Study on Performance Aging of Nonmetal Low Voltage Metering Cabinet Shell in Typical Environmental Conditions

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Abstract—One of the key technologies in the field of smart grid measurement is to make a breakthrough in the detection and evaluation of high availability materials in smart measurement equipment. Under the comprehensive cross action of multi environment, how to combine the nonlinear evolution and mathematical model to analyze the complex environment into the feature combination of multiple single environmental factors, and how to find the key parameter features to express the aging life of materials is the focus and difficulty of the research. On the basis of service life model, the research on protection measures and life assessment technology of smart grid measurement equipment can make the equipment realize wide area application and high availability under worse conditions.

1. PREFACE
The quality inspection and analysis data on the performance and function of on-site operation metering equipment show that the protective shell will suffer serious quality degradation after long-term operation, especially the low-pressure metering box shell, which is the first line of defense for metering equipment, is more prominent. According to Q / GDW 11008-2013 technical specification for low pressure measuring box, the measuring box used by State Grid Company is mainly divided into four materials: continuous hot-dip galvanized steel plate, austenitic non-magnetic stainless steel cold-rolled steel plate, polycarbonate resin + acrylonitrile butadiene styrene resin (PC + ABS), glass fiber reinforced unsaturated polyester molding plastic (SMC), of which PC + ABS and SMC are two non-metallic plastic materials. It is widely used, and the aging problem of the shell is more complex. The following problems, such as box damage, equipment corrosion, leakage erosion, etc., have greatly damaged the safety of power consumption of thousands of households, resulting in huge economic losses and bad social effects. Therefore, it is necessary to carry out the aging research and evaluation of the non-metallic low-pressure measuring box shell.

At present, the research and evaluation of aging of non-metallic plastic materials such as polycarbonate (PC) are mainly based on the accelerated aging test data in the laboratory, and the main research focuses on the effects of photooxidation aging [1-2], hygrothermal aging [3], high temperature...
and high humidity accelerated aging [4] and other tests on the structure and performance of PC. Some research institutions or manufacturers have carried out the natural exposure test, but the natural exposure test is mainly applied to the environmental adaptability and quality inspection and control of parts and materials in the automobile industry [5,6]. Yuan Honghui [7] et al. Studied and compared the results of accelerated aging of paint in xenon lamp and natural outdoor exposure in the laboratory, and proved that there was a good correlation between the two tests. Accelerated aging test in the laboratory can be used to evaluate the durability of paint and paint system. Fedor GR [8] exposed 15 samples of different polymer materials in Florida, Arizona and Ohio for up to 2 years. Compared with the accelerated aging test in the laboratory, it was found that the accelerated aging in the laboratory with humidity cycle was similar to the degradation mode of outdoor aging. Zhang Xiaodong et al. Studied the natural exposure test results of PC in typical humid and hot areas in Hainan [9], jieganxin et al. Compared and analyzed the aging behavior of PC after outdoor natural aging test under typical humid and hot conditions (Qionghai) and dry heat conditions (Turpan) [10], found that the aging degree of PC under humid and hot conditions was more serious than that under dry and hot conditions, and explored some failure mechanisms. The results of literature research show that there is little research on the correlation between accelerated aging and natural exposure test of nonmetal low-pressure measuring box shell at home and abroad. Therefore, through the laboratory accelerated aging research and natural exposure test of the low-pressure metering box shell, collecting the test data of the metering equipment under different working conditions will help to find the performance changes of the metering equipment in different environments, and lay the foundation for further exploring the natural failure mechanism of the protective shell of the metering equipment and carrying out the condition evaluation of the metering equipment.

2. TYPICAL ENVIRONMENTAL CONDITIONS
In terms of geographical distribution, the business coverage of the State Grid Corporation is the southernmost to Zhangzhou, Fujian (23°30′N), the northernmost to Mohe, Heilongjiang (53°33′N), and Fuyuan, Heilongjiang (124°20′E), West to Kashgar, Xinjiang (75°59′east longitude), spanning sub-tropical, warm-temperate, moderate-temperate, cold-temperate, plateau climate zones and other major natural climate zones. In order to take advantage of the most extreme local climate environment, and to evaluate the function and long-term operational reliability of the measurement equipment, the State Grid Corporation of China chose Mohe, Heilongjiang (cold temperate continental monsoon climate, with a maximum temperature of 26 °C in summer, an extreme temperature of -52 °C in winter, and a severe cold period. 8 months), Turpan, Xinjiang (continental dry desert climate, annual sunshine over 3000h, surface temperature up to 70 °C), Tibet Yangbajing (highland temperate monsoon semi-humid semi-arid climate, 4300m above sea level) and Meizhou Island, Fujian (Marine subtropical monsoon climate, average annual rainfall of 1350mm) Four geographical locations with different types of climate, established a typical environment of measuring equipment for high-cold, high-dry, high-altitude, high-salt-fog, and high-humidity measurement with 10kV live operation real-time monitoring Test base. Fujian Meizhou Island is a high salt fog and high humidity and heat environment test base, located 42 kilometers southeast of the center of Putian, Fujian Province, only 1.82 nautical miles from the mainland, with an average annual temperature of 21 °C. It is a typical subtropical maritime monsoon climate with annual rainfall. About 1000mm, the climate is mild, the humidity is very high, and the coastal landform is simple. The wind direction is blown from the ocean to the land all the year round. The wind speed is also relatively large, and sometimes there are typhoons. The Specific Meaning of NQI.

3. TYPICAL ENVIRONMENTAL TEST METHODS
In order to fully simulate the actual installation and operation of the low-voltage metering cabinet, the low-voltage metering cabinet is suspended and installed in an outdoor test area of a typical environmental test base, and a static exposure test is performed. This test scheme uses a direct-
connected low-voltage metering cabinet without the need to install energy meters, acquisition terminals, disconnectors, and circuit breakers. The material covers PC + ABS, SMC, and the structure type can select single-phase single-meter, three-phase single-meter. Position, single-phase nine-epitope or three-phase two-epitope.

The outdoor test area is equipped with test racks, and single-row, double-row, or triple-row structures can be selected independently according to the site conditions of typical environmental test bases. Low-voltage metering cabinets are installed in rows and walls. The spacing between the cabinets should be set so that adjacent test cabinets are not blocked from each other. The distance between the bottom edge of the bottom row of test cabinets and the ground is not less than 30cm to ensure that each low-voltage metering cabinet is fully exposed to In the environmental test conditions, as shown in FIG. 1, the specific arrangement form is adjusted according to the actual conditions such as the site conditions of the outdoor test area of each typical environmental test base and the selected low-voltage metering cabinet structure type.

![Figure 1. Low-pressure metering cabinet outdoor static test layout](image)

According to calculations, in order to ensure the sufficient number of test spline samples, the number of low-voltage measurement cabinets to be mounted is not less than 50. Before mounting the test cabinet, first perform non-destructive tests such as visual inspection and marking test to ensure that the low-pressure metering cabinet functions normally, and then according to GB / T 1043.1-2008 "Determination of impact performance of plastic simply supported beams. Part 1: Non-instrumentation "Chemical impact test" and GB / T 9341-2008 "Determination of the flexural properties of plastics", cutting test blocks from the cabinet body to prepare test strips, and then recording the corresponding test data after performing the plastic impact test and the flexural property test. Finally, the low-pressure metering cabinet is mounted for a certain test period and removed after sufficient outdoor exposure tests, and then processed according to GB / T 1043.1-2008 and GB / T 9341-2008 to prepare test specimens for plastic impact test and plastic bend performance. Measurement test, record test data.

4. TEST RESULTS AND ANALYSIS
On September 23, 2019, the project team selected a sample of a single-phase single-meter low-voltage measuring cabinet mounted by a manufacturer at a typical environmental test base in Meizhou Island, Fujian. The material of the cabinet is PC + ABS, and the base mounting date is 2016. On December 28, the outdoor exposure test cycle under typical environmental conditions lasted up to 1,000 days, and the sample after the test is shown in Figure. 2.
4.1. Color difference
According to Q / GDW 11008-2013 "Technical Specifications for Low-Pressure Metering cabinets", the housing should be gray (Pantone Cool Gray 1U or Pantone Cool Gray 4U). The test samples of the low-voltage metering cabinet before mounting all meet this requirement. Figure X shows that the housing of the low-voltage metering cabinet is yellow after being mounted. Because the low-voltage metering cabinet is suspended and left standing, the protective cover at the circuit breaker (in the red cabinet in Figure X) has been sliding down for a long time, so the plastic under the protective cover is plastic. The material was originally gray without being fully exposed. Measurement with a CM-2300d color difference meter manufactured by KONICA MINOLTA, INC. Showed that the color difference data on the front of the yellow door panel is,

\[
\begin{align*}
L \text{ value: } & 79.77, \ A \text{ value: -1.47, } B \text{ value: 21.98} \\
L \text{ value: } & 81.14, \ A \text{ value: -2.61, } B \text{ value: 4.40}
\end{align*}
\]

The colorimeter test results show that after outdoor exposure, the B value increases significantly, and the color shifts significantly toward the yellow direction.

4.2. Plastic impact strength
The plastic impact measurement test uses XCJD-5 micro-controlled simply supported beam impact tester produced by Chengde Jinhe Instrument Manufacturing Co., Ltd., with an impact speed of 2.9m / s, a pendulum lifting angle of 150 °, and a center distance of 230mm. 5J pendulum, moment \( PL = 2.6795 \text{ N} \cdot \text{m} \), test method refer to GB / T 1043.1-2008 "Determination of impact performance of plastic simply supported beams-Part 1: Non-instrumental impact test", Q / GDW 11008-2013 "Low-pressure measurement cabinet Technical Specifications" and other standards.

The test splines were extracted from the housing of the low-pressure metering cabinet by mechanical cutting. The naked eye can see the color difference between the two sides of the splines, which are yellow and off-white. And the impact splines were brittlely fractured.
Figure 3. Spline after plastic impact test

The impact strength of the test strip plastic after a typical environmental test is shown in Table 1.

| Numbering | Width (mm) | Thickness (mm) | Impact strength (kJ/m²) |
|-----------|------------|----------------|------------------------|
| 01#       | 10.21      | 3.55           | 7.0688                 |
| 02#       | 10.20      | 3.39           | 8.2024                 |
| 03#       | 10.20      | 3.62           | 5.0263                 |
| 04#       | 10.21      | 3.56           | 5.7626                 |
| 05#       | 10.20      | 3.50           | 5.6836                 |
| 06#       | 10.19      | 3.41           | 4.8363                 |
| 07#       | 10.21      | 3.52           | 5.5103                 |
| average   |            |                | 5.8103                 |

Check the test records of plastic impact performance before the typical environmental test in December 2016, as shown in Table 2.

| Numbering | Width (mm) | Thickness (mm) | Impact strength (kJ/m²) |
|-----------|------------|----------------|------------------------|
| 01#       | 9.97       | 3.65           | 89.4794                |
| 02#       | 10.02      | 3.59           | 91.2826                |
| 03#       | 10.04      | 3.53           | 84.2409                |
| 04#       | 9.96       | 3.57           | 84.6383                |
| 05#       | 10.05      | 3.55           | 81.3650                |
| 06#       | 9.99       | 3.67           | 80.9556                |
| 07#       | 10.01      | 3.63           | 88.0112                |
| average   |            |                | 85.5470                |

Comparing the data in Table 1 and Table 2, the impact strength of plastics is severely attenuated after a typical environmental test, with the attenuation degree reaching 93.21%.

4.3. Flexural strength of plastic

The plastic bending property test uses the WDW-2 microcomputer controlled electronic universal testing machine produced by Chengde Jinhe Instrument Manufacturing Co., Ltd. This machine can
produce a maximum test force of 2kN, the test force accuracy is ± 1%, and the test force measurement range is 2 % -100% Fs, the displacement measurement accuracy is ± 1%, the speed range is 0.01mm / min-500mm / min, the speed accuracy is ± 1%, and the maximum compression stroke can be 600mm. The test method refers to GB / T 9341-2008 "Determination of Bending Performance of Plastics" and Q / GDW 11008-2013 "Technical Specifications for Low-Pressure Metering cabinets" and other standards. The test uses a loading speed of 2mm / min.

Similarly, a mechanical cutting process is used to extract the splines from the low-pressure measuring cabinet shell, and the numbers are set to 08 # ~ 14 # for testing. The splines are shown in Figure 4 after the test.

![Figure 4. Splines after plastic bending test](image)

The bending strength of the test specimen plastics after a typical environmental test is shown in Table 3,

| Numbering | width (mm) | thickness (mm) | Bending strength (MPa) |
|-----------|------------|----------------|------------------------|
| 08#       | 10.17      | 3.34           | 79.2                   |
| 09#       | 10.19      | 3.34           | 82.8                   |
| 10#       | 10.14      | 3.55           | 84.8                   |
| 11#       | 10.16      | 3.41           | 78.2                   |
| 12#       | 10.12      | 3.39           | 77.3                   |
| 13#       | 10.13      | 3.63           | 83.1                   |
| 14#       | 10.19      | 3.52           | 89.8                   |

average value 81.6

Query the test records of plastic impact properties before the typical environmental test in December 2016, as shown in Table 4,

| Numbering | width (mm) | thickness (mm) | Impact strength (kJ/m²) |
|-----------|------------|----------------|-------------------------|
| 08#       | 10.13      | 3.45           | 89.2                    |
| 09#       | 10.10      | 3.46           | 90.3                    |
| 10#       | 10.12      | 3.45           | 90.0                    |
| 11#       | 10.13      | 3.47           | 92.3                    |
| 12#       | 10.12      | 3.50           | 90.1                    |
| 13#       | 10.17      | 3.49           | 92.2                    |
| 14#       | 10.13      | 3.50           | 89.4                    |

average value 90.4
Comparing the data in Table X and Table X, the bending strength of plastics is not significantly attenuated after typical environmental tests, and the degree of attenuation is 9.73%.

5. SUMMARY AND OUTLOOK
After 1000 days of natural exposure test, the color of PC + ABS non-metallic measuring box changed from gray to yellow, and there was obvious photo oxygen aging phenomenon, which was caused by the high ultraviolet intensity of the island. It was found that the impact strength of the shell of the measuring box decreased significantly after 1000 days of natural exposure, and the performance of the shell of the measuring box obviously failed, which was brittle fracture in terms of the section morphology. However, the degradation of the bending strength of the plastic was weak, and the impact strength and bending strength did not maintain the same change trend, which indicated that the PC + ABS material under the condition of high salt spray and high humid heat, the cracking direction of mass mainly occurs in the direction perpendicular to the shell distribution. If we want to further explore the aging mechanism of PC + ABS, we need to introduce SEM and FTIR to analyze the cracking products. In addition, relying on the natural aging test under extreme conditions designed by four provincial experimental bases, a large number of key index test data of non-metallic materials in typical environments of high cold, high dry heat, high altitude, high salt fog and high humid heat are studied, and the nonlinear evolution and service life model of material aging under the comprehensive cross action of multiple environmental stresses are abstracted, based on which the anti-aging and service life models of measuring equipment are studied Service life assessment technology will also be the key research direction of the project team in the future.

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