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Ceramic insulators coated with titanium dioxide films: Properties and self-cleaning performance

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ABSTRACT

Ceramic insulators used in power transmission lines were coated with titanium dioxide films with the aim of reducing atmospheric soiling accumulation over its surface. Properties as adhesion, thickness, roughness and phase composition of films were evaluated. Contac angle was also measured. Dry-flashover and leakage current electrical tests were carried out in coated and un-coated insulators to evaluate the influence of titanium dioxide film in electrical properties. The in-service behavior of coated and un-coated insulators installed in power transmission towers were evaluated in two sites with different soiling source. Surface characterization of insulators before and after field exposition was performed by Micro-Raman Spectroscopy. The coatings exhibited self-cleaning properties and electrical properties of insulators were not affected. After 5 months of exposure in the energized power line, a decrease in the surface soiling was observed in Balsillas (organic soiling). Nevertheless, in Calera (inorganic soiling) self-cleaning effect was not observed.

1. Introduction

The soiling of in-service electrical insulators exposed to the atmosphere is a major problem in power transmission lines. It is produced by deposition of particles from air which can be natural or generated by artificial pollution as a result of industrial, agricultural or construction activities [1–3]. Another source of polluting agents, considered natural, is bird excrement [4]. Pollution distribution on the insulators in non-uniform due to their shape and their position in-service, weather conditions and the action of the electric field [5]. Rain does not always clean the insulator surface, especially under strong marine or industrial pollution, or when rain is not regular enough. The accumulation of particles on the insulator surface mixed with moisture conditions can reduce the dielectric proprieties of insulator and increase the leakage currents [6]. This can cause flashovers, insulator perforation, ruptures and corrosion of metallic elements [7]. The flashover probability in polluted insulators considerably increases as the conductivity of the contamination layer increases. This phenomenon is the main external cause of insulators rupture at nominal voltage. Generally, flashover in overhead transmission lines is defined as the dielectric breakdown of air in the vicinity of the insulating surface. The initial discharge generally occurs in the air, because it has a comparatively low dielectric strength [2,8]. The increase in frequency of maintenance programs in high incidence areas is a soiling consequence [8] and leads to increased costs for cleaning and replacement of insulators. Furthermore, frequent service outages increase economic losses and user dissatisfaction, affecting the competitiveness of utilities.

Common preventive maintenance plans include water washing as the most used alternative. In sites with high pollution deposition, the insulator washing is expensive and requires much manpower and water [9]. Other methods involve the application of silicones or grease on the insulator surface before being put into service [3]. This alternative is relatively expensive, but its main disadvantage is that it gradually lose their dielectric and viscosity properties, and for that, it is necessary to remove and reapply the coating. The frequency of this activity can vary from months to several years, depending on the type and level of contamination and the environmental conditions [10]. Another solution is related with the insulation coordination, in which the Basic Insulation Level (BIL) of the transmission line can be oversizing to increase the withstand voltage stresses and the leakage path length on the insulation to reduce the flashover probability or just modifying

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their insulator geometry to reduce the particles deposition. However, this procedure is restricted by tower dimensions [11]. Finally, room temperature vulcanized (RTV) coating is an effective method against soiling, but presents some disadvantages like low mechanical strength and poor aging performance [12].

The main challenge to develop protection alternatives against insulators soiling is to find good durability solutions, with the aim of reducing the frequency of maintenance actions. In the electrical transmission and distribution towers in many countries, this type of maneuver involves complex logistics for reducing service affectations, which greatly increases costs, especially in remote areas.

A novel method for reducing soiling in ceramic insulators, developed in CIDEMAT was evaluated in this work. The method involves the application of a continuous coating of titanium dioxide with self-cleaning characteristics. Self-cleaning surfaces avoid organic matter (and in some cases the inorganic compounds) adhering to the surface. This effect can be achieved through photocatalytic reactions within a titanium dioxide thin film coating. Moreover, these super-hydrophilic surfaces attract water, forming a continuous film on the surface that easily flows over dragging the dirt and dust [13,14]. Titanium dioxide films are very stable, non-toxic nor polluting [15,16]. The costs of applying the film for each insulator are approximately 4 USD and it can be applied in used insulators after a simple surface cleaning. On the other hand, the authors have found that these coatings have better resistance to erosive wear than ceramic substrate [17].

In this study, properties as adherence, thickness and roughness of coatings were evaluated, and the contact angle on the coating surface was measured. By means of dry-flashover and leakage current tests the influence of the titanium dioxide coating on the electrical properties of insulators was analyzed. The in-service performance of coated insulators was evaluated in two electrical transmission towers located in two rural sites with different characteristics, by visual evaluation of degree of soiling and characterization of insulators surface before and after field exposure.

2. Materials and methods

Titanium dioxide coatings were applied on glazed ceramic insulators employed in overhead lines and substations with operating voltage exceeding 33 kV. In this case, suspension cap-and-pin insulators, 254-mm diameter, were used. The coating is transparent and coated insulator has a brighter appearance compared to uncoated insulators.

2.1. Evaluation of coating properties

Initially, contact angle was measured on the coating surface to evaluate their hydrophilicity. The measurements were done before and after UV irradiation at different times. Such irradiation is essential in order that the coating acquires self-cleaning properties and was performed in a Q-UV/SE weathering chamber. The wavelength of ultraviolet light was 254 nm. The Drop Method was used to measure the contact angle, according to ASTM C-813 standard [18]. Coating adhesion to ceramic substrate was evaluated according to ASTM D-3359-02, Method B [19], and the coating area under test was observed with a Nikon Eclipse E200 light microscope.

The thickness and the roughness of the coating were measured using an AFM-A NanoScope III multimode 3100, digital instruments (Veeco) with a silicon AFM tip used in the tapping mode and a scan rate of 0.2 Hz. AFM technique also allowed observing the morphology of the coatings. Identification of phases present in the coating was performed by Micro-Raman spectroscopy with confocal HORIBAN JOBIN YVON equipment, Model LabRAM HR, using a He/Ne laser (632 nm, 17 mW, at room temperature).

Fig. 1. Biological soiling of insulator in Balsillas.

2.2. Electrical tests

Insulators with and without coating were submitted to dry flashover voltage tests at industrial frequency and leakage current tests [20,21], maintaining the same relative humidity (∼83%) and temperature (∼23 °C) conditions. These tests were performed only before field exposure to ensure that the coating does not affect the electrical properties of insulators, which was a prerequisite for their installation on energized towers for field evaluation. Dry flashover voltage was obtained as the value of the voltage at the moment that the flashover occurs. These tests were made for each insulator repeating the measurement five times, and the final value was the average value of the five times test. The leakage current was measured on the grounding conductor connected to the insulator. This conductor was passed through a micro-ammeter before going to ground. The voltage applied to the conductor varied between 0 kV and about 40 kV, and the current value was sensed by an Auto ranging Digital Multimeter True RMS and AC voltage frequency of 100 kHz True RMS.

2.3. Field exposure

For the field exposure, two power transmission towers located in sites with different types of soiling were selected. In both sites, strings of insulators with and without coating were installed horizontally, and a visual assessment of individual insulators was done after five months of exposure. The first site, called Balsillas, is rural and has high humidity and strong wind currents, which facilitates the growth of biological type organic pollutants, mainly algae. The second site, called Calera, is also rural, although soiling occurs primarily because of its proximity to a cement factory that emits significant amounts of particulate matter. Both tropical-humid sites have high soiling rates. Insulators installed in such sites must be replaced after one year or less. Fig. 1 shows an insulator, fully covered with biological soiling, retired after 9 months in Balsillas (before installation of coated insulators).

Temperature and relative humidity were recorded continuously in both sites during exposure period. Upon completion of field tests, exposed insulators were analyzed by Micro-Raman spectroscopy, in order to observe possible changes under the influence of exposure environment and to identify the compounds present in those cases where soiling was evident.