

Thermal Behavior of a Three Phase Inverter for EV (Electric Vehicle)

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Abstract—Power modules including IGBT are widely used in the applications of motor drivers in Electric Vehicle. The thermal behavior of these modules becomes more important to choose the optimum design of cooling system. In this paper, we propose a RC thermal model of the dynamic electro-thermal behavior of IGBT PWM (Pulse Width Modulation) inverter modules. This model is used to estimate the maximum junction temperature of the module. The thermal behaviors of the junction and power dissipation are studied with and without influences between the module components. The electro-thermal model is implemented and simulated with MATLAB simulator.

I. INTRODUCTION

The EV became more energy effective than vehicle using fuel combustion. Main electrical components for electric vehicle are battery, inverter and motor. The inverter is the most important electrical component which converts the direct current of the battery into the alternating current. This inverter is composed by silicon devices. The physical phenomena which condition the electric behavior of the devices based on semiconductor are closely related to the component's temperature. And reciprocally, the temperature of component is strongly related to the power dissipation. There thus exists a coupling between the electric behavior of the power components and the thermal impact of all the structure. So, in the electronic engineering design, particularly the components and the power electronics systems, it is necessary to consider the thermal evolution during the operating cycles in order to increase the reliability of the power systems.

This paper presents a RC thermal model for electro-thermal simulation for EV inverter module. This simulation can predict the dynamic thermal behavior of EV inverter devices. The thermal influences between the module components devices have been studied.

II. THERMAL INTERACTION AND THERMAL MODEL

The studied module is the Semikron module SKM 75GB 123D (75A/1200V) which contains two IGBTs and two Diodes in antiparallels. The structure of the module contains primarily eight layers of different materials, each one of it is characterized by its thickness L_i , its thermal conductivity K_i ,

density ρ_i and its heat capacity C_{pi} . Table 1 show the materials properties of the various layers of module as shown in figure 1. These values are given by the manufacturer and/or of the literatures [1-3].

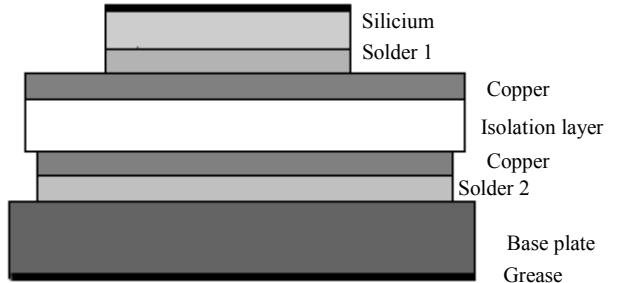


Fig. 1. Example of the module structure

TABLE I
THERMAL PARAMETERS OF A POWER MODULE

Material	L (mm)	K (W/mK)	ρC_p (J/Kcm 3)
Silicium	0.4	140	1.7
Solder 1	0.053	35	1.3
Copper	0.35	360	3.5
Isolation	0.636	100	2.3
Copper	0.35	360	3.5
Solder 2	0.103	35	1.3
Base plate	3	280	3.6
Grease	0.1	1	2.1

In the power module, the heating flow diffuses vertically and also laterally from the heating source. So, a thermal interaction happens inside the module between the adjacent devices when they operate together. This thermal interaction depends from:

- The dissipated power value of the various components.
- The disposition of the chip components.
- The boundary condition at the heat spreader.

Fig. 2 shows the thermal influence between the different components of the module. We notice that each component has a thermal interaction with the others and we supposed that each module have zero interaction with other modules.

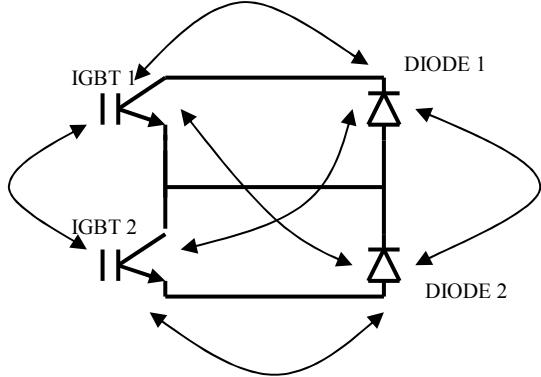


Fig. 2. Different thermal influences between the module components

Literature proposes some thermal circuit networks for electro-thermal simulation for the semiconductor device. For example the finite difference method (FDM) and the finite element method (FEM). In our study we have used the FEM technique to model our inverter module. Figure 3 shows the thermal circuit example obtained by the FEM of IGBT1 without thermal interaction.

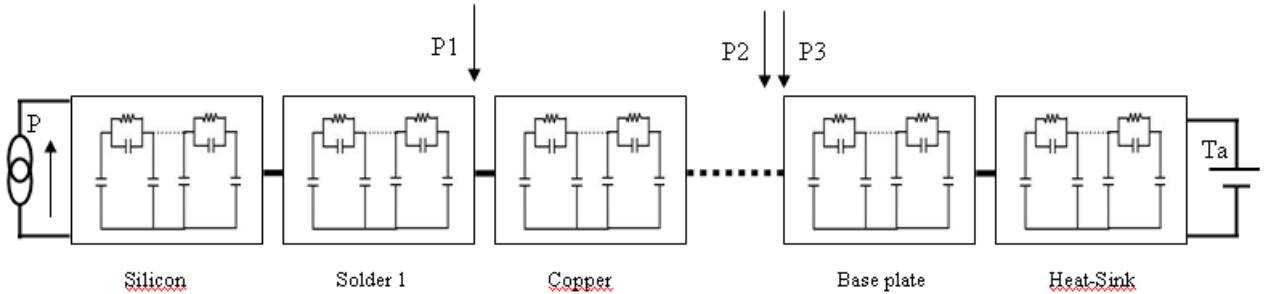


Fig. 4. Thermal model of IGBT module

III. ELECTRICAL MODEL OF IGBT MODULE

The electric model used for IGBT and diode is the model implemented in the SimPowerSystems library of MATLAB (V7.0). To ameliorate the electric behavior of this model some modification are introduced [4-7].

From experimental results in previous work we deduce than the static electrical characteristics of IGBT and diode are dependent on the temperature [8]. We can express the voltage drop at the boundaries of the IGBT in the linear zone by:

$$V_{ce} = V_0 + R_0 I_c \quad (1)$$

Where:

$$V_0 = 0,53 - 3,17 \cdot 10^{-3} T_{j(IGBT)} \quad (2)$$

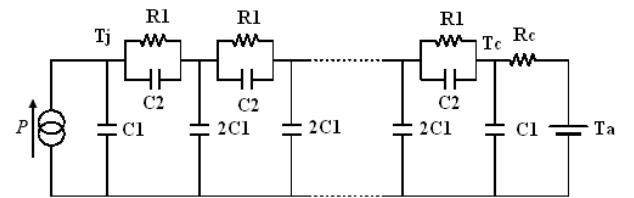


Fig. 3. Thermal circuit obtained by the FEM

Where:

- P is the input power dissipation device.
- Tj is the junction temperature.
- R1 is the thermal resistance.
- Rc is the convection resistance.
- C1 and C2 are thermal capacitances.
- Ta is the ambient temperature.

In order to introduce the thermal interaction between the different components of the module, we inserted three other current sources P1, P2 and P3. These sources are deduced from the structure of IGBT module.

The source P1 is the power loss of DIODE1; it is introduced at the interface between the silicon and the copper materials because the IGBT1 and the DIODE1 ships are bounded on the same copper area. The source P2 and P3 are power loss of IGBT2 and DIODE2, they are introduced between solder 2 and base plate because all module components have the same base plate. So the thermal circuit network of IGBT1 becomes as the figure 4.

$$R_0 = 9,28 \cdot 10^{-2} - 2,9 \cdot 10^{-4} T_{j(IGBT)} \quad (3)$$

We can express the voltage drop at the boundaries of the DIODE in the linear zone by:

$$V_d = V_1 + R_1 I_d \quad (4)$$

Where:

$$V_1 = 0,92 - 4,2 \cdot 10^{-3} T_{j(diode)} \quad (5)$$

$$R_1 = 2,1 \cdot 10^{-2} - 1,11 \cdot 10^{-5} T_{j(diode)} \quad (6)$$

Thus, the new electric IGBT and diode model become very dependent on the junction temperature, figure 5 and 6 show the eletro-thermal model of the IGBT and diode implemented in the MATLAB simulator.

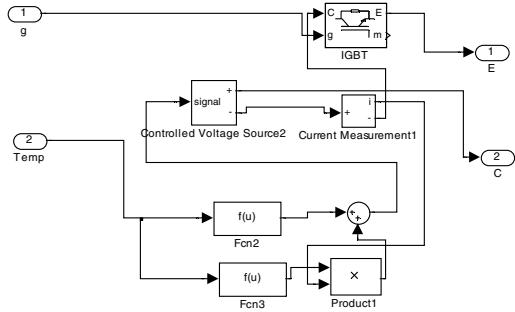


Fig. 5. Electro-thermal model of IGBT implemented in MATLAB

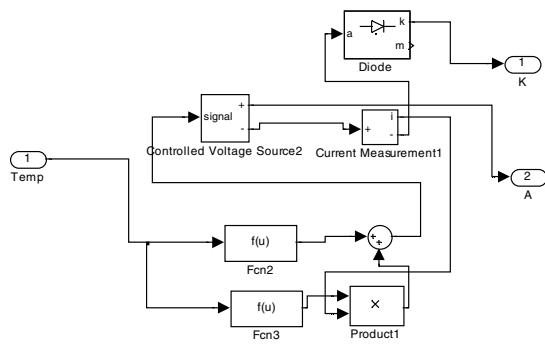


Fig. 6. Electro-thermal model of diode implemented in MATLAB

IV. ELECTRO-THERMAL COUPLING SIMULATION

Fig. 7 shows a diagram of an electro-thermal simulation technique of power IGBT modules. In figure 7, an electrical model is coupling with a thermal model. The instantaneous value of the device power loss is injected to the thermal model, in which the thermal characteristics of the module are defined. Then, the instantaneous device temperature is generated by the thermal model, and the temperature dependent device model parameters are determined via this instantaneous device temperature. These calculations are performed simultaneously using a circuit simulator. So, the device and the thermal models are essential components of the electro-thermal simulation.

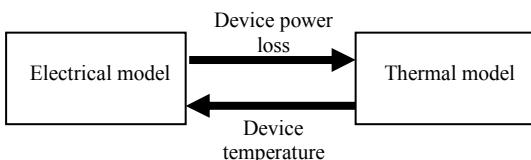


Fig. 7. Diagram of the electro-thermal coupling simulation

V. ELECTRO-THERMAL COUPLING SIMULATION

The inverter simulation was implemented in the MATLAB simulator [9] using the electro-thermal models of IGBTs and diodes. A PWM was implemented in the MATLAB simulink to command the IGBTs. The inverter is coupled with a three phase motor[10]. In our study we set the battery voltage at 120 V, the modulation index at 0.8, a modulation frequency at

100Hz and a switching frequency at 8 kHz. For the IGBT thermal module the ambient temperature is fixed at 33°C.

Figure 8 shows the circuit implemented and simulated in the MATLAB simulator.

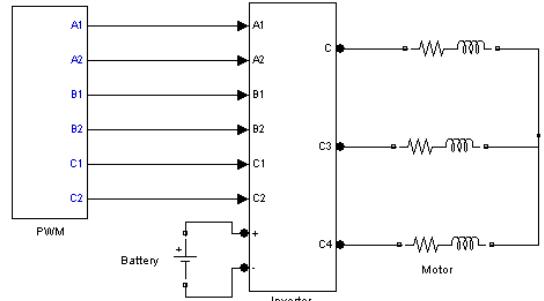


Fig. 8. Circuit used in simulation

From this simulation, the load current for each phase, the power dissipation and the junction temperature for inverter devices can be deduced. Figure 9 shows the simulated three-phase inverter current waveform. The maximum output current reach 42 A.

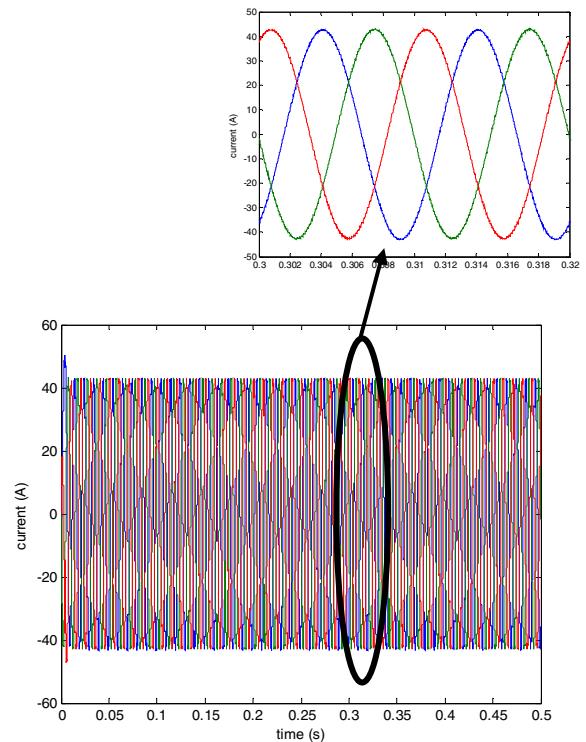


Fig. 9. Simulated three-phase inverter current waveform for each phase

In the electro-thermal simulation tow different thermal models have been used: with and without thermal influence. Figure 10 and 11 show the IGBT and diode junction temperature with and without thermal influence. It is clear that the thermal interaction between module components have a huge influence on the junction temperature.

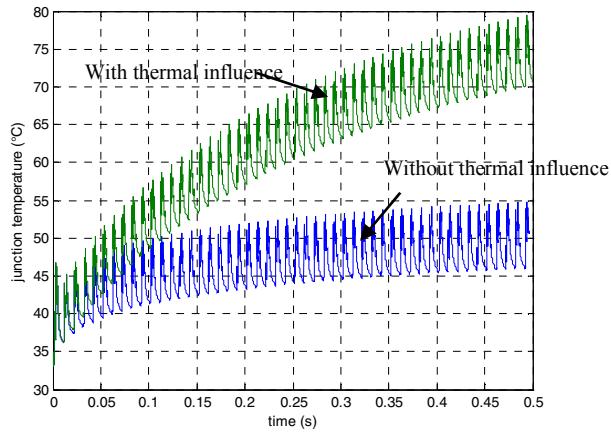


Fig. 10. IGBT1 junction temperature

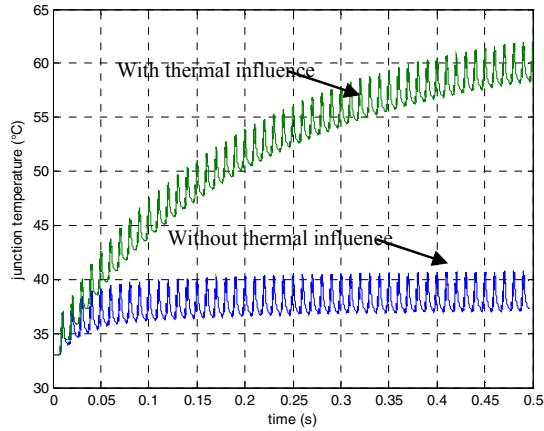


Fig. 11. DIODE1 junction temperature

The power loss of IGBT1 is shown in figure 12. Figure 13 shows the instantaneous power dissipation for two IGBT thermal models. A zoom in the last figure shows that the thermal interaction has effect on conduction loss. The conduction loss of IGBT1 decrease with thermal influence about 9 Watt.

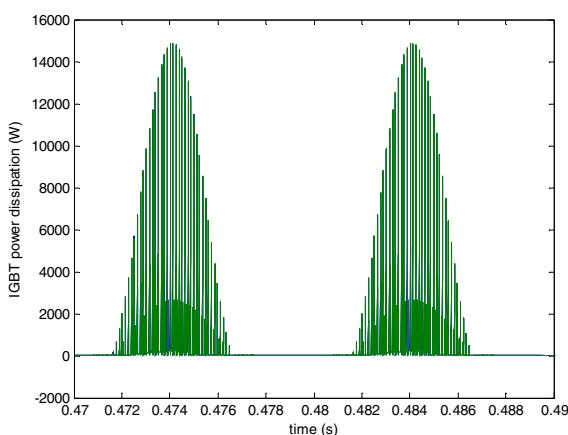


Fig. 12. IGBT1 power loss

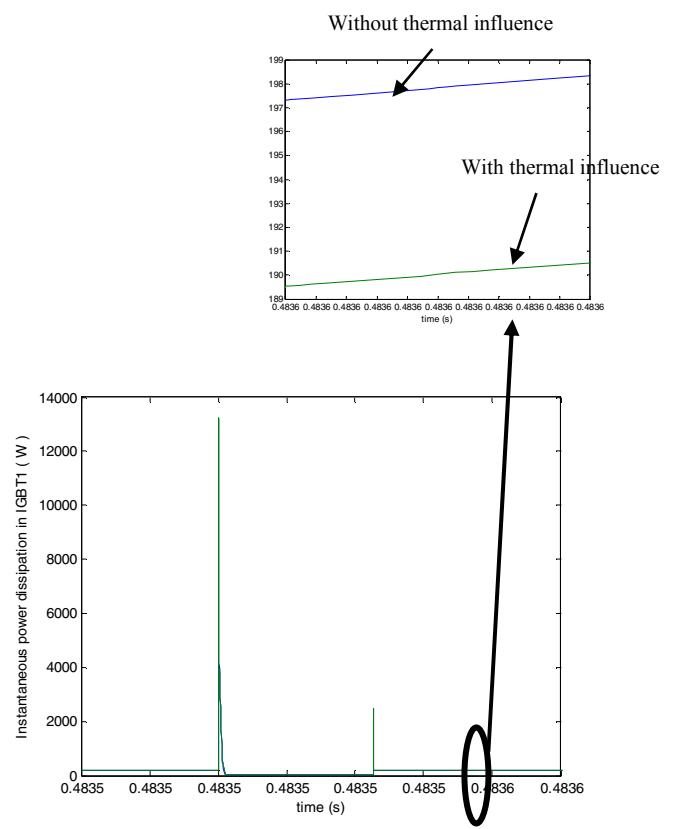


Fig. 13. Instantaneous power dissipation in IGBT1

VI. CONCLUSION

We propose a simplified calculation method for dynamic electro-thermal behavior of IGBTs in PWM inverters. Thermal influences between different components have been studied. This thermal interaction depends mainly on the components dissipated power and the boundary condition at the heat spreader. An experimental study is necessary to compare with simulation result.

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