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To Succeed, Control Your Speed

Using MV VFDs to eliminate waste and promote efficiency, reliability and quality.

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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.

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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 percent of its full load capacity. By matching the motor speed to the reduced capacity of 70 percent, a 50 percent 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.

Big Motors, Bigger Savings

A VFD is an electronic device that electronically alters the frequency and / or 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 / or 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 percent energy use reduction in a motor consuming 50 kW is 20 kW. The savings associated with a 20 percent 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.

Leading Medium Voltage VFD Applications in Major Vertical Industries	
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

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 single-speed 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.

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.

Advantages of Medium Voltage VFDs over Alternative Solutions
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

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 percent rated FLA) than soft-starters that still draw up to 300 percent inrush current.

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

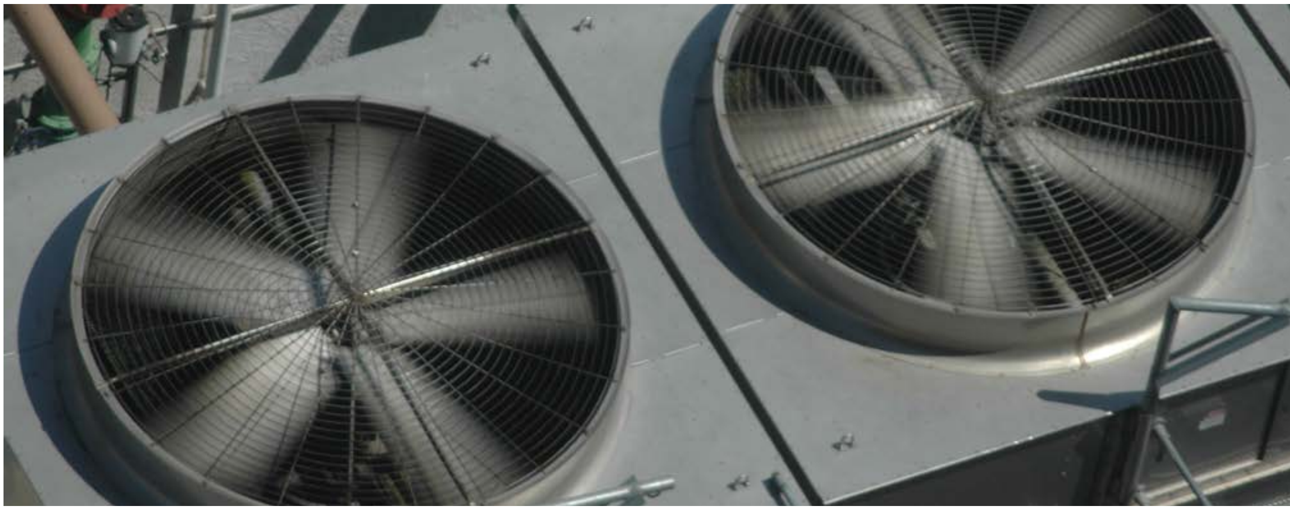
Starters that electrically alter the motor winding connections can allow the same motor to operate at two speeds—typically full speed and 50 percent speed. Operation at the reduced speed when the motor is lightly loaded can reduce the electrical energy consumption of the motor. This can represent significant 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.

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 percent 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 percent speed, applying a VFD to this motor will reduce electrical energy consumption by approximately 400 kW—or $320,000 per year.



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 and / or hydraulic energy that is generated by the equipment operating at full speed or a fixed reduced speed.

VFDs inherently generate only the mechanical and / 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 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.

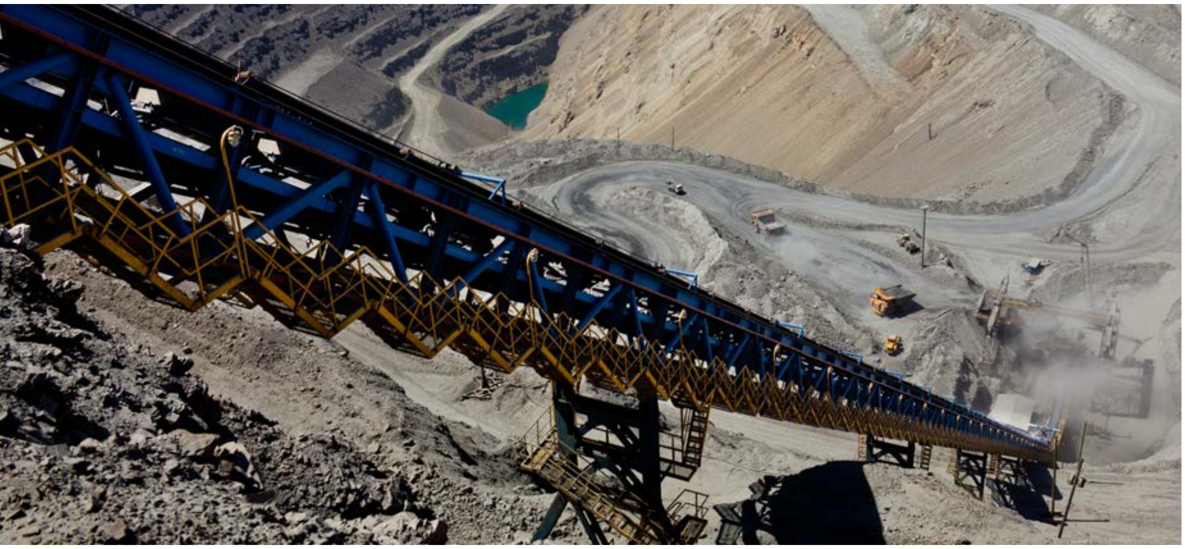
Medium Voltage VFDs vs. Mechanical Transmission Methods

Mechanical transmissions are often installed between a full-speed 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 percent 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.

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. 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.

Conclusion

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.

Energy-Only Payback		
	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

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.

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