Corrosion Failure Analysis of Electrical Equipment in Distribution Power System under High Temperature and High Humidity Environment

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Abstract. The problem of corrosion failure of distribution automation terminal in hot and humid environment is very prominent, which seriously restricts the development of smart grid in southern power grid. Therefore, this paper chooses three overhead FTU terminals as the research object to study characteristics of corrosion failure of distribution automation terminal. The corrosion failure analysis was carried out by SEM and EDS. EDS data showed that the content of oxygen in corrosion region was significantly higher than the slight corrosion region, the presence of sulfur and chlorine indicated that the corrosion environment was mainly a humid environment containing sulfur and chloride. SEM found that the corrosion failure of terminal equipment is mainly due to the environment such as high temperature, humidity, chloride ion and sulfur. At the same time, the exposure of substrate is caused by the damage of plating layer or leakage plating which was further development of corrosion. Therefore, according to the corrosion characteristics of distribution automation terminal in hot and humid environment, the corresponding protective measures ensuring the safe operation of distribution automation system is proposed, which can extend the service life of distribution automation terminal and provide reliable basis for the future empirical test.

Keywords: Southern Power Grid, Distribution Automation Terminal, Humid and Hot Environment, Corrosion Failure, Protective Measures

1. Introduction
The distribution automation terminal, which has the functions of telecommunication, telemetry, remote control contactor and remote transmission, can monitor the electrical parameters of the distribution lines equipment and identify the faults. It can collect and monitor the important electrical parameters monitoring points and switch status signals of the distribution network equipment in real time and online, which can be used for the construction and upgrading of the smart grid automation. Therefore, the quality management of distribution automation terminal directly affects the long-term stable operation of distribution automation system. It analyzes the causes of mildew and rust, and puts forward the rust prevention measures by using coating and
increasing cleaning [1]. The degree of corrosion is classified [2]. The relationship between the environment with high humidity and salinity and metal corrosion is analyzed [3]. It briefly introduces the current situation of the distribution automation system of Hangzhou Electric Power Bureau, and analyzes the precautions of environmental operation management of the automation terminal equipment according to the local situation [4]. It analyzes the characteristics of the development of intelligent power equipment in each link, points out the influence and role of intelligent power equipment and technology in the intelligent power grid [5]-[7].

The distribution automation terminal is not only an important part of the automation construction level about smart grid, but also a positive embodiment of promoting the distribution network intelligent dispatching control system in the 13th five year plan for power development. In order to ensure the stable operation of distribution automation terminal under severe environmental conditions, it should pay attention to environmental adaptability.

2. Running Defects

2.1 Regional Environmental Characteristics of China Southern Power Grid
Most of the five provinces in southern power grid are in humid and sub-humid climate areas, accompanied by the phenomenon of high temperature, high humidity, high irradiation and high salt mist.

2.2 Analysis of Operation Defects of Distribution Automation Terminal of China Southern Power Grid

![Figure 1](image)

**Figure 1.** Number of terminal defects of Guangzhou Power Supply Bureau in 2008-2017

Figure 1 includes data in three states: not put into operation, put into operation, and out of operation.

The analysis shows that the terminal equipment leaving the factory in recent three years has a relatively stable operation and a low failure rate. The main reasons are that detection is gradually standardized and terminal equipment are in the early stage of the life cycle. Terminal equipment leaving the factory in 2008-2011 is in the later stage of the whole life cycle. Theoretically, the failure rate should be the highest, but due to this time period nearly 50% of the leaving factory terminals have been out of operation, the failure rate is relatively low. The operation period of the leaving factory terminal equipment from 2012 to 2014 is between 3-5 years, which is relatively stable but has the highest defect rate.

In Table 1, power management module, control board and battery is affected by humid and hot environment, because these components are precision electronic components, which are easily affected by high temperature, high humidity and other factors, and the failure treatment cost of these components is high and the cycle is long.

**Table 1.** Classification and statistics of main defects of distribution automation terminal
### 3. Impact Analysis

#### 3.1 Environment of High Temperature and High Radiation

In the humid and hot environment area under the jurisdiction of southern power grid, when summer comes, the temperature will rise sharply. Some of the surface temperature will reach more than 40°C, while the overhead terminal will be directly exposed to the sun outdoors, resulting in the surface in a high temperature state for a long time, even breaking the allowable limit. The internal temperature of the distribution automation terminal will be higher due to the operation and heat dissipation of internal parts. As the distribution automation terminal is a kind of airtight device, it is unfavorable for heat dissipation. As shown in Figure. 2 and Figure. 3 below, once the temperature continues to be too high, the equipment materials and wire insulation layer will accelerate aging, resulting in hardening and embrittlement crack.

| Serial number | Defect type                  | Defect analysis            |
|---------------|------------------------------|----------------------------|
| 1             | Communication module         | Frequent signal            |
| 2             | Data setting exception       | Reconfigure parameters     |
| 3             | Power management module      | Muggy environmental factors|
| 4             | Main control panel           | Muggy environmental factors|
| 5             | Battery                      | Muggy environmental factors|

![Figure 2](image1.png)

**Figure 2.** Corrosion morphology of FTU outer tank in high temperature environment

![Figure 3](image2.png)

**Figure 3.** Corrosion morphology of FTU aviation socket in high temperature environment

#### 3.2 Environment of High Humidity

Relative humidity, which is greater than 80%, is called high humidity. Relative humidity, which is less than 40%, is called low humidity or dry. Most of the five provinces of China Southern Power Grid are in high humidity environment.

When the equipment is in high humidity environment for a long time, condensation will occur inside the equipment, which is a special phenomenon in high humidity. As shown in Figure. 4 below, the harm of condensation to the equipment is mainly caused by the small water, which can cause equipment corrosion, insulation strength reduction, mold growth, short circuit, even the increase of leakage current and finally causing accidents.
3.3 Environment of High Salt Fog

In the coastal area, the air mixes with sea fog, and there are a lot of salt, sulfur and other components in it. It is harmful for the automation terminal equipment, which will directly lead to the damage of electrical components. At the same time, it will also cause rust of steel parts, rust at contact points, oxidation, expansion or contraction, resulting in poor contact, fracture and damage. As shown in Figure. 5 below, the general galvanized and painted metal components, which are used in the environment of high salt fog, have begun to rust in about half a year.

Figure 5. Corrosion morphology of FTU PCB in high salt fog environment

4. Corrosion Test

4.1 Test Method

As is shown in Figure. 6, SEM and EDS are used to analyze the corrosion products of the failed distribution automation terminals, and the causes of corrosion were analyzed. The analysis includes different materials such as terminal shell, aviation plug, PCB board, operating handle, grounding terminal, galvanized bolt, etc. The material corrosion mechanism and anti-corrosion process are studied in combination with the temperature and humidity alternating environment simulation test.

Figure 6. Flowing chart of corrosion test

4.2 Sample Screening

As shown in Figure.7 below, the test piece is three sets of FTU (Zhuhai Xuji Electric Company). Since many terminal devices delivered from 2008 to 2011 have been out of operation and those delivered from 2015 to 2017 are in the early stage of their life cycle, the failure rate is relatively
low. In order to make the test data more representative, FTU delivered from 2012 to 2014, which has failed, is taken as the test sample, and the corrosion test of all areas on the sample is completed.

**Figure 7.** Failed FTU sample of overhead terminal 4. Results and analysis

### 4.3 Test Result

**Table 2.** Energy spectrum (element) analysis table (#1 sample)

| #1 sample | element (wt%) |
|-----------|--------------|
| Operation handle | C:0.83; O:3.78; Cr:9.13; Mn: 15.17; Fe: 71.09 |
| SPS aviation plug | C:0.61; O:2.06; Cr: 5.78; Ni: 91.55 |
| BATT aviation plug | C:1.04; O:4.99; Cr:25.72; Ni:6 2.73; Zn:5.52 |
| TA aviation plug | C:0.71; O:31.07; Co:2.98; Ni:6 5.24 |
| Ls aviation plug | C:0.91; O:9.41; Cr:32.37; Ni:3 9.71; Zn:17.60 |
| GND terminal | C:1.09; O:14.52; Cl:0.66; Cr:8.42; Mn:13.51; Fe:61.80 |
| Power supply plug | C:0.78; O:4.19; Cr:1.18; Cu:7.4 8; Ni:17.44; Zn:68.93 |

| #2 sample | element (wt%) |
|-----------|--------------|
| Operation handle | C:0.83; O:3.78; Cr:9.13; Mn:15.17; Fe:71.09 |
| SPS aviation plug | C:0.61; O:2.06; Cr:5.78; Ni:91.55 |
| BATT aviation plug | C:1.04; O:4.99; Cr:25.72; Ni:6 2.73; Zn:5.52 |
| TA aviation plug | C:0.71; O:31.07; Co:2.98; Ni:6 5.24 |

**Table 3.** Energy spectrum (element) analysis table (#2 sample)

| #3 sample | element (wt%) |
|-----------|--------------|
| Operation handle | C:0.83; O:3.78; Cr:9.13; Mn:15.17; Fe:71.09 |
| SPS aviation plug | C:0.61; O:2.06; Cr:5.78; Ni:91.55 |
| BATT aviation plug | C:1.04; O:4.99; Cr:25.72; Ni:6 2.73; Zn:5.52 |
| TA aviation plug | C:0.71; O:31.07; Co:2.98; Ni:6 5.24 |

**Table 4.** Energy spectrum (element) analysis table (#3 sample).
Table 5. Monitoring data of air pollutants in typical industrial cities and seaside

| Place              | Nitrogen dioxide | Sulfate | Ammonia | Sea salt particles |
|--------------------|------------------|---------|---------|--------------------|
| Industrial cities  |                  |         |         |                    |
| Coastal areas      |                  |         |         |                    |

4.4 Data Analysis

Affected by the hot and humid corrosion environment, not only the shell of the automatic terminal equipment is corroded, but also the key parts such as the switch-operating handle and the board of setting value control, the grounding terminal and all aviation plugs are covered with different degrees of corrosion. The humid hot corrosion environment is mainly the humid environment of sulfur and nitrogen, and industrial cities and coastal areas are the main representatives. The following table is the semi quantitative pollutant test conducted by the membrane sampling method at typical stations.

Figure 8. Coating quality defects of FTU aviation plug

| #3 sample          | sight corrosion area | element (wt%) | corrosion area |
|--------------------|----------------------|---------------|----------------|
| Operation handle   | C:1.02;O:4.66;Cr:7.51;Mn:17.06;Fe:69.75 | C:0.88;O:28.84;S:2.78;Cl:2.28;Cr:4.01;Mn:23.29;Fe:37.92 |
| SPS aviation plug  | C:0.75;O:3.12;Cr:4.63;Ni:91.50 | C:1.22;O:26.24;Al:0.97;S:3.16;Cl:0.97;Ni:31.68;Cu:7.64;Zn:28.11 |
| BATT aviation plug | C:0.92;O:5.74;Cr:20.08;Ni:57.51;Zn:15.75 | C:1.33;O:22.45;S:3.30;Cl:2.36;Cr:2.99;Ni:14.17;Cu:10.18;Zn:43.22 |
| TA aviation plug   | C:1.09;O:29.07;Co:1.71;Ni:68.13 | C:9.87;O:21.29;Si:1.15;S:2.94;Cl:1.65;Ca:1.09;Ni:25.29;Cu:22.22 |
| Ls aviation plug   | C:1.11;O:7.55;Cr:22.71;Ni:34.51;Zn:34.12 | C:1.40;O:21.62;S:2.53;Cl:4.39;Cr:5.18;Fe:2.04;Ni:28.97;Cu:14.39 |
| GND terminal       | C:0.99;O:15.24;Cr:9.28;Mn:17.18;Fe:57.31 | C:10.45;O:31.93;Al:1.28;Si:1.01;S:4.91;Cr:2.57;Mn:12.87;Fe:34.98 |
| Power supply plug  | C:0.56;O:5.93;Cr:2.32;Cu:6.55;Ni:19.41;Zn:65.23 | C:1.47;O:31.53;Si:0.93;S:4.67;Cl:1.51;Ca:0.94;Ni:34.64;Zn:24.32 |
As can be seen from the data in Table 5, the pollutants of nitrogen dioxide, sulfur and ammonia in typical industrial cities such as Guangzhou and Foshan are significantly higher than those in other stations, while the coastal air pollutants are mainly sea salt particles, with the highest concentration in Wanshan Island.

The EDS data of the three samples shows that the oxygen content in the corrosion area increases significantly compared with that in the slight corrosion area. Then the surface of the samples is oxidized, with sulfur and chlorine, which indicates that the corrosion environment is sulfur and chlorine environment. The surface of aviation plug is covered with coating. The data analysis shows that nickel is detected due to slight corrosion, indicating that the corrosion only occurs on the surface. After corrosion, the samples not only detect copper, some even detect iron as the base material, indicating that the coating has gradually failed after corrosion. Some of the base materials are exposed, and corrosion has begun. Combined with SEM, it is found that a large number of corrosion products with coarse particles are produced on the surface of the material due to corrosion. The corrosion failure of materials is mainly due to the damage or missing plating of the coating, which causes the substrate to be exposed. Formula (1) is the reaction formula of material corrosion mechanism.

\[
\begin{align*}
SO_2 + H_2O & \rightarrow SO_3^2^- + 2H^+ \\
2SO_3^2^- + O_2 & \rightarrow 2SO_4^2^- \\
2Fe + O_2 + 2H_2O & \rightarrow 2Fe(OH)_2 \\
4Fe(OH)_2 + O_2 + 2H_2O & \rightarrow 4Fe(OH)_3 \\
2Fe(OH)_3 & \rightarrow Fe_2O_3 + 3H_2O \\
Fe & + 2H^+ \rightarrow Fe^{2+} + H_2↑ \\
2Ni & + 2H^+ \rightarrow 2Ni^+ + H_2↑
\end{align*}
\]

SO\text{2} in the environment dissolves to form acid medium, which corrodes the coating and the substrate. CL destroys the dense oxide film, which makes the corrosion worse.

The test results show that the main causes of corrosion of automation terminal equipment are as follows:

1) High temperature, humidity, chloride ion, SO\text{2} and other atmospheric environment accelerate the corrosion of terminal equipment, and the various components of corrosion products are mainly oxides, sulfides and chlorides;

2) The coating quality of each component is poor, some parts are missing plating, and the substrate is exposed.

In view of the above factors, reasonable protection scheme and measures should be selected in combination with the installation environment and corrosion of distribution automation terminal.

4.5 Corrosion Protection

Based on the analysis of different corrosion mechanisms of distribution automation terminals, combining with corrosion environment monitoring and environmental test standards, the following protection measures are recommended for distribution automation terminals in hot and humid environment:

1) Through the analysis of corrosion mechanism, it is necessary to select materials that are more suitable for the environment to achieve a certain anti-corrosion effect. Environmental simulation tests are made for different materials with different treatment processes and different
processing methods to evaluate and select the materials with the best treatment process and establish environmental technical requirements.

(2) Improve the coating quality, carry out coating related tests, and select the best coating thickness and plating process.

(3) The temperature and humidity in the operation environment of electrical equipment can be controlled by the combination of vapor phase antirust and desiccant. The test of corrosive gas simulation can be used to carry out in the laboratory. Managers can select representative electrical equipment for field application to verify its protection effect.

(4) The chemical catalytic filter module is used to filter the air inlet, control the environment in the electrical cabinet, make the corrosion environment milder and achieve the effect of corrosion alleviation. The environmental corrosion grade after the application of the technology is characterized by the micro t corrosion test copper strip and corrosion online monitoring technology.

5. Conclusion
Through the laboratory corrosion test of FTU of distribution automation terminal, the following conclusions are drawn.

(1) Through the corrosion test, the corrosion data of the terminal equipment is obtained, which truly reflects the corrosion characteristics of the working terminal equipment in hot and humid areas.

(2) In view of the influence of high temperature, high irradiation, high humidity and high salt fog on distribution automation terminals, corrosion protection measures are proposed to provide reliable data for the next stage of failure assessment.

(3) By analyzing the corrosion mechanism of automation terminal in hot and humid environment, managers can pay more attention to the safety performance of terminal equipment. They should strengthen the monitoring ability of corrosion environment on site, eliminate the abnormal conditions in the operation of terminal equipment in time, ensure the safety of staff and power system, and provide effective and feasible method for the intelligent development of southern power grid.

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