

ELECO'2007
International Conference on Electrical and Electronics Engineering
Bursa, Turkey

**NUMERICAL SIMULATION AND ANALYSIS OF IGBT TURN-OFF
CHARACTERISTICS: dV/dt CAPABILITY**

Ly. BENBAHOUCHE¹, A.MERABET²

¹ *Department of electronics, F.A.S University, Setif, 19000, Algeria, Fax: 00 213 (36) 92.51.34*

¹ *E-Mail : Lybenbah@yahoo.fr*

² *Laboratoire de physique et mécanique des matériaux métalliques, département d'optique et mécanique de précision, faculté des sciences de l'ingénieur, Université Ferhat Abbas de Sétif, Algérie.*

Topic : Power electronics and applications

Abstract.

About fifteen years ago, the challenge of simulation in power electronics was to predict and understand the global behaviour of various topologies of devices. For years, this fact could be observed in microelectronics, whereas in power electronics simulation has mostly been restricted to system design. Recently, the insulated gate bipolar transistor (IGBT) has gained increasing acceptance as a power transistor for a variety of power electronic applications. At the same time, the ever increasing calculation power of computers allows representing the devices more accurately to aid to design of the switching section (design of the snubbers, prediction of the current and voltage overshoots, study and optimization of the losses in the switch etc...)

The aim of this paper is to represent numerical simulation of both the turn-on and turn-off switching characteristics of an IGBT taking account of the external circuit (in hacheur mounting). In this paper, we will focus on simulation of switching behaviour at turn-off for inductive load with freewheeling diode. Simulation study on the device (IGBT) was performed using two-dimensional numerical simulator.

The main purpose of this paper is to point out some mechanisms relating to the (dv/dt) capability on different commercial IGBTs devices (IXYS) for

examination of the response at turn-off with variations in gate charge (by changing gate series resistance Rg) and in

temperature. I hope that this paper can contribute to the understanding the dv/dt capability of different commercial IGBTs devices operation, show how it relates to some underlying physical mechanisms and achieve high power switching efficiency, reduced cost, improved reliability and reduced parasitic. Comparison between measurements and simulation shows good agreement.

Keywords: Numerical Simulation, IGBT, (dv/dt) Capability.

1. INTRODUCTION

With the increasing acceptance of the IGBT as a new power switching device in both discrete and Integrated power circuit for various power electronics application, the importance of simulation in the Research and the ever-increasing calculation power of computers allow representing more accurately the device.

Today's IGBT technology combines the advantages Of the power Mosfet and the bipolar transistor, high Switching speed with ease of control and comparably low saturation voltage during the on-state [1,3]. These features led to a widespread application of this power device. A schematic of the structure of two of the several thousand cells of an IGBT is shown in figure.1, and it equivalent circuit is shown in figure.2.

This circuit consists of an n-channel mosfet driving the base current of p-n-p transistor.

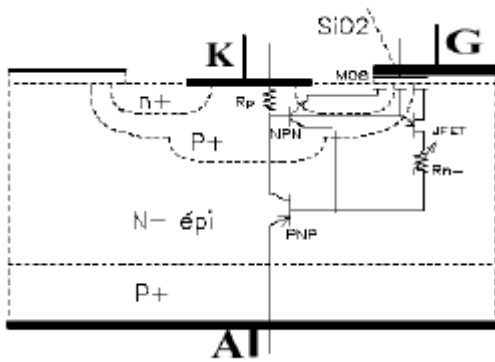


Fig. 1. Cross-section of basic IGBT structure [1,2].

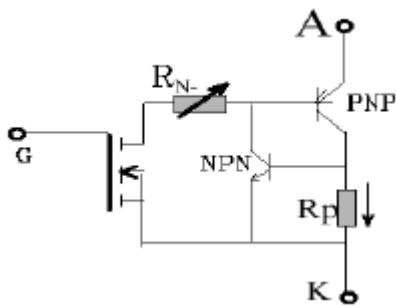


Fig.2. Basic equivalent circuit for IGBT [1,2].

The aim of this work is to simulate the switching waveforms and the short circuit failures, in a complete power electronic circuit, with adequate accuracy and reasonable computing time.

2. SWITCHING PERFORMANCE

In this section, the parameters that govern the transition between the turn-on and turn-off states are analyzed.

2.1. TRANSIENT ANALYSIS

For predicting the switching transients characteristics of IGBT, as a result of the interaction

Between the device and the circuit, fig.3 shows the turn-on and the turn-off waveforms of a commercial IGBT device (IXYS serie).

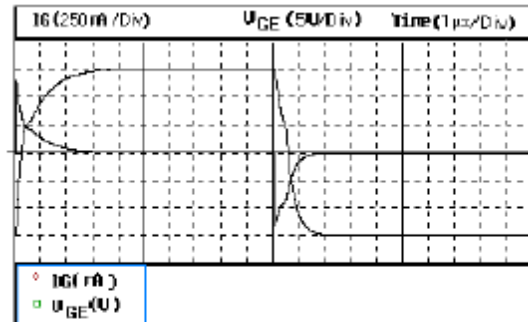
2.2.1.1. TURN ON

During the turn-on state, the Mos part of the IGBT (see fig.2) is mainly responsible for the performance, whereas the bipolar transistor influences turn-off and steady state behavior.

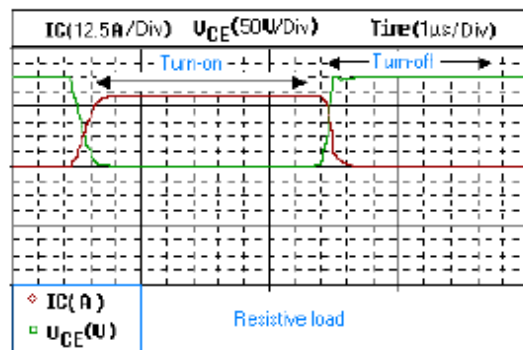
2.2.1.2 TURN – OFF

The major turn – off characteristics of an IGBT, is its tail current. The form of this tail current depends strongly on the technology. The whole tail current is considered as the bipolar part of the IGBT current, the

part of the current decreasing much slower than the Mos current. In this case, the abrupt drop in applied gate voltage from V_G to zero, is assumed to occur at the terminal gate G. The voltage V_{GE} can then decrease with time below the threshold voltage V_T , before the decrease of collector current I_C in IGBT.



(a) : (I_g, V_{ge})



(b) : (I_c, V_{ce})

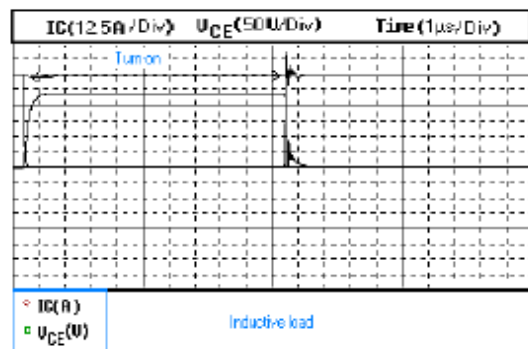


Fig.3. Simulated transient Characteristics of IGBT with resistive and inductive load.

The composite waveforms corresponding to turn off state shown in fig.3 are analyses as follows.

The voltage V_{GE} decrease with time until the gate voltage reaches the value required to obtain saturated collector current equal to the load current I_L . The collector current will remain at I_L whereas the collector voltage will begin to rise toward E, because the load current cannot be diverted from the IGBT into the diode

until V_{CE} exceeds V_L . The collector voltage will rise linearly from the on-state voltage drop V_{on} to the load voltage. At this point, the freewheeling diode D will turn-on. To achieve this, it is essential that the IGBT collector voltage exceed the load supply voltage E .

3. SWITCHING ENERGY

The switching power losses P_T in fig.4, are determined using multiplication point by point of I_c and V_{CE} . In fig.4, we can explain that the power dissipation during the turn-off transient of IGBT (IXYS) occurs during Δt (some hundred of nanoseconds), where both the current and voltage are large.

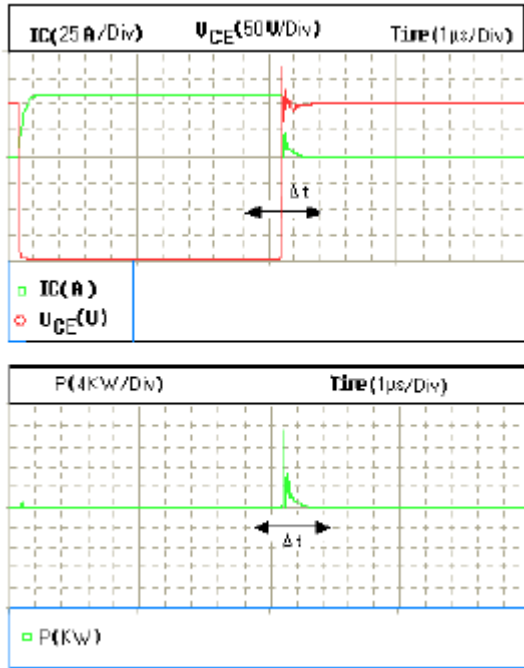


Fig.4. Simulated Switching Power Characteristics of IGBT.

4. dV/dt CAPABILITY

In this section, our approach consist to study the capability of IGBT at turn off for inductive load with freewheeling diode, using the circuit model shown in fig.5 as a result of interaction between the device and the circuit. It is necessary to consider a specific type of load for analysis, here, the inductive load is then considered because it reflect the industrial applications. The inductance L_s is the stray inductance not clamped by the diode D (freewheeling diode).

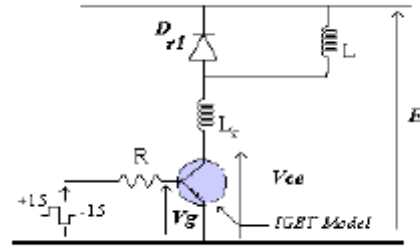


Fig.5. Inductive Switching Circuit using Power IGBT [7].

In this section, we will try to simulate and study the variation of (dV/dt) capability of a commercial IGBT device (IXYS series) by changing gate resistance R_g , C_d capacitance of the freewheeling diode and temperature.

5. RESULTS AND DISCUSSION

5.1. INFLUENCE OF GATE RESISTOR

The main purpose of this section is to prove the influence of R_g on (dV/dt) value and we will try to clarify this point which deserves more attention. However, works [1,7] prove the influence of R_g on turn-off characteristics of IGBT experimentally. e.g.: delay time, (dV/dt) and (dI/dt) .

Fig.6 displays the simulation results obtained at turnoff with varying the gate resistor R_g in range of 4.5 and 1k. As can be seen from these waveforms that the (dV/dt) capability becomes independent of the gate resistance at very high gate resistance. The simulation results, observed decrease in the (dV/dt) capability with increasing gate resistance, which is compared and confirmed with experimental results [1,7]. Then, the preceding analysis indicates that is important to design the gate drive circuitry to obtain a low gate resistance if a high (dV/dt) capability is desired.

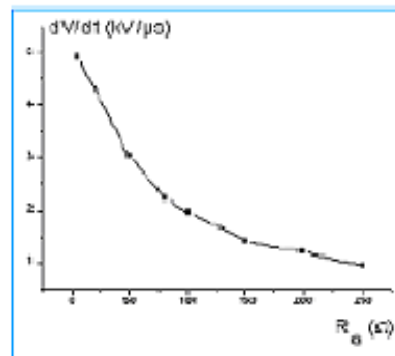
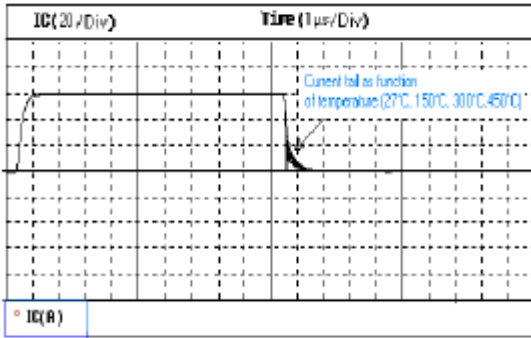


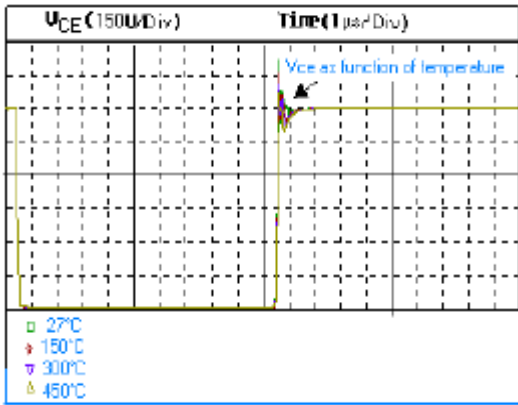
Fig.6. Simulated (dV/dt) values as function of gate resistance.

5.2. INFLUENCE OF TEMPERATURE

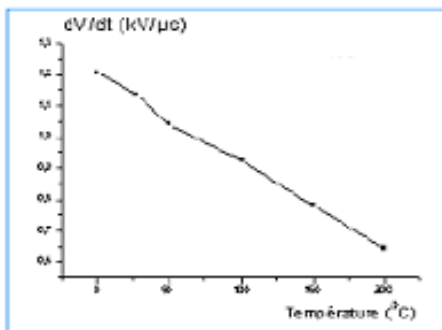
In this section, we try to improve the influence of temperature on the the dv/dt capability at turn-off behavior of IGBT. Fig.7 shows, in increasing temperature, the P-base resistance will also increase, because of a reduction in the carrier mobility. This, cause a reduction in (dV/dt) capability as temperature increase.



(a) I_c waveforms



(b) V_{ce} waveforms

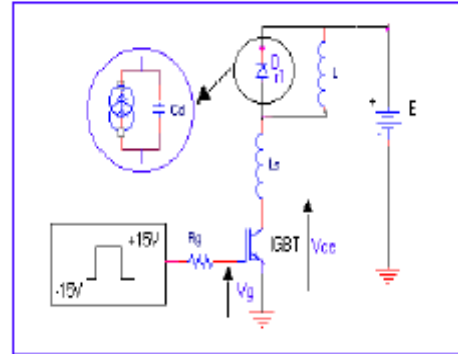


(c) Simulated (dV/dt) values as function of temperature.

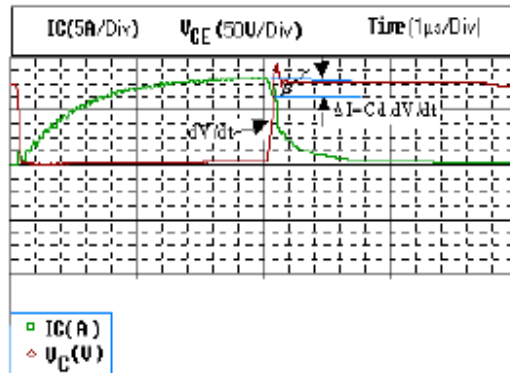
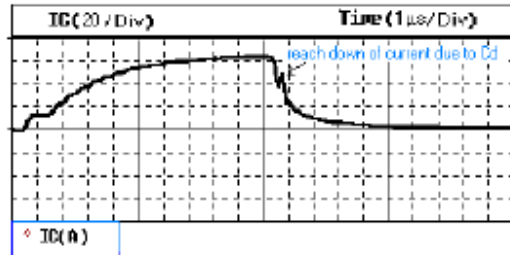
Fig.7. Simulated characteristics of IGBT as function of temperature.

5.3. INFLUENCE OF C_d FREEWHEELING DIODE

The internal stray capacitance c_d of the freewheeling diode, interfere all the more as the IGBT is fast or very fast because the (dV/dt) is very high. This kind of device (IXYS) permit to deviate by way of freewheeling diode a part of IGBT current, which explain the light reach down of collector current I_c in IGBT (see fig.8.) and which can although observed experimentally by [7].



(a) : Circuit.



(b) : Simulated transient Characteristics I_c and V_{ce} of IGBT.

Fig.8. Presence of stray interior capacitance at freewheeling diode.

6. Conclusion

In conclusion, this paper presents a detailed study of switching behavior during turn-off for inductive load with freewheeling diode. Also, this paper explains the strong influence of gate resistance R_g , cd capacitance of the freewheeling diode and temperature at turn-off state of actual commercial IGBTs (IXYS serie).

The preceding analysis indicates that is important to design gate drive circuitry to obtain a low gate resistance if a high (dV/dt) capability is desired.

All simulation results presented in this paper are validated, compared and showed good agreement with the measured data.

References

- [1] B. JAYANT BALIGA, " Modern power devices", General Electric Company, Shenectady New York, December 1987.
- [2] POUL. STANGERUP , " The Simulation Program-ESACAP PC - Implemented Network And System Simulation demonstrated by Applications ", Examples (2V).
- [3] Ly.Benbahouche et al, " New numerical power IGBT model and simulation of its electrical characteristics", IEEE Conference, ISBN:0-7803-726-X, pp 211-214, Smolenice Castle Slovakia, 2002.
- [4] Ly.Benbahouche, "Modeling and simulation the steady state and transient characteristics of the power Insulated Gate Bipolar " Master Thesis U.F.A, Setif, Algeria 1996.
- [5]ALLEN. R. HEFNER, "An improved understanding for transient operation of the power Insulated Gate Bipolar Transistor (IGBT)" IEEE Trans. Electron Devices. Vol.5. No.4. October 1990.
- [6]F.Calmon, "Participation du comportement électrothermique des IGBTs(Transistor Bipolaire à Grille Isolée) ", Thèse de Doctorat, INSA Lyon, France 1995.
- [7] B. JAYANT BALIGA, " Temperature behavior of Insulated Gate Transistor characteristics", Solid State Electronics, Vol.28,No.3, pp 289-297, 1985.