Hydrophobicity transfer mechanism evaluation of field aged composite insulators

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Abstract*- Surface hydrophobicity is a critical property of silicone rubber composite insulators. It is the primary advantage in comparison to ceramic and therefore is the first to be investigated when field aged insulators are examined. Initially hydrophobicity was evaluated by static contact angle measurements. However field and laboratory investigations have revealed that in the case of outdoor high voltage insulation, it is the dynamic performance that is critical and especially the capability of hydrophobicity recovery, available due to a low molecular weight molecules migration mechanism. This mechanism efficiency is related to the material formulation but also to the experienced service conditions and the aging degree of the insulator. Therefore laboratory evaluation of field aged insulators can be considerably beneficial for both researchers and utilities. In this direction the hydrophobicity recovery efficiency of three field aged insulators, with two different base polymers is investigated in this paper. Both static and dynamic measurements are performed, according to the CIGRE guidelines. The results verify the superiority of silicone rubber polymer and reveal a recovery time exceeding 10 hours. Not considerable differences have been observed due to aging in this case. Further investigation is required, in order to be able to correlate this behavior to the insulator efficiency.

***Keywords*— Hydrophobicity, Transfer, EPDM, SIR, LMW, Migration**

I. Introduction

Pollution of high voltage insulators is a problem for many outdoor high voltage installations worldwide with a great impact to the network operation and reliability. In an effort to minimize the possible problems and power outages due to pollution, many utilities adopted the application of composite insulators, instead of ceramic, although the expected insulator service lifetime is considerably less. The primary advantage that motivates this selection is the hydrophobic surface behavior, available in the case of composite materials [1].

The improved field performance of composite insulators and coatings has been proved by many applications worldwide. In all cases considerably lower levels of surface activity in pollution conditions have been observed [2]. However it is also evident that periods of hydrophobicity loss also take place. During these periods the performance of a composite insulator is similar to a ceramic, thus the outage possibility is considerably increased. Consequently, the capability of maintaining the hydrophobic behavior in field conditions, becomes a critical issue, considering that the deposition of hydrophilic contamination cannot be postponed.

This capability is probably the primary advantage of Silicone Rubber (SIR), which has imposed this material as the optimum and lately the only selection in this field [3-5]. Both field performance and laboratory investigations have revealed the material capability of recovering the surface behavior, as a result of a migration mechanism, of Low Molecular Weight (LMW) silicone rubber molecules, from the material bulk to the surface and further within the deposited contamination film [6]. The existence of this mechanism has been verified by laboratory investigations [3-11].

Therefore, the insulator efficiency is strongly dependent on the mechanism efficiency, which will further determine the application reliability. The time necessary to complete a recovery cycle, can be indicating for the material efficiency, when correlated with the service conditions experienced and especially the rate of deposition. For example a recovery cycle of 30 hours can be sufficient in a case where the necessary time for the accumulation of the critical pollution amount is more than a week. On the other hand, for the same service conditions a recovery cycle exceeding a period of 60 hours can be critical.

There are many parameters that may determine the duration of the recovery cycle. The material synthesis and age, the conditions experienced and properties of the deposited contamination are the most critical among them. As a result the insulator behavior can differ from case to case. Therefore, in order to evaluate the recovery capability of an insulator, an evaluation test has been introduced by Cigre WG. D1.14 [2], where a specific type of an artificial contaminant is adopted and the recovery process is investigated by contact angle measurements.

In this study, the recovery capability of three composite insulators is evaluated. All three are insulators selected for the 150kV power network of Crete, a Greek island with intense pollution problems. Among them one is new (ins A) and has not been installed in the field and the other two (ins B and C) are field aged. Firstly a review of the recovery mechanism concept is presented. Further the implemented test technique is analyzed and the test results are presented. Finally the insulators performance is evaluated based on the considered test results.

II. Hydrophobicity Transfer Mechanism

Polymeric housings or coatings made of silicone rubber (SIR) are known to maintain their hydrophobic properties even under severe polluted conditions. If a polluted SIR insulator is sprayed with water, distinct water droplets will be observed on the contaminated layer and finally the water will not be absorbed by the pollutants (Fig.1). Thus the total hydrophobic performance of a polluted SIR insulator avoids the wetting of the accumulated pollution layer and the formation of surface conductive films. This unique advantage of silicone rubber over other polymeric materials is due to the hydrophobicity transfer mechanism.

(a)

(b)

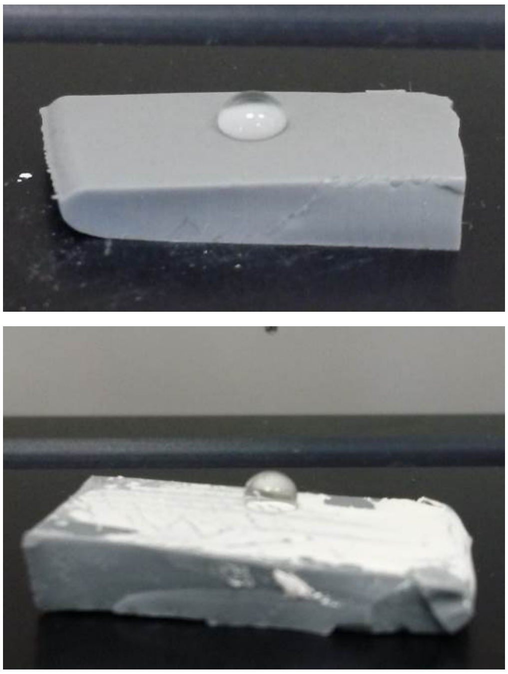

Fig 1: Hydrophobic behavior of: (a) clean SIR shed , (b) polluted SIR shed.

Hydrophobicity transfer mechanism refers to the migration of low molecular weight (LMW) components from the bulk of the SIR to the pollutant surface through the pollution layer. LMW components are short length backbone chains of silicone polymer [4] which tend to migrate from the bulk to the surface [5] (Fig.2). The LMW components are produced both in the polymerization procedure of silicone rubber and/or its degradation [5, 6]. The LMW components could be either linear or cyclic with the former seems to be more effective for covering the deposited pollutants [6].

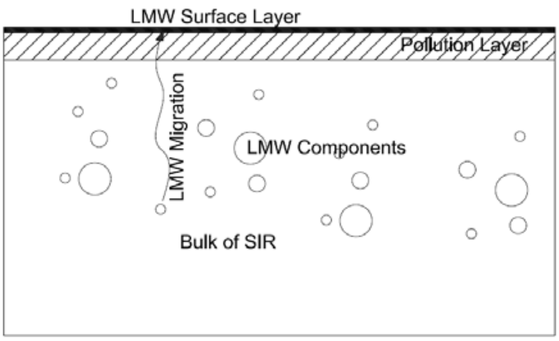

Fig 2: Migration of low molecular weight components from the bulk to the surface of the polluted SIR insulator.

In the literature many mechanisms have been proposed for the transfer of hydrophobicity, some of them refer to evaporation, diffusion and adsorption of LMW components [6]. The content of LMW components is estimated to be 3% for new SIR insulators and 5% for RTV coatings in cyclic formation [6]. The ageing of insulators could either prevent the hydrophobicity transfer mechanism by the crosslinking of the polymeric surface and the decomposition of LMW components or contribute to the formation of LMW components by the scission of the longer backbone chains to shorter [4]. In addition the migration of LMW components from the bulk to the pollution layer can be influenced by the material structure, pollution composition, ageing mechanisms and environmental factors [3-11]. Thus the hydrophobicity transfer speed is strongly related to the type of silicone rubber material, the age, the thickness of the bulk material, the thickness and the type of the deposited pollution layer, the temperature and the humidity [3-11].

Furthermore, depending on the material formulation, the applied stresses in service conditions, the resulting material deterioration due to aging and the properties of the deposited contaminants, the recovery process requires a specific period of time, which is critical for the material efficiency. In order to evaluate the efficiency of a composite insulator in the field it is necessary to correlate the recovery period to the pollution model evident in each case, i.e. the time necessary to acquire a surface contaminants film with a value of conductivity, sufficient to support the development of surface discharges, that may develop to a flashover.

III. Experiments

A. Specimens

In this study, in order to evaluate the condition of a number of 150kV composite insulators operating in the Transmission System of Crete (Fig.3 b), an evaluation procedure has been developed and implemented [12]. Among the tests performed the evaluation of hydrophobicity is considered critical and it is investigated by static contact angle measurements and hydrophobicity transfer.

The insulators presented in this paper were installed in different areas of the high voltage network of Crete for a period of 17 years. They have been exposed to different ageing mechanisms, nevertheless, since installation pollution failures have not been observed. Furthermore a new insulator made of silicone rubber is used as reference. Tables I and II summarize the main details of the investigated insulators.

B. Experimental Method

Specimens about 10x10x5mm were sampled from the upper sheds of insulators' polymeric housing. Attention was given during the sampling process to ensure about similar thickness of the samples. Following the samples were cleaned with the aid of ultrasonic cleaner and deionized water to remove the field pollution. Then the samples were stored for 24 hours at room temperature.

A slurry made of 70% silica powder SiO_2 (grain size 3μm) and 30% deionized water by weight was applied on the surface of the samples with the aid of a soft brush trying to deposit the similar thickness about 0.5mm and roughness of the artificial pollution layer to all samples (Fig.4).

The samples with the artificial pollution layer were stored at room conditions for 24h. During this period static contact angle measurements were performed on the polluted samples' surfaces in order to evaluate the hydrophobicity transfer mechanism. Figure 5 describes the experimental procedure followed.

(A) (B) (C)

Fig 3 (a): Composite Insulators; (A) new, (B) field aged EPDM, (C) field aged SIR.

Fig 3 (b): 150kV Network of Crete.

TABLE I
INSULATORS DESCRIPTION

Insulator	Sheds (small/large)	Arcing Distance (mm)	Operation Voltage (kV)
A	18/19	1400	110
B	23/24	1600	110
C	40	1600	110

TABLE II
INSULATORS DETAILS

Insulator	Polymeric Material	Elemental Composition Al (%)	Years on line	Pollution Severity (IEC 60815)
A	SIR	0	New	None
B	EPDM	11.2	17	Heavy
C	SIR	7.7	17	Medium

Fig 4: Deposition of slurry on samples surfaces (left), Contact angle instrument KSV-CAM 101(right).

Sampling specimens from field aged insulators
↓
Samples' cleaning
↓
Samples' storing in dry conditions
↓
Initial contact angle measurements
↓
Deposition of pollution slurry on the samples' surfaces
↓
Contact angle measurements in certain time intervals
↓
Estimation of hydrophobicity transfer mechanism

Fig 5: Experimental procedure

The contact angle measurements were performed at 23°C temperature, 50% humidity and 755 mmHg barometric pressure. The measurements were taken until the artificial polluted specimens of new insulator obtain their initial hydrophobicity.

IV. MEASUREMENTS

Static contact angle was measured on the surface of the artificial pollution layer deposited on the samples to evaluate the hydrophobicity transfer development. The hydrophobicity measurements were conducted in accordance to IEC 62073 method A with the aid of the KSV-CAM 101 instrument (Fig.4). Water droplets about 10 μl in volume were applied with a glass syringe on the artificial pollution layer of the samples. The measurements were taken in certain time intervals, specifically 3 measurements were taken for the first 6 hours and then one measurement every six hours within 24 hours. The contact angle measurements can provide information for the hydrophobicity transfer speed. Figure 6 shows the hydrophobicity measurements during the experiment procedure. The initial points which are not connected with curves are the initial contact angle measurements of the samples before the application of the artificial pollution layer.

Figure 7 shows the gradual increase of hydrophobicity during the experiment procedure and the transition of the hydrophilic polluted surface to hydrophobic for insulator A.

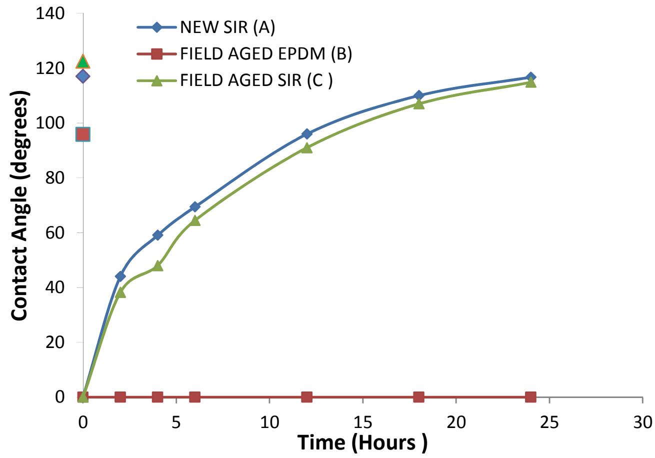

Fig 6: Hydrophobicity transfer speed

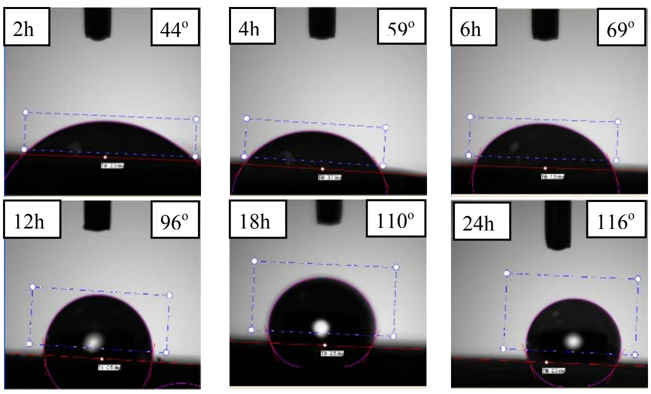

Fig 7: Contact angle measurements during the experiment procedure for insulator A

V. RESULTS & DISCUSSION

The contact angle measurements showed different hydrophobicity transfer behaviour of SIR and EPDM insulators. As expected EPDM insulator did not present dynamic hydrophobic properties [5]. The EPDM insulator samples covered with the artificial pollution are totally hydrophilic even after 24hours of slurry application. The artificially polluted EPDM samples were totally wetted when water droplets were applied on their surfaces and they could not recover their initial hydrophobicity.

On the other hand the contact angle measurements of polluted SIR samples showed that hydrophobicity transfer mechanism was able. Despite the 17 years field ageing of silicone rubber insulator, its hydrophobicity transfer speed was about the similar to the new one SIR insulator. The contact angle measurements on SIR insulators independent of their age indicated that they recover their initial hydrophobicity within first 24 hours after the slurry application. Noteworthy is the fact that the initial contact angle measurement of the field aged SIR insulator showed superior hydrophobicity performance which was related to the excellent condition of the insulator despite its field ageing.

VI. CONCLUSIONS

The hydrophobicity transfer mechanism of two 17 years field aged composite insulators from 150kV network of Crete and a new one SIR insulator was studied. Specifically the experiment procedure was performed in EPDM and SIR insulators. The hydrophobicity transfer mechanism was investigated by measuring the static contact angle on the artificial pollution layer deposited on the samples' surfaces under room conditions in certain time intervals.

The results showed that there is a strong correlation of the polymeric material with the hydrophobicity transfer mechanism. The hydrophobicity transfer mechanism was investigated for SIR insulators in contrast to EPDM insulators. Further work is needed involving more field aged insulators and contact angle measurements along the polymeric housing for the better evaluation of the hydrophobicity transfer mechanism.

ACKNOWLEDGEMENTS

This work was partly supported by the Polydiagno research project (project code 11SYN-7-1503) which is implemented through the Operational Program "Competitiveness and Enterpreneurship". Action "Cooperation 2011" and is co-financed by the European Union and Greek national funds (National Strategic Reference Framework 2007-2013).

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