Variable Frequency Drives

Purchasing Tips

Analyse the System as a Whole

Since the process of converting incoming power from one frequency to another will result in some losses, energy savings must always come from optimizing the performance of the complete system. The first step in determining the energy savings potential of a system is to thoroughly analyse the operation of the entire system. Detailed knowledge of the equipment operation and process requirements are required in order to ensure energy savings.

The most promising candidates for realizing energy savings are systems for centrifugal fans, blowers and pumps that have been designed to meet peak loads but actually operate at reduced load for extended periods. The following discussion pertains to centrifugal systems, but the same principles can be applied to other systems. Evaluating the energy-saving potential of a centrifugal system should include the following steps:

1. Develop a complete understanding of the process requirements and the equipment to which the centrifugal machine supplies fluid.
2. Obtain complete engineering specifications and performance curves for the centrifugal machine.
3. Obtain specifications for all components of the system, including dampers, valves, ducts or pipes, and heating or cooling coils.
4. Develop a load/time profile for the system. This step is critical for calculating accurate energy savings. For each component, list annual hours, all flow conditions and the input power to the centrifugal machine.
5. For each point in the above step, calculate the input power required by a VFD-driven motor and centrifugal machine delivering the same flow. Input shaft power can be determined from the centrifugal machine performance curves.
6. For each operating point, calculate the difference in power resulting from adding a VFD, and multiply each by the number of hours of annual operation. The difference is the energy savings resulting from installing a VFD.

The above process requires qualified staff with sufficient expertise with all components of the system, from VFD through to the process equipment.

Pump and fan affinity laws govern the relationship among speed, flow and input power. The laws state:

- flow is proportional to speed
- pressure increases with the square of the speed
- power increases with the cube of the speed

When speed is reduced to 75 percent of design speed, flow decreases to 75 percent, outlet pressure decreases to 56 percent, and the input power requirement drops to 42 percent of full-speed values. For a similar flow reduction with a throttling valve or damper, the input power drops to only 80 percent. Note that pressure falls off more rapidly than flow.

VFD and Motor Selection

Once you have verified the energy savings achievable using a VFD in your application, the following topics should be considered when selecting a motor and drive combination.

Introduction

What Is a Variable Frequency Drive?

Adding a variable frequency drive (VFD) to a motor-driven system can offer potential energy savings in a system in which the loads vary with time. VFDs belong to a group of equipment called adjustable speed drives or variable speed drives. (Variable speed drives can be electrical or mechanical, whereas VFDs are electrical.) The operating speed of a motor connected to a VFD is varied by changing the frequency of the motor supply voltage. This allows continuous process speed control.

Motor-driven systems are often designed to handle peak loads that have a safety factor. This often leads to energy inefficiency in systems that operate for extended periods at reduced load. The ability to adjust motor speed enables closer matching of motor output to load and often results in energy savings.

How Does a VFD Work?

Induction motors, the workhorses of industry, rotate at a fixed speed that is determined by the frequency of the supply voltage. Alternating current applied to the stator windings produces a magnetic field that rotates at synchronous speed. This speed may be calculated by dividing line frequency by the number of magnetic pole pairs in the motor winding. A four-pole motor, for example, has two pole pairs, and therefore the magnetic field will rotate 60 Hz / 2 = 30 revolutions per second, or 1800 rpm. The rotor of an induction motor will attempt to follow this rotating magnetic field, and, under load, the rotor speed "slips" slightly behind the rotating field. This small slip speed generates an induced current, and the resulting magnetic field in the rotor produces torque.

Since an induction motor rotates near synchronous speed, the most effective and energy-efficient way to change the motor speed is to change the frequency of the applied voltage. VFDs convert the fixed-frequency supply voltage to a continuously variable frequency, thereby allowing adjustable motor speed.

A VFD converts 60 Hz power, for example, to a new frequency in two stages: the rectifier stage and the inverter stage. The conversion process incorporates three functions:

Rectifier stage: A full-wave, solid-state rectifier converts three-phase 60 Hz power from a standard 208, 460, 575 or higher utility supply to either fixed or adjustable DC voltage. The system may include transformers if higher supply voltages are used.

Inverter stage: Electronic switches - power transistors or thyristors - switch the rectified DC on and off, and produce a current or voltage waveform at the desired new frequency. The amount of distortion depends on the design of the inverter and filter.

Control system: An electronic circuit receives feedback information from the driven motor and adjusts the output voltage or frequency to the selected values. Usually the output voltage is regulated to produce a constant ratio of voltage to frequency (V/Hz). Controllers may incorporate many complex control functions.

Converting DC to variable frequency AC is accomplished using an inverter. Most currently available inverters use pulse width modulation (PWM) because the output current waveform closely approximates a sine wave. Power semiconductors switch DC voltage at high speed, producing a series of short-duration pulses of constant amplitude. Output voltage is varied by changing the width and polarity of the switched pulses. Output frequency is adjusted by changing the switching cycle time. The resulting current in an inductive motor simulates a sine wave of the desired output frequency. The high-speed switching of a PWM inverter results in less waveform distortion and, therefore, lower harmonic losses.

The availability of low-cost, high-speed switching power transistors has made PWM the dominant inverter type.

Applications

Variable speed drives are used for two main reasons:

- to improve the efficiency of motor-driven equipment by matching speed to changing load requirements; or
- to allow accurate and continuous process control over a wide range of speeds.

Motor-driven centrifugal pumps, fans and blowers offer the most dramatic energy-saving opportunities. Many of these operate for extended periods at reduced load with flow restricted or throttled. In these centrifugal machines, energy consumption is proportional to the cube of the flow rate. Even small reductions in speed and flow can result in significant energy savings. In these applications, significant energy and cost savings can be achieved by reducing the operating speed when the process flow requirements are lower.

In some applications, such as conveyers, machine tools and other production-line equipment, the benefits of accurate speed control are the primary consideration. VFDs can increase productivity, improve product quality and process control, and reduce maintenance and downtime. Decreasing cost and increasing reliability of power semiconductor electronics are reasons that VFDs are increasingly selected over DC motors or other adjustable speed drives for process speed control applications.

Motors and VFDs must be compatible. Consult the manufacturers of both the VFD and the motor to make sure that they will work together effectively. VFDs are frequently used with inverter-duty National Electrical Manufacturers Association (NEMA) design B squirrel cage induction motors. (Design B motors have both locked rotor torque and locked rotor current that are normal.) De-rating may be required for other types of motors. VFDs are not usually recommended for NEMA design D motors because of the potential for high harmonic current losses. (Design D motors are those that have high locked rotor torque and high slip.)

Additional Benefits of VFDs

In addition to energy savings and better process control, VFDs can provide other benefits:

- A VFD may be used for control of process temperature, pressure or flow without the use of a separate controller. Suitable sensors and electronics are used to interface the driven equipment with the VFD.
- Maintenance costs can be lower, since lower operating speeds result in longer life for bearings and motors.
- Eliminating the throttling valves and dampers also does away with maintaining these devices and all associated controls.
- A soft starter for the motor is no longer required.
- Controlled ramp-up speed in a liquid system can eliminate water hammer problems.
- The ability of a VFD to limit torque to a user-selected level can protect driven equipment that cannot tolerate excessive torque.

Savings in VFDs?

The potential energy savings from installing a VFD is illustrated in the following example. Here, a 40 hp motor is used in an HVAC system with a flow-control damper. The system operates 365 days a year with the load/time profile shown in Table 1. The damper is removed and a VFD installed. The estimated annual energy savings realized from the use a VFD is shown in Table 1.

Table 1. Potential Energy Savings From Replacing a Damper With a VFD

Airflow Volume (percent of maximum)	Daily Operating Time (hours)	Energy Consumed Using a Damper (kWh/ year)	Energy Consumed Using a VFD (kWh/ year)	Difference in Energy Consumption (kWh/ year)
50%	2	18 500	4 800	13 700
60%	3	29 300	9 800	19 500
70%	6	61 700	26 800	34 900
80%	6	63 300	35 900	27 400
90%	4	44 200	32 600	11 600
100%	3	34 200	35 200	–1 000
Total	**24**	**251 200**	**145 100**	**106 100**

The above example shows a possible electrical energy saving of 106 100 kWh per year, resulting from replacement of the existing damper-control system with a VFD.

Will the motor withstand the repetitive voltage stresses from use of a VFD?

General-purpose induction motors are not designed for repetitive voltage overshoots that exceed line voltage plus 1000 volts. With a 230 VAC system, overshoots may not exceed this limit, but with a 575 VAC system, overshoots are likely. Repeated voltage stresses may lead to insulation breakdown and premature motor failure.

To use a VFD with an existing general-purpose motor, additional filtering and transient protection may be required. NEMA definite-purpose motors rated "Inverter Duty" are recommended for use with VFDs. These motors can withstand repetitive voltage spikes that are 3.1 times the rated RMS voltage.

Is motor cooling adequate for extended operation at very low speeds?

Cooling often depends on motor speed, such as with totally enclosed fan-cooled (TEFC) motors. To meet constant torque loads, therefore, a motor should not be operated at less than 30 percent speed without additional cooling. Consider a larger motor, constant speed cooling or a totally enclosed non-ventilated (TENV) motor for these conditions. Motor thermal protection devices will prevent high-temperature damage when motors operate continuously at very low speeds. With variable torque loads such as centrifugal machines, the rapidly decreasing power at low speed reduces cooling problems.

Will harmonics affect nearby sensitive equipment?

Additional line filtering is often required to reduce the propagation of harmonics and radio frequency interference (RFI) to other equipment. Short leads between the motor and the VFD help minimize RFI propagation. When leads are longer than 15 metres (50 feet), reactive filters are recommended. Motor leads should also be enclosed in a rigid conduit to reduce RFI.

Is the VFD starting torque and acceleration/deceleration adequate for the load?

The VFD breakaway torque is less than the motor locked rotor torque and is limited by the VFD maximum current rating. This current rating also limits the rate of load acceleration. Acceleration, deceleration and maximum current are user-programmable.

Can a VFD be used for all types of loads?

Yes. VFDs for use with constant torque loads should be rated for operation at 150 percent load for a period of one minute. Variable torque loads such as fans and pumps are easier to start, and therefore the VFD overload rating is lower. The drive should be matched to the load.

Does the application have a high static pressure or head?

Applications in which a minimum pressure must be maintained may not be suitable candidates for a VFD. For example, if high pressure is required even at low flow, it may not be possible to significantly reduce pump speed. When speed and flow reduce, so does pressure. For this application, other energy-saving strategies such as parallel pumps may offer more energy savings. Check the pressure limitations in your system. More information on VFD pumping applications is in Variable Speed Pumping - A Guide to Successful Applications, available from the U.S. Department of Energy's Industrial Technology Program.

What type of enclosure is required?

Check the ratings of both the drive and its enclosure to make sure that they are suitable for the climate to which they will be exposed (i.e., outdoor weather protection).

Is speed control accuracy important for my application?

Most VFDs incorporate a user-programmable, constant volts-to-frequency ratio over the operating frequency range of the drive. For more accurate speed control, a flux vector control strategy with either direct or indirect measurement of rotor flux may be required.

Is direction of rotation affected?

The phase sequence of the supply connection to the VFD does not affect the rotation direction of the drive. Changing the phase sequence between the drive and the motor will change the direction of rotation of the motor. Be sure to verify rotation before connecting the drive to the equipment. Some equipment may be damaged if rotation is reversed. If a bypass contactor is used with a VFD, be sure that the rotation direction is correct during bypass operation

Does the application require dynamic braking?

Load braking is usually accomplished by switching in a power load resistor across the DC bus to dump excess energy. This is usually an optional feature that is available only with some drives.

How many motors can be operated on a drive?

More than one motor on a drive is common. All receive the same frequency, so they change speed in unison. Each motor must have its own overload protection.

Do I require remote monitoring or flexible control and set-up software?

You may need drive monitoring and set-up software with RS-485 multi-drop communication. RS-485 allows monitoring and control of several drives from a remote location.

Do I need bypass switching?

Bypass switches are sometimes used so that a motor can operate when connected directly to the utility power supply. This enables operation of the motor when the drive is out of service.

Reference:

http://oee.nrcan.gc.ca/industrial/equipment/vfd/vfd.cfm?attr=24