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Reliability of directly-molded polymer surge arresters: Degradation by immersion test versus electrical performance

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ABSTRACT

This technical report describes an experimental analysis of metal–oxide surge arresters applied to power distribution network. This analysis is performed from periodical measurements of leakage current of the samples and hydrophobicity of the external polymeric housing correlated to the aging/degradation process by saline water immersion at 90 °C for 3 months, in order to simulate 20 years of field application. Based on this evaluation, the useful life and time degradation of polymer arresters are analyzed from the progressive variation of their electrical characteristics as a function of the immersion time.

1. Introduction

Surge arresters are widely used in power distribution and transmission networks to protect systems against transient overvoltages from lightning and switching events [1–3]. Usually, these protection devices have an average useful life that varies from 20 up to 25 years, even in critical operation conditions [4].

Polymer-housed arresters composed of zinc oxide (ZnO) varistors are usually subject to environmental and electrical stresses. In tropical regions, these devices are more exposed to moisture ingress because of the high air moisture, temperatures and isokeraunic indices, which represent the principal cause of failures in porcelain and polymer-housed surge arresters [5,6]. The moisture ingress into the arrester housing results a progressive increase of the leakage current due to the overheating of the active parts, continuous degradation of the varistor discs and conductor interface among them.

The overvoltage surge protection using polymer-housed arresters in the distribution network is relatively a recent technique, dated from 1986 [6,7]. Currently, some few technical reports are available in the literature dealing with the electrical performance of surge arresters taking into account the aging process and the progressive degradation by environmental factors. Many issues related to reliability, security and maintenance of power transmission/distribution systems could be significantly improved from the previous knowledge or estimation of the electrical performance of these surge protection devices as a function of the physical–chemical degradation along of the useful life [6].

Lahti proposed an extensive methodology to detect moisture ingress into surge arresters, by DC leakage current, AC power loss and partial discharge measurements [7]. As a general conclusion, Lahti suggested that for demanding ambient conditions with high humidity stresses (e.g. tropical regions and rain forests) the arrester types require to be selected with care, with a particular attention to the resistance to moisture ingress.

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The literature shows two main tests to evaluate the moisture ingress in polymer arresters: by humidity chamber and by water immersion.

The first test consists of a chamber with controlled humidity and temperature, according to the region to be studied. The surge arresters are immersed into the humidity chamber and the moisture ingress is evaluated based on the DC leakage current behavior [8]. This test represents an aging process by combination of two or more stresses, such as: very humid ambient conditions, AC signal, surge current impulses, mechanical stresses, dry air periods and many other combinations representing additional stresses. The purpose of the additional stresses are to obtain a wide range of leakage current behavior possible in a given atmospheric conditions.

The water immersion test consists of a chamber where the arresters are totally immerse in 70–100 °C saline water in order to achieve a faster diffusion process in the polymeric housing. The DC leakage currents are periodically monitored through the immersion process. Before measurements, the arresters are cooled to ambient temperature and the surface of the housing are dried out [8,9]. The DC leakage current measurements are carried out several times throughout the test series to obtain sets of internal leakage current curves as a function of the immersion time.

Other tests combining humidity and impulse current stress or AC stress with internal moisture content are described in details in Refs. [6–9]. There are a few variations of combined test series to evaluate the moisture ingress and aging of surge arresters based on electrical measurements. However, the most of these combined tests are given by combination of the two main procedures described in this section.

This research proposes an analysis of ZnO surge arresters with silicon housing submitted to aging process by water immersion and periodical monitoring of their electrical performance. However, differently of the prior researches, the water temperature is controlled at 90 °C and the electrical tests are performed based on the MCOV and the AC leakage current measurement.

In references [7–9], the DC leakage current was monitored in order to detect the moisture ingress into the metal–oxide arresters. This new approach proposes the AC leakage current measurement based on the maximum continuous operating AC voltage (MCOV). This technical characteristic is given in the datasheet of any surge arrester model and manufacturer. Furthermore, the analysis of the surge arresters based on the AC power signal represents a more realistic situation, since these devices are used in AC power systems. Thus, this paper proposes the analysis of the moisture ingress into polymeric surge arresters by measurements of the AC leakage current instead the DC current, which can be performed based on the MCOV.

Another proposal of this research is to estimate, from an approach based on the technical literature, the average useful life of the arresters of each manufacturer. A final evaluation of the hydrophobicity level of the external silicon housing is carried out at the end of the immersion test, correlating their physical–chemical characteristics to the electrical performance associated with the active components of these protection devices. This experimental research is performed based on twelve polymer-housed arresters provided by three worldwide-known manufacturers and based on the *International Electrotechnical Commission* (IEC) recommendations, ANSI standards and STRI Hydrophobicity Classification Guide.

2. General characteristics of metal–oxide surge arresters

In order to provide a brief background of the subject-matter approached in this research, an introductory description is presented on the electrical characteristics and the constructive structure of metal–oxide surge arresters with polymeric housing.

Initially, the conventional equivalent representation of a metal–oxide arrester is introduced, emphasizing its electrical parameters. Thereafter, a general description on the physical structure of polymer-housed arresters is presented.

2.1. General characteristics of polymer-housed surge arresters

The non-linear electrical behavior of a metal–oxide surge arrester is practically resumed by its voltage–current curve, intrinsically related to the electrical and constructive characteristics of the varistor column. Fig. 1 shows samples of typical voltage–current curves of a generic ZnO surge arrester, considering the three operation regions for DC and AC operation at 20 °C and at 100 °C.

The function indicated by I_R is the active current through the surge arrester. The term I_C is the capacitive current of the surge arrester. In nominal operation conditions, a conventional surge arrester has a leakage current in the range of hundreds of microamperes, e.g. a 10 kV/10 kA arrester has a leakage current between 600 up to 800 μA.

Fig. 1 shows that the leakage current is classified into three operation ranges, which are function of the voltage at the terminals of the surge arrester. These operation regions are classified as: low electric field (region 1), medium electric field (region 2) and high electric field (region 3) [10].

The electrical characteristics associated with a metal–oxide arrester can be expressed based on several models. One of the most used equivalent electric circuit is presented in Fig. 2 [11].

The inductance L is associated with the geometry of the metal–oxide varistors. The resistance of the ZnO microstructures (metal–oxide grains in the range of a few micrometers), which represent great part of the varistor composition, is practically represented by R_g and the term R_P is the non-linear resistance of the granular barrier among ZnO microstructures (these two resistances are variable with the physical–chemical constructive characteristics of each metal–oxide surge arrester). The term C is the capacitance dependent of the dielectric constant among the inter-granular barrier, which varies according with the manufacturing process [11].

Therefore, based on Fig. 2, the current I_R is the active current through the non-linear resistance R_P and the capacitive current I_C is the displacement current associated with the dielectric composition of the granular barrier among the ZnO microstructures.

2.2. Constructive structure of ZnO surge arresters with polymeric housing

The varistor elements, which represent the active component of the surge arrester, are mainly composed of ZnO with many other doping metal oxides, e.g.: bismuth oxide (Bi_2O_3), cobalt oxide (CoO), chromium oxide (Cr_2O_3), manganese oxide (MnO), antimony trioxide (Sb_2O_3) and others. In fact, the additive metal oxides

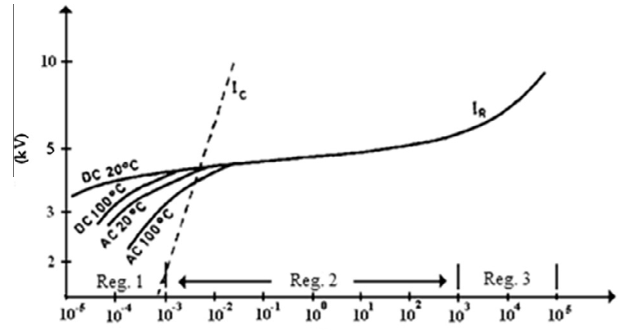

Fig. 1. Voltage–current curves for the conduction regions of ZnO surge arresters.