POTATO FAN VFDs

PHASE 2 REPORT

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Nathan Oberg performed the research discussed in this report as a University of Idaho Ph.D. candidate.

1.0 EXECUTIVE SUMMARY

1.1 INTRODUCTION

Potato storage ventilation systems are designed to move air through stored potatoes in order to remove the heat of respiration and control product temperature. During holding periods, most storage managers reduce ventilation rates. This can be done by reducing fan run hours, or reducing the number of operating fans.

Another way to control the ventilation rate is by adjusting fan speeds with Variable Frequency Drives (VFDs). This method has the advantage of dramatically reducing energy consumption at reduced fan speeds. At 50% speed, a fan will produce 50% flow but consume only 15% power.

Three years of full scale trials conducted by the University of Idaho have shown that VFDs save energy, reduce potato shrinkage, and have no adverse quality problems. VFD owners also report decreases in utility bills, potato mass loss, potato pressure bruising, and condensation, as well as increased operational flexibility.

1.2 UNIVERSITY OF IDAHO FIELD TRIALS

Commercial field trials were conducted over three successive storage seasons to evaluate the impact of VFD fan speed control on energy use, shrinkage, and potato quality. The field trials were conducted at a typical split-plenum storage, 100,000 cwt (hundred weight) per bay (5,000 ton per bay) capacity. One bay used VFD fan controls, and the other bay used more traditional on/off fan controls.

In each season fan energy use was significantly reduced with VFD fan speed control, yielding an average reduction of 40.3%. Similarly, VFD use minimized shrinkage in each season, for an average reduction of 0.8%. VFD use did not impact tuber quality, as defined by specific gravity, sugar concentrations, or fry color, in any storage season. The results of the commercial trials demonstrate the potential benefits of VFD fan speed control. Under many scenarios VFDs have the potential to reduce energy use and shrinkage, with no negative impact on stored potato quality.

Table 1: University of Idaho Field Trial Summary

Year	1	2	3
Storage Season	2000-2001	2001-2002	2002-2003
Variety	Shepody	Russett Burbank	Russett Burbank
Holding Days	60	125	240
Non-VFD Fan Energy	48,000	82,800	125,120
VFD Fan Energy	32,000	45,670	71,376
Savings, kWh	16,000	37,130	53,744
Non-VFD Shrinkage	2.4%	3.8%	3.2%
VFD Shrinkage	2.0%	2.1%	2.8%
Savings	0.4%	1.7%	0.4%
Fry Color	Unaffected	Unaffected	Unaffected
Specific Gravity	Unaffected	Unaffected	Unaffected
Glucose	Unaffected	Unaffected	Unaffected
Sucrose	Unaffected	Unaffected	Unaffected

1.3 ENERGY ECONOMICS

The electricity bill savings will be larger as more of the following factors are present:

1. Long storage season
2. High energy price
3. Lots of hours when outside air (OSA) is available for cooling (OSA cooling hours increase with colder weather and/or higher storage temperatures.)
4. Building designed for high ventilation rates
5. Utility incentives will pay part of VFD cost

Energy savings for a 300,000 cwt storage in Quincy WA were calculated at 408,000 kWh and $9,600 per year using VFD controls. Assuming the VFD project costs $26,000 for this storage, the VFDs would pay for themselves in 2.7 years based on energy savings alone.

1.4 MASS LOSS (SHRINK) ECONOMICS

Once holding temperatures are reached, any extra ventilation air beyond what is necessary to remove the heat of respiration and building loads will cause unnecessary drying of the potatoes. The result is reduced load out and packing weights.

If the University of Idaho results are taken as typical, VFD fan controls could reduce shrinkage by 0.4% or more over a storage season. On the sample storage, a 0.4% shrinkage savings would increase load out weights by 1,200 cwt and increase sales income by $6,000 for sales at $5.00/cwt. This extra revenue reduces the VFD payback period from 2.7 to 1.7 years.

This example was calculated with a net energy cost of $.0236/kWh. Energy pricing in other parts of Washington, Idaho, and Oregon can be nearly twice as expensive. Economic payback for VFDs depends on many factors and can vary widely. Given the potential for energy savings, reduced shrinkage, and increased operational flexibility, VFD installation should be strongly considered for any new storages and most existing storages.

2.0 FACTORS AFFECTING VFD SUITABILITY

2.1 POTENTIAL OBSTACLES TO VFDS

The following obstacles may reduce the benefits of VFDs.

2.1.1 Storage Season Length

The majority of energy savings and product quality benefits occur during winter holding, after suberizing (curing) and cool down. A storage site should spend at least 30 days in winter holding before VFDs are considered. Typically a site is loaded in late September, and could start reducing fan speeds as early as Nov 15th or Dec 1st.

Some growers have multiple buildings and unload the buildings at a steady rate from November through June. Ideally the grower would outfit the medium and long term buildings with VFDs, but this is not always possible to predict.

2.1.2 Building Air Flow Rate

If the building is older and was designed at 10 or 12 cfm/ton, it may not be possible to reduce fan speeds very far during winter holding periods without raising the temperature difference between return air and plenum air (ΔT). Once the tubers are at their holding temperature, the air temperature is close to the potato temperature. ΔT is often used to indicate the difference in temperature between return and plenum air, as well as the difference between pulp temperatures at the top and bottom of the pile.

If an evaporative cell or refrigeration coil is fouled, the building may never achieve the design air flow rates, which would limit the potential fan speed reduction. A 20 CFM/ton building with fouled equipment may only operate at 17 CFM/ton. On the other hand, many buildings operate at lower pressure drops and higher flows than design ratings. This would allow for additional reductions in fan speeds.

2.1.3 Poor Air Distribution

Buildings with booster fans in the plenum or return air may suffer from poor air distribution at full load conditions. Such sites would similarly suffer from poor air distribution with VFDs. It is generally believed that if a site has good air distribution at design conditions, that it will have good distribution at reduced flows.

2.1.4 Cold Variety-Warm Location

If a low temperature variety, such as Russet Norkotah is being held at 38°F in a warm location, the available OSA hours will be limited. If all fans must operate whenever OSA is available to maintain the desired ΔT, then benefit of VFDs will be reduced.

2.1.5 Tight ΔT Requirements

Very tight ΔT requirements force the ventilation rates and fan speeds to be higher. VFD installation sites with .8°F and .5°F ΔT requirements are able to reduce fan speeds to 63%-75% during winter holding. VFD sites with 1.5°F or 1.0°F ΔT requirements can commonly operate at 35%-60% speed during winter holding.

2.1.6 Aggressive Fan Reduction Practice

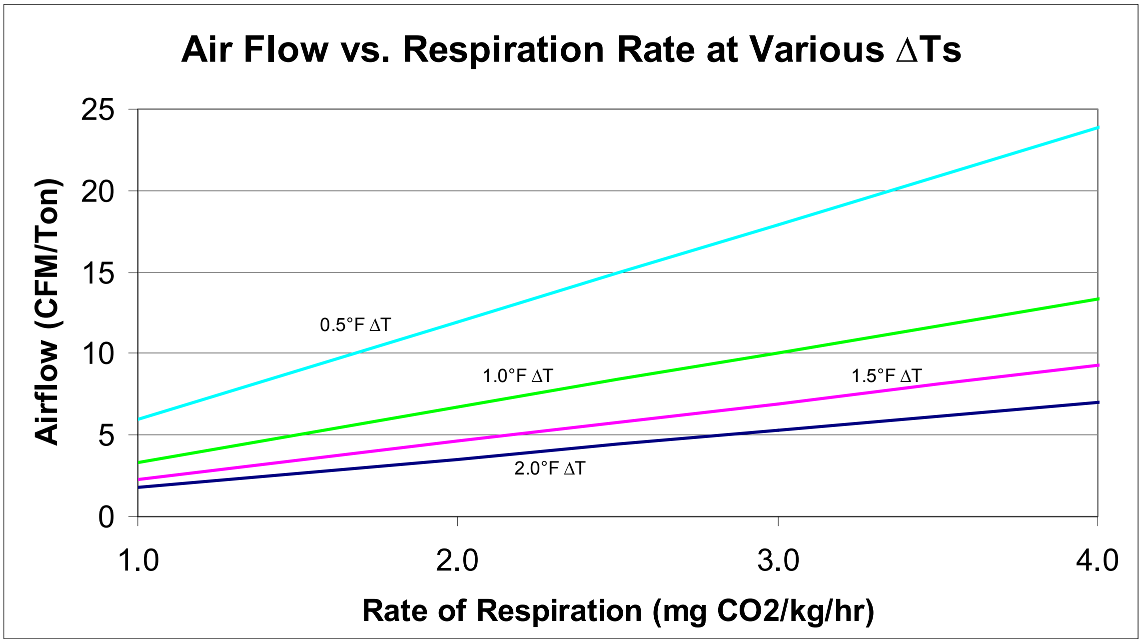
Occasionally a grower will have an aggressive fan reduction practice, where during winter holding 2 out of 4 fans (or similar) are shut off and run times are extended. This grower is capturing part of the energy savings and product quality benefits that could be had through VFDs. The economic difference between the two operations may not be enough to justify VFD installation.

Most fan reduction practices only shut off 1 out of 4 or 5 fans. There is a significant difference between this practice and a VFD practice. In these cases, VFDs are probably justified.

2.2 MAINTAINING ΔT

During winter storage, a healthy crop would be expected to have a rate of respiration of about 3 mg CO_2/kg/hr. As the figure below shows, a ventilation rate of 18 CFM/ton is required to maintain 0.5°F ΔT. If 1.5°F ΔT is acceptable, the ventilation rate can be reduced to about 7 CFM/ton. With VFDs this reduction can be accomplished by slowing the fans down, reducing electrical costs, and improving product quality without prolonged fan off periods.

Figure 1: Air Flow vs. Respiration Rate for ΔT



The ventilation rates in this figure account only for the respiration heat load. Increased building loads in the spring would require additional ventilation. Respiration rate varies with variety, crop condition, and storage length.

2.3 NON ENERGY OR QUALITY BENEFITS

2.3.1 Increased Operational Flexibility

Storage sites with one fan have no choice but to control ΔT by adjusting fan run times. Sites with 4 fans can't operate 2 ½ fans. This forces the operation to over-ventilate to the next whole fan. With VFDs, the fan speeds can be adjusted in 1% or smaller increments.

2.3.2 Increased OSA Hours

With slower air velocities through the evaporative cooler, the air has more time to approach the saturated wet bulb temperature, resulting in cooler air. Reducing fan speeds also reduces the heat load and temperature gain by the air. Both of these effects will slightly increase the available OSA hours.

2.3.3 Reduced Condensation

Condensation can be a significant problem during fan off periods in cold weather. With VFDs the fan off periods can be significantly reduced or eliminated without over ventilating the crop.

2.4 VFD COSTS

The cost to retrofit an existing storage building to VFDs can range from $100 per fan horsepower to $300 or more depending on contractor, motor protection devices, electrical modifications, VFD brand, etc. This report uses $175/hp for typical retrofit situations. Anyone curious about project costs is strongly encouraged to obtain a bid from a local electrical contractor or ventilation contractor.

For new construction, the incremental cost of VFDs can be as low as $100/hp. Motor starters are eliminated, VFD rated motors can be specified, re-work is eliminated, and the design will accommodate VFDs from the outset. Anyone considering new construction should thoroughly evaluate VFDs.

3.0 STORAGE PRACTICES

3.1 PRACTICES

Cascade Energy Engineering visited many potato storage sites during the development of this report and interviewed the operators. The following discussion represents most of the operations encountered.

3.1.1 Observed Non-VFD Storage Practices

In Grant County Washington and Northern Oregon, most sites ventilated whenever OSA was available during winter holding. Some shut a fan down during the cool winter months, but usually didn't go below 75% horsepower.

Near Twin Falls Idaho, the most common practice was timed run ventilation with all fans operating between 10 and 16 hours per day. Some times these were broken into shorter periods such as 6 hrs on 6 hrs off to reduce condensation problems.

3.1.2 Observed VFD Storage Practices

Several VFD sites limited their maximum fan speed to 55 Hz, or 92%. This provides a 20% fan energy reduction during suberizing and cooling to holding temperature periods, but reduces air flow by 8%.

All VFD sites ventilated whenever OSA was available during winter holding. Design ventilation rates varied from 17 to 20 CFM/ton. Winter holding fan speeds varied from 35% to 75%. Holding temperature and ΔT requirements made a big impact on fan speeds. Sites holding at 38°F or with ΔT requirements at .8°F or below tended to operate with fan speeds between 55% and 75% when using OSA. Sites holding at 46°F with ΔT requirements near 1.5°F tended to operate between 35% and 55% speed when using OSA. Building design had an impact, with the 17 CFM/ton building operating with fan speeds about 15% higher than nearby 20 CFM/ton buildings holding at the same temperature and ΔT.

During refrigerated operation, most VFD sites increased their fan speeds to between 70% and 100%. This was to avoid evaporator coil icing. None of the VFD sites had experienced coil icing with VFDs, but increased the fan speeds as a precaution.

3.2 MANUAL AND AUTOMATIC VFD CONTROLS

Roughly half of the VFD sites manually adjusted the fan speed. Operators would evaluate crop condition, run times, and ΔTs once per day and adjust fan speed. The rest of the VFD sites used automatic fan speed controls. Automatic fan speed control should best prevent over or under ventilating the crop and save the most energy. Automatic controls are now offered by a variety of ventilation contractors, and likely several others besides those listed below.

The ventilation contractors listed below can supply and install VFDs and automatic controls.

- The Gellert Company, www.gellert.com (888) 435-5378, Twin Falls ID
- Industrial Ventilation Inc., www.ivi-air.com (800) 444-7152, Nampa ID
- JMC Ventilation & Refrigeration, www.jmcvr.com (877) 586-9893, Kennewick WA

All of the VFD controllers adjust fan speed to maintain the target ΔT that the user enters. All controllers have a minimum fan speed setting. Additional features are constantly changing. Contact a dealer to find out what their controller offers.

4.0 FAN SYSTEMS

4.1 AFFINITY LAWS

In theory, fan power is proportional to the cube of the fan speed. At 50% speed, the fan power would be 50% x 50% x 50%, or 12.5%. Air flow is proportional to fan speed. At 50% speed a fan would produce 50% flow while only consuming 12.5% power. In reality, 50% speed operation consumes about 15% power due to VFD losses. A 20 CFM/ton building can operate at 10 CFM/ton using about 15% power.

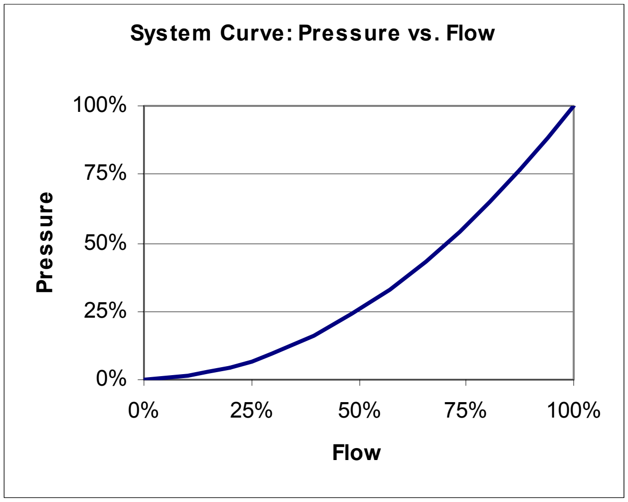
Accounting for VFD losses, fan power can be modeled as %Fan Power = %Fan Speed$^{2.7}$ / VFD Efficiency. VFD efficiency can be estimated at 95%.

4.2 FAN CURVES AND SYSTEM MODELING

4.2.1 System Curves

Each building has a unique relationship between pressure and flow. In theory, pressure is proportional to the square of flow. Many potato storage buildings are designed at 1.25" water column static pressure.

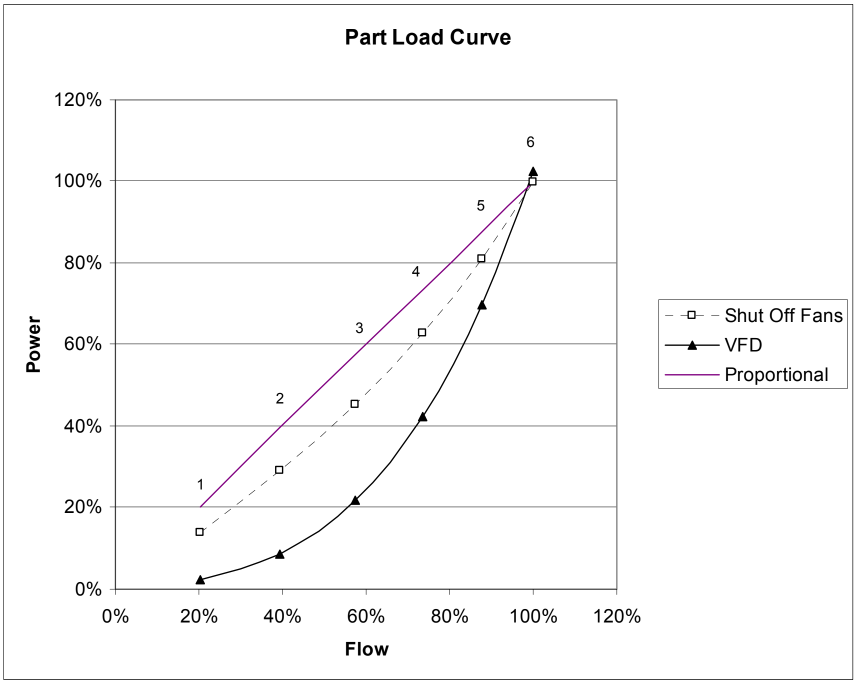
Figure 2: System Curve



4.2.3 Shutting Fans Off vs. VFDs

The following discussion and figures are for a ventilation system with six identical fans.

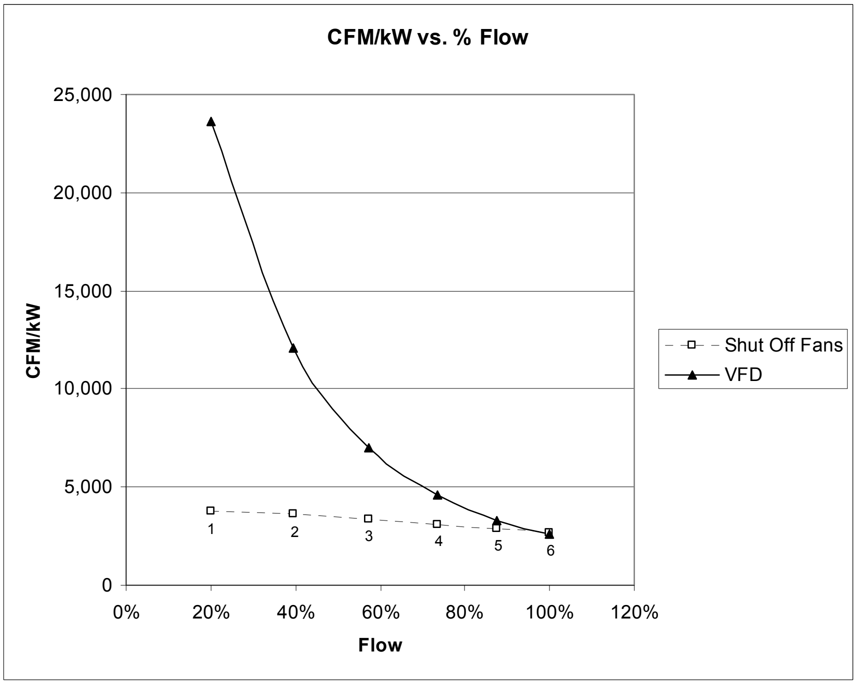
Figure 3: Power vs. Flow, Part Load Curves



When a fan is shut off, the operating static pressure falls, and the remaining fans produce slightly more flow and use slightly less energy. This is indicated by the black squares in the figure above. Note that this building can not operate between the squares, only at them.

Another way to look at the issue is to compare air flow per unit power across the operating range. Note in the figure below that shutting fans off results in slight increases in efficiency, but VFD control results in huge efficiency gains at reduced flows.

Figure 4: CFM/kW vs. Flow



4.3 AIR HEATING

Air heating can be a concern in warmer climates with limited OSA availability. With VFDs at reduced speed, the air is heated less than it would be by reducing the fan count as shown in the figure below. This would have the effect of extending OSA time slightly.

Table 2: Air Heating

Fans On Line, or Equivalent VFD Flow	**6**	**5**	**4**	**3**	**2**	**1**
Shut Off Fans Air Temp Rise, °F	1.2	1.1	1.0	0.9	0.9	0.8
VFD Air Temp Rise°F	1.2	0.9	0.7	0.4	0.3	0.1

5.0 VARIABLE FREQUENCY DRIVES

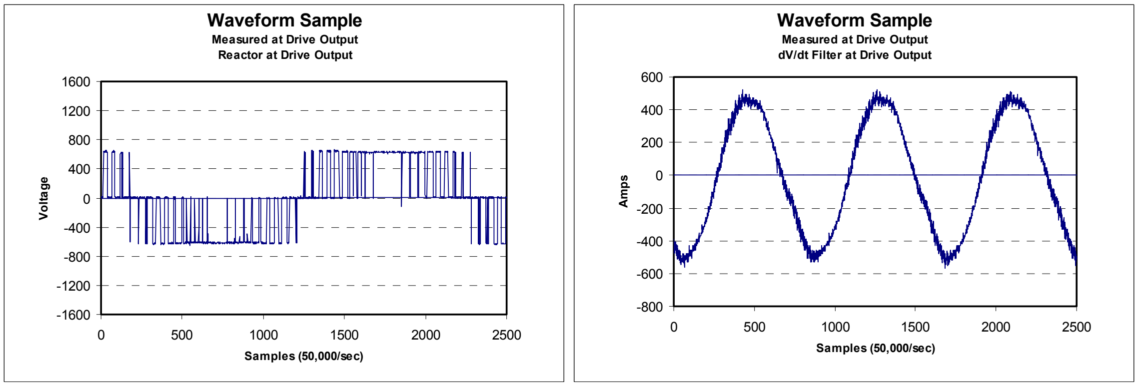
5.1 HOW A VFD WORKS

The VFDs pictured below serve (3) 15 hp fans and (3) 20 hp fans at Lamb Weston's Warden 1 storage facility.

Figure 5: VFDs at Lamb Weston 1, Warden WA

VFDs work by taking the 60 Hz AC power, converting it temporarily to DC, then converting it back to Pulse Width Modulated (PWM) AC power with adjustable frequency. The drive's input voltage is a smooth sinusoidal wave, but the output will look something like the figure below.

Figure 6: VFD Output Voltage and Current

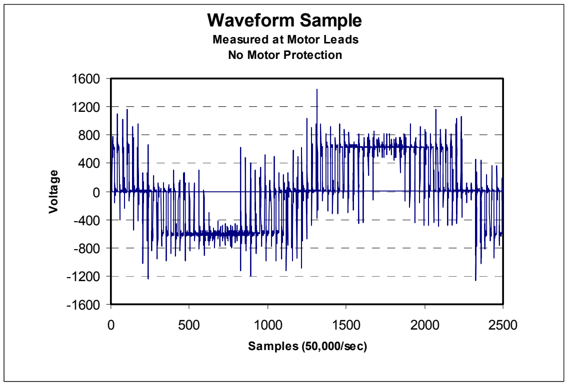


By varying the duration of the voltage pulses, the VFD can produce a nearly sinusoidal current output at any frequency desired.

5.2 MOTOR PROTECTION

If the lead lengths between the VFD and the motor are long, or multiple motors are controlled by the same VFD, damaging reflected voltage waves can form. These standing voltage waves can break down the motor winding insulation. An example of this is shown below.

Figure 7: VFD Output Voltage, Reflected Waves



5.2.1 VFD Rated Motors

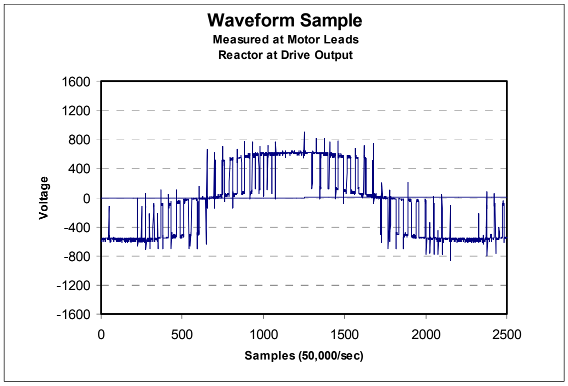
All motor manufacturers make a line of “VFD Rated” or “Inverter Duty” motors. They are built to withstand these voltage spikes. Other motors may or may not withstand them, and some additional form of motor protection is usually recommended.

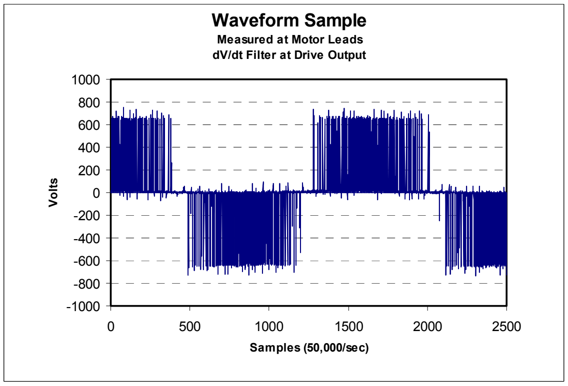
For new construction, it is best to install inverter duty motors. Load reactors may also be advised. When retrofitting existing buildings, the existing non-VFD rated motors can generally be used, but some level of motor protection may be necessary.

5.2.2 Load Reactors and Output Filters

The first level of motor protection is a load reactor. These act like a buffer, moderating the worst voltage spikes.

The next level of motor protection is the dV/dT output filter. This filter stops the voltage from exceeding a certain level, providing extra assurance that voltage spikes do not harm the motor.





5.3 VFD BYPASS CONTACTORS

The VFDs shown below each serve a 15 hp fan and have a bypass contactor in the cabinet.

Figure 8: VFDs with Bypass Contactors, Thaemert Farms

A bypass contactor allows the operator to quickly bypass the VFD should it fail, and operate the system with non-VFD practices. Most air systems with multiple fans don't have bypass contactors. If one VFD fails, the system can get by with out it for a day or two until a new VFD is installed. A bypass contactor can cost almost as much as a spare VFD. If bypass contactors are desired, compare the additional cost with the cost of a spare VFD.

This report is available on the web in PDF format at cascadeenergy.com. The authors can be contacted below:

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