Power Savings Techniques for Electric Motor Systems
by Infineon Technologies AG

Battery-operated consumer products such as mowers, weeders, blowers and drills have been around for more than a decade with only incremental design changes giving incremental improvements in power, efficiency and battery life. Now these applications are on the verge of a significant design change that will give much larger improvements in nearly all performance measurements. The main enabler for these next generation designs is the high integration and low cost of motor control electronics. This TechNote examines the design features of the various electronic components for high efficiency battery operated consumer drives.

Overview Of Current And Next-Generation Systems

Currently, most consumer battery-operated electric motor products use a dc motor and an on/off switch. Depending on the product the on/off switch may be replaced by a single MOSFET that is connected to a user-operated trigger via a simple timer circuit (eg the trigger on a drill, or the high/low speed switch on a blower). The MOSFET is pulsed on and off with a duty cycle related to the position of the trigger, button or switch (see Fig. 1a). This open-loop system requires the operator to close the loop to control the speed, or torque, of the motor by manually adjusting the trigger, button or switch. The driving factor in these designs is price. Motor efficiencies are often in the range of 40% to 70%.

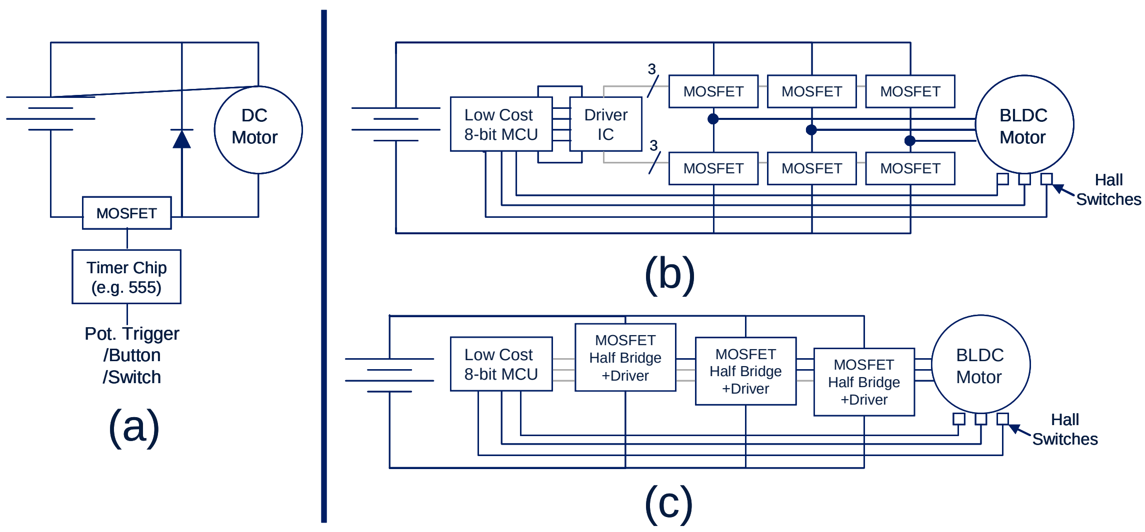

Fig. 1: (a) Electronics In Traditional, (b) High Efficiency, (c) Highly-Integrated High Efficiency Battery-Operated Motor Control Systems

High efficiency designs are moving to brushless dc (BLDC) motors which require power electronics and intelligence for control. A typical system for control of a BLDC motor is shown in Fig. 1(b) and a highly-integrated version of the same system in Fig. 1(c).

BLDC motors require power electronics (in this case 6 MOSFETS), position sensing (eg Hall effect switches) and usually some sort of intelligence (eg an 8-bit microcontroller). To interface the microcontroller to the MOSFET a driver circuit is also required.

Costs and Benefits

From Fig. 1 it is fairly obvious that the electronics cost and complexity for a high-efficiency system is significantly increased. Less obvious are the system level benefits of such a solution which can be placed into 3 categories : efficiency, reduction of mechanical complexity and increased system performance. In many cases these system level benefits more than offset the added cost and complexity of the electronics.

System Efficiency

The BLDC motor by itself is significantly more efficient than the typical low-cost dc motor found in battery-operated tools, typically 80% to 95%.

Further efficiency gains can be made by controlling the motor's speed so that it can match the actual load requirements. For example, most dc motor-driven cutting tools (such as lawn mowers) are designed so that the rotor speed under no load is significantly faster than the required cutting speed. This ensures that when the motor is loaded the rotor will not slow below the minimum cutting speed. In these kinds of applications a large amount of energy is used just to overcome wind resistance because the current required to spin a blower or a cutting tool in air is proportional to the square of the rotor speed. Using a BLDC motor with a microcontroller for speed regulation allows the no-load speed to be the same as the loaded speed since the microcontroller can detect and compensate for load variations (see Fig. 2). This makes the system much more efficient and also reduces wind noise. This feature alone can result in more than 40% system efficiency gains.

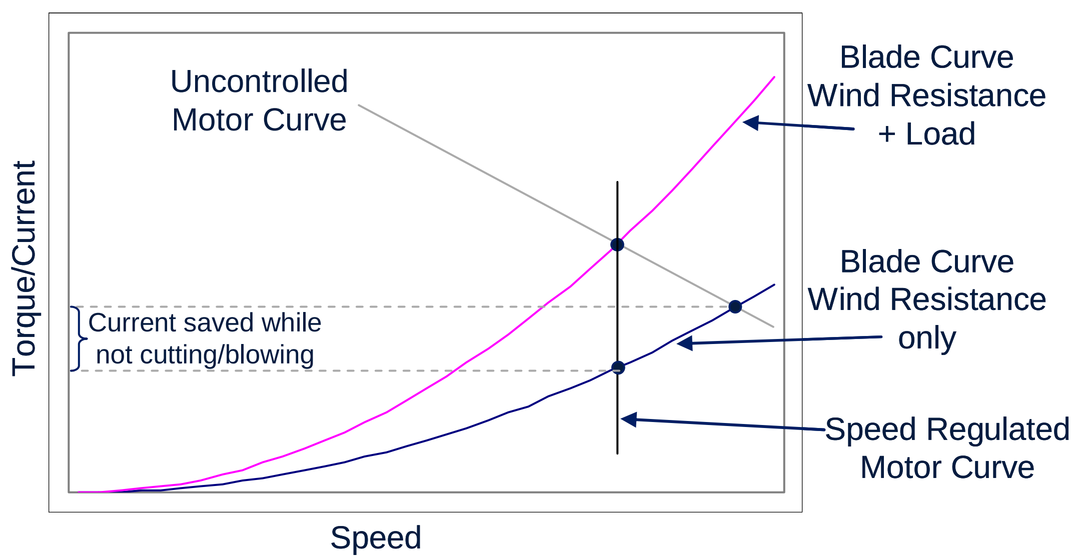

Fig. 2: Smart Speed Regulation Allows Reduction In Unloaded Motor Speed

Reduction of Mechanical Complexity

Using an electronically-controlled BLDC motor allows for removal of many mechanical components. For example, in many bi-directional systems (eg a power drill, and some blowers) the direction of the motor is changed by a mechanical switch that physically rotates the position of the brushes inside the dc motor. This system requires a moving housing for the brushes and a mechanical lever inside the motor housing. With a electronically controlled BLDC the direction changing mechanism can be replaced with a simple switch which can be fed into any of the digital I/O pins of the microcontroller.

The wide speed range and high torque constant of a BLDC motor also allows for the reduction and, in some cases, elimination of a gear box. Running the motor in a field-weakening mode allows for high speed, while running in normal mode allows for high torque.

Increased System Performance

The high torque to volume ratio of BLDC motors means that the motor size can be decreased thus reducing the volume and weight of the product. This is greatly desired in hand-held systems. The ability to regulate the motor current, especially at startup and stall, means that excess battery currents can be eliminated. This not only increases the amount of time between battery charges, but also increases the overall lifetime of the battery. So a high-efficiency system is often a smaller, lighter, system with a reduced lifetime operating cost.

Choosing components for a high efficiency system

Before choosing the components for a high-efficiency system the architecture must be decided. The discrete system of Fig. 1(b) gives more options for selecting the appropriate MOSFET and often results in a reduced total component cost, but requires more area and is more difficult to assemble. The highly-integrated system of Fig. 1(c) is a nice option for space-constrained designs and is easier to assemble -- but often results in a slightly-higher total component cost.

When selecting MOSFETs for the solution of Figure 1(b), there are many silicon vendors and they all claim to have the best devices, each specifying their parts slightly differently. A good way to compare MOSFETs in switching applications is use a figure of merit (FOM) that compares the MOSFET on-resistance and the total gate charge:

$$\text{FOM} = R_{DS(on)} * \text{Total Gate Charge} \qquad \textit{Lower is better}$$

The highly-integrated system of Fig. 1(c) is possible due to innovations in integration techniques for power semiconductors and driving circuits from semiconductor vendors. A high-side and low-side power MOSFET along with driver and protection (over-current, over-temperature, etc) circuitry can now be integrated into a single package the size of a TO-263 or TO-220 for currents up to approximately 40 A. This type of technology is new, so unfortunately there is not yet a wide selection of parts from multiple vendors.

When selecting a low-cost microcontroller for a high-efficiency system, it is important to note some of the features that are now available. Low-cost 8-bit microcontrollers are readily available in small packages with integrated Flash memory or ROM, on-chip oscillators (meaning no external crystal or resonator is required), ADCs and peripheral sets designed for BLDC motor control. Some useful hardware features for controlling a BLDC motor are automatic Hall effect sensor decoding and noise filtering, high frequency (for accurate PWM generation) and high resolution (for speed measurement) timers, and the ability to synchronize ADC clocking to PWM.

Conclusion

High-efficiency battery-powered electric motors are about to enter the market and the increased system performance that they offer will ensure their popularity. Although the concepts are not new, it is only recently that power semiconductors and microcontrollers have reached the price and integration points required for penetration into this huge market. The addition of a microcontroller will make the system smarter and will ease the integration of even more advanced features, many of which have not yet been conceived.

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