Analysis of water leakage of generator stator bar

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Abstract. In modern society, the demand of power generation is gradually increasing. As the main equipment of power plant, the stability of its operation is very important. There may be some defects in the materials and manufacturing process of the domestic water-hydrogen-hydrogen generator, which may cause water leakage of generator stator bars and generator failure. This may threaten to the stability of power system. This paper analyzes the leakage accident of generator stator bars in recent years and puts forward some solutions and precautions.

1. Introduction

In March 2019, one water-hydrogen-hydrogen generator of a power plant began to be overhauled, and on May 13, after the completion of the overhaul, it was connected to the grid.

In June 2019, the hydrogen leakage of the generator exceeded the standard. The hydrogen leakage was 12.98m³/d, which was higher than the 11 m³/d required by the operation standard. After that the end cover, hydrogen cooler and cooling water system of the generator were checked for leakage, it was found that the hydrogen content in the inner cooling water tank was as high as 5%.

After the generator was shut down, it was found that the hydrogen content in the inner cooling water tank was between 3.15% and 7.5%, preliminarily it was judged that there was leakage in the inner cooling water system of the generator.

Open the end covers on both sides of the generator, check and find that there is water leakage at the lower layer of stator slot 8 at 2 o'clock on the steam end. It was shown below.
Subsequently, the manufacturer's process and quality inspection personnel of the generator carried out diagnosis and analysis. In order to completely eliminate the leakage defect of the stator bar, it developed a plan to replace the leaking bar and decided to replace the lower bar No. 8, with a planned duration of 20 days.

In the process of replacement, another 6 leaking stator bars were found. After disassembled the 8 lower layer stator bar, it was found that two hollow wires and three solid wires were broken at the edge of water box. The fracture material was analysed by metal test.

The reason for the fracture was that the stress concentration part at the edge of the outer strand soldering area was under the action of high frequency alternating load, forming fatigue crack without breaking and expanding, and finally fracture failure occurred. Therefore, add the samples of lower layer stator slot 8, lower layer stator slot 36 and upper layer stator slot 11 of steam end.

By adding the test report of sampling samples, it is concluded that the cause of strand cracking is metal fatigue.

2. Equipment Overview

Generator parameters are as follows

| Table 1. Generator parameters.  |
|-------------------------------|
| Generator parameters           |
| Model            | QFSN-600-2YH | Rated Capacity | 666.667MVA |
| Rated Power | 600MW       | Rated Voltage  | 20kV       |
| Rated Current | 19245A       | Rated Speed    | 3000rpm    |
| Rated Power Factor | 0.85         | Cooling Mode  | water-hydrogen-hydrogen |
3. Generator inspection

3.1. Statistical analysis of hydrogen leakage
In March 2019, the hydrogen leakage test of generator is qualified, in May 2019, the hydrogen leakage test of generator is qualified, and in June 2019, the hydrogen leakage test of generator is unqualified. See the figure below for the record of hydrogen supplement in June.

| Date     | Time  | Hydrogen supplement/m³ | Hydrogen leakage/m³ | Hydrogen discharge and supplement/m³ |
|----------|-------|------------------------|---------------------|-------------------------------------|
| 20190601 | 18:30 | 31.43                  | 9.88                |                                     |
| 20190604 | 11:20 | 25.70                  | 8.41                |                                     |
| 20190606 | 11:10 | 18.82                  | 12.98               | 42.13                               |
| 20190607 | 01:20 |                        |                     |                                     |
| 20190608 | 11:10 | 25.97                  | 8.41                |                                     |
| 20190609 | 23:55 |                        |                     | 42.8                                |
| 20190611 | 00:35 | 23.63                  | 9.27                |                                     |
| 20190612 | 00:35 | 27.71                  | 27.71               |                                     |
| 20190613 | 10:50 | 24.60                  | 13.44               |                                     |
| 20190614 | 11:20 | 27.24                  | 27.24               |                                     |
| 20190615 | 01:05 |                        |                     | 46.78                               |
| 20190615 | 11:45 | 26.05                  | 26.05               |                                     |
| 20190616 | 10:45 | 15.14                  | 15.70               |                                     |
| 20190617 | 09:30 |                        |                     | 50.91                               |
| 20190617 | 22:10 |                        |                     | 31.75                               |
| 20190618 | 13:10 |                        |                     | 45.70                               |
| 20190618 | 16:00 |                        |                     | 33.49                               |
| 20190618 | 23:55 |                        |                     | 36.90                               |
| 20190619 | 04:20 |                        |                     | 55.60                               |
| Total    |       | 246.29                 | /                   | 386.06                              |

3.2. Water quality analysis of the stator cooling water
Before the overhaul, the copper ion in the cooling water of the generator stator did not exceed the standard. After the grid connection, the copper ion in the cooling water of the generator stator was 40.72μg/L, which exceeded the standard. After the water exchange treatment, the copper ion content still had no obvious downward trend. When the ion exchanger resin was replaced, the copper ion content decreased to 11.03μg/L. The conductivity of stator cooling water is kept below 1.5μs/cm, which is not over standard.

3.3. Stator Bar inspection
Melt the water box at the steam side of the lower bar of No.8 slot, check and finally confirm the internal water leakage of a hollow strand of the lower bar of No.8 slot, as shown in the figure below.
The water pressure and air pressure tests were carried out on 42 upper stator bars, and it was found that the hollow strand of No.11 upper stator bar at the steam end was leaking, the external insulation of No.12 and No.13 upper stator bar had wear marks, and the insulation of No.37 upper stator bar at the excitation end had oil oozing out. Then, helium leak detection was carried out, and it was found that there was leakage at the nose end of No.7 upper line bar and No.36 lower line bar at the excitation end, and further inspection found that there was leakage point at the hollow strand line at the bottom of No.36 steam end. It was found that there were cracks or leakage points on 7 wires in the lower layer of No.8 groove, the upper layer of No.11, the upper layer of No.12, the upper layer of No.13, the lower layer of No.36, the upper layer of No.37 and the upper layer of No.7 excitation end. There was no abnormality in the chemical composition of 8 and 36 strands. The results of metallographic analysis show that the microstructure is normal. The grain size of 8 strands and 11 strands is about 0.02mm. There are several folding defects on the inner wall of hollow strand.

Based on the above results, the main reasons for the leakage of the stator bars are as follows: the edge of the water box of the stator bar is the variable cross-section area and the stress concentration area of the whole stator bar; at the same time, this part is the heat affected area of the brazing, and the grain growth results in the decrease of the strength, toughness and anti-fatigue performance of the stator bar compared with the normal part. Under the action of high frequency alternating load, the stress concentration part at the edge of the outermost strand brazing zone of the bar along the line forms fatigue crack and expands continuously, and finally fracture failure occurs.

4. Vibration analysis of the generator

According to the vibration data report from 2017 to 2019, during normal operation, the shaft vibration value and bearing vibration value of unit 2 are within the allowable range, and it is generally considered that the generator could operate for a long time without restriction in this area.

| time         | items    | 7 shell (μm) | 8 shell (μm) |
|--------------|----------|--------------|--------------|
| 2017 First quarter | X direction | 87           | 61           |
|              | Y direction | 64           | 57           |

Table 3. The shaft vibration value and bearing vibration value
On May 2019, this generator was started for the first time after overhaul. When it was ready for over speed test, at 14:46, the rotating speed of the unit increased from 1840rpm to 2550rpm, the vibration of the No.7 shell increased to the trip value (254μm), and the turbine tripped. At 15:00, the rotating speed dropped to 650rpm, and the vibration of the No.7 shell dropped to 250μm, and then the axle vibration probe was damaged. It can be seen from the spectrum diagram of No.7 shell that the basic frequency accounts for more than 90% and the phase changes greatly compared with that in the process of turbine speed-up. It can be judged that the friction occurs at No.7 shell. During the whole process, the maximum shaft vibration of No.5 shell is 210μm, that of No.6 shell is 230μm, that of

| Time         | Items                  | 7 Shell (μm) | 8 Shell (μm) |
|--------------|------------------------|--------------|--------------|
|              | bearing vibration      | 21           | 5            |
|              | X direction            | 61           | 82           |
| Second quarter | Y direction           | 85           | 70           |
|              | bearing vibration      | 42           | 20           |
|              | X direction            | 60           | 80           |
| Third quarter | Y direction           | 84           | 71           |
|              | bearing vibration      | 42           | 20           |
|              | X direction            | 59           | 80           |
| Fourth quarter | Y direction          | 84           | 72           |
|              | bearing vibration      | 42           | 20           |
|              | X direction            | 61           | 77           |
| First quarter | Y direction           | 81           | 71           |
|              | bearing vibration      | 42           | 19           |
|              | X direction            | 60           | 76           |
| Second quarter | Y direction          | 81           | 69           |
| 2018         | bearing vibration      | 42           | 19           |
|              | X direction            | 61           | 77           |
| Third quarter | Y direction           | 81           | 71           |
|              | bearing vibration      | 42           | 19           |
|              | X direction            | 62           | 76           |
| Fourth quarter | Y direction          | 80           | 69           |
|              | bearing vibration      | 42           | 18           |
|              | X direction            | 62           | 76           |
| First quarter | Y direction           | 80           | 69           |
| 2019         | bearing vibration      | 42           | 18           |
|              | X direction            | 51           | 70           |
| Second quarter | Y direction          | 77           | 77           |
|              | bearing vibration      | 25           | 8            |
No.8 shell is 450μm, and that of other bearing is less than 200μm. The maximum shaft vibration of No.1~No.6 shell of steam turbine is below the trip value. After checking that there is no abnormality under the condition of turbine barring, check that the turbine works normally when it is flushed again to 600rpm, there is no friction noise on the spot, and the speed continues to rise, and the vibration of each shells is normal after the fixed speed of the turbine generator is 3000rpm.

Due to the abnormal vibration of electromagnetic force, the metal fatigue is usually caused by the end vibration. The dynamic characteristics on stator end windings test data of the generator over the years are retrieved.

Modal test analysis is the vibration test analysis to determine the modal parameters of the system. The identification methods of modal parameters can be divided into time-domain method and frequency-domain method. The time-domain method is a method to identify modal parameters directly from the time-domain response data centre; the frequency-domain method is based on the measurement of the frequency response function, using the least square method to estimate the modal parameters. Frequency domain method is generally recognized as a mature and effective method, which is used in this power plant.

Through the analysis and fitting of the collected frequency response function by the modal test analysis software, the natural frequency, main mode shape and damping of the system can be obtained. Because the electromagnetic force at the end of the winding is similar to the elliptical distribution, the resonance threat caused by the elliptical vibration mode and electromagnetic force of the generator is the largest.

| Annual | Measuring position | Frequency | Damping |
|--------|--------------------|-----------|---------|
| 2008   | Steam end          | 86.29     | 1.950   |
| 2013   | Steam end          | 72.74     | 5.380   |
| 2019   | Steam end          | 47.44     | 2.028   |
| 2008   | Excitation end     | 111.83    | 3.934   |
| 2013   | Excitation end     | 108.70    | 2.704   |
| 2019   | Excitation end     | 111.84    | 6.036   |

The electromagnetic force inside the winding is mainly the radial force generated by the interaction between slot current and slot leakage. The electromagnetic force at the end of the winding is generated by the interaction between the end current and the magnetic flux leakage at the end of the stator and rotor, and its frequency is twice of the fundamental frequency which is 100Hz. As shown in the table above, the elliptical mode frequencies at the excitation end of the generator steam end are avoided from 100Hz, but the elliptical mode frequencies at the steam end have changed greatly from those at the factory. The local looseness at the winding end is reflected.
5. Preventive measure

In the aspect of reducing the vibration of generator, the looseness of all kinds of fasteners and connectors at the end of stator coil of motor, and the reasonable optimization of the tightening and binding process of wire rod, to minimize the vibration of wire rod, so as to restrain the occurrence of metal fatigue. Optimize the forming and brazing process of stator bar, improve the product quality of bar, prevent the formation of bar stress concentration area, control the grain size of heat affected zone of bar brazing, and avoid abnormal growth. Install online vibration monitoring device at the original failure position and the position in question to carry out online vibration monitoring during operation.

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