Motors and Variable Speed Drives

The cost of energy consumed by a motor over its life is far greater than the purchase cost of the motor. By taking account of efficiency when purchasing equipment you can save a lot of money over the life of the motor.

A whole-of-system approach to optimising your motor systems can reduce your business' operating costs and improve your bottom line. Improvements to the motor and the motor systems can reduce energy use by around 25% to 40%.

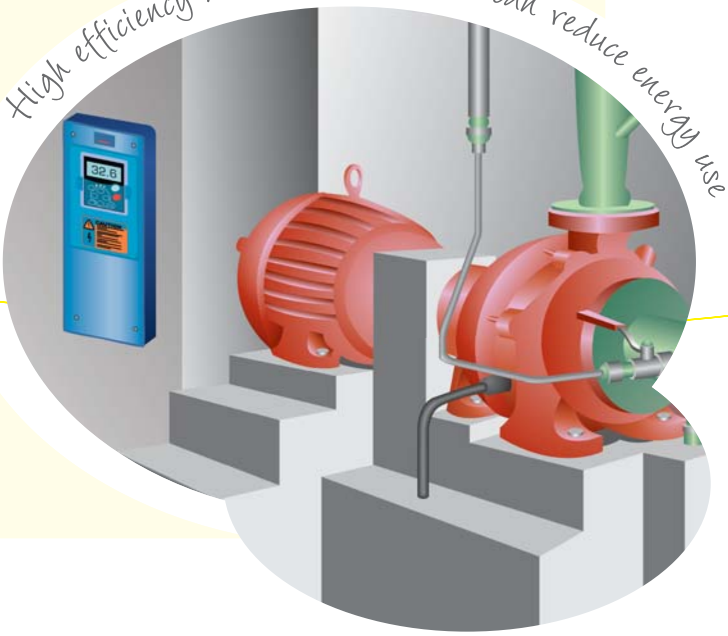
Facts and Figures

- It is estimated that electric motors account for over 80% of the total electricity consumed in the Australian industrial sector. More than 90% of all electric motors in industry are alternating current (AC) units.
- More than 1.7 million three-phase electric motors are operating in Australia, accounting for more than 28% of the country's electricity use.
- It is estimated that 37 million tonnes of greenhouse gas emissions per year, over 8% of Australia's total emissions, results from electric motor use.
- If the energy consumed by electric motors were reduced by 25%, the annual greenhouse gas emission savings would be equivalent to taking approximately 1.8 million cars off the road.
- The electricity bill for electric motors in Australian industry is approximately $3 billion per year.
- Pumps and fans can account for up to 40% of the total motor use in industrial applications.

Types of Motors

There are two main types of motors, AC (Alternating Current) and DC (Direct Current). Most motors in industry are AC induction motors. Both AC and DC motors, usually operate on 415V supply and can have a range of control devices fitted to them including:

- variable speed drives for AC induction motors (allow speed control)
- soft starters (reduce the impact on electrical components at start up)
- variable speed drives for DC motors.



High efficiency motors and VSDs can reduce energy use

Motor Efficiency

There are a number of ways to reduce the energy used by motors and drive systems. The key strategies are: increased motor efficiency and sizing the motor to match the load.

High Efficiency Motors

The efficiency of a motor is the ratio of mechanical power output to electrical power input. Mathematically, this is expressed as:

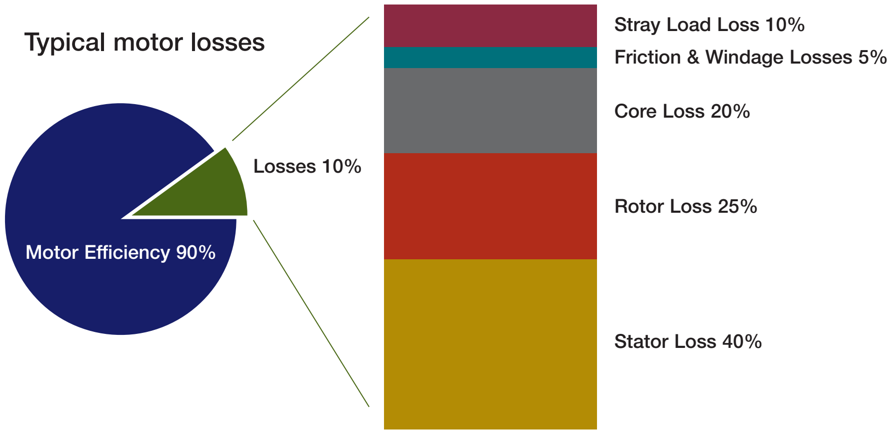
$$\text{Efficiency} = \frac{\text{Output Power}}{\text{Input Power}} \times 100\% = \frac{\text{Input Power - Losses}}{\text{Input Power}} \times 100\%$$

High efficiency motors simply minimise the losses within a motor. Motor losses occur independently of where the motor is used. This means that high efficiency motors can be used almost anywhere.

Assuming an efficiency improvement of 2.7% over a standard motor, a high efficiency motor will save about $1600 over a 15 year period. The cost for an 11kW high efficiency motor is only about $270 more than for a standard efficiency motor giving a simple payback of around 2.5 years.

As a purchaser of high efficiency motors, the most important thing you can do is have your supplier confirm what efficiency their motors are and how much more it costs for higher efficiency motors. This will help you in estimating the cost savings of the purchase over the longer term.

Typical motor losses

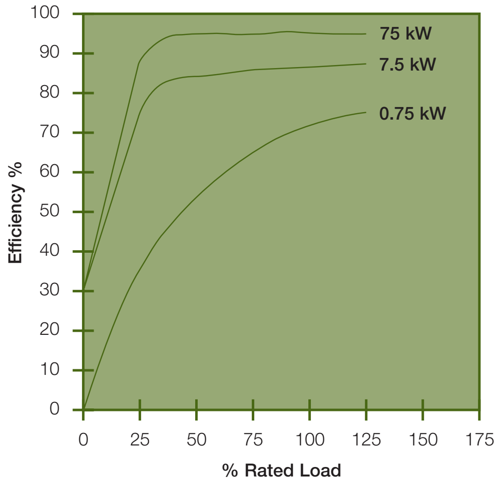


Motor over-sizing

Generally, the greatest improvement in system efficiency is likely to be gained by correctly sizing the motor to the load. A high efficiency motor (partly loaded), may use more energy than a smaller, less efficient motor in the same application.

Operations where the motor is operating at less than 60% of its rated load should be reviewed as the motor can often be replaced cost-effectively in these situations.

Typical Motor Efficiency at different loads



Minimum Energy Performance Standards

Legislation has been introduced to regulate the minimum efficiency of motors sold into the Australian market. This Minimum Energy Performance Standard (MEPS) for motors took effect on October 1st, 2001 and affects all motors from 0.73 kW to 185 kW.

The new Australian Standard covering motor efficiency is AS/NZS 1359:2000. Not only does it specify the minimum energy performance of motors, but it also requires new motors to be labelled with an energy performance label. This will allow you to assess the relative efficiencies between different motor types when purchasing a motor.

This does not mean all motor efficiencies will be the same. It just removes the most inefficient motors from the market. The efficiencies outlined in AS/NZS 1359.5:2000 should only be accepted as an absolute minimum when specifying equipment. These minimum efficiencies (for a limited size range) are shown in the following table.

Minimum efficiencies for high efficiency motors

Motor Size (kW)	Minimum efficiency (%) for 'high' efficiency motors (4 pole, 1440 RPM, full load)
0.75	80.5
1.5	83.5
3	86.0
5.5	87.9
7.5	88.9
15	90.8
55	93.5
90	94.4

Source: Extract from table 3.1 AS/NZS 1359.5:2000 - Minimum 'High Efficiency'-Test Method A.

Variable Speed Drives (VSDs)

Variable Speed Drives (VSDs) can achieve significant energy savings. Reducing fluid flow using VSDs can be done economically by regulating the speed of the motor. Industrial experience has shown that depending on the application, VSDs can save 25% to 40% of energy consumed by centrifugal pumps, fans and blowers.

In recent years, the price of VSDs has reduced and reliability has increased. This now makes their use even more attractive.

The input power of a fan is proportional to cube of the flow. For example, if 100% flow requires full power, 75% flow theoretically requires $(0.75)^3$ = 42% of full power. Although this is the theoretical saving under zero static head conditions, even in practical applications, a substantial energy saving can be achieved.

The equation forms for Fan Laws

$$[Q2 / Q1] = [N2 / N1]$$

$$[P2 / P1] = [N2 / N1]^2$$

$$[HP2 / HP1] = [N2 / N1]^3$$

Where:
Q1, Q2 = initial and new volumetric flow rate (l/s)
P1, P2 = initial and new pressure or head (kpa)
N1, N2 = initial and new fan speed (rpm)
HP1, HP2 = initial and new input fan power (kW)

When estimating the saving from VSD applications, it is useful to use the Fan Laws, which relate air (fluid) flow, input power and motor speed.

Energy can be wasted in some common areas. When using VSDs, it is best to avoid:

- creation of excess pressure
- more flow through the system than is necessary
- high frictional losses created from high average flows
- multiple pipes or ducts carrying fluid that is not being used.

Most energy savings from the application of VSD's are available in the use of centrifugal fans or pumps.

An example of how the Fan Laws may be applied in practice is a hospital that has a centralised plant supplying a chilled water system with two flow requirements.
The system is controlled by an electronic actuator that throttles the water flow based on the system requirements.

With the throttle fully open, the flow rate is 80 l/s while power consumption has been measured at 20 kW.

When the flow rate reduced to 65 l/s using the throttling valve the power consumption is measured at 18 kW.

The system operates for 8,760 hours per year divided into 60% and 40% for the throttled and un-throttled conditions, respectively. By installing a VSD, savings can be calculated as follows.

$[HP2/HP1] = [Q2/Q1]^3$

As $[HP2/HP1] = [Q2/Q1]^3$

$HP2/20\ kW = [65\ l/s/80\ l/s]^3$

$HP2 = [65\ l/s/80\ l/s]^3 * 20\ kW$

HP2 = 10.77 kW

This shows that for the 60% of the time that the system is throttled, the savings would be in the order of:

8760 hours/year * 60% *
(18 kW - 10.77 kW) = 38,001 kWh.

Ask yourself these questions

- Does your production volume fluctuate?
- Do you currently use multi-speed motors?
- Do you use dampers, control valves, or recycle loops to control flow?
- Would you benefit from remotely controlling your motor operations?
- Does your process require very accurate control of speed and torque?
- Do you have speed control systems which do not perform satisfactorily?
- Do any of these systems operate for more than 80 hours per week?

If you answer 'yes' to any one of these, you could benefit from using a VSD.

Strategies for reducing energy use in motor drive systems/applications

Pumps and fan systems account for almost 40% of all motor applications in industry. Pumps can be oversized, mismatched, worn, poorly installed, or operating effectively in an imperfect control system. All of these factors play an important part in energy consumption.

To maximise the energy savings of your motor system, you will need to take a systematic approach. There are two main steps in this approach:

- motor selection and management, and
- system optimisation.

Motor Selection and Management

Motor selection and management involves getting the best out of your motors. Making sure they convert the electricity into motive power or 'useful work' in the most efficient way possible.

High efficiency motors - should be a consideration for every piece of equipment that is purchased with an electric motor.

- Ask whether high efficiency motors, especially motors with operating hours, above 4,000 hours/year, can be fitted to the equipment you are about to order.
- Request efficiency figures and price premium from the supplier.
- Evaluate the benefits of using high efficiency motors. Check local availability and delivery lead time for spare high efficiency motors.

Motor Repair and Replacement - depending on the size of the motor, re-winding may appear to be a cheaper option than buying a new motor. Without taking into account any losses in efficiency, this could be true. You must ensure that you take into account the life-cycle costs of the unit, including the new efficiency of the re-wound unit.

- Losses in rewound motors can increase by up to 20% which is equivalent to an approximate 1.5 to 2.5% drop in full-load efficiency.
- A 3% decrease in efficiency is possible for motors older than 15 years that have been rewound more than once.

You should ask your re-winder if they are a member of the "Electrical Apparatus Service Association"? If so, they should be working under a *Code of Re-winding Practice* that aims to improve the efficiency of re-wound motors.

System optimisation

System optimisation involves getting the best out of your system and making sure it doesn't waste electricity through neglect, wastage, or poor management.

Control Selection - the motor system controls play an important part in maximising energy savings. Maximum savings are achieved only when motor systems are controlled properly.

A good guide as to what sort of controls may be suitable depends on the type of system. Systems can be defined as follows:

- steady - constant load, single operating point
- discrete - two to four operating points
- variable - greater than four operating points.

Control options that are suitable to different types of systems are included in the following table.

Control options to maximise energy savings.

	Type of System		
	Steady	**Discreet**	**Variable**
Control Options	Reduction of impeller diameter	Multiple speed motors	Variable speed drive
	Variable inlet guide vanes	Variable inlet guide vanes for fans	Variable inlet guide vanes for fans + multiple speed motor
	High efficiency motors	High efficiency motors	High efficiency motors
	Equipment upgrade (new pump)	Booster pump/fan	Booster fan + variable inlet guide guidevanes

Impeller Turn Down (pumping systems) - if your pumping system is set to a constant operating point and is throttled, then reducing the size of the impeller may be the best option. By reducing the size of the impeller, the throttling valve may be opened and system pressure and friction losses will be reduced, saving energy. Your equipment supplier should be consulted before making changes, and should also be able to assist you.

Variable Inlet Guide Vanes - (only applicable to fan applications). Reducing the flow of air supplied to the fan saves energy. As a result the fan does less work and less air is delivered. These devices are relatively inexpensive, but are limited to non-corrosive applications, where minimum flow requirements are 85% of full flow. Where flow control needs to be below 85%, the variable inlet guide vanes can be combined with multi-speed motors to increase their effective range.

Time based controls - as with other equipment, motor system energy consumption should be managed by minimising the running times. You should:

- install timers to start and shut down systems and avoid running systems when not required
- adjust start up times to suit seasons and your business' activities
- install 'after hours' control buttons, which will operate the system for the required period and then shut it down.

Sensor Location - the location of sensors used to control VSD's or other equipment is critical to minimising energy consumption. For example, when placing a duct static pressure sensor in an air conditioning system, it should be placed about $^{2}/_{3}$ down the longest duct run.

This allows the system to control the optimal duct pressure, minimising fan energy. If the sensor is too close to the fan, the duct pressure is most likely higher than necessary.

Eliminating Unnecessary Flow Paths - systems often change over time as equipment is added or removed and pipework is made redundant. Unnecessary pipes, high friction fittings such as tees or elbows, all add friction to the system and increase energy consumption and should be removed where possible.

Reducing Frictional Losses - optimising pipe, pump and duct sizing is best done when designing the system, but even after installation, cost effective upgrades can be made. Frictional losses are related to the velocity of the fluid. Generally, lower flows equates to lower losses.

Other frictional losses occur as systems age and corrosion, turbulence, contaminants, filter blockages, or changes in operating conditions alter the flows. The pipe flows should be periodically reviewed to ensure the system is not using too much energy.

Improving Inlet and Outlet Conditions - fine tuning of many pump and fan systems can involve optimising the inlet and outlet conditions by 'straightening' the system either side of the pump or fan. This reduces turbulence and increases efficiency.

Maintenance (alignment, cleaning, seals, pipe corrosion) - poor alignment of a motor and its load can increase the motor's power consumption significantly. Running clearances on all rotating parts should be checked as impellers and casings can get worn, or experience scale build up.

Filters, fans, pipes and ductwork can all suffer corrosion or scale build up. Each of these increases friction and decreases efficiency.

A systematic maintenance program should include checks on parts of the system that affect energy consumption. Mechanical seals have been found to save up to 8% of a pump's energy consumption over gland packings and reduce product loss, mess, and maintenance costs. You should:

- make sure your motors and loads are aligned correctly
- include areas of the system in the maintenance program that are likely to affect power consumption
- investigate the use of mechanical seals on your pumps.

More Information

If you would like more information regarding motors and drive systems you should contact a consultant or engineer or visit the Federal Government's Motor Solutions Online Website. If you want to know more about choosing energy efficient appliances or any other matters relating to energy use, simply phone SEDO's **Energy Smart Line** on **1300 658 158** or visit the Sustainable Energy Development Office's website at **www.sedo.energy.wa.gov.au**

Acknowledgments: Federal Government's Motor Solutions online

Sustainable Energy Development Office
Government of Western Australia

Published in December 2002 by the Sustainable Energy Development Office Level 9, 197 St Georges Terrace, PERTH WA 6000. Printed on 100% recycled paper