CURRENT THINKING ON...

VARIABLE DRIVE SPEEDS

BY JIM BISGROVE, ENERGY MANAGER, SOUTHEND HOSPITAL NHS TRUST

In terms of energy efficiency it is not surprising that the variable speed drive (VSD) has become a significant technology. An estimated 65 per cent of industrial energy is used by electric motors, predominantly in induction motors. To understand the significance of VSDs' contribution to energy reduction it is important to first consider the huge numbers of induction motors. The simplicity, low cost, low maintenance, robustness of induction motors has lead to this type of motor being extremely common in industry and building services. Second, it must be realised that this energy consumption can be minimised in only two general ways:

- Making motors themselves more efficient;
- Efficient control of speed at which the motors run.

While improvements in motor design and construction have yielded energy efficiencies in use, the variation of speed was not so common before the advent of VSDs. This is because the speed of this type of motor is governed by the frequency of the AC power. To understand why this is, it is necessary to appreciate some basics of induction motors.

Induction motors are constructed from a cylindrical cage-like rotating element (rotor) which is encased within an outer wound wire stationary element (stator). The rotor is not electrically connected to the stator. As AC electricity flows in the stator a magnetic field is induced which turns the rotor at a speed close to that of the magnetic field, normally between 90 per cent-95 per cent of the field rotation. Since the speed of the magnetic field inside the motor is completely dependant on the frequency of the AC power supply, then so is the speed of the rotor. As previously stated, there are many practical reasons for the use (and continued use) of induction motors so the ability to vary the speed of this very common type of motor eliminates the limitation of fixed speed and opens the possibilities for energy reductions.

To the layman a VSD is an electronic power converter that is fed with fixed frequency electrical energy and is able to vary the frequency of the output power to an electrical device. In UK buildings this normally means a 50Hz single or three phase electrical supply coupled to an induction motor. VSDs (or sometimes called variable frequency drives, as this describes what they do) allow the speed of an induction motor to be varied. Before the development of VSDs the ubiquitous induction or squirrel cage motor had to run at a fixed speed and any speed variation achieved by either linkages or separate controls acting on other parts of the system that the motor was driving.

It should be noted that there are a number of methods of

VSDs eliminate the limitations of fixed-speed motors

PIC COURTESY ABB

WELCOME...

Energy in Buildings and Industry and the Energy Institute are delighted to have teamed up to bring you this Continuing Professional Development initiative.

This is the fourth module in the fourth series and focuses on Low-energy heating system design. It is accompanied by a set of multiple-choice questions. To qualify for a CPD certificate readers must submit at least eight of the ten sets of questions from this series of modules to EiBI for the Energy Institute to mark. Anyone achieving at least eight out of ten correct answers on eight separate articles qualifies for an Energy Institute CPD certificate. This can be obtained, on successful completion of the course, for a fee of £15 (for members) or £25 (for non-members).

The articles, written by a qualified member of the Energy Institute, will appeal to those new to energy management and those with more experience of the subject. The following topics will appear in the forthcoming issues of EiBI: metering/monitoring; photovoltaics; underfloor heating; air conditioning; and heat pumps.

If you miss any of the modules in the series let me know (mark.thrower@btinternet.com) and we will send the missing modules in 'pdf' format to you either by either e-mail or on a CD..

The previous 30 modules from the first three series are also available free of charge. Please contact me by e-mail if you would like to receive these.

MARK THROWER, MANAGING EDITOR

Produced in association with energy INSTITUTE

externally varying the speed of the driven load when the driving motor is operating at a constant speed. These include:

- belt or chain drive;
- gear box;
- idler wheel drive;
- eddy current coupling

All the above are separate devices which are mechanically driven by the output of a constant speed motor. Each has differing characteristics that lend themselves to specific tasks and in certain situations will be the first choice solution for a specific task, but none of them actually alter the speed of the motor.

VSDs on the other hand control torque (the twisting force) and speed of an induction motor by variation of the frequency and the voltage applied to the motor.

In terms of the detailed design VSDs are invariably built by combining three operations. The first section commonly comprises a full wave bridge rectifier and a large capacitive filter to convert the incoming power from AC to DC. Some manufacturers have now replaced the usual input diodes with power transistors, which switch in phase with the supply voltage sine wave, significantly reducing harmonics.

The second section is a power DC filter which comprises a number of high power DC capacitors. The DC filter will commonly include one or two DC chokes in series with the rectified DC. The detailed electronic design of this part of the drive is important to the performance of the drive as the filter contributes to reducing undesirable by-products of the VSD such as heat emission, EMC/RFI radiation and harmonics.

After the DC filter, the smoothed DC feeds an inverter section which contains a series of solid state switches. In modern VSDs these switches are components called insulated (or isolated) gate bipolar transistors (IGBTs) which is a recent electronic development. The early IGBTs of the 1980s were problematic but current third generation ones are very fast, rugged and have excellent tolerance to overloads. Controlling the times when these solid state switches are opened and closed produces a collection of square waves or pulses that combine to cause a sinusoidal current, at the required voltage and frequency, to flow in the motor circuit. This is known as pulse width modulation (PWM). The wave form can only approximate a sinusoidal wave, as the output from the inverter is digital so the curves are not smooth. The output switches operate at a high frequency, typically between 2KHz and 20KHz which is why a high frequency whine can often be heard from the drive. The higher the switching frequency the smoother the wave form fed to the motor, but also the greater electrical losses from the VSD. As induction motors are electrically quite robust a jagged wave form is not usually a problem, except that it causes inefficiencies in the motor. A compromise can be achieved at commissioning between losses in the VSD and losses in the motor.

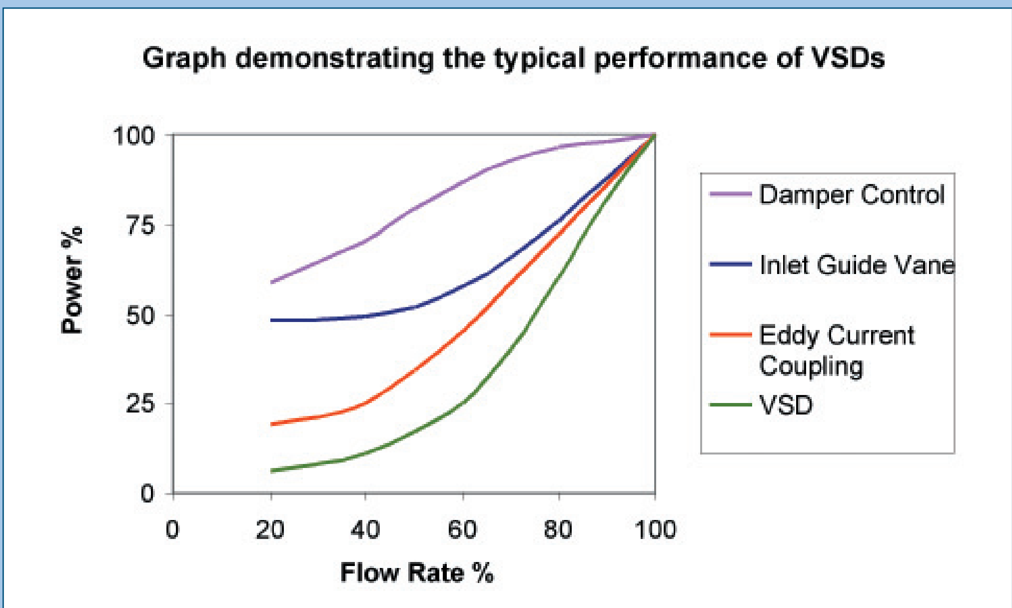
Internal circuitry in VSDs has to be capable of withstanding very high rates of change of voltage within very short time spans to give long service. Hence the quality of modern electronic components, particularly IGBTs, incorporated in today's drives make an important contribution to the success of this technology. This, along with advances in data processing power, are the major technological advances which have improved VSDs so much in recent years.

An electric motor driven system can often conserve energy by running at a speed that varies according to the operation it is performing. For example, the speed of a pump may need to change dynamically to respond to the conditions, and all the time that full performance is not required the system could be "turned down" to save energy. Thus VSDs are well suited to systems that have to cater for varying load. This could be variable torque or variable speed and although there is a huge spectrum of applications where varying the motor speed could save energy, pumps and fans have been the most common. In recent years the use of VSDs is also becoming a very common way of meeting a variable load in refrigeration compressors.

Additionally, in these systems a motor would be sized for the system to meet a theoretical design maximum flow rate or pressure (frequently with a design margin). It often transpires that this level of performance is not required in practice and a reduction in performance, achieved by some form of throttling in the fluid flow, is necessary at commissioning. While throttling will reduce the energy requirement, a much greater energy saving is yielded by motor speed control.

Firstly the process of control is more efficient. This has been demonstrated by a number of sources including manufacturers and academic study. The graph below indicates typical relative efficiencies of control devices for an induction motor driven fan air system. This graph indicates the relative efficiency of VSDs over other techniques for controlling flow. At 80 per cent airflow, the energy consumption of damper control is 97 per cent of maximum and guide vanes 76 per cent of maximum but only 51 per cent using a VSD.

Further, at 50 per cent airflow, the commonly used guide vane system results in the fan motor absorbing over three times the energy of a motor controlled by VSD.




A new standard for harmonics in the building sector, BS EN 61000-3-12, will become mandatory from 2008

Relatively small reductions in flow yield considerable energy savings. This bit of physics is well explained in the CPD Module 004, 2003 and obviously holds true today, but the graph demonstrates how much more efficient the flow regulation is when achieved by a VSD. The significance in terms of energy saving of this characteristic is profound considering the number of systems driven by motors, fans and pumps that are overrated by 10 per cent-30 per cent and then throttled back by use of flow regulation. A good rule of thumb that amply demonstrates the high proportion of energy that can be saved by designing in or retrofitting VSDs is a centrifugal pump or fan running at half speed consumes only one eighth of the energy (12.5 per cent) compared to one running at full speed. This is because the power absorbed by a pump or fan is proportional to the cube of the volume flow or the motor speed. For instance, reducing the pump speed to 80 per cent only requires 51 per cent of the power.

The second general advantage VSDs have over other means of flow control is by simple virtue of a modern VSD's convenience and compatibility with other controls such as PLC and BEMS. For example, systems that ventilate large public spaces where occupancy varies considerably throughout the day would traditionally have operated at constant speed during open hours. Using VSDs in association with external sensors can enable the same system to be controlled on interior air quality. Simply dropping the speed of the fan during quite periods can be arranged by BMS and air quality sensors providing a control voltage to a VSD. The ability to accept external 0V to 10V control signal is built into most modern VSDs. This system saves electrical energy absorbed by the fan, wear and tear (thus maintenance) on the motor and also reduces the cooling and heating requirements of the system.

Drives are often used in some form of automation process and so they are now including additional functionality and controls to simplify the automation process.

In fact modern VSDs can now do much more than adjust the speed of a motor. Many models are equipped with a wide range of functions and optional hardware.

Some examples of what is available are:

- PID controllers to control the motor based on an external signal deviation from set point;
- Soft starting - a combination of torque and acceleration control, used to prevent large motors from damaging a system when it starts, also avoiding the need for star-delta start and associated control gear; and
- Error reporting - to keep a record of power quality and faults that assist in troubleshooting

Due to cost reductions over recent years VSDs have now started to be used as commissioning controllers, enabling systems to be set up to deliver the design intent with greater convenience and efficiency than traditional methods.

Including VSDs in new plant is becoming an obvious choice, but opportunities to save energy by retrofitting VSDs and achieving an acceptable payback have to be searched out. Any motor that is lightly loaded and running for extended periods would make a good candidate for retrofitting a VSD. Typical examples of these would include any combination of the following circumstances:

- Motors drawing less than 80 per cent of full load current for 4000 hours per year;
- Heating pumps in (potential) variable volume systems;
- Chilled water pumps in (potential) variable volume systems;
- Ventilation fans in full fresh air systems where the system could be adapted to respond to occupancy;
- Ventilation systems in place of recirculation dampers; and
- Fans in variable volume air conditioning or all air heating systems.

The biggest drawback to VSDs is that they produce harmonics in the electrical supply system. Harmonics are high frequency noises which causes problems with power quality. Since many devices such as transformers are designed to be operated with clean, sinusoidal electricity, harmonics overheat motors and transformers and cause efficiency losses in power systems. The typical total harmonic distortion from a standard VSD across all the harmonic orders is about 30 per cent, which may be significant in itself for a large VSD, but this phenomena is also cumulative if a number of VSDs are installed on the same electrical system. Harmonics can be reduced by installing filters on the feed side of the VSD and many modern VSDs, particularly on smaller units, designed for general building services applications, have these filters built in.

Harmonics have attracted much attention in recent years as manufactures strive to reduce the down side in their products. Performance improvements include features such as "Active Bridge" and "Swinging Choke". This is a complex issue that cannot be discussed further here, as the treatment of harmonics depends on circuit conditions, motor load etc, but the fact remains that the latest generation of VSDs have really improved in this area.

Practical considerations of heat dissipation, installation space and maintenance should also be considered. Most VSD devices emit between 2 per cent and 6 per cent of the power they handle in heat, so well ventilated panels are necessary. Space requirement is becoming less of an issue as the unit size has reduced in recent years, and maintenance mainly consists of cleaning to ensure the heat sinks work effectively. Caution is needed when working on VSDs as they do tend to remain live (charged) for some time after they have been electrically isolated.

Under the new building regulation approved documents, Part L requires that ventilation fans should be capable of achieving a specific fan power at 25 per cent of its design flow rate which is no greater than that achieved at 100 per cent. It also states that all fans above 1100 W should have a means of efficient variable-flow control. Clearly this will encourage more VSDs

VARIABLE SPEED DRIVES

SERIES 4 / MODULE 4

QUESTIONS

Please mark your answers on the sheet below by placing a cross in the box next to the correct answer. Only mark one box for each question. You may find it helpful to mark the answers in pencil first before filling in the final answers in ink. Once you have completed the answer sheet in ink, return it to the address below. Photocopies are acceptable.

1. Which of the following is NOT a reason for induction motors being extremely common in industry and building services?
- ☐ Simplicity
- ☐ Low cost
- ☐ Low maintenance requirement
- ☐ Longevity of the commutator

2. How could speed control be achieved in a system powered by an induction motor without a VSD?
- ☐ Varying the voltage to the motor
- ☐ Restricting the current to the motor
- ☐ Connecting a mechanical device to the output of the motor
- ☐ Applying the power to the motor in short pulses

3. What function does the inverter section of a VSD's electronics undertake?
- ☐ Improving the system power factor
- ☐ Filtering out harmonics
- ☐ Restricting the current to the motor
- ☐ Switching the DC input in short pulses to simulate AC

4. In a centrifugal fan system, at 50 per cent airflow, how much more energy would a typical guide vane system absorb than a motor controlled by a VSD?
- ☐ Over 3 times
- ☐ Two and a half times
- ☐ Twice as much
- ☐ Less than one and a half times

5. What is (PWM)?
- ☐ Primary wound magnet
- ☐ Post winding modulation
- ☐ Pulse width modulation
- ☐ Primary width mode

6. What is the main electrical problem with a VSD?
- ☐ Overheating
- ☐ Harmonics
- ☐ Single phasing
- ☐ Voltage regulation

7. What is one of the two main areas of improvement in VSD technology in recent years?
- ☐ Use of modern IGBTs
- ☐ Superior product support
- ☐ More robust housing
- ☐ Tolerance of RFI

8. In what situation can the best energy reduction be achieved by introducing VSDs?
- ☐ Where the load on the system is large
- ☐ Where the load on the system is variable
- ☐ Where the load on the system is constant
- ☐ Where the load on the system is small

9. What does the speed of an induction motor depend on?
- ☐ The supply voltage
- ☐ The supply resistance
- ☐ The supply frequency
- ☐ The supply current

10. What criteria do VSDs meet that allow them to qualify for ECAs?
- ☐ They are energy efficient
- ☐ They feature on the ETL
- ☐ They meet the requirements of the building regulations
- ☐ Because their purchase price is only a very small part of the whole life cost

Name .... (Mr. Mrs, Ms) ....

Business Address ....

Town ....

....

Post Code ....

email address ....

Tel No. ....

Completed answers should be mailed to:
The Education Department, Energy in Buildings & Industry,
P. O. Box 825, GUILDFORD, GU4 8WQ

TVSDs have great compatibility with control systems such as BMS

to be installed in new building projects, but as many of the mechanical and electrical systems are now "controlled items" these rules will apply in many circumstances to refurbishment as well.

As VSDs rectify the incoming supply, electrical harmonics are produced and the current waveform is much distorted, particularly with drives without reactors (filtering devices). This can cause a very poor power factor. While the displacement power factor can be maintained at a reasonable level, the distortion power factor can be low (0.7) and cannot be corrected with capacitive power factor correction only improved with expensive filters. Although, a poor power factor is not a legislative issue, paying for the correction or for the cost of operating a low power factor is wasteful.

Power quality effects have long been an issue for VSDs and a number of standards cover this area of concern. The Institute of Electrical and Electronic Engineers (IEEE) Standard 519–1992 explains the reasons for limiting harmonics and provides recommended limits. A recent European standard IEC/EN 61000-3-12 approved at the end of 2004 sets strict limits for harmonics generated by individual pieces of equipment including VSDs, and has driven considerable improvement in this area.

Nearly all of a motor's whole life cost is spent on energy, the purchase price only accounts for a very small proportion so purchasing a VSD to reduce energy consumption is logical. Even if the end user is a cash limited small to medium size enterprise, it may well find VSDs qualify for an interest-free government loan from Action Energy. In addition, all UK profit making organisations can claim Enhanced Capital Allowances (ECAs) from investment in VSD technology as VSDs appear on the Government's Energy Technology List (ETL). There is a huge range of VSDs covering most situations on this list.

Enhanced Capital Allowances (ECAs) are a tax relief given by reducing the taxable profits of the business. The scheme extends the capital allowances for investment in plant and machinery by allowing the costs of assets purchased from the ETL to be written off against a business's taxable profits. The main rate of allowances for plant and machinery is 25 per cent a year on a reducing balance basis, ECAs enable businesses to claim 100 per cent of the investment in the year that the expenditure was incurred.

Further details can be found on the Inland Revenue's website at www.inlandrevenue.gov.uk/capital_allowances/eca-guidance.htm. This special treatment is available for "designated" energy saving plant and machinery published on the ETL which can be found at www.eca.gov.uk/etl/search.asp?