Refrigeration – variable evaporator fan speed

Installing variable speed drives (VSDs) on refrigeration evaporator fans enables fan speed to be modified to match varying cooling loads. At low loads, reducing the speed of a fan decreases the power requirement of its motor significantly: reducing fan speed by 20 percent can reduce power consumption by approximately 50 percent. Where cooling loads are relatively constant, multi-speed motors may be cheaper and more efficient than motors equipped with VSDs and should also be considered.

Background

Refrigeration in agriculture is used mainly for cold storage to keep products fresh by reducing humidity and bacterial growth. Products are kept at low temperatures as per Food Safety Practices requirements, typically below five degrees Celsius in the case of hazardous foods (e.g. raw meat, dairy products) and below 15–20 °C in the case of raw fruit and vegetables.

Where installed, refrigeration can account for a significant amount of a farm’s total electricity use, usually between 30 and 60 percent.

![Diagram of a typical refrigeration system](image)

A typical refrigeration plant incorporates large drives such as compressors, fans and pumps to supply the required cooling load. A simplified diagram of a typical refrigeration system is shown in Figure 1.

Fan-coil evaporators are used in most industrial cold-storage applications. Normally, the evaporator fans are driven by fixed-speed motors and run at full speed, turning on and off to control temperature inside the cold store. The evaporator fan motor is a continuous heat load on the cool room which, in turn, is an additional load on the refrigeration plant.

Variable speed drives

By implementing variable speed drives (VSDs) on evaporator fan motors, fan speed can be modified to match varying cooling loads. At low loads, reducing the speed of the fan decreases the power requirement of its motor significantly, as power is proportional to the cube of speed. For example, reducing fan speed by 20 percent can reduce power consumption by approximately 50 percent (NSW Government: Office of Environment & Heritage, 2011).

Total energy savings will depend on the cooling load profile, and the number (and size) of evaporators in each cold room, but typically, can be up to 80 percent of the fans’ electricity usage, which can be approximately 25 to 35 percent of the total refrigeration energy (NSW Government: Office of Environment & Heritage, 2011).

The VSD equipment is the largest cost item in the total project cost, and depends on the number and size (kW) of the fan motors required. The typical VSD cost ranges between $100 and $300 per kilowatt for drives below 100 kW.

How do VSDs work?

The following chart shows that as fan speed is reduced, the fan 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 – most commonly used in the case of evaporator fans – switching fans on and off.

![Impact of fan speed on power requirement](image)

1 Schneider Electric 2011 Pricing Guide, AC Drives and Sofstarts
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This relationship between pump performance (flow, head, and power) and speed is explained by the Affinity Laws. An important implication of these laws is that:

Reducing the speed of a fan by 20 percent will result in power savings of almost 50 percent.\(^2\)

This shows the importance of variable speed drives as an energy-efficiency measure.

The chart below illustrates power savings with respect to room load by installing VSDs on the evaporator fans. As the graph indicates, savings are greatest at low room loads. The horizontal line between loads of 10 and 50 percent indicates that a minimum fan speed of 50 percent has been considered in the modelling, which is typical for most evaporator fans.

![Figure 3: Power savings versus cold-store load (NSW Government: Office of Environment & Heritage, 2011).](image)

Additional energy savings can be achieved via a reduction in load within the cold store, due to reduced amounts of heat being introduced into these rooms as a result of the slower-running fans. Compressors unload less and condenser fans operate less as a result, adding another 20 to 50 percent to the direct fan-energy savings (Hilton, 2013).

To implement a variable fan speed control system, the following equipment is required:

- variable speed drives for each evaporator – a single VSD can control all fans in one evaporator, and
- sufficient control-system hardware and software capability to define the control logic.

Key steps in evaluating a variable fan speed control system are:

1. Assessing the load profile of the cold store and determining the average room load percentage (this can be estimated by analysing the number of starts and stops made by evaporators during the day in order to determine typical operating hours), and
2. estimating the energy savings associated with the average load (as shown in Figure 3).

Worked example

A cold room has seven evaporators, each one equipped with three 0.5 kW fans that run continuously except during defrost (two hours per day). The fans are driven by fixed-speed motors (i.e. with no speed control and running at full speed at all times). The cooling load in the cold store varies across the year due to changes in storage levels as well as seasonal weather conditions. It is estimated that the load varies as follows:

<table>
<thead>
<tr>
<th>Percentage of operating hours</th>
<th>Percentage of room load</th>
</tr>
</thead>
<tbody>
<tr>
<td>25%</td>
<td>90%</td>
</tr>
<tr>
<td>50%</td>
<td>80%</td>
</tr>
<tr>
<td>25%</td>
<td>60%</td>
</tr>
</tbody>
</table>

Table 1: Example cooling load fluctuations for a room throughout the year.

Evaluate the cost benefit of installing variable speed drives on evaporator fans to enable a speed control system that better matches cooling supply to varying conditions.

**Estimate current running cost:**

Running time = 8,760 hrs p.a. - (2 x 365 hrs (defrost time))

= 8,030 hrs p.a.

For seven evaporators with three 0.5kW fans each, the total power is:

= 3 x 0.5 kW x 7

= 10.5 kW

At an electricity price of $0.15/kWh, the annual running cost is:

= 84,315 kWh/yr x $0.15/kWh

= $12,650 p.a.

**Estimate savings from implementing a VSD:**

Using the chart in Figure 3 to estimate the reduction in fan power at different room load percentages, the electricity consumption after the VSD retrofit is:

<table>
<thead>
<tr>
<th>Time (%)</th>
<th>Time (hrs)</th>
<th>Room load (%)</th>
<th>Power reduction (%)</th>
<th>Power (kW)</th>
<th>Electricity (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25%</td>
<td>2008</td>
<td>90%</td>
<td>30%</td>
<td>10.5^*0.7 = 7.4</td>
<td>14,755</td>
</tr>
<tr>
<td>50%</td>
<td>4015</td>
<td>80%</td>
<td>50%</td>
<td>10.5^*0.5 = 5.3</td>
<td>21,079</td>
</tr>
<tr>
<td>25%</td>
<td>2008</td>
<td>60%</td>
<td>80%</td>
<td>10.5^*0.2 = 2.1</td>
<td>4216</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>40,050</td>
</tr>
</tbody>
</table>

Table 2: Example calculations for power consumption after VSD retrofit.

The electricity savings are:

84,315 – 40,050 = 44,265 kWh p.a. (53% savings, equivalent to $6,640 p.a.).

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\(^2\) The Affinity Laws are portrayed by the following relations:

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

Where:

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

As the workings below show (where \( N_1 \) and \( N_2 \) are the original and new fan speeds respectively, and \( P_1 \) and \( P_2 \) are the original and new power consumptions), reducing the speed of a fan by 20 percent results in a power reduction of almost 50 percent:

\[ N_2 = N_1 \times 0.8 \]

\[ P_2 = P_1 \times \left( \frac{N_2}{N_1} \right)^3 = P_1 \times \left( \frac{0.8 N_1}{N_1} \right)^3 = P_1 \times (0.8)^3 = P_1 \times 0.51 \]
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**Estimate total cost and project payback**

Assumptions:
- that one VSD is required for each evaporator (total power rating 1.5kW);
- that the VSD budget price is $300/kW; and
- that the installation cost = 100% of capital cost + $2000 for PLC programming.

Equipment cost = \(7 \times 1.5kW \times $300/kW = $3150\)

Installation cost (100% of capital cost) = $3150

PLC programming = $2000

**Total installed cost = $8300**

The simple payback for the project is:

\[
\frac{$8300}{6640} \text{ p.a} = 1.3 \text{ years}
\]

**Key factors when evaluating quotes**

Certain key parameters need to be considered when comparing quotes for variable speed drives (VSDs).

- VSDs have losses in the form of heat and their efficiency normally ranges between 95 and 99 percent. Check the rated VSD efficiency when comparing different devices.
- VSDs cause harmonics that may reduce the motor efficiency. Though losses are typically low (approximately one percent), assessment of VSD harmonics is recommended to check whether harmonic filters will be required to protect the fans’ motors.
- VSD budget prices are typically between $100 and $300/kW for low-voltage units below 100 kW in size 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 switchroom (cable length) and whether a dedicated cabinet is required (for VSD protection and refrigeration requirements).
- Check whether there are any motor limitations related to recommended minimum speed (e.g. overheating) and whether these have been taken into account in estimated savings.

**Further Information**


**References**


[Accessed November 2013].