A 1000A 6.5 kV Power Module Enabled by Reverse-Conducting Trench-IGBT-Technology

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Abstract

A reverse conducting IGBT module based on the well-established high insulation 6.5 kV-package platform for single switches is presented. The function of the IGBT-switch and the freewheeling diode is integrated into a single die enabling the higher current rating of 1000A. The maximum allowed junction temperature remains at 125°C as for the existing 6.5kV module portfolio. The ampacity enhancement is enabled by the significantly improved thermal resistance due to the increased effective silicon area for both operation in IGBT- and diode-mode. Additional benefit results from a reduction of the switching losses by proper gate control schemes during diode operation. The ampacity increase towards 1000A is therefore done without any cutbacks of the power cycling reliability, yet an increase of the effectiveness.

Module Design

In Infineon’s commonly known 6.5 kV IGBT-modules IGBT and freewheeling diode chips are assembled in parallel connection on six AlN substrates, which are mounted on an AlSiC base plate. Within the new 1000A - 6.5 kV module all former chips positions are replaced with the RCDC-chips (Reverse Conducting IGBT with Diode Control). This RCDC-chip, which is a reverse conducting IGBT in trench technology designed for hard switching, has been recently introduced [1]. The functionality of an IGBT-switch and a freewheeling diode is given by this single chip solution. Due to the integration into the existing module platform of high insulation modules the outer diameters as well as the pinning remain unchanged.

Thermal Behavior

One of the major advantages of the RCDC technology is the significant improvement of the thermal resistances within the module (R_th_JC) and towards the cooler (R_th_CH), which allows for an increased ampacity while the junction temperature remains at 125°C. This is in contrast to previously announced 1000A modules in the field of 6.5kV applications, which rely on an increase of the junction temperature to 150°C [2].

The reason for the improved thermal resistances is the increase of the effective silicon area available during operation in IGBT- as well as diode-mode. While in previous 6.5 kV modules with footprint 140x190 mm² 24 parallelized silicon dies are contributing to IGBT mode, now 36 RCDC chips serve for heat spreading. In the case of diode-mode the improvement is even higher due to three times more active dies in parallel compared with the common IGBT module. Since the same silicon volume is used during IGBT and free-wheeling mode the thermal
coupling during IGBT- and diode-mode has to be taken more seriously into account than for standard IGBT, where the thermal coupling between the spatially separated IGBT and diode dies occurs mainly via the substrate and base plate [3]. However, a beneficial reduction of the thermal ripple is observed, which can lead to an additional improvement of the power cycling reliability. By the means of FEM-simulation the Zth-curves of IGBT-mode, diode-mode and the thermal coupling have been investigated (fig 1). The Rth_JA of the IGBT-mode is reduced by roughly 20% and of the diode-mode even by roughly 50% compared to the FZ750R65KE3 module.

Fig 1: Simulated Zth-curves of the FZ1000R65KR3 module during diode and IGBT-mode as well as for the thermal coupling of IGBT- and diode mode. The heat sink is modelled via a 3mm Al plate and a heat transfer coefficient of 8000W/m²K, a 100µm 1W/m²K heat conductive paste is applied.

Electrical Behavior

The new RCDC-module with footprint 140x190mm² (FZ1000R65KR3) is rated at a nominal current of 1000A, which is a power increase of 33% compared with the well-established IGBT3 trench technology module. The IGBT-output and transfer characteristics are depicted in fig 2a, b. The diode characteristic depends on the gate voltage actually applied to the module and can be seen in fig 2c. This is a remarkable feature of the RCDC as it allows controlling the on-state voltage but accounts for dedicated current direction detection during inverter operation. The blocking capability of the module is enabled only for gate voltages VGE lower than the threshold voltage.

The gate voltage dependent diode behavior allows for a dynamic reduction of the switching losses during diode recovery and thus IGBT turn on by a smart gate control during diode conducting mode and before commutation, respectively. A schematic of a gate control pattern for the combination of lowest on-state and switching losses for a given half-bridge configuration is shown in fig 3a, b. Applying a gate voltage step to the RCDC in diode conduction mode short before commutation reduces the switching losses by sweeping out the stored charge carriers just before the turn on of the according IGBT and is referred to as desaturation of the RCDC in diode mode. Essential parameters of the desaturation are the desaturation duration tdesat and the locking time tlock, which ensures an avoidance of a phase leg short circuit. Figure 3b shows a variant of the gate control pattern: The RCDC-diode conducts in a “pre-desaturated” stage at
an applied gate-voltage of zero volts; to achieve same dynamic losses the necessary desaturation durations are much shortened.

The dynamic switching losses of four typical operation modes for the RCDC in diode mode: a) \( V_{GE} = -15 \text{ V}, \) no desaturation pulse; b) \( V_{GE} = -15 \text{ V}, \) \( t_{\text{desat}} = 50 \mu\text{s}; \) c) \( V_{GE} = 0 \text{ V} \) no desaturation pulse; d) \( V_{GE} = 0 \text{ V}, \) \( t_{\text{desat}} = 20 \mu\text{s} \) are demonstrated in fig 4. The desaturation of the RCDC-diode shows an enormous reduction of the IGBT turn-on and diode recovery losses of 34% and 40%, respectively. A major advantage compared to the previously presented reverse conducting module in the field of 6.5 kV applications [4] is the improved impact of the desaturation pulse with respect to loss reduction at even shortened desaturation durations.

![Fig 3: a) Half-bridge configuration with two FZ1000R65KR3 modules: Module “A” in IGBT and module “B” in diode mode. b) Gate control pattern with desaturation pulse applied to module “B” in diode mode; c) Variant of a gate control pattern with a pre-desaturated module in diode mode](image)

![Fig 4: IGBT turn-on losses \( E_{\text{on}} \) and diode recovery losses \( E_{\text{rec}} \) for the gate control patterns of fig 3b and c with and w/o desaturation pulse for \( V_{CC}=3.6kV, I=1000A \) at 125°C](image)

**Summary**

The paper presents a 1000A hard switching reverse conducting IGBT module dedicated for the voltage class 6.5 kV. It allows for an increased output power of inverters having the same footprint and maximum rated junction temperature 125°C as the standard IGBT module. Despite the higher output power the achievable power cycling capability remains on the same level, yet some improvement is expected by the decrease of the thermal ripple. By the option for smart gate control even with short desaturation durations the switching losses are significantly reduced and the loss balance as well as the effectiveness is enhanced.

**References**