Variable speed drives on pumps

The installation of variable speed drives (VSDs) on pumps can be an effective energy-saving measure. Lowering the speed of a motor by just 20 percent can produce an energy saving of up to 50 percent. Variable speed drives can be installed on all pumps, including those associated with HVAC systems. The VSD needs to be connected to a control signal and may also require installation of measurement devices or controllers, which typically are included in costing. The financial viability of installing a VSD depends on the motor application and operating hours. VSDs tend to be most economical when used on large pumps.

Variable speed drives on pumps

NSW Farmers recommends that all farmers with significant pumping expenses investigate the costs and benefits of installing variable speed drives (VSDs).

Pumps are everywhere in agriculture, essential both for irrigation and for heating, ventilation and cooling (HVAC). In the intensive sectors, VSDs can halve energy consumption in some applications, with savings rapidly covering the costs of the technology. Energy savings can vary significantly depending on the characteristics of the system and the type of operation. Typical savings range from 30 to 50 percent (US Department of Energy, 2004).

Assessing suitability

Pumps that experience highly variable demand conditions are often good candidates for VSDs. In such cases, electronic controls vary the frequency and voltage supplied to the motor, which regulates the motor speed and, in turn, adjusts the pump’s output.

Not all pumps and applications will benefit from having VSDs, however.

VSDs are not recommended for systems with high static head or pumps that operate for extended periods under low-flow conditions.

A further consideration is the operating environment of the pump and the relative sensitivity of VSDs and their digital control systems to environmental conditions. For example, it may be unwise to install expensive VSDs in locations with a high likelihood of lightning strike.

Costs and retrofitting

In principle, VSDs can be installed on any pump; however, this is not always practical or cost-effective.

The VSD needs to be connected to a control signal and may also require the installation of measurement devices or controllers, which typically should be included in the costing of the measure. The financial viability of installing a VSD depends on the motor application and operating hours. VSDs tend to be most economical when fitted to large pumps.

VSD budget prices are typically $100 to $300/kW for low-voltage units of less than 100 kW, and can be 30 to 80 percent higher for high-voltage ones.

VSDs can be retrofitted on existing motors but limitations related to the recommended minimum speed (e.g. overheating) must be checked. Harmonics can also reduce the motor’s efficiency, so it is recommended that you check whether harmonic filters are required to protect your motor.

Mechanical benefits

As opposed to common flow-control methods such as throttling valves or bypass systems, the principal advantage of VSD technology is that it better matches the fluid energy the system requires with the energy the pump delivers to the system.

The pump’s power is proportional to the cube of the motor’s speed; therefore a significant reduction in power (and energy savings) can be achieved by reducing the speed of the motor. A VSD can alleviate the need to throttle the flow (and lose energy), or allow the water or refrigeration fluid to be pumped more slowly, reducing frictional energy loss. Soft start and stop capabilities also reduce mechanical and electrical stress as well as the risk of water hammer.

Technical explanation

Figure 1 (overleaf) shows that as the motor’s speed is reduced, the pump curve moves downwards to the left and flow and head are reduced, resulting in lower power consumption. If a VSD was not used in this flow-control application, the flow would need to be reduced by throttling, bypassing or switching the pump on and off.

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1 Schneider Electric 2011 Pricing Guide, AC Drives and Softstarts.
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This relationship between pump performance (flow, head and power) and speed is explained by the Affinity Laws.2

For example, reducing the speed of a pump by 10 percent results in a 27 percent reduction in power:

\[
N_2 = N_1 \times 0.9
\]

\[
P_2 = P_1 \times \left(\frac{N_2}{N_1}\right)^3 = P_1 \times \left(\frac{0.9N_1}{N_1}\right)^3 = P_1 \times (0.9)^3 = P_1 \times 0.73
\]

These laws apply only to systems with no or very low static head. With significant static-head contribution, operating points move to the left. At slower speeds, the pump doesn’t produce enough head to overcome static head and ‘hydraulic shut-off’ occurs.

**Worked example**

A water pump runs continuously, delivering water at a flow rate of 350 L/min and a head of 30 m. Flow is controlled via a throttling valve and it has been estimated that process flow requirements are as shown in table 1. The motor is 92 percent efficient.

<table>
<thead>
<tr>
<th>Percentage of annual operating hours</th>
<th>25%</th>
<th>50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of design flow</td>
<td>100%</td>
<td>70%</td>
</tr>
</tbody>
</table>

Table 1: Estimated operating hours and flow for example pump.

Estimate the energy savings if a VSD is retrofitted to a pump to control flow as per process requirements.

The input power of the pump at 350 L/min and 30 m is calculated as:

\[
P = \frac{g \times \rho \times Q \times H}{1,000 \times \eta_p \times \eta_M}
\]

Where:
- \(P\) = pump input power (kW)
- \(g\) = gravitational constant = 9.81 (m/s²)
- \(\rho\) = density of fluid (kg/m³) = 1,000 kg/m³ (water)
- \(Q\) = pump flow rate (m³/s) = \(\frac{350\text{ (L/min)}}{1,000 \times 60}\)
- \(H\) = head developed by the pump (m) = 30 m
- \(\eta_p\) = pump efficiency (%) = 84%
- \(\eta_M\) = motor efficiency (%) = 92%

Therefore:

\[
P = \frac{9.81 \times 1,000 \times \frac{350}{1,000 \times 60} \times 30}{1,000 \times 0.84 \times 0.92} = 2.22 \text{ kW}
\]

With this power requirement, the annual electricity usage is:

\[
\text{Annual electricity use} = 2.22 \text{ kW} \times 8,760 \text{ h/yr} = 19,460 \text{ kWh p.a.}
\]

Using the Affinity Laws to calculate flow and head at different speeds, the following operating points are determined:

\[
Q \propto N_1; \quad H \propto N_1^2; \quad P \propto N_1^3
\]

Where:
- \(Q\) = flow rate
- \(H\) = head
- \(P\) = power absorbed
- \(N\) = rotating speed

\(N_1\) and \(N_2\) are the original and new fan speeds respectively, and \(P_1\) and \(P_2\) are the original and new power consumptions.

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2 The Affinity Laws are portrayed by the following relations:

\[
Q \propto N_1; \quad H \propto N_1^2; \quad P \propto N_1^3
\]
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Reducing the flow rate would decrease pump efficiency. It is assumed that the efficiency of the pumps at 75 percent flow would be 77 percent and the efficiency at 50 percent flow would be 70 percent. Motor efficiency does not decrease significantly until the motor loading drops below 50 percent; thus it is assumed the motor remains 92 percent efficient. The annual electricity usage is calculated below.

<table>
<thead>
<tr>
<th>Time</th>
<th>% Flow</th>
<th>Flow (L/min)</th>
<th>Head (m)</th>
<th>Pump effic.</th>
<th>Power (kW)</th>
<th>Elec. (kWh/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25%</td>
<td>100%</td>
<td>350</td>
<td>30</td>
<td>84%</td>
<td>2.2</td>
<td>4,865</td>
</tr>
<tr>
<td>25%</td>
<td>80%</td>
<td>250</td>
<td>23</td>
<td>77%</td>
<td>1.3</td>
<td>2,906</td>
</tr>
<tr>
<td>50%</td>
<td>70%</td>
<td>180</td>
<td>20</td>
<td>70%</td>
<td>0.9</td>
<td>4,003</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11,775</td>
</tr>
</tbody>
</table>

Table 2: Annual electricity use calculations

The electricity savings are therefore:

Annual electricity savings = 19,460 kWh − 11,775
= 7,685 kWh p.a. (39% savings)

Key factors when evaluating quotes

Variable speed drives result in losses in the form of heat; normally, their efficiency ranges between 95 and 99 percent. When comparing different devices, check their rated VSD efficiency.

VSDs also cause harmonics that can reduce the efficiency of the motor. Though losses are typically low (approximately one percent), it’s recommended that you assess the associated harmonics to check whether harmonic filters will be required to protect your motor.

VSD budget prices are typically $100 to $200/kW for low-voltage units and can be 30 to 80 percent higher for high-voltage ones. Installation costs will vary depending on the distance between the motor and the switch room (cable length) and whether a cabinet is required to meet VSD protection and refrigeration requirements.

Further information

Technology guide: variable speed drives (VSDs)
www.carbontrust.com/media/13063/cta070_variable_speed_drives.pdf

Pumps and fans, opportunities, case studies and key resources

References


