ENERGY EFFICIENT ELECTRIC MOTORS

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1 Preface

The electricity sector has a particular importance in the EU-15 energy sector, with electricity generation accounting for about 35 % of total primary energy use and about 30 % of man-made CO_2 emissions. The total European Union electricity consumption is about 2000 TWh/a and demand is forecast to grow at about 2 % per year. Actions must be taken to reduce the growth in electricity demand in the domestic, commercial and industrial sectors. These actions are all based on a common principle: they must be economically viable and achieve proper energy savings. For example the efficiency improvement cost must be paid back in a reasonable time by the electricity saved.
This paper describes measures to transform the market and foster the penetration of more energy efficient electric motors. Although electric motors have an efficiency which is much better than that of internal combustion machines an improvement of the efficiency by a few percentage points will result in large energy savings. This is due to the large amount of energy that is transformed in electric motors, typically about 60 % of the electricity consumption in industrialised countries.
Lighting by comparison accounts for just about 10 % of the EU's electricity consumption.

2 Introduction

A drive system is composed of several subsystems such as:

- power electronics
- controller for speed or/and position
- electric motor
- gearbox or/and coupling
- load e.g. pump, fan, compressor.

Although big energy savings can be achieved by looking at the complete system and in particular through the implementation of variable-speed drives, here the focus is on the electric motor itself.
About 90 % of the total motor electricity consumption is done with ac. three phase induction motors in the power range from 0.75 kW to 750 kW. A break down of the electricity consumption by end-use is given in Table 1.

Table 1: Electricity consumption by end-use

Type of load	Industrial sector	Tertiary sector
Motors	69 %	36 %
Lighting	6 %	30 %
Other	25 %	34 %

The growth rate of the motor load in the industrial sector is estimated to be 1.5 % and for the tertiary sector 2.2 %. The ac motor electricity consumption in 2010 for the industrial and the tertiary sector will close to 900 TWh. Table 2 provides an overview of the ac motor consumption by power range.

Table 2: AC motor electricity consumption in 2010

Power range kW	Industrial consumption TWh	Tertiary consumption TWh
0.75 - 7.5	148	109
7.5 - 37	136	75
37 - 75	103	25
> 75	258	18
	645	227

Energy efficiency improvement is a rather complex phenomenon because of the variety of actors involved: manufacturers, retailers, original equipment manufacturers (OEM's), consumers and consultants /1, 10, 11, 12/.
There are a number of barriers to the penetration of energy efficient drives:
- consumers' lack of information
- consumers' lack of capital for investment
- equipment owner not paying for running cost.

The main barriers to energy efficiency are:
a) A large amount of motors is sold to OEM's, whose main concerns are price and delivery time rather than efficiency.
b) Those departments of a company responsible for buying motors are often under pressure to recover their investments as quickly as possible. They are not responsible for buying energy.
   Maintenance managers make purchase decisions on replacement and not on energy efficiency.
c) The majority of motors when they fail are rewound, because repair is usually cheaper than a new motor purchase. Therefore, rewinding reduces the maximum theoretical penetration rate for efficient motors. The penetration rate is estimated to be around 6 % per year, based on an average life of 15 years.

To judge by past experience the timeframe required for the diffusion of innovations can be quite long.

3 Test methods

For testing motor efficiency two main test standards exist:
- IEC 34-2 mainly used in Europe
- IEEE 112 used in the USA.

Although the IEC method is easy to use, it overestimates efficiencies by up to 2 % for motors small than 10 kW and underestimates them slightly for motors larger than 700 kW. The IEEE is more accurate, but is not perfect either because it relies on the accuracy of the torque transducer.
There can be a 4 % variation between efficiencies determined using the IEC or IEEE methods. The key problem for the IEC method is how to take account of stray load losses in the motor. They are assumed to be 0.5 % of the motor input, but this is inaccurate for small motors. CENELEC, the European standardisation body and IEEE experts work on new revised standards.

In 1997, the US introduced minimum efficiency levels in accordance with EPACT legislation. In Europe in 2000 motor manufacturers belonging to CEMEP, signed a voluntary agreement to designate the efficiency classes of electric motors. Motors are classified according to EC/CEMEP in three efficiency classes (Fig. 1):
- EFF 1 (high-efficiency motors)
- EFF 2 (improved-efficiency motors)
- EFF 3 (standard motors).

Part of the agreement is that EC motor manufacturers have voluntarily agreed to reduce the market share of EFF 3 motors by at least 50 % by the end of 2003.
The agreement applies to 2- and 4-pole 50 Hz squirrel-cage induction motors in the power range: 1.1 kW ... 90 kW.
Efficiency measurement is based on the segregated-loss method according to IEC 60034-2, while the tolerance is given according to IEC 60034-1.
The efficiency class is stamped on the motor rating plate and information is provided on rated efficiency and efficiency for 75 % of full load.
Special features have to be observed, when the energy efficient motor is exported to the USA. The efficiency must be measured and certified by a test laboratory recognised by NVLAP. Then the manufacturer must send a declaration of conformity to the Department of Energy, which provides a certification number (CC-Number) to the manufacturer. The nominal efficiency and the CC-Number must be stamped on the rating plate.

4 Structure of Drive Systems

As a motion control system consists of several parts: supply, converter, control system, electric motor, mechanical coupling and the load, the future of the drive technology will be influenced by:

- power electronic components
- control strategies
- electric motors
- microprocessors and digital signal processor technologies.

Beside the pressure of increased productivity and improved product quality there is also concern for better energy efficiency.
Energy conservation and sufficient operation of a drive can be provided by the right choice of motor, inverter and control in combination with the load. The efficiency of induction motors in the power range of a few kW is in the range of 80% and above. However, efficiency of driven equipment such as pumps and fans is much lower. Pumps are designed to operate at maximum efficiency at certain head-flow condition. Operation at other conditions will lead to heavy decrease in efficiency /12, 13/.

Much more attention must be paid to improve the efficiency of driven equipment. For example, the power consumption of compressor motors can be reduced by closing of air leakages. For the open loop control of an induction motor drive the variation of the speed can be provided by altering the parameters voltage and frequency. This can be done with the help of: machine-driven converters and power electronics equipment.
The developments of the power electronic devices have created various converter circuits for a.c. drive systems:

-VSI
- CSI (self-commutated)
- VSI with chopper
- CSI (load-commutated)

-PWM
- PWM (double ended)
- Series a.c. resonant.
- Matrix
- Cycloconverters

Power-electronic systems are circuits with semi-conductors which provide a wide variation of electrical parameters with low losses.
Main applications of inverters are the control of voltage, current and frequency of electric machines. In doing so the torque and speed of the drive will vary. Besides that, inverters are used for induction heating systems, electrolysis systems, charging units and couplings between d.c. and a.c. grids /14, 15/.

A few selected applications for variable speed drives for energy conservation in handling systems for fluids and air are considered. The use of any variable speed drive replacing constant speed throttling valve or by-pass systems will result in energy savings. There may be few exceptions. The requirements for energy conservation variable speed drives are:
- payback period should be attractive
- easy maintenance
- high reliability
- stepless change of speed or stepped change of speed.

5 Energy Saving Approaches

To provide a high efficiency for electric drives it is necessary to find a system which is optimal from the viewpoint of both engineering and economics. A principle approach to solve that problem is shown in Fig. 2.

The efficiency of electrical machines depends on the type, size and quotient of partial load over nominal load. Improvement of the efficiency can be obtained with the following methods:
- Reduction of size (replacement of the motor), when the motor operates in an area of partial load (line A-B in Figure 2; increase of efficiency by 3 %)
- Increasing the size (replacement of the motor), when the motor is operating with a higher partial load (line C-D in Figure 2; increase of the efficiency of about 3 % although the ratio P/P_N is low).
- Voltage reduction, when the motor is permanently operating with partial load. In many cases an easy method can be applied to reduce the voltage: If an asynchronous motor is operating in delta connection it can be switched to star connection. Therefore the phase voltage is reduced to $1/\sqrt{3}$, the current and the torque are reduced to 1/3 and the machine is again operating with high efficiency (line E-C in Figure 2).

The basic need for the future of variable speed drives is for simplicity.
Simplicity in context of the approaches used to obtain:
robustness, performance, efficiency, cost.

The multiple dimensions of simplicity are:
hardware simplicity, functional, manufacturing, set-up/tuning, diagnosis/repair.

Simplicity pervades all aspects of the design, manufacturing and application. Technology risk is reduced by obtaining understanding and developing a strong sense about hardware and manufacturing.

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7. List of abbreviations

OEM	... original equipment manufacturers	VR	... variable reluctance
AC	... alternating current	SR	... switched reluctance
CEMEP	... European Committee of Manufacturers of Electrical Machinery and Power Electronics	EU	... European Union
		EC	... European Commission
DC	... direct current	EPACT	... Energy Policy Act (US)
PM	... permanent magnet	Nd-Fe-B	... Neodym-Iron-Boron

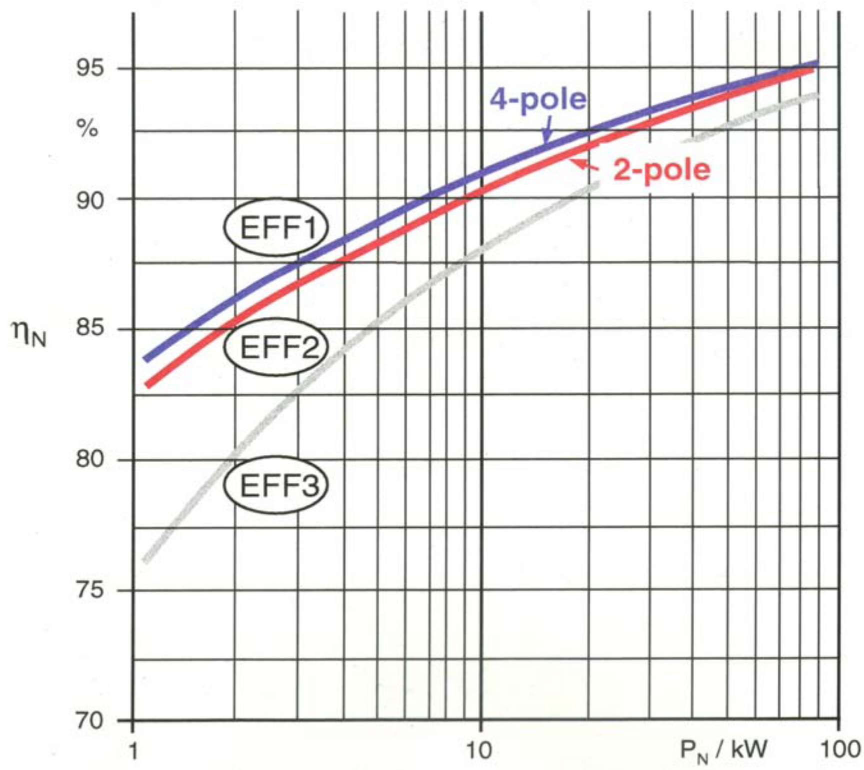

Fig. 1: Classification of efficiency

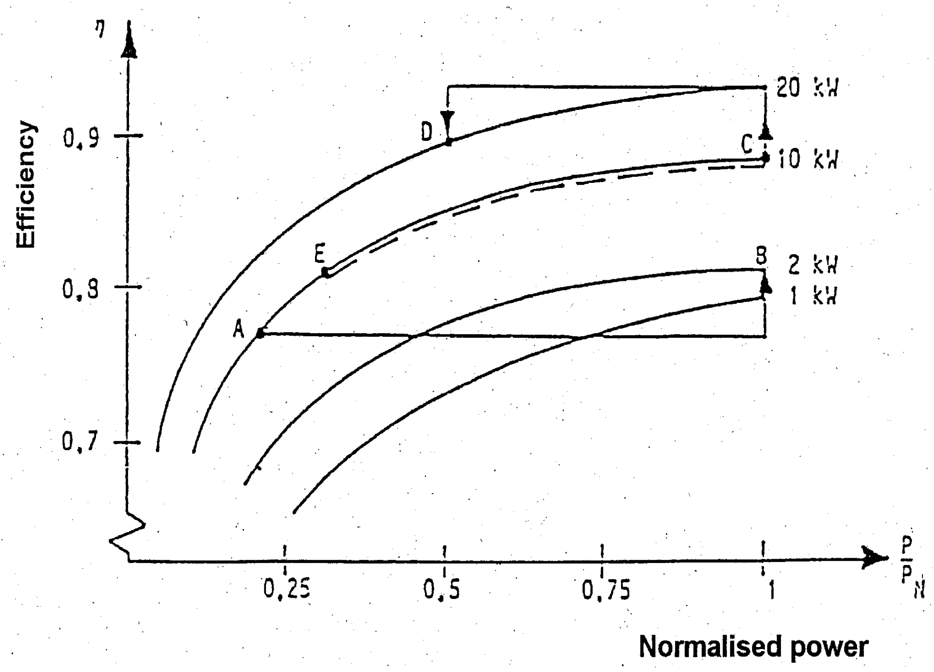

Fig. 2: Operation improvements