Temperature Analysis of Stator Winding of Large Synchronous Generator in Fault

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Abstract. In this paper, a three-dimensional model of large-scale synchronous generator stator winding is established. Based on the basic theory of heat transfer, the finite volume method is used to calculate and analyze the temperature field of the stator winding. The distribution law of the stator winding temperature field under normal conditions is obtained. The influence of the blockage of the stator hollow strand on the stator winding temperature is summarized.

Introduction

The blockage of hollow strands of large water-cooled steam turbine generators is one of the most common failures. According to statistics, in recent years, the failure frequency of stator hollow strands in 300MW and 600MW steam turbine generators is still high, and the blockage of hollow bars will cause the stator bar temperature to be too high and burned. There are many reasons for the blockage of the turbine generator hollow strands. The main reasons are: the control of the PH value of the cooling water is not strict, resulting in chemical reaction between the water and the copper wire, resulting in the precipitation of copper oxide, which will block the hollow strands in severe cases; The inlet pipe strainer ruptures, causing impurities to enter the waterway, which can also cause blockage of the hollow strands. After the hollow strands are blocked, the cooling water stops flowing and the cooling capacity of the hollow strands decreases significantly [1].

At present, domestic and foreign scholars have done a lot of research on this. Among them, American scholar Joseph A. Worden analyzed the cause, diagnosis and maintenance of the stator winding blockage of the water-cooled steam turbine generator, and concluded that the cooling water in the idle strand can cause corrosion of the copper wire, causing the winding blockage and the motor temperature to rise. High [2]. The literature [3] pointed out that due to the existence of the cooling water electric conduction flow, the traditional measuring instrument cannot be used when measuring the temperature, which brings certain difficulty to the temperature rise measurement. The author proposed a test applied to the insulation resistance of the motor. The method reduces the experimental time. However, the law between the blockage of the hollow strands and the temperature field of the stator windings has not been summarized. In this paper, a 300MVar camera is taken as the research object to investigate the temperature variation of the stator windings after the hollow wires of the motor are blocked.

Model Establishment and Boundary Conditions

Temperature Field Three-dimensional Model

In this paper, the temperature field distribution of the stator winding of the motor is studied. According to the given motor parameters, the three-dimensional model of the stator winding is established, as shown in Figure 1.
Boundary Conditions

1) Set the inner circle and outer circle of the stator of the camera to the heat dissipation surface. Given the heat dissipation coefficient and the ambient temperature, the heat dissipation coefficient is obtained by the following formula:

   Internal heat dissipation coefficient:
   \[ \alpha_w = \frac{1 + 0.125v_n}{0.045} \]

   External heat dissipation coefficient:
   \[ \alpha_c = \frac{1 + 0.24v_w}{0.045} \]

   In the above formula, \( v_n \) is the circumferential speed of the rotor, \( v_w \) is usually an empirical value of 5. The calculated inner circle heat dissipation coefficient is 50.27 W/m\(^2\)•K, and the outer circle heat dissipation coefficient is 50 W/m\(^2\)•K.

2) The water inlet temperature is 45°C, the water flow speed is 1.5 m/s, the water outlet temperature is 45.207°C, the air inlet temperature is 45°C, the wind speed is 26.6m/s, and the wind outlet pressure is 5000 Pa.

3) Solve the stator core in the domain model. The stator windings are all heat sources. The heat resistance is given according to the resistance increase coefficient obtained above, and the insulation, the wedges and the spacers are made adiabatic.

Settlement Results and Analysis

Normal Temperature Field Analysis

Figure 1. Three-dimensional moxing of stator winding.

Figure 2. Stator winding temperature under normal conditions.
Figure 2 shows the temperature distribution of the stator winding. It can be seen that the temperature of the wedge near the slot is the lowest. This is because the wedge is placed away from the winding at the inlet of the air passage, away from the heat source and does not heat itself. The temperature of the cooling water in the line and the strand is maintained at 45 °C, and there is no obvious temperature rise compared with the temperature at the inlet of the waterway. The temperature of the solid strand at the same radial height is significantly lower than the temperature of the stator tooth, indicating cooling water cooling. The performance is very good, can take away a lot of heat, not only can effectively cool the hollow strands, but also take away most of the heat of the solid strand; for the entire stator winding, due to the strong cooling capacity of the water, therefore, up and down The temperature of the layer hollow strands is not much different, but because the resistance increase coefficient of the upper layer winding is larger, the heat generation is more serious. Under the same heat dissipation structure, the solid strand temperature in the upper layer winding is greater than the temperature of the solid strand in the lower layer winding. In the upper winding, the four solid strands near the slot have the highest temperature, which can reach about 100 °C. This is because the skin effect is obvious and the heat is severe. At the same time, only one waterway acts on the heat dissipation here, and the temperature of the four solid strands away from the slot is relatively high. Since the resistance increase coefficient of the winding is significantly smaller than the resistance increase coefficient of the winding at the slot, the heat is relatively low. Severe, so even if only one waterway is cooled, the temperature is significantly lower than the temperature of the solid strand at the slot; likewise in the lower winding, the temperature of the solid strand near the slot and away from the slot is relatively high, but due to The resistance increase coefficient of these two windings is not large and the difference is not large, so even if only one waterway is cooled, the temperature is relatively low. Except for the solid strands with higher temperature, the temperature of other strands is maintained at 62 °C~ 80 °C.

**Temperature Field Analysis of Hollow Strands Blocked**

When studying the problem of blockage of hollow strands, when one or several hollow strands are blocked, it is considered that the flow of cooling water in the hollow strands where the plugging occurs is zero, and the flow rate of cooling water in the other hollow strands is constant. Because the eddy current loss of the upper winding is large, the heat is also more serious. When analyzing the temperature field when the hollow strand is blocked, in order to reduce the calculation amount, only the upper winding clogging is considered to be a serious situation, in actual working conditions. Underneath, the position and number of blockage of the hollow strands are uncertain. Therefore, in this chapter, the temperature distribution and size change of the camera are adjusted in the case where the strands of different positions with different axial positions (ie changing the inlet temperature) are blocked. The study was conducted and the position and number of the hollow strands are shown in Figure 3.

![Figure 3. Winding number.](image-url)
The No. 1 hollow strand is now blocked, and the results are shown in Figure 4. As can be seen from the figure, except for the blocked No. 1 hollow strand, the other hollow strands can be well cooled. Due to the better cooling ability of the water, the temperature of the solid strand near the hollow strand is also relatively high. Lower, in the out-of-phase slot, because the resistance increase coefficient of the upper winding is greater than the resistance increase coefficient of the lower winding, the upper winding heat is more serious, and the cooling water in the upper hollow strand takes more heat to make the cooling water. The heat dissipation capacity of the hollow strands is significantly reduced. Therefore, the temperature of the solid strands in the upper winding is slightly larger than the temperature of the solid strands in the lower winding; the temperature of the wedge from the notch to the bottom of the groove is gradually increased, and the cold air is from the notch. Entering the blown stator winding and the surface of the stator core, the blocked air No. 1 hollow strand is severely heated, and the cold air cannot take away the heat in time, so the temperature of the whole wedge wedge changes drastically; the highest temperature in the stator winding is blocked. At the No. 1 hollow strand, the temperature can reach 240.68 °C. The high temperature here has a relatively large influence on the solid strands nearby, making the No. 1 hollow stock. The solid strands near the wire and the insulation temperature are significantly higher, reaching 150 °C.

![Figure 4. Stator winding temperature when the No. 1 hollow strand is blocked.](image)

Table 1 shows the maximum temperature of different parts in the calculation area when the No. 1 hollow strand is blocked. According to the above analysis, when the No. 1 hollow strand is blocked, the maximum temperature of the outlet and the hollow stock The highest temperature of the line is the No. 1 hollow strand. It can be seen from the table that when the No. 1 hollow strand is blocked, the temperature at the outlet rises sharply. When the inlet temperature is 60 °C, the outlet temperature is the highest, reaching 246.78 °C, and the inlet water temperature is 55 °C, the outlet maximum temperature increased by 2.73 °C. It is found from the table that when the inlet water temperature increases by 5 °C, the maximum temperature increases by about 2.7 °C; when the hollow strands are blocked, the heat dissipation of the blocked hollow strands is directly affected, due to the skin effect. The temperature of the hollow strands is significantly higher than the temperature of the solid strands at the same radial height. When the hollow strands are clogged, the heat dissipated by the windings cannot be taken away in time. Therefore, the temperature rises rapidly, from Table 4-1. It can be seen that when the inlet water temperature is 45 °C, the maximum temperature of the hollow strand reaches 239.39 °C, which is 0.82 °C higher than the temperature at the outlet, and the maximum temperature of the hollow strand rises when the temperature rises by 5 °C. It is about 2.7 °C.
Table 1. Maximum temperature of each part of the stator winding.

<table>
<thead>
<tr>
<th>Water inlet temperature(℃)</th>
<th>Outlet temperature(℃)</th>
<th>Hollow strand temperature(℃)</th>
<th>Solid strand temperature(℃)</th>
<th>Insulation temperature(℃)</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>238.57</td>
<td>239.39</td>
<td>205.20</td>
<td>221.44</td>
</tr>
<tr>
<td>50</td>
<td>241.31</td>
<td>242.11</td>
<td>208.23</td>
<td>224.32</td>
</tr>
<tr>
<td>55</td>
<td>244.05</td>
<td>244.85</td>
<td>211.28</td>
<td>227.21</td>
</tr>
<tr>
<td>60</td>
<td>246.78</td>
<td>247.57</td>
<td>214.32</td>
<td>230.09</td>
</tr>
</tbody>
</table>

The left and right hollow strands are numbered, numbered 1-6 from the slot to the bottom of the slot, and the hollow strands are blocked, and the stator windings are simulated to extract the highest stator windings when different hollow strands are blocked. Temperature, the highest temperature distribution law obtained is shown in Figure 5. From the stator slot to the bottom of the slot, as the radial height of the blocked hollow strand changes, the maximum temperature drops first and then rises. Among the six left hollow strands, the maximum temperature of the stator winding after the blocked No. 2 hollow strand is significantly lower than the maximum temperature of the stator winding after the hollow strand is blocked. According to the previous analysis, the difference between the two is 60 ℃. However, as the position of the blocked hollow strand gradually approaches the bottom of the groove, the temperature change will not be so obvious. This is because the smaller the heat density of the hollow strand at the notch, the less heat it generates, so the highest after clogging The temperature will decrease. When the No. 6 hollow strand is blocked, the maximum temperature of the stator winding is slightly higher than the maximum temperature of the stator winding when the No. 5 hollow strand is blocked. This is because the No. 6 hollow strand is located at the bottom of the tank, although there is no The No. 5 hollow strand has severe heat, but its heat dissipation performance is poor. When the No. 5 hollow strand is blocked, the right side and the upper and lower four hollow strands can cool it. However, the No. 6 hollow is blocked, only the three hollow strands can be cooled, so that the heat dissipation effect is poor, so the maximum temperature when the No. 6 hollow strand is blocked is greater than the maximum temperature when the No. 5 hollow strand is blocked. The highest temperature distribution law when each hollow strand on the right side is blocked is the same as the highest temperature distribution when the left hollow strand is blocked, and the maximum temperature decreases as the radial height of the blocked hollow strand decreases. The maximum temperature difference between the No. 1 and No. 2 hollow strands is the most, and the difference between the two is 41 ℃, which is 20 ℃ lower than the highest temperature difference when the left and No. 1 hollow strands are blocked. Because the radial heights of the same number of hollow strands on the left and right sides are different, the heat density is affected by the skin effect. Under the same number, the position of the right hollow strand is closer to the bottom of the tank, and the heat density is smaller. Less heat, so the temperature is lower, the temperature difference is relatively small, the highest temperature when the right 3#-6 hollow strands are blocked is slightly smaller than the highest temperature when the left hollow strands are blocked, because The closer to the bottom of the trough, the smaller the heat density, and the greater the heat dissipation capacity of the water. Therefore, the maximum temperature is similar when the left and right hollow strands are blocked. When the No. 5 hollow strand is blocked, the left and right hollow strands The highest temperature of the line, this Therefore, when the No. 5 hollow strand is blocked, the highest temperature appears at the notch to achieve the strand. The blocked No. 5 hollow strand has a good heat dissipation and good heat dissipation performance. When it is blocked, its temperature is higher than that at the notch. The line temperature is low, so the highest temperature is the same on both sides.
Figure 5. Maximum temperature of stator winding when different hollow strands are blocked.

Summary

In this paper, the temperature field of the stator winding under normal conditions is obtained by simulation calculation of the temperature field when the hollow strand is blocked. On this basis, the temperature field of the stator winding blocked by the hollow strand at different radial positions is calculated and calculated. It was found that when a hollow strand was blocked, the temperature of the stator winding was the highest when the hollow strand closest to the slot was blocked, and the maximum temperature was 240.7 °C, and the position of the blocked hollow strand gradually approached the bottom of the groove. The maximum temperature of the stator winding drops first and then rises, and the closer to the slot, the more obvious the temperature rise.

References


