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Thermal Analysis of Motor Controller for Electric Vehicle

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***Abstract*—It is key facility that motor controller of electric vehicle driving system ensures electric vehicle operating correctly. Its thermal characteristics effects the reliability of system directly. Based on thermal calculating function of PSIM, power losses calculation model and temperature calculation model of three-phase bridge inverter circuit that is main heat source in motor controller are be established. Under rated load, the sinusoidal pulse width modulation (SPWM) is used to produce switching signals and the thermal characterization of controller is assessed. At the same time, the temperature of prototype is tested. The results verified the effectiveness of the models.**

***Index Terms*—Thermal characterization, electric vehicle, controller; inverter circuit**

I. INTRODUCTION

In recent years, with the rapid development of economy, people pay more and more attention to the problem of energy and environment. Electric vehicles have been paying close attention in many fields as one way to eliminate exhaust gas emission and reduce dependence on oil, such as the electric truck used in subway construction and the tunneling construction [1].

The key part of electric vehicle is motor and controller that is used to control starting, stopping, accelerating and decelerating the vehicles. The reliability of controller consisting of DC link capacitors, high power electronics modules and so on directly affects regular work of electric vehicle [2]. In the running process, the main thermal source of controller is power dissipation of the power electronic module, which could result in temperature rising [3]. If the heat from power dissipation doesn't be effectively dissipated, temperature rise on electronic components would exceed allowable values and reduce the absolute performance [4]. So, the thermal design and characteristics of controller affect the reliability of entire system.

Inverter circuit consists of the power electric modules, which generates the amounts of heat at work. In this paper, the thermal calculation model based on PSIM is established. Under the rated operation state, the temperature of controller is calculated, the results of which is compared to the temperature measurement of prototype controller. The experiment results verify the validity of the model.

II. OPERATING PRINCIPLE OF CONTROLLER

The typical structure of electric driving system of electric vehicle is shown in Fig. 1, which is composed of battery back, controller, and motor. The basic function of the controller is to convert the direct current of the battery back into three phase alternating current to run the motor [5]. Major components of the controller include power supply circuit, inverter circuit, and cooling system. In general, the voltage-source circuit is applied to the inverter circuit [6]. The parameters of power electric module include voltage, current, and thermal design, which are calculated according to the power level.

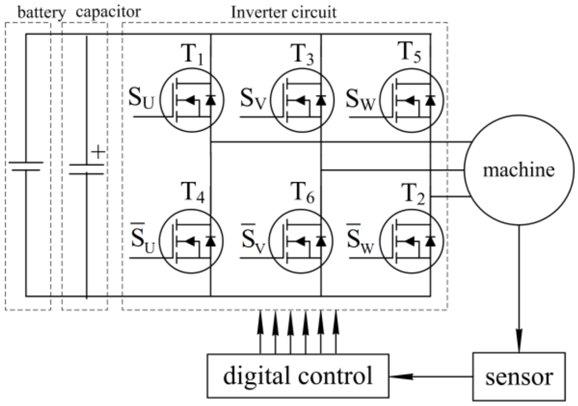

Fig. 1: The frame of electric driving system

III. THERMAL DESIGN OF INVERTER CIRCUIT

A. Lectotype of power electric module

The inverter circuit consists of intelligent power module (IPM), which integrates together IGBT and driving circuit. The power module in the inverter circuit is powered by PM150CVA120 IPM of MITSUBISHI, its built-in driving and protecting function may ensure the reliability of the system and make the control circuit be simple. The protecting functions include over-voltage protection, over-current protection, and overheat detection.

The voltage and current of this type are 1200V and 150A, respectively. The maximum service temperature is 150°C.

B. Loss Model

Power dissertation of IPM includes conduction losses and switching losses. If the switching frequency is high, switch consumption is not ignored [7]-[8]. In the running process, the duty ratio of the IPM is changing, even if it operates in steady state. The losses are related with the duty ratio, which would complicate the calculation of the losses. This paper calculates power losses and temperature based on PSIM.

According to the function of three-phase full bridge inverter circuit, the power losses calculation model is established in PSIM, which is shown in Fig. 2. IPM denotes power module model. The SPWM circuit is applied to generate switching signals to make the IPM turn on and off. P_Q and P_Q are used to measure the transistor losses and the anti-parallel diodes losses, respectively. The total losses of IPM is calculated by Ptotal. Vdc is direct voltage, which is

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144V. RL is load.

The transistor losses and the anti-parallel diodes losses include two parts, the conduction losses and the switching losses. The thermal calculation of the selected type IPM requires inputting absolute maximum ratings, electrical characteristics, and thermal characteristics. Based on the thermal model, power losses of inverter circuit are calculated under the 10kW rating condition.

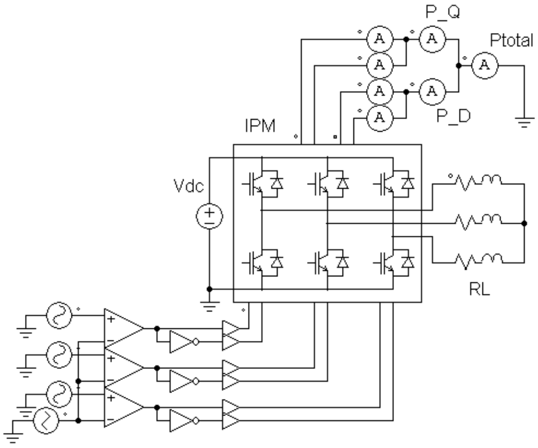

Fig. 2: power losses calculation model

The conduction losses and switching losses of the anti-parallel diodes is 3.1W and 52.1W, respectively. The total anti-parallel diodes losses is 55.2W. The conduction losses and switching losses of the transistor is 34.0W and 217.1W, respectively. The total transistor losses is 251.1W. So, the power dissipation of the IPM is 306.3W.

IV. THERMAL DESIGN

The thermal calculation results show that electronic packaging shell does not have the capabilities to dissipate heat on its own, which requires the cooling system. In general, the cooling system is composed of receipting heat generated by the source, conducting heat, and radiating heat away into space. The IPM is installed on the heat sink, the heat of which is dissipated by means of heat conduction. In the heat transfer process, thermal resistance exists [9], which can describes as [10]:

$$R_s = \frac{\text{temperature difference}}{\text{total losses}}$$

If the temperature difference between surface temperature of the heat sink and ambient temperature is set as 25°C, the thermal resistance of contact part of the IPM and the heat sink is as follows:

$$R_{sipm} = \frac{25}{306.3} \approx 0.08\,°\text{C/W}$$

Based on the thermal resistances of the heat sink and the IPM, the temperature calculation model of the heat sink is designed, which is shown in Fig. 3. 0.16°C/W and 0.26°C/W are the transistor to case thermal resistance and diode to case thermal resistance, respectively. 0.018°C/W is contact thermal resistance of the IPM and the heat sink.

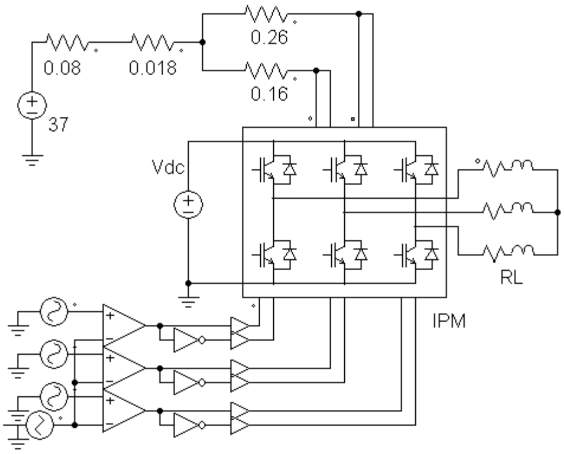

Fig. 3: The temperature calculation model of the heat sink

V. RESULTS AND DISCUSSION

To be comparisons with the results of test, ambient temperature is set to 37°C in using the temperature calculation model. In PSIM, the temperature of heat sink is calculated by using the model. The temperature of heat sink is 64.1°C. The junction temperature of IPM is 118°C, which is within safety permission.

Fig. 4 shows the result of temperature testing of prototype controller. The asterisk in the diagram denotes the measured temperature value of heat sink. The temperature at the starting test is 36.9°C，which equals the ambient temperature. After the test lasts for 145 minutes, the temperature trends to stable. The temperature value is 63.9°C.

Comparison results show that power losses calculation model and the temperature calculation model are reasonable, which can help to optimize the controller design and reduce development time.

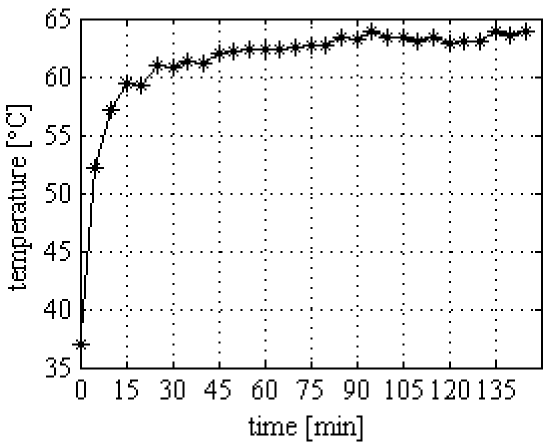

Fig. 4: The temperature test curve of the controller

VI. CONCLUSIONS

For the motor controller, power electric module is the main heat source. In order to design the cooling system, it is need to calculate the power losses of power electric module and thermal resistance of cooling system.

Based on PSIM, the power losses and the temperature calculation models are modeled. The results of calculation and experiment show that the models are reasonable and this method is feasible.

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