Electric Power Systems Research 117 (2014) 202–209

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Application of unusual techniques for characterizing ageing on polymeric electrical insulation

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ARTICLE INFO

Article history:
Received 16 October 2013
Received in revised form 17 August 2014
Accepted 24 August 2014
Available online 16 September 2014

Keywords:
Replica technique
Polymeric housing insulation
Microstructure characterization
SEM
Aging
Electrical insulation

ABSTRACT

The degradation process caused by electrical stresses and weather conditions on electrical non-ceramic insulation was analyzed with non-destructive techniques. Traditional replica technique was introduced as a novel method to characterize microstructure changes on polymeric insulation. Static contact angle and roughness measurements were also used to characterize non-ceramic insulation. These non-conventional techniques have shown to be appropriate for evaluating aging on electrical insulation surfaces of bushings and surge arresters installed in electrical substations. The replica technique has drawn attention for being an innovative analysis test for characterizing polymeric insulation.

1. Introduction

Polymeric composite insulating materials, also known as non-ceramic materials, have been used as housing insulation in high power electrical devices such as: insulators, surge arresters and bushings. Generally, non-ceramic insulation is made of silicone rubber, EPDM and Ethylene Propylene Rubber (EPR)/silicone alloys, and inorganic fillers. They came to have a strong commercial interest and were considered a mature product since the early 1990s [1,2]. While rubber composites' performance is generally satisfactory, polymeric insulating materials are much prone to aging than their ceramic counterparts. Hence, it is of practical interest to investigate the performance and the chemical changes of polymeric housing insulation under field conditions. A comparison of laboratory aging test results with those obtained in natural environments yield useful information on long term performance.

In order to obtain information of the degradation process, the insulating material must be characterized by different techniques. Visual observation, hydrophobicity classification and surface pollution evaluation are part of the physical characterization for polymeric housing insulation. Some others involve electrical measurements as leakage current measurement and corona monitoring. In addition, material characterization is carried out by Fourier Transform Infrared (FTIR) spectroscopy, chalking analysis and surface microstructure observation. These techniques have been widely used to characterize polymeric outdoor insulation [3–6].

Some other methods that have also been used for characterizing non-ceramic materials include: light emission, thermal imaging, and acoustic measurements [7]. In addition, diagnostic methods as laser induced fluorescence and quality control of internal interfaces are still under development. Each of these characterization techniques reveals a part of the degradation process that is also affected by high pollution, extreme weather conditions and electrical stresses.

However, some of the relevant characterization tests commonly require a sample of housing material to be cut off. Examples of these tests are: chemical analysis, FTIR spectroscopy, sessile drop technique hydrophobicity measurement and scanning electron microscopy microstructure observation. Consequently, it is difficult to use these powerful methods for evaluating aging and degradation process of polymeric housing materials in field.

In this paper, we take advantage of some nondestructive techniques to characterize non-ceramic electrical insulation in laboratory and in field. These include hydrophobicity evaluation by

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http://dx.doi.org/10.1016/j.epsr.2014.08.019
0378-7796/

measuring static contact angle, roughness of the polymer surface, and microstructure analysis by the novel application of the replica technique to polymeric insulating materials.

For the polymer microstructure analysis, the replica technique is adapted to non-ceramic insulation. This has shown to be appropriate to follow up structural changes of the housing materials. The materials used for this investigation include polymeric insulation based on EPDM and silicon rubber. They were aged in an accelerated way in laboratory, under different weather conditions and electrical stresses [8]. Moreover, we introduce the evaluation of polymeric insulation within field by using the replica technique, plus the roughness and contact angle measurements. The obtained results have been correlated to electric field distribution and leakage current measurements.

2. Unusual techniques used for characterizing aging

In this work, the unusual techniques used for characterizing aging on polymeric electrical insulation are hydrophobicity, surface roughness, and microstructure replication. Additionally, leakage current is monitored by recording frequency and range of peak currents, using a custom-built data acquisition system [9]. The electric field distribution is measured before and over the course of the test period, with an instrument that was originally developed at Hydro-Québec [10].

2.1. Hydrophobicity

A hydrophobic surface has a water repellent property, whereas a hydrophilic surface can be easily wetted. The contact angle that a drop makes when it comes into contact with a solid surface is a measure of the surface wettability. The most commonly used method for evaluating hydrophobicity is the so called sessile drop technique. However, it is generally only applicable in the laboratory.

The hydrophobicity of the housing polymer is evaluated by placing a drop of distilled water on the previously cleaned (with ethylene alcohol) polymeric surface. Then, a photograph of it is taken with a high resolution digital camera. By digital image analysis and the use of special software, the contact angle is measured. The data of the contact angle were obtained from the mean of six to nine measurements that were made to different drops placed on the surface.

2.2. Surface roughness

Roughness is the measure of a surface texture. It initially indicates the surface profile that a material has due to the manufacturing process. It could be used to measure the aging degree since an increase in roughness due to surface erosion is expected. The roughness measurements were made with a roughness profile meter (Mitutoyo SJ-201), and at least three evaluations were made for each roughness data point. All measurements and surface characterization were made off-line.

2.3. Microstructure replication

Replication is a non-destructive technique, generally used to evaluate microstructure changes caused by service failures in metallic materials. It records and preserves the topography of a microstructural surface as a negative relief on a thin foil of polymeric material. Replica can be observed with the use of an optical microscope, where standard magnification ranges from 50 to 1000×. On the other hand, if the reproduced surface is properly prepared with the application of a conductive support, the replica can also be observed with a scanning electron microscope (SEM). This provides the possibility of observing reproduced microstructure aspects with a higher magnification. While using SEM examination, special care should be taken because the electron beam can produce excessive heating of the surface and then possible deformation of plastic material.

Table 1
Material characteristics of samples.

Sample no.	Device	Material	Place of test
1	Surge arrester	EPDM-ATH[a]	In field
2	Surge arrester	EPDM-ATH[a]	Laboratory
3	Surge arrester	Silicone Rubber	Laboratory
4	Hollow core bushing	Silicone rubber-ATH[a]	Laboratory
5	Hollow core bushing	Silicone rubber	In field

[a] ATH = alumina tri-hydrated.

Table 2
Weather cycles designed to the accelerated aging test.

Cycle	Cycle time (h)	Applied AC voltage 66.4 kV rms
Salt fog	24	Yes
Dry + UV	12	Yes
Clean fog	24	Yes

Because of the acceptance of replication as a non-destructive test for metallic surfaces in field, the replica technique has been standardized by international standard organizations like ASTM (E 1351), ISO (3057) and NORDTEST (NT NDT 010). However, this technique has not been commonly used for microstructural analysis of polymer insulating materials or for other kind of rubbers and plastics. In this paper, the replica technique is introduced for being used to characterize non-ceramic materials.

The surface microstructure replication of polymeric housing materials is made using cellulose acetate film (0.05 mm thickness) supplied by Goodfellow Cambridge Limited. As softening solvent, analytic grade acetone by Aldrich Chemical is used. Replication is made softening an acetate foil of 2 cm × 2 cm in acetone, and then placing it on a cleaned surface of non-polymeric insulation, in order for it to be analyzed. After the solvent is evaporated and the foil is hardened again, the foil is removed and observed by using a Carl Zeiss DSM-960 scanning electron microscope.

3. Evaluated equipment and aging methodology

The unusual techniques to characterize aging on polymeric electrical insulation were evaluated on three surge arresters and two hollow core bushings. One surge arrester and one hollow core bushings were installed in field while the other devices were aged in laboratory. The main characteristics of these devices and the place of test are presented in Table 1.

The sample 1 was installed in a 115 kV line of a coastal power substation located in the North of Mexico, where the geographic conditions are Mediterranean-like humid and with low rain. The sample 5 was installed in a 230 kV dead tank breaker at a generation plant also located in the North of Mexico, but far away from the coast. All the conventional outdoor insulation of the substation and the generation plant has been historically washed at least several times per year.

The samples 2–4 were used for accelerated aging tests in laboratory, using a multistress environment chamber (5.1 m wide × 5.7 m high × 7 m long), to promote surface aging of non-ceramic insulation [8]. The chamber was conditioned to apply UVA-340 light exposure with an average of 0.65 W/m^2, salt fog: 5150 μS/cm, clear fog: 50–70 μS/cm and water flow rate: 1.35 l/min. The applied voltage was phase to-ground 66.4 kV rms throughout the test. The used methodology to age the testing samples consists of three cycle sequences [8], as shown in Table 2: the first one consists in stressing the insulation for a period of 24 h in salt fog, followed by a 12 h dry