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Aspects of moisture ingress in polymer housed surge arresters

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ABSTRACT

Polymers have been extensively applied in the industry, especially in energy system e.g. due to their good processability and insulation properties. However, all polymers are permeable in different extent, which requires a good knowledge about the process of permeation through these materials. In this study the moisture dynamics of four different surge arresters were studied in several ways,—at first by analysing the moisture diffusion properties of the housing polymers and finally by testing the full arrester structures against moisture ingress. Housing polymer composites were evaluated using thermogravimetric analysis and differential scanning calorimetry while the polymers' ability to withstand moisture diffusion was studied by water vapor transmission rate measurements. Moisture ingress behavior of the full surge arresters was examined by daily measurements of internal resistive leakage current along 30 days immersion test. Although correlations were found between the material composition and the diffusivity through the polymer, the moisture dynamic is deemed to be much more complex in the full surge arrester. Moisture permeation through separate housing material samples was typically high compared to internal leakage current formed in real arresters which highlights the main conclusion drawn,—internal structures and long term quality of interfaces are the key issues in preventing moisture induced degradation in metal oxide surge arresters.

1. Introduction

With permanent need for increased reliability of energy system, the performance of distribution surge arresters has become a significant concern, especially in countries with high probability of atmospheric discharges. To be able to predict possible failures and thus improve the operational electricity network condition it is necessary to know and understand the main causes of failures associated with these protective devices. Some of the main reasons for metal oxide surge arresters malfunction is described by Ref. [1] and studied by Ref. [2] to create a feasible technique for monitoring their condition.

Several studies involving silicon carbide arrester [3,4], MOSA[1] with porcelain housing [5] and MOSA with polymeric housing [6,7] have showed that moisture ingress was by far the most prominent cause of arrester failures. Although modern polymer housed arresters have in general shown better performance against moisture ingress in the field [8–10], the polymer materials in the other hand always allow moisture permeation [11]. This relation emphasizes the fact that their field performance is much more complicated matter than just the moisture ingress through housing polymer. Therefore, it is extremely important to acquire comprehensive data regarding the mechanisms that allow the formation of water and consequently lossy layers inside the arresters. Understanding and correctly estimating the moisture dynamics in surge arresters with polymeric housing is essential for improving the manufacturing process, operation and maintenance of MOSAs and to ensure the correct behavior of the equipment/facilities protected by them.

Water can be formed in the internal parts of surge arrester as a result of partial discharge activity and the consequent chemical reactions or it can penetrate into the arrester by capillary effect through imperfections in the housing, sealing structures, cracks, etc. or by diffusion through polymeric housing [6]. In this way, the arrester design (void free, good sealing) is deemed a very important feature in the arrester behavior which can contribute to minimize the final moisture collection. It is in practice a harmful aspect,—surge arrester structures must be designed in such a

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[1] Metal oxide surge arrester.

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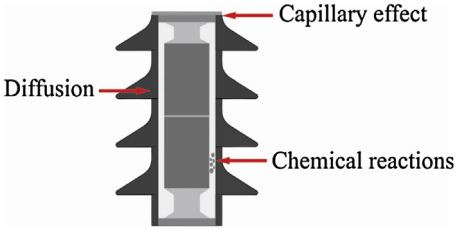

Fig. 1. Moisture formation in polymer housed surge arresters (Adapted [15]).

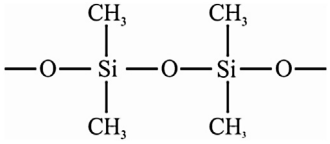

Fig. 2. Polydimethylsiloxane chemical structure (Adapted [19]).

way that no voids or gas spaces can be allowed directly below the housing material.

Although good reports exist concerning the moisture diffusion in insulator housing [12–14] as well as regarding the behavior of complete devices in moisture ingress tests [15,16], the full picture of the moisture dynamics and formation of detrimental internal leakage currents in real MOSAs is still incomplete. This paper attempts to assess the performance of polymer housed metal oxide surge arresters of four designs in moist conditions, by studying the moisture permeation properties of housing materials as well as formation of moisture induced internal power losses in complete arresters, by means of various experimental tests. Even though this work focuses mainly on distribution class arresters it is expandable to higher class arresters.

2. Moisture dynamics in surge arrester

A permeation process comprises a sequence of events, in which sorption, diffusion and desorption takes place [17]. All polymers are permeable to gases and vapors to different extents and because of their relevant ability to resist high electric fields with negligible conduction layer, they have been extensively used for insulating applications, notably for surge arrester. MOSAs are mostly used outdoors what means they are constantly subjected to environmental conditions, such as rain, wind, solar radiation and pollution, introducing a constant humidity stress on the housing surfaces. The external factors have great influence in their correct behavior; however, internal factors as design and material quality also affect its performance.

Moisture inside surge arrester, for example, may occur due to internal chemical reactions when there is internal discharge activity in the presence of suitable materials [15]. Since this process demands some gas space, it normally does not take place in distribution MOSAs where such structures are in practice no longer in use for newest MOSAs generations. The moisture can also penetrate surge arrester by capillary effect [18] through a thin crack, etc. It can occur due to some manufacturing defect, cracks or corrosion on the end cap seals caused by aging. However, with the technological development on production of polymeric MOSA, the above mentioned problems are rather rare nowadays. Instead, moisture permeation by diffusion takes place in all polymers when the stresses are high enough [15], which needs to be carefully analysed in order to indicate whether it is significant or not in polymeric housings. The moisture formation possibilities in polymer housed surge arrester are depicted in Fig. 1.

Diffusion through a polymer is shown to normally follow the Fick's laws, although for certain filled materials a slightly different Langmuir type model is shown to fit, in case strong physical or chemical interaction with absorbing water molecules is exhibited. These models are quite nicely presented for example in Refs. [12,13]. In fact, the water molecule possesses a really high solubility in polymers and can diffuse even in a hydrophobic polymers [11]. Understanding this process is thus fundamental to the evaluation of polymer housed metal oxide surge arresters, especially those used in tropical climate areas, which present high air humidity during the majority of the year.

3. Composition of polymers used as surge arrester housing

Composite polymers are mixtures of different substances (organic and/or inorganic). The most important substance of the composite material is the polymer (macromolecule) usually called polymer matrix, on which fillers and additives are added. Most of the fillers used in polymeric compounds are inorganic elements added in large quantities (well more than 10% of the compound weight in case of housings) and has the function of modifying some of compound's property without dissolving in the matrix. On the other side, most of the additives included in the polymer formulation are organic and used only in a small proportion (typically less than 1% of the compound mass). Currently the most common polymers applied to insulation purpose are silicone rubber, ethylene propylene rubber, ethylene propylene hexadiene monomer and ethylene vinylacetate.

3.1. Silicone rubber

The silicone rubber compound presents unique dielectric and surface properties and for this reason is perfect as insulating material. Probably the most known silicone molecule is the polydimethylsiloxane (Fig. 2) and to convert the silicone molecule into silicone rubber it is usual to replace some methyl groups in the main chain by vinyl groups, so the polymer matrix is composed by (vinylmethyl-*co*-dimethyl) siloxane–P(VM-*co*-DM)S.

The molecular structure of silicone rubber consists of a main chain with silicon and oxygen atoms perfectly intercalated. Each silicon atom is bound to two methyl (CH_3) molecules which are typically organic.

Aside from polymer matrix, the silicone rubber compounds have two important macro-constituents inorganic fillers: alumina trihydrate and silica.

The alumina trihydrate is a crystalline material also known as aluminum hydroxide, which main purpose is to decrease the compound flammability and improve some specific dielectric properties (as increase in surface current/discharge resistance).

In some situations the ATH[2] can be replaced by magnesium hydroxide described by molecular formulation ($Mg(OH)_2$). Although MH[3] is more resistant to thermodegradation than ATH [20] (as highlighted in Fig. 3) it is economically unfeasible for most application.

The silica (molecular structure—SiO_2) can be found in a crystalline or amorphous form, but as the major function is to improve the mechanical properties of silicone rubber compounds (i.e., hardness, maximum elongation, tensile strength) the crystalline silica arrangement is preferred to amorphous form, even though the last one being cheaper. Another important aspect that makes silicone rubber widely used in insulation applications is the ability to repel water molecules in liquid state. The hydrophobic characteristic pre-

[2] Alumina trihydrate.
[3] Magnesium hydroxide.