Protecting Power Transistors in Automotive Inverter Design

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With the advent of hybrid and electric vehicles, inverter drive technology has moved into the automotive realm. Applications range from low power for air conditioning and heating to high power for drive and regenerative braking systems. Common to all these systems is a need to maximize operating lifetime by protecting the power switching transistors in the inverter designs.

The inverter in an automotive system is a key element of the electrical power supply for motor control. It takes the relatively low DC battery voltage and converts it to high-voltage AC, using power switching to regulate energy delivery (Figure 1). A microcontroller sends the switching signals, using isolated gate drivers as the interface between the low-voltage microcontroller and the high-voltage power switches.

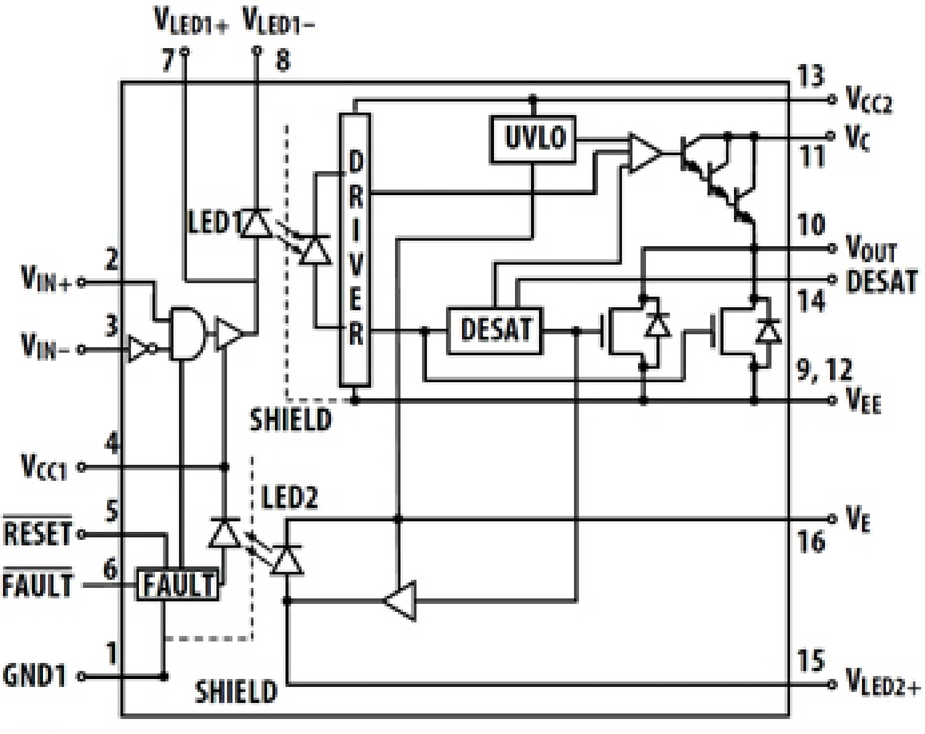

Figure 1. Inverters in automotive systems use power-switching IGBT devices to control motor power, but these devices need protection to ensure long operating life.

Many new types of power switches, such as silicon carbide, are being evaluated for use in automotive inverters, but the top contender today is the IGBT. These power transistors have a long history of service in handling high voltage and high power, but have developed a weakness. In the desire to minimize power losses in IGBTs, succeeding generations of IGBTs have sought to reduce both switching and conduction losses. In reducing conduction losses, however, there has often been a compromise made with robustness.

Fault Detection Prevents Damage

A reduction in the conduction loss of an IGBT often leads to an increase in short circuit current, which in turn reduces short circuit survival time. Many types of internal or external fault conditions in an inverter can result in short circuits or short-like current overload conditions in one or more of the inverter's IGBTs. Examples include phase-to-phase output short circuits, overshoot conditions on inverter bridge legs, and low drive voltage to the IGBT. Because the IGBT can quickly become damaged as a result of these faults, for converter designs should have fast and reliable IGBT short circuit detection and protection circuits.

Some, but not all, of these faults can be detected using phase current sensors. A better alternative is to detect the load current level at each IGBT individually. There are several methods of detecting the current level, such as shunt resistors or split emitter IGBT, that generate a voltage signal proportional to the IGBT load current. When this signal crosses a set threshold it then triggers protection mechanisms. But because the IGBT's maximum tolerable current depends on process variations, operating temperature, and gate voltage, it is often necessary to set the load current trigger threshold at quite a conservative level, limiting the IGBT's operating range.

A third alternative is to detect when the IGBT is coming out of saturation by monitoring the collector-emitter voltage (V_{CE}). Under normal operating conditions the IGBT is in saturation mode and V_{CE} is low. With an output short circuit or low gate drive condition, however, the IGBT moves into linear mode and V_{CE} rises, leading to excessive power dissipation and resultant device failure. Detecting this desaturation (DESAT) condition achieves the same fault-detection result as monitoring output current, but has the advantage that it monitors the IGBT's actual operating condition and effectively reduces the influence of many external factors, enabling higher power utilization of the IGBT.

Just as important as the detection of the fault, however, is an inverter design's fault resolution. By the time the fault condition is detected, for instance, it is possible that quite a considerable current is flowing. If the IGBT is shut off very quickly, the fast di/dt together with unavoidable parasitic connection inductance can potentially cause back EMF exceeding the IGBT's peak voltage rating, damaging the IGBT and defeating the over-current protection philosophy. This problem can be mitigated by implementing a soft shut down of the IGBT, which reduces the di/dt by increasing the gate discharge time in the event of a fault condition.

Fault resolution also has a system consideration. Autonomous fault detection can be implemented and configured to simultaneously shut down all other gate drivers at the same time. Alternatively the fault detection may be configured to isolate fault detection and shutdown to each IGBT separately, which allows the implementation of a graceful fault and shutdown strategy that is often desirable in automotive traction applications. This autonomous fault detection can also include signaling to the microcontroller that is managing the automotive power system to provide additional response options.

Reliability is Essential

The implementation of these fault detection and IGBT protection circuits in automotive systems must have several key features, including low cost, compact size, and extreme ruggedness. The extreme ruggedness is essential because automotive quality and reliability expectations are typically much higher than many consumer application and industrial applications. Further, this increased level of reliability often has to been obtained in a more hostile environment than other applications, including wide temperature extremes and high levels of radiated and conducted electromagnetic (EM) noise.

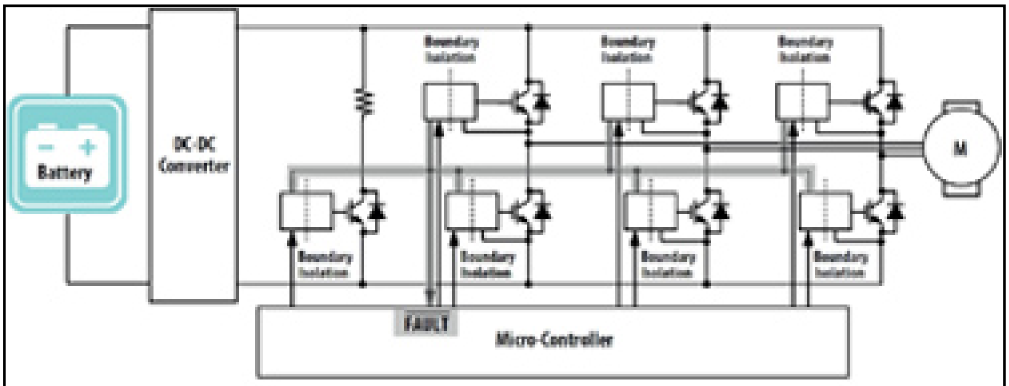

Figure 2. Integrating fault detection and soft shut-down, the Avago ACPL-38JT IGBT gate drive optocoupler addresses the error conditions that can damage inverter power switches.

A highly integrated solution such as Avago’s ACPL-38JT gate drive optocoupler (Figure 2) addresses all these needs by building in DESAT detection and under-voltage lockout (UVLO) circuits with isolated fault signaling and soft shut-down, all into the IGBT gate driver. Avago’s optical isolation includes a transparent Faraday shield around the optical receiver to help reduce EM noise coupling, and it uses a purpose-built LED to ensure long operating life at high temperatures. The integrated protection circuitry eliminates a number of discrete components to lower cost while addressing system reliability by addressing all the fault conditions, including low gate drive, that can trigger damage to the power switching transistor.

Using a single integrated device for the gate drive and IGBT protection circuits also helps increase system reliability by eliminating discrete-component failure points. In addition, an integrated device helps reduce both design and regulatory approval efforts by providing a complete, pretested design. The ACPL-38JT, for instance, is manufactured and tested in accordance with TS 16949 and AEC-Q100 automotive guidelines and has a -40°C to 125°C operating temperature rating.

As high-power electrical systems become increasingly important in automotive design, fault protection will prove essential for ensuring long operating life. Using integrated solutions that provide both detection and response mechanisms for the power switches in inverter designs address this need in a compact, low-cost, and highly reliable form.