Variable Frequency Drives and Energy Savings

It's more than just fan and pump applications

by: Stephen Prachyl

SIEMENS

When discussing energy savings and variable frequency drives (VFD) the attention often focuses on a centrifugal fan or pump application. However, you should not overlook other applications which also have large potential energy savings and energy recovery. Applications involving regeneration, power factor correction, common bus applications or a combination of the three can also quickly achieve a significant reduction in energy use.

Centrifugal Applications

When a centrifugal fan or pump is used with mechanical flow control, converting the application to an adjustable speed AC drive can reduce energy costs by 10 to 60 percent if the fan or pump is designed to operate between 40 to 80 percent of full speed. This usually provides a return on investment which is in the 6 to 24 month time frame. These savings are derived from 2 components:

1. The Laws of Affinity, which shows an operating range that produces the most flow or pressure per horsepower (see figure 1).
2. The removal of any mechanical flow device that limits the flow of a fan or pump while the motor turns the application at a fixed speed (see figure 2 and 3).

Moreover, the AC drive installation continues to save energy for many years after the initial payback period.

The Laws of Affinity state:
Flow is proportional to shaft speed
Head (pressure) is proportional to the square of shaft speed
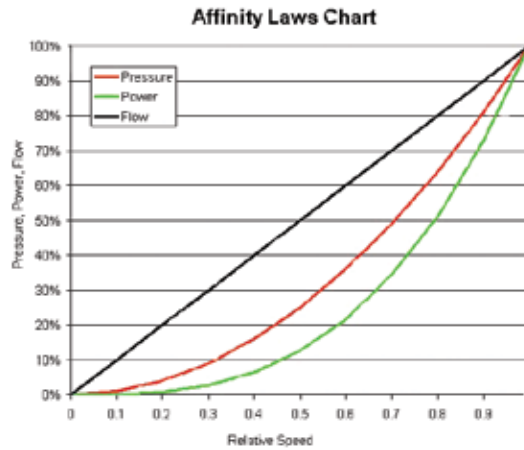Power is proportional to the cube of shaft speed

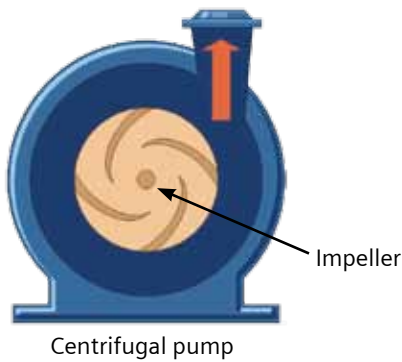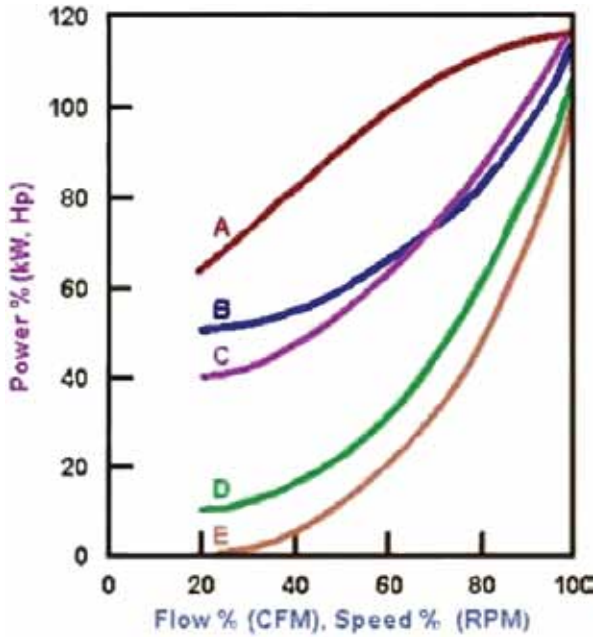Centrifugal pump

Affinity Laws Chart

Figure 1

When comparing the different methods of mechanical flow control it is clear to see only a VFD gets close to the maximum efficiency of the theoretical fan curve (see Figure 2) or Pump Flow (Figure 3).

Curve A – Discharge Dampers
Curve B – Variable Inlet Vanes
Curve C – Eddy Current Clutch
Curve D – Variable Frequency Drive
Curve E – Theoretical Fan Curve

Figure 2
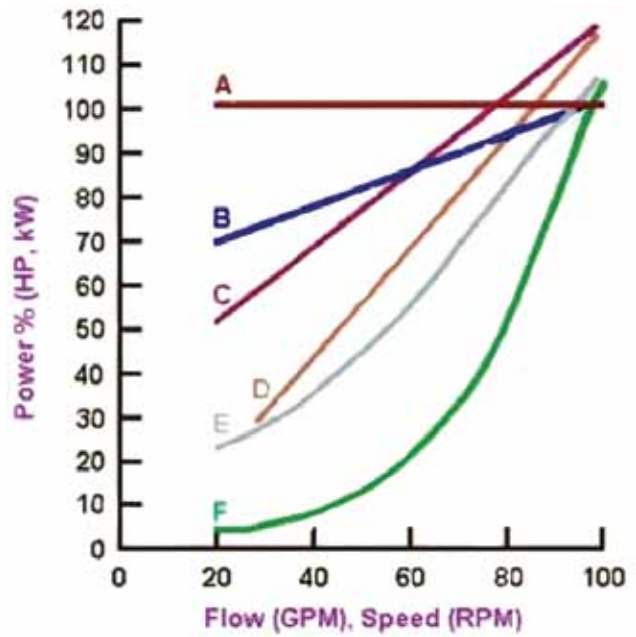
Curve A – Diverting Valve
Curve B – Throttling Valve
Curve C – Hydrostatic Drive
Curve D – Mechanical Drive
Curve E – Eddy Current Clutch
Curve F – Variable Speed Drive

Figure 3

Regeneration

An AC motor may act as either a motor that turns electrical power into mechanical power or as a generator that converts mechanical power into electricity. It all depends on whether the motor is turning a machine that requires power to turn the load or if the load will, at times, overhaul the motor. This overhauling condition may exist in several types of applications:

1. **Periodic Deceleration:** When a load is stopped quickly and the inertia of the load wants to keep turning such as a large drum. (In this case the cycle time, or how many times the load is stopped over time, as well as the magnitude of the stopping power required determines how much energy can be recovered)
2. **Continuous Deceleration:** When a load such as a decline conveyor operating under the influence of gravity will overhaul the motors speed and the drive is used to regulate the speed in a slower controlled fashion than what the natural physics of the application would produce. This would also be a general description for a hoist and crane application. (See figure 4)
3. **System Tension/Holding Torque:** When two sections of a machine are used to create tension on the material between them such as on the metal strip in a strip mill. The two sections may be running at the same speed, but the process may require a certain amount of tension on the strip to run properly. This means the lead section will run in the forward direction and pull the strip and the following section will also run in the forward direction and at the same time provide the needed torque in the reverse direction of the strip thus creating the proper tension.

In each of these examples the motor and drive combination has the ability to **"recover"** the electrical power produced by the motor that is acting as a generator and sent by the drive to the utility company. How much energy is saved depends on the application, but it can be significant. One such application where significant savings can be recovered is a gearbox test stand. When the gearbox is tested, a single drive and motor combination is used to turn the gearbox while another drive and motor is used on the other end of the gearbox to simulate the load. Done correctly this application will operate using a very low amount of total energy because the amount of energy used to turn the gearbox is the same amount of energy that is recovered from the simulated load on the gearbox, minus the losses in the system. The one critical item to determine if the application is regenerative or not, is whether the load is trying to turn the motor (regenerative recovery) at any time or if the motor is being used to turn the load.
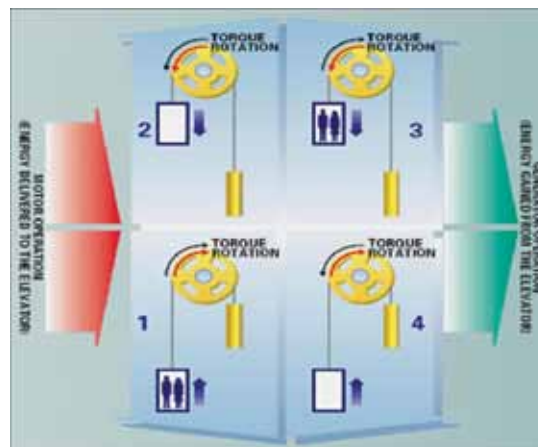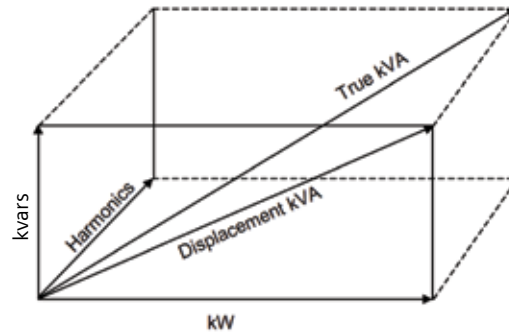

Figure 4

[1] Overhauling is a condition where the mechanics or physics of the load mechanically cause the motor to turn faster than the speed the drive is commanding the motor to turn.

Power factor

AC power has two basic components: voltage and current. When these two components are not in sync (called Power Factor Displacement: see figure 5), AC power is wasted through inefficiency. Moreover, when the AC power has a high level of harmonic content called Power Factor Distortion, the displacement and distortion are multiplied by each other, which further decreases efficiency.

Total PF = Distortion PF x Displacement PF

A graphic example of Total Power Factor:

Therefore, getting the Power Factor Displacement close to unity is very important. (See Figure 6).
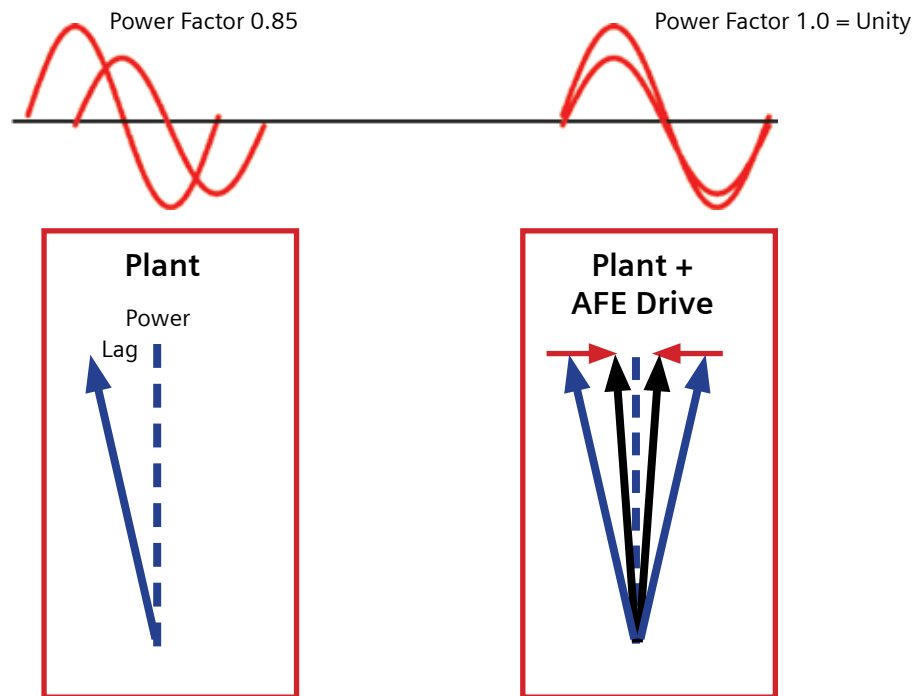

Figure 5   Figure 6

If you have every received a bill from a power utility company penalizing your plant loading there is a good chance you have a Power Factor Displacement issue. Even if the power company does not charge a penalty to the user, the user may be paying for the wasted power.

Power Factor Displacement Example Calculation   **Power Factor Displacement Model**

$kW = kVA * pf$
3 phase power(kW) = (1.732*Volt*Amp)(Power Factor)

Power Factor = cos (θ)
kvar = Wasted Power

Example: 0.85 Power Factor
100kW 480VAC, 3 phase Motor Load
*100kW / (480V*1.732* 0.85) = **142 Amps***
kVA = kW / PF = 100kW / .85 = <u>117.65</u> kVA
*q = cos-**1** (0.85) = 31.8°*
*kvar consumed = kVA*sin(q)=117.65 kVA*sin(31.8°) = <u>**62.1 kvar = wasted power**</u>*

Example: 1.0 Power Factor
100 kW 480VAC, 3 phase Motor Load
*100 kW / (480V *1.732*1.0) = **120 Amps***
*kVA = kW / PF = 100kW / **1** = <u>100</u> kVA*
q = cos-1 (1) = 0°
*kvar consumed = kVA*sin(q) = 100 kVA*sin(0°) = <u>0.0 kvar</u> = **<u>no wasted power</u>***

While each utility may charge differently, two common ways that utilities charge are by kVA (Lower PF = higher Amps) or by kW with a PF penalty.

Examples of Utility Power Factor Penalty clauses:

If power factor is less than 90 percent, the measured kw demand will be multiplied by the ratio of 90 percent divided by the actual power factor. (Reference source: GoColumbiaMo.com)

100kW motor with 0.85 Power Factor (100kW * 0.9) / (0.85 PF) = 105 kW
In this case the increase in cost is 5 percent of your bill, in addition to, the cost of the wasted kvar as pointed out in the previous example.

Adjustment of demand for power penalty clause

Demands will be adjusted to correct for average power factors lower than 95 percent. Such adjustments will be made by increasing the measured demand l percent for each 1 percent or major fraction thereof by which the average power factor is less than 95 percent lagging. (Reference source: *www. clarkpublicutilities.com.)* In this case, the penalty increase is 1 percent for every 1 percent the power factor is below 0.95 in addition to the cost of the wasted KVAR as pointed out in the previous example.
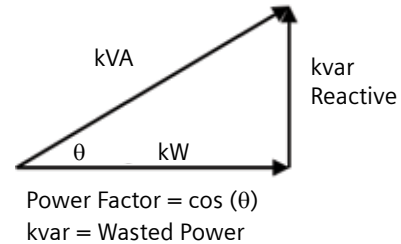
While power factor correction devices, such as capacitors and filters, exist on the market today there is an often overlooked method for correcting power factor displacement. An AC variable frequency drive, used with an AC motor will operate at about 0.95 power factor which is typically 5 to 10 percent better than an across-the-line motor. Furthermore, there is at least one Active Front End (AFE) AC drive available in the market today that has the ability to adjust its' power factor from 0.8 leading to 0.8 lagging and which meets IEEE 519 harmonic standards with 4% or less harmonics. (A standard 6 pulse AC drive with a diode rectifier converts input AC voltage to DC bus voltage, with a typical harmonics level of 30 to 40 percent.) This means the drive can improve the present power factor displacement in a facility.

Distortion Power Factor describes the decrease in average power transferred due to harmonics. For a complete description of this see IEEE 1549-2010.

$$distortion\ power\ factor = \frac{1}{\sqrt{1 + THD_i^2}} \quad THDi = Total\ Harmonic\ Current\ Distortion$$

How much this costs and how much can be saved depends on the amount of displacement and distortion that currently exists.

Common bus benefits

When there are multiple drives in one location the common bus system is usually the most efficient way to operate and can incorporate the energy savings and recover concepts that have been previously discussed. However, if there is a regenerative drive and motor section in the system it is ideally suited for maximizing energy recovery and cost savings. The reason is that losses are generated when power is converted from the AC supply to the DC Bus or from the DC Bus to the AC supply. When you have multiple standalone drives, the power must go through two or more AC to DC conversions and two DC to AC conversions (see figures 7 and 8). In a common bus configuration, power only goes through one AC to DC conversion in the motoring direction. When an inverter section of the drive regenerates power to the DC Bus, the power goes straight to another inverter, which is motoring via the common DC Bus link, and does not have to travel through a converter at all. This method eliminates two conversion points where energy would be lost which increases efficiency by two to four percent for each regenerative section. The more sections there are which are regenerative, the more energy savings are accumulated. In addition, when a common bus solution is used with an Active Front End, it will have the ability to do Power Factor Correction, which further increases the savings of a common bus system. The gearbox test stand is a great example of a common bus solution. There is one forward motoring drive motor section and one regenerative drive motor section. In this specific case, the two drive and motor sections were rated at 1000 Amps @ 690VAC each. Yet the incoming AC line and input modules were able to be sized at less than 1000A 690VAC. The reason this is possible is that one of the two sections required 1000A in the motoring or torque producing direction, while the other section that provided the load was able to recover, through regeneration, close to 1000A, less the losses in the system. Therefore, the amps generated from the recovery section almost canceled out the 1000A from the section providing torque to turn the gearbox and the input AC could be sized at slightly larger than the losses of the system, which in this case was roughly 200 Amps at 690VAC. This resulted in a lower installation cost due to the smaller AC to DC section and the application recovered $75,000 per year in energy costs which translates to about a four-year payback.
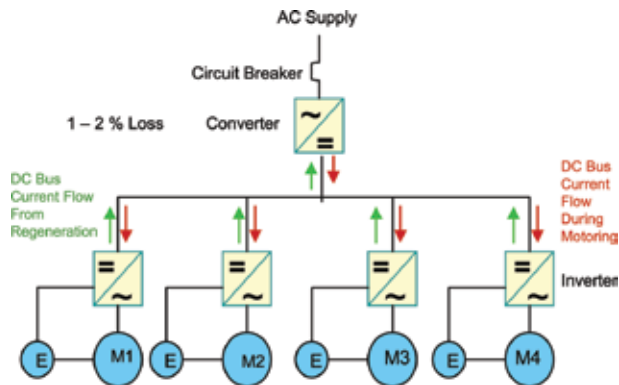
Legend: Red – motoring; Green – regeneration
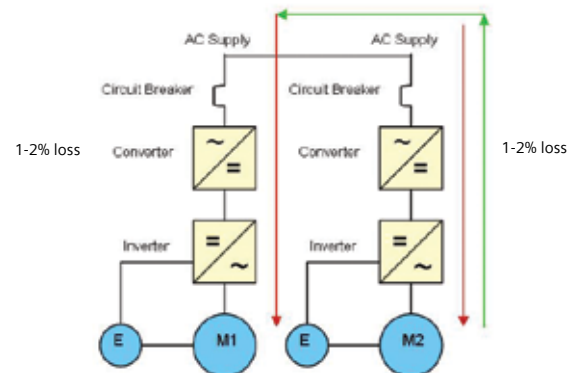
Figure 7 Common bus example

Figure 8 Standalone drives

This application combined the efficiency of a regenerative system in a common bus configuration. If the plant would have had a Power Factor Correction issue, the common bus solution would have been able to accumulate those savings into this total as well.

Total Common Bus savings = Common Bus Configuration + Regeneration + Power Factor Correction

In conclusion, when using an AC drive and motor combination there are many different applications and methods where the energy savings and the energy recovery can be significant. While there is typically a lot of focus on the AC drive and motors' initial installation or retro-fit cost, each application should be reviewed to get the maximum amount of operating cost savings resulting from energy savings and energy recovery. In many cases, the energy savings and operating costs which are saved are much larger than the cost of the installation.

Author Bio:

Stephen Prachyl, is a General Motion Control and Low Voltage Drives Industry Marketing Manager for Siemens Industries, Inc. Stephen has worked in the industrial automation and drives industry for over 25 years with Reliance Electric, Rockwell Automation and currently Siemens Industries, Inc. He received a Bachelors of Engineering Technology Electronics from Texas A & M University and an MBA – Beta Gamma Sigma from Cleveland State University.