Applications of combined MOSFET - IGBT power leg with reduced switching losses

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Abstract

This paper discusses power legs built upon the combination of a MOSFET and an IGBT. The suggested combined use of those different switches is intended to be applied in PWM controlled single and three phase inverters. The main advantage of the presented topology is the reduced switching losses in the overall inverter topology compared to the classical pure IGBT and MOSFET topologies. The paper presents and compares experimental results for the proposed power leg and the conventional pure IGBTs and pure MOSFETs legs. Realized applications of the proposed power leg are shown.

1. Introduction

In many applications where PWM controlled invertors are used, conventional means of reducing losses, such as soft switching [1,2] and resonance circuits [4,5,6,7] are inapplicable. Furthermore, in some of those applications such as motor control and distributed generation, where a significant part of the load (the motor in the first case and the grid in the second) is inductive, losses from the freewheeling diode reverse recovery are a major part of the switching losses. This means that realizing scheme with MOSFETs leads to significant turn-on losses due to the poor quality of the MOSFET's freewheeling body diodes and their high reverse recovery time. Using IGBTs on the other hand has disadvantage of increased turn-off switching losses due to the IGBT's tailing current.

2. Proposed solution using combination of a MOSFET and an IGBT.

The introduced topology's main advantage versus the conventional MOSFET or IGBT topologies is the reduction of the total losses in the switches. When only MOSFETs are used there are larger switching losses during the turn-on due to the high reverse recovery of the MOSFET's body diode. IGBTs on the other hand, have smaller turn-on losses by the absence of a parasitic body diode and the opportunity of using a better freewheeling diode, but however they have larger losses during the turn-off because of tail currents. By putting a MOSFET and IGBT in one leg the losses can be reduced combining the better properties of the two switches.

Figure 1 shows the presented topology. For simplification of the analysis the suggested MOSFET-IGBT leg is integrated in a classical H-Bridge inverter. There are two combined power legs comprising transistors S1, S2 and S3, S4 and their freewheeling diodes D1, D2 and D3, D4. To operate effectively the inverter should be controlled using PWM where the IGBT is conducting and the MOSFET is modulating. There is no imperative constrains on whether the IGBT or the MOSFET is on the top or in the bottom of the leg.

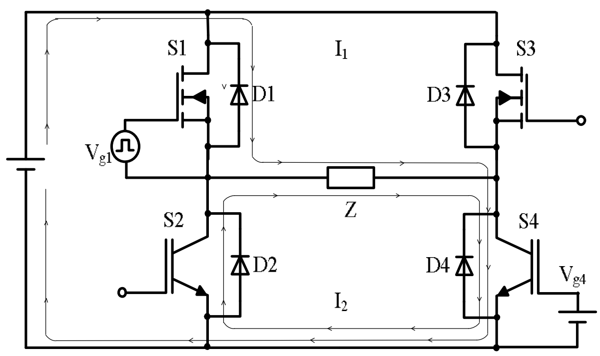

Fig. 1. Suggested combined MOSFET and IGBT leg in a classical H-Bridge inverter.

The effects in the suggested topology can be explained as follows. The discussion takes place for half a period of the modulated output voltage (given sinwave PWM) where S4 is constantly conducting and S1 is modulating. In this way there are two main currents flowing in the in the inverter. I_1 the current from the supply that flows when S1 is switched on and I_2 the current from the energy stored in the inductance of the load Z which flows when S1 is switched off. If the topology is pure MOSFET then current I_2 will flow through the body diodes of MOSFETs therefore causing higher turn-on losses due to the low quality of those diodes in terms of reverse recovery. In the suggested topology I_2 flows through the integrated diodes of the IGBTs. Those diodes have better qualities and therefore the losses will be less (Figure 2 and Figure 3).

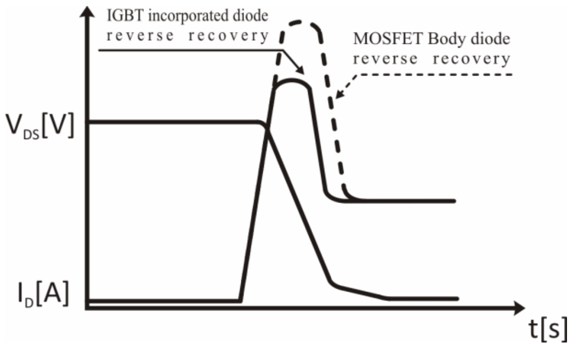

Fig. 2. Turn-on losses caused by the reverse recovery of freewheeling diode in IGBT and MOSFET topologies;

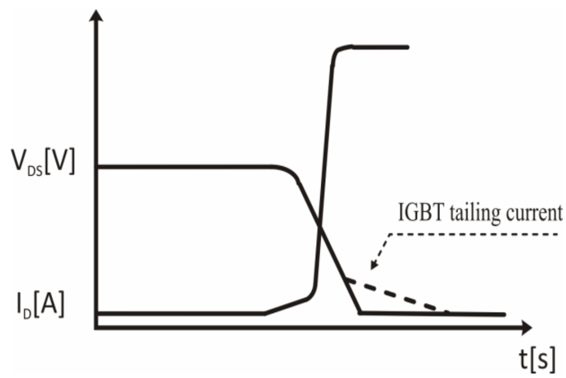

Fig. 3. Turn-off losses in IGBT and MOSFET topologies.

The suggested topology is improved compared to the pure IGBT leg as well in terms of turn-off losses because the high frequency modulation signal is applied on the MOSFETs which have lower switching losses compared to IGBTs due to the lack of tailing currents (Figure 3).

The total loss reduction of the MOSFET & IGBT bridge is shown in Figure 4 using the typical waveforms.

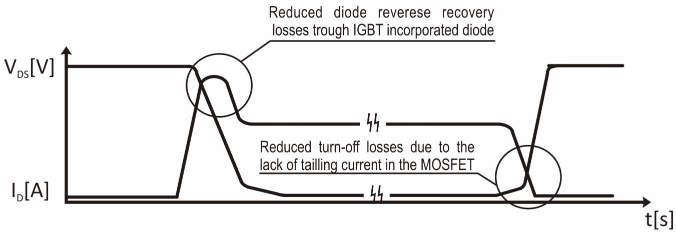

Fig. 4. Switching losses reduction of an IGBT&MOSFET leg.

3. Experimental verification of the proposed power leg.

The experimental results presented in this paper were obtained by testing three power leg configurations – pure MOSFET, pure IGBT and MOSFET-IGBT combination. In all cases the load was inductive. The tests for the three configurations are carried out for the same load, frequency and transistors, data for those components is provided in table 1. The test set-up for IGBT-MOSFET is shown on figure 5. The test set-up for MOSFET or IGBT topologies are similar (S2 is replaced with a MOSFET, or S1 replaced with an IGBT).

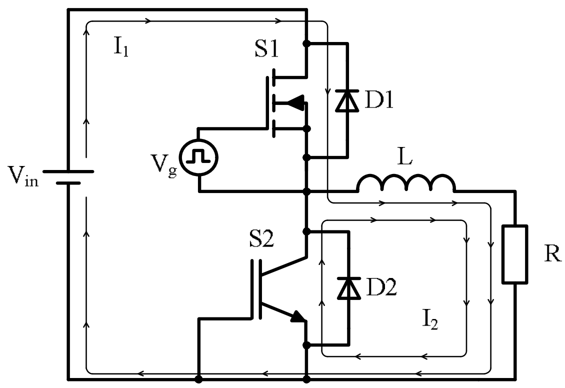

Fig. 5. MOSFET and IGBT test circuit

Components	value
R	30Ω
L	8,5mH
S1,D1(MOSFET)	STW26NM60
S2,D2(IGBT)	IRGP4062D

Table 1. Experimented set up for MOSFET-IGBT power leg, 50 kHz

The verification is realized first by comparison of the turn ON wave forms of the suggested leg with a pure MOSFET leg wave forms and secondly, by comparison of the turn OFF wave forms of the suggested leg with a pure IGBT leg wave forms.. It is evident from figures 6 and 7 that the MOSFET-IGBT topology has no peak current during turn-on, and from figures 7 and 8 that during turn-off there is no tail current, resulting in reduced switching losses.

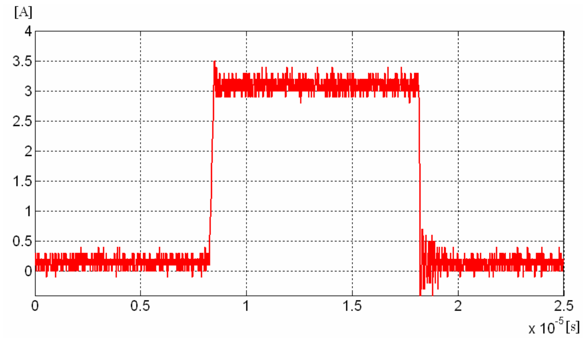

Fig. 6. Turn-on current of the proposed combined MOSFET-IGBT leg (less turn ON switching losses)

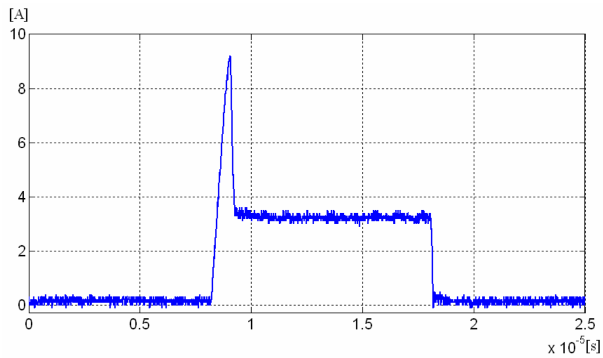

Fig. 7. Turn-on current trough a pure MOSFET leg.

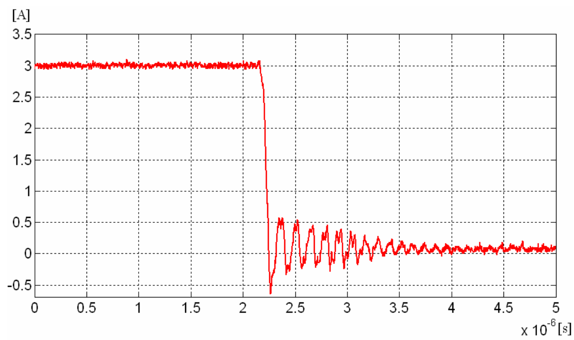

Fig. 8. Turn-off current of the proposed combined MOSFET-IGBT leg (lack of tailing current)

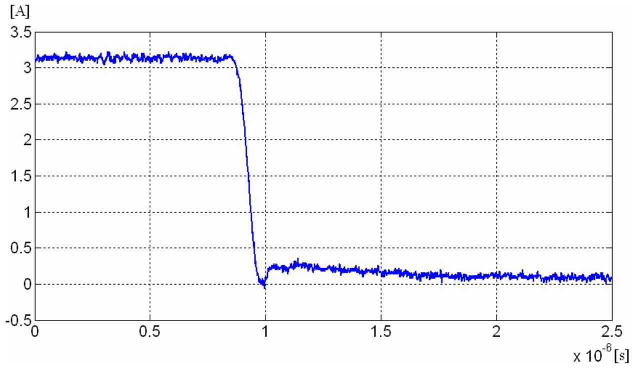

Fig. 9. Turn-off current trough a pure IGBT leg.

4. Applications of the propsed power leg in BLDC motor control, in variable speed generation and in grid injection

The suggest topology was build with the intention to be used in a system for distributed generation, where the generator is variable speed BLDC machine. Thus the topology was tested working as 1) three phase BLDC motor control (since the generator is not self starting), 2) a three phase variable speed control for the BLDC generator (figure 10), 3) as single phase sinwave inverter and 4) as a single phase grid injector (the schematic of the single phase injector is similar to the one presented in figure 1, and thus is not provided). The described applications were tested separately and as a whole device as well. The combined MOSFET-IGBT topology proved its functionality and efficiency.

The experimental efficiency of the converter system realized by the combined MOSFET-IGBT is 97%; when realized by pure MOSFET legs is 94% and realized by pure IGBT legs is 96%.

In respect to prices of the switches, the proposed topology is estimated to be less expensive then MOSFET topology and slightly more expensive then IGBT topology.

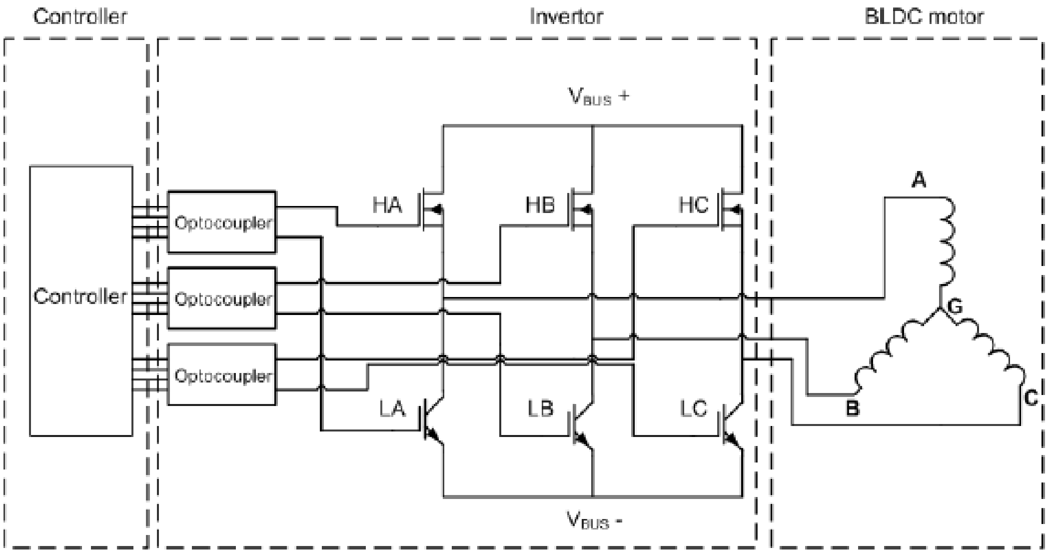

Fig. 10.IGBT-MOSFET Combination in BLDC motor/generation control.

5. Conclusions.

This paper presents a configuration aimed at losses reduction by using a novel power leg combining a MOSFET and an IGBT. The advantage of this combination of two different switches leads to the turn-on losses reduction by using the faster freewiling diode of the IGBT, and the

turn-off loss reduction obtained by using the effect of MOSFET's lower turn off losses because of the lack of tailing current, typical for IGBTs. The introduced leg structure can be successfully applied in motor and generator control and in grid injecting systems.

6. Literature.

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