How to cut switching loss in motor control

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Guest columnist Alfred Hesener, European marketing director at Fairchild Semiconductor, describes how good design of power switches can help reduce losses in motor control circuits.

Energy-saving drives with brushless DC motors can be found everywhere, and the dust has settled somewhat, since the challenge consists of integrating a complex electronic control circuit into the motor, at realistic cost levels, to enable relevant advantages for the user.

Significant potential for increasing the performance is with the power stage driving the motor, that sits like a "muscle" between the microcontroller and the motor. The switching and conduction losses in this stage affect the necessary size and thermal design of the application.

Figure 1 shows a typical application circuit, where the module block diagram shows the high level of integration, reducing external component count. On the far left sits the microcontroller, that can control all power switches of the three half bridges individually. Depending on the application, low pass filters may be required to help suppress wrong triggering due to noise.
In this circuit, three sense resistors have been implemented, to measure the currents in each motor phase. Depending on the control algorithm, these may or may not be needed, for example in the case of sensorless control.

For a complete application, only an auxiliary supply, EMI filter, input rectifier and bus cap are required. In particular, the bootstrap diodes for generating the drive voltage for the highside switches are integrated as well, only a few passive components are needed in addition.

The gate drive circuit, usually one of the more critical parts of the circuit, is completely integrated inside the module, and is tested at the end of the module production line, making the application design much easier and increasing reliability in the production.

With these new power switches, the power dissipation can be reduced up to 25%. This reduction allows many improvements. On one hand, the heatsink and the overall thermal design can be much more compact and cost-effective. At identical output power, the design can be more compact, which can be a big advantage especially for applications like pumps or fans, as explained further below.

Generally speaking, a smaller drive electronics can allow the use of controlled motors in applications where this was not possible before. And, reduced usage of materials implies lower manufacturing, transportation and recycling cost, all summed up in the lifecycle cost.

On the other hand, the maximum output power could be increased while keeping the existing design parameters identical.

A lower power dissipation with the same thermal design can also be an advantage for reliability, since with a lower thermal excursion the failure rate is reduced strongly.

And, this allows the introduction of different variations of the same design but with different output powers, reducing time to market.

Two application areas that benefit significantly from these advantages shall be analysed further: Pumps and fans. In both cases, high requirements for reliability and robustness exist, where a smaller application design can bring significant advantages.
With pumps, there is a big advantage in integrating the control circuit with the motor. This, however, has the disadvantage that the ambient conditions for the smart-power module are affected by the motor, especially its power dissipation, and less power dissipation is available for the module. Especially with pumps for warm liquids, such as for central heating, the power dissipation budget for the module is becoming quite small—every little percentage of improved efficiency helps.

With fans, the ambient temperature usually isn’t that high, relaxing the situation. But a most compact solution is required, since the motor and its control circuit sit in the cross section area of the fan, reducing the area available for air transport, so a smallest solution is required.

Developing a highly reliable power electronics subsystem is not an easy task—especially the robustness and reliability requirements need to be considered in details, with the typically high current densities being an additional challenge. At the same time, the design shall be compact and cost-effective, at not too high electromagnetic emission levels, to ease qualification and compliance testing.

A smart power module that defines many application-relevant aspects through its design will simplify this task. Many of the critical interconnects, especially the gate drive circuits, are already realised inside the module, reducing design time and effort. The availability of pin-compatible modules with different output powers is an interesting option to realise a portfolio of drive options. Here, the thermal design needs to be compliant with the maximum power dissipation to be expected, whereas the PCB design can usually be kept identical.

The main disadvantage of electronically controlled DC motors is that a control circuit is needed. But that is also its biggest advantage! This control circuit allows for the implementation of additional functionality, providing added value for the user.

Examples for this include compressors for refrigerators that will not turn on and off with a loud noise but will run with lower rotational speed, adapted to application needs, and much lower noise volume, or a heating pump, where through dynamic adjustment of the parameters significant energy savings are possible. And when some object is mechanically blocking the pump, it may rotate backwards to try and unblock, impossible with old-fashioned drives.

Currently, new technologies for power switches are being discussed, which are based on wide bandgap semiconductor materials. Despite some spectacular reports on performance, these technologies can be considered far from industrial usage, since the new materials cannot yet be produced cost-effectively and with good yield, and the failure mechanisms and reliability aspects are not well enough studied, especially for use in industrial applications with high requirements on reliability and robustness.

Further functionality will find its way into future smart power modules, they will become even more smart. One approach could be to integrate the control ICs, but additional protection functions or other power electronics components are possible.

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