SERIES **17**

CPD fundamentals THE CONTINUING PROFESSIONAL DEVELOPMENT PROGRAMME

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MARK THROWER MANAGING EDITOR

Make drives and motors efficient

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An electric motor is a device for converting electrical energy to rotary kinetic (movement) energy in order to power a process. Examples of processes include HVAC fans and pumps, a washing machine, and a process conveyor belt. Indeed, motors are found in a vast majority of equipment in our everyday life.

Electric motive power is likely to form a large part of an organisation's energy consumption, especially as a typical motor will consume energy ten times its purchase cost over its lifetime. Motor use is significant in the UK, Europe and indeed across the world.

In the UK fans use approximately 40 per cent of all electricity in HVAC systems. In the USA electric motor-driven systems and motor-driven components in appliances and equipment account for more than 25 per cent of the primary energy consumption in both the residential and commercial sectors.

According to the European Union electric motors and appliances that they power use almost 50 per cent of the electricity in Europe. In industry, machines driven by electric motors consume two thirds of all electrical energy. They are found in machines such as elevators, cranes and cooling systems. More efficient motors could save EU member states around 135TWh of electricity by 2020 – equivalent to the annual electricity consumption of Sweden. This means over 60m tonnes of CO_2 emissions will be avoided.

When an electrical current is applied to the motor, a rotating magnetic field is created around the stator. This induces currents and associated magnetic fields in the rotor, causing the rotor and shaft to spin. The shaft is mounted on bearings and is thus able to rotate freely.

There are three mains types of motors: alternating current (AC) (see Fig. 1) motors, direct current (DC) motors, and electronically commutated (EC).

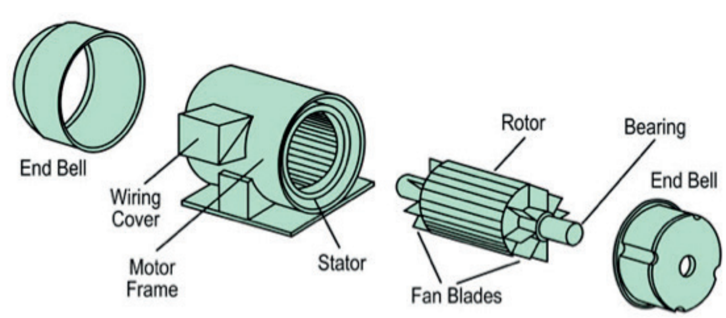
AC induction motors are either single speed or variable speed motors. Single speed AC motors are fixed-speed caged induction motors which use conventional alternating electric current (AC). They are ideally suited to applications where a constant motor output speed is required.

When viewed from the electrical input, there are single-phase and 3-phase induction motors. Single phase motors generally move small loads but can suffer up to a 10 per cent loss in efficiency compared to three-phase motors used in commercial buildings.

Electronically commutated (EC) motors are essentially brushless DC motors. Electronically commutated motors are now in wide use in the lower power categories due to their higher efficiency performance especially at part-load conditions.

In recent times permanent magnet motors have become increasingly used. A permanent magnet motor

Fig. 1. How it works. The AC motor



Produced in Association with energy institute is a type of brushless electric motor that uses permanent magnets rather than winding in the field. For residential and commercial sectors, they are becoming common, due to being increasingly cost-effective, and non-energy benefits such as reduced noise and the ability to reach higher rotational speeds.

Motors can range in size/scale from small motors (<0.75kW) for a remote control car to medium (0.75-375kW) to very large industrial shredder motors (over 375kW).

Electric drives are normally classified into three groups: individual, group and multi-motor drives.

If a single motor is used to drive or actuate a given mechanism and it does all the work connected with this load, it is called an individual drive. When groups of machines are organised on one shaft and driven or actuated by one motor, the system is called a group drive or line shaft drive. This can be economical overall as a single large capacity motor often costs less than multiple small motors.

A multi-motor drive consists of several individual motors which serve many mechanisms in production applications. This type of drive finds its application in complicated machine tools, travelling cranes, rolling mills, etc. For example, in a travelling crane three motors are used, one for hoisting, other for long travel motion and third for cross travel motion

Electrical motor efficiency is the ratio between shaft output power and electrical input power. If power output is measured in Watt then efficiency can be expressed as:

$$\eta m = Pout / Pin$$

where:
ηm = motor efficiency
Pout = shaft power out (Watt, W)
Pin = electric power in to the motor (Watt, W)

The efficiency of electric motors is different depending on the type of the motor. It is higher in high-power machines and lower in the low-power ones. It usually varies between 75 per cent and 95 per cent.

Efficiency losses occur in motors from a variety of sources:

• **copper losses:** this is electrical power lost in the primary rotor and secondary stator winding which is from resistance;

• **iron losses:** they occur as a result of magnetic energy dissipated when the motors magnetic field is applied to the stator core;

• **mechanical losses:** these include friction in the motor bearings and the fan for air cooling.

• stray losses: These are the losses that remain after primary copper and secondary losses, iron losses and mechanical losses. The largest contribution to the stray losses is harmonic energies generated when the motor operates under load. These energies are dissipated as currents in the copper winding, harmonic flux components in the iron parts, leakage in the laminate core.

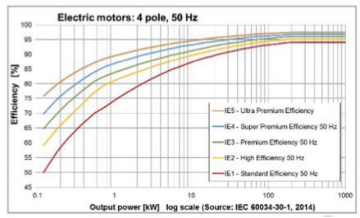
Date	Motor Range	EU Minimum Efficiency Standard
June 2011	Small and Medium: 0.75 kW to 375 kW	IE2 (with fixed or variable speed control)
January 2015	Medium: 7.5 kW to 375 kW	IE3 (with fixed or variable speed control) IE2 (with variable speed control)
January 2017	Small and Medium: 0.75 kW to 375 kW	IE3 (with fixed or variable speed control) IE2 (with variable speed control)

Difficulty dissipating heat

In general, as motor power increases, the efficiency of the motor at full load also increases. This is partially due to the difficulty in dissipating heat in smaller motors. Higher power motors also operate close to peak efficiency for a wide range of loading conditions.

The International Electrotechnical Commission (IEC) has published an international standard that defines five energy efficiency classes for single-speed, three-phase motors (IE1, IE2, IE3, IE4 and IE5). This standard has also been adopted as a European and UK Standard (BS EN 60034-30:2014).

Fig. 2 IE Code motor efficiency



Using the graph in Fig. 2, it can be seen that an IE1 10kW motor is around 86 per cent efficient and an IE5 10kW motor is around 95 per cent efficient. The manufacturer Grundfos states that changing an older pump with IE5 motors can result in 10 per cent energy savings and a 25 per cent reduction in payback time.

European electric motor energy-efficiency legislation (regulation 4/2014), was designed to ensure all motors sold in the EU from 2017 are rated at IE3 efficiency – unless connected to a variable speed drive, in which case an IE2 motor is acceptable. However there are some exclusions:

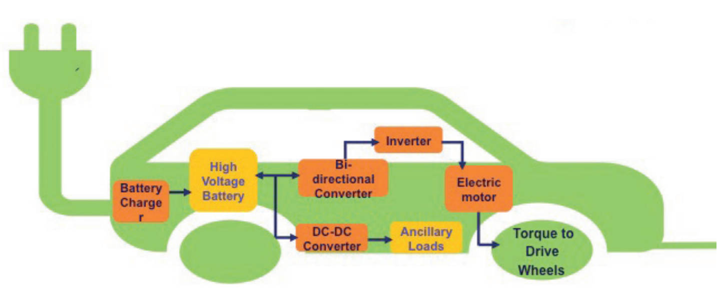
• motors designed to operate wholly immersed in a liquid;

• motors completely integrated into a product (e.g. pump or fan) where the motor's energy performance cannot be tested independently from the product;

• motors in potentially explosive atmospheres as defined in Directive 94/9/EC; and

• brake motors, where the brake cannot be removed or separately operated.

Fig. 3 Power path in an electric car



Growth of electric cars

Nobody could have failed to notice the growth in the use of electric cars. An electric car is propelled by one or more electric motors, using energy stored in rechargeable batteries. These developments could not have been possible without advances in motor technology alongside battery technology.

In practice, electric vehicles take in electricity into the batteries which store energy in direct current (DC), electricity is then fed into a DC/AC inverter where it is converted to alternating current (AC) electricity and this AC electricity is connected to a 3-phase AC motor to drive the wheels, It is notable that DC motors are also often used.

In recent production vehicles, various motor types have been implemented; Induction motors within Tesla cars and permanent magnet machines in the Nissan Leaf and Chevrolet Bolt.

Several electric cars now have a regen feature, such that during braking, the motor turns into a generator and delivers power back to the batteries.

The power of a vehicle's electric motor, as in other vehicles, is measured in kilowatts (kW). 100kW is roughly equal to 134 horsepower, but electric motors can deliver their maximum torque over a wide RPM range. This means that the performance of a vehicle with a 100kW electric motor exceeds that of a vehicle with a 100kW internal combustion engine, which can only deliver its maximum torque within a limited range of engine speed.

Energy is lost during the process of converting the electrical energy to mechanical energy. Approximately 90 per cent of the energy from the

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battery is converted to mechanical energy, the losses being in the motor and drivetrain.

There are now over 227,000 electric vehicles in the UK, this includes pure-electric vehicles (EVs) and plug-in hybrid vehicles (PHEVs). In the first eight months of 2019, more than 35,000 plug-in cars have been sold.

Starting induction motors

Different starting methods are employed for starting induction motors because the motor draws more current during starting in order to overcome its initial inertia. To prevent damage to the windings due to the high starting current flow, different types of starters are employed.

The simplest form of motor starter for the induction motor is the Direct On Line (DOL) starter which essentially connects the motor direct to the supply. It is viable for scenarios where the load driven by the motor can cope with shock produced by the high starting torque. This control method is often used to start small water pumps, compressors, fans and conveyor belts.

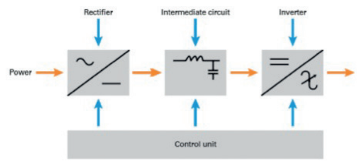
Star-delta or soft starters connect the motor to the power supply through a voltage reduction device and increases the applied voltage gradually or in steps. With this form of starter, the three-phase supply voltage to the stator windings can be switched between star and delta configurations.

Variable-speed drives (VSD) are now the most energy-efficient method to control motors. VSDs provide a means of driving and adjusting the operating speed of a mechanical load. Although they are also known as variable frequency drives (VFD), a VFD refers to AC drives only, while a variable speed drive (VSD) refers to either AC or DC drives.

VSDs can also implement soft motor starting and control based on external parameters such as temperature, low, humidity, and proximity sensors which detect when a system or motor is required to operate.

A VSD saves energy based on the Cube Law, by the Cube Law, power is proportional to the speed cubed, this means that a small increase in speed requires a lot more power, and

Fig. 4. Schematic of a VSD



a modest speed reduction can give significant energy savings.

The main components of a VSD are:

• **rectifier:** this changes the incoming alternating current (AC) supply to direct current (DC);
• **intermediate circuit:** the rectified DC supply is then conditioned in the intermediate circuit, normally by a combination of inductors and capacitors;
• **inverter:** the inverter converts the rectified and conditioned DC back into an AC supply of variable frequency and voltage. This is normally achieved by generating a high frequency pulse width modulated signal of variable frequency and effective voltage; and
• **control unit:** this monitor and controls the rectifier, the intermediate circuit and the inverter to deliver the correct output in response to an external control signal, i.e. temperature sensor.

Energy consumption of motors depends on the system load, configuration, and duty-cycle. Therefore knowledge of the specific duty and utilisation is key to defining the savings opportunity.

There are two main ways to control the speed of a VSD: networked or hardwired. Networked involves transmitting the intended speed over a communication protocol such as Modbus, Modbus/TCP, EtherNet/IP, or via a keypad, while hardwired involves a pure electrical means of communication.

Variable speed drives were previously marketed as "usable with any standard motor." However, premature failures of motor insulation systems began to occur as fast-switching, VSDs were introduced.

Avoiding motor failure

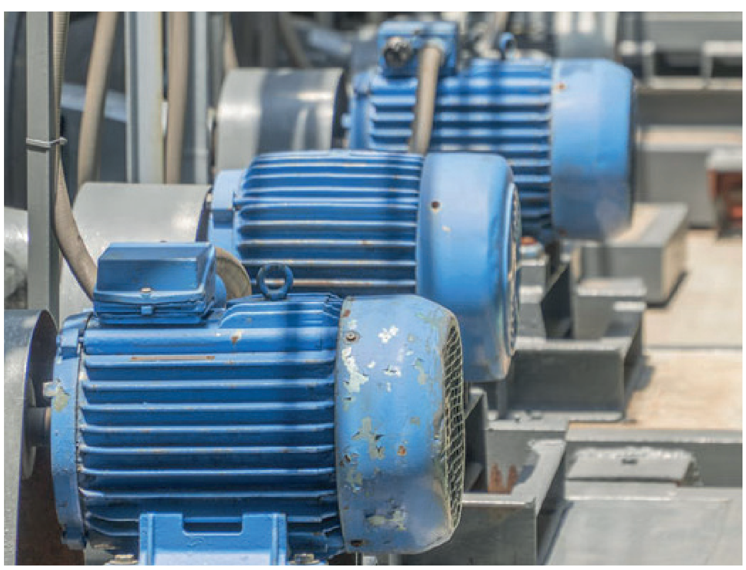
To avoid motor failure when considering a VSD upgrade consider the following:

• locate the VSD controller as close as possible to the motor, ideally less than 5m;
• contact the motor manufacturer for guidance on motor/drive compatibility;
• consider replacing the old motor with a premium efficiency 'inverter-duty' motor; and
• prioritise the use of a single VSD controller for each motor.

It is always useful to consider low-cost options for energy saving prior to installing costly frequency drives.

Motor sizes can be reduced if the drive train is more efficient, the load is well understood, and installed motor is deemed as oversized.

It is sometimes more cost-effective to replace a failed motor with a higher efficiency motor (HEM), rather than repair it. This is because rewind cost, especially for smaller motors can be high. Also, a failed motor that has been rewound can be 0.5-2 per cent less efficient than it was previously. Therefore, reduction in energy efficiency results in increased running costs. The replacement decision should be based on a comparison of the annual cost to own and operate the motors. For small motors and HVAC applications consideration should be given to EC motors.



VSDs are commonly used for cooling tower fans but variable flow cooling water loops with cooling towers are a recent innovation and are well worth consideration.

Because air-cooled chillers are typically equipped with multiple fans, the fans can be staged for part-load operation, delivering energy savings of up to 30 per cent.

Compressors currently used in self-contained commercial refrigeration are single-speed, hermetically sealed reciprocating compressors. Therefore, there is an opportunity for improved control at scale.

A variable speed drive (VSD), speed-controller or frequency-controlled air compressor automatically adjusts its motor speed to the air demand, whereas fixed speed or load/unload compressors, are either on full throttle or off. VSDs can deliver energy savings of 35 per cent on average in this application.

With a VSD, you avoid peak currents at start up and therefore reduce the peak load on the industrial or commercial facility, avoiding excess capacity charges and lower DUOS costs.

An alternative to VSDs could be sequential controllers. Where multiple fans, pumps or compressors are installed, sequential controllers can be used to sequentially start and stop equipment according to the process demands. While not as precise as variable speed control, significant energy savings can still be achieved.

PLCs (Programmable Logic Controllers) can be used to build 'intelligence' within a system. They can be programmed to predetermined schedules, or react to sensor inputs, and to ensure the motors operate only when required.

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CPD SERIES 17 | MODULE 05 | OCTOBER 2019
ENTRY FORM

DRIVES & MOTORS

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. **Which of the following is not a type of motor?**
   - ☐ Alternating current motor
   - ☐ Direct current motor
   - ☐ Alternating flow motor
   - ☐ Electronically commutated motor

2. **A 10kW motor purchase in the UK in 2019 needs to be minimum motor efficiency of?**
   - ☐ IE2 (with fixed control)
   - ☐ IE5 (with fixed control)
   - ☐ IE4 (with variable speed control)
   - ☐ IE3 (with fixed or variable speed control)

3. **A variable speed driven compressor will achieve energy savings of what per cent compared to a fixed speed compressor?**
   - ☐ 5 per cent
   - ☐ 15 per cent
   - ☐ 35 per cent
   - ☐ 65 per cent

4. **According to the EU motor efficiency legislation motors designed to operate wholly immersed in a liquid should achieve what efficiency class?**
   - ☐ IE2 (with fixed control)
   - ☐ None, they are excluded
   - ☐ IE4 (with variable speed control)
   - ☐ IE3 (with fixed or variable speed control)

5. **An IE5 10kW motor operates at an efficiency percent of about?**
   - ☐ 72 per cent
   - ☐ 95 per cent
   - ☐ 86 per cent
   - ☐ 99 per cent

6. **Rewinding a failed motor can reduce its efficiency by?**
   - ☐ 65 - 70 per cent
   - ☐ 18 – 20 per cent
   - ☐ 35 - 45 per cent
   - ☐ 0.5 – 2 per cent

7. **Which of the following is not a typical loss within a motor?**
   - ☐ Copper losses
   - ☐ Academy losses
   - ☐ Iron losses
   - ☐ Mechanical losses

8. **What does the regen feature in electric cars achieve when the car is breaking?**
   - ☐ It quickly stops the car
   - ☐ It alerts the driver of battery power level
   - ☐ The motor turns into a generator and delivers power back to the batteries
   - ☐ It reduces driver fatigue

9. **What statement best describes electronically commutated motors.**
   - ☐ It is a motor that provides nuclear capabilities to any standard motor
   - ☐ Electronically commutated motors are the largest size motors known to man
   - ☐ Electronically commutated motors only work in sea water
   - ☐ Electronically commutated motors are essentially brushless DC motors

10. **Energy consumption of motors does not depend on which of the following?**
    - ☐ System load
    - ☐ Hours of operation
    - ☐ Energy provider
    - ☐ Utilisation

Please complete your details below in block capitals

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This is the fifth module in the seventeenth series and focuses on **Drives & Motors**. It is accompanied by a set of multiple-choice questions.

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