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Realizing energy savings in water processing applications using medium voltage adjustable frequency drives

Written by:

Jim Yoho
Regional Sales Manager

Matt Skindzier
Product Manager

John Maurin
Application Engineer

Eaton Corporation
MV Drives
Arden, NC

Why uptime and energy efficiency matter in water processing

Making sure that systems and processes are up and running while improving energy efficiency (and cost) is crucial in water processing applications. During the recent recession, federal and municipal budgets tightened, limiting access to capital across the United States. At the same time, increased awareness of the environmental and economic benefits of sustainable operations is driving changes in industry regulations. Consequently, water utilities have had to quickly adapt to evolving industry regulations and realities by adopting new technologies to control costs and reduce energy requirements. Best practices within the municipal water industry today involve energy conservation, as well as process efficiency and reliability, with a strong emphasis on long-term benefits.

For a typical water treatment plant, electricity accounts for approximately 80% of all water processing costs, and 30–35% of the plant's operating budget. So, it is easy to see why power distribution and motor control practices have quickly migrated toward more efficient technologies. This is true for both new facilities and older processing plants, where equipment upgrades generate substantial efficiency improvements, reduce operating costs, and meet increased capacity requirements. Optimal solutions for new facilities and upgrades to existing plants strive to balance capital investment with long-term operating costs and equipment life.

Adjustable frequency drives control power, reduce cost

By matching power consumption to changing system requirements, adjustable frequency drives are increasingly relied upon to provide steady, efficient power for variable speed applications. Adjustable frequency drives also protect valuable motor and pump assets by controlling power and minimizing trauma placed on the system by starting and stopping pumps. As a result, municipalities can often calculate the return on investment for medium voltage adjustable frequency drives in terms of months, not years.

Adjustable frequency drives are among the most technologically sophisticated methods of motor control and have benefited from years of evolution in motor starting technology. Traditional across-the-line starters apply full voltage to motor terminals, which can sometimes generate high inrush currents, causing stress to mechanical equipment. Reduced-voltage starting has evolved to help manage inrush currents and peak voltages, and is required by some utilities to prevent excessive voltage drops in the supply grid. Solid-state soft-starter technologies have also emerged to further eliminate shock to mechanical equipment, as they reduce the load and torque applied to the motor powertrain during startup. Using SCR technology, soft starters provide a greater degree of control for reduced-voltage starting to help avoid motor coupling and shaft damage, prevent rotor and winding failure, and stop drive belt squeal and breakage. Additionally, reduced-voltage soft-starters offer a wide range of current limit settings, providing greater control flexibility. For pumping processes, in particular, soft starters also help avoid "water hammer" in pipes by reducing line pressure so valves can close gently and prevent a surge wave.

Medium voltage adjustable frequency drives are the most sophisticated means of motor control and have become more prevalent in variable speed applications at water processing facilities. Adjustable frequency drives offer all the protective features of reduced-voltage and soft starters, while variable speed control allows the process to match energy consumption with process demands. With a typical motor duty cycle in a variable speed pump or fan application, the energy savings that results from using an adjustable frequency drive in place of a traditional starter with mechanical speed control (valves, mechanical braking, and the like) can be significant. By matching power consumption directly with process requirements and maintaining optimal operating parameters at all times, the energy savings realized by using adjustable frequency drives can generate investment payback periods of less than two years.

Increasing process efficiency

Water treatment plants typically rely on centrifugal pumps, and maximizing their efficiency yields significant process energy and cost savings. Centrifugal pumps are most efficient when they operate within designed pressure head and flow rate ranges. The pump performance curve (**Figure 1**) illustrates the relationship between a pump's flow rate at full speed and required pressure head. As pump impeller diameter increases or decreases, the pump performance curve shifts up or down, accordingly.

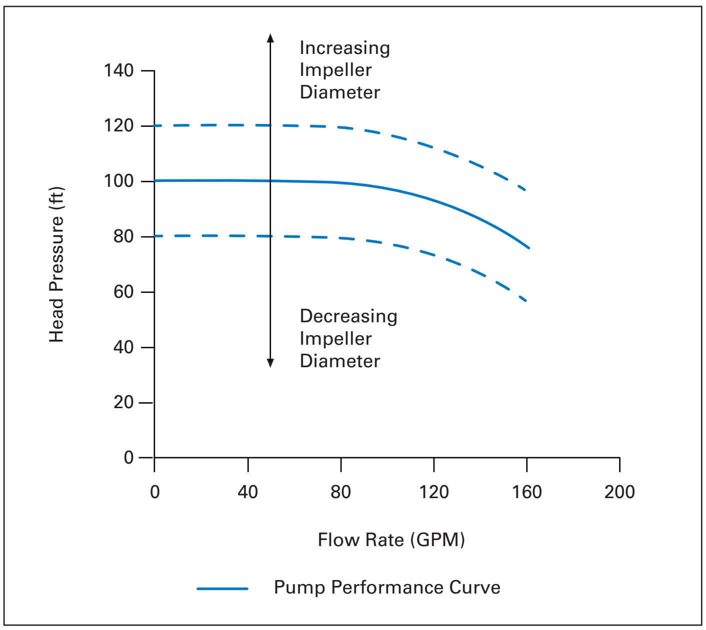

Figure 1. Impeller Diameter Impact on Pump Performance Curve

To determine the most efficient operating point of the pump, it is important to look at the system performance curve, which describes the flow rate that occurs given the system pressure. The system performance curve accounts for the pump design and entire balance of system—including static pressure head inherent to the system and pressure head from friction losses through the pipe and valve system. A pump will operate at its most efficient operating point, or the best efficiency point (BEP), where the pump performance curve crosses the system performance curve (**Figure 2**). In the example below, the pump requires approximately 90 feet (ft) of pressure head to generate a BEP flow rate of 120 gallons per minute (GPM).

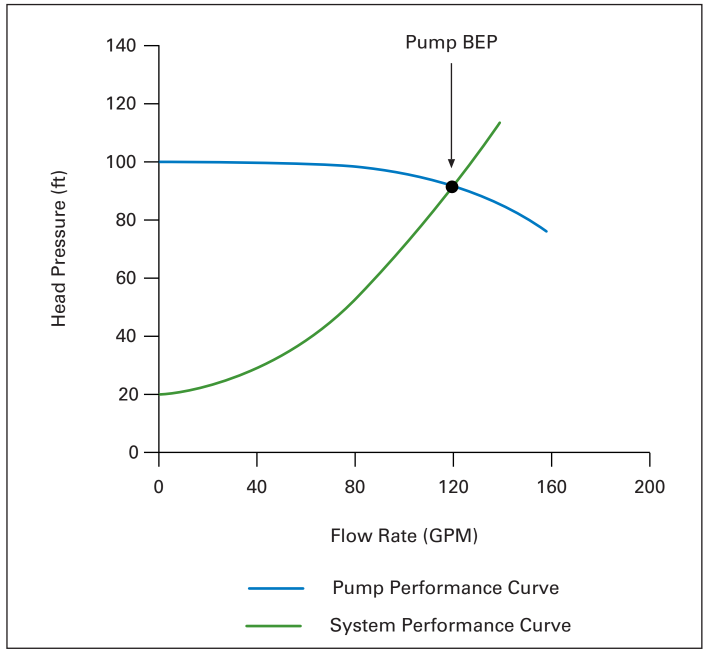

Figure 2. Pump System Best Efficiency Point (BEP)

With more traditional motor control methods using across-the-line starters, 100% of the pump's power is used at all times. Throttling valves are typically used to restrict flow or vary system output, shifting the system performance curve. Note that although flow is restricted, the motor is still operating at 100%—and is consuming power accordingly. Using a throttling valve to control flow is much like driving your car with your foot on the gas and using the brakes to control speed; it is both inefficient and taxing on the system.

Figure 3 shows how partially closing the throttling valve shifts the system performance curve; the pump BEP is shifted inward, indicating that the pump requires a higher-pressure head to achieve the desired flow rate. So, the pump now requires 100 feet of pressure head to achieve a flow rate of 80 GPM. The energy required to operate the pump at the desired flow rate is proportional to the head pressure required, and is represented by the shaded area.

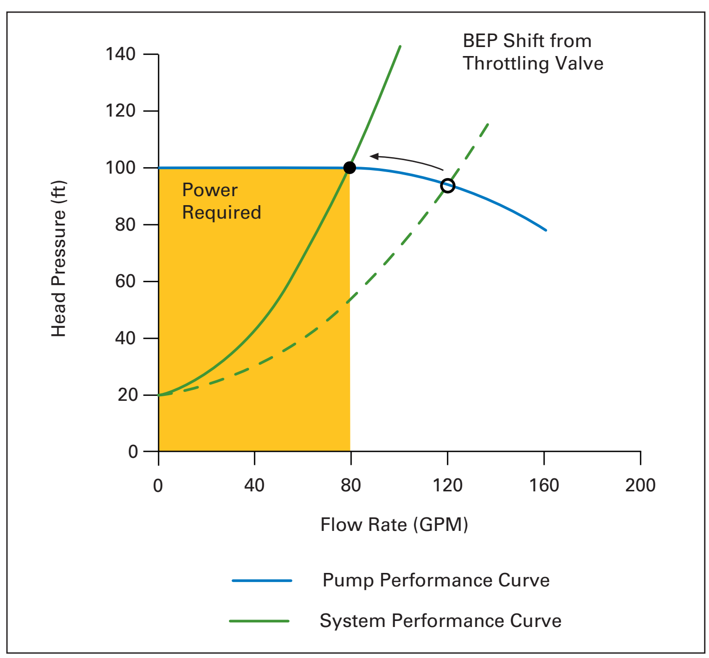

Figure 3. Throttling Valve Impact on Pump System BEP

Applying an adjustable frequency drive to control the process flow rate dramatically reduces the energy required. The drive reduces the rotary speed of the pump impeller, which has the same effect on the pump curve as reducing the diameter of the impeller (as in **Figure 1**). The new BEP (**Figure 4**) is at the intersection of the adjusted pump performance curve and the (unchanged) system curve. Now the amount of energy required to achieve a flow rate of 80 GPM is considerably less.

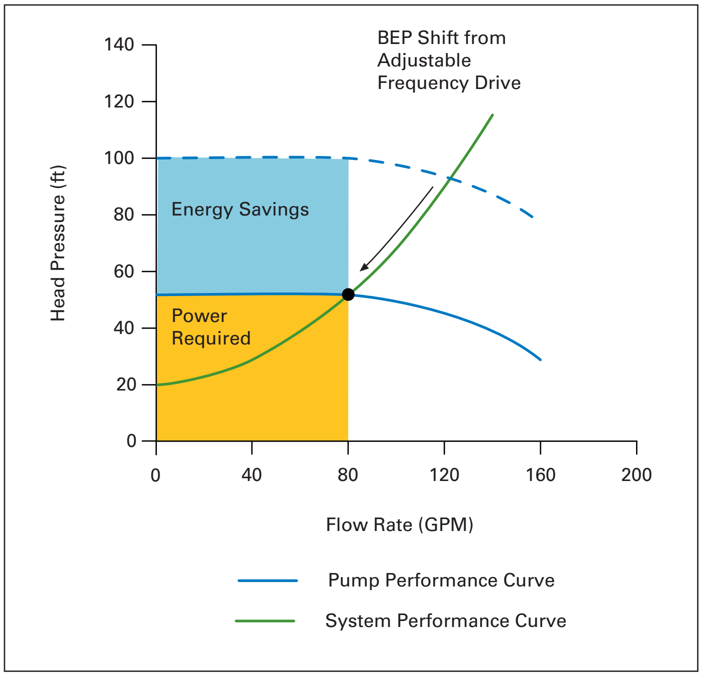

Figure 4. Variable Frequency Drive Impact on BEP

For centrifugal devices, system performance can be determined by using the "Affinity Laws." The Affinity Laws demonstrate the relationship between the rotational speed (RPM), flow rate (Q), pressure head (H), and power (P) for a centrifugal pump. These laws allow you to determine the theoretical load requirements and potential energy savings when using adjustable frequency drives to control a centrifugal pump.

$$\frac{Q_1}{Q_2} = \frac{RPM_1}{RPM_2} \qquad \frac{H_1}{H_2} = \left(\frac{RPM_1}{RPM_2}\right)^2 \qquad \frac{P_1}{P_2} = \left(\frac{RPM_1}{RPM_2}\right)^3$$

Figure 5. Affinity Laws for Centrifugal Devices

The pump flow rate is directly proportional to the rotary speed of the pump or motor. However, the amount of power required by the pump is proportional to the cube of rotary speed. Thus, the power required to operate a pump at 50% speed is only 12.5% of full system power. While the concept of saving energy through reduced power output is widely understood, the affinity laws demonstrate that the power savings from reducing operational speed is substantial—because of the exponential relationship between pump or motor rotary speed and power consumption.

The economics of variable speed control

Despite the high sticker price of a medium voltage adjustable frequency drive, the drastic reduction in energy consumption that is realized as a result of variable speed control can result in significant energy savings. By closely matching power consumption with process requirements, it is not atypical for a medium voltage adjustable frequency drive to return a payback period of less than 24 months. The example below illustrates how this can occur with a typical pump duty cycle.

For the purposes of this example, we assume operation of a 2000 hp AC motor for a typical pumping application. The AC motor has an efficiency of 95% and is controlled by a 2000 hp adjustable frequency drive with a typical efficiency rating of 97%. The facility has an assumed electricity cost of $0.06 per kWh.

For this example, the pumping operation has a duty cycle requiring operation at 50–80% full speed for a majority of the year (see **Table 1**, below), and assumes that the operation is shut down for two weeks per year for regular maintenance.

Table 1. Pump Duty Cycle

% Flow	Time (Hrs)	Time (%)
100	840	10
90	840	10
80	1260	15
70	2100	25
60	1260	15
50	1260	15
40	840	10
30	0	0
20	0	0
10	0	0
Total	8400	100

With no speed control (across-the-line starting), the pump runs at virtually 100% speed for the entire 8400 hours of operation. The total power requirements and resulting energy cost are calculated below.

$$\text{Annual Energy Requirements} = \frac{2000\text{ hp}}{.95 \times .97} \text{ X } \frac{.746\text{ kW}}{1\text{ hp}} \text{ X } 8400\text{ hrs} = 13{,}600{,}434\text{ kWh}$$

At $0.06 per kWh, the resulting annual energy cost is $816,026. To calculate the annual power requirements and energy cost for the operation using an adjustable frequency drive, recall that per the pump affinity laws described above:

$$\frac{P_1}{P_2} = \left(\frac{Q_1}{Q_2}\right)^3$$

Using the above equation, the required output shaft power can be calculated for each flow rate setting, represented by % Flow in **Table 1**, above, and in **Table 2**, on **page 4**. Using the same calculation shown above, the annual energy requirements and energy cost for each % Flow setting can be estimated. **Table 2**, on **page 4**, depicts the energy requirements for the adjustable frequency drive.

Table 2. Annual Energy Cost with Adjustable Frequency Drive

% Flow	Time (Hrs)	Time (%)	Output Shaft Power (hp)	Annual Energy Requirements (kWh)	Annual Energy Costs ($)
100	840	10	2000	1,360,043	81,603
90	840	10	1458	991,472	59,488
80	1260	15	1024	1,044,513	62,671
70	2100	25	686	1,166,237	69,974
60	1260	15	432	440,654	26,439
50	1260	15	250	255,008	15,300
40	840	10	128	87,043	5223
30	0	0	54	0	0
20	0	0	16	0	0
10	0	0	2	0	0
Total	8,400	100		5,344,971	320,698

In the above example, the annual energy cost to operate the pump using an adjustable frequency drive for variable speed control is $320,698, a total annual energy cost savings of $495,328 (60%) over the annual energy cost using across-the-line starting. At this level of annual energy savings, the up-front cost for an adjustable frequency drive can easily be recovered within the first two years of operation.

The Energy Savings Calculator for Fan and Pump Applications at www.eaton.com/SC9000 can be used to model the energy savings using variable speed control for any variable pump of fan duty cycle. While the up-front investment for an adjustable frequency drive can be significantly higher as compared with other motor starter types, the above example illustrates how using an adjustable frequency drive in a variable speed application can generate substantial energy savings to recover the incremental investment within a relatively short period of time. With such a compelling value proposition, it is easy to see why the use of adjustable frequency drives in water processing applications is growing at a rapid pace.

Eaton Corporation
Electrical Sector
1111 Superior Ave.
Cleveland, OH 44114
United States
877-ETN-CARE (877-386-2273)
Eaton.com

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