Smart Handling with Surge Current in PFC Using Silicon Carbide Schottky Diode

The Silicon Carbide diodes are widely used in different applications with aim to reach high efficiency and power density. The optimization process behind CoolSiC™ G6, the new sixth generation of Silicon Carbide Schottky diodes reduced conduction losses, but at the same time caused the lowering of the surge current parameters in certain areas. However, the resulting performance of the CoolSiC™ G6 fulfills application requirements well.

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With the adoption of SiC Schottky diodes in PFC topologies, a bypass diode has been used in order to restrict the forward current through the SiC diode in case a surge current affects the mains of the power supply. Figure 1 illustrates how the bypass diode is usually implemented in a classic PFC. The bypass diode conducts only when the rectified voltage is higher than the output voltage (e.g. surge events).

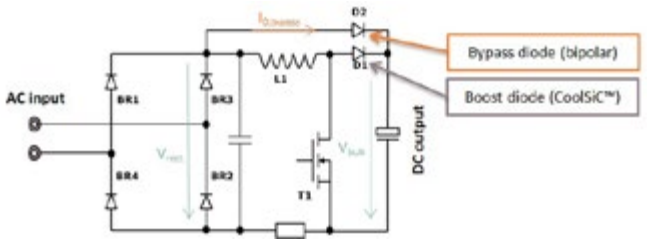

Figure 1: Simplified circuit of a classic PFC

The first test had the original set-up of the 800 W PFC evaluation board1 and it was performed with the bypass diode implemented. In order to show the worst possible surge current conditions, the following test set-up was selected:
Input voltage: V_{in} = 90 V AC
Switching frequency: f_{sw} = 130 kHz
Output power: P_{out} = 800 W
Surge pulse: V_{surge} = 4 kV, Z = 2 Ω, φ = 90°, L-N configuration

The surge immunity test was carried out at 90° (i.e. positive voltage pulse added on top of the sine wave). Specifically, a combination wave test using an impulse voltage wave of 1.2/50 µs with a 4 kV peak value was selected. The test is defined by the standard IEC 61000-4-5, which applies to telecom requirements.

This study includes the worst possible conditions in the PFC circuit with respect to surge immunity. When the lowest input voltage is applied, the highest current enters the circuit. At this operation point, the highest current flows through the PFC choke, and saturating it. This saturation leads to a reduction of the inductance and a decrease in the choke features. The saturated choke cannot contribute much in limiting the surge current pulse when the surge happens. This leads to higher stress on the boost diode, while more surge current is routed through it instead of being routed via the bypass diode. In this precise scenario, the boost diode experiences the highest stress (the highest current flows via the boost diode).

The first screenshot of current waveforms was captured on the boost diode (IDH06G65C6) and bypass diode (S5K) in order to show the current split between these two diodes during the surge event. The waveforms were captured, when the surge pulse was applied to the power supply input (800 W PFC). Both diodes were conducting simultaneously approximately 80 µs at peak current values:
- Boost diode (IDH06G65C6): $IF_{,max}$ = 23.4 A,
- Bypass diode (S5K): $I_{F,max}$ = 308 A.

Beside current waveforms was captured also input voltage, which was rapidly increased at the surge pulse. The tested board has MOV (metal oxide varistor), which clamps high voltage during the surge event. The MOV impacts on the current flow through the bypass diode as well as the boost diode.It was applied a differential mode surge pulse, which caused a special behavior on the current flow through bypass diode. There were two current pulses after the surge event. The first pulse came at the point when the surge pulse was applied. The second pulse was secondary effect of the MOV clamping. When the MOV was clamping, the rectified voltage was decreased and the bypass diode stopped conducting. When MOV released, the voltage on the input increased and the second pulse through bypass diode was injected.

The current through the boost diode was smooth since the PFC choke was limiting fast transients. In operation conditions the boost diode (the Silicon Carbide diode) did not see any additional stress. The current through the diode was within the specification.

The second scenario considered the surge immunity test without the bypass diode in the circuit. The bypass diode was de-soldered from the 800 W PFC board. That means all features of bypass diode were disabled. In order to have the same test conditions as in previous scenario were applied the same input voltage, output load, and the surge current.

When surge pulse passed the circuit, the current through the boost

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diode increased to 24 A. This current value is still within the specification of the surge current given in the datasheet. The boost diode (CoolSiC™ G6) passed the test, but the bridge rectifier (LVB2560) failed due to the too high voltage stress.

The CoolSiC™ G6 diode is not limiting the surge immunity of the PFC stage, even if no bypass diode is used. The comparison between designs with and without bypass indicates the clear benefit of the bypass diode. It fully protects the PFC circuit against high surge current, and does not generate any additional power losses under steady-state conditions because it conducts only when the voltage on the anode is higher than on the cathode. Therefore, it is a safety component which conducts only rarely, under conditions such as surge current.

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