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MARK THROWER MANAGING EDITOR

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SERIES **15** | MODULE **06** | **DRIVES & MOTORS**

Energy-efficient drives and motors

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The amount of energy used by electric motors is around 45 per cent of all global electricity consumption. This gives rise to around 6,000Mt of CO_2 each year. Motor-driven systems are also estimated to account for 65 per cent of industrial electricity use. As a result, they need to be a focus for energy-saving activity.

Electric motors are normally purchased as part of an item of equipment, for example, an air handling unit. This means in most cases the end user is not the direct buyer of the motor. The end user often only becomes a motor purchaser when replacing the motor. When specifying systems that include motors, the end user should consider specifying what performance level(s) they require from the drive system.

Ideally, all the energy efficiency aspects of a motor-driven system are addressed at the system design stage. However, electric motors are not only efficient machines they are highly reliable, typically with a life span of over 15 years. This means that opportunities to upgrade existing motors may be limited. Although the scope for motor replacements may be limited, there will be 'legacy' systems that offer the potential for retrofit improvements.

Table 1. Potential savings estimated by CEMEP

Area of potential savings	Potential saving
Increased use of energy-efficient motors	10 per cent
Electronic speed control	30 per cent
Mechanical system optimisation	60 per cent
Total	**100 per cent**

Before looking at the elements of a motor-driven system it is important to consider the purpose of the system. For example, a water circulation pump, how is it controlled? Is it running 24x7 when only needing 8x5? The magnitude of savings here (in the region of 75 per cent) is many times the potential savings in the motor and drive system.

Motor is heart of the system

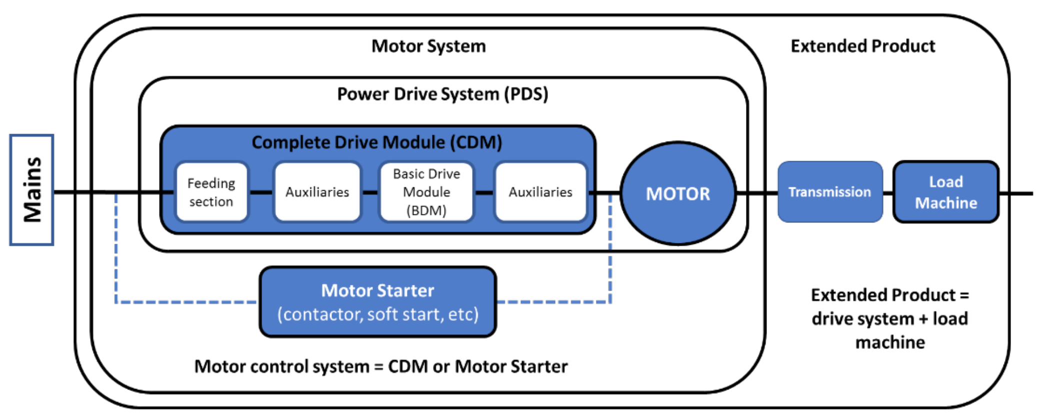
The heart of the system is the motor, to which is added motor control – ranging from a simple starter to a variable speed drive (VSD). Then, unless a direct drive system, a transmission system (typically belts or gearbox) is connected to the 'load machine'. While there have been developments in motor efficiency the scope for savings in other elements of the system is more significant. Potential savings estimated by CEMEP (European Committee of Manufacturers of Electrical Machines and Power Electronics) are shown in the table above.

Focus on whole system

This suggests that 90 per cent of the savings potential occurs outside of the motor – hence a focus is required on the whole system.

This approach is reinforced by European Standard EN 50598 Part 2 - Energy efficiency indicators for power drive systems and motor starters. (This standard covers performance in the power range 0.12kW to 1,000kW.)

While motors come in a wide variety of types and sizes, the three-phase, ac, cage induction motor is the most common motor encountered in energy



EN 50598 Drive System Description

Source EN 50598

management. The main components of this motor are the stator, rotor, casing, bearings and cooling fan. The stator windings carry the load current which creates a rotating magnetic field which induces current in the rotor forming a second magnetic field; the two fields interact, the rotor turns and torque is produced.

Wide range of motor sizes

Other types of motor that may be encountered include single phase, dc, permanent magnet, switched reluctance and the electronically commutated motor (ECM).

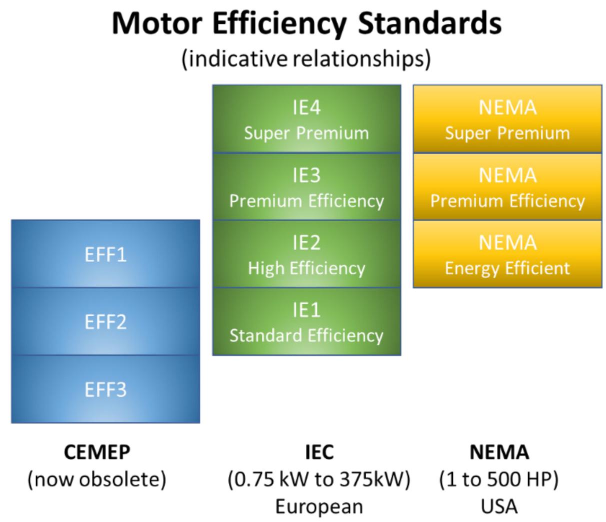
Motors can range in size from a few watts (a computer disc drive) to several MW for industrial machines. The motor rating (kW) is the shaft output power, so the electrical power required at full load will be the shaft power divided by the motor efficiency. Larger motors are typically more efficient than smaller motors. For example, a 0.75kW motor might be 80 per cent efficient while a 132kW motor might be 95 per cent efficient. This is because the physical size of the smaller motor restricts the engineering scope for higher efficiency. However, this is not to make a case for installing oversized motors.

Research has shown that the typical motor operates at about 70 per cent of full load capacity. But some motors run at a significantly lower loading, maybe 50 per cent or less, which leads to inefficiency and energy wastage. This is because the efficiency of a motor decreases with decreasing load. Higher efficiency motors have flatter curves in the 60-100 per cent load area, but drop off significantly below this, so any system with a motor running under 50 per cent load may be a case for a re-sized motor.

Correct size for duty

As a rule, motors should be 'right sized' – that is correctly sized for the intended duty. This sizing covers the running load and the torque required to start the machine. Starting torque should be investigated and confirmed before any re-sizing. Needing a high starting torque can lead to having a motor that is larger than would be required for a similar load that had a low starting torque.

In the early 1990s there were just two efficiency categories, standard motors and Higher Efficiency Motors (HEMs). Initially, there were no published standards to specify the performance of a HEM. This changed in 1999 when the industry-led body, CEMEP, introduced the EFF rating.



Under this scheme the highest efficiency motor was rated EFF1 and the lowest was EFF3.

In 2008 IEC 60034 provided an international standard for motor efficiency and introduced the IE classification system. Under this IE1 is the lowest efficiency class with IE4 the highest.

The European Directives relating to motor-driven systems are Directives 2009/125/EC & EU 640/2009 Minimum Energy Performance Standards (MEPS). These directives require:

- from 16 June 2011 motors between 0.75 and 375kW placed on the market for the first time had to have a minimum efficiency class of IE2;
- from 1 January 2015 motors between 7.5 and 375kW had to have a minimum class of IE3 or IE2 if operated with a VSD; and
- from 1 January 2017 motors between 0.75 and 375kW need to have a minimum efficiency class of IE3 or a minimum IE2 if operated with a VSD.

The introduction of MEPS means that all new installations should meet higher standards. It also means that as time passes the availability of lower efficiency motors for replacements will decrease.

It should be stressed that MEPS specifies a minimum requirement – exceeding it may deliver further cost-effective savings.

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

Speed of loaded motor

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.

Where the speed of the load machine matches the motor speed a direct drive can be used. To have different speeds a transmission system is needed to couple motor and load. The most common approach is the belt and pulley drive. Using this the speed of the load can be at a fixed ratio relative to the motor speed.

Sometimes a speed change transmission may be used even if the load and motor have the same speed. For example, a load with a nominal speed of 750rpm could be matched

Table 2. The speed of an AC cage 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

Table 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

with an 8-pole motor. However, in practice it would be more cost-effective to use a lower cost 4-pole motor with a belt and pulley 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. It is possible to use a mechanical variable speed drive, but the preferred choice is for an electronic variable speed drive.

The electronic variable speed drive is also known as the inverter or variable frequency drive (VFD). In simple terms a VSD works by using power electronics to change the frequency of the power supply to the motor – one of the two factors determining motor speed. VSDs also provide other benefits in terms of motor control and protection. Among these is power factor improvement.

VSDs on fans and pumps

VSDs, for energy saving, are typically best employed on fans and pumps – this is because these loads follow the cube law. With the cube law the power is proportional to the speed cubed. An example of this is reducing the speed of a fan by 20 per cent reduces the power required by 50 per cent. This type of load is known as a variable torque load. Note: Where a static lift is required with a pump system the cube law does not apply to that component of the load.

With constant torque loads, for example, air compressors, conveyors or crushers, the speed/power relationship is proportional. This means that a 50 per cent reduction in speed delivers a 50 per cent reduction in power.

A third type of load is constant power, for example, machine tools. With these, changing speed does not save power. VSDs used here are for process speed control, not energy saving.

For energy saving the VSD is best suited where it is known that the load it drives varies – for example, variable volume ventilation systems, variable flow rate pumping systems and air compressors.

Due to the efficiency of the drive, when running a VSD at 50Hz there will be a slight increase in the total power used. Accordingly, to save energy the VSD needs to run below 50Hz. It should be noted that VSDs can also be used to 'overspeed' motors and by running them above 50Hz energy use will be increased.

Some legacy industrial systems may use variable speed dc motors. The performance of modern ac motors with VSDs now matches the performance of dc systems and will have significantly lower maintenance costs making replacement potentially cost effective.

When installing VSDs there are a number of aspects to be considered including motor insulation, cabling, harmonics and power quality. Motor insulation can be an issue for some older motors when run significantly below their nominal speed as overheating may lead to motor failure. Guidance should be sought from the supplier(s).

Switched reluctance drives can also be used – for example, in air compressors or applications where very high speeds are required. These tend to be more expensive than conventional motors with VSDs.

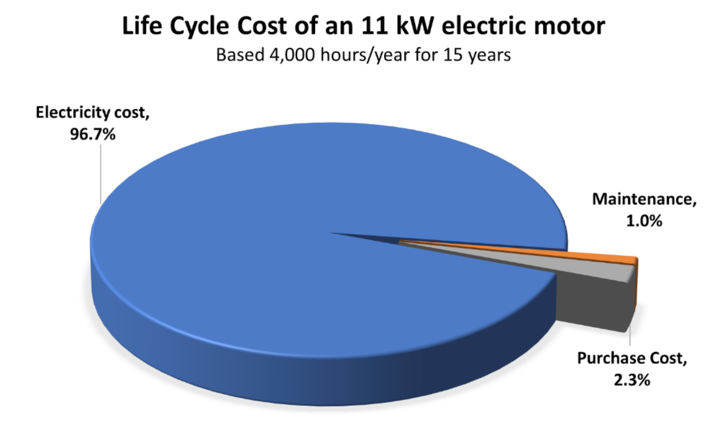
Use systems only when needed

Large energy savings can be made by only operating systems when they are needed. However, the frequency of start/stop cycles may be limited to prevent damage to the motor or system. Power spikes from starting may also be an issue creating stress on the distribution system and increasing demand charges. With a direct on-line starter there can be a current surge of seven times running current when starting the motor. This can be overcome by using a 'soft starter'. A soft starter is an electronic starter that controls the power supply to the motor and delivers a smooth start with minimal over current. (It can also provide a soft stop option) In addition to avoiding power peaks and motor overheating, a soft start also reduces the mechanical impact of starting. The energy savings by using a soft starter come from the ability to switch the motor on/off more frequently to match demand requirements. A soft starter will be more expensive than a conventional starter, but it provides better motor protection and costs less than a VSD.

Motor repair or replace?

There are two main failure modes of electric motors. One is failure of the motor insulation/windings the other, failure of the bearings. According to the IEA just over 50 per cent of motor failures are bearing related. Good maintenance of motor systems reduces the chances of failure.

A correctly installed, well maintained motor that is the right type and size for its duty will be very reliable and have a long life. However, when a motor does fail there are two actions to be taken. First is failure analysis to identify the cause and determine if there was an inherent fault in the system or its installation. Next is establishing if the motor should be repaired or replaced. Ideally this decision should have been made before the motor failed. As a general guide if a motor is a 'stock' type with a duty of 2,500 hours or more a year or a motor below say, 3kW there may be lifecycle cost benefits in replacing the motor with a higher efficiency model rather than repairing.

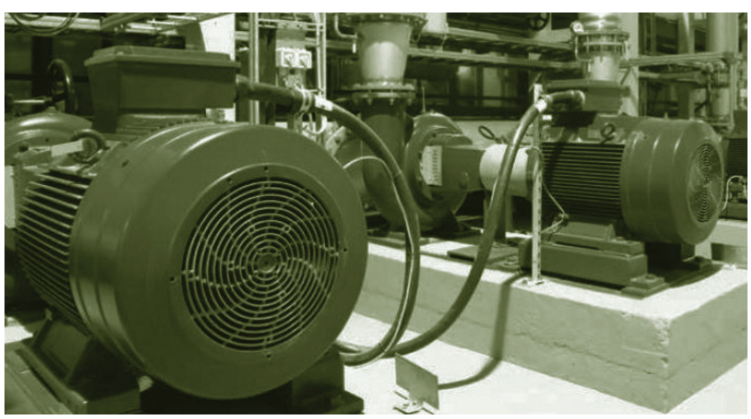


For very large motors, or specialist motors or motors with very low running hours a repair maybe more economical. When looking at upgrading a failed motor the financial appraisal should be based on the marginal cost of the higher efficiency motor. That is, the cost difference between the like for like replacement, or repair and the enhanced efficiency motor. The argument here is that the motor must be repaired/replaced anyway, so it is the additional or marginal cost that needs to be met by energy savings, not the total motor price. It rarely makes economic sense to replace an existing working electric motor with a higher efficiency model.

Life cycle costing considers the costs of buying and operating over the lifetime of the equipment. For a motor with a reasonable level of continuous use the energy costs can be in excess of 95 per cent of the life time cost. This suggests that spending a little more money on the motor and its control system can make significant costs savings over its lifetime.

Electronically commutated motor fans

A recent development is the EC fan unit which is a fan directly coupled to an electronically commutated dc motor. These offer variable speed control, reduced noise levels and claimed energy savings of up to 70 per cent. These units are ideal for air handling units (AHUs), fan coil units (FCUs) and air-cooled condensers. EC fans are typically available in smaller motor sizes with the largest currently on the market being around 5kW. In a HVAC system with a number of smaller fans an upgrade to EC fans might be an option to consider.



Performance measurement

Measuring only current (amperes) is a flawed method for determining motor power as the power factor at the load will not be known. Tachometers can be used and the load inferred from the speed and slip. However, the most accurate way to assess the power usage of an electric motor is by using a power meter or logger. For larger motors consideration should be given to permanent metering.

Drive system installation & maintenance

Whilst a small improvement in overall efficiency can be obtained by taking a motor up an efficiency class, this can all be lost if the drive system is not correctly installed and maintained.

When installing, the alignment of the drive system is critical. The larger the system the more important this is. Misalignment, within mechanical tolerances, can add as much as 10 per cent to energy use and lead to early failure. It is good practice to use laser alignment tools where possible and to check alignment each time belts are replaced.

A key maintenance aspect for both motors and VSDs is ventilation. With motors the air vents need to be kept clean. With VSDs a common cause of failure is overheating – this can occur when the drive unit has been fitted in an unventilated cabinet. Another issue can be excess particulate matter getting into the motor. Where these conditions exist, appropriate protective measures are required.

Pro-active management of motor driven systems

Motors are an example of technology that is often fitted and then forgotten. To ensure a long and efficient life for a motor it is recommended that a pro-active management approach is used. This includes having a motor inventory, making the repair/replace decisions ahead of motor failure, preventative maintenance and a formalised process for reviewing performance and identifying opportunities for improvement – often referred to as a motor management policy.

References:

Energy-efficiency with electric drive systems – CEMEP

CTV048 Motors and drives technology overview guide – Carbon Trust

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CPD SERIES 15 | MODULE 06 | NOV/DEC 2017

ENTRY FORM

DRIVES & MOTORS

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.

QUESTIONS

1. What percentage of industrial electricity use is accounted for by motor driven systems?

- ☐ 35 per cent
- ☐ 45 per cent
- ☐ 55 per cent
- ☐ 65 per cent

2. Below what level of loading is it worth looking at re-sizing a motor?

- ☐ 85 per cent
- ☐ 75 per cent
- ☐ 65 per cent
- ☐ 50 per cent

3. Under the CEMEP rating scheme what was the most efficient motor?

- ☐ EFF1
- ☐ EFF2
- ☐ EFF3
- ☐ EFF4

4. Under IEC what is the lowest efficiency class?

- ☐ IE1
- ☐ IE2
- ☐ IE3
- ☐ IE4

5. At what date was it a requirement for motors between 0.75kW and 375kW to be IE3 or IE2 with a VSD

- ☐ January 2015
- ☐ January 2016
- ☐ January 2017
- ☐ January 2018

6. What would be the nominal speed of a 4-pole induction motor running on a 50Hz supply?

- ☐ 3,000
- ☐ 1,500
- ☐ 1,000
- ☐ 750

7. What is the speed of a 4-pole motor running on a 30Hz supply?

- ☐ 1,200
- ☐ 900
- ☐ 600
- ☐ 300

8. A fan is an example of what type of load?

- ☐ Constant torque
- ☐ Variable torque
- ☐ Constant power
- ☐ Maximum torque

9. What level of current surge can occur when starting a motor?

- ☐ 3 times load
- ☐ 5 times load
- ☐ 7 times load
- ☐ 10 times load

10. What percentage of motor failures are accounted for by bearings?

- ☐ 20 per cent
- ☐ 35 per cent
- ☐ 45 per cent
- ☐ 50 per cent

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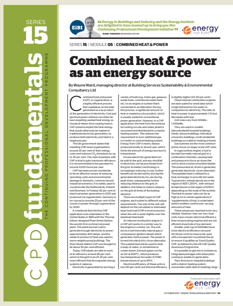

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