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Simulation Analysis of Temperature Field and Flow Field of High Power Inverter

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Abstract. For high power inverter, the internal temperature distribution directly affects its performance. In this paper, based on the finite volume method in Ansys Icepak, the temperature field and the flow field of a high power inverter are simulated and analyzed. According to calculating the power loss and heat dissipation of elements in the inverter, the temperature field and the flow field inside the cabinet under steady state operation are obtained. From the results of the simulation, the working temperature of component in inverter can be obtained and the performance of the cooling system of the inverter can be evaluated.

1. Introduction

Inverter is a very important power equipment which converts DC into AC. In many inverters, the most core part is power electronic devices such as IGBT and diode. For IGBTs and diodes in inverter, the problem of heating cannot be ignored. Studies show that the temperature of devices increase by 10℃, the loss doubled [3]. Therefore, it is abundantly significant to study the temperature field and flow field inside the inverter.

At present, computer-based tools are widely used to study various laws of fluid motion by applying various discrete numerical analysis methods, which belongs to the Computational Fluid Dynamics (CFD) [4]. Compared with direct tests, CFD simulation can greatly reduce the cost of research and it is not limited by the test environment. Furthermore, it can modify the simulation conditions as required at any time to obtain the required simulation results which is highly operable. Ansys Icepak is a software for analyzing electronic heat dissipation and has been widely used in various industries of electronic products research and development process. In the simulation analysis of temperature field and flow field of complex system, the finite volume method is adopted in most cases. With this method, the simulation result of higher precision can be obtained.

In this paper, the temperature field and flow field of a high power inverter simulated in Ansys Icpak. By giving the internal structure layout and thermal load arrangement of the inverter cabinet, the inverter model is preprocessed by Ansys SpaceClaim (SCDM) software. Then, according to the given operating conditions, the temperature field and flow field of the inverter are simulated in Ansys Icepak software. From the results of the simulation, the distribution of the temperature field and flow field inside the cabinet under steady state operation of the inverter can be obtained. Based on the simulation results, the working temperature of component in the inverter can be gotten and the performance of the cooling system of the inverter is evaluated.

2. Fundamental theory

2.1. Three basic ways of heat transfer

There are three ways of heat transfer inside the high power inverter, including heat conduction, thermal convection and thermal radiation.

Pure heat conduction occurs only in solids and follows the Fourier's law:

$$\phi = -\lambda A \frac{\Delta t}{\Delta x} \tag{1}$$

Where ϕ represents heat flow, λ represents thermal conductivity, A represents area perpendicular to the direction of heat flow, $\Delta t / \Delta x$ represents temperature gradient.

Thermal convection is generally divided into natural convection and forced convection which conforms to Newton's cooling law:

$$\phi = hA(T_w - T_f) \tag{2}$$

where T_w is solid surface temperature, T_f represents cooling fluid temperature, ϕ represents convective heat transfer, h represents convective heat transfer coefficient and A represents solid wall heat exchange area.

Thermal radiation satisfies Stephen Boltzmann's law:

$$\phi = \varepsilon A \sigma (T_a^4 - T_b^4) \tag{3}$$

Where ϕ represents heat flow, ε represents surface emissivity, A represents radiation surface area, σ represents stephen constant, T_a represents emitter surface temperature and T_b represents receiver surface temperature.

2.2. Fluid control equation

Fluid motion must follow three sets of governing equations, including mass conservation equation, momentum equation and energy conservation equation.

The mass conservation equation is the continuity equation:

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0 \tag{4}$$

Where u, v and w are velocity components in x, y and z directions respectively, ρ represents density.

The momentum equation in the x direction can be described as follows:

$$\begin{aligned} &\frac{\partial(\rho u)}{\partial t} + u\frac{\partial(\rho u)}{\partial x} + v\frac{\partial(\rho u)}{\partial y} + w\frac{\partial(\rho u)}{\partial z} \\ &= -\frac{\partial P}{\partial x} + \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right) + \rho f_x \end{aligned} \tag{5}$$

The momentum equation in the y direction can be described as follows:

$$\frac{\partial(\rho v)}{\partial t}+u\frac{\partial(\rho v)}{\partial x}+v\frac{\partial(\rho v)}{\partial y}+w\frac{\partial(\rho v)}{\partial z}=-\frac{\partial P}{\partial y}+\mu(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2})+\rho f_y \tag{6}$$

The momentum equation in the z direction can be described as follows:

$$\frac{\partial(\rho w)}{\partial t}+u\frac{\partial(\rho w)}{\partial x}+v\frac{\partial(\rho w)}{\partial y}+w\frac{\partial(\rho w)}{\partial z}=-\frac{\partial P}{\partial z}+\mu(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2})+\rho f_z \tag{7}$$

Where u, v and w are velocity components in x, y and z directions respectively. μ represents fluid viscosity coefficient, p represents pressure on the fluid micro-body, ρ represents density, f_x, f_y and f_z are acceleration in x, y and z directions respectively.

The law of conservation of energy is the basic law that must be satisfied by a flow system containing heat exchange:

$$\begin{aligned}&\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}\\&=\frac{\lambda}{\rho C_p}(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2})+S_T\end{aligned} \tag{8}$$

Where u, v and w are velocity components in x, y and z directions respectively, T represents fluid temperature, λ represents thermal conductivity of fluid, ρ represents density, C_p represents constant pressure specific heat capacity of fluid, S_T represents viscous dissipation term.

3. Physical model

3.1. Inverter structure

The internal distribution structure of the high power inverter is shown in Fig. 1.

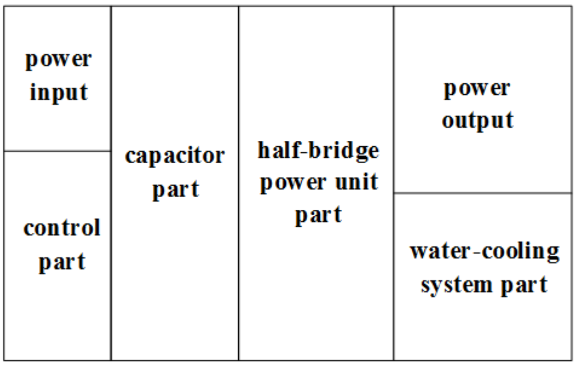


Figure 1. Internal structure of the inverter

The basic structural layout inside the inverter consists of five parts, including power input, control part, capacitor part, and half-bridge power unit part, power output and water-cooling system part.

3.2. Heat source analysis

The main heating parts of the inverter are six power units which consist of diodes and IGBTs. In the case of one operating cycle (T=60s), the total loss energy of the inverter is 989.24kJ and the loss distribution of a single power unit is shown in Fig. 2.

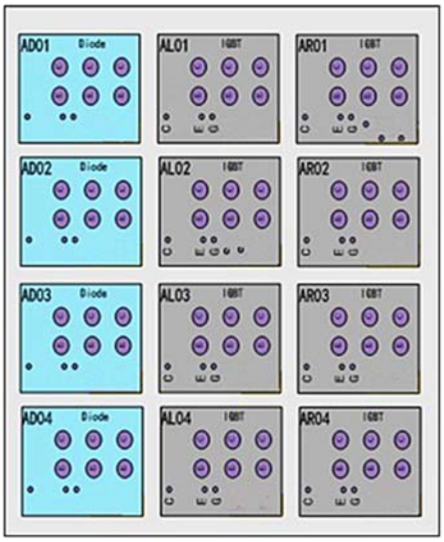


Figure 2. Total loss per power unit in one cycle

In Fig.2, AD01-04 are diodes, AL02-03 and AR02-03 are IGBT2, and the others are IGBT1.

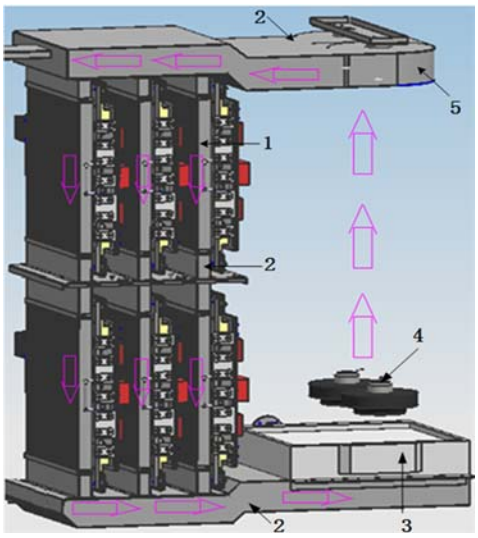
In other parts of the inverter, the heat loss of the device and the resistance are relatively small, so it can be ignored. The thermal parameters of the main power devices in each power unit are listed in table 1.

Table 1. Thermal parameters of main power devices

Name	Single device power (w)	Temperature range
Diode	236.62	-40℃~125℃
IGBT1	210.17	-40℃~125℃
IGBT2	240.2	-40℃~125℃

3.3. Wind path analysis

The complete air duct of the inverter is shown in Fig. 3.



1-radiator; 2-wind tunnel; 3-air-water heat exchanger;
4-axial fan; 5-Centrifugal fan

Figure 3. Complete air duct of the inverter

As shown in fig. 3, the inverter adopts a closed circulating air cooling system with an air-water heat exchanger. There are two centrifugal fans in the power output part, there are two axial fans in water-cooling system part, and there are six radiators in the half-bridge power unit. Each of the two radiators is installed in a separate duct.

3.4. Model pre-processing

Because the original model of the inverter is very complicated, it cannot be calculated in Ansys Icepak directly. So it must be processed to meet the Ansys Icepak requirement. In this paper, SCDM is used to process the inverter model. After processing the model, it can be imported into Ansys Icepak and the model is meshed. The quality of the mesh directly determines the accuracy and convergence of the solution calculation. The model which is built and meshed is shown in Fig. 4.

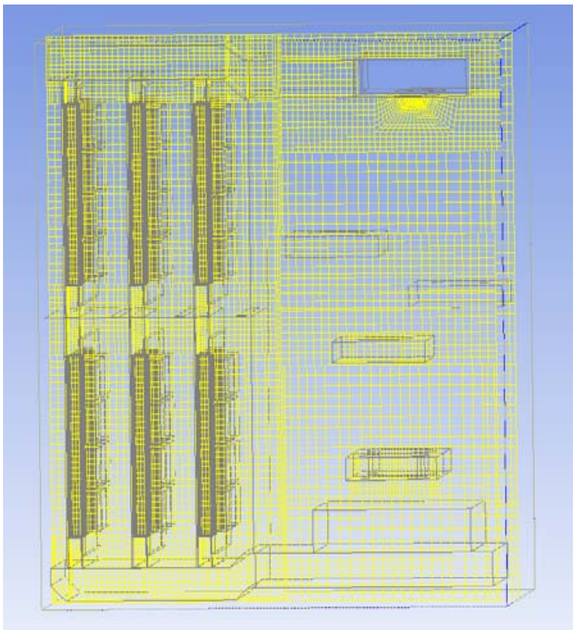


Figure 4. Inverter meshing model

There are many slender and relatively small devices in the inverter model. Therefore, the discontinuous should be used in meshing method. The advantage of this method is to reduce the number of meshes without affecting the aspect ratio of the mesh.

4. Flow field analysis

After processing and meshing the model of the inverter, it can simulate the internal flow field of the inverter in Ansys Icepak. The velocity vector field of Y-axis direction of the inverter is shown in Fig. 5.

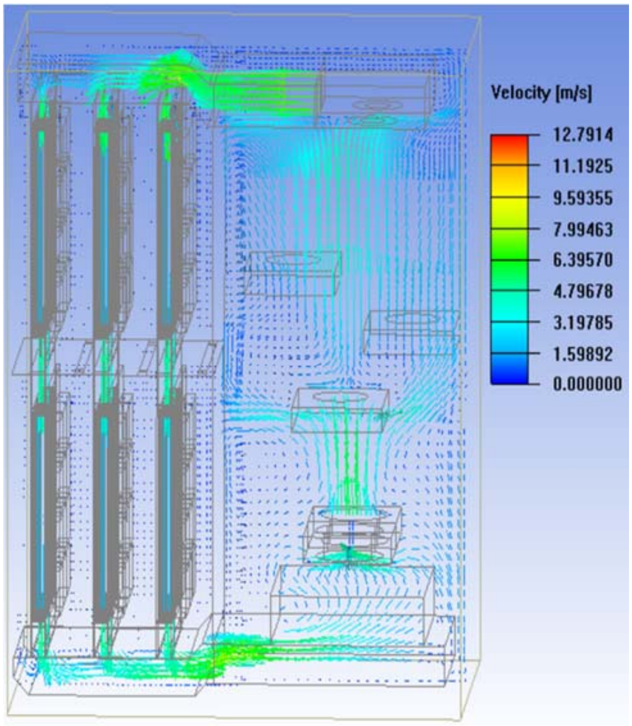


Figure 5. Y-axis direction speed vector

It can be seen from Fig.5 that flow direction of the air is essentially in line with the design route which is shown in Fig. 3. There is a small amount of eddy before the gas flows through the axial fan and the current transformer into the centrifugal fan. The highest flow speed in the inverter is about 12.20m/s. The velocity at the inlet of the radiator is higher than that at the outlet. The velocity at the inlet is about 8.15m/s, and the velocity at the outlet is about 4.87m/s. The flow performance of the fan in the inverter is listed in table 2.

Table 2. Flow performance of the fan in the inverter

name	**Air volume（m^3/s）**	**Pressure drop（N/m^2）**
axial fan 1	0.412174	75.4194
axial fan 2	0.41184	75.5606
Centrifugal fan1	0.20917	497.952
Centrifugal fan2	0.202295	505.618

It can be seen from table 2 that the sum of flow of two centrifugal fans is 0.411 m^3/s, which is 1480 m^3/h. The simulation results are close to the air volume of the air-water heat exchanger which is designed to 1500 m^3/h.

5. Temperature field analysis

The temperature field distribution inside the inverter is shown in Fig.6. The environment temperature during the process of simulation is set to 13℃.

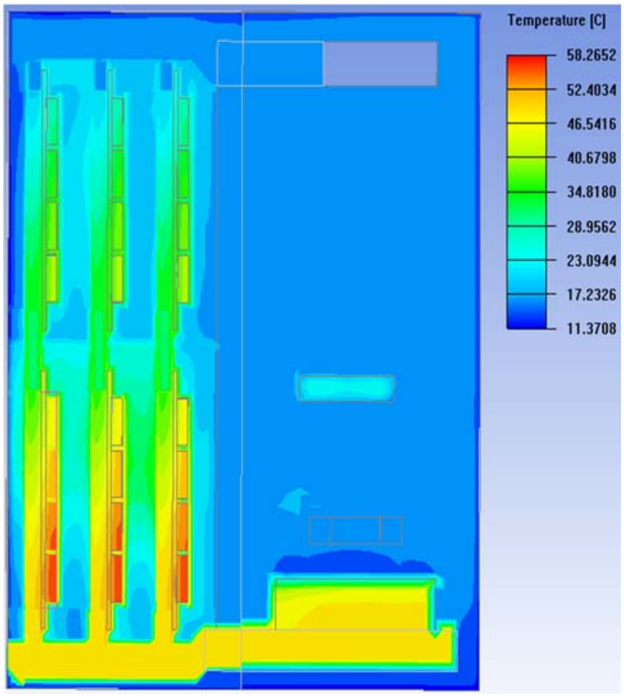


Figure 6. Temperature field distribution of inverter

It can be seen from Fig.6 that the highest internal temperature of the inverter is about 58.26℃ which locates in the lower part of the inverter. And the lowest temperature is about 12℃near the axial fan. Because the air just flows out of the air-water heat exchanger, most of the heat has been taken away by the water flow in the air-water heat exchanger. It also reflects the heat dissipation effect of the air-water heat exchanger. From the result of the temperature filed, the temperatures of all components in the inverter are in the temperature range of the device which are listed in table I and the cooling system of the inverter has good performance.

6. Conclusion

The flow field and temperature field of a high power inverter are simulated in Ansys Icepak software in this paper.

Through the analysis of the flow field distribution inside the inverter, the flow direction of air basically conforms to the design route. In the cabinet, there are no independent air ducts for other devices except the power unit and the relevant air duct of the radiator, so a small number of eddy areas appear. This part of the eddy current area is caused by the flow characteristics of the fan. But it's basically in the area where the non-primary thermal sensitive elements are located. Therefore, it has little influence on the temperature distribution characteristics of the inverter.

The simulation results of temperature field show that the temperature of power elements inside the inverter increases gradually from top to bottom. The highest temperature is about 58.26℃ in the lower part of the inverter. The temperature range of the power element is within the range of the temperature parameters of the device shown in Table I, and there is a high temperature margin.

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