Analysis of Factors Affecting the Working Performance of Brush slip ring system in Special Environment

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Abstract. In the marine environment, the wear of carbon brushes in the brush slip ring system of doubly-fed generators is accelerated and the replacement frequency is relatively high. In this paper, an experimental platform is built to simulate the working environment of the carbon brush slip ring system in the marine environment, and the factors causing the accelerated wear of carbon brushes are explored, so as to make suggestions on operation and maintenance of the brush slip ring system. The composition of the oxidation film on the contact surface of the brush slip ring has been quantitatively analyzed to provide a basis for determining the content of the oxidation film.

1. Introduction

Compared with traditional energy, offshore wind energy is of the advantages of abundant resources, high wind speed, low turbulence, more generating capacity for wind turbine generator, no land restriction, and less noise impact, etc. However, there are also some problems, such as the difficulty of development technology, the high cost of investment, and the difficulty of operation and maintenance, etc. The economic and social value of offshore wind power development is increasingly recognized and more and more scholars join in the research of offshore wind power, so the cost of offshore wind power will become lower and lower.

The offshore wind energy has many advantages over the land, but the brush slip ring of offshore wind turbines is prone to various defects due to its long-term operation in outdoor bad atmospheric environment, inadequate management and lack of daily maintenance. Brush slip ring is the key component of all kinds of equipment components in power grid generators, and has the highest failure rate. Its working condition directly affects the security and stability of power grid. For example, there are many phenomena such as pound erosion, overheating of conductive circuit, and jamming, etc., which seriously affect the safe and stable operation of equipment, and bring great hidden dangers to the operation of power grid. However, the marine environment is much more complex than the terrestrial environment. The common air-cooled cooling method is used in the sea. The air carries not only dust, but water vapor containing a lot of salt. We usually call it salt fog, which has a much greater impact on wind turbines than dust. First of all, salt fog will accelerate the corrosion of metal devices and make them fail prematurely. Secondly, salt fog has a great impact on the insulation of electrical devices, and the corrosion of the metal parts inside the devices will greatly reduce the service life of
electrical devices. Therefore, the anti-salt fog technology of wind turbines has become one of the core technologies in the research and development of offshore units.

In literature [1], the research methods of atmospheric corrosion are introduced; the research methods of atmospheric corrosion behavior are analyzed in detail; the method of salt spray experiment is described in detail. It also pointed out that salt spray test can be used as an artificial accelerated test method to test the performance of metal materials. Corrosion rings in offshore wind farms and experimental schemes abroad are introduced in literature [2]-[4]; Literature [5]-[8] is of a detailed introduction to the anti-corrosion technology of wind turbines in marine environment. However, none of the above studies can systematically give the main factors affecting the performance of carbon brush slip rings in the marine environment. Based on the existing research, this paper designs an experimental platform to explore the main factors affecting the performance of carbon brush slip rings in the marine environment. After a series of experiments, the experimental results are summarized, and the main factors affecting the brush slip ring system in marine environment are analyzed.

2. Carbon brush slip ring structure

Figure 1 1—Slip ring lead; 2—#1Brush; 3—#2Brush; 4—Slip ring; 5—Insulating bush; 6—#3Brush;

Figure 1 shows the simplified structure of carbon brush slip ring, mainly including slip ring lead, carbon brush, slip ring, and insulating bush. Because of the special environment in the marine environment, the working environment of carbon brush slip ring is harsh; the failure rate of carbon brush is high; the replacement cycle of carbon brush is small, and a lot of manpower and materials are consumed.

3. Equipment and method

3.1. Testing system

Figure 2 Schematic diagram of experimental device in brush slip ring system
As shown in the Figure 2, the slip ring device is fixed on the rotating shaft of the asynchronous motor through the coupling, and the three leading wires of the slip ring are connected in star shape. The lead material is connected in a symmetrical ring with copper bars, and the neutral point is set in N. The brush and its accessories are fixed on the corresponding slip ring surface according to the operating requirements, so that the slip ring system of the brush meets the given operating conditions, that is, the asynchronous motor is on the outside of the salt spray test chamber, and the whole brush slip ring system is on the inside of the salt spray test chamber. During the experiment, the asynchronous motor drives slip ring to run at a certain speed through the coupling.

3.2. Experimental method
After analyzing the working environment of offshore wind turbines, the experiment adopts the method of control variables to control the working current, ambient temperature, salt mist concentration, and ventilation and heat dissipation of the brush slip ring, and to research the wear pattern of carbon brushes in different working environments.

4. Result and conclusion
By controlling the different currents of carbon brush, the influence of current size on wear pattern of carbon brush is studied. It can be seen from Figure 3 that under the conditions of different current, wearing capacity of brush is different in the same period and too large or too little electric current will increase the wear and tear, so appropriate running current is helpful for reducing the wear of carbon brushes.

![Figure 3 Average wearing capacity of carbon brush under different currents](image)

For the temperature test, due to the work environment of carbon brush slip ring is about 40 degrees in marine environment, the experiment with three sets of temperature about 40 degrees is carried out. According to the diagram form, wearing capacity of carbon brush is different. When the temperature is lower, the wear of carbon brush decreased greatly, so the controlling the working environment temperature of carbon brush slip ring can reduce the wear of carbon brush.
Compared with the terrestrial environment, in addition to the high and varied temperature and humidity, there are NaCl particles in the atmosphere of the marine environment. To explore the influence of NaCl content in salt fog on the wear of carbon brushes, experiments were carried out at different salt fog concentrations. As shown in the figure, the wear of carbon brushes at different salt fog concentrations can be seen from the Figure 5. The higher the wear of carbon brushes, the more serious the wear of carbon brushes. It can be seen that the atmospheric salt particles in the marine environment will affect the working performance of carbon brushes.

As can be seen from the Figure 6, when there is no ventilation, the wear of carbon brushes is more serious. When there is ventilation, the wear of carbon brushes decreases. This is because when there is ventilation, the temperature of salt fog box is lower, and the wear of carbon brushes is not that bad. When there is no ventilation, the wear of carbon brushes will increase because of the increase of ambient temperature, and carbon powder deposited can also increase the wear of carbon brushes.
5. Component analysis of oxidation film

The oxidation film on the surface of the slip ring is not static, but in a dynamic equilibrium state of alternating wear and regeneration during the operation of the slip ring. The normal thickness of the oxidation film is in the range of 8-100μm\[^1\], generally 25μm. It is found by electron microscopy that the contact surface between the carbon brush and the slip ring is contacted by countless points. Generally, the contact surface is only a few thousandths of the total area of the carbon brush. The contact area is determined by the speed of the motor, the hardness of the slip ring material, the processing accuracy, the yaw, the material of the carbon brush and the pressure on the carbon brush, etc.

The oxidation film is of very good lubricity. The metal oxidation film plays an important role in improving the contact voltage drop. The carbon film plays an important role in improving friction and reducing wear on the metal oxidation film. The composition of oxidation film has always been the focus of scholars’ attention and research. Based on the percentage of element content, the percentage of main elements in oxidation film can be obtained by energy spectrum analysis, of which, 71.09% is carbon; 12.17% is oxygen; 7.08% is sodium; 7.11% is chlorine; and 2.25% is copper. The content of five components of oxidation film is shown in the following figure.

![Figure 7 Energy spectrum diagram of oxidation film components](image)

![Figure 8 Component content of oxidation film](image)

It can be seen from the Figure 8 that the carbon content is the highest. In addition to oxygen, sodium and chlorine, there are copper elements. To explore the valence state of copper elements, the energy spectrum analysis of copper elements has been specially made. The energy spectrum of copper element is shown in the Figure 9.
Figure 9 Energy spectrum diagram for valence state analysis of copper element

It can be seen from the figure 9 that the valence state of copper in the oxidation film is not unique. It contains both monovalent and bivalent copper. Energy spectrum analysis provides a basis for determining the material composition of the oxidation film.

6. Conclusion

There are many factors affecting the performance of carbon brushes in marine environment. The test results show that current, working environment temperature, salt mist content and ventilation will affect the service life of carbon brushes. Too large or too little electric current will aggravate the wear of carbon brushes, and the wear resistance of carbon brushes will be guaranteed under appropriate current density; the wear of carbon brushes can be reduced at lower environmental temperature, and the wear of carbon brushes can be reduced by lowering environmental temperature; the salt particles in atmosphere are an important reason for aggravating the wear of carbon brushes, and adding desalting fog device can be used to prolong the service life of carbon brushes and reduce the number of replacing carbon brushes; the proper ventilation can also help reduce the wear of carbon brushes, or increase the dust-extraction unit, which will prolong the service life of carbon brushes. In addition to carbon, oxygen, sodium and chlorine, the oxidation film contains monovalent and bivalent copper elements, and does not contain common impurities, such as calcium in water.

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