Advanced protection for large current full SiC-modules

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Abstract

This paper presents an advanced overcurrent detection and short circuit protection method for large current full-SiC modules using current sense source terminals. Test results obtained with a newly developed gate driver (for SiC modules) are presented and discussed herewith. This new driver incorporates overcurrent detection, soft-shut-down and active overvoltage clamping.

1. Introduction

The new 800A 1200V full SiC module - FMF800DX-24A was developed [1; 2] for high power applications allowing either high switching frequencies (in the range of 30 to 100 kHz) or high efficiency or high power densities.
Employing SiC technology facilitates a drastic reduction in the switching losses [3] compared to the Si IGBT. On the other hand, the static losses should be carefully adjusted without sacrificing the ability to handle short circuit conditions. The low on resistance of the SiC MOSFET is inversely proportional to the chip short circuit capability. The Fig. 1 shows the trade-off between the SiC MOSFET on resistance $R_{DS(on)}$ and the short circuit capability E_{SC} of the chip.

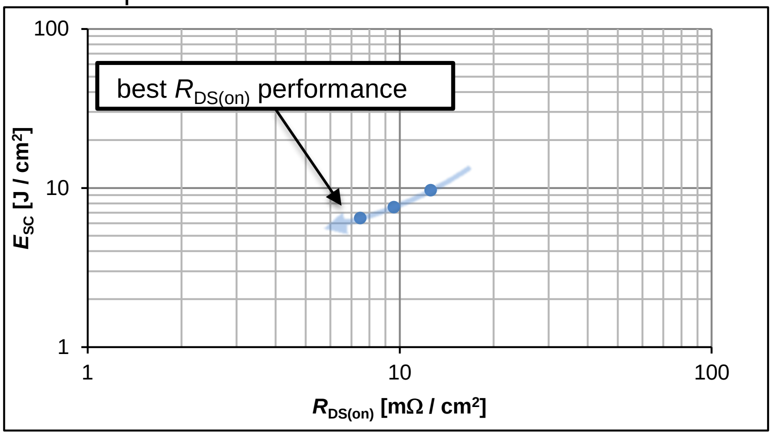

Fig. 1. Trade off between SiC MOSFET on resistance and short circuit capability

Taking into account the limited SC-endurance capability of today's SiC MOSFET-chips (in the range of a few microseconds) the availability of a separate current sense terminal is a promising option for reducing the response time and accordingly the energy dissipated during SC-turn-off in the MOSFET chip. Furthermore the MOSFET on resistance can be tuned for lower values. By using this option, overcurrent conditions (adjustable to any level) can be detected easily and appropriate countermeasures for SC-turn-off can be initiated in the gate driver. As a result the SC-current level and the SC-energy dissipated in the MOSFET can be remarkably reduced.

2. Full SiC-MOSFET short circuit capability

The FMF800DX-24A uses eight connected parallel 100 A SiC MOSFET-chips for one switch. The typical gate source threshold voltage $V_{GS(th)}$ is in the range of 1 V. For the short circuit capability of the module the total distribution of $V_{GS(th)}$ must be taken into consideration. Fig. 2 shows the short circuit limitation of an FMF800DX-24A module as a function of the gate source threshold voltage $V_{GS(th)}$. The measured maximum short circuit time (solid line) is between 3 µs and 4 µs. The measured maximum short circuit energy is about 18,4 J. Based on the device limiting constrains in the datasheet, a maximum short circuit time of $t_{SC(max)}$ = 2 µs is specified which shall not be exceeded by the user. But by using the conventional SC-detection method which detects the desaturation of the MOSFET, it is not easy to realize a safe turn-off during such a short period. This was the motivation to propose an advanced SC-protection method employing current sense source terminals.

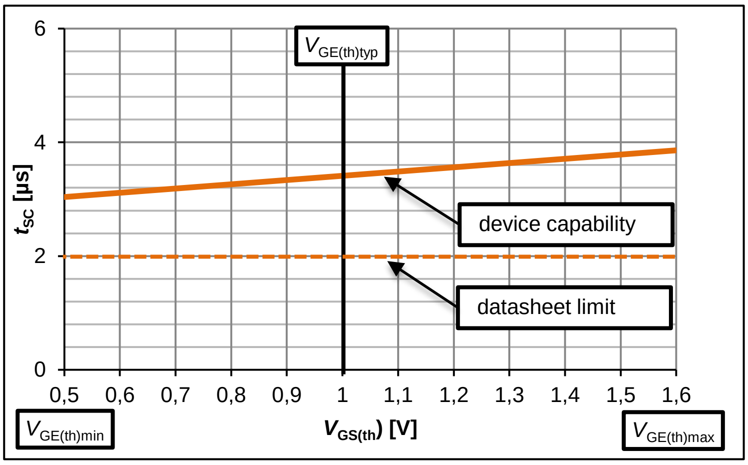

Fig. 2. Short circuit capability of FMF800DX-24A full SiC Module. V_{GS}=+15 V, T_J=150 °C, V_{DD}=850 V

3. Advanced method for detecting overcurrent or short circuit

The 100A 1200V SiC MOSFET chips used in the FMF800DX-24A have an isolated source area on top of the source metallization. This small source area is connected to the sense terminal. Thus an earmarked portion of the total source is provided at the sense terminal. A picture of the MOSFET chip and its equivalent simplified electrical circuit is shown in Fig. 3.

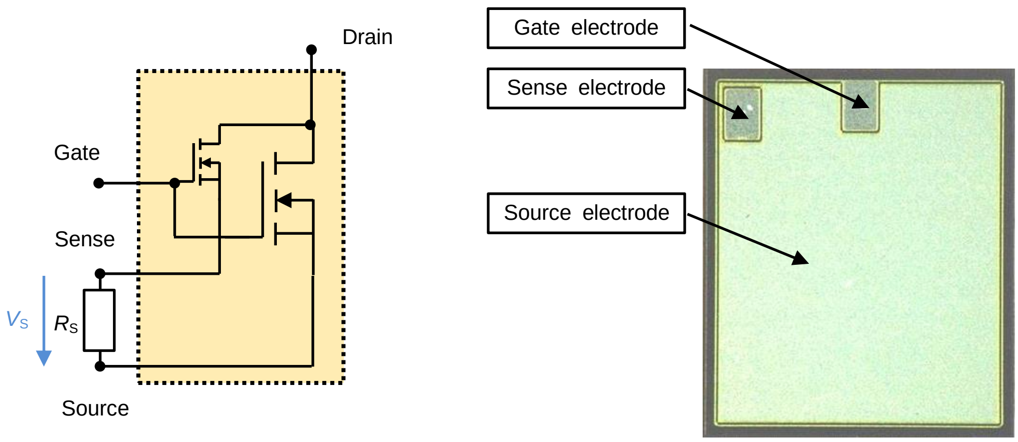

Fig. 3. SiC MOSFET chip with current sense terminal

The monitored source sense voltage across the sense and source terminals can be used for detecting overcurrents. The current through the sense resistance is proportional to the main source current. The ratio between the sense current and main source current is in the range of 1:61500. It has to be noted that the sense voltage (V_S) across the shunt resistance (R_S) depends on the junction temperature (T_J) as shown in Fig. 4. By considering this current dependency and T_J – dependency, an appropriate shunt resistor value (R_S) can be selected setting the needed overcurrent trip level.

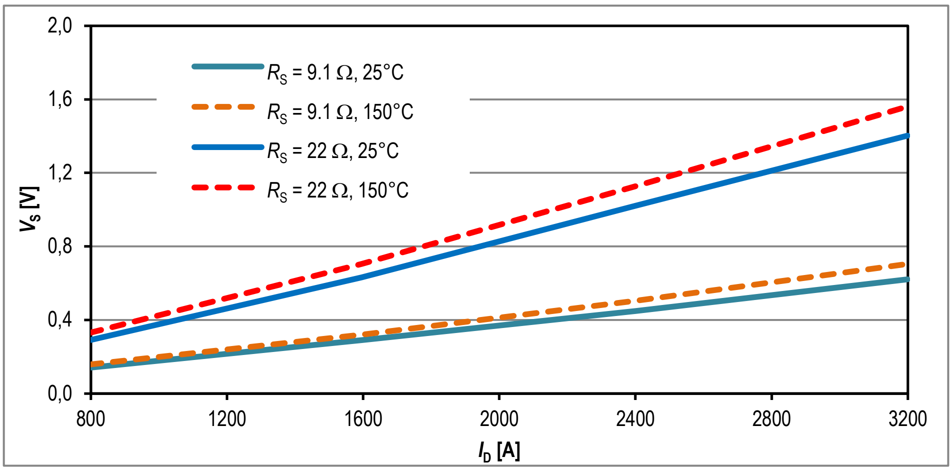

Fig. 4. Relationship between drain current and sense voltage

4. Gate driver realization for FMF800DX-24A protection

The efficiency of the advanced protection method of FMF800DX-24A by current sensing was practically realized by using the reference design RDHP-1417 with implemented core gate driver 2SC0435T [4; 5] providing overvoltage protection and overcurrent detection. For the overvoltage protection, active clamping is employed [6]. For overcurrent detection, the designated sense voltage triggers the soft shut down function of the gate driver. Principle equivalent circuit of the gate driver employed is shown in Fig. 5.

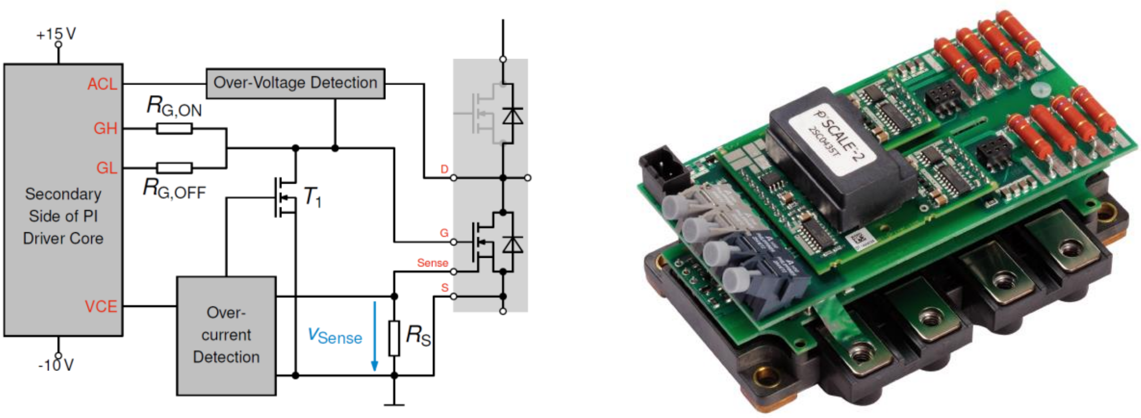

Fig. 5. A photograph of the gate driver employed (right) and its corresponding equivalent circuit diagram (left).

5. Overvoltage protection

Turning-off high load currents with a high di/dt will result in large over voltage spikes across

the device being switched. If the power module is operated below the set overcurrent trip level, it is recommended to add additional measures to the gate driver in order to prevent the turn-off over voltages from exceeding the rated break-down voltage of 1200 V. The preferred method is the implementation of Active Clamping along with an additional d*v*/d*t* feedback (in this case the gate driver does not actively turn-off the power module and no fault signal is reported to the host controller).
Fig. 6 shows turn off waveforms at 800 A and 1600 A with FMF800DX-24A device. In both cases the overvoltage protection limits the overvoltage spike safely below the break-down voltage of 1200 V.

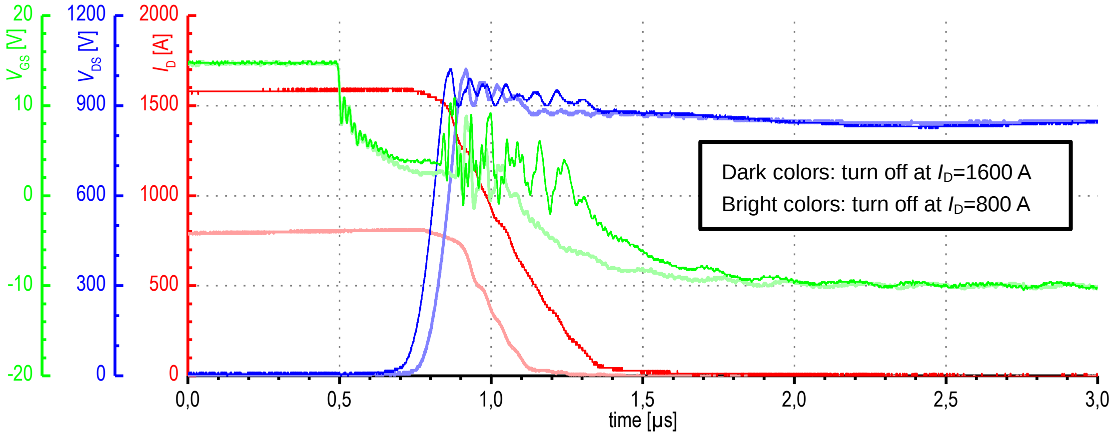

Fig. 6. MOSFET turn off wave forms at nominal and two times the nominal module current.

Conditions: V_{DD}=850 V, T_J=25 °C.

6. Overcurrent detection

At the evaluated gate driver the overcurrent trip level was set to about 2000 A (2,5 times the rated current). Once the trip level is reached, the gate driver actively turns-off using the soft shut down function and transmits a fault signal to the host controller. Fig. 7 shows an example of a turn-off event where the actual load current is slightly below the trip level of the overcurrent detection circuitry. Furthermore Fig. 7 shows the turn off event at the point of overcurrent detection and soft shut down for comparison. The power module has no significant overvoltage spike at such a soft shut down event.

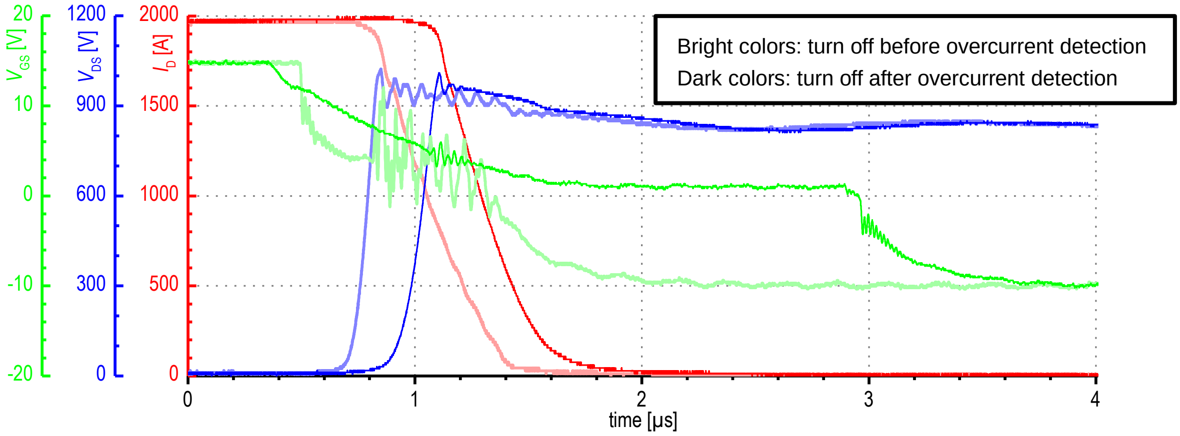

Fig. 7. Overcurrent detection and soft shut down at 2,5 times of rated current

Conditions: V_{DD}=850 V, T_J=25 °C.

7. Short circuit protection

To verify the effectiveness of the overcurrent detection in case of a short circuit event, the short circuit test was performed at a DC-link voltage of V_{DD}=850 V and a short circuit inductance (L_{SC}) of about 170 nH. The result of this measurement is shown in Fig. 8. The overcurrent was detected at about 2000 A after which an immediate soft turn off was initiated. The short circuit time was about 1µs. And the calculated short circuit energy (E_{SC}) is 0,65 J. The two critical aspects: short circuit time and short circuit energy are significantly lower than the critical boundaries with respect to the module. By using the soft shut down function, overvoltage during a short circuit turn off event was maintained well below 1000 V.

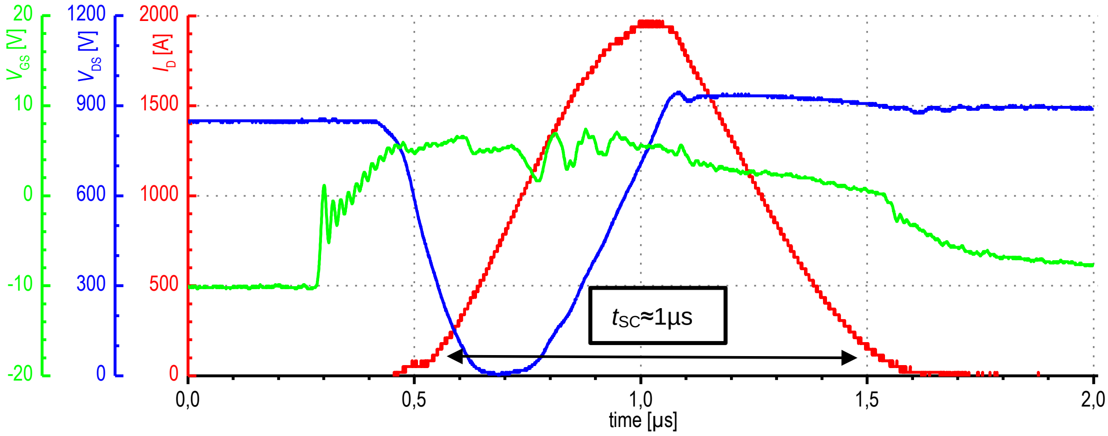

Fig. 8. Evaluation result during a short circuit event. Conditions: V_{DD}=850 V, T_J=25 °C.

8. Conclusion

The newly developed Mitsubishi Electric 800A 1200V full SiC Module FMF800DX-24A offers a unique ultra-compact solution for safely operating highly efficient power converters in the range of several 100kW. For this full SiC module, Power Integrations has developed a gate driver reference design (RDHP-1417). It uses the current mirror source terminal of FMF800DX-24A for providing overcurrent detection in short circuit conditions. Furthermore the implemented active clamping and soft shut down functions are able to limit overvoltage spikes when high currents are turned-off.

References

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