Assessment of Field Aged Composite Insulators Condition in Crete

N. Mavrikakis, K.Siderakis, D. Pylarinos and E. Koudoumas

***Abstract*--** **The performance of high voltage insulators utilized in overhead transmission and distribution lines is a key factor for the reliability of power systems. Surface hydrophobicity is a material oriented property and thus strongly correlated to the aging mechanisms experienced in service conditions. Although significant improvement has been achieved from the first generation of composite insulators to the third that is available today, there is still a need for evaluating the material condition so as to maintain the desired levels of reliability. For that purpose, field inspection techniques, such as IR and UV monitoring and leakage current have been implemented in service. Laboratory evaluation is also required aiming to obtain reliable information regarding the operational efficiency of a group of insulators that are in service. In the case of Crete, more than 50% of the installed insulators are composite using Silicone Rubber as housing material, with a service age from 2 to 20 years. During this period, no flashovers or other insulator faults have been recorded for the SIR insulators. However, their operational condition is under concern mainly due to their age. In this direction a program has been established, aiming to evaluate the insulator performance and further set the basis for the development of an on - line diagnostic technique. In this paper the laboratory evaluation procedure adopted for the case of Crete is presented and analyzed.**

Index Terms*-- *Composite Insulator, Field Aged, Laboratory Evaluation Techniques, Silicone Rubber

I. Introduction

The introduction of composite insulators in high voltage networks, during the last 20 years is included in an effort to develop reliable operation with limited maintenance needs [1] - [4]. Composite insulators can provide improved field performance, due to their surface hydrophobic behavior and further their capability of maintaining this feature, even after the deposition of hydrophilic contaminants. Further the number of composite insulators in service is considerable and in many cases an average age of ten to fifteen years can be assumed [4], [5]. The network reliability dependence on the efficiency of composite insulators becomes critical and condition assessment of the insulators in service is thus a requirement for a utility.

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There are many aging mechanisms that are able to have an impact on the performance of a composite insulator [6] – [10]. This occurs considering that the primary advantage of hydrophobicity is related to the material structure and is available to materials with low strength [1], [4]. Consequently the ability of various mechanisms to change the material structure and composition may result to a degradation of the insulator efficiency and thus to a performance failure.

In order to reduce the failure probability the need of diagnostic techniques is evident. However due to the many parameters that have to be investigated and the strong relation to the material condition, efficient insulator diagnostics, requires a procedure including various techniques [11], the results of which, when combined may reveal the real condition of the insulator.

The appropriate procedure is not the same in all cases. Specific features and conditions, for different service environments, such as the aging mechanisms present, must be considered. Also the facilities available, the investigator experience and the evaluation significance are also issues to consider.

In this study, the aim is to develop an optimum evaluation procedure, which will be implemented in the case of coastal systems. The first system that will be implemented is the power system of Crete. In this case a 150kV transmission system is in operation, with more than 50% of the transmission line insulators made of Silicone Rubber and a considerable amount of RTV Silicone Rubber coatings applied in high voltage substations [12] – [14].

II. Aging in Composite Insulators

In the field of outdoor composite insulators, many polymer materials have been implemented, such as EPDM, EPR, EPM, alloys EPDM with SIR, ethylene vinyl acetate and cycloaliphatic, aromatic epoxy resins, high density polyethylene (HDPE), polytetrafluoroethylene (PTFE), polyurethane (PUR), polyolefin elastomers and others [15], Among them, although it is not the most hydrophobic, the material that has dominated the field is silicone rubber, available in three forms, i.e. room temperature vulcanized (RTV), high temperature vulcanized (HTV) and liquid silicone rubber (LSR) with the later two implemented in composite housings and the first in coatings.

The advantage available in Silicone Rubber, is the presence of the hydrophobicity transfer and recovery mechanisms. These two mechanisms have gained paramount importance, since they are responsible for the efficient operation of the housing after the deposition of a contaminant layer, which is usually hydrophilic [16] - [18]. Therefore, the possible influence of the various aging factors to these mechanisms becomes the primary issue to be investigated and further evaluated [19, 20].

Aging is possible due to many reasons in field conditions. The possible aging mechanisms are usually classified in four categories [21]:

- Thermal Aging
- Electrical Aging
- Environmental Aging
- Mechanical Aging

In all cases, an impact to the material formulation and structural bonding can be detected and changes to the efficiency of the hydrophobicity mechanisms occur. The primary aging stress, according to 20 years experience in Crete and the available international literature is the surface electrical activity due to corona and dry band discharges, present in the case of hydrophobic behavior and in the later cases in periods of hydrophobicity loss. In addition, other parameters, such as UV also have an influence, but due to the material properties, can be considered to be less critical and evaluated in a second stage.

III. DIAGNOSTIC TECHNIQUES

In order to evaluate the condition of outdoor insulators, several techniques, from field inspection methods to advanced material analysis techniques, have been proposed [20] – [27]. The purpose of the diagnostic methods is to determine the present condition of the examined composite insulators and further estimate the remaining lifetime. The results of the diagnostic methods could facilitate the operator of the power network in making decisions for the maintenance or the replacement of the installed fleet, contributing in the reliability of high voltage power network.

In this study an evaluation procedure is proposed, consisted of field and laboratory techniques, according to standards of international and national organizations (Fig.1). The aim is not only to detect the deteriorated insulator but also to provide more information for the field ageing mechanisms. Specifically, the field inspection is the first and the more definite stage of the evaluation aiming to detect degraded insulators. The results of the field techniques indicate the performed tests of the laboratory evaluation. Generally the laboratory evaluation procedure of the field insulators is performed after the field techniques, consisted of electrical, physical and material analysis techniques. Finally the combination of the laboratory inspection and the field inspection will determine the degradation level and the possible ageing mechanism.

A. Field Techniques

The first category is consisted of field inspection methods and on field measurements [22], [23], [28], [29]. The majority of the field techniques is macroscopic, non-destructive and is performed by training the existing power network operator staff. Visual observation of the field composite high voltage insulator condition and hydrophobicity classification are the tests mostly performed during the field inspection [22].

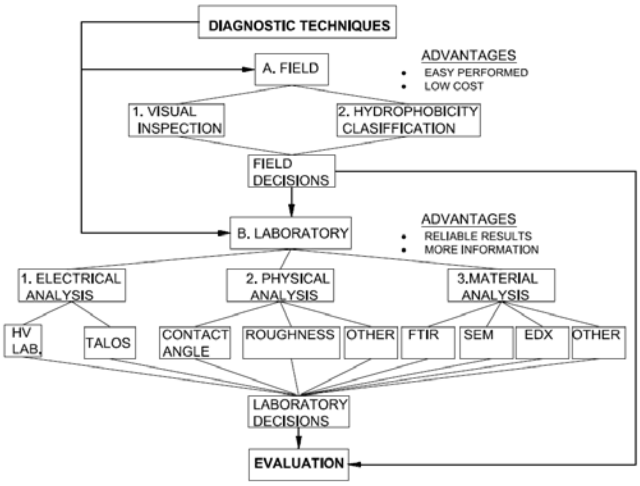


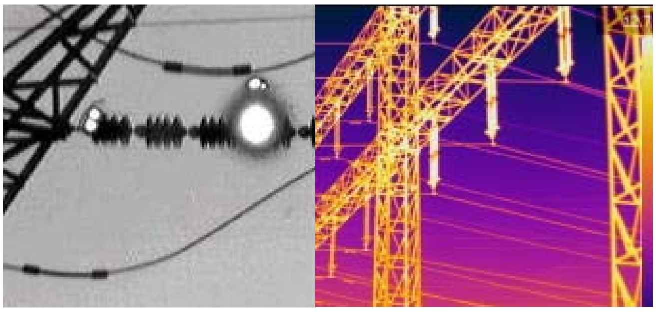
Fig. 1: A proposal evaluation procedure of field composite insulators

Visual observation includes an intensive visual scanning of the structural parts of the field composite insulator, namely polymeric housing, corona rings, and metal fittings [23].The usage of binoculars or telescope is desirable to get reliable results due to small size of the faults. Alternatively the visual observation could be performed by climbing on tower, using bucket truck or helicopter but the last methods are more expensive and time-consuming. Fig. 2 shows 2 degraded insulators the first caused by bird attack and the second by partial housing discoloration and intensive pollution.

Fault Insulator caused by bird attack in Crete | Partial housing discoloration and intensive pollution

Fig. 2: Fault insulators in high voltage power system of Crete

Additionally, employing of a camera or a video recording device is necessary during the visual observation procedure for further off-field examination. Moreover the recorded photographs can be used as a reference in field inspection to come. The comparison of photographs among two field inspections is an indicator for the accelerating level of the field composite insulator degradation. The visual observation is focused only to the external surface of the composite insulator without providing information for the internal defects. For this reason, the visual inspection is combined with expensive techniques such as infrared (IR) and ultraviolent (UV) inspection. The IR inspection indicates the presentation of high leakage current values and intensive electrical discharges [28]. Also indications of core problems can be identified. The most expensive UV camera could detect all the electrical discharge activities; including corona discharges but not internal faults of the composite insulator. The results of the UV camera and the IR are not enough for evaluating the degradation level of the field composite insulator. Fig. 3 shows photographs of high voltage overhead lined by using UV and IR camera.



Inspection with UV camera [30] Inspection with IR camera [31]
Fig.3: Electrical discharge activities in overhead high voltage lines

Furthermore acoustic techniques have been proposed for detecting the electrical discharges in high voltage systems by performing on field measurements, but they are proved complicated because of the disturbance introduced by external discharges [25].

The hydrophobicity classification; as an indicator of deterioration of composite insulators is performed in the field by applying the STRI Guide [22]. It is suggested to process this test after the mishandling of the composite insulators from the high voltage network but it can be also performed on the tower. The evaluation of the housing material hydrophobicity is based on a spray test method. The combination of the visual observation and the hydrophobicity classification could be an indicator for the performance of the outdoor high voltage insulator. The test is performed by using a common spray bottle, distilled water and a camera. The photographs of the wetting surfaces of the field insulators are compared with typical photographs of the STRI [22] guide for a quickly classification of the insulator surface. There are 7 typical hydrophobic categories according to guide [22]. Fig. 4 shows the differences between the hydrophobicity classification of the composite insulators installed in the high voltage network of Crete.

Hydrophobic class 1 Hydrophobic class 7 Hydrophobic class 1
Fig. 4: Hydrophobicity classification of field composite insulators in high voltage network of Crete according to STRI [22]

The combination of visual observation and hydrophobic classification is necessary in order to provide results for the composite insulator degradation level, thus for the installed fleet of high voltage composite insulators. The later requires a mapping of the installed fleet of composite insulator in the high voltage power network. Finally the results of the last field inspection, will determine the severity of the next procedure and. the most considerably degraded insulators can be used for further laboratory analysis.

B. *Laboratory Techniques*

Laboratory techniques include more advanced evaluation methods than the field techniques. The implementing tests are mainly microscopic and can be achieved by employing scientific staff. The majority of the laboratory techniques are destructive because small samples must be extracted from the insulator in order to be evaluated. Laboratory techniques must be performed in scientifically equipped laboratories with standardized conditions.

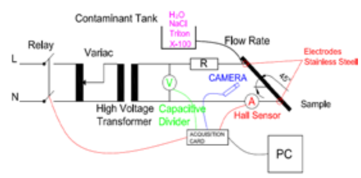
The laboratory techniques are performed after the field evaluation, as an advanced stage of degradation assessment, considering the relevant increased cost and complexity of the procedure. The results of the field techniques determine the sampling insulator area for the laboratory evaluation. The laboratory techniques are consisted of electrical, physical and material analysis methods [32].

B.1 Electrical Analysis Techniques

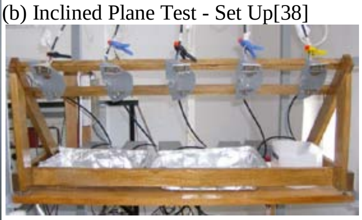
Electrical analysis techniques are well defined by national and international standards guidelines and tests [26], [27], [33] – [36]. Some of them aim to simulate the field ageing conditions. Salt fog test [26],[27], tracking wheel test, rotating wheel dip test, the inclined plane test [33] - [35] and IEC 61109 [26],[27] 1000h can be found in the literature. Especially, the evaluation of resistance to tracking and erosion could be performed with the inclined plane test as described in the IEC 60587[33] –[35] and the ASTM D 2303[34]. Dust and fog tests of the ASTM 2132 [36] standard and rotating wheel test of IEC 61302 can also provide useful information [20]. In order to evaluate the resistance against corona and ozone the IEC 60343can be used.

B.1.1 Tests in indoor high voltage laboratory

The indoor high voltage tests are performed in appropriately equipped high voltage laboratories. Such setups are available at the high voltage laboratories of Technological Educational Institute of Crete and of Aristotle University of Thessaloniki. The performed tests include evaluation of housing material resistance against tracking and erosion according to IEC60587 (Fig. 5) [35]. In addition Dynamic Drop Test (DDT) [37] and corona test [37] are performed in order to evaluate the hydrophobicity efficiency of the polymeric housing against simultaneous stress by drops and voltage and against corona discharges respectively.



(b) Inclined Plane Test - Set Up[38]



(a) IPT in progress (c) Mounting of the samples in IPT
Fig 5: Inclined Plane Test Details

In order to evaluate the polymeric housing of the composite insulator samples with specific dimensions are needed according to employed tests. Because this is impossible to perform in the commercial high voltage composite insulator a new sampling procedure is implemented (Fig. 6).

In order to be tested, samples need to be thoroughly cleaned in order to acquire reliable results. The samples are cleaned with distilled water before being extracted from the composite insulator housing (Fig. 6) and then an ultrasonic cleaner is employed in order to further remove the surface pollution of the samples. It must be noted that cleaning with chemical solutions is not acceptable because the polymeric housing is vulnerable to chemical solutions.

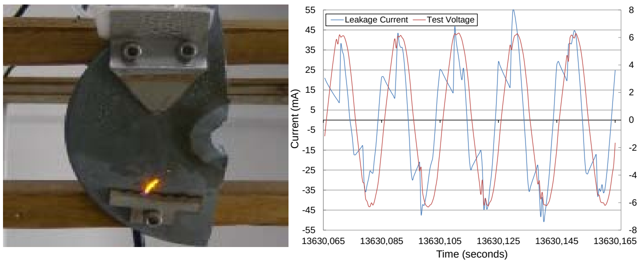
Sampling from a field high voltage composite insulator; 150 kV network of Crete

Ultrasonic cleaning of the samples

Fig. 6: Sampling and samples cleaning

In order to control, measure, store and operate the test set-up in indoor laboratories there is the need of a system which can control the general operation. For this reason a central computer is employed and a specialized software has been developed. The measurements are taken by electrical sensors. The sensors are connected to a data acquisition card which is the central board of all connections (inputs/outputs) not only for the measuring but also for the control. The acquisition data are processed and stored by the software the later manages the output connections of the main board. In addition a camera is employed for safety reasons such as general supervision of all test setup.

In Fig. 7 partial discharge activity on the polymeric housing during the I.P.T procedure is illustrated combined with the surface leakage current and voltage measurement during the I.P.T procedure. In addition to the electrical measurements during the test procedure, mass loss, hydrophobicity and erosion are measured after the test, in order to evaluate the condition of the polymeric housing after the accelerated ageing. The initial results of the IPT [35] indicate that this test could provide reliable results for the insulator performance [38].



Partial discharge activity on the polymeric housing surface of the composite insulator during the I.P.T procedure

Leakage current (blue) and test voltage (red)measurents during the Iinclined plane test procedure

Fig. 7:Partial discharge activity (left) and measurements (right) during IPT procedure

The advantages of the indoor high voltage applied tests are the standardized setup, the absence of noise in the measurements and the quickly evaluation of insulator material through the accelerated laboratory ageing. In addition these measurements are reproducible. The disadvantages of the electrical analysis techniques in indoor laboratories are the high cost of the high voltage equipment.

B.1.2Tests in Outdoor High Voltage Laboratories

The outdoor high voltage tests are performed in coastal outdoor high voltage test station of Hellenic Electricity Distribution Network Operator in Crete (TALOS test station) [39] (Fig. 8). During the testing period the electrical activity of the insulator is recorded and breakdown voltages (Fig. 9) and leakage currents are measured. In addition to electrical measurements, meteorological data such as wind, temperature, UV radiation, pressure, humidity rainfall are recorded and pollution measurements are performed. In order to examine the performance of the field insulators there is the need of long exposure of the insulator in the outdoor laboratory under their nominal operation assessments.

Fig. 8 : Suspension 150kV Insulators in Outdoor High Voltage Laboratory in Crete (TALOS)[39]

The main advantage of the outdoor high voltage laboratories is the study of field ageing mechanisms of the insulators in real time. On the other hand the cost of the equipment is much more expensive than the indoor laboratories. In order to work an outdoor high voltage laboratory specialized scientific team is needed with the aid of a training high voltage staff from the power network operator.


Fig. 9 : Flashover of post outdoor 150kV insulators in TALOS[39]

The combination of the results from indoor and outdoor high voltage laboratories could provide the necessary information for the insulators performance during their operation.

B.2 Physical Analysis Techniques

The condition of the field aged insulators is related with their physical performance and specifically with the hydrophobicity [32]. The loss of the hydrophobicity is a possible indicator for the degradation of the housing material of the composite insulators. The hydrophobicity is a dynamic property of composite insulators especially in silicone rubber insulators. Hydrophobicity is measured with static and dynamic contact angle measurements IEC62073.Despite the hydrophobicity other physical properties of the housing material could be examined such as resistance to physical and chemical degradation, hardness, roughness, hydrolysis, resistance to water immersion, tear strength, resistance to UV radiation and resistance to flammability as described in Cigre Guide [19].

The physical measurements are performed in the Center of Materials Technology and Photonics of Technological Educational Institute of Crete. Until now there was the need to evaluate the hydrophobicity of the polymeric housing of composite insulators thus contact angle measurements are performed by using a contact angle device (Fig. 10).


Fig. 10: Contact angle device (left) and measurement (right)

In order to be representative the results of hydrophobicity measurements for the insulator a lot of samples along the polymeric housing must be taken. After that the samples must be cleaned with distilled water so as to remove the surface pollution. The initially results of the contact angle measurements shows that this measurement could be indicate the degraded polymeric housing [38].
The disadvantage of contact angle technique is the huge number of the samples and the measurements must be repeated many times for each sample, thus this technique is time consuming.

B.3 Material Analysis Techniques

The material properties are defined by their structural compounds. In order to evaluate the properties of the housing materials of composite insulators material analysis techniques could be performed. The most used in the literature are Fourier Transform Infrared Analysis (FTIR) spectroscopy, Scanning Electron Microscopy (SEM), X-ray photoelectric spectroscopy (XPS), Energy Dispersive X-Ray (EDX) spectroscopy, Secondary Ion Mass Spectroscopy, Electron Probe Micro Analyzer, Thermogravimetric Analysis (TGA), X-Ray Diffraction Analysis (XRD) and others [25] under development.

The material analysis is performed in the Center of Materials Technology and Photonics of Technological Educational Institute of Crete. Until now three diagnostic techniques are used in CEMATEP in order to detect the degraded polymeric housing of composite insulators namely FTIR, SEM and EDX.

FTIR spectroscopy is used to detect the structural bonds of the housing material. In FTIR radiation which is produced from a source is passed through the sample. Some of the infrared radiation is absorbed by the sample and other transmitted. The operation of FTIR is based to the fact that each different material has a unique combination of atoms thus a unique absorbance in FTIR spectra. A FTIR spectrum provides information for the absence of a bond and simultaneously for the amount of the material present according to peak area integration of the specific bond. Fig. 11 shows a FTIR spectrum which represents the absorbance radiation of a silicon rubber with alumina fillers insulator.

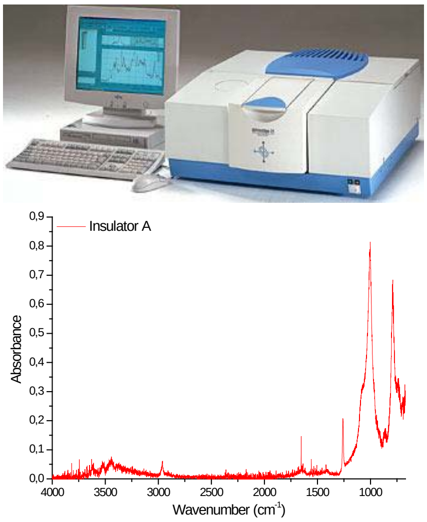


Fig. 11: FTIR spectrum of a SIR insulator of 150kV network of Crete

Scanning Electron Microscopy (SEM) (Fig.13) is used to detect the topography of the materials. A focused beam of electrons shoot the examined sample; the atoms of the later interact with the electrons and producing various signals which are related with the produced images. A high vacuum is performed before the scanning of the sample with the electron beam. The SEM results are related to the surface roughness and to the presence of surface micro-cracks (Fig. 12) which could be important factors for the initial levels of degradation of the material.

Energy Dispersive X-Ray (EDX) is used to detect the elemental composition of the materials. The analysis (Fig. 13) could obtain information for the elemental composition changes of the composite insulator housing material caused by the field aging mechanisms.

The advantage of material analysis techniques is the reliability of the measurements. On the other hand, the material analysis of the composite insulator polymeric housing is time-consuming method due to the small size of samples which are needed.

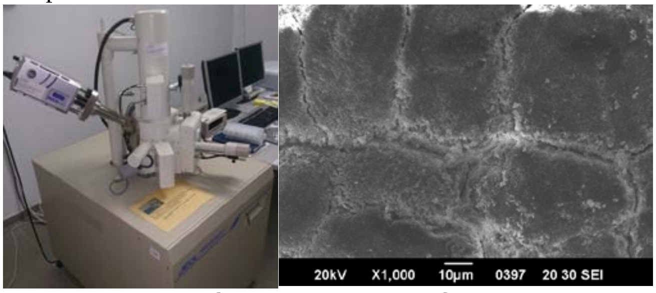


Fig. 12: Scanning Electron Microscope with EDX spectrometer; CEMATEP(left) and cracks on the surface of a composite insulator housing of 150 kV network of Crete (right)

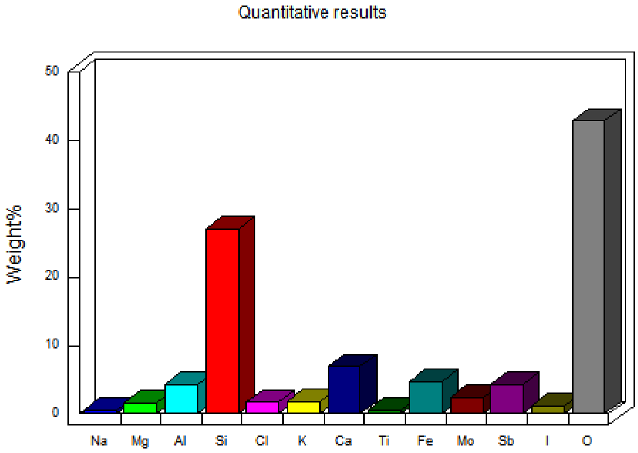


Fig. 13: EDX analysis of a field SIR insulator of 150kV network of Crete

IV. CONCLUSIONS

There are many aging mechanisms that are able to have an impact on the performance of a composite insulator. Aging mechanisms affect the material structure of composite insulators thus they may cause network failure by degrading composite insulators. In order to reduce the failure probability the introduction of evaluation procedures is necessary. The applied evaluation procedure must be different according to the specific assessments of the network. A new evaluation procedure of high voltage composite insulator is implementing in the 150kV network of Crete by adopting international and national standards and diagnostic techniques. Specifically the field techniques are consisted of more macroscopic techniques and they can apply on the field. The results of the field techniques are the indictor of the applied laboratory techniques. Laboratory techniques are more microscopic and focus not only to ensure the results of the field techniques but also to provide more information for the ageing mechanisms. Due to the high cost and the expensive equipment of the laboratory techniques, the sampling is extremely important. A well defined evaluation procedure must include initially macroscopic and then microscopic approach including electrical, physical and material analysis techniques due to the material properties correlation with the structural compounds. The correlation of the field, and laboratory techniques is a key factor for a reliable evaluation procedure.

V. ACKNOWLEDGMENT

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VII. Biographies

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