Improved Self-Protected Intelligent Power Modules with Increased Efficiency for 10 kW to 100 kW Motor Drives

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Since their introduction twenty years ago, Intelligent Power Modules(IPMs) have evolved with improvements in efficiency, functionality, and protection effectiveness. Key features of today's IPMs include full gate CSTBT chips that achieve low loss while maintaining short circuit ruggedness by utilizing a dedicated control IC. Temperature sensing has been moved onto the IGBT chips from the isolating substrate to provide individual chip protection. Today's IPM provides features and advantages that are difficult, if not impossible, to implement in a conventional IGBT gate drive. These state-of-the-art features have been implemented in six and seven pack IPMs with ratings up to 150 A at 1,200 V and 300 A at 600 V for applications up to 10 kW. Until now, IPMs with these features have not been available for higher inverter ratings. The development of the new IPM series extends the performance and protection functionality to dual modules with ratings from 200 A to 600 A at 1,200 V and from 400 A to 900 A at 600 V for applications between 10 kW and 100 kW. The new series maintains package compatibility with the conventional modules to ease adoption into existing designs. This includes control terminal location, dimension and spacing.

Drive and Protection

The new IPM is based on the 5th generation CSTBT IGBT chip with multiple chips in parallel to achieve the desired module current rating. The sophisticated protection functions are integrated into dedicated control IC circuits. The control strategy is the same well established approach that is used in the existing conventional IPMs. This protection concept is based on three primary protection functions: control supply under voltage (UV); over temperature (OT); and over current (OC) or short circuit (SC). Under voltage protection ensures that the gate drive conditions are appropriate for the IGBT chip. Over temperature is sensed directly on the chip. Over current is detected using current mirror emitter technology, which is key to reducing the stress on the IGBT during a short circuit event. Typical IGBT SC protection relies on destaturation detection of the IGBT which allows high dissipation in the IGBT during the short circuit. The unique current mirror emitter technology measures a small fraction of the collector current and uses this real current information as a criterion for over current/short circuit detection. Figure 1 shows the internal circuit diagram of the IPM. The current mirror emitter is shown along with its shunt that provides the detection signal to the control IC.

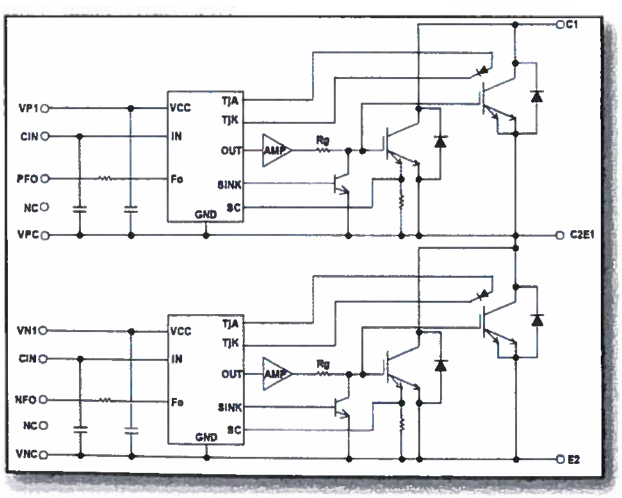

Figure 1.

Control Supply Under-Voltage

The internal control circuits of the IPM operate from an isolated 15 V supply. The gate drives for the IGBT chips are derived from this power supply. Since active area or linear operation of an IGBT is catastrophic, the control power supply must not fall below 15 V within a minimum tolerance. The IPM control circuit monitors the voltage level and if, for any reason, it drops below a specified under-voltage trip level, the power devices will be turned off and a fault signal will be generated.

Over Temperature

The new IPM has a temperature sensor that is part of the surface of each IGBT chip. If the on-chip temperature exceeds the over temperature trip level the internal control circuit of the IPM will protect the power devices by disabling the gate drive and ignoring any control input signal until the over temperature condition is resolved. Previous IPMs only detected the case temperature (base plate temperature) and once the threshold temperature of the substrate mounted temperature sensor was reached, the control IC blocked the gate signal and protected the IGBT. This approach has disadvantages because the temperature sensing is remote from the IGBT chip and reacts slowly because of the thermal time constants of the various construction layers of the module. Consequently, the temperature sensor's information does not reflect the real junction temperature and has a time delay. Base plate temperature based protection can prevent failures from over temperature due to cooling or thermal grease problems. However, this protection is insufficient in cases of locked rotor or low output frequency. The temperature protection of the current IPM resolved this by detecting the temperature on the surface of the IGBT chip but it was implemented at one of the corners. Further study found that there could be a significant difference between the temperature detected at the sensor and the actual maximum junction temperature. This could be handled by assuming an offset in temperature but the offset would have a load dependency that would prevent a precise protection level. The ideal is for the location of the temperature sensor to match the hot spot on the chip. This has been achieved by locating the temperature sensor at the center of the chip for the new IPM series.

Short Circuit

Modern drives require short circuit protection to ensure that load shorts or system controller malfunctions commanding a shoot through condition are not catastrophic for the drive. The current mirror emitter technology permits OC and SC protection that is much more effective than can be achieved with destaturation detection. The SC protection is implemented in both the P and N side IGBTs so that there is protection against ground faults as well. As a further improvement the new series contains a tuned negative feedback in the emitter which reduces the peak current during short circuit. The timing diagram for the control and protection is shown in Figure 2.

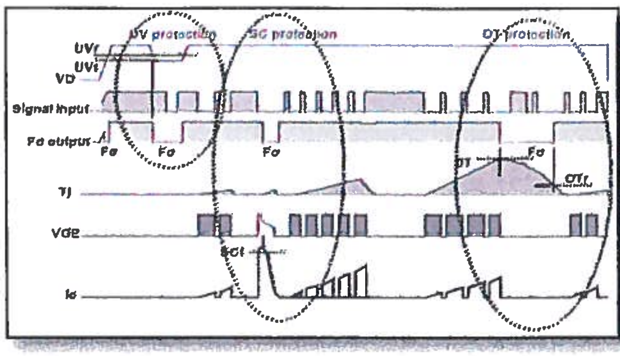

Figure 2.

Electrical Characteristics

In addition to keeping switching losses low to achieve high efficiency, the switching behavior must be well controlled to avoid oscillations requiring filtering to meet EMI standards. Figure 3 shows a switching test for the new 600 V module. The results are well behaved at both turn on and turn off with no oscillations even at comparatively short pulse widths. The switching losses have been matched to those of the conventional IPM while the conductions losses were reduced by upwards of 30 percent.

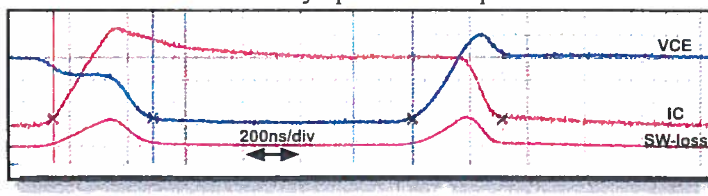

Figure 3.

In addition, a new wiring bonding process has been adopted to improve power cycling capability. The previously described improvements in short circuit detection have been tested at high gate drive and a starting junction temperature of 125°C as shown in Figure 4. Safe turn off is achieved and the waveforms are very well behaved. This reflects the negative feedback provided by an internal signal trace on the substrate which acts to reduce the gate-emitter voltage during the short circuit. Further, the current mirror emitter detection of the short circuit is near

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instantaneous reducing the temperature rise and stress on the IGBT compared to conventional desaturation techniques, which require a blanking time delay to avoid false tripping. A loss

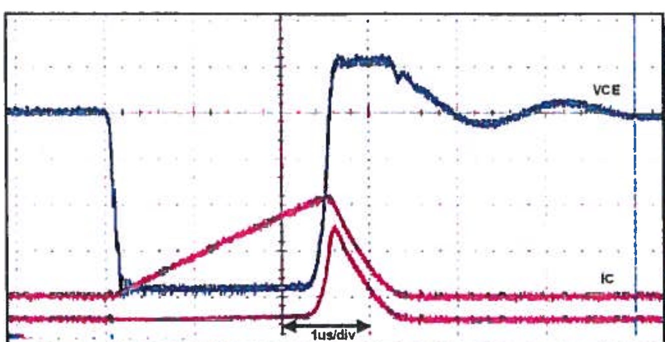

Figure 4.

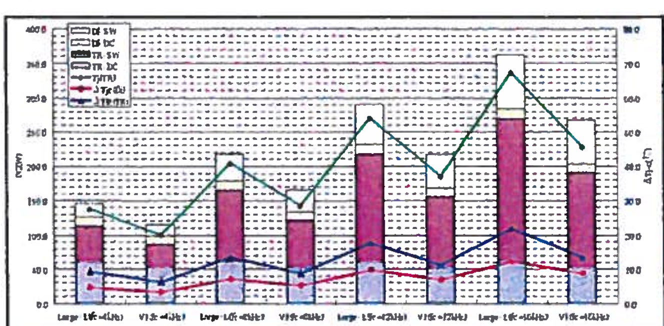

Figure 5.

comparison was carried out between the new series and the conventional series at operating frequencies between 4 and 16 kHz. Figure 5 details the loss reductions achieved in a PWM inverter operating on 600 V bus at 0.8 PF with 110 Arms output using modules nominally rated at 300 A.

Conclusion

A new series of IPMs has been developed with improved efficiency and performance based on CSTB chips with on-chip temperature sensing, current mirror emitter technology, negative feedback and improved manufacturing technology.

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