WHITE PAPER

Improving end-to-end system efficiency with VSDs and magnet-assisted synchronous reluctance motor technology

Modernizing motor systems can improve efficiency and reduce costs

In industry today, a large percentage of motors have been in service for a long time. For example, in the US, it is estimated that over 60% of motors used by industry are over 10 years old.[1] While many of these motors may still be in good working condition, older designs are nonetheless still less efficient than modern motors. This impacts not just the cost of running a motor, but also the efficiency and energy consumption of systems overall. Therefore, by updating to newer, more efficient motor systems, industry stands to gain from both energy and cost savings throughout their operations. In this white paper we will focus on two proven methods of improving motor system efficiency: replacing an older motor with an IE5 motor with an integrated drive, and adding a variable speed drive to control the motor.

Systems that use older motors are less efficient
About 70% of the electricity used in industry is consumed by electric motor systems.[2] Many of these motor systems are installed in facilities which typically have long equipment life-cycles and long periods between investments and upgrades. Therefore, the motors in use are often many years old. For example, in the US, most of the electricity used by industrial motor systems is consumed in the plastic/rubber, paper and primary metal industries.[3] In these industries, and most others, the motors in use are likely to have IE3 or even IE2 efficiency. One of the reasons that these older motors are less efficient is that they have higher losses than more modern designs.

The cost of this inefficiency over the years can be significant. On average, electricity costs account for about 96% of the total life-cycle cost of a motor, while the purchase price accounts for only 3%.[4] As a result, there are significant potential financial benefits to improving motor system efficiency long before the end of the equipment lifecycle – the long-term savings far outweigh the initial costs.

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Many industrial motor systems are used in applications which have long equipment life-cycles.

Incentives to improve energy efficiency
Motor age and efficiency are increasingly of interest because many countries and states have set targets to reduce energy use and emissions. To achieve these targets, they use a carrot and stick approach. As expected, the stick side of the equation involves tighter regulation and more stringent requirements, which put pressure on industry to improve efficiency. However, the higher price of new motors is often an impediment to investment in more efficient options.

On the carrot side of the equation, financial incentives can be used to tempt companies to invest in newer motors. Indeed, in an effort to further support energy efficiency, the UN has issued policy guides that outline different types of financial incentives and assistance that can be used to encourage the adoption of energy efficient motors.[5] As a result, incentives are available in many markets. For example, utilities across the US offer financial incentives to upgrade to more energy efficient equipment and tax deductions are available for commercial buildings that reduce energy use.[6, 7] In addition, also in the US, the CARES Act provides financial support to improve building energy efficiency and decrease utility costs, including funding for school districts to upgrade their facilities.

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Financial incentives to upgrade to newer, more efficient motors are available in many markets.

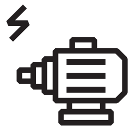
IE5 motors offer ultra-premium efficiency
The most common type of motors currently in use in industry are induction motors. Most of these older motors typically have an IE3 efficiency class. Now, however, there is a new generation of ultra-premium efficiency motors available: IE5.

So what's the difference between the different IE classes? Currently, there are five international classes specified by the IEC, ranging from IE1 to IE5, with IE1 being the least efficient and IE5 the most efficient. Each class of efficiency equates to 20% lower motors losses. For example, IE4 motors have 20% lower losses that IE3 motors, while IE5 motors have 40% lower losses than IE3 motors.

Note that although NEMA does not yet have equivalent standards available for IE4 and IE5, some manufacturers already offer motors that will be compliant. In particular, IE5 class motors are already known as "ultra-premium efficiency motors".

IEC standards and the equivalent NEMA standards

NEMA	IEC
Standard Efficiency	IE1
High Efficiency	IE2
Premium Efficiency	IE3
No Standard	IE4
No Standard	IE5



Each class of efficiency = 20% less motor losses

Clearly, replacing IE3 motors with more efficient ones would reduce industrial energy use. It is estimated that if 80% of the world's installed industrial motors were replaced with IE5 ultra-premium efficient motors, 160 terawatt-hours of energy per year would be saved, which is equivalent to more than the annual power consumption of Poland.[8]

Reaching IE5 efficiency with magnet-assisted synchronous reluctance motors

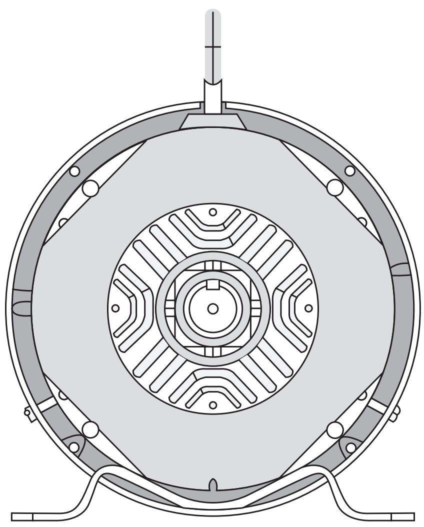
Currently, magnet-assisted synchronous reluctance motors offer the most efficient performance available. This type of motor will reliably deliver IE5 performance when it is paired with a variable speed drive (VSD). Together, magnet-assisted synchronous reluctance motors with VSDs enable significant efficiency gains over induction motors across a wide speed range, and they offer particular benefits when operated with partial loads. Integrated motor drive packages are available in standard sizes meaning that they can be used as drop-in replacements for other NEMA motors.

Note that synchronous reluctance motors require VSDs to enable precise control of the motor speed and torque, and ensure that they operate with the optimal efficiency. It's also worth noting that the IE5 class applies to the motor but not the drive: the VSD enables the motor to run with IE5 efficiency.

How magnet-assisted synchronous reluctance motors work

A synchronous reluctance motor has two main components: the stator and the rotor. The stator is very similar to that of an induction motor, with coils of wire that produce a rotating magnetic field. However, the rotor design is very different from a traditional induction motor and it works on a different principle – no current is induced in the rotor. The rotor is made from multiple laminated iron layers and its shape is precisely designed to guide magnetic reluctance. Permanent magnets are also incorporated into the rotor to add torque generation and field strength.

Because the rotor guides magnetic reluctance throughout its structure, when the stator applies a rotating magnetic field, the rotor aligns itself with the magnetic field and "locks" into position. This enables it to rotate at exactly the same speed as the magnetic field. In other words, the rotor moves synchronously with the magnetic field, which is why this type of motor is called a synchronous reluctance motor.

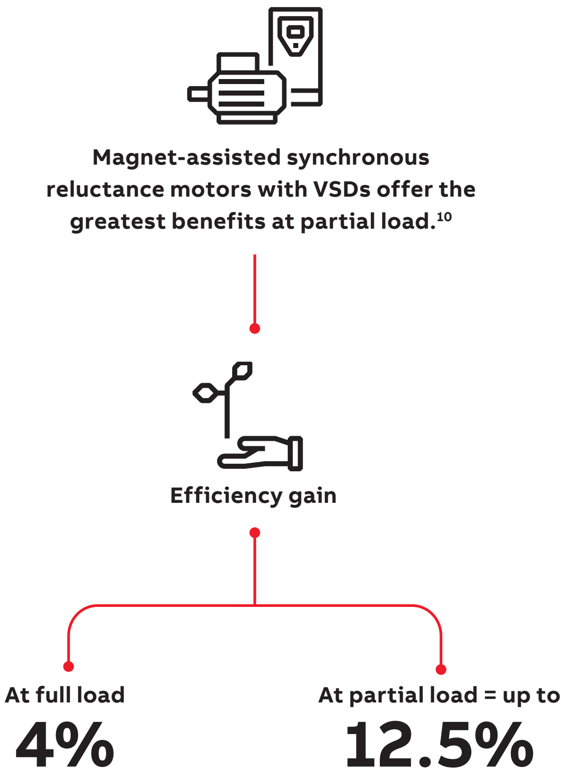


The rotor in a magnet-assisted synchronous reluctance motor is made from multiple laminated iron layers and its shape is precisely designed to guide magnetic reluctance. It also incorporates magnets to add torque generation and field strength.

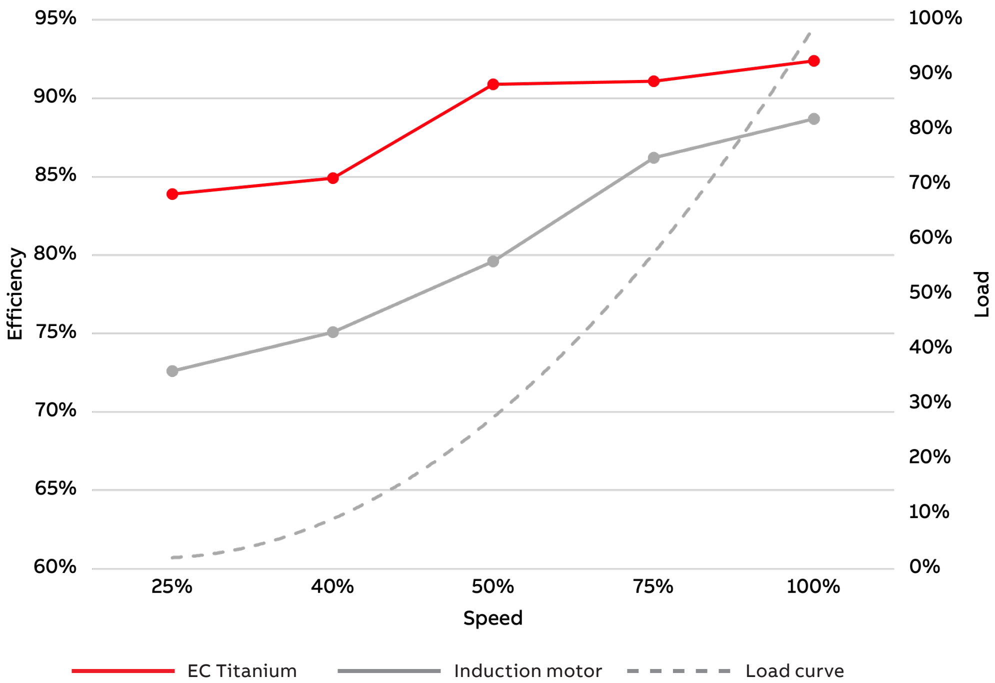
Benefits of magnet-assisted synchronous reluctance technology
Magnet-assisted synchronous reluctance motors have several benefits over induction motors. Firstly, they are more efficient. This is because there are no losses in the rotor because no current is induced. The higher field strength provided by the magnets further improves overall efficiency. Next, magnet-assisted synchronous reluctance motors are well suited to both continuous as well as variable torque applications and they maintain their efficiency over a wide torque, speed and load range. This makes them particularly efficient in applications that require lower speeds and load points, and they have excellent partial load performance.

Magnet-assisted synchronous reluctance motors also have a lower operating temperature than induction motors. This is because no current is induced in the rotor and because they have a higher power density. This type of motor has a power factor of 0.92 to 0.98, meaning that they deliver more horsepower per amp than an equivalent induction motor. The result is that they can be operated with smaller power converters and the motors can run as much as 20% cooler than an equivalent induction motor.[9]

Because they have a higher power density and lower current draw, magnet-assisted synchronous reluctance motor and VSD packages can be much more compact than equivalent induction motor installations. For example, with ABB's EC Titanium™ technology, the drive is small enough to be integrated into the motor for quick and convenient plug-and-play installation.



Efficiency vs Speed & Load



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For pump and fan applications with variable speed and variable torque (load), EC Titanium integrated motor drives display superior efficiency performance over induction motors at rated and partial load speed points.[11]

Variable Speed Drives
Optimizing energy management

VSDs can help motor systems run more efficiently, and although they are required to operate synchronous reluctance motors, they can also be used successfully with other motor systems too, including older induction motors. In fact, VSDs offer great potential for improving the efficiency of many motor systems across different industries. For example, in the US, on average, only 16% of industrial motor systems use variable speed drives.[12]

Direct speed control improves efficiency
A VSD controls the frequency and voltage of the electricity fed to a motor. This enables it to vary the torque and speed of the motor and the application it powers directly. Because the VSD can run the motor at the optimum speed for the application, no energy is wasted through mechanical speed controls like valves, gears, throttles or brakes. As a result, motor systems controlled by VSDs can operate more efficiently than motor systems without drives, especially systems that run at partial load. For example, adding a drive to a fixed speed across-the-line system that uses mechanical throttling to control flow or pressure can result in system efficiency savings of up to 25% thanks to the variable speed control.[13]

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Improving the efficiency of HVAC systems can translate to significant savings over a building's lifetime.

Benefits for system efficiency

The most common industrial applications that use motor systems are HVAC, pumping, and blower filters on compressor systems. It's worth pointing out that the design of the fan or pump is the primary contributor to the overall efficiency. Nonetheless, improving motor system efficiency can still significantly improve the efficiency of the application.

VSDs match energy consumption to actual energy need
In systems like HVAC, pumps and compressors, it is very common to regulate speed or flow mechanically, which consumes more energy than the application actually requires, and also necessitates an oversized motor and power supply. In contrast, if the speed or flow is controlled by the motor directly using a VSD, the system only consumes the actual amount of energy required by the application, and no more. And the motor and power supply can be "right-sized" rather than oversized, further reducing energy consumption.

Another benefit of VSDs is that because they can precisely control the motor speed they also enable better rpm tolerances and improved process stability.

Most HVAC systems operate at 80% load or less more than 99% of the time.[15]

Integrated motor drive technology enables IE5 efficiency over a broad operating range
Many industrial systems operate at partial load and most older motors suffer from a noticeable drop in efficiency when operated outside their peak operating range. In contrast, magnet-assisted synchronous reluctance motors offer a broad peak operating range, which enables them to run with IE5 at any speed and at partial load. This means that VSD-motor packages like EC Titanium can be configured to the optimum settings for each individual application and deliver improved overall system performance and efficiency.

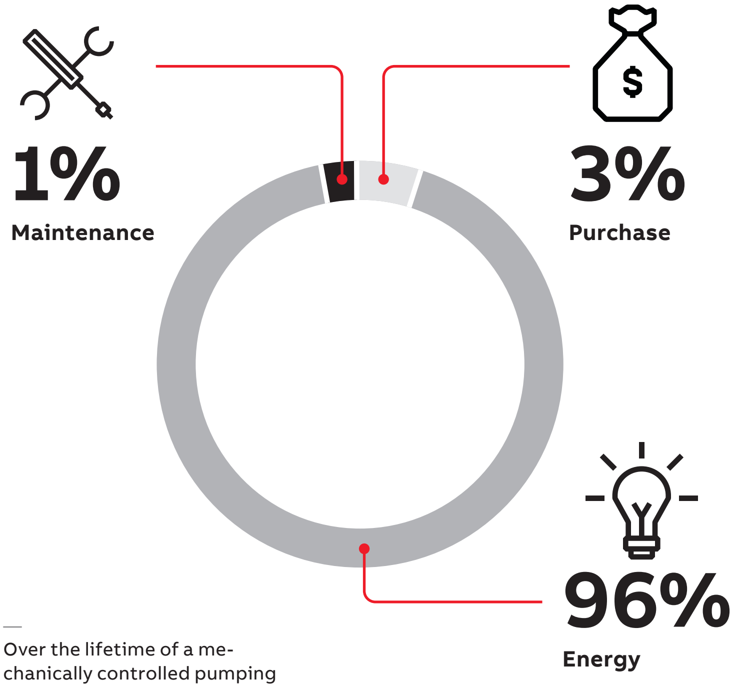
In addition, because they are available in standard NEMA sizes, integrated motor drive packages can easily be retrofitted to improve the efficiency of existing equipment, without further modification.

It's worth noting that IE5 VSD-motor packages offer the greatest benefits over older motor systems at partial load. At full load, the incremental energy savings are around 4%, while at partial load the savings are much greater, at around 12.5%. Since systems like HVAC operate at 80% load or less more than 99% of the time, updating them to IE5 efficiency is clearly worthwhile.[10,15]

In the US, 42% of the electricity consumed by industrial motor systems is used by pumps, fans and blowers (21% pumps, 21% fans & blowers).[14]

Better lifetime efficiency for the whole system
IE5 magnet-assisted synchronous reluctance motors with drives enable better overall system efficiency. With pumps and fans, which are usually run at partial load, this translates to better wire-to-water and wire-to-air efficiency. And, although replacing older motor systems with more efficient ones does carry an initial financial cost, the long-term savings over the lifetime of the application far outweigh the cost of purchase. In fact, the initial investment can often be paid back in as little as one to three years.

It's important to realize that these energy and cost savings apply to the whole system and not just to the motor-drive package. For example, improving the efficiency of motor systems in an HVAC installation improves the efficiency of the whole HVAC installation. Since HVAC systems account for about 50% of energy consumed by an average commercial building, improving the efficiency of HVAC systems can translate to significant savings over the building's lifetime.[16]



Over the lifetime of a mechanically controlled pumping system the majority of the cost comes from the energy used to run the motor.[4]

By enabling customized, optimized fan design, integrated motor drive packages can boost overall system efficiency at partial speeds by over 20%.[17]

In addition, magnet-assisted synchronous reluctance motors operate at lower temperatures than induction motors. This improves their reliability and extends their operational life, which therefore lowers maintenance requirements and costs throughout the lifetime of the application, as well.

In the bigger picture, when companies improve their energy efficiency and use less electricity this lowers demand on the grid, freeing up capacity at utilities. In turn, this means that fewer utilities need to be built and emissions are reduced.

Flexibility of design

Compared to traditional induction motors, which deliver peak performance and efficiency at fixed operating points, magnet-assisted synchronous reluctance motors offer much more flexibility. Because they can deliver optimum efficiency at a wide range or speeds and torques, they can be sized and configured to match the needs of the system. This makes it much easier for designers to optimize the performance of their designs and the system overall. In addition, motors are usually built into systems, like fan assemblies. This means that with older motors the efficiency of the assembly is fixed and if you want to change operating speeds while maintaining the same level of efficiency, it's likely that you will have to change the motor to do so. However, with VSD control and a magnet-assisted synchronous reluctance motor you can simply change the settings.

Although motors and drives are just components in the overall system, modernizing these components can still pay off. For older installations that lack a VSD, a convenient option is to replace the motor with an integrated motor drive package. These are small enough to fit into the space vacated by the existing motor, and they provide the benefits of magnet-assisted synchronous reluctance motors and VSD control. By doing this, designers can keep their preferred fan or pump design in operation, while also improving its overall efficiency and flexibility.

SUCCESS CASE

Improving pump efficiency with an IE5 EC Titanium motor

A pump system was tested with several different types of motors and the resulting total system efficiency was compared.[18]

Motor type	Total pump efficiency
IE5 EC Titanium motor	**67.9%**
IE5 SynRM motor	**64.0%**
IE3 induction motor	**60.7%**

This high figure of 67.9% was unexpected and it shows how much of a difference EC Titanium motor technology can make to overall system efficiency compared to traditional induction motors.

Comparison of an IE3 induction motor and an IE5 magnet assisted synchronous reluctance motor.[19]

Induction motor (IE3)	Magnet-assisted synchronous reluctance motor (IE5)	Difference
Average unit consumption per day (seven-day test duration) **57.69 kWH**	Average unit consumption per day (seven-day test duration) **45.1 kWH**	**12.59 kWH**
Estimated monthly energy cost per unit: **$198.38**	Estimated monthly energy cost per unit: **$155.04**	**$43.30** per month per unit

Energy reduction:
20%

Annual savings:
$520
per unit

Estimated return on investment:
18-24
months

Conclusion

As reviewed in this white paper, there are several proven ways to improve the energy efficiency and thus reduce the operating costs of industrial processes that currently rely on older motors. Adding variable speed drives to directly regulate motor speed and eliminate mechanical speed and flow control is one method. Updating motors to newer, IE5 designs like magnet-assisted synchronous reluctance motors is another. When a VSD is combined with an IE5 magnet-assisted synchronous reluctance motor in a single package, like ABB's EC Titanium integrated motor drives, upgrading can also be quick, easy and convenient. Moreover, IE5 VSD-motor packages give users the flexibility to select the best components for their needs and configure the whole system for the optimum performance and efficiency at a range of different speeds and torques.

All in all, using VSDs and upgrading to IE5 motors can significantly reduce overall energy use. Better still, the initial investment is likely to pay back within a few years, while the energy and cost savings will last for the entire lifetime of the installation, which can be 20 years or more.

(1) Lawrence Berkeley National Laboratory, U.S. industrial and commercial motor system market assessment report, Volume 1: characteristics of the installed base, January 2021, Page 67, permalink: https://escholarship.org/uc/item/42f631k3

(2) https://www.globalefficiencyintel.com/new-blog/2017/infographic-energy-industrial-motor-systems and Fong, J.; F. Ferreira; A.M. Silva; and A.T. De Almeida, "IEC61800-9 System Standards as a Tool to Boost the Efficiency of Electric Motor Driven Systems Worldwide," Inventions, 2020, 5, 20; https://www.mdpi.com/2411-5134/5/2/20/htm

(3) Lawrence Berkeley National Laboratory, U.S. industrial and commercial motor system market assessment report, Volume 1: characteristics of the installed base, January 2021, Page 67, permalink: https://escholarship.org/uc/item/42f631k3

(4) https://www.eia.gov/todayinenergy/detail.php?id=13431
And U.S. Department of Energy, Improving Motor and Drive System Performance: A sourcebook for Industry, 2014, page 47; https://www.energy.gov/sites/prod/files/2014/04/f15/amo_motors_sourcebook_web.pdf)

(5) UN Policy Guide, U4E Policy Guide Series, Accelerating the Global Adoption of Energy-Efficient Electric Motors and Motor Systems, 2017, pages 55-6, https://united4efficiency.org/wp-content/uploads/2017/09/U4E-MotorGuide-201709-Final.pdf

(6) https://www.energystar.gov/buildings/save_energy_commercial_buildings/finance_projects and https://openei.org/wiki/State_Rebate_Program

(7) https://www.energy.gov/eere/buildings/179d-commercial-buildings-energy-efficiency-tax-deduction

(8) Based on an assumption of 300 million industrial motors currently in service worldwide. Global sales from 2016 to 2020 amounted to roughly 200 million motors. Omdia, "Low Voltage Motors Intelligence Service," 2020; and U.S. Energy Information Administration, international data: electricity, 2019, Poland; https://www.eia.gov/international/data/world/electricity/electricityconsumption

(9) https://library.e.abb.com/public/d6837003ea734da98450459f39e886df/ABB_HVAC_webinars_FASR_System_Performance_21_10_2020.pdf

(10) Based on ABB laboratory tests.

(11) Based on ABB laboratory tests of 3 HP, 1800 RPM, 460V motors.

(12) VSDs: Lawrence Berkeley National Laboratory, U.S. industrial and commercial motor system market assessment report, Volume 1: characteristics of the installed base, January 2021, Executive summary, Page x; permalink: https://escholarship.org/uc/item/42f631k3

(13) For an example of the calculations involved, see "Program Insights: Variable frequency drives," Consortium for Energy Efficiency, 2019; https://www.cee1.org/content/variable-frequency-drives

(14) Lawrence Berkeley National Laboratory, U.S. industrial and commercial motor system market assessment report, Volume 1: characteristics of the installed base, January 2021, Executive summary, Page viii; permalink: https://escholarship.org/uc/item/42f631k3

(15) U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, DOE/GO-102014-4356, Improving Motor and Drive System Performance: A Sourcebook for Industry, page 27; https://www.energy.gov/sites/prod/files/2014/04/f15/amo_motors_sourcebook_web.pdf)

(16) Commercial Buildings Energy Consumption Survey, EIA, 2016

(17) Based on ABB experience and measurements.

(18) Based on independent OEM testing.

(19) Actual customer test results.

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