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THE DESIGN OF THE HEAT SINKING IN HV-VFD

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ABSTRACT

In this paper, the design of the heat sinking in the 6kV /2500kW variable frequency drive system is studied. Forced air cooling technology is applied in the drive system. Based on the calculation of power losses, the heat sinks are designed according to the relation between power losses and temperature rise. Then, the scheme of air conduit is presented, which include: front air intake, sealed wind cavity and back air outtake. The heat sink is joined into the close wind cavity separately. The experiment results show that the heat sinking is satisfied.

Keywords: *HV-VFD, heat sinking, forced air cooling*

I. INTRODUCTION

Recently, along with high power electronic devices developing, high voltage to high voltage variable frequency drive is aimed by people [1-2]. [1~3] show that the design and realization of the High Voltage Variable Frequency Drive (HV-VFD) are the emphasis, but the heat sinking is taken lightly. In fact, the performance of the heat sinking decides whether the HV-VFD works in stable and safety.

Generally, the heat sinking of the HV-VFD is designed to aim at power electronic devices. The reason lays on that the power losses are mainly produced from these power electronic devices. At the same time, the power electronic devices are sensitive to the temperature. The change of the temperature will influence the devices turning on and off process. When the temperature rises too high, the devices will break down. So, we will lay our strong emphasis on analyzing and designing the heat sinking for HV-VFD in this paper.

Forced air cooling is a very effective cooling type. In our HV-VFD, this cooling type is adopted. In the following sections, the design and realization are discussed in detailed.

2. DESIGN PRINCIPLE OF HEAT SINKING

2.1. Selection Principle of Heat Sink

Heat sink is a forced convection heat spreader. It is used to protect the power electronic chip from the heat quantity provided by it self. Heat transmission is similar to electrical transmission. The transmission process can be divided steady

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state and transient state. The heat transmission abides the thermal circuit Ohm's law:

$$\Delta T = PR_{th} \quad (1)$$

Where, ΔT is the temperature deviation, K ; P is the power losses, W ; R_{th} is the thermal resistance, K/W.

When hest sinks are used for the power electronic chips, the thermal resistance of the heat transmission system is composed by three parts: thermal resistance of junction to case, R_{thjc}, thermal resistance of case to heat sink, R_{thch}, and thermal resistance of heat sink to ambient, R_{thha}. Because thermal resistance R_{thjc} is decided by the chip manufacturer, we design the heat sink by selecting suitable R_{thch} and R_{thha} to fit demand. Generally, equation (1) is wrote as

$$\Delta T = P(R_{thjc} + R_{thcs} + R_{thsa}) \quad (2)$$

This is the basic equation used in heat sinks design and selection.

In the selection, the following parameters must be given firstly: (1) Effective space volume; (2) maximum operation junction temperature T_{jmax}; (3) R_{thjc}; (4) dissipation power P_{Loss}; (5) ambient temperature T_A; (6) cooling method.

And then, the maximum permission thermal resistance can be calculated as:

$$R_{th} = R_{thjc} + R_{thcs} + R_{thsa} = (T_{j\max} - T_A)/P_{Loss} \quad (3)$$

R_{th} is the primary parameter for selecting heat sinks.

2.2. Design Principle of the Cooling Fan and Flue

The crucial parameters of the cooling fan are wind pressure and air flow. Under the condition of forced air cooling, the thermal resistances of the heat sink are influenced by wind pressure and air flow. So the wind pressure of the cooling fan should be selected based on the wanted thermal resistances of the heat sink. The relationship between the thermal resistance and the wind pressure can consult the curves offered by manufacturers.

There are some experiential equations to select the air flow. Equation (4) is the one of them [4].

$$P = \frac{Q \times 10^{-3}}{\rho c(T_0 - T_A)} \quad (4)$$

Where, Q is the total heat dissipation in the cabinet, W; ρ is air density, kg/m^3; c is the specific heat of the air, kJ/(kg·K); P is the rate of flow, m^3/s; T_0 is the temperature of the air in exhaust port, K; T_A is the ambient temperature, K.

The design principle of the cooling flue includes: (1) the flue should induct the airflow to impact the surface of the heat sink to enhance heat exchange; (2) and windage resistance should be reduced to decrease the head loss of the airflow. Besides, the air outlet should ensure that the hot airflow can successfully be vented.

3. HEAT SINKING DESIGN FOR 6KV/2500KW HIGH VOLTAGE AND HIGH POWER VARIABLE FREQUENCY DRIVE

In the paper, the design of the heat sinking is aimed at the NPC HV-VFD. Fig.1 shows the principle configuration of the HV-VFD. As show in Fig.1, to get a good performance dc source and reduce the harmonics injected into power grid, the rectifier of the drive is a 24-pulse diode converter which is composed by 4 three-phase uncontrolled rectifiers. And the core semiconductor devices are high power and high voltage diodes. The inverter of the drive is a three-level based on neutral-point-clamped converter, of which the core semiconductor devices are high power and high voltage IGCTs (Integrated Gate Commutated Thyristors), T_1~T_4, and fast recovery diodes, D_1~D_2. The output voltage of the drive is 6kV and the capability is 2500kW. Among the design process of heat sinking, the power losses of devices must be calculated or estimated firstly.

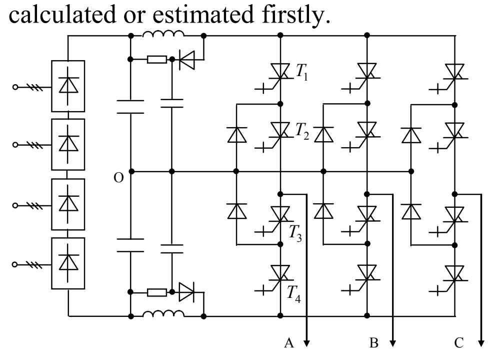


Fig.

Figure1. The circuit of the HV-VFD

3.1. Power Losses of Rectifier Diodes

For three-phase diode rectifier, the power losses of the rectifier diodes can be approximately calculated by equation (5):

$$P_{Diode} = \delta I_m V_F + 0.5 I_m V_{DM} t_{rr} f + (1-\delta) I_{rm} V_R$$

(5)

Where, δ is the duty ratio; I_m is the maximum on-state current, A; V_F is the on-state voltage, V; V_{DM} is the off-state voltage, V; t_{rr} is the reverse recovery time, s; I_{rm} is the off-state current, A; V_R is the reverse voltage, V.

For the equation (5), the fist section denotes the on-state power losses of the rectifier diode; the second section denotes the power losses during reverse recovery process and the last section denotes the off-state power losses. Generally, the on-state power losses are principal.

According to equation (5) and (3), the thermal resistanceof heat sinks used for rectifier diodes can be calculated and the heat sinks can be selected. In this paper, the thermal resistances of rectifier diode heat sinks should be less than 0.2K/W.

3.2. Power Losses of IGCTs

The power losses of the IGCT include on-state power losses, switching power losses and off-state power losses. The off-state power losses can be neglected because they are very little. On-state power losses and switching power losses have relation to the work states of the IGCT. For three-level inverter, switching states of IGCTs are presented as Table 1:

Table 1. Switching States Of One Leg For Three-Level İnverter

Switching symbols		Switching states of IGCTs			
		T1	T2	T3	T4
$V_{AO}>0$	high level	On	On	Off	Off
	0 level	Off	On	On	Off
$V_{AO}<0$	High level	Off	Off	On	On
	0 level	Off	On	On	Off

As can be seen from Table 1: (1) T1 and T4 work in switching state for one half period and in off-state for the other half period; (2) but T2 and T3 work in switching state for one half period and in on-state for the other half period. So, the power dissipations of T2 and T3 would more than those of T1 and T4. That is to say, T2 and T3 have stricter request to the heat sinking.

The on-state power losses of the IGCT can be calculated using equation (6):

$$P_{on-state}(T) = V_{T0} I_{TAV} + r_T I_{rms}^2 \qquad (6)$$

Where, V_{T0} is threshold voltage, V; I_{TAV} is average on-state current, A; r_T is slope resistance, Ω; I_{rms} is RMS on-state current, A.

The switching power losses include turn-on power loss and turn-off power loss. It can be calculated by equation (7):

$$P_{sw}(T) = (E_{on} + E_{off}) \cdot f_{sw} \qquad (7)$$

Where, E_{on} is IGCT turn-on energy per pulse; E_{off} is IGCT turn-off energy per pulse; and f_{sw} is switching frequency. Here, E_{on} and E_{off} can reference the energy curves provided by ABB Semiconductors AG.

So, the total power losses of the IGCT can be calculated using equation (8):

$$P(T) = P_{on-state}(T) + P_{sw}(T) \qquad (8)$$

According to equation (3) and (8), the thermal resistances of heat sinks used for the IGCTs can be calculated and the heat sinks can be selected. In this paper, the thermal resistances of IGCT heat sinks should be less than 0.04K/W.

3.3. Power Losses of Fast Recovery Diodes

Being similar to rectifier diodes, the power losses of fast recovery diodes also include on-state power losses, reverse recovery power losses and off-state power losses. The power losses calculation can reference the rectifier diodes. In this paper, the thermal resistances of the fast recovery diode heat sinks should be less than 0.088K/W.

3.4. Heat Sinks Selection

As analyzed above, IGCTs are stricter with heat sinks than rectifier diodes. Here we only discuss the heat sinks selection of IGCTs. XF97-A showed in Fig.2 is especially developed for IGCTs. It is an air cooling heat sink and has many advantages such as small volume, large effective heat delivery surface and great heat sink efficiency.

Figure 2. XF97-A heat sink

Table 2. Thermal characteristics of XF97-A (pole piece diameter: 78mm)

Pressure drop (Pa)	Air flow (L/s)	One side of the heat sink is utilized R_{thc-a} (k/W)	Both side of the heat sink are utilized R_{thc-a} (k/W)
300	38	0.0300	0.0412
400	45	0.0280	0.0371
500	51	0.0260	0.0347
600	66	0.0252	0.0329
700	60	0.0244	0.0312
800	65	0.0237	0.0300

The thermal characteristics indicated that this type heat sink can satisfy the requirement of IGCT with suitable pressure drop and air flow conditions.

4. SELECTION OF COOLING FAN AND FLUE

To select cooling fan and flue correctly, the total thermal power per cabinet must be calculated. In this process, the power losses buses and snubber circuits must be considered together with the power losses of power electronic devices. And then, air flow of the fan can be calculated by equation (4) and pressure drop of the fan can be decided according to the thermal resistance requirement of heat sinks. The calculation results show that the fan of every cabinet pressure drop should not be less than 700Pa and air flow not be less than 1.1m^3/s. Then the fan can be selected.

To obtain good heat sinking performance, the scheme of front air intake and back air outtake is designed for our HV-VFD. Fig.3 (a) shows the illustrative drawing. And one upper arm power stack is presented in Fig.3 (b). As can be seen, in order to form “parallel” air passage, several IGCTs or fast recovery diodes are clamped using multiple XF97-A heat sinks. This type power stack also provides other benefits: it is readily installed and simplifies the design of the flue.

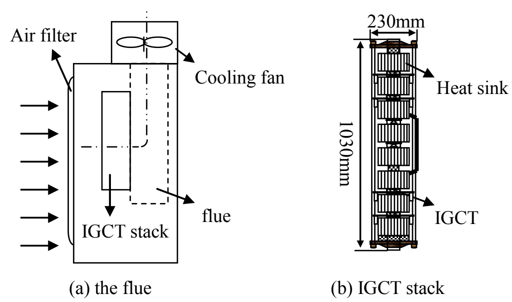


Figure 3. The design of the cooling flue

The IGCT stacks are mounted in the front of the cabinet and a sealed wind cavity is designed in the back of the cabinet. Each heat sink of the IGCT stack is connected to the wind cavity using an induced draft duct. The cooling fan mounted on top of the cabinet forces the air enter the cabinet from the intake and draw through the heat sinks then enter into wind cavity and get out from the outtake.

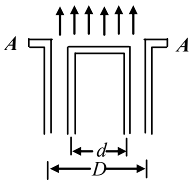
In order to prevent dust and particle from entering into the cabinet, the air intake is provided with an air filter.

5. EXPERIMENTATION RESULTS

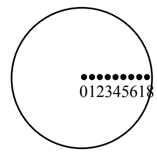
In order to verify the design of the cooling fan and flue, air flow measuring experimentation is carried out according to Fig.3 (a).

Measure section is selected as export of the cooling fan, A-A, which is shown in Fig.4. There are nine measuring points and their positions are: r_0=0 , r_1=25mm , r_2=50mm , r_3=75mm , r_4=11

0mm , r_5=131mm , r_6=152mm , r_7=173mm , r_8 =195mm. Pitot tube is used to measure air velocity.



Fan export



Collocation of measuring points

Figure 4. Air flow measuring experimentation

The results of the measuring experimentation are shown in table 2~3.

Table 2. The results with input voltage 300V

Measuring point	0	1	2	3	4	5	6	7	8
Point position r_i (mm)	0	25	50	75	110	131	152	173	195
Height of liquid column l_i (mm)	12	11	11	13	57	39	21	18	12
Air velocity u_i (m/s)	6.785	6.496	6.496	7.062	14.788	12.232	8.976	8.310	6.785
Airflow	Q =1.135 m^3/s								

Table 3. The results with input voltage 380V

Measuring point	0	1	2	3	4	5	6	7	8
Point position r_i (mm)	0	25	50	75	110	131	152	173	195
Height of liquid column l_i (mm)	15	14	14	15	62	49	46	19	16
Air velocity u_i (m/s)	7.586	7.329	7.329	7.586	15.423	13.711	13.285	8.538	7.835
Airflow	Q =1.296 m^3/s								

The results show that the cooling fan and flue can meet the requirement of the heat sinking.

6. CONCLUSION

Heat sinking design is a crucial problem for developing HV-VFD. In the paper, the heat sinking system for 6kV/2500kW variable frequency drive is studied. In order to obtain good cooling performance, a special IGCT stack and cooling flue are designed. The test results show that the heat sinking is satisfied.

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