

# Research of Current Distribution in IGBT Modules with Multiple Chips in Parallel

M.Bäßler<sup>1</sup>, M.Münzer<sup>1</sup>, S.Burkert<sup>2</sup>

1) eupec GmbH, Max Planck Str.5, D-59581 Warstein Germany, Tel: +49-2902-764-2290, Fax: +49-2902-764-1150, email: marco.baessler@eupec.com

2) Otto-von-Guericke-Universität, Universitätsplatz2 Magdeburg Germany

## Abstract

In the present paper studies of the module internal switching losses are shown. Emphasis is on paralleling of the chips in an IGBT module. The analysis started with simulations. With the aid of a miniaturized Rogowski coil, the loss distribution in the module was determined. With an infrared measurement, the effects of the module internal switching symmetry was verified.

## I. Introduction

Today IGBT modules with current ratings of up to 3600A and blocking voltages up to 6,5kV are available. Unfortunately, it is not possible to build single IGBT and diode chips with a sufficient chip area for each current rating. Today the largest 1200V IGBT is rated up to 150A. To reach higher current ratings in IGBT modules it is necessary to parallel IGBT chips as well as diode chips. In the design of such an IGBT module various properties have to be taken into account. A very symmetric distribution of the total losses is desirable. This would lead to a homogeneous heating of the module.

A parallel connection of IGBT can influence both the static behaviour and the dynamic behaviour. The static behaviour is influenced by module internal conduction paths and  $V_{cesat}$  or  $V_f$  variation. With knowledge of the Kirchoff-laws, static imbalances of the circuit resistances can easily be avoided by an optimal DCB and bond layout in the module. In the observed EconoPACK™+ module influences of the module internal line resistance are so small that in real measurements only the dominant influences of the chip variations could be measured. Therefore, the thermal heating caused by static losses is uniform.

The dynamic switching behaviour is dominated by the magnetic field distribution in the module. As current density in the modules increases influences due to magnetic fields get more intense. The system of magnetic coupling in a module is too complex to do predictions about

current sharing without simulations or measurements.

In our work, the distribution of the switching losses is being considered. Three methods were used for that purpose. In the first attempt via simulation, qualitative statements for the module internal switching performance are collected. Measurements with an improved Rogowski coil enabled a more precise picture of the symmetry of the design. Finally, the effect of switching losses was investigated via temperature measurements in an inverter.

In the present paper the studies were applied to an EconoPACK™+ as an example. This Sixpack consists of three separate systems. Every system (Fig.1) is a half bridge configuration, which is built up from three identical DCBs. On every DCB a complete half bridge with a current rating of one third of the module is mounted. Each functional element is built up by paralleling three chips, in this way.

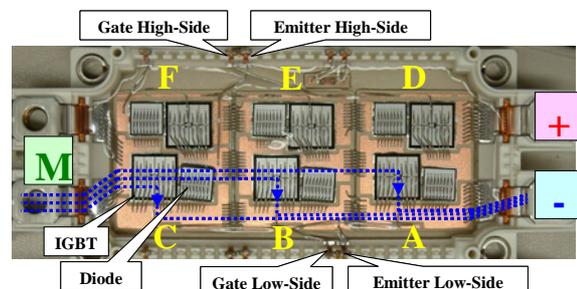


Figure 1: One System of the sixpack EconoPACK™+ from eupec; the lines describe the current flow through the Lowside; the letters indicate the positions of the six IGBT

## II. Expectation attitude:

We begin with a look at the current flow through the low-side of an EconoPACK™+ system. In figure 1 the current through the paralleled IGBTs is shown as dotted lines. The current flows from phase output (M) over the IGBT chips A, B and C to the emitter connection (-) of the low-side. Obviously, the conducting path of the emitter is narrower than the collector conducting path,

which runs in parallel to the emitter path. In addition, the current distributes differently from DCB to DCB. On every DCB, approximately 1/3 of the total current flows through the IGBT. Therefore, the current density increases on the emitter conducting path from DCB to DCB. Also, the electro-magnetic field strength increases with the enlargement of the current density along the emitter path. Therefore the inductive coupling of the load current on the gate of IGBT A will be different from the coupling on the gate of IGBT B or IGBT C. Therefore it is conceivable that all IGBTs switch differently.

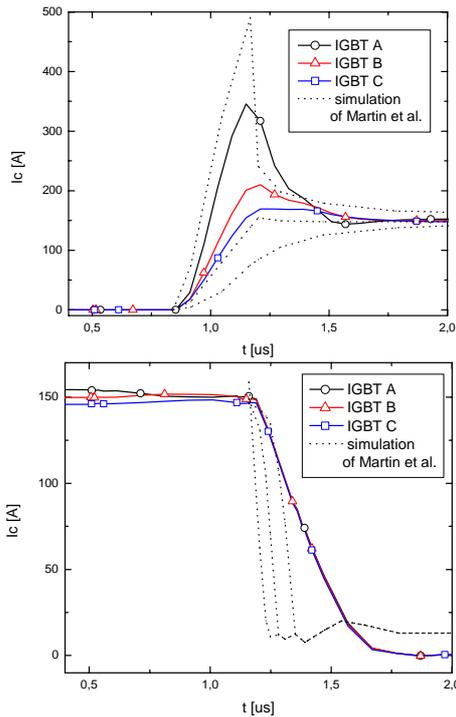


Figure 2 Simulation of switching behaviour of the Lowside, turn on (top) and turn off (bottom)

The group of Martin et al. [1] simulated the EconoPACK™+ in their work. The computation shows that an unsymmetrical gate connection in a module can lead to an asymmetric current sharing while switching the IGBT. As a result of simulation IGBT A would have to undertake the entire diode recovery charge while switching-on. Our own computations show a much less pronounced current imbalance (Fig.2). For a correct simulation, it is important to have the correct model of the resistors, inductance and of the magnetic coupling between paths. The necessary parameters for our simulation were extracted from a state of the art field simulation. This simulator generates an equivalent circuit, for P-spice, from a 3D-Cad drawing. The switching

behaviour was then simulated with P-spice. In contrast to the computation of Martin et al. in our results no difference can be observed during current fall at turn-off. Both simulations, those from Martin et al. but also ours, show that the IGBT connected in parallel turn on differently. But the own computations show a far less current distribution. It is assumed that IGBT A turn on faster than IGBT B or C. This leads to the assumption that the loss distribution is uneven. In this context it is necessary to mention that the stress level of the IGBT derived from simulations is significantly lower than the maximal allowed chip stress, which was tested in the chip characterization.

Analysis of the high-side retains qualitatively similar results.

### III. Method of measurement:

To determine the losses of the single IGBT the product of current and voltage must be integrated (formula 1).

$$E = \int (U * I) dt \quad (1)$$

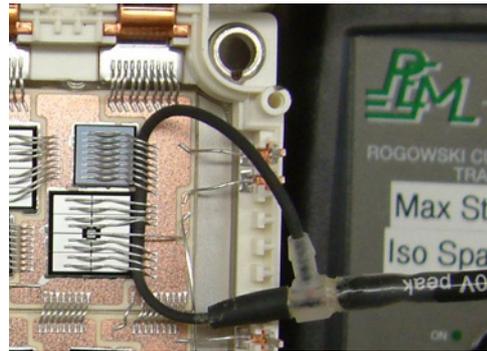


Figure 3 Miniaturized Rogowski coil under the emitter bond of an IGBT to measure the single IGBT current

To examine the modules we built some FS450R12KE3 modules from eupec without isolation gel. The voltage measurements were carried out at the corresponding auxiliary connections. The current measurement of the different IGBT paths was carried out with a miniaturized Rogowski coil. For the measurements of the IGBT currents the Rogowski coil (Fig.3) was mounted under the emitter bonds of IGBT and diode and fixed within the module. The current of the individual IGBT A, B and C was measured, in this way.

### IV. Switching behaviour

At turn-off (Fig.4) it is interesting that only in the time of the Miller plateau a significant imbalance of current can be observed. This effect of current

sharing during the Miller phase was examined by Joyce et al. [2] on two IGBT in parallel. The intensity of current sharing is influenced by differences in Gate-Emitter resistance in the module, variations of chip internal gate resistors as well as variations of the threshold voltage of the single IGBT chip. The investigation of four devices showed no correlation to module design. The reason for a missing current correlation lies in the dominance of chip variations. During the Miller phase the collector voltage is still close to zero, therefore the differences in current are not noticeable in a loss analysis. After the end of the Miller phase the current level of all single IGBT goes back to a similar value before switching. When the voltage reaches the DC link voltage the current starts to decrease. All three IGBT showed comparable current tails. To summarize, it is not amazing that the turn off losses are similar, as verified for four devices.

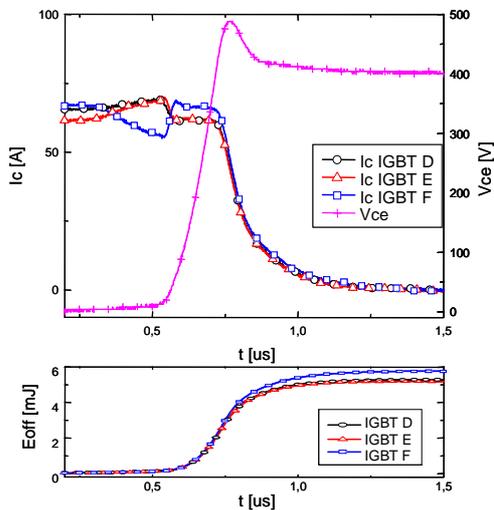


Figure 4 Turn off behaviour; measured switching characteristic (top) and switching losses (bottom)

During the turn on phase (Fig.5) the IGBT chips are much more influenced by module internal stray inductance. In all examined systems, the IGBT D switched on with highest speed and showed the highest current peak. IGBT E and IGBT F show similar turn on behaviour among each other. The differences in turn on behaviour are also detectable in the switching losses. For a thermal contemplation of the module symmetry, the total losses are important. Therefore, for further consideration the turn on and turn off losses are added. Because variations of the dynamic and static chip characteristics have an influence on the loss distribution several systems are examined. By average over several systems Chip influences could be eliminated.

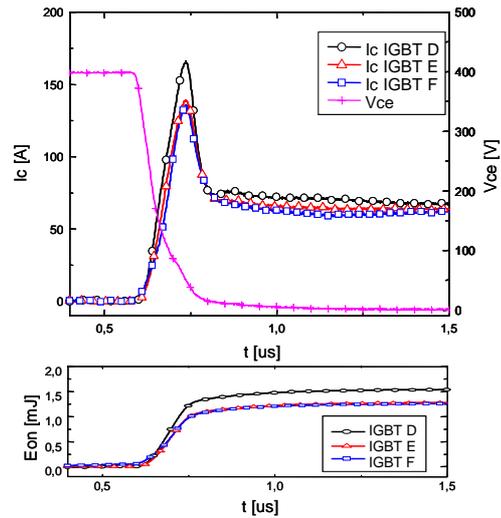


Figure 5 Turn on behaviour; measured switching characteristic (top) and switching losses (bottom)

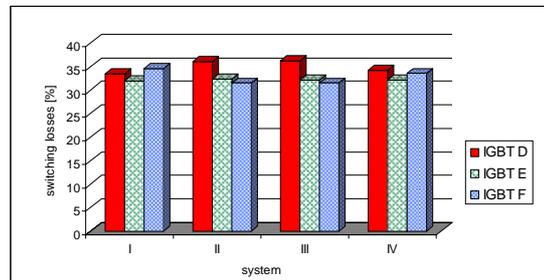


Figure 6 Total switching losses of 4 observed Systems

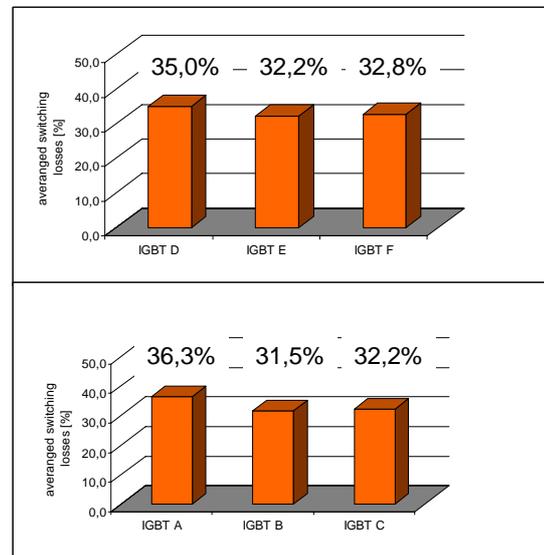


Figure 7 Averaged total switching losses Highside (top) and Lowside (bottom)

Figure 6 shows the total switching losses of the 4 examined high side systems. Fig. 7 (top) shows the mean total switching losses of each chip position of the high-side

IGBT. The loss of IGBT D is only 2-3% higher than IGBT E or IGBT F. IGBT E and IGBT F show similar dynamic losses. Fig 7(bottom) shows the mean total dynamic losses of the low-side. In this case IGBT A shows approximately 4-5% more total losses as IGBT B or IGBT C. However, under real operation conditions not only the dynamic losses but also the static losses lead to heating. Since the static symmetry in the module is very good the difference in total losses is again less.

## V. Consequences for inverter operation:

The question about the effect of the unsymmetrical switching on the real operation of an IGBT module has still to be considered. For answering the question, an EconoPACK™+ module was put into a 3 phase PWM inverter and was examined with an infrared camera. Figure 8 shows results of the study. The module was screwed onto an air cooled heat sink without fan. The output current of the individual phases was set to an amplitude of approximately 200A and a sinusoidal frequency of 50Hz.

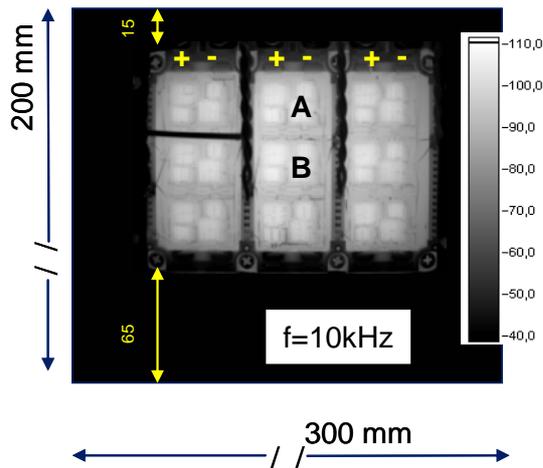


Figure 8 Infrared measurement, switching frequency = 10kHz, output frequency=50Hz I<sub>cmax</sub>=200A (sinusoidal), the black area around the module outlines the used heatsink geometry

The dynamic power dissipation can be varied by the switching frequency, while the static losses stay the same for a fixed amplitude.

In order to evaluate the influence of static heating tests at two different switching frequencies were performed.

Frequency increase leads to a rise in temperature which is established by additional dynamic power dissipation, only. The strongest deviations in losses are between IGBT A and B. Therefore, IGBT A and B are compared at the

following. It is also to expect that rising frequency increases the temperature difference between IGBT A and B.

The measurements (Fig. 9) show that the influence of the imbalance is minimal. The temperature indeed increases with the frequency. But IGBT B shows a higher temperature than IGBT A for both frequencies. And although the dynamic losses increase by around factor 5 the temperature difference between IGBT A and IGBT B is still similar. That means, that the heat sink geometry in addition to the static losses has a much more dominating influence on the temperature distribution than the symmetry of the dynamic losses.

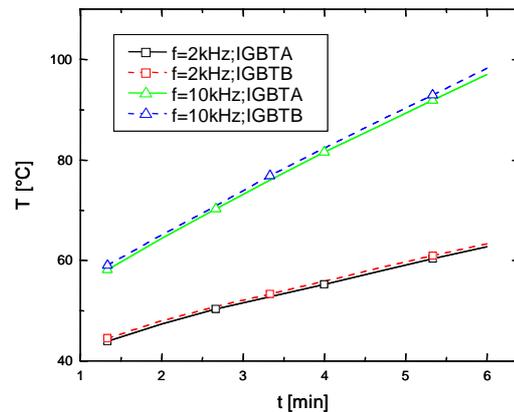


Figure 9 Temperature vs. time for IGBT A and B at switching frequencies of 2 and 10 kHz

## VI. Conclusion:

In the design of a module symmetry of losses is important. But a dynamic symmetry of 100% is not realistic. For evaluation of a module it is necessary to simulate and measure the module. It is not possible to judge a complex lay out without such an in depth investigation. Measurement of the device with an improved Rogowski coil have shown that loss distribution even in a visible asymmetric module differ only 2-5%. With infrared - measurement it could be verified that minor module internal asymmetries are neglectable. The heat sink geometry in addition to the static losses has a larger influence to the total losses and the temperature distribution.

## References

- [1] C.Martin,J-L.Schanen, E.Clavel, R.Pasterczyk "Power Integration: electrical analysis of new emerging package", EPE 2003-Toulouse
- [2] J.C.Joyce "Current Sharing and Redistribution in High Power IGBT Modules" PhD-thesis 2001, University of Cambridge