Delivering higher efficiency in motor drive applications

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Electric motors consume around half of all the electricity produced worldwide and it's not hard to see why. They provide the motive force for many of today's essential and nonessential activities; motors, pumps and fans can be found in an ever-widening range of products, from small consumer items to large industrial machinery. With a solid foundation in existing applications their numbers will grow inexorably, while the emergence of new applications such as electric vehicles (both manned and unmanned) means there will be significantly more in operation over the years to come.

The efficiency involved with energy conversion has always been significant and with electric motors the conversion happens twice; first to create the electricity to drive the motor, and then converting electricity into motive force. Not surprisingly, the inefficiency of electric motors is becoming a high priority for consumers, industries and even governments.

Legislation drives innovation

Energy efficiency has always been an important aspect of product development: compensating for inefficiencies costs money in terms of removing unwanted heat, supplying more energy than is strictly necessary or adding additional materials. However, in recent decades the need for more efficient products, specifically any product classed as energy-related, has led to legislation. For example, any energy-related product that meets specific criteria and is intended for sale within the European Union must now comply with legislation that will be based on the Framework Directive 2009/125/EC. This includes products that are sold in volumes in excess of 200,000 per year, have a significant environmental impact and present significant potential for improvement.

Legislation aside, it is clear that efficiency begins with design and in the case of DC motors that starts with the motor's selection. The most widely used DC motor style today is still the brushed DC motor, although due to the type of applications now emerging, the number of Brushless DC Motors (BLDC) in service is growing strongly. The third type of DC motor widely used today is the Stepper Motor, which is a close relation to the BLDC but is limited to applications with more specific needs (such as servo systems).

Perhaps the most widely deployed of all motor designs is the AC induction motor, while the Permanent Magnet Synchronous Motor (PMSM) could be seen as its eventual replacement. Efficiency in AC induction motor design is largely related to applying Power Factor Correction (PFC), which can significantly improve performance in typical applications such as HVAC equipment, home appliances and industrial applications. For fixed-speed applications, driving an AC induction motor is relatively simple; the speed is directly related to the frequency of the drive voltage. For variable speed and/or torque applications, a PMSM may be better suited. However, while they are more efficient than an AC indication motor, driving a PMSM also incurs greater complexity.

Digital signal control

Motor control offers an opportunity to increase efficiency at the design stage. Understanding the driver requirements of each type of motor, and the style of motor that is most appropriate for a given application, can help deliver higher efficiency in every context.

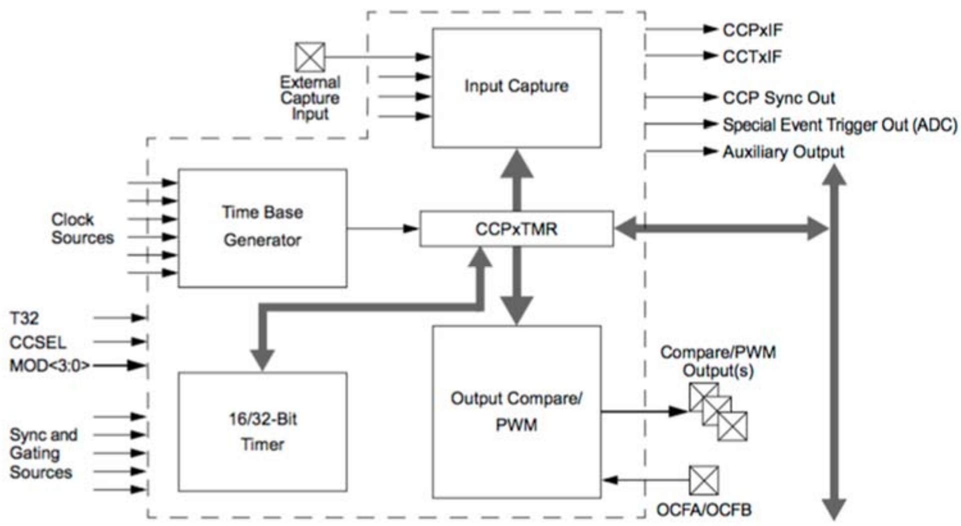
In very simple terms, a motor comprises three parts: the part that moves (typically it will rotate, but linear motors are also available); the part that is fixed; and the part that generates the electromagnetic field. Traditionally these parts are known as the rotor, stator and commutator respectively, although their names and functions may differ, which can add to any confusion that may already exist.

In a brushed DC motor, coils are energised to create the electromagnetic force, which causes the rotor to move. The brushes are used to deliver the voltage and current to the coils via the commutator. As the motor rotates the brushes constantly make and break the circuit, which results in two of their disadvantages: electrical noise and mechanical wear. However, they remain popular because of their low cost and relatively simple drive circuit; speed is controlled by the voltage applied, while torque is controlled by the current.

Modern microcontrollers (MCUs) are well placed to provide the level of performance and computational functionality needed to develop highly efficient control loops for AC and DC motors. Many MCUs today will support signal processing capabilities, enabling them to process complex algorithms in real time using direct or derived positioning data. This is important because an increasing number of applications now strive to remove the need for sensors giving positional data. Techniques such as measuring back EMF mean control circuits are now able to determine the rotor position without sensors, thereby saving cost and complexity, and as a result further improving relative efficiency.

While many MCUs are still general purpose in nature and suitable for many applications, there is an increasing number of specialist devices coming to market that target motor drive, offering increased levels of integration. This includes devices that combine Power Factor Correction with PWM generation in a single device. There are also many MCUs that feature peripherals developed specifically for motor drive applications.

This complexity is increasingly becoming the domain of application-specific Digital Signal Controllers (DSCs); a new class of device that combine the functionality of a Digital Signal Processor with the flexibility of a general purpose MCU in a single device. An example is the PIC32MM0064GPL, a family of microcontrollers directly addressing low-cost motor control applications. Based on the MIPS32 microAptiv UC core, it integrates core-independent peripherals and includes the Multiple Capture/Compare/PWM (MCCP) module, which is perfectly optimised for motor drive and control requirements. The Figure below shows a conceptual block diagram of the MCCP module as featured in the PIC32MM0064GPL.

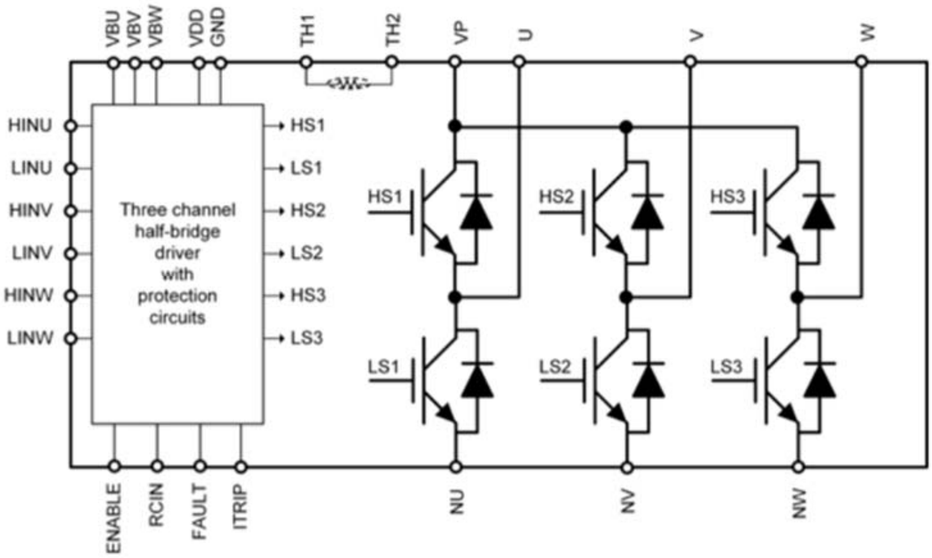


(Source: Microchip)

Dedicated drivers

With a BLDC motor the drive becomes more complex. Instead of brushes, transistors are used to make and break the coil energising circuit, while the speed and torque are controlled by the on/off ratio/duration of the drive transistors. Normally this takes the form of a Pulse Width Modulated (PWM) signal used to drive the coils. This is further complicated by the use of single- two- and three-phase motors, which deliver progressively smoother rotational motion by increasing the number of phases (and therefore PWM signals) in each case.

There are now many integrated devices available that provide the drive stage for motors including BLDCs, PMSMs and Stepper Motors. Typically, they comprise the gate drivers needed to drive external power MOSFETs used to excite up to three phases of a motor. A good example of such a device is the STK5C4U332J-E from On Semiconductor; an Intelligent Power Module for 3-Phase motor drive suited to driving PMSM, BLDC and AC Synchronous motors. A functional block diagram of the device is shown in the Figure below.



(Source On Semiconductor)

Choosing the right MOSFETs can have a significant impact on efficiency. As in most applications, transistors with a lower on-resistance provide the best solution and in motor drive circuits this will normally dictate the use of N-Channel MOSFET; they offer a lower RDS(on) than P-Channel MOSFETs for a given area. However, it is important to realise that a larger MOSFET requires a higher gate charge to turn it on. This charge takes time to build and dissipate, and can significantly impact the speed at which a motor may operate and, as a result, its overall efficiency for a given application. Another parameter that can influence the maximum switching frequency is the cross-capacitance between the Drain and Gate. RS stocks a wide range of appropriate power MOSFETs that have been developed for motor control applications. One example is the StrongIRFET Power MOSFET from Infineon, which is optimised for low RDS(on) and high current capability.

Next Steps

Developing a motor control application can be challenging, but RS supports this through an expanding number of development kits, such as the 300W BLDC Motor Control Application Kit from Infineon, the 3-Phase BLDC motor driver expansion board for STM32 Nucleo family from STMicroelectronics and even the Arduino Motor Shield which is also TinkerKit compatible. For developers targeting a mechatronics application, the PICDEM Mechatronics Demonstration Kit from Microchip offers a comprehensive development environment that includes an on-board stepper motor and on-board BLDC.

Conclusion

It is a staggering statistic that around half of all electricity generated today is used to drive motors. This trend is set to continue in both relative and absolute terms as the number of applications that employ electric motors increases daily.

Efficiency in energy conversion is the eternal goal; the laws of thermodynamics may preclude lossless conversion, but every part of a percentage improvement in efficiency now represents huge amounts of energy saved. With environmental factors now providing significant motivation to make electric motors even more efficient, and the world's governments putting legislative measures in place to ensure manufacturers respect the need for greater efficiency, we can expect semiconductor vendors to rise to the challenge and continue developing solutions that deliver improvements. For more resources on motor drive and control applications, visit tthe RS website: http://uk.rs-online.com/

Web references:

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Microchip PICDEM Mechatronics demonstration kit:
http://uk.rs-online.com/web/p/products/6231109/