en•er•gy ('e-n&r-jE) – the vigorous exertion of power

Reducing energy costs and increasing energy efficiency is

ALL ABOUT POWER

Trying to figure out how to cut more costs out of your operation?

The following series revisits how variable frequency drives (VFDs) may help you reduce your energy costs and improve your operating performance, and includes some case studies of pump and rotary equipment applications that use VFDs.

Variable Frequency Drives

Achieving Energy Efficiency and Maintaining Power Quality

Jeff Theisen, Rockwell Automation

Talk about phenomenal potential for energy savings: Motor systems consume approximately 63 percent of the $33 billion spent each year on electricity by domestic manufacturers. More than half of these motors are used in either fan or pump applications. This is why so many manufacturers are looking at VFDs to reduce the power consumed in fan and pump applications.

A few decades ago, manufacturers assumed that energy costs were simply uncontrollable. Not any more. That thinking became outdated with the advent of variable speed drives and power-monitoring technologies capable of making energy a manageable expense – one that can be controlled by adjusting key processes to use less energy.

The ability to save energy is a given in industrial settings today. Tools and techniques to limit energy expenditures now include motor controllers, software and power monitoring, and control devices capable of reducing energy costs and helping manufacturers control expenses better than ever before.

Fan Applications

As a rule, energy consumption in a fan or pump application varies by the motor's cube of speed, also called centrifugal load.

For example, if the speed on a fan's motor can be decreased by half, the energy used to power the motor actually decreases by 7/8. This equation, which can also be applied to pump operations, mathematically illustrates the point: $(1/2)^3 = 1/8$.

Most fan applications do not require the full amount of air movement that fans are designed to produce. So, to vary airflow, fan applications use methods such as:

- cycling (generally used in residential settings, not applicable in industrial settings)
- outlet dampers
- variable inlet vanes
- variable-speed drives

In industrial settings, variable speed drives are generally the most effective means of controlling energy use because they control actual motor speed. Inlet vanes and outlet dampers only control the amount of air an applica-

Cubic Feet per Minute (CFM)	Duty Cycle	Horsepower (HP)	Weighted HP
100	10	35	3.5
80	40	35	12.4
60	40	31	12.4
40	10	27	2.7
		TOTAL =	32.6

Chart 1. Outlet Dampers

Cubic Feet per Minute (CFM)	Duty Cycle	Horsepower (HP)	Weighted HP
100	10	35	3.5
80	40	18	7.2
60	40	7.56	3.024
40	10	2.24	0.224
		TOTAL =	13.948

Chart 2: Variable Speed Drives

tion receives, not motor speed.

Charts 1 and 2 show the actual amount of energy used when controlling air flow using either outlet dampers (Chart 1) or variable speed drives (Chart 2).

The figure in the right-hand column of Chart 1, weighted horsepower, calculates the average horsepower used during a fan's on-off cycle, including the power needed to ramp up to speed and slow down.

Weighted horsepower is important because it provides a glimpse into the amount of energy each motor uses to control air flow. Estimating power consumption and potential energy savings requires an actual load profile and a fan curve, both of which vary over the course of fan operation (since fans need to ramp up to speed before operating at desired capacity).

The weighted horsepower of a fan is calculated by the percent of time a fan operates at a given power point. Calculations are summed to produce the weighted horsepower that represents the fan's average energy consumption.

Similar calculations can provide weighted horsepower figures for variable speed operations in Chart 2. However, because the fan curve does not have enough information to read all horsepower values for operating points, formulas from Affinity Laws must be incorporated into the calculation.

The first point is obtained from the fan curve: 100 percent flow equals 100 percent speed, which equals 35-hp. The flow formula Q2/Q1 = N2/N1 can be substituted into the horsepower formula, $HP2/HP1 = (N2/N1)^3$ as follows:

When Q1 = 100 percent and HP1 = 35 HP, Q2 and HP2 have the following values:

Example: $(Q2/Q1)^3 \times HP1 = (80/100)^3 \times 35 = 17.92$

Q2 –	80%	60%	40%
HP2 –	18	7.56	2.24

Sufficient information is now available to calculate weighted horsepower for variable speed operations.

In the examples outlined in Charts 1 and 2, the outlet damper application has a weighted horsepower of 32.6, which is significantly higher than the variable speed drive's 13.948 weighted horsepower.

In a hypothetical situation where this same fan application is used 730 hours per month, with electricity costs averaging $0.07 per kWh, the dampered fan incurs more than $1,242 in energy costs. Meanwhile, the drive-controlled fan uses approximately $531 in electricity, representing a significant cost savings over the outlet damper system.

Pump Applications

Variable speed drives also contribute to energy savings for pump applications.

Controlling the speed of a pump is accomplished either through throttling the motor (mechanically changing the pump's speed) or employing a drive to control the motor's speed – thus controlling the amount of energy used by the pump motor.

Just as certain calculations can show the energy savings possible in fan applications, similar calculations can be used to estimate energy savings for pumps.

Generally, when pump speed is reduced by 20 percent from 100 percent, motor horsepower reduces by nearly 50 percent, as does Brake Horsepower (BHP) – the indicator of how much energy a pump motor is using. BHP is equivalent to the power necessary to do the work at a particular speed divided by the motor efficiency.

For example, a motor/pump is running on a system across the line that flows 450-gpm. However, when the demand is only 225-gpm the flow is reduced by partially closing a valve. According to a pump curve, the pressure increases from 180-psf to 200-psf, the efficiency reduces from 76 percent to 60 percent, and the horsepower requirement reduces from 30-hp to 26-hp. This same application on a variable speed drive will reduce the horsepower to 3.75.

Assuming a 225-gpm flow is required for 3000 hours a year at $0.07 per kWh, the comparison of costs for throttling versus a variable-speed drive system is dramatic:

It's important to note that the above example assumes the pump system does not have a static head, or great resistance to flow, as is often associated with long pipes or pump length that rises significantly. The higher the resistance to flow, the lower the potential energy savings. Motor and drive efficiencies were also not considered.

In addition to taking advantage of the Affinity Laws, another benefit includes relieving the stress on the mechanical system by not starting across the line – as opposed to a drive ramping up to speed. Tighter process control can also be realized with the correct drive utilization.

Harmonics and Power Quality

Power quality is an issue in all facilities using large amounts of energy, including harmonics often associated with variable frequency drives.

Harmonics are deviations from the sinusoidal fundamental AC line voltage and current. While most electrical power in North America operates at a frequency of 60 hertz, a harmonic frequency operates at a multiple of its fundamental frequency. So, in a 60-hertz system, the second harmonic would be 120-hertz, the third would be 180-hertz, and so on.

IEEE 519 ensures power quality by limiting the maximum current distortion caused by non-linear loads to limit the voltage distortion they would create, minimizing the likelihood of equipment failure due to the distortions.

In other words, limiting the harmonics on electrical lines, both in and around facilities, improves power quality.

The addition of harmonics to the sinusoidal fundamental current or voltage creates distortion. The greater the amplitudes of harmonics present, the greater the distortion in the electrical waveform. What this means, very simply, is that whenever a voltage or current does not look like a perfect sinusoidal waveform, it contains harmonics.

Unlike an AC motor operating across the power line, the current drawn from a distribution transformer feeding a typical AC drive is far from a sinusoidal waveform. This occurs because the drive is taking current from the transformer only during certain times of the cycle to convert the AC line voltage to a fixed DC voltage within the drive.

The drive then pulse-width modulates fixed DC voltage into variable-frequency voltage for the motor. The AC-to-DC conversion is what causes the harmonics. Current flows only during part of the cycle and is off during other parts of the cycle, creating an odd-looking current waveform. The distorted current creates voltage distortion.

Several methods and products can reduce line current harmonics created by drives. Even though the addition of line reactors or passive filters can help reduce the current harmonics, in some conditions they also will reduce the DC bus voltage within the drive in full-speed, full-load conditions. This prevents the drive from being able to provide full power to the motor, limiting the power out of the motor to about 95 percent of its nameplate rating.

Throttling

26 hp x 0.746 = 19.396 kW

19.396 kW x 3000 hrs. = 58188 kWh

58188 kWh x $0.07 = $4073.16

Variable speed drive

3.75 hp x 0.746 = 2.97 kW

2.97 kW x 3000 hrs. = 8392.5 kWh

8392.5 kWh x 0.07 = $587.48

Savings

$4073.16 – $587.48 = $3485.68 savings in energy costs using variable-speed drives

Chart 3. Comparison of Savings

Why install a 100-hp motor only to have its capability limited to 95-hp, especially under peak demand conditions? This is why multi-pulse solutions are a better fit for most situations, since no de-rating is necessary and such solutions are generally less expensive than other mitigation methods.

Manufacturers and users of industrial motors have more control over their energy costs today than they may realize. Likewise, power quality issues can also be mitigated with the technology that improves each year.

Regenerative drives that put excess energy back on electric lines are available, and drives are being developed with more and more robust features, such as positioning capabilities.

All of these features make drives an integral part of an energy savings program – far beyond the simple speed controllers they used to be.

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Jeff Theisen is a senior drive application engineer at Rockwell Automation, Drives Group, 6400 W Enterprise Drive, Mequon, WI 53092, 414-382-2000, www.rockwellautomation.com.