

# Motor technologies for **higher efficiency** in applications

An overview of trends and applications.



## Freedom of choice

– Control a wide  
variety of motor  
types with only one  
VLT®



# One VLT® for all

A steady stream of innovative technologies for three-phase motors claims to achieve the highest energy efficiency in commercial and industrial applications. This brochure provides an overview of the technologies and their applications, as well as the pros and cons of individual solutions.

## Adapted algorithms maximise system efficiency

Motor manufacturers employ a variety of concepts to achieve high efficiency in electric motors for industrial and commercial applications. Although all motor technologies in the same efficiency class provide comparable efficiency at the nominal operating point, they differ in many aspects such as starting behaviour or partial-load characteristics. For users, the main impact of the wide variety of motor technologies is that they need to find the right technology for their application in order to achieve maximum energy efficiency and associated savings.

In principle, nearly all motors can be operated with programmed curves that specify the required voltage for every speed or frequency (voltage versus frequency characteristics). However, the theoretical efficiency of each motor technology can only be achieved in practice with control algorithms specifically adapted to the individual technologies, as otherwise it is not possible to optimise operation for every operating point with variable load.

## Low system diversity in the plant

Nearly all common motor technologies described in this brochure need an electronic controller or can be driven by an electronic controller.

However, this raises an issue: can all of the motors be operated with just one type of controller? Otherwise users and operators run the risk of being compelled to use a very heterogeneous system landscape. In practice this means higher training costs for system designers, operators and maintenance personnel. Spare parts for different types of equipment also drives up costs.

For users, it is therefore advantageous to be able to operate all motor types with just one type of frequency converter, because this distinctly reduces the previously described extra effort and expense. As an independent manufacturer of frequency converters, Danfoss supplies a solution that can drive all standard motors commonly used in industrial and building automation applications.

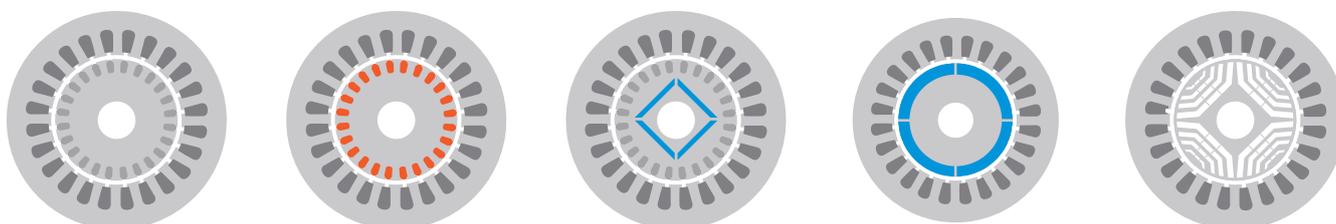
This allows plant operators to use the same operator interface, the same system interfaces, the same extensions

and proven, reliable technology over the entire power range. Spare parts management and maintenance are both simplified, and training costs drop.

## Easy commissioning and algorithms for optimal efficiency

As an independent manufacturer of drive solutions, Danfoss is committed to supporting all commonly used motor types and fostering ongoing development.

Danfoss frequency converters have traditionally offered control algorithms for high efficiency with standard induction motors and permanent-magnet (PM) motors, and now they also support synchronous reluctance motors starting with the VLT® AutomationDrive FC 302. Furthermore, the VLT® frequency converter makes commissioning just as easy as with standard induction motors by combining ease of use with additional helpful functions such as automatic motor adaptation, which measures the motor characteristics and optimises the motor parameters accordingly. This way the motor always operates at the highest possible efficiency, allowing users to reduce energy consumption and cut costs.



# Motives for improving energy efficiency

Depletion of fossil fuels, climate change and global warming are just a few of many reasons for significantly reducing energy consumption, and they have political consequences. For example, many countries worldwide – not only in the EU – have established mandatory efficiency classes for electric motors because motors are the link between the supply of electrical energy and the mechanical processes in the industrial and commercial sectors, which account for a large portion of energy consumption.

Two-thirds of total industrial consumption results from machines driven by electric motors. Savings of 38 billion kilowatt-hours per

year can be achieved in Germany alone in the industrial and commercial sectors and public institutions by replacing existing, decade-old drives by modern drive technologies. Extending this to the European level would allow consumption to be reduced by as much as 135 billion kilowatt-hours, equivalent to 69 million tonnes lower CO<sub>2</sub> emissions (source for all figures: ZVEI, “Motors and controlled drives”).

Minimum efficiency levels for electric motors are specified in the EU by Regulation (EC) no. 640/2009. Regulation (EU) no. 4/2014 expands the scope of the electric motors concerned.

## Motor technologies for compliance with new efficiency classes

The above-mentioned regulations establish new efficiency classes, whose current limits for IE1 (lowest class) to IE3 are taken from the EN 60034-30 standard. The EN 60034-30-1 standard defines the limits for IE4, which are not anchored in law. Changes to existing motor technologies, as well as new or rediscovered motor technologies, have been necessary to achieve the minimum efficiency levels of many of these classes. As a result, users are now confronted with a variety of trends in the

market. They also need to know what the various terms mean and what the different technologies have to offer. Is every type of motor equally suitable for every application?

## Efficiency class IE5

The EN 60034-30-1 standard also mentions class IE5 and outlines possible limit values for this class. However, it points out that engineering implementation is very difficult.

For this reason, class IE5 is not included in the discussion of the individual motor technologies in this brochure.

## IE5 classes for motor-frequency converter systems

Corresponding to the motor efficiency classes, IE classes for frequency converters and IE5 classes for motor-frequency converter systems are defined. Detailed information about these efficiency classes is available on [www.danfoss.com/vltenergyefficiency](http://www.danfoss.com/vltenergyefficiency) and in the Danfoss brochure “Ecodesign. We meet the strictest requirements – yours”.

## In a nutshell

The aim of this brochure is to provide a quick overview of the individual motor technologies. It describes the technologies and their characteristics, fields of use, and advantages or disadvantages in an easily understandable manner. In this way it helps users evaluate suitable motor technologies and asks manufacturers essential questions regarding their applications. The following motor types are addressed in the brochure:

- Standard induction motor
- Copper rotor motor
- Permanent-magnet (PM) motor
- EC motor (special case)
- Line-start PM motor
- Synchronous reluctance motor

Many electric motors and drives waste energy because they do not run in the optimal operating range. Consequently, developers of electric motors are devoting more attention to optimising the environmental compatibility of systems, and in particular their energy efficiency.





This selection of currently applicable and upcoming minimum requirements shows that the efficiency of electric motors is a worldwide issue.

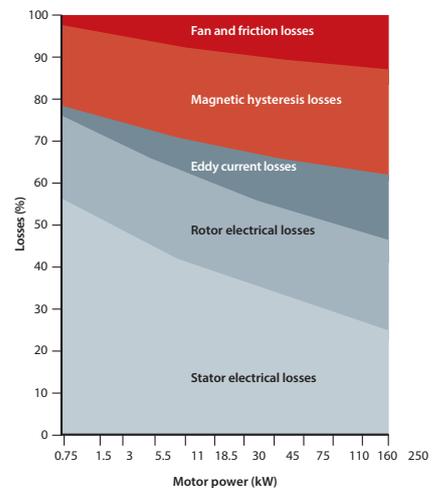
The Fraunhofer Institute for System and Innovation Research (ISI) reports that electric motors and corresponding systems account for 40 per cent of worldwide electricity consumption and are responsible for 6 billion tonnes of global CO<sub>2</sub> emissions, which corresponds to 20 per cent of total carbon dioxide emissions.

Another aspect of the environmental compatibility of electric motors is dimensioning. Making motors more compact reduces the amount of material used in manufacturing and the cost of disposal. Presently many motors are oversized as a result of “fear margins” in design and planning, and therefore operate with less than their rated load in most cases. They also operate at reduced speed and with reduced torque.

### Better motor efficiency

EU regulation 640/2009 compels motor manufacturers to comply with the required efficiency classes by specific deadlines and to supply corresponding motors (see Table 1).

That raises the question of how efficiency can be improved in order to achieve and maintain higher efficiency classes. One thing manufacturers focus on is trying to minimise losses in the rotor and/or stator. One way to do this is to use better lamination materials for these assemblies, and another is to use better electrical conductors, such as copper in cage rotors instead of lower-cost aluminium. However, that changes the current consumption unless the manufacturer takes suitable countermeasures. This means that users must check, on a case by case basis, whether other options are feasible when they are considering motor replacement.



Source: Standards for the efficiency analysis of electric motors – permanently excited synchronous motor technology, 2011. De Almeida, Ferreira and Fong.

### Step-wise intensification of requirements

In effect	MEPS in Europa	Applies to	Power range
16.06.2011	IE2	Motors	0.75-375 kW
01.01.2015	IE2	Motors	0.75-7.5 kW
	IE3 or IE2 + frequency converter	Motors	7.5-375 kW
01.01.2017	IE3 or IE2 + frequency converter	Motors	0.75-7.5 kW
2018	IE1 (expected)	Frequency converters	

Minimum efficiency requirements (MEPS) for motors

# Standard three-phase induction motors – the workhorse of industry

Three-phase induction motors, originally developed in 1889 by AEG, are still the workhorse in the industrial sector and are suitable for many applications. The popularity of three-phase induction motors has been strengthened by the development of soft starters and frequency converters. Soft starters significantly reduce starting current and usually connect the motor directly to the mains after the starting process. In addition, frequency converters enable precise and energy-efficient speed control. This makes the motors suitable for process optimisation.

## Technology

The motor operates on the basis of the Lorentz force, which causes electrically charged particles to move in a magnetic field. Magnetic interaction, which leads to rotary motion, arises from the magnetic fields generated in the stator (the stationary part of the motor) and the rotor (the moving part).

The stator winding is made from copper, while the rotor is implemented as a shorted-winding rotor with a cage made from aluminium bars.

## Achievable IE classes

The EN 60034-30-1 standard for motors assumes that the IE4 efficiency class can be achieved with three-phase induction motors operated directly from the mains.

## IEC frames

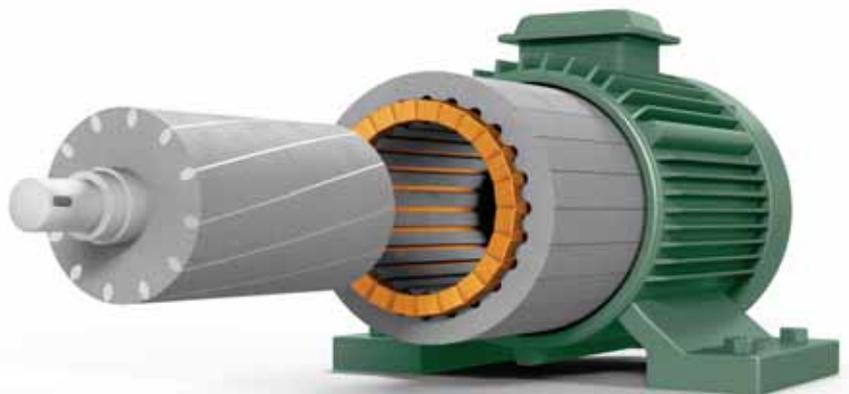
To improve efficiency, manufacturers often use better material or more laminations to fabricate the stators and rotors. In practice, this sometimes leads to an increase in motor size. However, all manufacturers strive to maintain IEC mounting dimensions in order to ensure compatibility with widely used motors in older systems. Consequently, the mounting dimensions (base distance, shaft height and shaft diameter) are usually the same, with only the stator diameter different in some cases.

## Frequency converter operation

Frequency converters provide smooth operation and optimal speed control. Problems in practice usually arise only when the motor insulation is not suited to the pulsed voltage output of the frequency converter.

## Particular aspects

Before replacing a motor to improve energy efficiency, users should check whether this is actually necessary. A 10-year-old induction motor is not necessarily inefficient. For example, the Danfoss VLT® DriveMotor FCM 300, available in a wide range of power ratings, already achieved the efficiency level of the current IE2 class when it was first introduced more than 10 years ago – and will continue to meet legal requirements beyond 2017. If however motor replacement is necessary or a different motor must be used in standard production machines, the user should check whether the more efficient motor conforms to the IEC mounting dimensions or if design changes are necessary.



Three-phase induction motor

# Copper rotor motors: better efficiency in standard induction motors

## Technology

Copper rotor motors are basically standard induction motors. They have the same structure and operating principle, but a different type of rotor material: instead of the usual aluminium cage, the rotor has a copper cage. Copper has lower resistance than aluminium, which reduces rotor losses. This advantage comes at the price of higher production costs. The high melting point of copper (approximately 1,100°C) compared to aluminium (approximately 660°C) leads to faster tool wear. Copper is also significantly more expensive than aluminium.

## Achievable IE classes

These motors typically achieve IE3 or IE4 efficiency.

## IEC frames

The frame sizes can comply with the IEC standard up to class IE4. In many cases versions with a smaller frame size are available.

## Frequency converter operation

Like standard induction motors, copper rotor motors can run from a frequency converter. Also like standard induction motors, problems only arise when the motor insulation is not suited to the pulsed output voltage of the frequency converter.

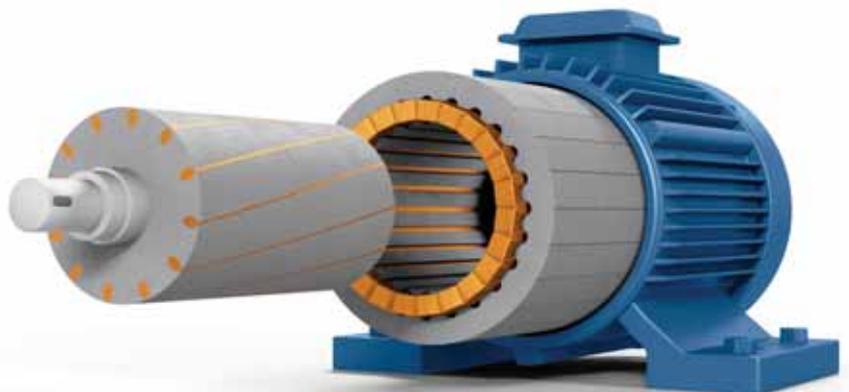
## Particular aspects

With regard to operation, users must bear in mind that copper rotor motors often have a higher starting current

due to the lower resistance. This must be considered in the design and when replacing existing three-phase induction motors.

In practice there have even been cases where the different starting torque or jerks during starting have led to damage.

The motor slip is also less as a result of the lower losses. This means that the nominal speed is higher, and with it the speed of the driven machine. Depending on the specific application, this may cause the driven machine to operate with suboptimal efficiency.



*Three-phase induction motor with copper rotor*



# Permanent-magnet (PM) motors

Permanent-magnet (PM) motors are becoming increasingly popular. The technology has been known and used for a long time, for example in servo motors. What is new is that PM motors with their relatively high efficiency are now available in standardised IEC mounting dimensions.

## Technology

Unlike three-phase induction motors, PM motors (as the name suggests) do not have rotor windings but instead permanent magnets, which are either mounted on the surface of the rotor or buried in the rotor. In the simplest case the stator has the same form as that of an induction motor, but motor manufacturers are also working on optimised designs.

PM motors are synchronous motors, which means there is no slip between the rotating fields of the rotor and stator as in three-phase induction motors. The necessary rotor magnetisation is provided by the permanent magnets, without any associated losses. This reduces rotor losses and raises motor efficiency. PM motors have distinctly better efficiency than induction motors in reduced-speed operation.

## Achievable IE classes

In practice current PM motors achieve efficiency levels between IE3 and IE4.

## IEC frames

Compared to induction motors with similar efficiency (e.g. IE3), PM motors can be significantly smaller.

## Frequency converter operation

The motors can operate with frequency converters without any problems. In fact, they usually need an electronic controller for operation.

## Particular aspects

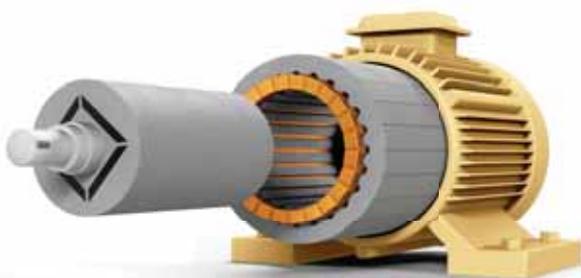
A significant drawback of PM motors is the need for a frequency converter or controller for operation. The controller must also receive a rotor position feedback signal in order to optimally adapt the magnetic field to the position of the permanent magnets and generate rotation. That is why such systems often have an encoder.

However, there are manufacturers (including Danfoss) that can operate PM motors without an encoder.

Two other drawbacks of these motors are the risk of demagnetisation at high current and high temperature, which however rarely occurs in practice, and motor servicing. Due to the strong magnets in the rotor, removing the rotor from the stator is difficult and requires special tools.

## Price evolution of PM motors

Rare earth elements are necessary to produce the magnets, and their prices rose sharply over the last decade, due to strongly increased demand and a shortage of availability. However, prices have dropped significantly in the last two years, in part due to the opening of new mines for these raw materials.



*PM motor with buried magnets*



*PM motor with surface-mounted magnets*

# Line-start PM motors

## Technology

A line-start PM motor is a hybrid combination of a three-phase induction motor and a PM motor. It has a cage rotor, but it also has magnets buried below the cage. This results in a complex rotor structure, which makes the motor more expensive. However, it has a significant advantage over normal PM motors: it can run directly from the mains without a controller. The cage winding is active in the starting phase. After the motor accelerates to the speed determined by the mains frequency, it becomes synchronised and has the same high efficiency as a PM motor.

## Achievable IE classes

When operating from the mains, line-start PM motors achieve efficiency levels between IE3 and IE4.

## IEC frames

The available frame sizes conform to the IEC standard. Smaller frame sizes are also available.

## Frequency converter operation

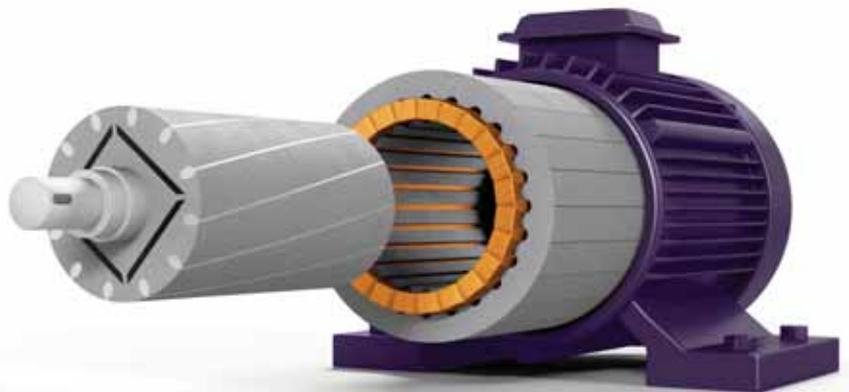
All line-start PM motors can also operate with frequency converters. However, it must be noted that efficiency is typically lower with frequency converter operation – 5 to 10 per cent less than with mains operation. This is due to the damping effect of the cage winding.

## Particular aspects

The first drawback is seen during starting: the motor may briefly run backwards. This alternating starting torque is also present in mains-operated induction motors, but it is much stronger in line-start PM motors. The alternating torque causes torque peaks as high as 7 to 17 times the rated torque. Nevertheless, the motor cannot start with a heavy load and does not have strong dynamic characteristics. Voltage sags and load jerks can cause the motor to drop out of synchronisation and therefore run with lower efficiency.

The motor runs at synchronous speed when operating from the mains, which causes a shift in the working speed of the load.

The considerations regarding rare-earth elements also apply to this motor because it also uses permanent magnets.



*Line-start PM motor with buried magnets and rotor cage*

# Synchronous reluctance motors

Synchronous reluctance motors are based on a technology that has been known for a long time. In the past they were optimised for torque or frame size, but now the focus is on energy-efficient design.

## Technology

These motors utilise reluctance force, which results from changing the magnetic reluctance. New, specially designed rotor cutouts guide the magnetic field lines inside the rotor to produce reluctance torque with high energy efficiency.

Versions of synchronous reluctance motors with line-start capability are also available now. Like line-start PM motors, they have an additional shorted winding in the rotor. These motors have very good efficiency. However, the efficiency drops by 5 to 10 percent with frequency converter operation (as for line-start PM motors), due to the damping effect of the shorted rotor winding.

## Achievable IE classes

The efficiency achieved in practice ranges from IE2 to IE4, even with new designs, but is closer to IE2 at relatively low power levels. These motors only achieve IE4 efficiency at power levels starting at approximately 11 to 15 kW. They also have very good low-speed characteristics at this power level and above.

## IEC frames

The available frame sizes conform to the IEC standard. Smaller frame sizes are also available.

## Frequency converter operation

Synchronous reluctance motors also need a frequency converter for operation, with the exception of the direct-on-line (DOL) version, which can operate directly from the mains.

## Variant for direct start on power

As for the line-start PM motor, the manufacturer combines the principle of the synchronous reluctance motor with the cage rotor of asynchronous machines. To do so, he fills voids in the rotor with aluminum bars and performs short-circuiting at both ends. In this way, the motor starts directly on mains, but also provides a better power factor when it comes to nominal speed.

The disadvantage here is that the additional damping of the cage winding once again produces higher losses in the motor.

## Particular aspects

The holes in the rotor laminations made necessary by the design degrade the power factor, which leads to overdimensioning by one or two power ratings depending on the type of frequency converter. No instabilities due to the rotor design are known at present.

The previously-mentioned power-dependent limitations on efficiency and under partial load conditions must be taken into account.



*Synchronous reluctance motor*

# EC motors

There are many different types of EC motor in practice, such as small servo motors with power ratings of a few watts or motors in building automation systems. They have a reputation for extremely high efficiency. This is fully deserved, in particular for very small drives – the original application area for these motors – where they are distinctly better than universal or split-pole motors (efficiency approximately 30%).

## Technology

As for PM motors, the rotor is fitted with magnets and the winding is in the stator. EC motors built according to the original concept operate with a commutated DC voltage. This is why they are also called brushless DC motors (BLDC) or electronically commutated motors (ECM).

In terms of technology, BLDC motors are AC motors, so the designation BLDC may be somewhat confusing.

To counter the drawbacks of the BLDC concept, such as relatively high phase currents and torque ripple, manufacturers have developed better control algorithms. For example, sensorless algorithms are now available. In building automation applications, EC motors differ from the previously described PM motors primarily in their construction as external rotor motors, for example fan motors.

## Achievable IE classes

The efficiency of current EC motors presently lies between IE2 and IE4, depending on the model.

## IEC frames

EC motors compliant with the IEC standard are fairly rare. EC motors with relatively high power (more than a few hundred watts) are mainly used in fans and blowers.

## Frequency converter operation

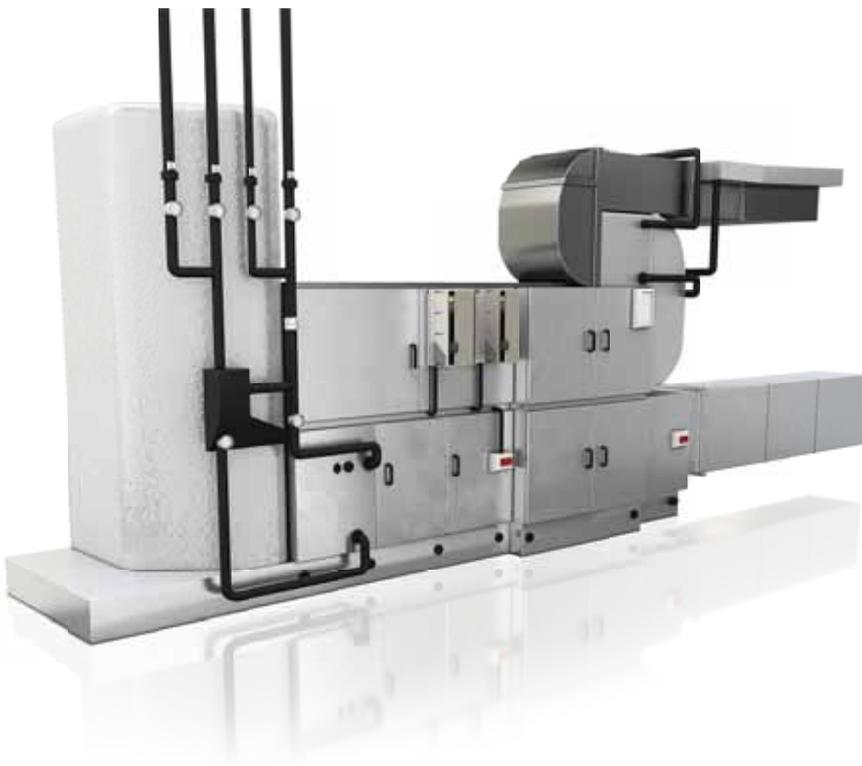
EC motors always need electronic controllers, regardless of whether they operate according to the original concept or the optimised concept.

## Typical applications

EC motors are often used in fans and blowers for building services, usually in the form of external-rotor motors, and as servo motors with relatively small power ratings.

## Particular aspects

The term “EC motor” is often used for a variety of different concepts. For users this makes it difficult to distinguish between conventional BLDC motors and improved types with higher efficiency, which are similar to PM motors. Due to the use of permanent magnets, EC motors are subject to the same considerations regarding rare-earth elements as PM motors.



# System optimisation: system analysis and potential

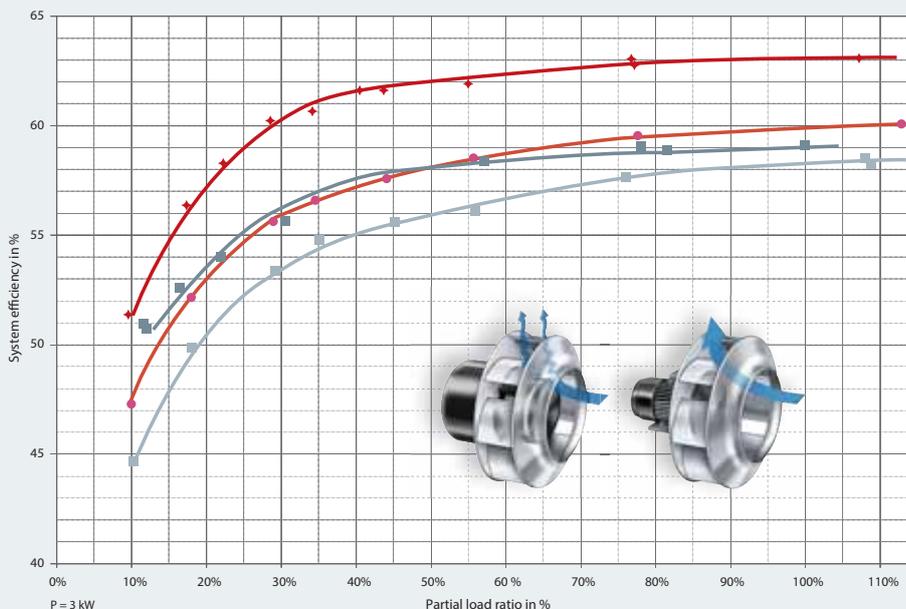
According to the German Association of Electrical and Electronics Manufacturers (ZVEI), approximately 10% of the potential savings in drive systems can be achieved by using motors with higher efficiency. Variable-speed operation yields potential savings of approximately 30%. However, the biggest source of potential savings (approximately 60%) is optimisation of the overall system. Consequently, for all measures the operator should always consider the impact on the overall system and check whether various approaches to reducing energy consumption can be combined. These include optimised pipe routing during remodelling, as well as the possibility of utilising the software functions of modern frequency converters.

The potential savings with different forms of energy differ significantly from one sector to the next. For example, the industrial sector has a considerably higher demand for process heat than the trade sector. The greatest potential savings are usually found in the area with the highest consumption. For example, the industrial sector accounts for approximately 43% of electricity consumption, while the trade, commercial and service sectors account for only 23%.

An exact knowledge of the system and technology is essential for determining the potential savings in the various sectors. Only then is it possible to judge whether or not specific measures are cost-effective.

Regardless of whether the question involves new or existing plants or machines, operators should first analyse the current status of the overall system before taking measures to reduce energy consumption. This enables them to better identify solution approaches and facilitates subsequent verification of whether the implemented measures are effective and achieve the desired savings.

## Overall system efficiency is a team effort



As confirmed by measurements at the Institute of Air Handling and Refrigeration, maximum system efficiency can only be attained by combining the best possible components. For example, the Danfoss EC+ system reduces losses in a fan by up to 11% with an optimal combination of frequency converter, motor and fan impeller. The very good motor efficiency of the EC fan is counteracted by the less favourable geometry of the impeller, resulting in a system efficiency some 3 to 5% lower.

- + EC+ fan with PM motor
- EC fan
- Fan with standard motor (IE3)
- Fan with standard motor (IE2)

# Summary

As the descriptions of the various motor types have shown, the legal and commercial demands for higher energy efficiency have greatly stimulated the motor market. Many different motor types employing conventional as well as new technologies are jostling on the market and competing for favour with users. It will be very exciting to see which technology or technologies manage to prevail over the long term.

Motor evolution is by no means finished. For example, manufacturers are already experimenting with ferrites instead of conventional magnets. The results of the first tests are very promising.

For users, it is important to examine each situation carefully to see whether the use of high-efficiency motors is worthwhile. For example, IE4 is not always the right choice due to the associated high costs or, in the case of applications with many load cycles, the higher inertia.

Finally, it must be borne in mind that some of the drawbacks mentioned for the various motors can be mediated by optimisation measures, such as the starting behaviour of line-start PM motors. However, such measures may in turn give rise to other drawbacks. The aim of this brochure is to make it easier for users to discuss motors with manufacturers in order to jointly find or develop the best drive solution for the application concerned.

Motor	Achievable efficiency	IEC type	Frequency converter operation	Applications	Comments
IM	IE3/IE4	IE3 or above sometimes difficult	No difficulties	Nearly all applications.	IE3/IE4 may not conform to IEC mounting dimensions.
IM with copper rotor	IE3/IE4	Compatible. Can also be smaller.	No difficulties	Nearly all applications.	Higher starting currents and different starting torques compared to IM. Must be taken into account in system design and for retrofitting.
PM	IE3/IE4	Compatible. Can also be smaller.	Always needs a controller. Some frequency converters need position feedback. Better efficiency at low speeds than DASM.	Nearly all applications.	Occasional high prices for required rare earth elements. Current price trend downward.
LSPM	IE3/IE4	Compatible. Can also be smaller.	Possible. Efficiency approximately 5 to 10% lower than mains operation.	Cannot start under heavy load, low dynamic performance, problems with weak mains supplies and load jerks.	Very good motor efficiency if the limitations are acceptable in the application. Rare earth issues similar to PM motor.
EC	IE3/IE4	No	Always needs a controller	Low power, EC fans, servo motors	Higher efficiency than other technologies at relatively low power (below 750 W). System efficiency is often degraded in centrifugal fan designs with the motor integrated in the fan hub. Rare earth issues similar to PM motor.
SynRM	IE2–IE4	Compatible. Can also be smaller.	Always needs a controller. Better efficiency at power levels above approximately 11–15 kW; comparable to PM at relatively low speeds. Larger FC often necessary due to poor power factor.	At present mainly pump and fan applications starting at roughly 11 to 15 kW.	Motors still relatively new on the market. Advantages primarily in the region above 11–15 kW at present.

IM Three-phase induction motor  
 PM Permanent magnet  
 LSPM Line-start PM  
 EC Electronically commutated  
 SynRM Synchronous reluctance  
 FC Frequency converter

# Motor operation with frequency converter

## Suitability, efficiency, optimisation

### Why use frequency converters?

The use of motors with higher efficiency adds another new aspect to the use of frequency converters. First, the speed control achievable using a frequency converter offers enormous potential for reducing energy consumption and costs. Second, some of the motor technologies can only be used with this technique.

### Which motors are suitable for use with a frequency converter?

The biggest load for the motor is the pulsed output voltage of the frequency converter, which the frequency converter uses for modelling the output voltage. The slew rate of the output voltage puts a load on the insulation system of the motor. For the last 10-15 years, this load hasn't really caused a problem because modern insulation resists these voltage peaks. However, when older motors are used, the load on the coil may lead to a failure unless suitable output filters are used for the frequency converter. In this case,  $dU/dt$  or sine-wave filters are recommended to reduce voltage peaks and protect the insulation.

### Thermal stress

With their adjusted control, many modern frequency converters, such as those available from Danfoss, are also capable of providing the fed input voltage at the output. Therefore the motor heating in standard motors (up to frame size 315) then lies in the range of the additional heating caused by mains tolerances and is therefore negligible. For example, for frequency converters with a lean DC link, which are not capable of generating the full mains voltage at the mains nominal frequency,

motor insulation of insulation class F is recommended, as the motor temperature may increase by up to 10 K.

### Bearing load

Adverse conditions (mains voltage, earthing, shielding,...) may cause frequency-controlled motors (normally only from frame 132 onwards) to fail due to bearing damages caused by bearing currents. For example, this may be by discharging currents in the lubricating film of the bearing, which occur impulsively and damage the bearing over time. Simple measures (good earth connection, screened motor cables, insulated bearings, special bearing greases...) reduce the bearing currents and thus the risk of a failure.

### Drive system design

When combining frequency converter and motor, the power data in kW provides initial orientation. For fine-tuning, however, the necessary currents or apparent powers need to be matched (this is especially true for synchronous reluctance motors!). It is important that the frequency converter is capable of providing the overload necessary for the application. This is typically 110% for fans and pumps and 160% for conveyor belts or lifters.

### Optimisation

If a frequency converter one size larger than actually necessary is used for an application, for example to allow a higher overload, this does not have negative energy consumption effects due to the high efficiency level. This is different for a motor, where over-

dimensioning has a significantly higher influence. Depending on the motor design, the efficiency at the operating point of the application may even be higher than at full load when choosing a larger motor.

Frequency converters utilising control methods adapted to the motor technology provide ideal magnetisation during operation, including at partial load. This is also the case for (strongly) alternating loads. For example, Danfoss frequency converters for PM motors follow the MTPA (maximum torque per ampere) concept, which permits the best possible energy efficiency for every motor design.

### More information

The majority of the standard three-phase motors on the market run completely problem-free with modern frequency converters. During the selection and installation process, users should pay attention to the respective characteristics of the various technologies. However, this will not be a big challenge for professionals. The previous sections offered a short summary of the topic. Find more information on the safe and energy-efficient design of drive solutions from Danfoss' practical planning guides.

# The vision behind VLT®

Danfoss is a market leader in the development and manufacture of frequency converters – serving new customers daily.

## Environmental responsibility

### Danfoss VLT® products – considering people and the environment

All production sites for VLT® frequency converters certified to ISO 14001 and ISO 9001.

Danfoss' activities take employees, jobs and the environment into consideration. Production processes produce minimum noise, emissions and other environmental impacts. In addition, Danfoss seeks to protect the environment when disposing of waste and end-of-life products.

### UN Global Compact

Danfoss has confirmed its commitment to social responsibility by signing the UN Global Compact. Our subsidiaries are aware of their responsibility with respect to local conditions and practices.

### Energy savings through VLT®

The energy saved in the annual production of VLT® frequency converters is as much as that generated by a large power station each year. Improved process control optimises product quality and reduces waste and wear on the production lines.



## Dedicated to drives

Danfoss VLT Drives is a global leader in the area of drive engineering and manufacture. In 1968 Danfoss introduced the world's first mass-produced frequency converters for three-phase motors, and since then has specialised in drive solutions. Today, VLT® stands for reliable technology, innovation and expertise for drive solutions within many different branches of industry.

## Innovative and intelligent frequency converters

Danfoss VLT Drives, headquartered in Graasten, Denmark, employs 2500 staff for the development, production, consulting, sales and maintenance of Danfoss drive solutions in over 100 countries.

The modular frequency converters are manufactured according to customer requirements and supplied fully assembled. This ensures that every VLT® is a state-of-the-art device when delivered.

## Trust the world experts

To ensure the consistent high standard of quality of our products, Danfoss VLT Drives controls and monitors every important product element. The group has its own research and software development department as well as modern production facilities for hardware, power modules, printed circuit boards and accessories.

VLT® frequency converters are used in diverse applications worldwide. The experts of Danfoss VLT Drives support customers with extensive specialised knowledge relating to specific applications. Comprehensive advice and a fast service ensure an optimal solution with high reliability and availability.

A project is only complete when our customers are fully satisfied with the drive solution.

