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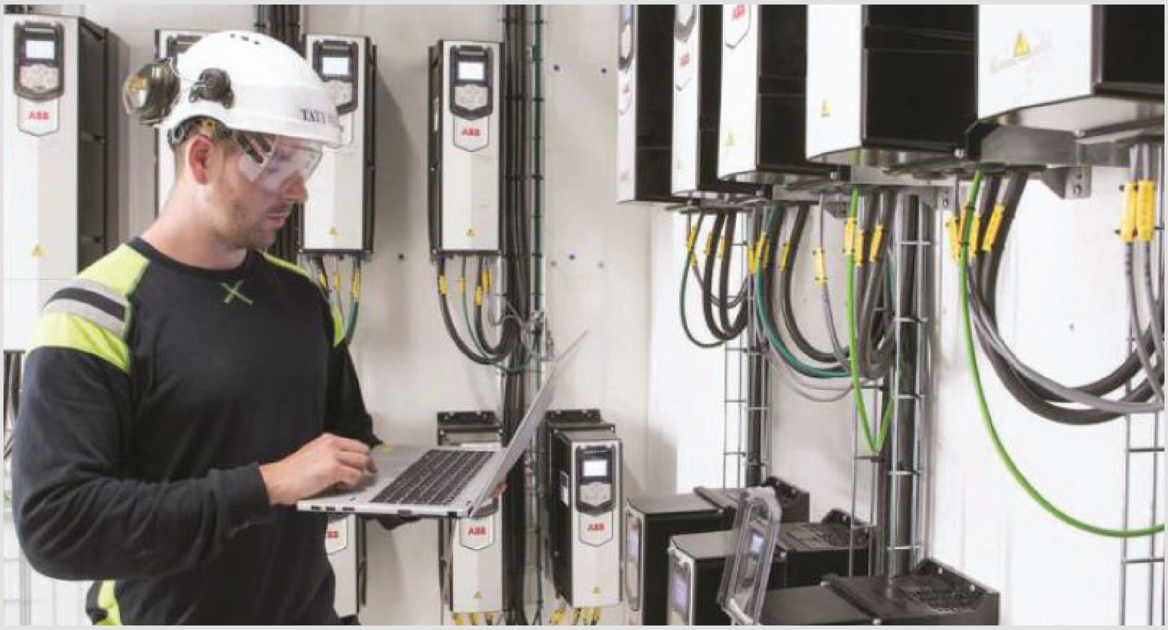

Variable speed drives

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According to International Energy Agency, electric motor systems use around half of global electricity. It is also estimated that across the UK and EU some 8bn motors are in use. For the UK it is estimated that electric motor and drive systems account for over 60 per cent of UK industrial electricity demand. In practice, a large part of this is accounted for by fans, pumps and compressors – both refrigeration and air. This makes addressing energy use in motors and drives an important topic to address.

In simple terms an electric motor is a machine used to convert electrical power into mechanical power. Electric motors are highly efficient at this conversion. Larger motors can be over 96 per cent efficient with smaller motors typically being above 80 per cent.

While a motor can be high efficiency this does not mean that the complete motor-driven system is efficient. The complete system needs to be critically evaluated. This should always start by having an understanding of the load – the job of work that is to be undertaken. From the energy saving point of view, the question 'does this work need to be done at all?' is a good place to start. Having decided a job of work needs to be done the next step is to do it as efficiently as possible. Some loads will be fixed duty – the solution here is to have an efficient, fixed-speed drive system. However, where the system load can be varied or modulated the scope for energy saving is present.

Energy savings up to 40%

Using variable speed drives (VSDs) to control motor systems can typically save 15-40 per cent of energy used in applications where the load on the system is variable. The use of VSDs is particularly effective in fan and pump applications where they might be used to replace mechanical methods of output regulation. For example, a 20 per cent reduction in fan speed can lead to a 50 per cent reduction in energy use.

CEMEP (European Committee of Manufacturers of Electrical Machines and Power Electronics) reports that global electrical energy consumption could be reduced by 8 per cent if VSDs were used in every suitable application. They also note that 75 per cent of VSDs are used on fans, pumps and compressors.

The speed of an AC induction motor is determined by the number of poles in the motor and the frequency of the AC supply – fixed in the UK at 50Hz – so in practice the motor speed is determined by the number of poles.

It should be noted that the actual speed of a loaded motor is less than its nominal speed as a result of slip. For example, a fully loaded' four-pole motor at 50Hz might run at 1,425rpm, not the nominal speed of 1,500rpm.

The motor needs to be coupled to the load. Where the speed ratio is 1:1 this can be a direct coupling. Where the speed of the load is a ratio of the motor speed a common solution is the pulley and belt drive.

In industrial applications gearboxes are also used – particularly where very low speeds are required. The efficiency of gearboxes can range from 85-90 per cent for a worm and gear gearbox to around 98 per cent for a helical gear box. Pulleys and gearboxes provide a stepped, fixed speed change.

There are a number of 'mechanical' options to provide a variable speed output:

- **variable pitch drive** – the pitch diameter of one or both pulleys in a pulley and belt drive is made adjustable;
- **hydraulic hydrostatic drive** – uses a positive displacement hydraulic

The speed of an AC induction motor is determined by the number of poles

Number of Poles	2	4	6	8	10
Nominal Speed	3,000	1,500	1,000	750	600

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pump and motor to provide the variable speed output;

- **hydrodynamic drive** – two impellors coupled together with hydraulic fluid; and
- **hydro-viscous drive** – has a number of discs on the input and output shafts with a thin film of oil between them.

There are also other mechanical 'capacity' control options for specific applications such as inlet guide vanes for fans to provide a variable air volume. While devices like these control the capacity of the fan, in many systems dampers are used to 'throttle' the air volume – or valves for fluid flow.

Options for variable speed

When comparing variable speed drives to other capacity control methods the analogy of driving a car is worth considering. Using a throttle valve or damper is like driving a car with the accelerator in a fixed full power position and then using the brake to control speed.

The options for variable speed motors are:

- **DC motors** – this was a traditional solution for variable speed applications but often with longer term maintenance issues;
- **variable speed motors (AC)** – often a solution for smaller applications. One example is the ECM or electronically commutated motor. This is a good option for fan coil units, condensing units etc. Another is the switched reluctance motor found in air compressors; and
- **AC motors & variable speed drives (VSDs)** – these are the most common application for energy saving and HVAC applications.

The electronic variable speed drive is also known as the inverter or variable frequency drive (VFD). A VSD works by using power electronics to change the frequency of the power supply to the motor. Frequency being one of the two factors determining motor speed (the other being the number of poles).

As an example, if we had a four-pole motor running at mains frequency (50Hz) its nominal speed would be 1,500 rpm. If we wanted it to run and 600 rpm the supply would need to be 'converted' to a 30Hz supply. See below

The process for achieving a variable frequency supply is to convert a 50Hz AC supply to a direct current (DC) and then by a process of pulse width modulation (PWM) synthesise an AC supply with a different, controllable frequency.

The VSD is a proven, reliable technology for controlling the speed of an AC motor. To deploy the concept of the VSD we need to look at the types of motor load and the benefits using a VSD might offer. It is important when looking at loads to understand torque. Torque is the rotating force produced by a motor – typically measured in Newton metres (Nm). Torque combined with speed becomes the motor power.

Typical applications for the three main types of motor load

LOAD TYPE	APPLICATIONS
Constant Power	Centre Winders Machine tools Paper machines Traction control equipment
Constant Torque	Agitators Compressors Conveyors Crushers Mixers Positive displacement pumps Stirrers
Variable torque	Centrifugal pumps Fans

Three common types of load

There are three common types of motor load:

- **constant power** – here the power requirement is fixed and torque is inversely proportional to speed (see Fig. 1). Examples include machine tools and centre winders. With these applications changing speed does not save power. VSDs for constant power loads are used for process control, not energy saving.
- **constant torque** – with this type of load the torque output is constant and the power is proportional to speed (see Fig. 2). This means that a 50 per cent reduction in speed delivers a 50 per cent reduction in power. Examples include conveyors, air compressors & crushers
- **variable (quadratic) torque** – the most common load type (see Fig. 3) – torque is quadratically (square law) associated with speed while power is cubically proportional to speed (cube law). Examples include fans & pumps. However, in a pump system where a static lift is required the cube law does not apply to that component of the load.

For a variable torque load where
Q = flow rate;
P = power and
N = speed
$Q1/Q2 = N1/N2$ and
$P1/P2 = (N1/N2)^3$

Speed of a four-pole motor at different frequencies

Frequency (Hz)	60	50	40	30	20	10
Nominal Speed (rpm)	1,800	1,500	1,200	900	600	300

A common example of this is reducing the speed of a fan by 20 per cent reduces the power required by 50 per cent.

When looking at torque it is important that the 'starting torque' of an application is understood as this may have an impact on motor size and selection. For example, a motor may appear to be oversized, but that size of motor is required to meet the starting torque of the specific application.

Need to run below 50Hz

While VSDs are very efficient there are some losses. Typical efficiency ratings are in the range of 92-99 per cent. However, this means that if a VSD is driving a motor at its nominal speed the overall power consumption will be greater than if the motor was running at that speed without the VSD. In simple terms, for sustained energy saving the VSD needs to run below 50Hz. It should also be noted that VSDs can also be used to 'overspeed' motors and by running them above 50Hz energy use will be increased.

For a VSD to deliver energy savings the speed needs to be controlled. Manual control is normally used only in process applications. For effective VSD deployment there needs to be an automatic control loop. The type of sensor, location and protocol will depend on what is being controlled. For example, a VSD might be used to vary the air volume of an extract ventilation system for an underground car park. The control parameter here would be carbon monoxide. The protocol will be to control the ventilation rate to limit the build-up of carbon monoxide (CO) from car exhausts.

For this to function correctly it is important to position the sensor(s) in the right place(s) – and set the correct CO control levels. It is then critical that the system is fully commissioned – i.e., checking that it works as intended. Energy surveys have documented instances of VSDs installed but either not commissioned or having the controls 'tampered' with. Issues like this can be addressed with regular recommissioning.

In HVAC applications VSDs are normally installed for their energy savings potential. However, in some cases they can be installed as 'commissioning' tools for 'fixed' duty installations. The argument to support this application is that typically electric motors run at only about 70 per cent of their full load and in many fixed rate applications the flow (water or air) is throttled to meet the design requirement. By using a VSD a precise speed to match the duty can then be selected during the commissioning process – optimising the power use. It also provides scope for recommissioning should the duty of the system change later.

Often new equipment is supplied with a matched VSD. However, there are still many opportunities for retrofitting VSDs to existing fixed-speed installations. In these situations, it is always good practice to seek advice from the VSD supplier when selecting the variable speed drive. In addition to matching the drive to the load there may be issues with the existing motor to be addressed.

The cooling for a typical AC motor is delivered by a shaft-mounted fan that rotates at the same speed as the motor. This can mean at lower speeds the cooling effect is reduced (this problem is overcome in DC motors by having a separate motor to drive the cooling fan). Combined with this reduced effect cooling the VSD may also increase the heating effect on the motor. This can potentially lead to an early failure of the motor. Insulation breakdown and overheating issues are more likely with older motors. As a result, in some cases, it may be appropriate to replace the motor when fitting a VSD.

Harmonic distortion

Another aspect to be considered is that of harmonics. Harmonic distortion is a form of electrical 'pollution' that can cause problems if it is above certain limits. These problems can include cables overheating, motors becoming noisy with torque oscillations leading to mechanical resonance and vibration. Harmonic currents are created by non-linear loads connected to the power distribution system.

Common non-linear loads include VSDs, welding supplies and uninterruptible power supplies. In VSDs the type of rectifier used has a significant impact. Budget VSDs often have 6-pulse rectifiers. Harmonic performance can be improved by having 12, 18 or 24 pulse rectifiers – however, this is at a cost. A 24-pulse unit might be double the cost of a 6-pulse unit. Other mitigation options are IGBT rectifiers, large chokes or active filters. Expert advice is recommended in this area to avoid future problems.

Following Brexit, the UK is still following the ecodesign requirements for motors and drives. Prior to 1 July 2021 it was permitted to use an IE2 (efficiency) motor fitted with a VSD in place of the required IE3 motor. However, with effect from 1 July 2021, this is no longer acceptable.

Fig. 1 The power requirement is fixed and torque is inversely proportional to speed

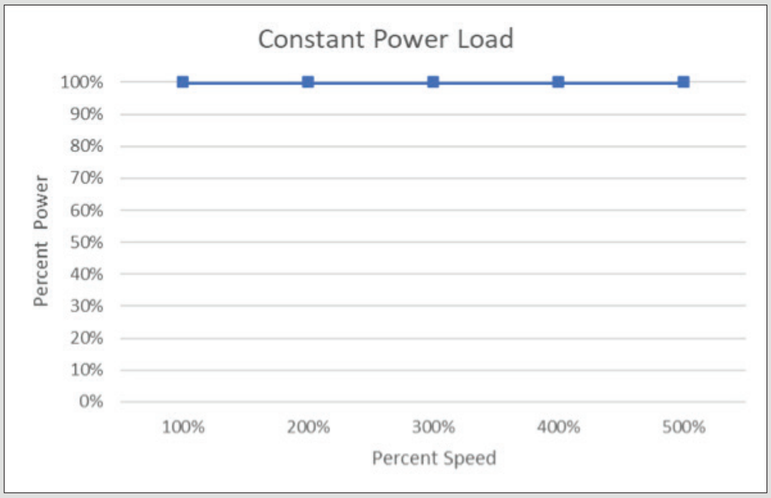


Fig. 2 Torque output is constant and power is proportional to speed

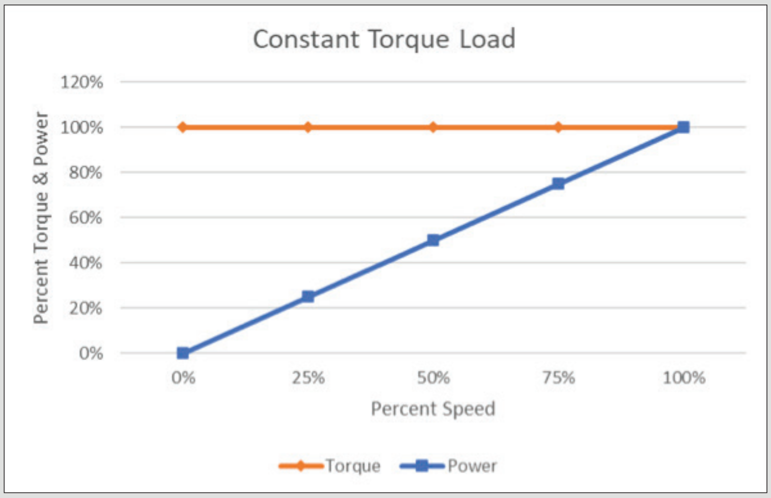
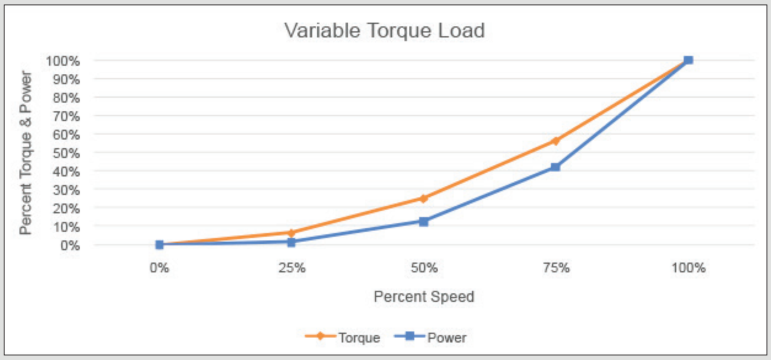


Fig. 3 Variable torque load is the most common. Examples include fans and pumps



The regulation also stipulates the efficiency of variable speed drives. Variable speed drives have two levels of efficiency (IE1 and IE2). The regulation now requires all drives in scope to reach the IE2 level. This means that the power losses of VSDs for motors with a rated output power equal to or above 0.12 kW and equal to or below 1,000 kW shall not exceed the maximum power losses corresponding to IE2 standards.

As well as energy saving in many applications, VSDs can also offer the following benefits:

- programable starting, stopping and braking - which can reduce system stresses and prolong life as well as providing the ability for more frequent stops and starts;
- improved power factor – AC motors typically have a power factor of less than 0.85 and this decreases with lower loadings in some cases below 0.5 – a VSD can bring the power factor closer to unity; and
- dynamic response – comparable to DC drives, but with lower costs.

However, there are some disadvantages to VSDs including:

- while they can have a wide rangeability they cannot operate the same as a control valve at low flow or near zero flow conditions – in these applications a control valve may still be required even if a VSD is used; and
- for some specialist applications the speed of response of VSDs may be slower than that of a control valve.

VSDs are not plug and play

We tend to think of electronics as plug & play, fit and forget – but this is not true for variable speed drives. A number of important issues need to be considered. One of the most significant is the cooling the VSD. Power electronics generate heat and if that heat is retained in a closed enclosure it can lead to overheating of the drive with subsequent failure. Typical problems here might include air vents becoming blocked in a dusty atmosphere; drives being installed in closed cabinets and overheating.

The Energy Technology List (ETL) is a government list of energy efficient plant and machinery. For a product to be listed, it must meet the ETL's energy-saving criteria - typically set at the top 25 per cent of products in the market. In the past, equipment on the ETL qualified for Enhanced Capital Allowances (ECA) - a tax benefit - however, ECAs ended in April 2020. The ETL still remains a good source of product related information for energy savings.

The ETL covers two categories of VSD products:

- variable speed drives for line operated AC motors; and
- variable speed drives for converter-fed motors.

https://etl.beis.gov.uk/products/motors-drives/variable-speed-drives

When correctly installed and used on fans and pumps with variable duty, VSDs can provide significant energy savings by matching the input power to the duty required. VSDs are proven technology and if installed correctly will provide years of service. However, in retrofit applications it is always advised to involve specialists in the selection and installation of the drive. ■

FURTHER READING

1) CTV048 Motors and drives technology overview guide – Carbon Trust
2) Technical guide No. 6 - Guide to harmonics with AC drives - ABB Drives
3) The Control Techniques Drives & Controls Handbook – The Institution of Engineering & Technology ISBN 9781849190138

CPD SERIES 19 / Module 09

Variable Speed Drives

ENTRY FORM

Please mark your answers below by placing a cross in the box. Don't forget that some questions might have more than one correct answer. 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, return it to the address below. Photocopies are acceptable.

Questions

1. What is the nominal speed of a 6-pole motor with a 50hz supply?

☐ 1,500
☐ 1,000
☐ 750
☐ 600

2. A 20 per cent reduction in fan speed can lead to what percentage power saving.

☐ 20 per cent
☐ 30 per cent
☐ 40 per cent
☐ 50 per cent

3. Which rectifier would be best from a harmonic viewpoint?

☐ 6-pulse
☐ 12-pulse
☐ 18-pulse
☐ 24- pulse

4. For a constant torque load what is power proportional to?

☐ The inverse of speed
☐ Speed
☐ The square of the speed
☐ The cube of the speed

5. Which of these is a constant power load?

☐ Compressor
☐ Machine tool
☐ Centrifugal pump
☐ Axial fan

6. What is the range of efficiency ratings for VSDs?

☐ 92-99 per cent
☐ 89-95 per cent
☐ 85–90 per cent
☐ 80-95 per cent

7. With a centrifugal pump, what part of its duty does not follow the cube law?

☐ Loads below 25 per cent
☐ Friction losses
☐ Static lift
☐ Loads above 75 per cent

8. What does ECM stand for?

☐ Electronic Circuit Management
☐ Electronically Commutated Motor
☐ Electronic Compatibility Method
☐ External Control Module

9. From when did the ecodesign requirements not allow the use of a IE2 motor with a VSD?

☐ 1 July 2021
☐ 1 July 2020
☐ 1 July 2019
☐ 1 July 2018

10. When might a control valve still be used with a VSD application?

☐ When rapid response closing is required
☐ To trim flow at near 100 per cent flow rate
☐ When the VSD is oversized
☐ To reduce noise

Please complete your details below in block capitals.

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