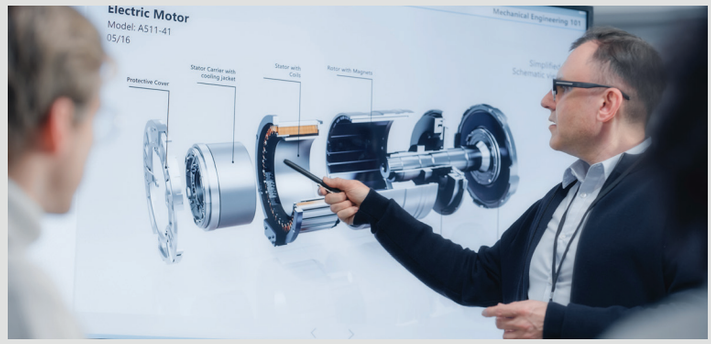
Making motors and drives efficient

Adetunji Lawal, head of energy and carbon, Wates Group Limited



An electric motor is a device that converts electrical energy to rotary kinetic (movement) energy to power a process. Examples of processes include HVAC fans and pumps, washing machines, and conveyor belts. Motors are found in a vast majority of equipment in our everyday life.

Scale of motor energy consumption

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% of all electricity in HVAC systems.

In the USA, electric motor-driven systems and components in appliances and equipment account for more than 25% of the primary energy consumption in both residential and commercial sectors .

In Europe, there are over 8 billion electric motors in use and the appliances they power consume almost 50% of the electricity generation. In industry, machines driven by electric motors consume about 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 110 TWh of energy savings annually by 2030, equivalent to the electricity consumption of Netherlands. This means 40 million tonnes of CO_2 emissions per year is avoided.

How do motors work?

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 main types of motors: direct current (DC) motors, alternating current (AC) motors and electronically commutated (EC).

DC motors convert direct current electrical energy into mechanical energy. There are two main types of DC motors: brushed and brushless.

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

Electronically commutated (EC) motors are essentially brushless DC motors with permanent magnet and built in electronics that control the torque and speed of the motor. Electronically commutated motors are now widely used in the lower power categories due to their higher efficiency performance especially at part-load conditions.

Motors can range in size/scale from small motors for a remote control car to very large industrial shredder motors; small motors having an input of <0.75 kW, to large motors rated at >375 kW.

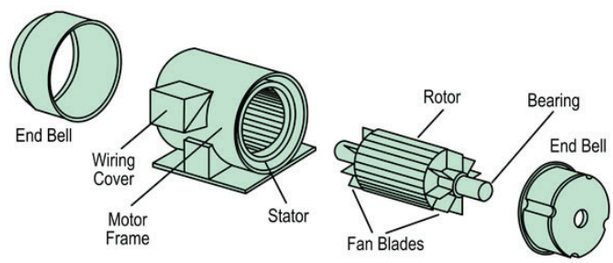
Electric drives are normally classified into three groups, namely individual, group and multi motor drives.

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, another for long travel motion and third for cross travel motion.

AC motor



How is a motor's efficiency defined?

Electrical motor efficiency is the ratio between shaft output power and electrical input power.

If power output is measured in Watts

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(W) then efficiency can be expressed as:
ηm = 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% and 95%.

While 100% efficiency is desirable, its useful to understand how 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 motor's magnetic field is applied to the stator core.
- **Mechanical losses** – includes 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, and leakage in the laminate core.

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.

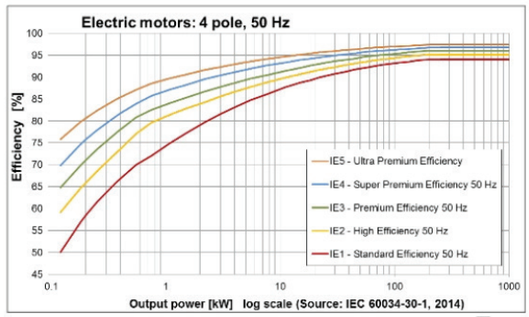
Regulatory view on motors?

The International Electrotechnical Commission (IEC) has published an international standard that defines 5 distinct 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).

Using the graph in **Figure 1**, it can be seen that an IE1 10kW motor is around 86% efficient and an IE5 10kW motor is around 95% efficient. Therefore changing an older pump with IE5 motors can result in 10% energy savings and a 25% reduction in payback time.

The UK, in recognition of energy use associated with motors, has set energy-efficiency legislation (statutory Instrument 2021/745). This ensures that motors sold in the UK from 2023 are minimum IE2 efficiency.

Figure 1



Motors in electric vehicles

An electric car is an automobile that is propelled by one or more electric motors, using energy stored in rechargeable batteries. Globally, electric cars are witnessing rising growth, a development only made possible by 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. 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. 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.

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.

Power path in an electric car



The power of a vehicle's electric motor, as in other vehicles, is measured in kilowatts (kW). 100 kW 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 100 kW electric motor exceeds that of a vehicle with a 100 kW 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 75% - 90% of the energy from the battery is converted to mechanical energy, the losses being in the motor and drivetrain.

In February 2024, there were over one million fully electric vehicles and a further 600,000 thousand plug-in hybrid vehicles in the UK. This is a significant rise from just under 300,000 combined full electric and plug-in hybrids in 2019.

How do we control 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; also, to prevent damage to the windings due to the high starting current flow.

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) present a most energy efficient method to control motors. VSDs provide a means of driving and adjusting the operating speed of a mechanical load. They are also known as variable frequency drives (VFD), however a VFD refers to AC drives

UK legislation for motor energy efficiency

Date	Motor Range	UK Minimum Efficiency Standard
1 July 2021	0.12 kW to 0.75 kW	IE2 (except if Ex eb increased safety motors)
1 July 2021	0.75 kW to 1000 kW	IE3 (except if Ex eb increased safety motors)
1 July 2023	0.12 kW to 1000 kW	IE2 for Ex eb increased safety motors
1 July 2023	>0.12 kW	IE2 for Single-phase motors
1 July 2023	75 kW to 200 kW	IE4 for 2, 4, or 6 pole 3-phase motors (except for brake motors, Ex eb increased safety motors & other explosion protected motors)

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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, flow, 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 a modest speed reduction can give significant energy savings. The Carbon Trust state that a 20% reduction in fan speed can result in a 50% reduction in fan energy use.

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.
- **Control unit** – this monitors 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.

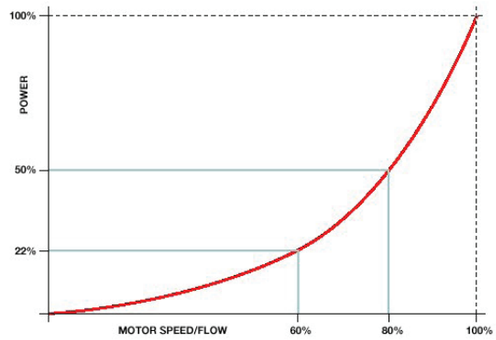
Energy consumption of motors depends on the system load, configuration, and duty-cycle; therefore knowledge of the specific duty and utilisation is key to defining the savings opportunity. It should be noted applications like crushers, elevators, and hydraulic pumps enjoy lower benefits from adopting VSDs.

VSD Control – 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.

Premature failures of motor insulation systems have been noted with fast-switching VSDs. To avoid motor failure when considering a VSD upgrade:

1. Locate the VSD controller as close as possible to the motor, ideally less than 15 feet.
2. Contact motor manufacturer for guidance on motor/drive compatibility.
3. Consider replacing the old motor with a premium efficiency 'inverter-duty' motor.
4. Prioritise the use of a single VSD controller for each motor.

A VSD saves energy based on the Cube Law



Opportunities for energy saving in commercial and Industrial sectors

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

Reduce motor size – motor sizes can be reduced if the drive train is efficient, the load is well understood, and installed motor is deemed as oversized. Although motors sized too large stay relatively cool in operation, they waste energy through inefficient operation.

Motor replacement – 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% 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.

Upgrade belt driven fans with direct plug fans – belt driven centrifugal fans commonly found in air handling units can be upgraded with direct plug drives, where the impeller is directly connected to the motor shaft. The benefit is that there are no power transmission losses, the energy the electric motor develops is transmitted directly to the impeller, which passes into the airflow and pressure development. Furthermore, cost savings in maintenance are achieved by removing the need to regularly replace belts and pulleys. Direct plug fans can also be VSD controlled.

Cooling water circulation and cooling towers – VSDs are commonly used for cooling tower fans but variable flow cooling water loops with cooling towers are a recent innovation.

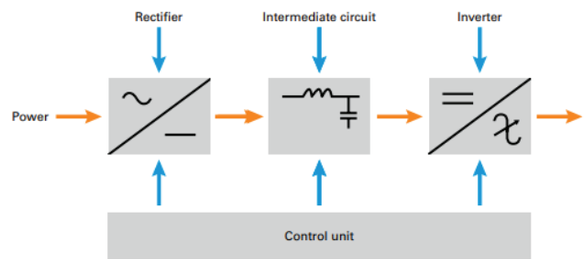
Fans for air-cooled chillers – because air-cooled chillers are typically equipped with multiple fans, the fans can be staged for part-load operation, delivering energy savings of up to 30%.

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

Air compressors – a variable speed-controlled 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% on average in this application[9].

Grid peaks reduction – with 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.

Schematic of a VSD



Alternatives to VSDs

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. Whilst 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 only operate when required. ■

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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 0.12kW single phase motor purchased in the UK in 2024 needs to be minimum motor efficiency of ?
- ☐ IE2
- ☐ IE5
- ☐ IE4
- ☐ IE3

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

4. An IE5 10kW motor operates at an efficiency percent of about?
- ☐ 72%
- ☐ 95%
- ☐ 86%
- ☐ 99%

5. Rewinding a failed motor can reduce its efficiency by?
- ☐ 65 - 70%
- ☐ 18 – 20%
- ☐ 35 - 45%
- ☐ 0.5 – 2%

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

7. What does the regen feature in electric cars achieve when the car is braking?
- ☐ 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

8. 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

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

10. According to the Cube law when applied to fans and pumps...
- ☐ Power is proportional to the speed cubed
- ☐ Power and speed are not related
- ☐ Speed can only be varied for motors rated over 375kW
- ☐ Power is function of reverse wind conditions above 1,000 feet only

11. What percentage of the energy from an electric vehicle battery is converted to mechanical energy?
- ☐ 25% - 30%
- ☐ 45 - 60%
- ☐ 65 - 75%
- ☐ 75 - 90%

12. What are the benefits of upgrading belt driven fans to plug driven fans?
- ☐ Reduced maintenance costs
- ☐ They can be VSD controlled
- ☐ Efficient power transmission from the motor to the impeller
- ☐ All of the above

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