Effect of acid corrosion on properties of composite insulator core rod

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Abstract. In recent years, there have been a number of composite insulator decay-like fracture faults characterized by resin degradation and irregular fracture morphology, which seriously threaten the safety and stability of power system. At present, the research of composite insulator's decay-like fracture is still in the initial stage at home and abroad, and there is no clear conclusion on the causes of its fracture, influencing factors and other important scientific and technical issues, and there is no unified understanding of the mechanism of decay-like fracture. In view of the above problems, this paper carries out acid corrosion test on core rod samples to explore the corrosion law of nitric acid on core rod and its influence on properties. The results show that acid corrosion is one of the factors causing the degradation of epoxy resin. With the increase of nitric acid concentration and soaking time, the degradation rate of epoxy resin accelerates, and the core rod sample gradually changes from emerald green to yellowish brown, then to light yellow, and finally to white hair like glass fibre. The effect of the sample under the long-time action of low concentration nitric acid is the same as that under the short-time action of high concentration nitric acid. Nitric acid will continuously erode into the core rod, resulting in the decrease of hardness and performance on the core rod surface.

1. Introduction
Silicone rubber composite insulators have been widely used in EHV (Extra-high Voltage) and UHV (Ultra-high Voltage) transmission lines because of their excellent anti-pollution flashover performance, high mechanical strength and low cost [1-3]. Silicone rubber composite insulator is composed of core rod, umbrella skirt, sheath and end accessories. Among them, the core rod is a structural component bearing the mechanical load of composite insulator, which is composed of glass fiber, epoxy resin matrix and the interface between them [2]. As an important component connecting conductor and tower, once the composite insulator is broken, it is easy to cause line drop accident and line outage. On the one hand, it will seriously affect the normal power consumption of users, affect people's life and destroy social harmony and stability; On the other hand, the line outage accident will affect the stability of the power grid, and even lead to the disconnection of the power grid, resulting in serious safety accidents.

The decay-like fracture of composite insulators is a new abnormal fracture phenomenon in transmission lines at home and abroad in recent ten year [4-5]. The composite insulator core rod is comprehensively crushed and damaged, and the mechanical and electrical properties of the core rod are completely lost [6-7]. According to the characteristics of section morphology, Xidong Liang and others put forward the "decay-like fracture" of composite insulator. It is defined as the abnormal
fracture phenomenon of composite insulator under the synergistic action of discharge, acid medium, current, moisture and mechanical stress [2].

At present, the research on the decay-like fracture of composite insulators is still in its infancy. The mechanism of core rod epoxy resin affected by various factors is not clear, so it is impossible to put forward targeted preventive measures. Existing studies believe that the cause of composite insulator aging is that there is an air gap between the core rod and the sheath due to poor sealing of the insulator sheath. During operation, water vapor invades, resulting in electric field distortion and partial discharge, resulting in the formation of nitric acid [2]. In view of the above problems, this paper starts with the acid factor, through the accelerated acid corrosion test of the core rod, explores the corrosion law of the core rod epoxy resin in nitric acid environment, and obtains the change law of the core rod performance.

2. Sample preparation and test method

A 24mm diameter acid resistant core rod produced by a core rod manufacturer is selected as the test sample, and the core rod is cut along the axis to obtain a semi cylindrical sample. The sample is 12cm long, with 30 pieces in total. In order to reduce the test error, all samples are the same batch of core rod produced by the same manufacturer. Divide every 6 of 30 samples into 1 group, numbered I ~ V groups, and the 6 samples in each group are numbered from 1 ~ 6, that is, all samples are numbered I-1 ~ V-6.

According to the existing research, the core rod will generate nitric acid under the condition of partial discharge [8-10]. The accumulation and function of nitric acid at the discharge of insulator core rod is a long process in field operation [11-12]. In order to facilitate laboratory research and accelerate the production of test phenomena, this paper uses 65% nitric acid to configure different concentrations of nitric acid solution to soak the insulator core rod in acid. Five different nitric acid concentrations (20%, 30%, 40%, 50% and 60%) were set for group I~V. During the test, prepare five beakers of the same capacity, put six samples in one group together into the beaker, pour the corresponding concentration of nitric acid solution into each beaker, make it pass through the sample, and seal the beaker mouth with a fresh-keeping film to avoid the concentration reduction caused by nitric acid volatilization during the test. The nitric acid soaking process is shown in Figure 1.

![Figure 1. Nitric acid immersion test.](image)

During the test, a sample with corresponding number was taken out every 10 days, number 1 was soaked for 10 days, number 2 was soaked for 20 days, and so on, the total length of the test was 60 days. The samples after nitric acid immersion corrosion treatment are rinsed with clean water and then put into a beaker filled with clean water for 30 days. The water in the beaker is replaced every 10 days. The purpose is to make the nitric acid in the samples precipitate sufficiently, reduce the impact of residual nitric acid on subsequent tests and improve safety. After soaking for 30 days, it can be considered that nitric acid has been fully precipitated from the sample.

Observe the appearance change of the sample after nitric acid corrosion, test its surface hardness with shore hardness tester, and measure the corrosion depth of the sample section with a scale. In the
process of using shore hardness tester, a constant force is applied to the sample to reduce the measurement error. The degradation effect of nitric acid corrosion on epoxy resin of core rod and its influence on mechanical properties of core rod were studied.

3. Results and analysis
After the nitric acid immersion test, take out 5 groups of samples from the clean water beaker and dry them. The appearance of the samples soaked in nitric acid is shown in Figure 2. After the sample is continuously eroded by nitric acid, the erosion trace can be clearly seen from the section, as shown in Figure 3. Use a scale to measure the erosion depth at the end of each sample. The variation curves of erosion depth are shown in Figure 4. At the same time, the hardness of the sample surface is measured by shore durometer. The higher the value, the greater the hardness, and the maximum range is 100. The variation curve of hardness is shown in Figure 5.

![Figure 2](image1.png)

(a) 20% concentration  (b) 30% concentration  (c) 40% concentration  (d) 50% concentration  (e) 60% concentration

Figure 2. Appearance diagram of nitric acid immersion results of composite insulator core rod.

![Figure 3](image2.png)

(a) 20% concentration  (b) 30% concentration  (c) 40% concentration  (d) 50% concentration  (e) 60% concentration

Figure 3. Corrosion trace of sample section at each nitric acid concentration.
Figure 4. Variation curve of sample surface erosion depth.

Figure 5. Variation curve of sample surface hardness.

It can be seen from the above figures that the core rod sample at 20% nitric acid concentration has no obvious change, the color remains emerald green, the surface is smooth, and the degradation of epoxy resin is not obvious. At the same time, from the cross section, the sample is basically not eroded, and there are only slight traces after soaking for 60 days. The hardness of all samples did not change and still maintained good mechanical properties.

At 30% nitric acid concentration, the color of the sample began to change with the increase of soaking time, and the sample soaked for 60 days had turned yellow green. The erosion depth on the sample section gradually increases from 0 to 1mm, and the inner glass fiber lines can be seen on the surface. However, because the corrosion degree is very shallow and still stays on the surface, there is no obvious softening phenomenon in the sample. The hardness of each sample remains unchanged, and the surface is still smooth without exposed glass fiber.

At 40% nitric acid concentration, it can be seen that the sample has a very significant change. The surface of the core rod gradually changes from emerald green to yellowish brown. The section erosion depth gradually increases to 2.1mm according to the trend of increasing about 0.5mm every 10 days, and the surface hardness of the sample begins to decrease. After soaking for 60 days, there are traces of degradation of epoxy resin on the surface of the sample, fibers are exposed, and the surface of the core rod becomes rough.

At 50% nitric acid concentration, the sample soaked for 10 days has changed to light yellow green, and gradually changed to light yellow with the increase of time. After soaking for 20 days, the surface of the sample began to show the bare glass fiber gradually, and the surface was no longer smooth. From the erosion depth curve, it can be found that the slope of the curve increases, indicating that the degradation of epoxy resin by nitric acid is accelerated. After soaking for 60 days, the erosion depth of the sample reached 4.6mm, nitric acid had penetrated into the sample, and the hardness of the sample decreased by 9%. The glass fiber on the sample surface lost the bondage of epoxy resin and began to become fluffy. After touching with hands, the glass fiber fell off.

At 60% nitric acid concentration, the epoxy resin on the surface of the core rod is seriously degraded, and the sample changes from light yellow to white. After soaking for 30 days, the epoxy resin on the surface of the sample was basically consumed, and the sample gradually changed into a bundle of hair like glass fiber, which was restored to the state before core rod pultrusion. It can also be seen from the section erosion depth that the sample soaked for 60 days reaches 5.5mm, and only a small part of epoxy resin is left on the section. The hardness of the sample decreased rapidly by about 9% every 10 days, and the final hardness of the sample decreased by 43.6%.

In conclusion, nitric acid has a strong corrosion degradation effect on core rod epoxy resin. With the increase of nitric acid concentration and action time, the degradation rate of epoxy resin continues to rise. Accordingly, the erosion depth of the core rod increases, resulting in a gradual decrease in hardness. Combined with the appearance diagram and hardness diagram of the sample, it can be found that the yellowing phenomenon will occur when the epoxy resin reacts with nitric acid, and the sample
will gradually change from emerald green to yellowish brown, but the hardness of the sample does not decrease significantly at this time, because the epoxy resin on the surface of the sample still has residues although it reacts with nitric acid, and the internal overall structure is complete, so the mechanical properties are good. However, when the sample changes from yellowish brown to light yellow or even white, it indicates that the epoxy resin on the surface is seriously degraded and a large number of soft glass fibers inside are exposed, resulting in a rapid decline in hardness. It can be found from Figures 3-4 and Figures 3-5 that the effect of the sample under the long-time action of low concentration nitric acid is the same as that under the short-time action of high concentration nitric acid. Therefore, although only a small amount of nitric acid will be produced in the actual operation, the epoxy resin of the core rod will be corroded and defects will be formed after long-time accumulation and action.

4. Conclusions

Acid corrosion is one of the factors causing the degradation of epoxy resin. With the increase of nitric acid concentration and soaking time, the degradation rate of epoxy resin accelerated, and the core rod sample gradually changed from emerald green to yellowish brown, then changed to light yellow, and finally reduced to white hairy glass fibre. The effect of the sample under the long-time action of low concentration nitric acid is the same as that under the short-time action of high concentration nitric acid. Therefore, in the actual operation process, although only a small amount of nitric acid will be produced, after a long time of accumulation and action, the core rod epoxy resin will also be corroded and form defects. Nitric acid will continuously erode into the core rod, resulting in the decrease of hardness and performance on the core rod surface.

Subsequently, material analysis will be carried out on the samples after acid corrosion to further explore the degradation mechanism of epoxy resin in acid. According to the degradation mechanism, targeted preventive measures are put forward, and the production process is improved to reduce the impact of acid on the performance of composite insulators and improve the service life.

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References

[1] Liming Wang, Zhonghao Zhang, Li Chench et al. 2016 Power System Technology 40(2) 608-613
[2] Xidong Liang and Yanfeng Gao 2016 Proceedings of the CSEE 36(17) 4778-4785
[3] Fulin Zhang and Shangang Zhang 2016 Power System Technology 40(2) 608-613
[4] Hao Shen 2020 Study on the Decay-like Degradation Mechanism of Epoxy Resin in the Core Rod of Composite Insulator Shandong University
[5] Zhihong Yuan 2019 Deterioration Characteristics and Mechanism of Materials in Composite Insulator under High Humidity North China Electric Power University
[6] Armentrout D L, Kumosa M and Mcquarrie T S 2003 IEEE Transactions on Power Delivery Pwrd
[7] Kumosa L, Kumosa M and Armentrout D 2003 Composites Part A (Applied Science and Manufacturing) 34(1) 0-15
[8] Kumosa M, Kumosa L and Armentrout D 2005 IEEE Transactions on Dielectrics and Electrical Insulation 11(6) 1037-1048
[9] Ru Feng Li, Guang Li and Xiang Li 2012 Shaanxi Electric Power 40(009) 69-71
[10] Gou B, Xie C, Xu H, et al. 2021 Engineering Failure Analysis 127(1) 105468
[11] Carpenter S H and Kumosa M 2000 Journal of Materials Science 35(17) 4465-4476
[12] Fuzeng Zhang, Lei Song and Ruihai Li 2012 High Voltage Engineering 38(11) 3093-3100