Advanced SOI Gate Driver IC with integrated $V_{CE}$-Monitoring and negative Turn-off Gate Voltage for Medium Power IGBT Modules

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Abstract— A novel approach for medium power IPMs is presented combining 600V and 1200V IGBT/FWD-inverter modules based on spring contact technology with advanced silicon on insulator (SOI) gate driver ICs with fully integrated $V_{CE}$-monitoring and negative turn-off gate voltage in a reliable cost effective package with excellent thermal conductivity. For the $V_{CE}$-monitoring of short circuit events the HV-diode and the processing circuit are fully integrated for each switch on the TOP and BOT secondary side. Thanks to the SOI technology which blocks voltages in both directions a negative turn-off gate voltage of -5V can be used for the first time inside an IC to prevent an unmotivated turn-on of the OFF-IGBT during switching of higher currents (>100A) inside a half bridge. The presented static and dynamic measurement results demonstrate the driver and system performance. The new system approach for medium power industrial drive applications supports the market trend towards intelligent power module solutions already known from the low power consumer market.

I. INTRODUCTION

Intelligent Power Modules (IPM) which combine both IGBT/FWD-power bridges and fully integrated gate drivers with driving and monitoring functions replacing conventional hybrid IGBT drivers are restricted to low power applications (600V, 1200V, ≤35A) [1],[2]. To develop the medium power market for currents up to 100A or even higher the extension of the gate driver IC performance is necessary. As shown in recent papers, gate driver ICs based on a high voltage SOI-CMOS platform technology presented in Fig.1 [3],[4] can overcome the most of the disadvantages of gate drive ICs which rely on conventional junction isolation. They provide complete latch-up immunity and the operational temperature range can be considerably extended up to 200°C [5] - ideal for module integration [6]. Advanced level shifter concepts allow negative secondary side offset voltages down to -30V [7] and even the signal transmission for the 1200V class can be realized by cascaded 600V transistors [8].

In this paper new extended functions are presented. To make these systems more safety against short circuit events a $V_{CE}$-monitoring is implemented for every switch. And second a negative turn-off gate voltage is used to prevent unmotivated turn-on during switching inside a half bridge and to reduce the switching losses.

II. $V_{CE}$-MONITORING

Fig.2 shows the block circuit diagram of a gate driver IC for a three-phase inverter and a seventh switch which can be used as brake chopper or PFC for the 600V class. The seven control signals from the microcontroller (LIN1..4, HIN1..3) are processed on the low side (short pulse suppression, interlock, dead time, amplification) and transmitted by medium voltage level shifters to BOT1…4 secondary sides and by 600V high voltage level shifters to the TOP1…3 high sides. On these secondary sides the control signals are reconstructed, filtered and amplified. The IGBT gates are driven by 1.4A/-1.4A output stages (source/sink). For every BOT- and TOP-IGBT a $V_{CE}$-monitoring is integrated on the secondary side to detect short circuits. The $V_{CE}$-monitoring circuit integrates the HV-diode, the current limiting resistance, filter components and the comparator. Further implemented functions are the under-voltage monitoring of all operation voltage supplies on the low and high side and the current monitoring by shunt at the –DC terminal (ITRIP).

Fig.3 shows the chip photography of this 600V Seven-pack gate driver IC with these implemented functions. The low side
driver core, the four secondary side gate driver stages for the BOT-IGBTs, the three isolated high side (600V) gate driver stages for the TOP-IGBTs with their 600V DMOST level shifters and 600V diodes (oval structures) and last but not least the 600V $V_{CE}$-diodes of the short circuit monitoring of each IGBT are clearly to see.

Exemplarily the Fig.4 shows the $V_{CE}$-monitoring in operation under hard short circuit conditions ($L$ low) in a 600V, 50A system at $V_{DC}$ of 500V. It is clearly to see that the $I_{CSC}$ increases to $5.2 \times I_{\text{nom}}$ (260A) and the IGBT goes in de-saturation. After the adjusted blanking time of app. 2.1$\mu$s the

Fig.4: 600V, 50A IGBT; $V_{CE}$-monitoring turns off TOP-IGBT at hard short circuit ($L$ low) after blanking time ($V_{DC}=500V, T_j=25^\circ C$)

Fig.5: 600V, 50A IGBT; $V_{CE}$-monitoring turns off BOT-IGBT under soft short circuit conditions ($L=200\mu H$, exceeds monitoring threshold at 6.2V ($V_{DC}=300V, T_j=25^\circ C$)
desaturation is detected and the IGBT is turned off by the secondary side. The turn-off voltage $V_{CE,max}$ is app. 630V. The $V_{CE}$-monitoring under soft short circuit conditions (L very high) is demonstrated in Fig. 5. The $I_{SC}$ increases very slowly and the monitoring threshold of $\approx 6.2V$ is reached after 420µs.

III. NEGATIVE TURN-OFF GATE VOLTAGE

The second new innovative feature is illustrated in Fig.6. It shows the typical operating conditions of the gate driver IC using $+15V$ gate voltage for turn-on and $-5V$ for turn-off. The microcontroller input signals are processed on the primary side of the gate driver IC on the same −DC potential. Medium voltage level shifters transmit the control signals to $V_N$ (e.g. $-5V$) to the secondary side. The gate signals for the output driver stages operate between $+10…-5V$ for the nMOS turn-off transistor and between $0V…+15V$ for the pMOS turn-on transistor. (The gate driver IC has internally a high flexibility and can operate at the output also from $-18V…+2V$ exemplarily for specific normally-on SiC-JFETs.)

Figs.7 and 8 present the switching waveforms of a BOT- and TOP-IGBT with $V_{GE}=0V…+15V$ inside a 1200V, 100A half bridge of an inverter at $V_{DC}=600V, I_{C}=100A$. Fig. 7 shows clearly, that during normal turn-on of BOT-IGBT a parasitic turn-on of TOP-IGBT happens, an additional cross current flows over the half bridge and increases the turn-on losses (13.46mJ). Further losses of 9.31mJ are generated inside the TOP-IGBT due to the cross current. It is influenced by $V_{GE,TOP}$ rise up to 9V (see Fig.8; $V_{th}$ of IGBT is 6.5V).

The turn-on of the OFF-IGBT (TOP) can be prevented by a negative turn-off gate voltage of $-5V$ as shown in Fig.9. So cross currents over the bridge can be suppressed and the losses are reduced significantly from 22.77mJ to 10.85mJ. This effect becomes even more significant if the collector currents increase (>100A) and two or more IGBT per switch are in parallel.

IV. IPM-PACKAGE TECHNOLOGY

Fig.10 shows the exploded view of a Converter-Inverter-Brake (CIB)-IPM on basis of the Mini-SKiiP product family for currents up to 150A and Fig.11 its circuit diagram with implemented $V_{CE}$-monitoring (DESAT) for every switch. The success of the module is based primarily on an innovative package without baseplate under the DBC substrate and with spring contacts for all main and auxiliary connections between...
DBC and PCB. This leads to an easy assembly construction with high thermal and power cycling capability, as well as vibration ruggedness. The new IPMs include a conventional DBC substrate with soldered and bonded devices (Rectifier Diodes, IGBTs, FWDs, gate resistors and temperature sensor (TS)) and the gate driver IC is glued directly on the DBC (excellent thermal conductivity [6]) and is connected by thin wire bonds (see Fig.12). The DBC substrate and the mounted devices are protected with silicone gel.

**V. SUMMARY**

Advanced silicon on insulator (SOI)-gate-driver-ICs with fully integrated \( V_{CE} \)-monitoring and negative turn-off gate voltage are presented for medium power 600V and 1200V IGBT/FWD-inverter modules based on spring contact technology. For the \( V_{CE} \)-monitoring of the short circuit event the HV-diode and the processing circuit are fully integrated for each switch on the TOP and BOT secondary side. Thanks to the SOI technology which blocks voltages in both directions a negative turn-off gate voltage of -5V can be used to prevent an unmotivated turn-on of the OFF-IGBT during switching of higher currents (>100A) inside a half bridge. Cross currents over the bridge can be suppressed and the turn-on losses are reduced from 22.77mJ to 10.85mJ inside a 1200V, 100A IGBT-half bridge. The new presented functions (\( V_{CE} \)-monitoring and negative gate turn-off voltage) can be used alone or in combination for 600V and 1200V drives.

**REFERENCES**


