Motor Control Circuits

Conserving Energy with Variable Frequency Drives

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Spiraling electric bills cause us to look for new opportunities to conserve. In most facilities many of the easy changes, such as high efficiency lighting, have already been completed. Now it is time to look at additional possibilities.

One additional easy change is the use of premium efficiency motors for new and replacement applications. Changing to premium efficiency motors on equipment that tends to run continuously or relatively long hours is usually easy because they are readily available from virtually all major motor manufacturers. The additional cost of these higher efficiency motors is easily paid off in a relatively short period of time, after which the operating cost savings can continue on for many years.

A natural next step is the use of variable frequency motor speed controls, especially on heating, ventilating and air conditioning (HVAC) systems. Variable frequency drives (VFDs) give us that opportunity because they can be easily applied to fans, pumps and blowers, which are variable torque loads (see sidebar).

One of the most common applications is on variable air volume (VAV) systems used in HVAC systems in large commercial and industrial buildings. Traditionally, these systems use constant speed fans and thermostatically controlled dampers that control chilled or heated air flow into different sections of the building. When the demand for heating or cooling is low the dampers close down and choke off the air flow. This increases pressure in the ducts, causing a slight drop in the energy needed from the fan motor. However, the size and design of the HVAC system must be set to handle the hottest day of the summer and coldest day of the winter, even though they tend to operate most of the time running at much lower average output levels.

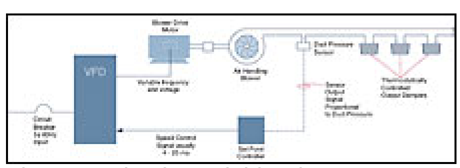

Figure 1: Simple Variable Air Volume Control

Variable Torque Loads

Three types of loads are commonly found where electric motors are used. Of the three types, the two most common are: constant torque and variable torque. Constant torque is a load where the torque required to turn

The new approach (Fig. 1) is to use a sensor in the duct to measure the pressure and automatically control fan speed to maintain a constant duct pressure regardless of how many dampers are opened or closed. In essence, it puts the system on "cruise control". Because of the unique characteristics of the variable torque blower load, dramatic energy savings result.

Similarly, VFDs can be applied to pumping systems. Rather than using throttling valves to control flow or pressure, the speed of the pump can be changed to regulate flow, pressure, and in some cases, temperature. Again, energy savings can be dramatic. In addition to saving energy, variable speed controls can reduce noise levels, wear and tear on the system and, in the case of HVAC systems, improve comfort levels.

How VFDs Work
Power (usually three phase) is rectified to direct current (DC) and filtered with large capacitors. The output of the rectifying and filtering produces power on what is known as the DC bus. In the case of a 460 volt control, this bus voltage is over 600 volts. The DC bus feeds the control's power output section, consisting of 6 high-speed electronic switches (called Insulated Gate Bi-Polar Transistors – IGBTs), which rapidly turn on and off to produce a series of variable width positive and negative voltage pulses. When filtered by the inductive motor winding, these pulses produce three phase currents in the motor windings that come very close to replicating the sine wave power the motor needs.

the shaft does not change with speed. A typical constant torque load would be a conveyor or positive displacement pump. In this case the horsepower and energy required todrive the load varies directly with speed. At half speed the horsepower (and energy required) would be roughly one half of that required at full speed.

The second common load is the variable torque load as found on fans, blowers and centrifugal pumps. On these loads full torque (and power) is required only at full speed. The torque required drops dramatically as the speed is lowered and power required drops even more dramatically. The table shows how dramatic the change would be on a 10 HP centrifugal pump or blower with speed changes.

Speed %	Horsepower	KW
100	10	8.1
75	4.2	3.4
60	2.2	1.8
50	1.3	1.1

It is this phenomenon, along with some other considerations, that makes this type of load so desirable as a conservation candidate.

The big difference between this synthesized 3-phase power and the original utility power is that the brain of the control is able to continuously adjust both the voltage and frequency of the output. In addition, the brain can limit the current, detect failures and regulate the acceleration rate of the motor, along with many other functions.

One of the fundamentals of using adjustable frequency to run standard 3-phase induction motors is that they can produce their rated torque over a relatively wide speed range, provided that the applied voltage is controlled in proportion to the frequency. For example, a 460 volt 3-phase motor that has a no-load speed of 1800 RPM with 60 cycle power applied will run at 900 RPM when operated on 30 cycle power, *but* the applied voltage must be reduced to one half of the motor's rated voltage, in this case, 230 volts at 30 cycles. The electronic controls do this very effectively, allowing relatively inexpensive standard induction motors that were once confined to single speed applications to be used for adjustable speed requirements.

HVAC Systems
The normal way that the duct pressure can be controlled involves two control components in addition to the VFD. The first device is a duct-mounted sensor that measures the pressure within the duct. In most cases, this sensor puts out a low power control signal that is proportional to the duct pressure. This signal is fed to a set point control (also called a PID control) that compares the sensor signal to a manually adjusted "set point." Some VFDs include the set point control as a part of their built-in logic, but for simplicity we will assume it is a separate item. The set point control creates a new output signal, usually 4-20 ma, that controls the output frequency of the VFD. The motor speed is controlled to be whatever it needs to be so that the pressure in the duct is maintained at a constant level regardless of the changing air volume requirement determined by the thermostatically controlled dampers throughout the building.

Pumping Applications
Similar control systems are used to regulate domestic water pressure in high rise office and apartment buildings. In the case of high rise

buildings, adjustable speed "booster" pumps are installed at several different levels in the buildings. Each booster pump regulates the pressure for several floors above its location. These pumps serve two main functions. They boost the pressure as necessary to get adequate pressure at the upper floors of the building and they control the pressure in the system as the flow requirements change hour by hour. Variable frequency controls allow smooth, efficient control of the system pressure.


Variable frequency motor speed controls can be easily applied to fans, pumps and blowers, making them ideal for use on heating, ventilating and air conditioning systems.

More Complex Systems
What has been covered so far is the simplest of the systems being used for variable air volume applications and constant pressure pumping applications. There are many other uses for VFDs in more complicated systems. For example, some of the more complex HVAC systems might involve variable speed return air fans to draw the air out of the conditioned space, exhausting some of it to the outside. This system would also be arranged to provide fresh make-up air from outside the building to replace the exhausted air.

On these more complicated systems the speed control signals for several VFDs may come from an energy management system (EMS Panel). By using the EMS control, additional energy saving features can be incorporated. Some of these controls can automatically reset temperatures and make up air flow during unoccupied periods.

Another substantial energy consuming part of many HVAC systems is the cooling tower, along with its pumps and fans. In this case VFDs can be used to control water flow and fan flow or both. Again, because these fans and pumps are variable torque loads, the energy savings for even relatively small speed reductions can be very substantial. Some more complicated systems may involve bypass systems where sets of contactors and starters are arranged to allow for 60 cycle (fixed speed) operation of the system in case the VFD fails or needs to be taken out of service for maintenance.

Motor Protection
The motors used with VFDs can be protected from overload and failure in several ways. Although conventional overload relays with heaters can be used, built into the VFDs is a system for continuously tracking motor current, measuring unbalance currents and shutting down in the event of fast heavy overload or a continuous smaller overload. This feature normally makes conventional thermal overloads with heaters unnecessary, provided the controls are properly programmed to match the motor's full load current.


Modern HVAC systems can handle the hottest days of summer and coldest days of winter with optimum efficiency.

An additional feature incorporated into many motors used in these systems is three normally closed winding thermostats (one per phase). They are connected in series and feed into the VFD control circuit. If motor over-temperature is detected, one or more of these thermostats will open and shut down the control. Winding thermostats have an advantage over conventional overload devices because they can detect overheat problems that might be caused by high ambient temperatures or lost motor ventilation in addition to overload conditions.

Control Protection
VFD Controls are normally protected by conventional circuit breakers. The control manufacturer's manuals should be checked for proper sizing, but sizing in accordance with *NEC*® Article 430.52 is the normal practice.

When motors are out of sight of the controls and disconnects are provided per Article 430.102(B), a control circuit interlock should be provided to shut down the control in the event that the disconnect is opened, especially where the control and motor are some distance apart.

VFD Selection
Control selection is fairly simple and is done on the basis of system voltage and motor full load amperage. Some controls will have higher ratings when they are used on variable torque loads. In this case a less costly control can frequently be selected.

Installation Guidelines
In general, the control manufacturer's manual should be followed for precise installation instructions. However, some general guidelines should be followed:

- Cable shields on control wiring should be grounded at the control end only.
- The low voltage control wiring from the sensors to the set point control and from the set point control to the VFD should be shielded twisted pairs and never run in the same conduit with power wiring.
- Shields from different control cables should not be interconnected.
- Input power leads and output leads should not be run in the same conduit or duct.
- Power output leads should be routed away from other cables.
- Spacing between wall mounted controls should be as suggested by the manufacturer.
- No power factor correction capacitors should be connected to the motor.
- The manufacturer's maximum cable length recommendation (between motor and control) should be followed.
- On multiple control installations separate conduits must be used for each control.
- Some manufacturers recommend that all conduit joints be bridged with a ground conductor bonded to each side of the joint.

Carrier Frequency
The carrier frequency is the rate at which the positive and negative pulses are generated by the high speed electronic switches. When the control is operated with a low carrier frequency, the motor can produce an annoying "singing" noise or whine. In many industrial applications this noise is not objectionable but in HVAC systems where motors are located in or near occupied space, the noise can be very objectionable. To eliminate this problem, the carrier frequency can be adjusted so it occurs above the audible range. This is often called the "quiet mode." To do this the carrier frequency might be adjusted to 8,000 hertz or higher.

Resonant Points
Frequently the flexibility of the ductwork allows it to become mechanically resonant with annoying vibrations at certain fan speeds. Fortunately VFDs have built into their logic the ability to avoid or skip over the troublesome frequencies.

If this becomes a problem, you need to manually run the control through the normal frequency range. This might be from 20 to 60 hertz. As the test progresses, the frequency of any resonating points should be noted. Once the troublesome points have been found, the control can be programmed to skip these points. Once this is done, fan speed changes will occur smoothly but the control will pass through the problem areas and not operate continuously at the selected troublesome frequency or frequencies. Although less often, similar resonant problems can occur in pumping systems and the solution is the same.

Summary
After the easy power conservation measures have been completed, it is time to move to the next steps in energy conservation. One very effective option is to refit HVAC systems with VFDs. This change allows the system's performance to be continuously optimized for conditions both inside and outside the building. The change can add to comfort levels, reduce maintenance requirements and, because of the nature of variable torque loads, save a great deal of money on monthly electric bills. As an added benefit, good design and the incorporation of an Energy Management System can result in savings on the natural gas, oil or electricity used as the source of heat and air conditioning in the facility.

URL: http://www.nfpa.org/itemDetail.asp?categoryID=1324&itemID=30494&URL=Publications/necdigest/necdigest%20Magazine/Current%20issue/Features/Motor%20Control%20Circuits

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