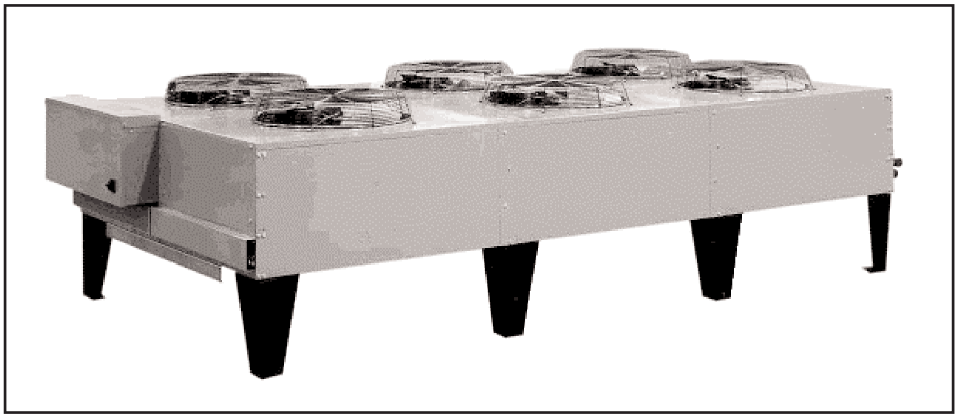
technical brief

Floating Head Pressure

Variable-Speed, Air-Cooled Condensers in Supermarket Refrigeration



Refrigeration systems account for a significant portion of annual energy use in modern supermarkets. The industry continues to develop new solutions to enhance energy efficiency and reduce energy use in these facilities. The energy efficiency of refrigeration systems has continued to improve steadily over the past decade. At the same time, supermarkets began to use larger and larger stores that required even larger refrigeration systems. The increased need for refrigeration continues to challenge the industry to find even more energy efficient solutions.

Several advances in technology have been incorporated in recent years. Most of these advances—more efficient compressors, motors and lights; larger condensers and evaporators; electronically-commutated display case fan motors; efficient display case doors without anti-sweat heaters; etc.—improve the efficiency of the system when operating at design conditions. To obtain even more efficiency, certain measures can be applied very effectively at part load or off-design conditions. Such measures include the use of multiple compressor racks to better match the refrigeration capacity with the load, intelligent defrost controls that initiates defrost only when needed, and floating the condensing head pressure when ambient conditions are cooler.

Floating the condensing head pressure of the refrigeration system down at lower ambient conditions can yield significant energy savings. There are several ways to control floating of the head pressure; however, one of the most common practices is to systematically cycle a number of fans in a multi-fan air-cooled condenser. One advanced way to further enhance the savings from the floating head pressure approach—and at the same time provide more stable control—is to use a variable speed drive to modulate the condenser fan speed.

Lowering the condensing pressure reduces compressor energy use by decreasing the compressor discharge pressure. This allows the compressor to provide the necessary mass flow rate of refrigerant—and therefore required refrigeration capacity—while using less compressor work. Providing the same capacity with less compressor power increases the efficiency of the refrigeration system.

Conventional Condenser Fan Control

The traditional air-cooled condenser used in supermarket applications is a horizontal slab coil heat exchanger with multiple propeller fans drawing air through the heat exchanger. Each fan is isolated to a separate section of the coil. This arrangement allows each fan to operate independently of the others without allowing air to bypass the coil through inactive fan openings.

The traditional means of condenser fan control is to sequence cycling of individual fans ‘on’ and ‘off’ based on condensing pressure and/or ambient temperature. Since each fan (or bank of fans) is on its own isolated section of the condenser coil, disabling a fan reduces the air flow (and therefore the heat transfer) for that portion of the heat exchanger coil. This causes

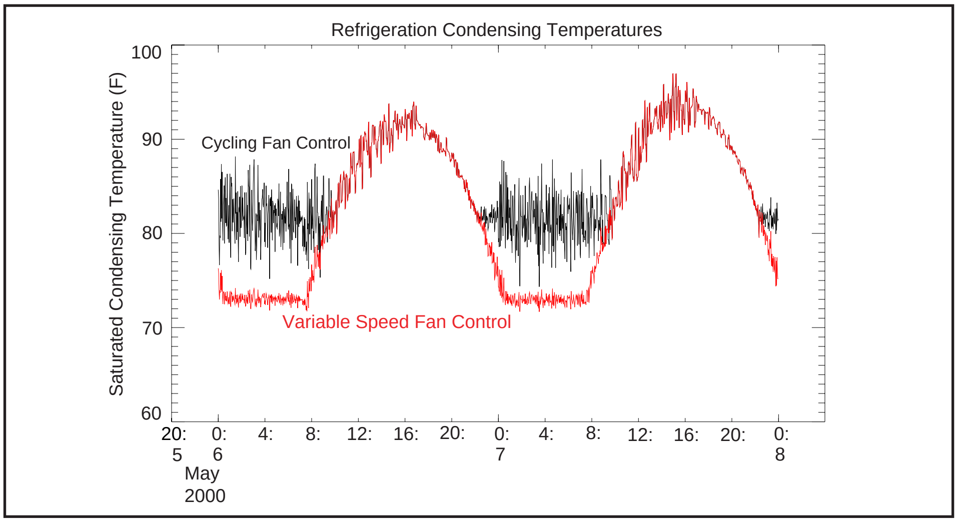


Figure 1. The saturated condensing temperature with cycling fan control is highly variable due to the coarse level of control. Variable speed fan control greatly reduces the variation and allows for a lower set point and greater energy savings.

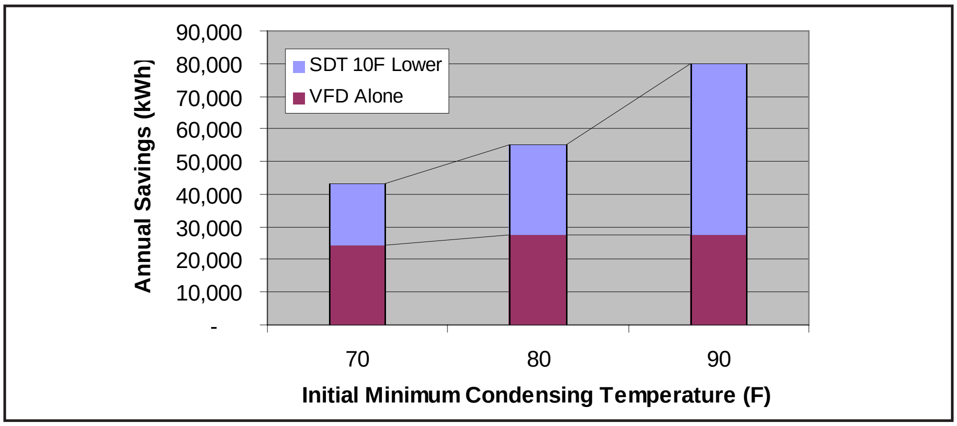


Figure 2. Annual energy savings from implementing variable speed fan control in a Minneapolis supermarket. The savings, predicted using EPRI Supermarket Simulation Tool (SST), are highest when starting from a higher minimum condensing temperature. A portion of the savings are due to the reduced fan energy due to variable speed operation (VFD Alone). The balance of savings are due to lowering the minimum condensing temperature by an average 10°F.

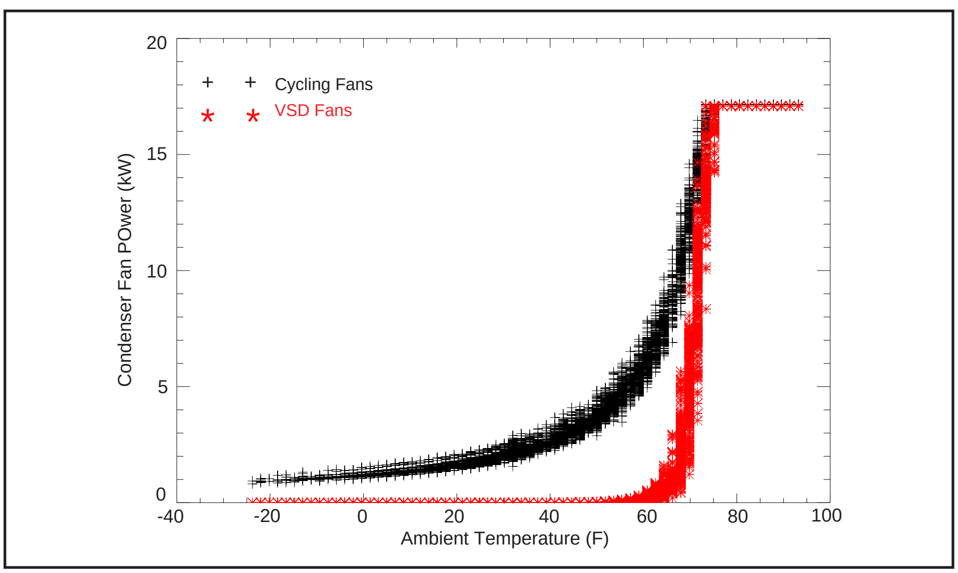


Figure 3. The trend of fan power with ambient temperature for cycling and variable speed fan control predicted with SST.

the condensing pressure of the refrigeration system to rise. When the pressure rises above preset level, the fan cycles back 'on', thereby increasing the heat transfer and decreasing the condensing pressure. An approximate condensing pressure set point is maintained by cycling individual condenser fans 'on' and 'off' using this "deadband' control approach (similar to a residential thermostat). As a practical measure, sometimes the fans next to coil endplates are not cycled in order to avoid mechanical failure and refrigerant leakage from expansion/contraction of the heat exchanger tubes with the endplates or tube sheets (though, some manufacturers can provide condenser coils with special tube sheets to address this concern).

Some of the condenser fans are also cycled based on ambient temperature to improve control stability. Mixed pressure and ambient temperature controls stage some fans off at cooler ambient temperatures (e.g., below 70°F) when heat rejection loads are more modest. This allows the pressure-controlled fans to provide a finer level of control by cycling fewer fans.

The pressure set point selected for fan control is usually the minimum condensing pressure required for reliable refrigeration system operation. This minimum pressure has sometimes been driven by the minimum pressure difference required across the expansion devices, though modern balanced port thermostatic expansion valves have generally eliminated this concern. In current systems, the compressor often sets the minimum pressure requirements. Compressors often have a minimum recommended condensing pressure that is necessary to provide proper operation. This requirement is driven by the need to maintain a pressure difference between the high and low side of the system to ensure good oil distribution or to prevent high refrigerant flow rates that could damage valves.

As a result, low temperature compressors can often operate at a lower minimum condensing pressure than medium temperature compressors. For instance Carlyle recommends that low temperature compressors (with saturated suction temperatures below -10°F) operate at condensing temperatures above 70°F. However, the lowest allowable condensing temperature on Carlyle medium and high temperature systems is 80°F.

Copeland's specifications generally allow both medium and low temperature compressors to both operate down to 70°F condensing. Industry "rules of thumb" based on compression ratio limits typically imply that even lower minimum condensing temperatures are possible—as low as 60°F condensing for a medium temperature system operating at 20°F suction and down to 40°F condensing for a low temperature system at -20°F.

Conventional condenser controls are often set to maintain a conservative minimum condensing pressure. These conservatively high settings—as high as 90–100°F—are typically necessary because of the coarse level of control provided by cycling fans on and off. Often a safety factor of 10–20°F is necessary to ensure that the condensing pressure never drops below the minimum level.

Figure 1 shows measured data from a supermarket condenser where the minimum pressure is maintained by cycling the fans. The saturated condensing temperature varies substantially as the fans cycle on and off—especially at night when minimum pressure is reached. The relatively modest heat rejection loads on the condenser at night also tend to exacerbate the fluctuations. In this case, the average condensing temperature at night with cycling fans was about 82°F. However, the instantaneous values ranged from 75°F to 88°F.

Variable Speed Fan Control

Variable speed fan control offers the potential for reduced energy use as well as tighter control of condensing head pressure. Figure 1 shows that with variable speed control, the tighter control of condenser pressure allows the set point to push closer to the lower limit without the risk of violating it. As a result, it is possible to safely lower the minimum condensing pressure and save additional energy by floating down the head pressure. The predicted condensing temperature with variable speed fan control is also shown on Figure 1. While similar performance would be expected during the day when ambient temperatures push the condensing temperature above of the minimum value, the finer level of control allows the condensing temperature to drop closer to the minimum limit at night. As Figure 2 shows, energy savings result from both the reduction in condenser fan power as well as reduced condensing temperatures.

The direct energy savings from variable speed fan operation result because fan power falls off as the "cube" of the air flow rate. Figure 3 shows the trend of condenser fan power with ambient temperature predicted by EPRI Supermarket Simulation Tool (SST). When the ambient temperature drops to 75°F, the condensing temperature has reached the minimum point and the fans start to cycle or modulate. For the variable speed fans, power drops off more quickly than for the case of cycling fans where power is directly proportional to the air flow.

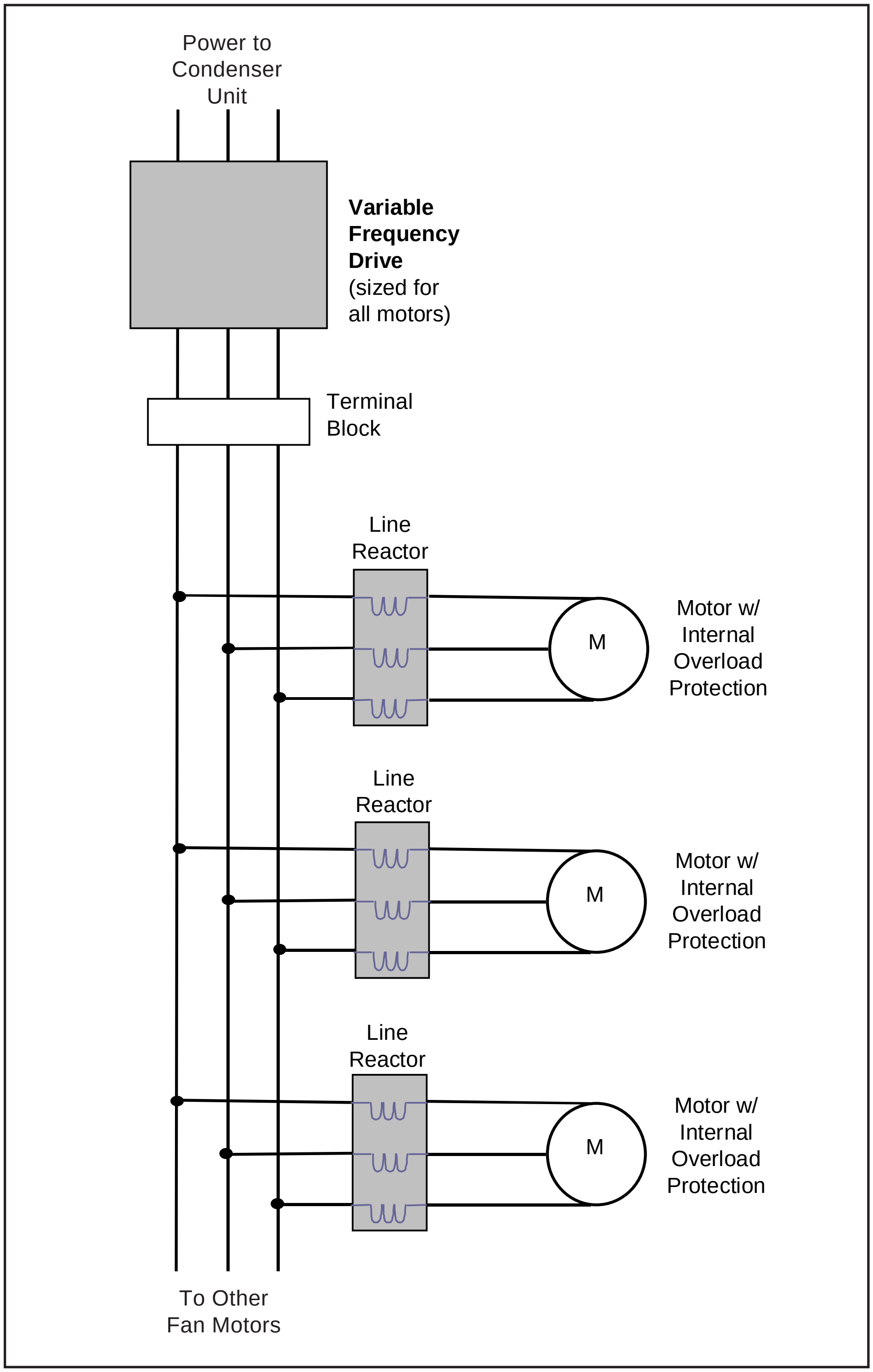


Figure 4. One properly-sized variable frequency drive (VFD) can be added to drive multiple fan motors. Line reactors, sized to each motor load, must typically be added to minimize harmonics and ensure motor life.

The energy savings are greatest at the intermediate temperatures as shown by the differences between the trends in Figure 3.

Installing a VFD

The fans on a supermarket condenser are typically wired through a single electrical connection. This makes it possible to put one variable frequency drive (VFD) in the condenser control box to control all the fans. Because precise pressure control is possible with a VFD, the traditional fan staging controls can be bypassed and all the fans can be varied together to maintain the minimum pressure set point. A pressure transducer and/or a signal from the store energy management system (EMS) are typically necessary to control the system.

Figure 4 shows how the VFD would be integrated into the 3-phase wiring in typical condenser control box. To mitigate the electrical noise and harmonic distortion that can result when one VFD controls several motors, manufacturers typically recommend that a "line reactor" be installed on each individual motor (as shown in Figure 4). A line reactor adds inductance in series with each line to the motor. The added inductance is typically 3 to 5% of the motor inductance. Typically a 5% reactor is used to protect motors installed on the load (or downstream) side of a VFD. If wire lengths from the drive to the motor are over 15 feet long, then an LC filter—which adds both inductance and capacitance—may be required. Table 1 summarizes the VFD sizing and installation issues that must usually be addressed.

Table 1
General VFD Installation and Sizing Issues to be Addressed

Issue	Rules of Thumb[1]
VFD Sizing	VFD must be sized based on 120% of the largest motor plus the sum of the remaining motor loads
Line Reactor Sizing	Reactors should be sized based on motor size, wire lengths, and site-specific voltages. LC filter may be required instead of a reactor in some cases.
Speed Control	VFD can be controlled using store EMS. If an EMS is not available, then a dedicated pressure sensor can be used with the PID control functions built into most VFDs.

Notes: [1]The specific recommendations from the VFD and motor manufacturer should be consulted.

VFD Economics

The estimated costs to install VFDs on the low and medium temperature condensers in a supermarket is about $300 per HP. Each separate condenser will need its own VFD. Individual VFDs also allows the low and medium temperature condensers to be controlled to provide a different pressure set point.

The VFDs would cost an estimated $7,100 to install in the Minneapolis supermarket example. This installation price includes the cost of line reactors to protect the multiple motors and considers the normal labor and profit a refrigeration contractor might charge. With savings of nearly $2,800 per year, the simple payback would be 2.5 years. On a new installation, the incremental costs of the VFDs would be even less and this control approach would be even more economic.

Summary

Variable speed control of air-cooled condenser fans is a new approach to fully realize the benefits of floating head pressure. Conventional methods of cycling condenser fans provide a very coarse level of control and have driven many supermarket designers and operators to select very conservative settings for the minimum head pressure. The finer degree of control offered with VFDs now provides to opportunity to lower condenser pressures as well as decrease fan energy use. The reduced costs of VFDs have made this approach cost effective in new and retrofit applications.

References

Supermarket Simulation Tool Version 3: Installation and User Guide, Product ID# 1001013. EPRI, Palo Alto, CA, 2000.

Internet resources for information on VFDs, Line Reactors and LC Filters.
1. www.magnetekdrives.com
2. www.vfds.com
3. www.automationdirect.com
4. www.galco.com

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