motor size to 1,000 kW and allow operation at about 70 percent of load, or 700 kW. The VFD would thus save 500 kW per hour — equating to a savings of $400,000 per year, assuming 8,000 hours of operation and power purchased at $0.10 per kWh.

Mechanical throttling devices are subject to mechanical degradation that tends to increase the hysteresis inherent to their design. For example, a damper mechanism may increasingly stick over time. These degradations further reduce performance and increase costs.

Utilizing a medium voltage VFD instead of a throttling device not only decreases the inherent hysteresis to the speed resolution of the VFD, but also eliminates mechanical degradation, reducing required maintenance while improving performance.

MINING EQUIPMENT APPLICATIONS

Figure 4. Medium voltage VFDs used in mining applications can improve speed control, lengthen maintenance intervals and lower the energy costs associated with operating the equipment.

ADDITIONAL BENEFITS

Depending on the particular application, medium voltage VFD installations can exhibit other benefits that may be difficult to quantify. Although these benefits don't apply in all situations, they can be significant in certain applications.

For example, synchronous transfer allows a single VFD to control the speed of multiple motors, which can not only reduce cost but also simplify operation and maintenance. Savings can be substantial as only one VFD needs to be purchased, installed and maintained. Of course, these benefits only apply when just one of the multiple motors is needed at any instant in time.

Sinusoidal VFD outputs can reduce the wear and tear on the motor, which can extend its useful life.

REFERENCES

1. Spitzer, David. Variable Speed Drives: Principles and Applications for Energy Cost Savings, Third Edition, ISA Press.
2. Harshman, Mark. "Variable-Frequency Drives Upgrade Reactor Circulating Pumps." Power Magazine. <http://www.power-mag.com/variable-frequencydrives-upgrade-reactor-circulating-pumps>.
3. Hebert, Daniel. "Soft Starters versus VFDs." Control. <http://www.controlglobal.com/articles/2010/vfd1005>.
4. Schiller, Kevin. "Medium-Voltage Drives to See Accelerated Growth Globally in 2013, Despite European Market Contraction." IHS Electronics & Media. <http://www.imsresearch.com/press-release/ Mediumvoltage_drives_to_see_accelerated_growth_globally_in_2013_despite_European_market_contraction&cat_id=115&type=LatestResearch>.
5. Rossiter, Steve. "Benefits of Variable Speed Drives." Energy Management Corporation. <http://www.emcsolutions.com/article_vfd_benefits.html>.

This benefit becomes more significant as the quality of the VFD output improves, and as the motor's operating hours increase.

Finally, purchasing the VFD and the motor from the same manufacturer can extend warranty life, as some suppliers will extend warranty periods in these cases, and can decrease operating costs due to a closer match between the VFD and the motor.

UTILITY REBATES

The economic and operational advantages achieved by applying VFDs to medium-voltage motors is overwhelming in many cases, particularly when utility rebates are taken into account.

For example, a project with motors totaling 10,000 Kw can result in a one-time rebate of almost $500,000. To further quantify, consider this application where a utility in Texas needed to choose between two options for the operation of eight 10,500 Hp induced draft (ID) fans, four per each for two new 850 MW power plants.

Option A would run each fan and its associated motor at full speed, and control the air flow output with vanes. Option B would use a VFD on each motor to control fan speed as required to deliver the precise required air flow. Each fan would be driven by a medium-voltage motor — 13.8 kV in the case of Option A and 6.6 kV for Option B.

Option B would cost $5,751,680 more to implement, but would result in annual energy savings of $5,524,887, equating to an energy-only payback period of just 1.04 years (Table 3). These savings don't take into account utility rebates, which vary significantly but are generally quite substantial. They also don't take into account the other benefits delivered by VFDs as detailed in this article.

Applying VFDs to medium-voltage motors provides the ability to do the same amount of work with less energy while increasing operational flexibility. Even modest speed reductions can result in large energy savings due to the relatively large motor sizes involved — especially when applied to centrifugal equipment.

In addition to energy savings, medium voltage VFDs allow control closer to set point, which improves quality, reduces raw material usage and increases throughput.

Finally, reliability is improved because the motor and its associated equipment is controlled to a speed that closely matches the load, which minimizes wear and tear as opposed to other solutions.

Achieving these significant gains is a multifaceted activity that can involve people knowledgeable in the electrical, mechanical, instrumentation, utility, chemical and hydraulic disciplines as well as plant operations and management.

Medium voltage VFDs are typically superior to alternative technologies. They should be considered for every medium voltage motor because even modest energy and operational savings can cost-justify VFD purchase and installation.

ECONOMIC ADVANTAGE

	Option A	Option B
No. of Fans	8	8
Control Method	IVC	VFD
Average / Year	$16,590,770	$11,065,883
Delta Energy	BASE	$5,524,887
Delta First Cost	BASE	$5,751,680
Energy-Only Payback (Yrs.)	BASE	1.04

Table 3. Option B would cost $5,751,680 more to implement, but would result in annual energy savings of $5,524,887, equating to an energy-only payback period of just 1.04 years.

MARK HARSHMAN is principal engineer for Siemens Industry. He can be reached at info.us@siemens.com.

Consider Changing the Speed not the Pump

Don't reflexively resort to brute force to provide enough head

By Andrew Sloley, contributing editor

THE STANDARD response to insufficient head for a centrifugal pump is to put a larger impeller in the pump, add pumps in parallel, or replace the pump with a larger one. However, solutions involving less brute force may do the trick.

Consider the product pipeline system from a small plant to a pipeline network (Figure 1). The pump handled either one of two feeds: a light stream (0.76 specific gravity) or a heavy one (0.91 specific gravity). The feeds were never mixed together. Due to downstream pipeline system constraints, the operation had to maintain a continuous feed rate of 540 gpm. The amount of time on each feed was varied as required.

Changes to the feed blending were being made upstream. The result would be that the total average feed rate to the pipeline would increase a slight amount. The relative amounts of the products also would shift, to a greater amount of light feed. The most significant alteration was a boost in heavy feed viscosity from 11.4 cP to 14.1 cP.

Normally, relatively small changes in viscosity have only modest impacts in plant piping systems. However, two factors combined here to make the viscosity change extremely important. First, the pipeline is long, extending for 32 miles — so, even small effects count for a lot. Second, the system has a drag reducing agent (DRA) added to cut pressure drop.

A DRA decreases pressure drop by making the laminar flow regime more stable. This extends the Reynolds number range for laminar flow. Laminar flow has much lower friction factors (and pressure drops) than turbulent flow. In laminar flow, pressure drop is proportional to viscosity. This meant that the viscosity change of the heavy feed from 11.4 cP to 14.1 cP would result in an increase in head losses in the pipeline system by 24% in laminar flow.

The final analysis of the flow system was much more complex because DRA performance was tested on the new feeds and the exact DRA blend and

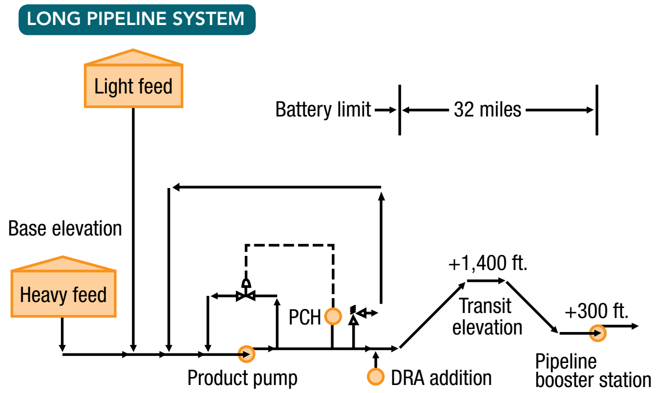


Figure 1. The length of the pipeline means that small fluid changes have a big impact.

concentration was changed to optimize overall performance. However, at the end of this analysis, it was more than abundantly clear that the pump still was significantly short of the head required.

Naturally, at this point, brute force solutions were discussed. However, a variety of factors kept them from being feasible or favorable. The pump already had the maximum size impeller. Reducing the flow rate with parallel pumps has little impact, as moving back on the pump curve (Figure 2) only increases the pump head by 150 ft., which isn't enough. Replacing a large pump such as this is an expensive proposition. Setting the pump operation based on the heavy product also incurred a large operating cost. The light product, having a viscosity of 0.65 cP, required much less head. Therefore, as a result, the existing installation for many years had been wasting power whenever it was pumping light product.

Pump speed is one other factor that can be modified to change pump performance. Pump head varies with the square of pump speed. The affinity law for total dynamic head (TDH) and pump speed (N) in rpm is:

$$\frac{TDH_2}{TDH_1} = \frac{N_2^2}{N_1^2}$$

This relationship holds when pump efficiency remains constant.

Pump speed can be varied by one of two methods: either through use of adjustable-speed or multiple-speed drivers. With adjustable-speed motors, an electronic control enables rpm to be changed to any point that falls within specific ranges. In contrast, multiple-speed motors can operate at more than one particular setting but aren't continuously variable between those speeds.

PUMP CURVE

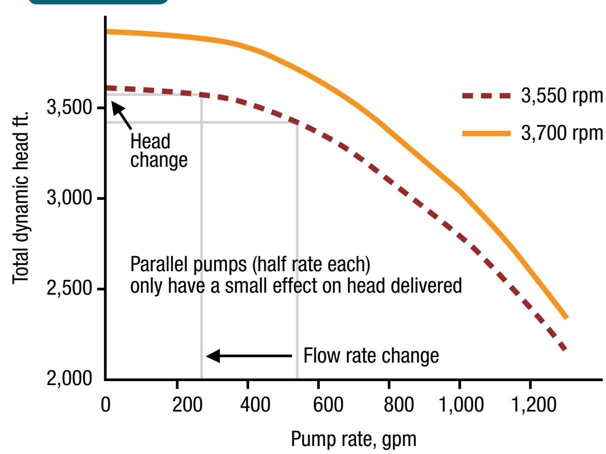


Figure 2. Matching speed to the head requirements of the feed provides fast payback.

For applications that must handle two vastly different feeds, a multiple-speed drive often provides a very good fit. However, here, the extra head required for the heavy feed didn't match up well with available standard speed combinations. Therefore, an adjustable-speed driver was selected instead. This unit typically operates at either 3,550 or 3,700 rpm. The power savings that accrue when the light product is being transfered more than make up for the lower efficiency of the adjustable-speed motor system. Indeed, the motor replacement would have offered a modest, but justifiable, return simply as an energy-saving project. Factoring in avoided capital costs made the overall economics very attractive.

By **ANDREW SLOLEY,** contributing editor

Asloley@putman.net