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Novel Thermal Analysis Platform for IPEM

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Abstract—A power losses estimation method integrating powerful analysis software Pspice and Origin capable of calculating losses on the key power components in integrated power electronics modules (IPEMs) was presented. The operational flow and the analysis principle of the losses estimation method were discussed. The three dimension thermal analysis model of ANSYS for a typical IPEM was built. The average power losses calculated with the method was inputted to ANSYS as the heat generation. The thermal simulation was done with the equivalent convective heat transfer coefficient of heat sink and printed circuit board(PCB) as boundary conditions. The simulation results are reasonable and the analysis platform with software Pspice, Oringin and ANSYS facilitates the thermal design of IPEM.

Keywords-Power losses estimation; thermal analysis; IPEM; Pspice; Origin; ANSYS

1. Introduction

The technology of power electronics has been developing by leaps and bounds to become the key technology essential to modern society and human life as well as to electrical engineering in the recent years due to many innovations in power semiconductor devices, electric power and control techniques[1]. As the technology is advancing, higher power density, better efficiency, better flexibility and higher reliability are desired for many applications. The state-of-the-art power electronics systems are mostly custom-designed with individual power devices and require a labor-intensive manufacturing process. The resulting products are usually characterized by problems in quality and reliability, long design cycles, and high costs. So the new design concept of power electronics devices is imperative. It is believed that the next level of improvement can be achieved only through a systems-level approach by developing integrated power electronics modules (IPEMs) or Power electronics building blocks (PEBBs), that enable greater integration and standardization within power electronics systems and their end-use applications[2, 3].

With the high power density, thermal management is a central packaging issue for the integrated power electronics module (IPEM) and becoming increasingly important[4]. An accurate estimate of the loss and the thermal simulation technology are required to aid in the design of these modules , ensure proper thermal management, and keep the operating temperature of the IPEMs within desirable limits.

Some approximation methods for estimating power electronics losses have been presented in the open literature [5],[6]. However, power losses estimation models with higher accuracy and lower complexity are rare, since higher accuracy models [5] usually turn out to be complicated ,witch results in an unacceptably large CPU time and memory storage. For simplified models , the approximation results may be obtained in a short time with less investment. But the results may not satisfy the requirements for some high precision evaluations. Conducting experiments is a good way to get accurate results. However, big investment in time, effort, and money is required to build the hardware platforms[6].

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In this paper, a power losses estimation and thermal analysis platform for three phase IPEM is built by integrating powerful analysis software including OrCAD Pspice, Origin and ANSYS. The platform can precisely quantify the losses including conduction losses and switching losses of semiconductor devices. And the thermal behavior of the three phase IPEM can be forecasted accurately. The integrated thermal analysis platform facilitates the thermal design of IPEM.

2. Proposed analysis platform

The platform operation consists of three parts: the Pspice simulation and the data extraction, the Origin analysis and thermal analysis with ANSYS. For a given topology, simulation is done in OrCAD Pspice , and all current and voltage data on all components are stored in probe data file. In the waveform window of Pspice , the power waveform can be obtained through calculation of the current and voltage data. Then the important data in a format that can be read by Origin is extracted. In Origin, power losses for all the key power components are calculated using the imported simulation waveform data. The obtained average power results are exported to ANSYS in thermal simulation. Simulation graphics are generated, which provides a clear picture for the power dissipation and thermal behavior in the module. The analysis platform is shown as Figure 1.

3. Models and analysis

3.1. Power losses estimation

A simulation model for power losses estimation of three phase IPEM has been built in OrCAD Pspice. To reduce the simulation time, the three phase model is simplified with only one IGBT(600V, 15A). The simple model is shown in Figure2.The voltage of 310V is the BUS voltage. Q1 is the power device IGBT. The series circuit with L and R2 is modeled as load. Figure 3 shows the instant power. The power loss of IGBT devices can be divided into conduction losses and switching losses (turn-on and turn-off loss). The power losses for the switches are calculated using the trapezoid rule[6]. The instant power is calculated as:

$$P(t) = i(t) \times u(t) \tag{1}$$

i(t) and u(t) are the instant current and voltage value for the IGBT. They are obtained from the Pspice simulation. Using trapezoid rule, the power dissipated from t1 to t2 is:

$$W(t) = \frac{[P(t_1) + P(t_2)] \times (t_2 - t_1)}{2} \tag{2}$$

The average power in one switching period is:

$$P_{ave} = \frac{\sum_{k=0}^{n} W(t_k)}{t_n - t_0} \tag{3}$$

According to these equations, the calculation is done in Origin. $\boldsymbol{P}_{\text{ave}}$ is 5.475 W. The calculated data will be the input of ANSYS analysis.

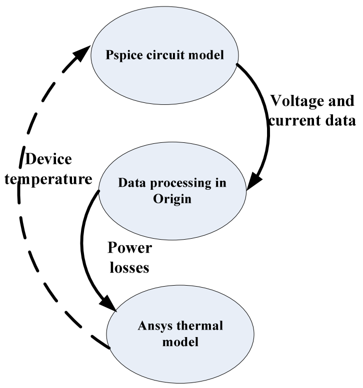

Fig.1. Analysis platform

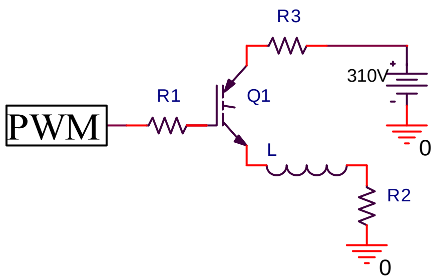

Fig. 2. Simulation model in Pspice

3.2. Thermal analysis in ANSYS

A typical module structure is shown in Figure 3. When the conduction body has internal heat source, the partial differential equation for heat conduction in three dimensions is

$$\lambda\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right)=-Q_{\mathrm{V}} \tag{4}$$

where λ is thermal conductivity, and Q_{V} is heat dissipation per unit volume[7].

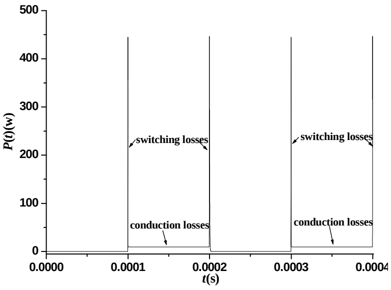

Fig.3. Instant power losses

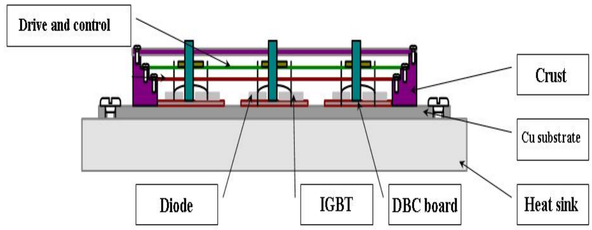

Fig.4. Schematic of typical module structure

According to the conduction equation, finite-element model was built in ANSYS. Table 1 summarizes the input parameters for the model. The schematic of the model is shown in Figure 4. Volumetric heat generation calculated from the output data of Origin was applied to the whole IGBT chip. In thermal analysis, the model was applied an equivalent convective heat transfer coefficient boundary conditions which is equivalent to the heat transfer of a heat sink. And the natural-convection heat transfer boundary conditions was applied to the surface of printed circuit board(PCB). The other surfaces of the model were assumed to be adiabatic. With the equivalent convective heat transfer coefficient of 300 $W\cdot(m\cdot K)^{-1}$and the natural-convection heat transfer coefficient of 10 $W\cdot(m\cdot K)^{-1}$, the simulation results of ANSYS are illustrated in Figure 5. It is shown that the highest temperature of 82.322℃ focuses on the IGBT chip and the heat affects the middle IGBT badly. A detailed analysis reveals that the clearance distance between driving PCB and silica gel will affect the heat distribution of driving PCB.

TABLE 1. INPUT PARAMETERS FOR SIMULATION MODEL

		Thickness (mm)	Dimension (mm)	Thermal conductivity($W\cdot(m\cdot K)^{-1}$)
Epoxy PCB		1	46×26	0.3
Silica gel		2.8	50×30	0.15
IGBT die		0.4	8×8	150
DBC	Cu foil	0.2	10×10	386
	Ceramic	0.4	10×10	28
Cu substrate		3	60×40	386

4. Conclusion

A powerful losses analysis platform for IPEM is presented. The detailed analysis principle are introduced and the power losses for IPEM is calculated. With the help of the power losses estimation platform, the thermal simulation is done in ANSYS. The typical module model is built. The power dissipation and thermal behavior in the module are illustrated. The proposed methods are helpful to the power losses estimation and thermal analysis in IPEM.

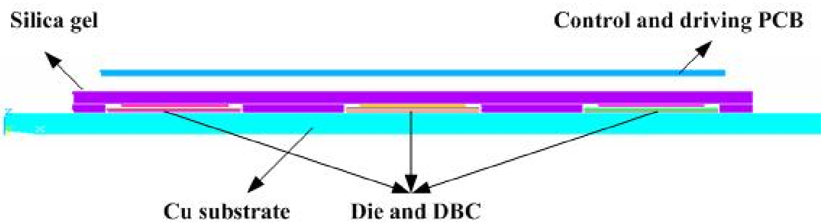

Fig.5. Schematic of the ANSYS model

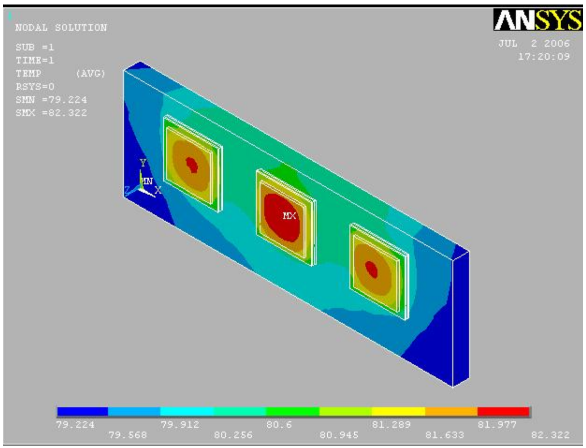

Fig.6. Results of thermal analysis

5. Acknowledgment

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