The Efficiency Trend in Motor Control

The trend towards higher efficiency for electrical motors started to accelerate at the turn of the century with advent of brushless permanent magnet motors and improved semiconductor cost and performance. Expanding into consumer products with the BLDC motor. Since then it has evolved to include the electronic commutation of ACIMs, revival of the SRM, and even removal of the magnets again with the SyncRM. A new family of 16-bit dsPIC33 Digital Signal Controllers (DSC) provides for these motors 5 V operation for improved noise immunity and robustness, well suited for devices operating in harsh environments such as appliance and automotive applications. **Erlendur Kristjansson, Product Marketing Manager, Microchip Technology Inc., Chandler, USA**

Efficiency is the Holy Grail in all electric motor based applications. If we look at the different applications that are using electric motors today we can see the trend of continued improvement towards higher efficiency and lower cost. For example, in cars the original approach for driving pumps and fans under the hood was the serpentine belt, but even though this is a convenient way to utilize the engine rotation to drive these actuators it is not very efficient. Taking these actuators and drive them with motors adds flexibility and improved efficiency. Another example is washing machines, were the primary motor type has been AC induction, but with increased requirements for energy efficiency in home appliances and more control of the washing cycle to reduce water usage, the use of permanent magnet synchronous motors in new designs has been become dominant.

Of course this trend has been heavily dependent on the improvement of the semiconductor components needed for the inverter stage and control. In the past the cost of the motor drive needed for electronic commutation has been a significant factor in limiting the use of synchronous motors in many applications. Today that is not as much the case and these motors have become the norm in many applications.

Motor options

The primary motor types that are being considered today in most applications where efficiency and dynamic controls are important are:

- AC Induction Motor (ACIM)
- Brushless DC Motor (BLCD motor)
- Surface Permanent Magnet Synchronous Motor (PMSM or SPM motor)
- Internal Permanent Magnet Synchronous Motor (IPMSM or IPM motor)
- Switched Reluctance Motor (SRM)
- Synchronous Reluctance Motor (SyncRM).

Efficiency of the various motor types can be ranked from most to the least efficient: IPM motor, PMSM, BLDC, SynchRM, SRM, and ACIM, with same order for power/torque density.

Of course the ACIM is the workhorse of industrial applications and the most common motor type in high wattage applications (>1kW). But with the increased demand for efficiency many ACIM installations are being updated with electronic commutation drives for improved efficiency. In applications were more dynamic control is needed the use

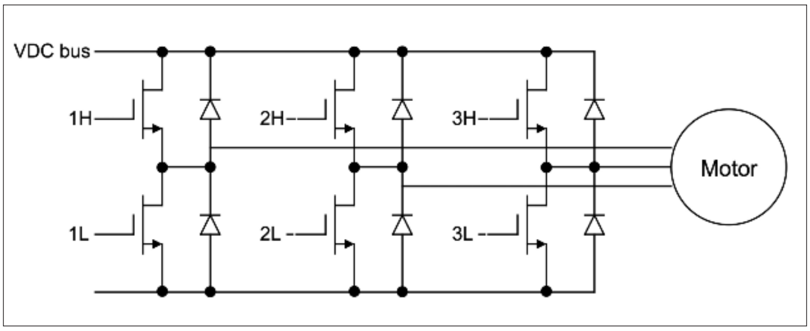
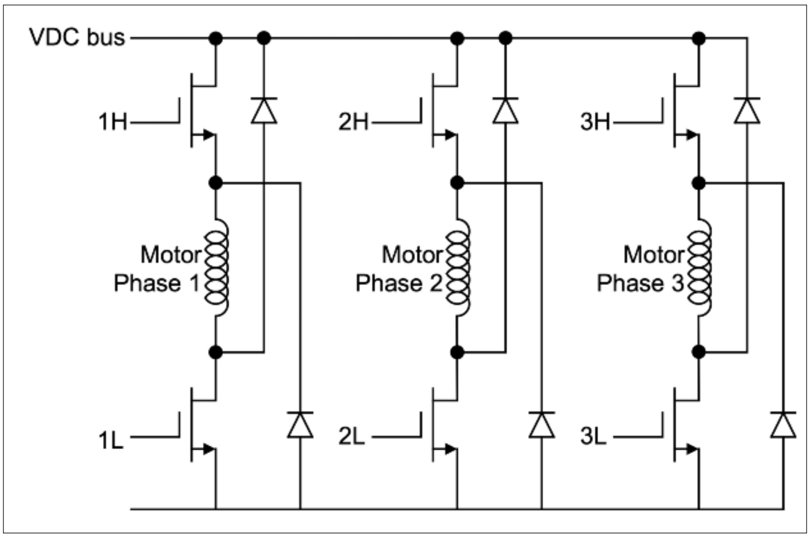


Figure 1: Motor drive circuity for synchronous motors (above) and SRM drives (below)



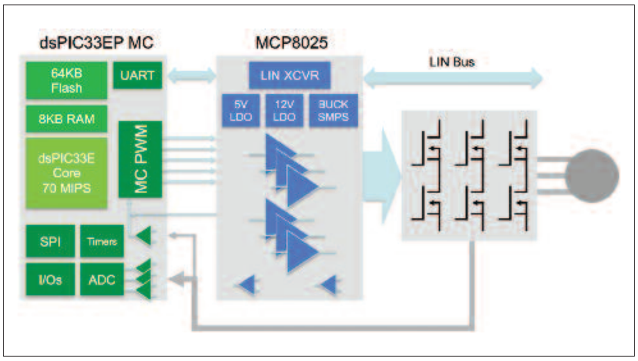


Figure 2: Automotive cooling fan implementation

of PMSM makes more sense. Then in some applications, were the cost is critical and factors like weight-to-torque ratio and robustness are needed, the use of SRM have been seen. Another classical industrial ACIM application is large HP (>15HP) compressors. Here SyncRM motors have started to appear as these are structured very similar to ACIMs, same stator design with different rotor, but for the same frame size you can increase the torque and efficiency, or reduce the frame size.

Then there is the applications were there haven't been any motors, like under the hood of a car. Here the electrical motor is used to replace the mechanical serpentine belt and increase efficiency as the load can come and go with motors, while with the belt it is always there even though it isn't needed. These days everything counts when it comes to efficiency and fuel economy. Here the trend has been from belt to BLDC motor to PMSM. Another application in cars that is utilizing electric motors is drive by wire. Here for example SRMs are being used to drive the hydraulic pumps in the brakes. The high-speed capability of the SRM can build up pressure quickly to allow for fast break response.

Another very different application space were the use of electrically commutated motors have had big impact, battery operated tools and appliances. With the improvements in battery technologies, like lithium-ion, we can now have vacuum cleaners and power tools utilizing the efficiency of the BLDC motors. Initially these applications used primarily brushed DC motors, but there was a limitation on speed and torque. With the higher power/torque density BLDC motors allow for reasonable weight, longevity and performance that is close to match the wired version.

In home appliances, washing machines, refrigerators, dishwashers, air conditioners etc., the primary workhorse, just like in the industrial space, has been the ACIM. Since the turn of the century the brushless synchronous motors, primarily BLDC motors and PMSMs, have become more and more important. The primary reason has to do with governmental efficiency requirements. The problem to do this transition away from ACIMs in the consumer product space has always been the cost, both for the motor and the drive circuit. Fortunately the cost for both has come down significantly to allow the majority of new appliances to utilize the more efficient technology.

Drive technology

As mentioned earlier the drive circuit (Figure 1) is an important part when using electronically commutated motors, actually mandatory. Without it nothing happens. For nearly all the motors that we are talking about the drive circuit has a very similar stucture (Figure 1 top). The odd man out is SRM (Figure 1 bottom). The biggest difference between these motor types is in the controls, i.e., how the drive signal is created for these circuits. This has to do with how each motor is constructed resulting in different electro-magnetic behaviors. This has to be considered when generating the voltages/currents waveforms for the motor so it operates optimally/efficiently.

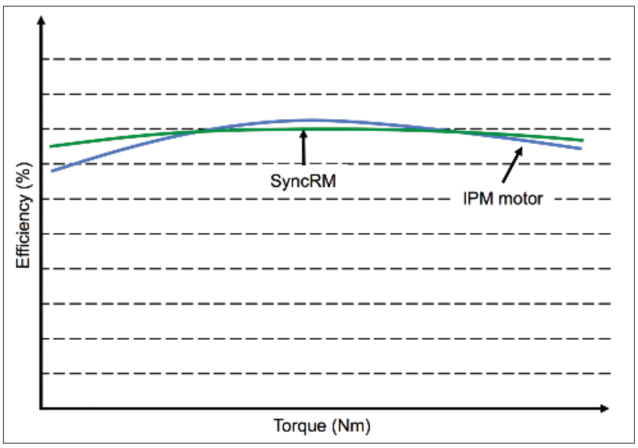
During the early days of the transitioning over to electronically commutated motors many of the targeted applications were very cost sensitive and as a result the BLDC motor was selected as it could be controlled with an 8-bit microcontroller using trapezoidal commutation. Even so the cost in some cases was still too high. Fast forward 15 years and the cost of high performance digital signal controllers and microcontrollers have come down enough to allow cost sensitive application use more advanced control algorithms like sensorless Field Oriented Control (FOC), for example circulation pumps for home heating systems or cooling fan for automobile (Figure 2).

So what does all these new fancy control algorithms give anyway? Why isn't the trapezoidal controlled BLDC motor good enough?

Efficiency

There are lot of talk about more efficient motors and drives, but in the end it is the whole system efficiency that matters. For example, we talked about the serpentine belt in car engines. Belt transmissions are very efficient, above 90 %, but don't it doesn't stop when something isn't needed. Instead it goes into idling, which has significant losses. So if we look at electro-mechanical systems there are additional losses like vibration, which can be caused by torque ripple, which are side effects of the way BLDC motor and SRM work. So based on the needs

Figure 3: Load/Efficiency curves (motor & drive)



of the application efficiency can be maximized further if the motor would run smoothly. This can be achieved by using an FOC algorithm or equivalent vector control.

Another factor is load the motor is running at. All motors have a load efficiency curve that looks something like the once in Figure 4 (this includes the drive). As can be seen, there is a peak, which is at the rated torque of the motor, but most applications don't have a fixed single load that the motor operates at. Some even have to work the full width of the operating range. An example of that is the air-conditioner compressor. Here the load changes based on how much the system has to cool or heat, and also during each piston cycle. Because compressors are nearly running all the time the use of IPM motors have become common as they have the highest efficiency. But, if we look at the efficiency curve an IPM motor and compare it to an equivalent SyncRM (Figure 3) we see that even though the IPM motor has higher efficiency at rated load the SyncRM's curve is flatter, i.e., the SyncRM maintains higher efficiency at lighter load making the over all efficiency for the application very similar to the IPM motor.

Conclusion

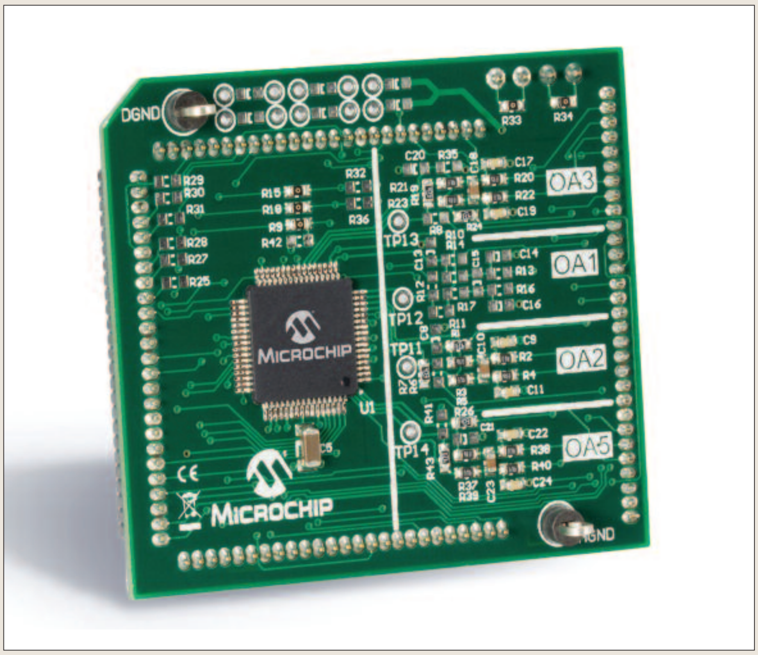
The trend towards higher efficiency for electrical motors started to accelerate at the turn of the century with advent of brushless permanent magnet motors and improved semiconductor cost and performance. Expanding into consumer products with the BLDC motor. Since then it has evolved to include the electronic commutation of ACIMs, revival of the SRM, and even removal of the magnets again with the SyncRM. What is important to remember in all of this is that the efficiency a system is the sum of all the pieces and how much you maximize it has to make financial sense. Therefore depending on the application there are different motor types and algorithms to chose from. There is no one motor technology that trumps all and therefore who ever is designing an electric motor based system has to understand the pros and cons of the available technologies.

5V dsPIC33 "EV" for Use in Harsh Environments

Microchip's new family of 16-bit dsPIC33 Digital Signal Controllers (DSC) with the dsPIC33 "EV" provides 5 V operation for improved noise immunity and robustness. It includes Error Correcting Code (ECC) Flash for increased reliability and safety, Cyclic Redundancy Check (CRC), Deadman Timer (DMT), and Windowed Watchdog Timer (WWDT) peripherals as well as a backup system oscillator and certified Class B software.

Other key features of this family include up to 6 advanced motor control PWMs, 12-bit ADC, and operational amplifiers, a combination for motor-control applications. The devices provide easy interface to 5V automotive sensors such as level or flow sensing, with improved noise immunity and enhanced reliability, and have 70 MIPS performance with DSP acceleration to execute smart sensor filter algorithms and integrate CAN communication software. For robust automotive touch user interfaces, the higher voltage operation enables more dynamic range and support for larger screen sizes. The dsPIC33EV devices offer up to 150°C operation with AEC-Q100 Grade 0 qualification enabling under-hood automotive applications.

The dsPIC33 "EV" family is supported by a C AN-LIN Starter Kit (DM330018) priced at $79.99 and a Motor Control Plug-In Module (MA330036), priced at $25.00, which is available to plug into the Low Voltage Motor Control Development Bundle (DV330100) priced at $369.00.



Microchip's dsPIC33 "EV" Motor Control Plug-In Module