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Study on Water Cooling Performance of IGBT Module in Wind Power Converter

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Abstract. Thermal design of IGBT is the key technology on wind power converter design. This paper introduced a theoretical calculation method of IGBT power loss which is applicable in wind power converter engineering applications. Meantime, the corresponding mathematic model was established. Considering the divergence of application environments as well as the characteristics of water-cooling heat dissipation, simulation models of two different inlet and outlet position radiators were built in Ansys software. And then the cooling capacity of these two types of radiators was analyzed though simulation. According to the simulation results, the ipsilateral inlet and outlet channel mode radiator was selected. After the sample production of the water cooling plate is completed, the experimental platform is built and the sample was verified. Finally, the experiment results indicated the rationality and practicability of the thermal design and simulation, which provided critical references of IGBT water cooling system design. In this paper, the performance of water cooling radiators is studied, which also provides a reference for the design of other high power electronic products.

Keywords. IGBT module, wind power converter, water cooling radiators

Nomenclature

Item	Description	Item	Description
MW	Million watt	IGBT	Insulated gate bipolar transistor
P	Power	I	Electric current
M	Modulation degree	φ	Phase angle
V	Voltage	r	Resistance
K	Coefficient	f	Frequency
E	Switching loss	Q	Volumetric flow rate (cfm)
T	Temperature (°C)	ΔT	Volumetric flow rate (cfm)
R	Thermal resistance (°C/W)		

Subscripts

Item	description	Item	Description
cond_Tr	Power of IGBT	cond_D	Power of diode
out	Virtual value	j	Junction
ce25°C	25°C rated on-off of IGBT	F_25°C	25°C rated on-off of diode
V_Tr	Temperature effect of v-drop of IGBT	V_D	Temperature effect of v-drop of diode
r_Tr	Temperature effect of resistance of IGBT	r_D	Temperature effect of resistance of diode
r_Tr sw	Pulse switching of IGBT	rr	Pulse switching of diode
cc	Bridge arm	rated	Referential
swTr_I	Current effect on IGBT switching losses	swTr_V	Voltage effect on IGBT switching losses

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swD_I	Current effect on diode switching losses	swD_V	Voltage effect on diode switching losses
a	Ambient	jc	Junction to case
ch	Case to heat-sink	ha	heat-sink to room ambient
max	Maximum		

1. Introduction

IGBT module is the core power device of wind power converter. The compact structure and high power density of MW stage converters, especially the power cabinets installed with IGBT power modules, often lead to unforeseen device overheating risk and reliability problems, and even affect the of product development progress [1].

IGBT module will produce high switching loss and on-state loss in the process of opening and closing, and the loss will be converted and accumulated in the form of heat. With the development of IGBT in the direction of high pressure, large capacity, miniaturization and integration, the calorific value per unit volume of IGBT increases gradually, and IGBT overheating has become the primary cause of its failure [2]. As the power level of wind power converter continues to improve, more than 3MW of full power converter has become the mainstream product of the market. Meanwhile, the water cooling heat dissipation IGBT module gradually replaces the air cooling heat dissipation IGBT module and becomes the main heat dissipation mode of the high power IGBT module.

This paper introduces a practical loss calculation method, the principle and model of water cooling heat dissipation, and replaces the water cooling plate with different flow channel form into the Ansys software. The thermal simulation models of ipsilateral inlet and outlet water radiator and heteroshed inlet and outlet water radiator are established. Finally, the heat dissipation performance of water-cooled radiator of converter product is tested experimentally, which verifies the correctness of simulation model and the rationality of heat dissipation system design.

2. Loss Calculation Method

Power loss in wind power converter design mainly includes IGBT and reverse parallel Diode, including on-state loss and switch loss. General loss refers to the loss caused by IGBT during conduction. The three-phase inverter circuit adopts SVPWM modulation mode to output the IGBT of sinusoidal current and the on-state loss of inverse parallel Diode [3-4].

On-state loss and switch loss (P_{cond_Tr}, $P_{cond\text{-}D}$) are described by (1) and (2):

$$\begin{aligned} P_{cond\_Tr} &= I_{out} \cdot \sqrt{2} \cdot \left(\frac{1}{2\pi} + \frac{M \cdot \cos\varphi}{8}\right) \\ &\cdot [V_{ce25^0 C} + K_{v_{Tr}} \cdot (T_j - 25^0 C)] + I_{out}^2 \cdot 2 \\ &\cdot \left(\frac{1}{8} + \frac{M \cdot \cos\varphi}{3\pi}\right) \\ &\cdot [r_{ce\_25^0 C} + K_{r\_Tr} \cdot (T_j - 25^0 C)] \end{aligned} \tag{1}$$

$$P_{cond\_D} = I_{out} \cdot \sqrt{2} \cdot (\frac{1}{2\pi} + \frac{M \cdot \cos\varphi}{8}) \cdot [V_{F\_25^0 C} + K_{v\_D} \cdot (T_j - 25^0 C)] + I_{out}^2 \cdot 2 \cdot (\frac{1}{8} + \frac{M \cdot \cos\varphi}{3\pi}) \cdot [r_{F\_25^0 C} + K_{r\_D} \cdot (T_j - 25^0 C)] \quad (2)$$

The switch loss includes two parts: turn on loss and turn off loss. The switch loss of IGBT and reverse parallel Diode can be defined by (3) and (4):

$$P_{sw\_Tr} = f_{sw} \cdot E_{sw} \cdot \frac{\sqrt{2}}{\pi} \cdot (\frac{I_{out}}{I_{rated}})^{K_{swTr\_I}} \cdot (\frac{V_{CC}}{V_{rated}})^{K_{swTr\_V}} \cdot [1 + K_{sw\_Tr}(125^0 C - T_j)] \quad (3)$$

$$P_{sw\_D} = f_{sw} \cdot E_{rr} \cdot \frac{\sqrt{2}}{\pi} \cdot (\frac{I_{out}}{I_{rated}})^{K_{swD\_I}} \cdot (\frac{V_{CC}}{V_{rated}})^{K_{swD\_V}} \cdot [1 + K_{sw\_D}(125^0 C - T_j)] \quad (4)$$

Wind power converter motor side, network side has three-phase IGBT power module each, which use water-cooled plate heat dissipation. Each radiator has two IGBT parallel forms.

3. Principle of Water Cooling System

To estimate the flow rate of the IGBT module and the junction temperature of the chip, it is necessary to establish the equivalent thermal resistance model of the IGBT water cooling plate, as shown in figure 1 [5].

Considering the worst operating environment of the converter, as well as the data obtained from the IGBT datasheet, the structure of the water-cooled radiator and so on, the various factors needed for the thermal calculation are determined by (5) and (6) [6-7]:

$$T_{\mathrm{j}} = (T_a)_{\max} + (R_{jc} + R_{ch} + R_{ha}) \times P_{\max} \quad (5)$$

$$R = \Delta T / P \quad (6)$$

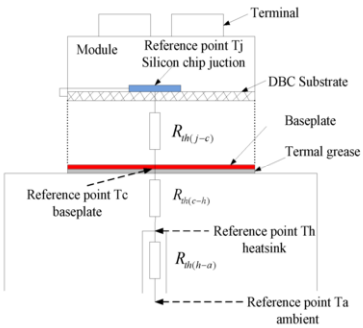

Figure 1. Equivalent thermal resistance network.

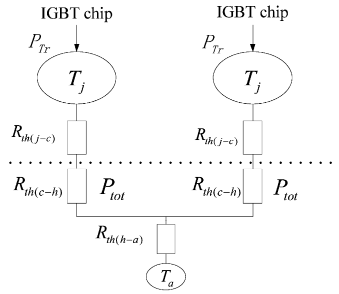

Figure 2. Thermal resistance network of two parallel modules.

For a two-parallel IGBT module radiator, the equivalent thermal resistance is shown in figure 2 [8].

The maximum working environment temperature of wind power converter is 45°C. The maximum junction temperature is 150°C in the specification of this type of IGBT module. According to the characteristics of temperature reduction of converter products, 105°C is adopted as the maximum junction temperature standard of the chip. The specification can be found R_{jc} to be 0.00295°C/ w, and R_{ch} to be 0.003°C/w.

The total loss of single module is 3362 watts, and the total loss of two modules is 6724 watts. The maximum temperature of the contact surface between the water cooling radiator and the IGBT module can be calculated to be 85°C, which can be used as the basis for the shape size of the water cooling radiator and the design of the internal flow channel.

According to the installation space of the IGBT module in the wind power converter and the design of the converter waterway system, the following parameters are determined, as shown in table 1.

Table 1. Radiator parameters.

Item	Data	Unit
Module loss	6724	W
Max-temperature	85	°C
Inlet water temperature	50	°C
Rate of flow	15	L/min
length*width*height	300*300*30	mm

4. Simulation and Experimental Research

According to the characteristics of the internal flow channel of the water-cooled radiator, two IGBT modules are at the mercy of the radiator to determine the two flow channel modes, which are solution 1, ipsilateral inlet and outlet water, solution 2, heteroskedastic inlet and outlet water structure, as shown in figures 3 and 4.

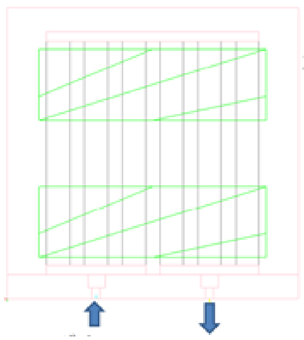

Figure 3. In and out of the same side.

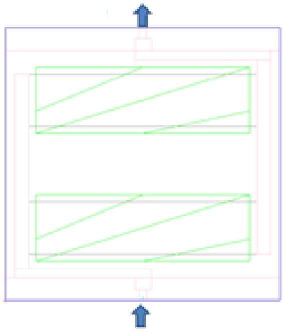

Figure 4. In and out of the different side.

4.1 Simulation Research

According to the design parameters of heat dissipation, the internal runner and fin design of two kinds of water-cooled radiators are carried out using the heat simulation software Ansys [9].

The temperature rise of the right downstream IGBT part is larger than that of the left upstream IGBT in scheme 1, so the right downstream IGBT part is calculated as the object, as shown in figure 5.

In scheme 2, the water flow rate of the IGBT below is small and the temperature rise is large, so the temperature rise calculation takes the IGBT below as the object, as shown in figure 6.

The temperature distribution cloud maps of scheme 1 and scheme 2, are shown by figures 7 and 8.

It can be seen from the simulation temperature distribution cloud diagram that the surface temperature distribution of the water-cooled radiator is more uniform and the maximum temperature is lower than that of the scheme 2. Therefore, option 1, ipsilateral inlet and outlet channel mode, further sample production and manufacture, experimental verification.

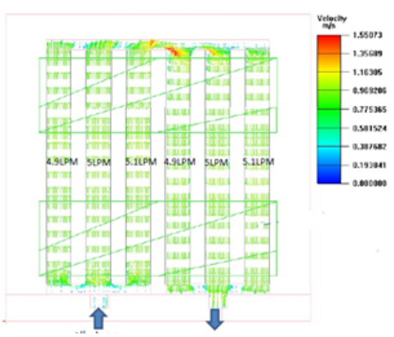

Figure 5. Flow distribution map.

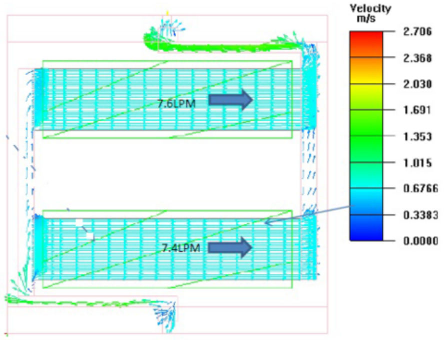

Figure 6. Flow distribution map.

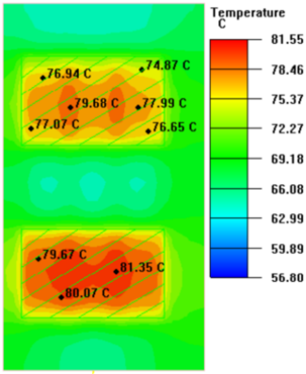

Figure 7. Temperature distribution.

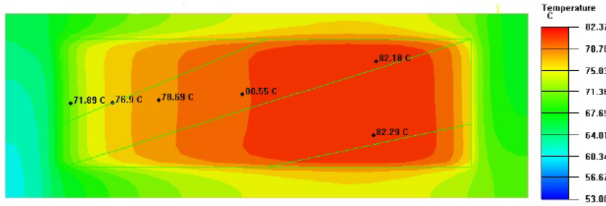

Figure 8. Temperature distribution.

4.2. Experimental Research

After the sample production of the same side inlet and outlet water cooling plate is completed, the experimental platform is built and the sample is verified. The block diagram of the experimental system is shown in figure 9.

The water-cooled plate sample is shown in figure 10.

The water-cooled plate is connected to the waterway system, the temperature measuring point is embedded on the surface of the water-cooled plate, the isothermal plate is installed, and the experimental circuit is connected, as shown in figure 11.

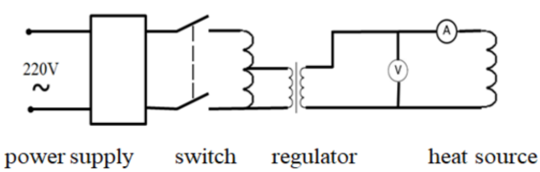

Figure 9. Diagram of the test system.

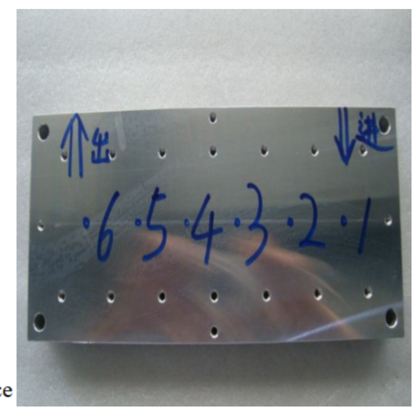

Figure 10. Prototype.

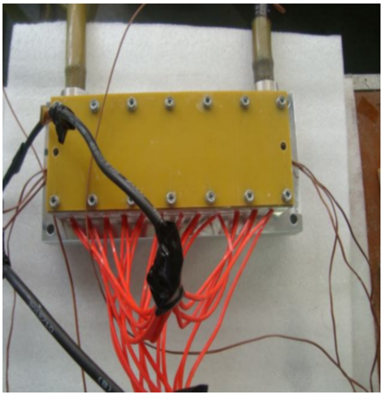

Figure 11. Diagram of the test connect.

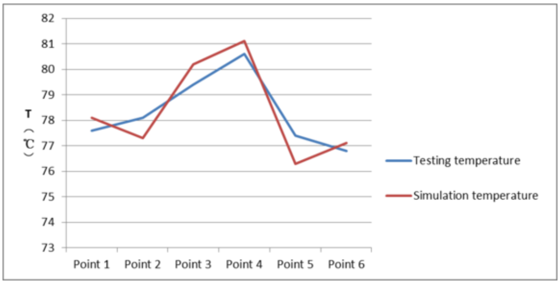

Figure 12. Experimental and simulation result.

Then turn on water cooling system, adjust flow rate to 15 L/min, and adjust the voltage input of the voltage regulator control circuit, measure the current and voltage in the circuit by current meter and voltmeter, and get the required power. The test data and simulation data are shown in table 2 and figure 12.

Table 2. Experimental and simulation result.

Point	Testing temperature (°C)	Simulation temperature (°C)	Error (°C)
Point 1	77.6	78.1	-0.5
Point 2	78.1	77.3	0.8
Point 3	79.4	80.2	-0.8
Point 4	80.6	81.1	0.5
Point 5	77.4	76.3	1.1
Point 6	76.8	77.1	-0.3

The experimental data are in good agreement with the simulation results. The Ansys software can accurately simulate the IGBT water-cooled radiator, and the heat dissipation performance of the water-cooled radiator reaches the design goal.

5. Conclusion

This paper provides a practical design method for IGBT module water-cooled radiator for wind power converter. The loss calculation method of IGBT module and the principle of water cooling and heat dissipation system are introduced respectively. By using Ansys simulation software, the difference of heat dissipation performance between the two water-cooled radiators is compared and analyzed. Besides, this paper compares the simulation analysis with the experimental test data, verifies the effectiveness of the design method, and provides an important reference for the design of wind power converter IGBT water-cooled radiator.

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