The changing face of industrial drives

The world is changing, with ever more focus being placed on efficiency and limited resources. The days of overrating a motor and inverter for an industrial application, and absorbing the increased energy costs, simply to achieve a desired application lifetime, are over. Here, we review some of the technologies now available that can bring higher efficiency enabling the right fit system for general-purpose drives and servo drives.

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Introduction

Electric motors have shaped the world and continue to do so, at every level. They range from small motors that automate simple functions around the home, to heavy-duty motors that can, quite literally, move mountains. The number and variety of electric motors now being used is phenomenal, so perhaps it is not surprising to learn that motors and their control systems account for almost half of all the electricity consumed worldwide.

Breaking that down further, around 30% of electricity generated globally goes to driving motors in industrial applications. In absolute terms, the amount of energy consumed by the world's industrial sector is expected to double by 2040.

With increased awareness of the cost of energy and limited resources, both in environmental and financial terms, the need for higher levels of efficiency in the way we utilize electricity to drive motors becomes more apparent.

Market overview

With such high volumes of electric motors being used across so many applications, it is clear that even a small increase in efficiency could have a large and positive impact. To better understand how this change may be achieved, it is relevant to examine the total market. In terms of revenue, the vast majority – 91% – of motors are classified as low voltage; less than 1 kVac. Just 9% of the total revenue is attributable to medium voltage drives (>1 kVac), which covers the oil and gas industry, rolling mills and other high power applications.

Within the low voltage segment of the market, around two thirds are classified as general purpose, which comprises standard and compact drives, and premium drives (Figure 1). Standard and compact drives includes motors used in pumps, fans and air compressors, as well as process automation. Premium drives covers industrial applications such as lifting gear and cranes, as well as emerging applications such as those found in the marine industry.

The remaining one third, around 31% of the total market (by revenue) is attributable to servo motors. This includes those applications that demand greater accuracy and control, such as robotics, material handling and machine tools.

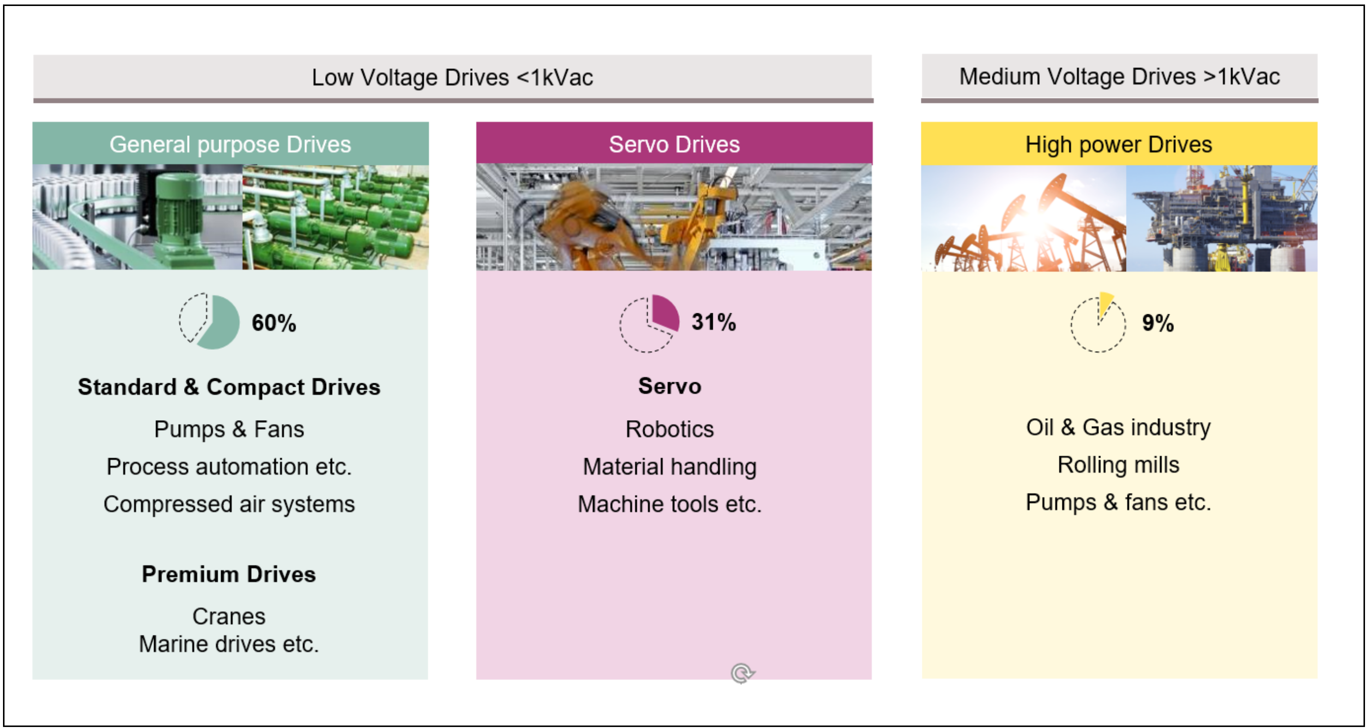

Figure 1 The majority of low voltage drives are integrated into pumps, fans, air compressors, and process automation systems[1]

It is also important to appreciate that, within the standard and compact end of the low voltage segment of the market, there are applications that can be classified as light duty and heavy duty. The primary difference from a drive point of view is that light-duty motors and controls must typically sustain an overdrive in inverter output current of 110% for short periods during acceleration, such as in pump and fan applications. Heavy-duty motors and controls will typically need to be designed to sustain an overdrive of as much as 150% of nominal inverter current (Figure 2). This higher overload current is, for example, attributed to the acceleration phase of conveyor belts.

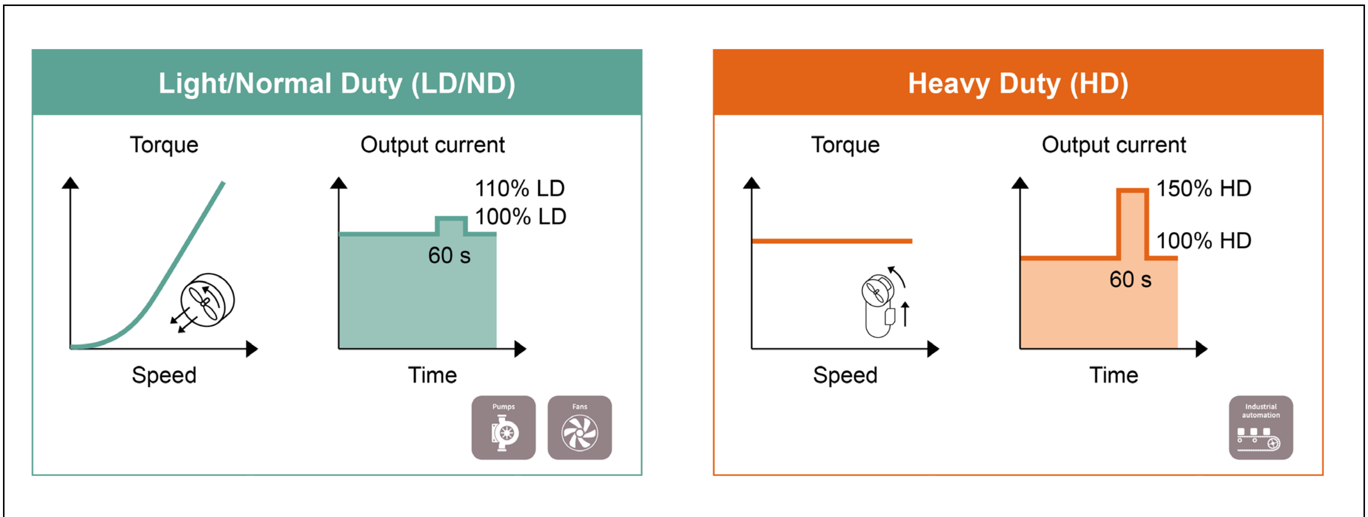

Figure 2 Overload capability defines a period of higher-than-rated current during acceleration operation of between 110% (light/normal duty) and 150% (heavy duty).

For servo motors, the sustainable overload may be greater, but for shorter periods. This is necessary, as the application will likely be moving for short periods of time but with high acceleration, such as a robot arm. In a high overload condition, this may result in 200% of inverter current for several seconds, or as much as 300% in very high overload situations.

Under these conditions, the inverter needs to deliver current levels that are higher than the rated maximum for the motor, hence the term overload. This has led to a culture of over-sizing both the motors, but especially the inverters, used in many applications in the belief that they will be less stressed by the overload, and last longer. The oversizing of the inverter reduces the thermal stress of the power semiconductors, achieving a longer lifetime. A survey conducted in 2017[2] found that over 56% of the motors surveyed were deemed to have been in service longer than recommended or expected. This is likely due to the fact that the majority (> 60%) were overrated for the application.

Overrating may result in a longer time in service, but it comes with unwanted side effects, one of which is that efficiency is inevitably low, as more power is being used than is strictly necessary. When power was cheap, in all senses of the word, this was not really an issue, but now that efficiency is driving design choices, it is time to start thinking about solutions that stay within the design envelope without impacting the working lifetime.

Another consideration is that the resources required to construct an oversized drive system are higher compared to a right-fit motor and inverter. Beyond the ecological improvement, this also results in an economic benefit from the lower initial costs of the drive system.

Low voltage drives – demands and requirements

There are excellent reasons for using low voltage drives, even when the application exceeds a power range of several hundred kilowatts. The same motor type and inverter platform can be used for a wide range of output powers, simplifying the integration of small drives, such as cooling fans (several kilowatts), as well as larger drives in applications such as water pumps (several hundred kilowatts). This helps the operator of a production facility to integrate the drive inverter into the existing environment.

In general terms, the drive circuit will be comprised of a rectifier to turn the AC source into a DC voltage that can be stored in a capacitor, and a chopper circuit to handle overhauling (when the load's kinetic energy causes the motor to continue rotating after power has been removed – effectively turning the motor into a generator). Also included in the circuit is an inverter, which turns the DC voltage into an AC voltage, which is normally variable in frequency and amplitude, to drive the motor (Figure 3).

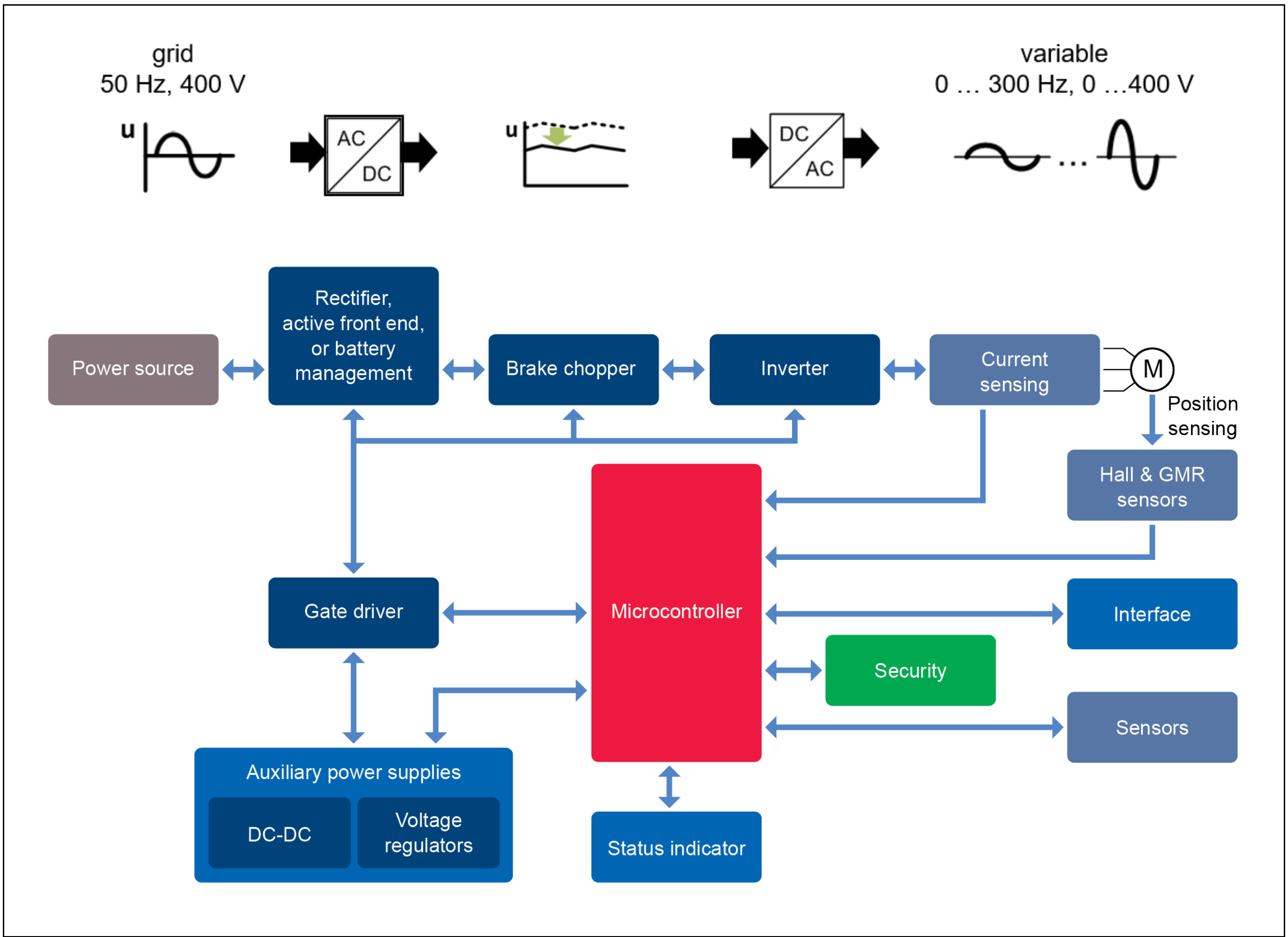

Figure 3 A typical block diagram of a convertor system for a variable speed drive

The efficiency of each of these three key stages directly dictates the overall efficiency of the inverter system. Starting with the rectifier, this can be achieved using a diode bridge. However to fulfill grid standards, such as minimizing the total harmonic distortion, an active front end (AFE) is typically used. Here a switching device such as an IGBT is normally preferred. Specifying the IGBT to handle the overload and overhauling requires a good understanding of the end application.

The chopper module is necessary to allow the energy generated by the motor during deceleration to dissipate. In a simple system, this would be achieved using heat dissipation by allowing the current generated to flow through some low-ohmic, high-wattage resistors. The control circuit necessary to achieve this will be a separate solution, and normally includes a switching device, often an IGBT (as outlined above). Regenerative choppers – or brakes, as they are also known – use the energy generated by the motor more productively by, for example, directing it to the batteries or capacitors that store the DC voltage. This can increase overall efficiency, while the design selection of the IGBTs used also has an impact on the efficiency of the other two key functions. If an AFE is used, this energy generated by the motor can be fed back to the grid.

The final stage is the inverter that takes the DC voltage and converts it back to an AC voltage to drive the motor(s). The voltage source inverter will normally employ IGBTs. For high-speed drives, SiC-

MOSFETs can be used enabling a higher switching frequency through lower switching losses, and by this a higher output frequency of the inverter. This in turn results in a higher rotation speed of the motor.

IGBT7 for drives

The unique and specific requirements of motor drive systems demand a new approach to IGBT design and, with the right IGBT technology, it becomes possible to create modules that are better positioned to address these needs. This is the approach Infineon has taken with the latest generation of its IGBT technology, IGBT7. At the chip level, IGBT7 uses micro-pattern trenches (MPT). This structure results in a significant reduction in forward voltage and increased conductivity in the drift zone (Figure 4). For applications with moderate switching frequency, such as motor drives, the IGBT7 delivers a significant reduction in losses over previous generations[3].

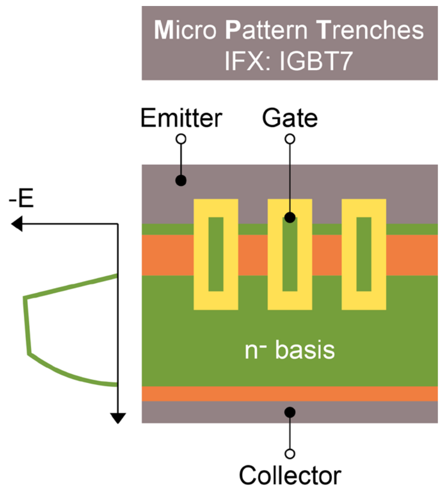

Figure 4 The use of Micro-Pattern Trenches (MPT) in IGBT7 reduces $V_{CE(SAT)}$ by 20% while keeping turn-off losses at the same level compared to previous generation devices.

When applied to the TRENCHSTOP IGBT7 power modules, the technology offers further benefits. As outlined above, voltage-source inverters are preferable where the method used to regulate power is typically Pulse-Width Modulation (PWM). The switching speed, dv/dt, of the PWM pulses can generate a parasitic current in the motor frame, negatively impacting the motor's bearings and damaging the motor-winding isolation, which can result in an early failure of the motor. Furthermore, the motor cables used can also produce voltage spikes at the motor terminals that depend on their length, which is another result of the switching speed. For this reason, IGBT7 supports variable and controllable dv/dt, adjustable via the gate resistor.

Another improvement offered by IGBT7 over the previous generation (IGBT4) is the freewheeling diode (FWD) that has also been optimized for drive applications. The forward-voltage drop of the emitter-controlled diode, EC7, is now 100 mV lower than the forward-voltage drop of the EC4 diode, with improved reverse-recovery softness (Figure 5).

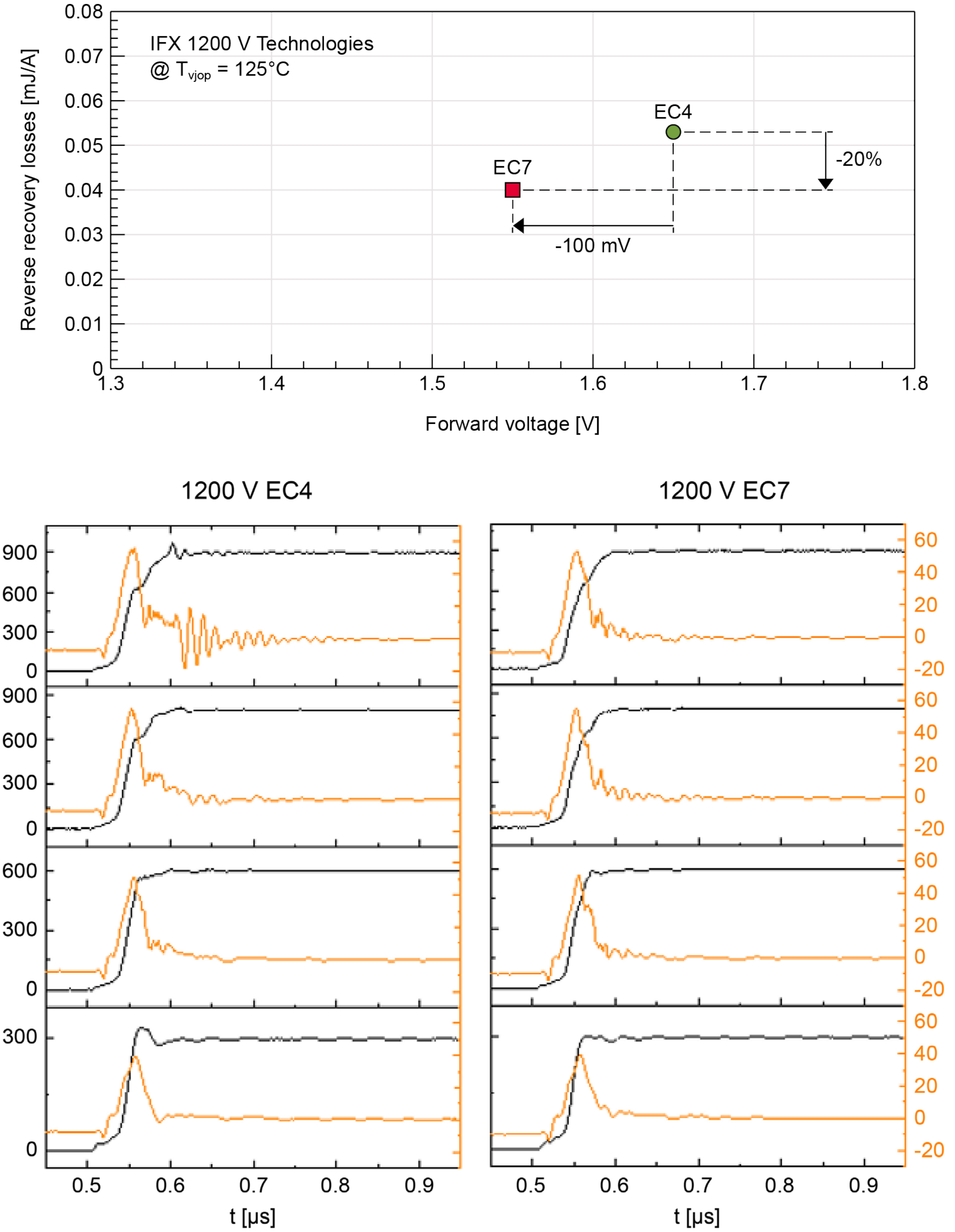

Figure 5 The freewheeling diode performance in the IGBT7 shows 100 mV less forward voltage than previous generation devices.

In terms of overload capability, IGBT7 is able to withstand a junction temperature (T_{vjop}) of 175°C for repetitive times. The previous generation IGBT4 was limited to a constant T_{vjop} of 150°C. This addresses the need of overload capability in inverter current which is useful for industrial drives. For detail information regarding the overload capability of IGBT7 see the dedicated application note[3].

In terms of power density, this means IGBT7 solutions can be implemented in packaging that is up to 35% smaller than previous solutions. This makes the modules viable with extended current ratings. These improvements in the underlying technology mean that the 1200 V TRENCHSTOP™ IGBT7 modules are available in well-established packages with enhanced current capability, including a 25 A PIM in the EasyPIM™ 1B package, 50 A in EasyPIM™ 2B and EasyPACK™ 1B, and 100 A in the EasyPACK™ 2B package.

This represents a significant advancement in package options, while maintaining pin-to-pin compatibility with IGBT4 modules. The lower losses and higher levels of robustness will deliver system cost savings, thanks to smaller heat sinks, which will also lead to more compact inverter design.

Another important parameter of IGBTs is the short-circuit withstand time t_{sc}. For IGBT7, t_{sc} is defined as 8 µs at a T_{vjop} of 150°C. This short-circuit withstand time (compared to 10 µs in IGBT4) enables systems to deliver lower power losses and improved thermal behavior. Furthermore, IGBT7 is designed for zero voltage turn-off, requiring only a unipolar gate driver power supply. This is achieved by the ratio of the input capacitor and is optimized to avoid parasitic turn-on, resulting in a simplified gate driver circuit.

Servo drives – demands and requirements

With more automation being used across industries, there is a corresponding increased demand for servo motors. Their ability to combine precise motion control with high torque levels make them the perfect fit for automation and robotics.

These two examples can have very different requirements, however. Automation, such as a conveyor system, might use several servo motors with relatively low torque in a distributed arrangement with one central control system. The cabling that connects the motors and the control system could carry both power and data. In a robotic application, it is more important to have the control localized together with the motor, preferably integrated into the joints of the robot. This eliminates the need for expensive cabling between the inverter and the servo motors.

The motors may be AC or DC, with brushed or brushless commutation. However, the most common option is the AC motor, with brushless commutation, following either a synchronous or asynchronous operation. The feedback is typically provided by an encoder on the shaft. This feedback allows the control system to maintain position and torque under variable load conditions.

One of the challenges with integrating the drive circuitry with the motor in a single package is managing heat dissipation. This refers to the heat generated by the switching devices used, whose sustained junction temperature must typically remain below 150°C (175°C in the case of IGBT7) for reliable operation. The design choice of switching device can be important in this respect. Due to the integration of the inverter and the resulting reduction in length of the motor cable, the switching speed can be increased without the risk of damaging the motor. This leads to a further reduction in switching losses. Therefore, SiC-MOSFET technology offers some advantages in terms of its switching efficiency. As it is more efficient, it generates less heat enabling a simplified integration of the inverter.

Nevertheless, IGBT devices are still attractive for standard servo drives. They offer a good cost performance ratio and are optimized for the need of servo drives, e.g. overload capability and short-circuit robustness.

SiC MOSFETs for servo drives

Silicon carbide (SiC) is a wide bandgap material used by Infineon to produce power components, including MOSFETs, that can carry higher levels of current and voltage while still delivering high switching frequencies and excellent efficiency. Infineon has been developing its SiC portfolio for 20 years.

Using its manufacturing expertise and long experience, Infineon has developed a SiC trench technology that offers higher performance than IGBT but with a comparable robustness, such as a short-circuit robustness time of 2 µs. Infineon's CoolSiC™ MOSFETs also address some potential problems inherent with SiC devices, such as unwanted capacitive turn-on. Furthermore, it has achieved this in the industry-standard TO247-3 package and now, with even better switching performance, in the TO247-4 package. Beside these TO-packages, the SiC-MOSFET is also available in Easy 1B and Easy 2B packages.

The 1200 V CoolSiC™ MOSFET offers up to 80% lower switching losses than the corresponding IBGT alternative, with the additional advantage of the losses being independent of temperature (Figure 7). However, as with IGBT7, the switching behavior (dv/dt) can also be controlled via the gate resistor, providing greater design flexibility.

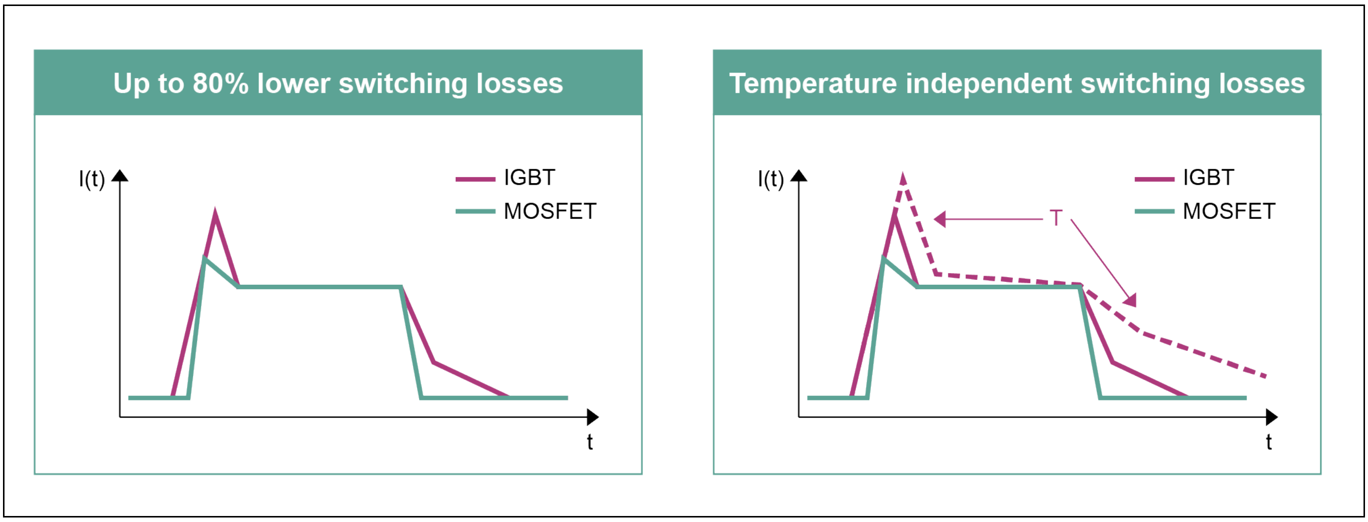

Figure 6 SiC MOSFETs offer up to 80% lower switching losses that are independent of temperature.

As a result, a drive solution using CoolSiC™ MOSFET technology can achieve as much as a 50% reduction in losses (assuming similar dv/dt), based on lower recovery, turn-on, turn-off, and on-state losses. The CoolSiC™ MOSFET also has lower conduction losses than an IGBT, especially under light load conditions.

In addition to the overall higher efficiency and lower losses offered, the higher switching frequencies enabled by SiC technology has a direct benefit for servo drives, both external and integrated, in more dynamic control environments. This is possible due to a faster response of the motor current under changing motor load conditions.

Putting it all together

Of course, while the integration of the rectifier, chopper and inverter into a single module delivers benefits in terms of power density and switching efficiency, motor drivers require a closed-loop system to function correctly and efficiently.

More specifically, whatever the switching technology used, it is imperative that it is complemented by the right gate driver solution. A gate driver is required to translate the low voltage control signal used to turn the switching devices on and off into the high voltage drive signals needed by the switches themselves. Typically, the control signal will come from a host processor. As each switching technology has its own unique characteristics in terms of input capacitance and drive levels, matching it with the right gate driver is essential. As a developer and supplier of all power technologies currently in use, Infineon provides optimized gate drivers for its Si-MOSFETs, Si-IGBTs, SiC-MOSFETs and GaN-HEMTs.

The control signals, generated by complex motor drive algorithms, will come from the host processor, or more commonly a microcontroller (µC). The high speed, real-time nature of motor drives requires the µC to be highly capable and, ideally, optimized for motor control. The XMC4000 family from Infineon, part of its XMC 32-bit industrial microcontroller range based on ARM® Cortex®-M4 cores, features a high-performance ARM® Cortex®-M4 core with floating-point capability and a single-cycle DSP MAC, making it ideal for executing real-time motor control algorithms. In addition, Infineon has integrated a range of peripherals aimed specifically at motor control, such as a 4-channel PWM interface with high (150 ps) resolution (Figure 8).

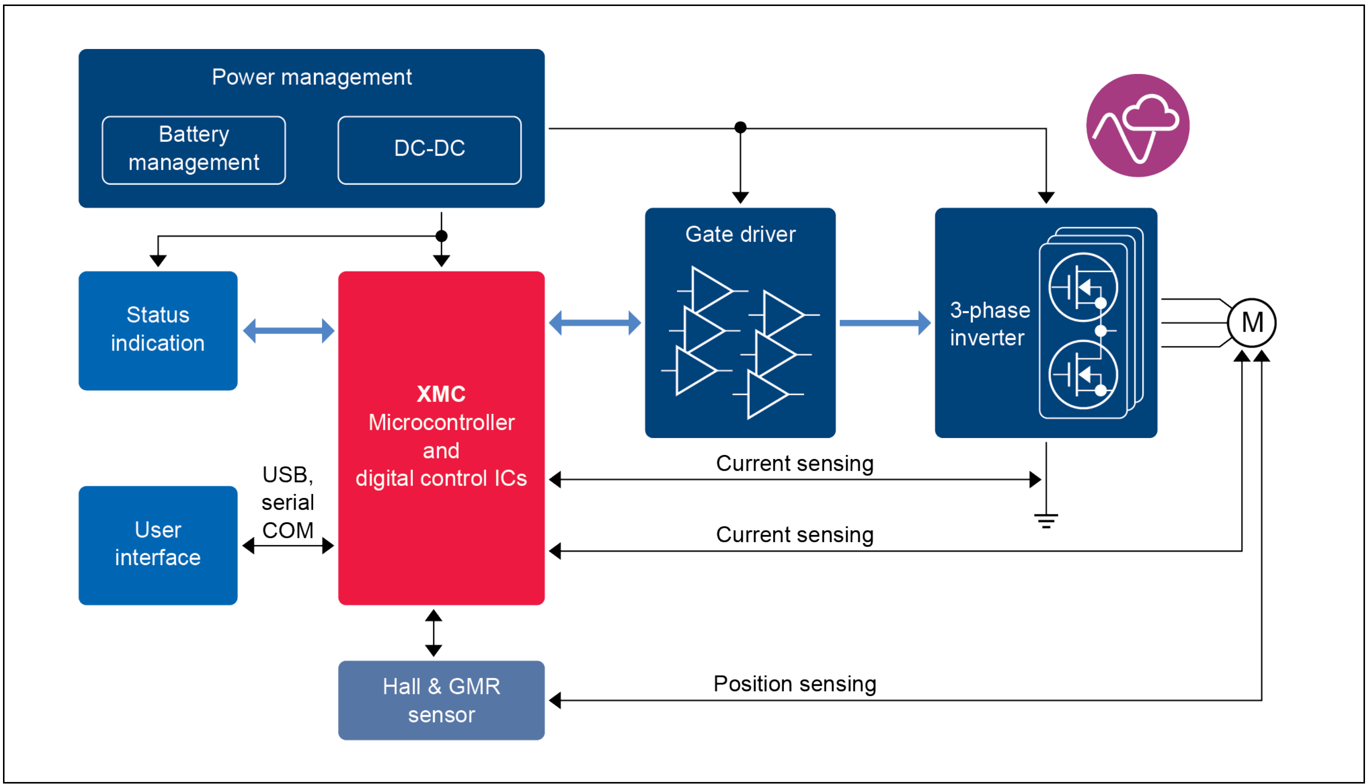

Figure 7 Coupled with an XMC microcontroller and a XENSIV™ current sensor, optimized drives for motor control can be developed around an IGBT or SiC inverter.

The final, but equally crucial, part of the control loop is the sensor that provides part of the feedback between the motor and the controller. In this respect, for brushless motors in particular, it is common to use current sensors. Infineon has developed a Hall-effect solution that removes the need for a ferromagnetic concentrator, making it simpler and less intrusive. This makes it ideal for fully integrated servo motors, for example.

The XENSIV™ range of current sensors, such as the TLI4970, are differential Hall-current sensors that offer a high field range with a low offset value. In addition, they feature no magnetic hysteresis, and exhibit good stray field immunity. Their compact size, thanks to the coreless concept used, supports high levels of integration, while their ultra-low power loss and functional isolation make them extremely flexible and reliable.

Summary

An ageing and inefficient infrastructure of electric motors is now being replaced, partly through necessity, but also in response to the demand for higher efficiency, in the face of continuously increased power demands. This level of change requires new technologies capable of delivering more efficient, energy-conscious solutions. The technologies outlined here, and the design approaches discussed, are available now and can be sourced from a single supplier with confidence in long-term supply and product reliability.

Full design support, for the entire motor drive system, is on offer to help manufacturers transition from overrated, inefficient inverters to a new age of sustainable and energy-conscious solutions.

References

[1] Industrial motor control sourcebook 2018

[2] Elektromotoren Fachtagung 2017

[3] Source: https://www.infineon.com/dgdl/Infineon-AN_201814_Trenchstop_1200V_IGBT7-AN-v01_00-EN.pdf?fileId=5546d46265487f7b01656b173ddc3600

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