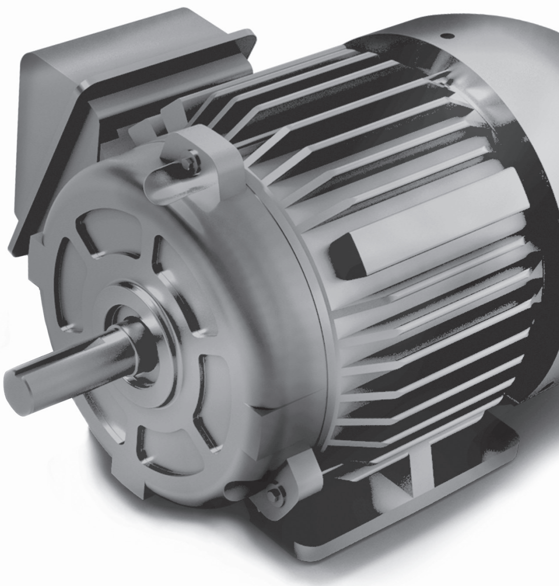
ZVEI: Die Elektroindustrie

Energy Efficiency with Electric Drive Systems

FUTURE OPPORTUNITIES

standards & laws
lifecycle costs CO_2 reduction
(EC) 640/2009
cutting energy costs MOTOR
SYSTEM APPROACH
Variable Speed Drive



Die Elektroindustrie

Energy Efficiency with Electric Drive Systems

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Contents

Foreword

Growth requires energy. The global economy's growth results in a steadily expanding demand for energy. This also causes an increasing rise in CO_2 emissions, resulting in climate change, whose progress and effects are not completely foreseeable at present. For securing the future of our planet, it is therefore crucial to eliminate the causes of climate change and to counteract any further rise in energy consumption sustainably.

The growing demand for energy has to be met from limited resources – a crucial reason for the continuing rise in energy costs. The development of electricity pricing will have a significant effect on corporate competitiveness. That is why the business community sees a lower level of energy consumption and correspondingly lower energy costs as a vital and motivating factor for its corporate success.

In December 2008, the European Union (EU) agreed on a package of directives and targets for climate and energy, which lays down ambitious goals. Up to the year 2020, the following Europe-wide stipulations will apply, which are often also referred to as '20-20-20 targets':

- 20 per cent less greenhouse gas emissions than in 2005
- 20 per cent proportion of renewable energies
- 20 per cent more energy efficiency

On 22 January 2014, the European Commission presented its roadmap for the EU's energy and climate policies up to the year 2030. Here, it goes even further and proposes a binding CO_2 reduction target of 40 per cent compared to the year 1990.

In order to achieve the climate change goals, the European Commission has enacted what is called the Ecodesign Directive. Economic reasons, as well as regulatory requirements, prompt an analysis of the total optimisation of drive systems, either using variable speed control or fixed speed solutions. Given the high potential savings in energy (up to 50 per cent), an analysis of the lifecycle costs is always worthwhile.

This brochure shows the potential offered by choosing the correct drive system to save energy and how the normative and legislative environment is defined on the national and international markets. The topic is rounded off by a look at future developments.

1 Energy Efficiency: a Future Opportunity for the Industrial Sector

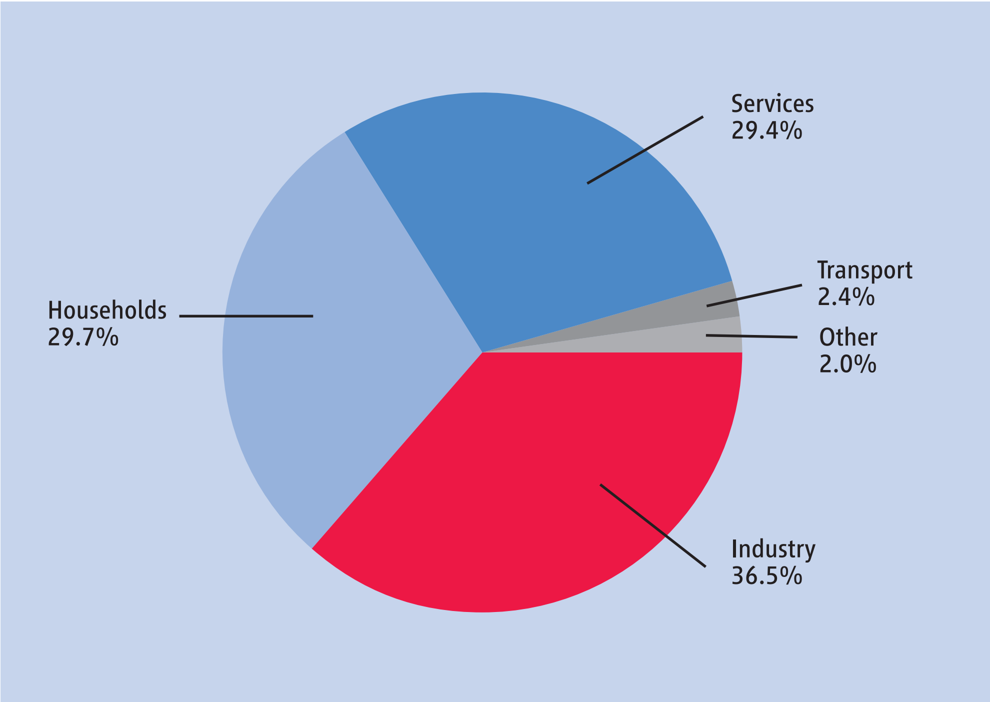
Energy efficiency is one obvious solution for key issues of the future: climate change, resource shortages and steadily rising energy costs. Its potential is very far from being exhausted. Especially in the industrial sector new actions are required due to rising energy costs, now that some 'low-hanging fruits', - the more easily achievable goals - have already been picked.

Industrial enterprises that wish to remain competitive in the future will have to keep a close eye on their energy costs. Given an industrial electricity price of 9 ct/kWh[1] and a general uptrend in electricity pricing, new energy-saving initiatives will definitely pay off. The companies concerned will thus also accept their social responsibility for the environment and for future generations.

High macro-economic benefits from energy efficiency

In 2010, the industrial sector was the biggest power consumer in Europe, with a share of 36.5 per cent in total consumption (Fig. 1), equivalent to 1.036 TWh (1.036 billion kWh).[2] Almost two-thirds of this, or 650 TWh, was accounted for by the energy consumption of electric motors and electric motor systems.[3] In the tertiary sector, a part of services, the total electricity consumption of motor systems is around 200 TWh.[4]

Figure 1: Electricity consumption by sector in Europe (2010)



Source: European Commission, DG Energy / Eurostat

[1] Eurostat, June 2014
[2] Energy markets in the EU, European Commission, DG Energy / Eurostat
[3] Bauernhansel, Mandel, Wahren, Kasprowicz & Miehe, Energieeffizienz in Deutschland, May 2013
[4] EUP Lot 11 Motors Final Report

In Europe, the savings potential of drive systems is about 89 TWh. This is equal to about 8 billion euros in energy costs per year: 72 TWh can be saved by using variable speed drives and 17 TWh by using energy-efficient motors.

The industrial and tertiary sector, however, are still using a large proportion of motors that do not meet the requirements of present-day efficiency classes or are not fully aware how to determine the additional benefits of variable speed control. The aim must therefore be to modernise this equipment as quickly as possible.

Definite benefits from energy efficiency for corporate users

The following two examples clearly illustrate the benefits to users from energy-efficient motors and variable speed drives.

- In the case of electric motors with a higher efficiency, the energy losses can be reduced significantly. An IE3 motor rated at 75 kW with an efficiency of 95.7 per cent, for example, is 1.7 per cent point more efficient than an identically rated IE2 motor (94.0 per cent). Given 6,000 operating hours per year, the higher efficiency means 30 per cent lower losses, and savings of around 689 euros a year.
- In an extraction unit, a fan rated at 7.5 kW is used. If the flow rate is not mechanically throttled, but controlled by means of a variable-speed three-phase motor to correspond to the quantity actually required, the annual savings of 756 euros in electricity costs can be achieved given 4,000 operating hours a year (see Section 7 for details).

The use of new, innovative, energy-saving technology pays off over the equipment's complete lifecycle. In addition, incentives for capital investment in energy-saving technologies are provided by means of tax relief arrangements and by subsidies for what are called cross-sectional technologies (see also Section 5).

Summary

In the context of the industrial sector's future competitiveness, energy-saving initiatives are a crucial issue. Almost two-thirds of energy consumption in the industrial sector is accounted for by electric motors and electric-motor systems. There are particularly high potential savings here using energy-saving motors and variable speed drives.

2 From the Grid to the Machine: Energy Efficiency in Drive Systems

The potential energy savings from electrical drive systems are approximately 40 per cent, through overall system optimisation (10 per cent from increased use of energy-efficient motors, 30 per cent from electronic speed control). Their essential components (switchgear or variable speed drive, electric motor and gear unit) therefore deserve particular attention.

About 60 per cent of total potential energy savings can be achieved by mechanical system optimisation of the machine itself (optimising pump impeller, fan blade angles etc). This brochure concentrates on the other potential savings that can be achieved by the design of the electrical drive systems. These are quite substantial as well, amounting to 40 per cent of the total potential (Fig. 2)

Figure 2: Potential savings from electrically driven systems

Potential savings from electrically driven systems	Potential savings in %
1. Increased use of energy-efficient motors	10
2. Electronic speed control	30
3. Mechanical system optimisation	60
Total	**100**

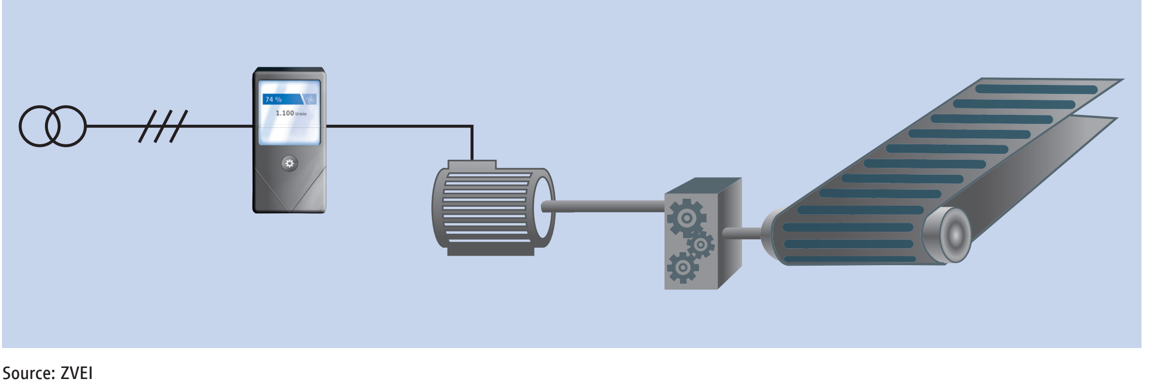
Source: Save reports from the EU

Focusing on the entire drive train

Electric drive systems essentially consist of the following components:

- a device for controlling the motors from the power grid, usually a contactor, soft-starter or variable speed drive;
- an electric motor that converts electrical power into mechanical power;
- a gearbox that adjusts the motor's mechanical speed to the working point of the driven machine (see also Fig. 3).

Figure 3: Schematic diagram of a drive train



Source: ZVEI

Some fixed-speed applications do not need a variable speed drive, merely a contactor for switching the motor on and off, or a soft-starter for soft motor start-up. In other applications, such as pumps, the speed of the electric motor is matched to the speed requirement of the machine, so that the gearbox is not required.

Variable speed drives

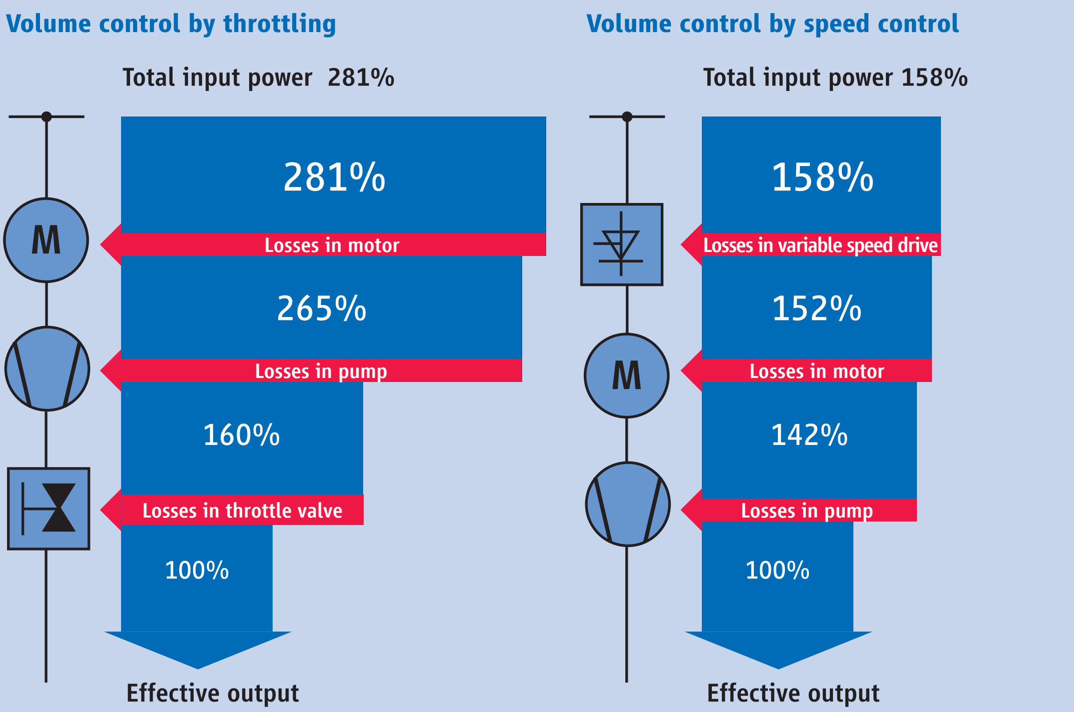
For speed control of a three-phase motor, the frequency and the voltage have to be varied. This is automatically done in a variable speed drive.

A wide power range of variable speed drives is available, from a few watts to several megawatts. Over the past few decades, their properties (start-up, power losses, size, cost) have been continually improved by the progress made in microelectronics and in power electronics. The performance of a controlled three-phase motor meets today's highest requirements. The efficiency of modern-day variable speed drives typically lies between 96 and 98 per cent (depending on power) and is determined by the efficiency of the power electronics.

The principal task of a variable speed drive is to control the motor's speed, conceptually equal to a variable electronic gearbox. Depending on the requirements of the process, the motor's speed can be changed to match the process need and thus optimize the energy taken from the grid.

This mode of process control offers enormous potentials in terms of energy savings, and is significantly more efficient than a throttle control, for example, in a pump application (Fig. 4). The European Union's Motor Regulation also permits the use of an IE2 motor with speed control using a variable speed drive as an alternative to a line-operated IE3 motor. The choice should depend on the application (see Section 3).

Figure 4: **Energy consumption at a pumping system: throttle and speed control compared**

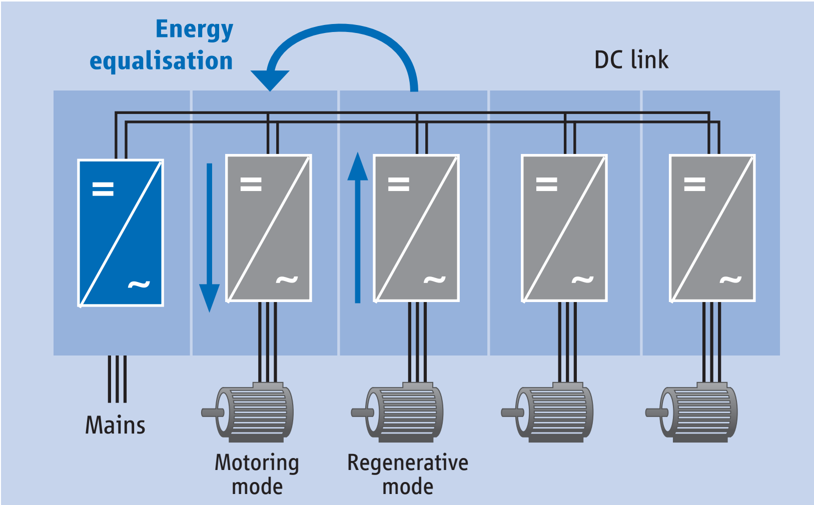


The effective output is in each case 100% hydraulic power at the pump. In the case of the throttle control, 2.81 times the useful output power has to be fed in. In the case of the variable speed control, by contrast, it is only 1.58. The losses are reduced to 1/3.

Source: ZVEI

Many variable speed drives provide additional options for an optimised energy efficiency of the drive system. If, for example, regenerative energy is produced by one drive, it can be fed back into the grid, instead of being converted into heat in a brake resistor – and thus wasted. It can also be made available to other drives operated in motor mode through a DC link. Instead of taking energy from the grid, in this case there is an efficient, direct energy equalisation between several different drives in an interlinked system (Fig. 5).

Figure 5: Energy equalisation between several drives



Source: ZVEI

Soft-starters

Controlling a three-phase motor using a soft-starter has beneficial consequences: conveyor systems start up without jerks, pressure surges in pumping systems are avoided, or start-up currents are reduced in the case of large rotating masses. Here, during a settable ramp-time the voltage fed to the motor is increased from zero to nominal using phase angle control and the start-up operation is thus controlled.

Soft-starters are cheaper than variable speed drives, and operate almost without any losses, as they switch the motor directly to the mains by a bypass contactor when full speed has been reached. For applications involving optimally sized motors, this configuration is better in terms of energy efficiency. In applications where the process permits energy to be saved by adjusting the speed, variable speed drives are preferable to a soft-starter, since with soft-starters the motor's speed cannot be controlled. Soft starters cannot realize the potential energy savings made possible by speed control. According to the EU's Motor Regulation, soft-starters may as from 1 January 2015 no longer be placed on the market with IE2 motors, but only with IE3 motors.

Motors

Electric motors principally convert electrical power into mechanical power, or to be more specific into speed and torque. Thanks to their principle of action, electric motors have a relatively high efficiency. A typical value for a 1.1-kW three-phase asynchronous motor lies at about 82 per cent; 100-kW motors have efficiencies of up to 95 per cent.

Motor losses are caused by various physical effects. Depending on the technology being used and the size of the model involved, the relative magnitude can vary. The most important loss factors are:

- Resistive losses in the motor windings;
- magnetic reversal and eddy currents;
- mechanical friction losses and parasitic effects.

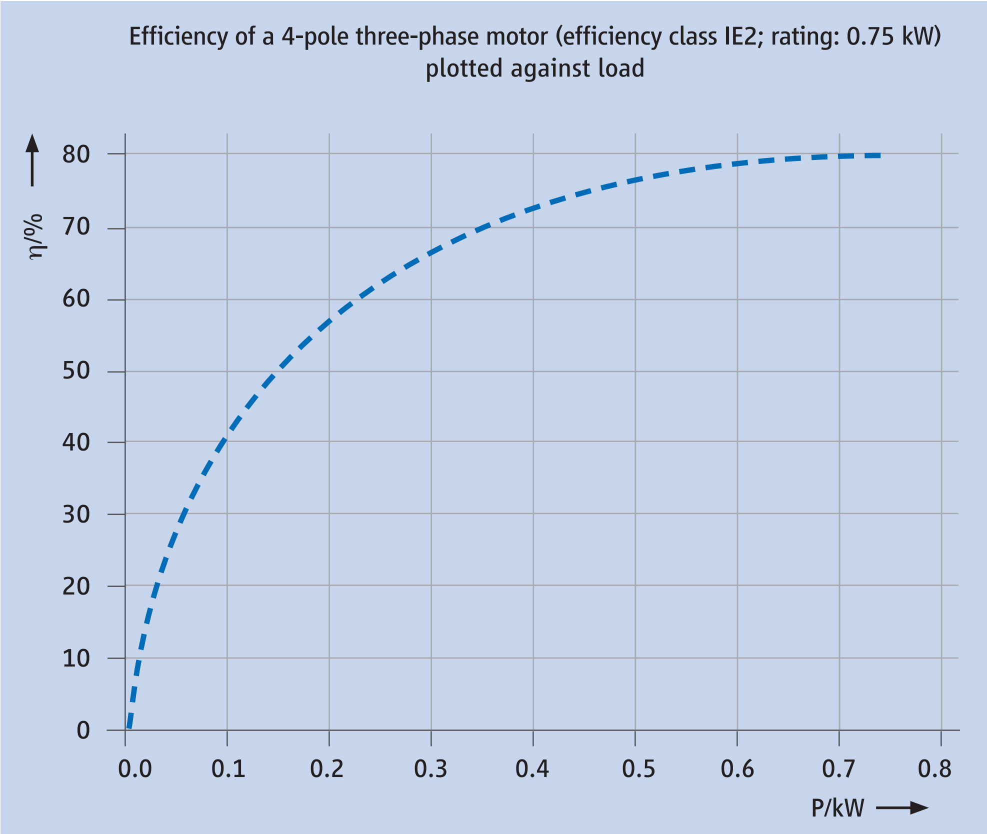
Depending on the motor's operating point (speed and torque), these effects have different influence on the motor's losses. While, for example, the power output decreases in proportion to decreasing torque, the motor's losses are not proportionally reduced. This means that the motor becomes more inefficient at partial loads. For energy-efficient operation, a motor should accordingly always be maximally utilised, and overdimensioning should be avoided (Fig. 6).

Three-phase line fed asynchronous motors in the rating range from 0.75 kW[5] are classified in efficiency classes IE1 to IE4[6] – the higher the number, the higher the efficiency. Motors of

[5] With the revision of the standard to create IEC 60034-30-1, three-phase motors are already being assigned to efficiency classes from ratings of 0.12 kW upwards (see also Section 3).

[6] Efficiency class IE4 was incorporated into IEC 60034-30-1 in March 2014 (see also Section 3).

Figure 6: **Motor efficiency against relative load**



Source: ZVEI

efficiency class IE2 are at present the market standard. Higher efficiency classes, by contrast, need additional technical efforts, e.g. a squirrel-cage rotor made of copper instead of aluminium or entirely different technologies. In order to reach efficiency class IE4, depending on the application/rating involved, not only asynchronous machines but also permanent-magnet or synchronous reluctance motors are used.

Gear units and geared motors

The nominal speed of three-phase asynchronous motors lies between approximately 750 and 3,600 rpm, depending on the number of pole pairs and the mains frequency. For many load applications, however, a much lower speed is required in conjunction with a larger torque. The speed here typically lies between 15 and 300 rpm. In order to match the motor's speed to the operating point of the work machine a gear unit must be used.

In general, a distinction is made between gears with coaxial and parallel axes as well as gears with crossing axes. The suitable gear unit type is selected based on the construction-related installation situation or based on criteria as load, noise or efficiency requirements.

The efficiency of a gear unit is influenced by the seal between the housing and shafts and the losses inside the unit (meshing, bearing friction, churning losses, additional losses). A basic distinction is made between helical, bevel and worm gear (Fig. 7).

Two-stage helical gear units can cover a gear reduction range of 1:5 to 1:60. The efficiency of these gear units is largely constant, regardless of the transmission ratio, and is between 96 and 98 per cent. Using a third helical gear stage, reductions of up to approximately 1:250 can be achieved; the efficiency then drops to about 94 per cent.

Bevel or worm gears are used where the output shaft is designed at right angles to the motor axis. Bevel gears are often equipped with a helical gear stage up- or downstream in order to realize higher reductions and then have an efficiency of about 94 per cent. Worm gears can have high reductions in only one stage, so one or two gear unit stages can be omitted. For achieving high efficiencies for high reductions, up- or downstream helical gear stages are used here as well. In many cases worm gears are used because of their quiet running and the possibility of self-locking operation for certain safety functions.

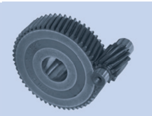
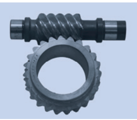
When selecting a suitable gear unit, the requirements of the application have to be taken into account.

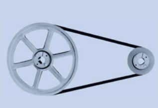
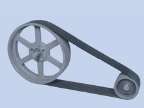
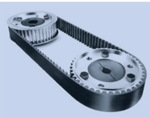
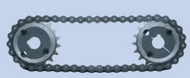
Ideally, torque is transmitted from the motor shaft or gear shaft to the driven machine by means of a rigid clutch. In this case there are practically no further losses. Belts or chains are used in many cases, enabling a further transmission ratio change. V-belts should be avoided, due to their slightly lower efficiency, and preference given to flat or serrated belts, or chains. Care must be taken to ensure that chains are particularly well lubricated.

Optimal dimensioning of energy-efficient drive systems

For the optimal sizing of energy-efficient drives, the process requirements with duty cycles have to be determined as accurately as possible. Overdimensioning, safety margins or 'fear factors' must be avoided, since all drive components are most efficient at full load. The efficiency is substantially reduced if a component is only being operated at low loads, e.g. if the full designed-in process power is utilised only during peak times. The nominal efficiencies on a rating plate may in this case be deceptive, and should serve merely as an initial guideline value.

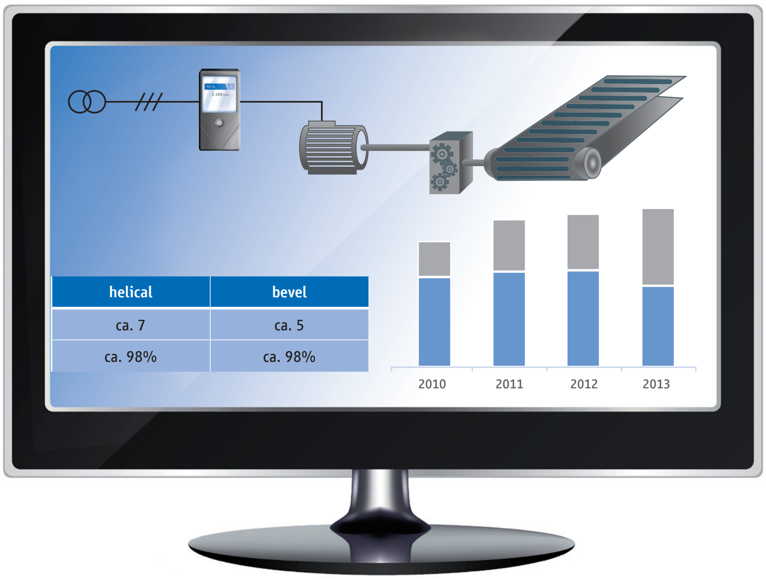
Figure 7: Gear types compared

			
gear type	**helical**	**bevel**	**worm**
Max. ratio	ca. 7	ca. 5	ca. 100
Efficiency	ca. 98%	ca. 98%	ca. 50% ... ca. 97%

				
gear type	flat belt	V-belt	serrated belt	chain
Max. ratio	5	8	8	6
Efficiency	96% ... 98%	92% ... 94%	96% ... 98%	96% ... 98%

Source: ZVEI

Figure 8: Engineering software as support for dimensioning and optimisation



Source: ZVEI

A supposedly more efficient component will not necessarily result in a lower power consumption of the drive system. A motor of efficiency class IE3 does not only have a better efficiency but also often a higher moment of inertia than an IE2 motor. If a process consists mainly of acceleration and deceleration operations, then due to the greater inertia more energy will be required than with a low-inertia motor.

In addition, the drive system's components can influence each other. The part-load efficiency of motors can, for example, be optimised using an intelligent variable speed drive (magnetisation adjustment). Considering the motor and the variable speed drive separately does not uncover this potential.

Overall, these examples demonstrate this: with system optimisation, the existing energy-saving potentials can be realized better than with component optimisation. Due to the complexity involved in this kind of overall approach, manual calculations are very elaborate or almost impossible. For this reason, many manufacturers of drive technologies offer supportive engineering software, designed to help the user determine the process requirements and compute the energy efficiency of a complete drive system (Fig. 8). Depending on the scope of the software, this takes due account of possible part-load efficiencies and the reciprocal influence of the components while also enabling different drive concepts to be compared in terms of their energy efficiency.

Summary

The individual components of the drive train in electrical drive systems have different energy-saving potentials. In many applications, the potential is particularly high for speed control of electric motors using variable speed drives. The motors themselves as well as the gear units also offer possible savings thanks to their high efficiency levels. A system optimisation helps to better maximise the potential savings.

3 Standards and Guidelines

There are various standards and guidelines that lay down the requirements for the eco-friendly design of electric motors and motor systems. The following provides an overview of the present and future regulations.

The Energy-Using Products (EuP) Directive (2005/32/EC) of 6 July 2005 defines the requirements for the eco-friendly design of energy-using products. On 21 October 2009, a revised version of this directive came into force, and the EuP Directive became the Energy-Related Products (ErP) Directive (2009/125/EC). The ErP Directive extends the requirements to cover the eco-friendly design of products relevant to energy consumption, but otherwise remains unchanged. As a framework directive, however, it is valid only for those products for which there is what is called an 'implementing measure' with product-specific requirements. For three-phase asynchronous motors, this is the case with the Regulation (EC) 640/2009 and the amending Regulation (EU) 4/2014.

Product-related statutory regulations

The Regulation (EC) 640/2009 of 22 July 2009 is the product-related regulation governing drive system technology. It defines the efficiency classes for motors supplied directly from the mains, the requirements for the use of variable speed drive technology and the time schedule for implementation.

Scope

The Regulation (EC) 640/2009 applies to three-phase asynchronous motors with a squirrel-cage rotor for 50 Hz or 50/60 Hz with the following properties:

- Rated voltage up to 1,000 V;
- Rated output from 0.75 to 375 kW;
- Number of poles 2, 4 or 6;
- Rated for continuous operation.

Exceptions

These statutory regulations do not apply to:

a) motors specified to operate entirely immersed in a liquid.

b) motors completely integrated into a machine (e.g. pumps, fans, gear units and compressors) and whose efficiency cannot be measured independently of this machine.

c) motors that are specified to operate exclusively under the conditions listed in the table below.

d) brake motors: motors with an electro-mechanical braking feature that acts directly on the output shaft without couplings.

Invalid since 26 July 2014	Valid from 27 July 2014[7]
At elevations of more than 1,000 m above sea level	At elevations of more than **4,000** m above sea level
At ambient temperatures above 40 °C	At ambient temperatures above **60 °C**
At ambient temperatures below -15 °C (any motor) or under 0 °C (water-cooled motor[8])	At ambient temperatures below **-30 °C** (any motor) or under 0 °C (water-cooled motor)
At coolant temperatures at the product inlet below 5 °C or above 25 °C	At coolant temperatures at the product inlet below **0 °C** or above **32 °C**

[7] Regulation (EU) 4/2014 (published on 6 January 2014), which amends the previous regulation (EC) 640/2009 for implementing Directive 2005/32/EC of the European Parliament and of the Council in regard to specifying requirements for eco-friendly design of electric motors.

[8] Correction (published on 19 February 2011): ambient temperatures below 0 °C in the case of water-cooled motors (instead of with air-cooled motors).

Time schedule for implementation

The individual requirements come into force in accordance with the following time schedule (Fig. 9):

- Since 1 January 2015, motors with a nominal output power from 7.5 to 375 kW placed for the first-time on the market must either be efficiency class IE3 or efficiency class IE2, but may then be operated/equipped only with a variable speed drive. Motors with a nominal output power from 0.75 to 7.5 kW placed for the first-time on the market must be at least efficiency class IE2.
- From 1 January 2017, the following regulation will apply: motors with a nominal output power from 0.75 to 375 kW placed for the first-time on the market must either be at least efficiency class IE3 or efficiency class IE2, but may then be operated only with a variable speed drive.

The most energy-efficient solution depends on the application involved, and should be determined in each individual case by the operator or planner of the system concerned. With full-load applications, an IE3 motor should be selected, while with variable load systems speed control with a variable speed drive can produce substantial savings.

Ongoing standardisation

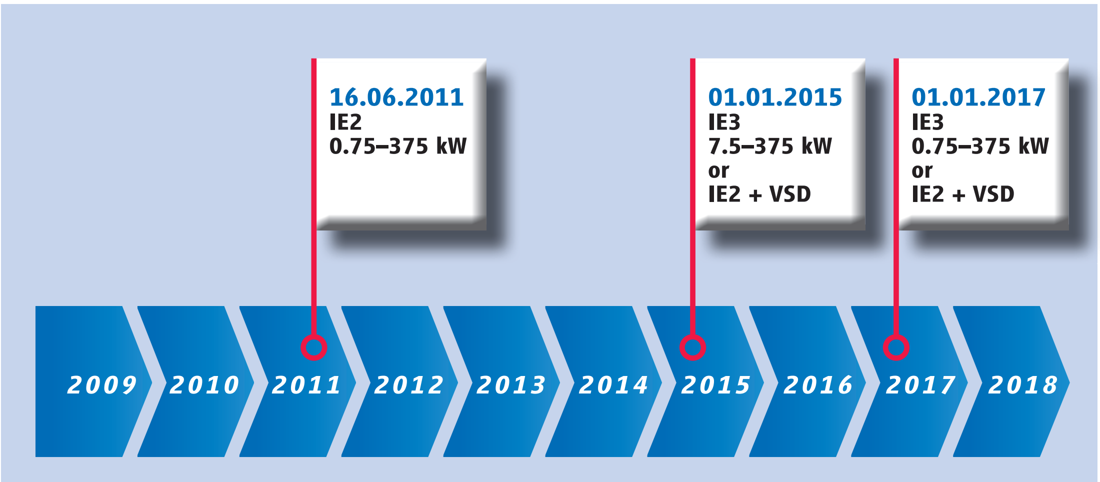
Standards are recommendations and become legally binding when used in statutory instruments and/or business agreements. The international standard IEC 60034-30-1, defines the efficiency classes (IE Code) for three-phase low-voltage motors directly connected to the mains:

- IE1 (standard efficiency)
- IE2 (high efficiency)
- IE3 (premium efficiency)

In future, the IEC 60034-30 standard will be divided into two parts:

- Part 1: Efficiency classes of line operated motors
- Part 2: Efficiency classes of inverter operated motors[9]

Figure 9: Implementing Regulation (EC) 640/2009



Source: ZVEI

[9] under discussion, date of publication not yet known

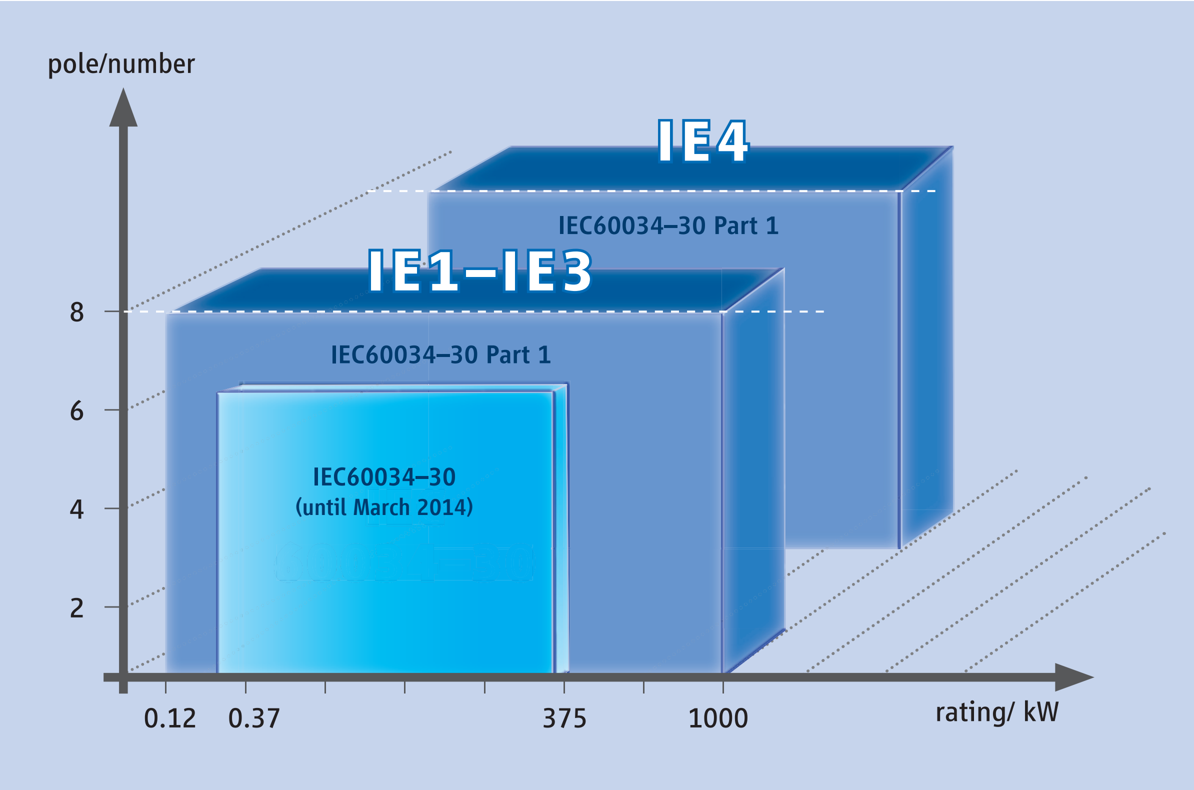
Extension of standard IEC 60034-30-1

The scope of the IEC 60034-30 standard, Part 1 Line-Operated Motors, has been extended and the new version published in March 2014 (Fig. 10).

The scope of the IEC 60034-30-1 standard with an additional efficiency class covers (Fig. 10):

- all motors running on the mains (e.g. single-phase motors and permanent magnet motors with starting cage);
- rated output from 0.12 to 1,000 kW;
- voltage range from 50 V to 1 kV;
- number of poles 2, 4, 6 and 8;
- all motors that are thermally able to run in continuous operation;
- temperature range -20 °C to +60 °C (nominal values at 25 °C), including smoke-venting motors with a temperature class of up to and including 400 °C;
- use up to 4,000 m above sea level (nominal values at 1,000 m);
- definition of IE4 efficiency values.

Figure 10: Differences in scope



Source: ZVEI

Differences in scope

The table below lists the scope of the international standard IEC 60034-30 and of Regulation 640/2009. It should be noted that the extended scope for the IEC 60034-30-1 standard does not influence the current statutory Regulation (EC) 640/2009.

	Which motor falls in which scope?	Standard IEC 60034-30: 2008 Class designations: IE1, IE2, IE3	EuP Directive/Regulation (EC) 640/2009 Minimum statutory requirement
1.	Standard three-phase asynchronous motor Note: also applies when the motor is installed in a machine Measuring the efficiency without aids such as shaft sealing rings, backstops, synchro-transmitters, etc.	Yes 0.75 to 375 kW Extension as per IEC 60034-30-1 to 0.12 to 1,000 kW 2-, 4-, 6-pole Extension as per IEC 60034-30-1 to 2-, 4-, 6-, 8-pole Continuous operation and intermittent operation, S3 (ON duration 80%)	Yes 0.75 to 375 kW 2-, 4-, 6-pole, continuous operation
2.	Gear motor	Yes	Yes
3.	Explosion-protected motor	Yes	No
4.	Brake motor: motor with an electro-mechanical braking feature that acts directly on the drive shaft without couplings.	Yes	No
5.	Motors that are completely integrated into a machine (e.g. pumps, fans, gear units and compressors) and whose efficiency cannot be measured independently of this machine.	No	No
6.	Other types of motor (e.g. permanent-magnet motors, pole-changing motors, motors for switching operation, such as servomotors).	No	No

Standards for the power drive system

Section 2 has already made it clear that optimising the energy efficiency of a drive system is significantly more challenging than simply optimising the efficiencies of the individual components. The new European standard EN 50598 takes this into account and describes in EN 50598 Part 2 how to calculate the nergy efficiency of a complete drive module (CDM) and the power drive system (PDS, CDM + motor). Standardisation is thus consistently progressing from the individual component to the entire drive system. This is called the 'extended product approach'.

The European standard EN 50598 consists of three parts. Part 1 and 2 contain definitions and descriptions of the energy efficiency for electric drive systems and their components in order to optimize the efficiency of a drive system.

Part 1: General requirements for setting energy efficiency standards for power driven equipment using the extended product approach and semi analytic model

It describes the responsibilities and tasks of the different interest groups using this standard as well as the necessary data flow.

Part 2: Energy efficiency indicators for power drive systems and motor starters

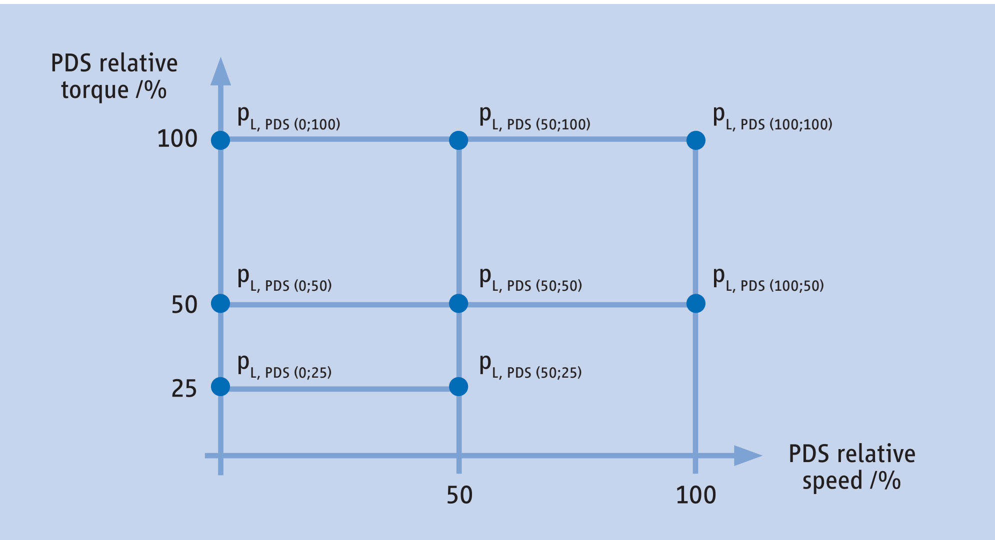
In this part energy-efficiency indicators are specified for power drive systems, motor starters and complete drive modules used for electrically driven work machines in the power range of 0.12 kW to 1000 kW. Losses and efficiency classes are defined:

- Definition of efficiency classes for motor systems and CDMs
- Definition of 8 operating points
- Methods for determination (measurement and calculation) of losses in the 8 operating points of a complete motor system and its components
- Measurement methods for CDMs
- Losses of the reference motor, the reference CDM and the reference PDS in the predefined 8 operating points

Part 3: Quantitative eco design approach through life cycle assessment including product category rules and the content of environmental declarations

Environmental aspects and product declarations of the drive components of power drive systems and motor starters are addressed in this part of the standard. The ecodesign topic is dealt with and essential environmental aspects for product design of motor systems (motor starters / variable speed drives, motor) are defined.

Figure 11: Operating points for a PDS

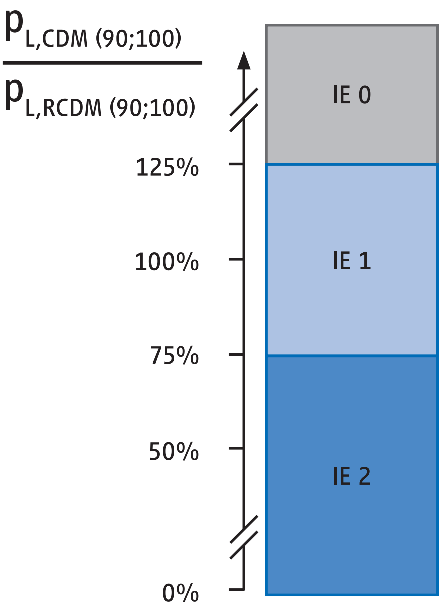


Source: ZVEI

Efficiency classes of variable speed drives

To avoid overmodulation and for reasons of comparability the efficiency classes of complete drive modules are defined for the 90/100 operating point (100 per cent current / 90 per cent motor frequency). The standard EN 50598-2 defines the relative losses (in relation to the nominal output power) of CDMs for the efficiency classes as IE0 to IE2. Compared to a reference CDM (defined in the standard as IE1) the IE2 CDM has at least 25 per cent less and the IE0 at least 25 per cent more losses (Fig. 12).

Figure 12: Illustration of IE classes for a CDM

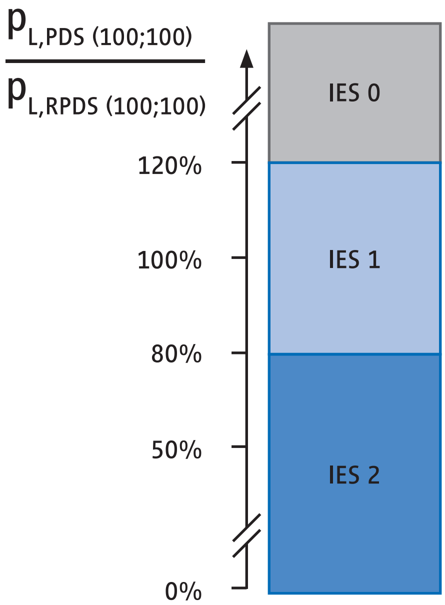


Source: ZVEI

Efficiency classes of electric drive systems (motor systems)

The efficiency classes for electric drive systems are defined for 100 per cent torque and 100 per cent motor speed. The standard EN 50598-2 defines the relative losses of the drive system for efficiency classes IES0 to IES2. Compared to a reference PDS (defined as IES1 in the standard) the IES2 system has at least 20 per cent less and the IES0 at least 20 per cent more losses (Fig. 13).

Figure 13: Illustration of IES classes for a PDS



Source: ZVEI

The addition of efficiency classes is not possible, an IE1 variable speed drive and IE1 motor doesn't automatically result in an IES2 for the complete system. Higher ordinal numbers in IE class in general mean reduced losses.

Summary

The Regulation (EC) 640/2009, in conjunction with the standard IEC 60034-30, lays down the requirements for eco-friendly design of energy efficient electric motors and the use of electronic speed control in Europe. The standard EN 50598 takes the system approach into account and defines efficiency classes for the complete drive module (CDM) and the power drive system (PDS).

4 The EU Motor Regulation: What You Need to Know

In the European Union only low-voltage three-phase asynchronous motors of efficiency class IE2 or higher may be placed on the market since 16 June 2011. This section deals with the requirements involved in this first stage of the Motor Regulation.

With the first stage of the European Motor Regulation, the legislators have prohibited the placing on the market of less efficient electric motors. In practice, this means that the manufacturer has to ensure that the motors conform to the regulation and (as is customary with other European directies) issue an EC Declaration of Conformity.

In the following sections, ZVEI explains some of the important statutory definitions based on the relevant legal regulations and publications.[10]

Placing on the market is defined as making a product available for the first-time on the market

Date of first-time placing on the market

Motors that were placed on the market before the deadline may continue to be sold even after the deadline has passed and be put into service and used in accordance with the rules applying before the deadline.

Practical example

Manufacturer A, identified by his name on or near the product, may place motors with an efficiency class IE2 with a rating of greater than or equal to 7.5 kW within the scope of the Regulations (EC) 640/2009 and (EU) 4/2014 on the market up to 31 December 2014. These motors shall be construed as having been legally placed on the market if up to this date they have passed from the manufacturer to another legal entity (e.g. distributors, LTD sales company of the manufacturer). They may then be resold, put into service and used even after the deadline of 1 January 2015.

Consignment warehouse

If a motor is delivered to a consignment warehouse, this is construed as being made available for the first-time either against payment or free of charge. This means it can be assumed to have been placed on the market.

Installed motors

Also included are motors that are installed in other equipment, and at first not placed on the market as a motor inside the member states of the EU. This ensures that the statutory regulations for imported products, e.g. machines, cannot be evaded.

Practical example

A circular saw that is imported into the European Union contains as a finished product a motor within the scope of Regulations 640/2009 and 4/2014. The installed motor must, when crossing a border (released from the customs warehouse), meet the requirements of Regulations 640/2009 and 4/2014, since at this point it is being made available for the first-time in a member state.

Repair

Repaired products without any significant change in their original rating, use or construction are not regarded as new products.

Practical example

A motor that was placed on the market before 16 June 2011 may be repaired and re-used even if it does not meet the requirements of Regulations 640/2009 and 4/2014. The delivery of a new spare motor is as a rule permissible only if it is in conformity with the regulation.

[10] Guidelines for implementing the directives drawn up in accordance with the new concept, ISBN 92-828-7449-0

Putting motors with variable speed drive into service

IE2 motors may be placed on the market for the first-time even after the deadline of 1 January 2015 under certain conditions. To be precise: the manufacturer must state on the motor and in the product information, in conformity with Regulation 640/2009, that the motor may be operated only with an electronic speed control.

If there is not enough space on the rating plate, ZVEI recommends that the manufacturer affix a sticker (Fig. 14) on the motor informing the user about the commissioning conditions involved.

ZVEI recommends that the information should be on the rating plate whenever possible. In many cases not all required information can be put legibly on the rating plate due to the size of the motor and the amount of information. Only if the size of the rating plate makes it impossible to mark all the information, an additional ‚sticker' just as permanent and visible as the rating plate must be used.

Figure 14: ZVEI warning sticker

Source: ZVEI

Interpretation of equipped with a variable speed drive

Although the term 'equipped with' is not defined in Regulation (EC) 640/2009 the interpretation is that 'equipped with' relates to putting into service. 'Putting into service' is defined as 'the first use of a product for its intended purpose by an end-user in the European Union.' ‚Putting into service' should not be confused with 'placing on the market' which is defined as making a product available for the first-time on the market.[11]

Export outside the European Union

The following cases do not involve placing a motor on the market:

- if the product is exported by a manufacturer from a member state to a country outside the European Union;
- if a manufacturer's product is transferred to an exporter (trader or machine manufacturer) who exports it independently or as an integrated component outside the EU. In order to avoid documentation problems for the manufacturer, the intention to export should in this case be fixed in writing between the manufacturer and the exporter (as his customer), e.g. in a delivery contract.

Practical example

A manufacturer based in the EU can produce and distribute motors of class IE1 within the scope of the Regulations 640/2009 and 4/2014 even after 16 June 2011, provided these motors are exclusively intended for export outside the EU. In this case, no CE marking may be affixed.

Market surveillance

Market surveillance is the responsibility of the EU member states. The member states shall designate the authorities responsible for market surveillance and specify the necessary tasks, powers and organisational arrangements. The market surveillance itself checks the identification and mandatory information on the product: the Declaration of Conformity and technical documents and device characteristics (random samples), particularly the efficiency that is measured in a certified laboratory.

Summary

The EU Motor Regulation contains clear stipulations for placing electric motors on the market. In Europe compliance is monitored by the member states.

[11] National Measurement Office (NMO), Executive Agency of the Department for Business, Innovation and Skills in UK

5 Lifecycle Analysis: When Energy Efficiency Pays Off

The lifecycle-cost approach is a must for every future-proof investment. In corporate practice the method of the payback period has been widely adopted, and is used for more or less every new investment.

The payback period, however, defines only when the capital employed has been recovered, but not the life time benefits, since the service life is not factored in.[12] The net present value method, by contrast, indicates whether a particular investment (despite a payback period of several years) can be recommended.

To assess different equipment investments in the long run, there are different tools available on the basis of the net present value method.

Figure 15: Motor scrapyard

Source: Cornelia Wohlrab/Fotolia.com

Replacing motors and systems

Efficient drive solutions based on highly efficient motors and modern-day variable speed drives are nowadays the state of the art, and are available in a wide variety. On the existing production lines in Europe with a service life of mostly over ten years, however, electric drives that do not conform to the energy efficiency classes now in effect are still being widely used. A systematic analysis of this production equipment with the aid of the net present value method shows the line's operator whether it is better to modernise an existing line or to continue operating it as before. This is an economical decision and depends mainly on the annual operating time and the energy price.

[12] Klima schützen – Kosten senken Leitfaden für effiziente Energienutzung in Industrie und Gewerbe, Bavarian State Agency for Environmental Protection, Augsburg 2004

The following example effectively shows that investments in an existing line with a longer period of amortisation can definitely pay off. This applies particularly for lines that are used for twelve years and longer, which in practice is very often the case. An interest rate of 2 per cent is used in the example.

On an existing line, a 75-kW motor with an efficiency of 92 per cent is installed. It is in operation for 5,000 hours a year. The status quo variant (i.e. the motor can be operated trouble-free for another twelve years) is compared below with the IE3 variant, i.e. the motor is replaced by a modern IE3 motor (75 kW, 95.7 per cent efficiency). The new IE3 motor, for example, costs 4,200 euros, plus additional installation costs of 500 euros.

Decision	Invest in €	Savings in €[13]		Savings discounted	Amortisation
		p.a.	aggregated		
Status quo	0	0	0	0	-
IE3 motor	4,700	1,249	14,988	8,509	ca. 4 years

In this example, the new motor will pay for itself only after approximately 4 years, but given twelve years of use this would mean an interest return of 81 per cent. By comparison, if the money were to be invested on the capital market, it would provide an interest return (including compound interest) of a 'mere' 27 per cent.

Decision	Invest in €	Savings in €[13]		Savings discounted	Savings invest	Interest return in %
		p.a.	aggregated			
IE3 motor	4,700	1,249	14,988	8,509	3,809	81.0

Decision	Capital investment in €	Interest in €		Interest incl. compound interest	Interest return in %
		p.a.	aggregated		
Bank (interest 2%)	4,700	94	1,148	1,261	26.8

[13] Electricity price 9 cent/kWh

Deploying an energy management system

The use of an energy management system (e.g. ISO 50001) offers an option for systematically acquiring and controlling the energy requirement of a drive system or of an entire company. Besides the modernisation of individual components, like electric motors, gear units and drive electronics, a system of this kind is another powerful tool for saving energy. With a fully functional energy management system, a company can transparently map out its energy flows, enabling it to identify the action needed for continuously upgrading its efficiency levels. Intelligent drive components like variable speed drives or soft-starters nowadays offer a multitude of measured values, e.g. current, voltage and cos phi, which can be transmitted to the energy data management system via commonly used field bus systems, such as PROFInet.

Another advantage: production companies in some European countries with a certified energy management system obtain relief from the energy and electricity tax.

Summary

In many capital investment projects, money is carelessly squandered, since in most cases only the payback period is taken into consideration. Particularly when a long service life is involved, however, investing in energy-efficiency initiatives will also pay off. In order to exploit all energy-efficiency potentials (also in existing installations), new framework conditions in the industrial sector (lifecycle analyses) and incentive systems have to be created by the politicians.

6 Vision for 2020

Electric drive technology is a key factor for reducing energy consumption in the European Union. A look into the not-so-distant future shows the importance that energy/resource-economical technology may have in the years ahead.

The politicians realised quite early on the huge potential of electric drive technology for energy savings, and had already in 2011 enacted some initial measures. As a consequence of the Motor Regulation (EC) 640/2009, the proportion of highly efficient motors of the IE2 and IE3 classes have increased significantly. One of the resulting beneficial side-effects is the increased perception of efficient motors by the users: many of them are changing directly from IE1 to IE3 motors, or are installing variable speed drives. The Motor Regulation, however, is only a first step, since the political pressure on the industrial sector to follow up with further resource-saving action will increase.

A vision for an energy- and resource-saving electric drive technology is mapped out below, as it might look from the viewpoint of the year 2020:

Political framework conditions encourage innovation and capital investment

The regulations introduced by the EU are proving to be a highly effective tool for defining the framework for energy savings based on electric drive technology. The demanding, but also realistic efficiency stipulations laid down by the legislators have met with very high acceptance among the manufacturers, the plant and machinery producers, and also among end-users. For an energetically optimised design, engineers can now define drive trains matched to the particular application concerned, supplied fully assembled by the manufacturer, or they put together energy-efficient components from different suppliers to create an optimal drive system. This flexibility encourages innovation and also enables manufacturers to outscore their local and global competitors by their knowledge on the drive level.

Practical market monitoring guarantees compliance with the high standards involved. Products that do not comply with the standards required therefore cannot endanger the cost-efficiency of investments in production, research and engineering.

It's systems, not components, that save energy

The transition in regulations from a component-based to a complete-system approach has made a major contribution to the savings targets achieved. Whereas line manufacturers and operators used to simply purchase devices that complied with the Efficiency Classes specified, nowadays users want energy-efficient systems, consisting of an electric motor, variable speed drive or motor starter all the way through to the gear unit and work machine. Energy management systems analyse and predict energy consumption, and the extended product approach enables the specialists at the plant and machinery manufacturers (but also appropriately trained users) to purposefully select the optimal measures without elaborate, lengthy and expensive series of tests.

One out of two drives is a variable-speed model

One key factor in optimising the energy balance is the increasing use of variable speed drives, whose proportion in electric drives has increased significantly. Whereas in 2012 only one in five new drives was a variable-speed model, the proportion nowadays, in 2020, has risen to about 50 per cent (Fig. 16). This enables substantial energy savings to be achieved, for example, with pumps, fans or compressors.

Variable speed drives are meanwhile just as common as illuminations with tungsten filaments used to be, and often even integrated into the motor as a constituent of a mechatronic system optimised for the application concerned. But so far not all applications where speed control would make sense have actually been fitted with variable speed drives. A further increase can therefore be anticipated.

Successful retrofits

Measures for relatively old electric drives already installed were important and successful. Selective subsidies have encouraged the replacement of motors with poor efficiency levels, and progressed the retrofitting of variable speed drives. The extension of the product approach from a mere efficiency focus to a focus on lifetime and carbon footprint has created additional impetus.

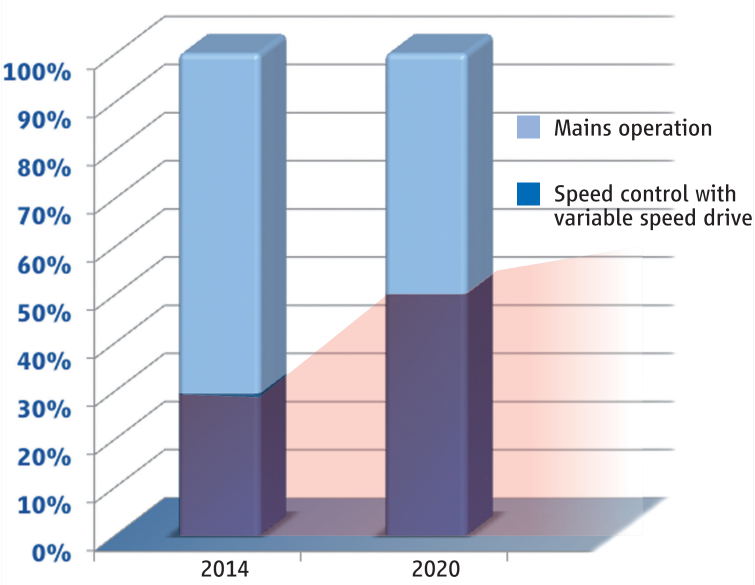
Further action needed

In order to make this vision come true, a number of urgently needed measures must be put into practice. The most important of these are:

- Definition of ambitious and realistic requirements for the energy efficiency of electric drives by the politicians;
- Securing combination options of efficient components to create efficient systems for users and line manufacturers;
- Use of the energy-saving potentials of installed drive trains by means of upgrades or retrofit jobs, e.g. through specific subsidies.
- Education

In order to reach the achievable goals, politicians will in the years ahead have to accomplish a difficult balancing act: they have to persuade users to deploy the technology, while at the same time communicating to them the relevant insights and possibility of selecting the best energetic solution. The industrial sector supports the politicians today and in the future by developing market-compliant solutions, plus finding and implementing ever-more-efficient approaches.

Figure 16: Anticipated increase in variable speed drives



Source: ZVEI

Summary

The avoidance of unnecessary power consumption is an important element for the energy supply of the future, and for assuring sustainability. The vision mapped out here shows the potential for advances in electric drive technology, but also what measures are necessary to translate this vision into reality.

7 Best Practice: Applications with Potential Savings

In the context of automation technology, the use of energy-efficient motors, of variable speed drives and of a cost-efficient motor/gear-unit combination plays an important role in saving energy. Various typical applications show how with an optimised drive solution the consumption, and thus the energy costs as well, can be dramatically reduced.

The additional costs for energy-saving technologies will be amortised in less than two years in many cases. The following examples of typical applications are based on an electricity price of 9 ct/kWh. Besides motors with a high efficiency class and energy-optimised gear units, variable speed drives offer particularly high potential savings.

Figure 17: **High potential savings with pump systems**

Source: Yury Maryunin / Fotolia.com

Pump drive: speed control instead of mechanical throttling

Pump systems offer significant potential savings, not least because they are mostly operated in the partial load range (Fig. 17). The delivery volume actually needed usually lies below the rated operating point, due to over-dimensioning of the system, and in many cases is regulated by mechanical control devices, such as valves or throttles. To give an example: at a coolant pumping station featuring five centrifugal pumps and five motors each rated at 55 kW in a production facility of the automotive industry, all pipe restrictors were removed and the throttle valves opened. To regulate the delivery volume, speed control with variable speed drives was used instead. This resulted in impressive energy savings of 60 per cent; the energy costs were reduced by 96,000 euros a year.

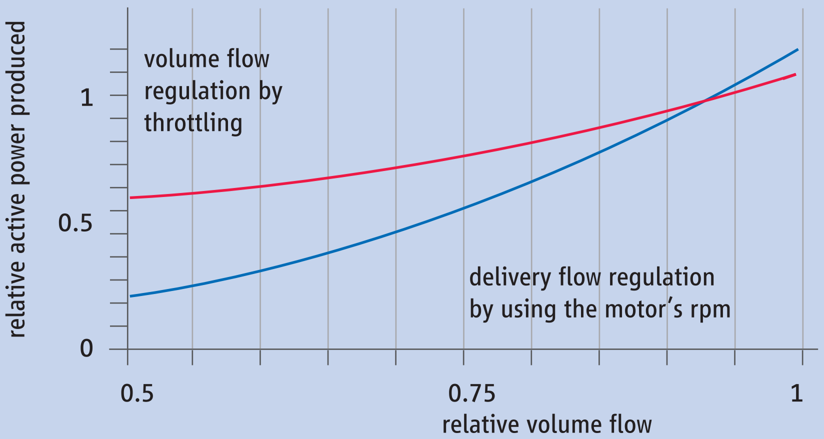
Fan drive: speed control instead of mechanical throttling

Fans have a wide range of applications. They range from small models for room ventilation via air-conditioning systems in buildings all the way to fresh-air and exhaust-gas blowers in cement plants. In the application described here, a fan with a power rating of 7.5 kW is used in the extraction system of a woodworking company. The flow rate is matched to the quantity actually needed using a variable-speed three-phase motor instead of being mechanically throttled. Given 4,000 operating hours, this saves 756 euros a year in electricity costs. The capital investment costs for the variable speed drive and control cabinet thus pay for themselves in around 25 months (Fig. 18).

Figure 18: **Fast amortisation for a fan drive**

Operating time	4,000 hours
Mean delivery flow	70% of nominal value
Input power, throttling	5.7 kW
Input power, speed control	3.6 kW
Energy saved	**8,400 kWh p.a.**

Fan, energy requirement comparison between mechanical throttling and electronic speed control



Source: ZVEI

Energy savings:
8,400 kWh

Electricity cost savings:
756 € p.a.

Payback time:
25 months

Variable speed drives: intelligent functions help to save energy

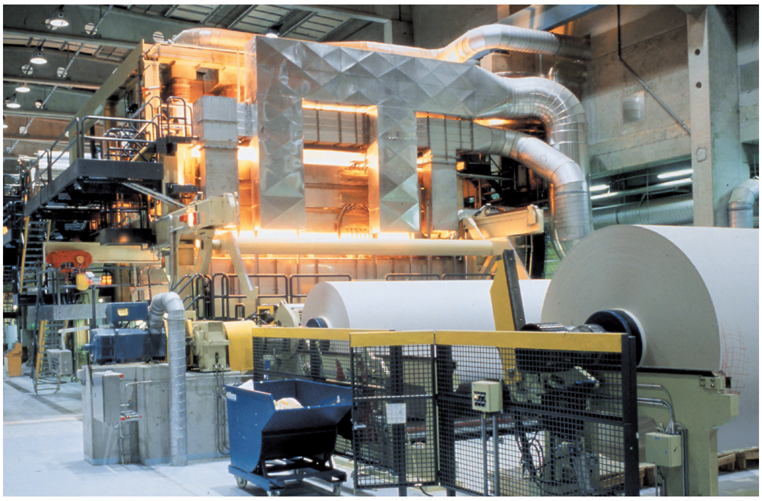
Modern-day variable speed drives incorporate intelligent energy-saving functions. Their users can fine-tune the process concerned in order to make optimum use of the energy available. One example is the energy-optimising mode, which increases the efficiency of the system comprising variable speed drive and motor, particularly in the partial-load range, by up to 20 per cent. Integrated energy efficiency computers support the users in analysing and optimising their processes.

Special variable speed drives for water and wastewater applications, moreover, offer intelligent pump control functions for individual pumps and multi-pump systems, designed to upgrade their energy efficiency (Fig. 19). At a pressure-boosting station with two 75-kW pumps and one 37-kW pump, a multi-pump control system, a pump priority changeover feature and a flow rate computation capability were used. When water consumption is low from the mains during the night, the small pump is activated, while during the daytime the two large pumps take over. This means the pumps can be run closer to their optimum operating point. By using variable speed drives with intelligent pump functions, the energy consumption was reduced by 30 per cent.

Figure 19: **Intelligent pump control functions for enhanced energy efficiency**

Source: ZVEI

Figure 20: **Multi-drive concept for a paper machine**



Source: ZVEI

Multi-drive concept: saving electricity by energy equalisation

In many applications, some of a system's drives are operated in motor mode, while at the same time others are operated in regenerative mode. Here, a multi-drive system with a DC bus is the preferable option instead of several separate drives. In contrast to a stand-alone drive, in the multi-drive concept several inverters of different ratings are supplied from a shared feed-in unit via a DC bus. Via this DC bus, efficient, direct energy equalisation can be provided by all inverters, without energy having to be converted into heat in a braking resistor or without any necessity for a regenerating unit. Examples here include conveyor systems or paper machines, in which the unwinder is run continuously in regenerative mode and the winder in motor mode (Fig. 20).

In the case of machines that are cyclically decelerated, as is the case, for example, with centrifuges and cranes, a feed-in/feedback unit is an obvious option. It feeds the braking energy back into the supply grid, and thus increases the machine's efficiency.

Summary

With drive systems, there are many options for saving substantial amounts of energy with the right solution for the particular application involved, thus also reducing the operating costs and contributing towards the energy turnaround. The amortisation period is often less than two years.

International Regulations for Energy-Efficent Motors

World-wide there are various national regulations for the use of energy-efficient motors, which either are already in effect or are still under preparation. This table provides an overview of the regulations in various industrial nations worldwide.

The table below shows the temporal development, the various standard classifications, broken down by IE Class, and the relevant rating ranges. The Efficiency Classes are based on the internationally valid standard IEC 60034-30. Country-specific designations may diverge from this standard. The significant exceptions in the national standard compared to IEC 60034-30 have been stated.

Country	IE	kW		No. of poles	2011	2012	2013	2014	2015	2016	2017	from	to	Significant Exceptions
 European Union	1	0.75	375	2,4,6								...	15.06.2011	All non-S1 and S6 motors Converter-fed motors 2015/2017 IE2 motors with indication ‚Use with VSD only' All ATEX 94/9/EG Motors designed for >+60 °C, <-30 °C, >4000 m Brake motors
	2	0.75	375	2,4,6								16.06.2011	31.12.2014	
		0.75	7.5	2,4,6								01.01.2015	31.12.2016	
	3	7.5	375	2,4,6								01.01.2015	31.12.2016	
		0.75	375	2,4,6								01.01.2017	...	
 Switzerland	analogous to European Union													
 Turkey	analogous to European Union (exception: motors designed for >+40 °C, <-15 °C, >1000 m)													
 USA	1	0.75	150	2,4,6								...	30.09.1997	All non-S1 motors Converter-fed motors Geared motors IE2 flange motors IE2 NEMA-Design C
	2	0.75	150	2,4,6								01.10.1997	19.12.2010	
		0.75	185	8								20.12.2010	31.05.2016	
		160	260	6								20.12.2010	31.05.2016	
		160	375	2,4								20.12.2010	31.05.2016	
	3	0.75	150	2,4,6								20.12.2010	31.05.2016	
		0.75	375	2,4								01.06.2016	...	All non-S1 motors Converter-fed motors
		0.75	260	6								01.06.2016	...	
		0.75	185	8								01.06.2016	...	
 Canada	1	0.75	150	2,4,6								...	30.09.1997	All non-S1 motors Converter-fed motors IE1 with Nema Design C stamp
	2	0.75	150	2,4,6								01.10.1997	11.04.2012	
		0.75	375	8								12.04.2012	...	
		160	375	2,4,6								12.04.2012	...	
	3	0.75	150	2,4,6								12.04.2012	...	
 China	1	0.55	315	2,4,6								01.06.2008	30.06.2011	All non-S1 motors Converter-fed motors Motors for 60 Hz only Unventilated motors Torque motors
	2	0.75	375	2,4,6								01.09.2012	31.08.2016	
	3	7.5	375	2,4,6								01.09.2016	...	
		0.75	375	2,4,6								01.09.2017	...	

Country	IE	kW		No. of poles	2011	2012	2013	2014	2015	2016	2017	from	to	Significant Exceptions
	1	0.75	185	2,4,6,8								…	31.03.2006	S2-motors
	2	0.75	185	2,4,6,8								01.04.2006	…	Converter-fed motors Geared motors
Australia	3													Underwater motors
	1	0.75	185	2,4,6,8								…	31.05.2006	S2-motors
	2	0.75	185	2,4,6,8								01.06.2006	…	Converter-fed motors Geared motors (motor flange part of the gear unit)
New Zealand	3													
	1	0.75	110	8								…	07.12.2009	All non-S1 motors
		0.75	150	6								…	07.12.2009	Converter-fed motors
Brazil		0.75	185	2,4								…	07.12.2009	Explosion-protected motors in Category 2/EPL B
	2	0.75	110	8								08.12.2009	…	
		0.75	150	6								08.12.2009	…	
		0.75	185	2,4								08.12.2009	…	
	3													
	1	0.75	7.5	2,4,6								2011	…	Brake motors
	2													Converter-fed motors
Chile	3													
	1	0.75	150	2,4,6,8								…	30.09.1997	All non-S1 motors
Mexico	2	0.75	375	2,4,6,8								01.10.1997	19.12.2010	
	3	0.75	375	2,4,6								20.12.2010	…	
	1	0.75	375	2,4,6								…		None known
	2													
South Africa	3													
	1	0.75	200	2,4,6,8								…	30.06.2010	S2-motors
	2	45	200	2,4,6								01.01.2008		Converter-fed motors (not pumps, fans, blowers)
South Korea		18.5	200	2,4,6,8								01.01.2010	31.12.2015	Explosion protected motors
		0.75	200	2,4,6,8								01.07.2010	31.12.2014	Unventilated motors
		37	200	2,4,6,8								…	31.12.2014	
		15	200	2,4,6,8								…	31.12.2015	
		0.75	200	2,4,6,8								…	31.12.2016	
		0.75	30	2,4,6,8								01.01.2015		
		0.75	15	2,4,6,8								01.01.2016		
	3	37	200	2,4,6,8								01.01.2015	…	
		18.5	200	2,4,6,8								01.01.2016	…	
		0.75	200	2,4,6,8								01.01.2017	…	

Die Elektroindustrie

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