R&D in TALOS High Voltage Test Station- Assessing aging and performance of polymer insulators

D. PYLARINOS
Hellenic Electricity
Distribution Network Operator
GREECE
dpylarinos@yahoo.com

K. SIDERAKIS
Technological Educational
Institute of Crete
GREECE
ksiderakis@staff.teicrete.gr

E. THALASSINAKIS
Hellenic Electricity
Distribution Network Operator
GREECE
E.Thalassinakis@deddie.gr

Abstract: - The performance of HV insulators is an important issue for power utilities, as insulators are scattered throughout the network and a single insulator fault may lead to an excessive outage. The performance of outdoor insulators is strongly correlated to local service conditions, mainly the experienced weather and the distance from pollution sources. The sea is considered a primary pollution source due to salt contamination and therefore coastal areas are generally considered heavily polluted. Hence, pollution is a major issue for the Greek power utility due to the country's location and geography, as extended network parts are coastal (especially island networks) and the local climate adds to the accumulation problem. Crete is probably the island that faces most problems due to the voltage level used (150 kV), the experienced strong winds and prolonged dry season, the island's shape and the coastal arrangement of the network. The Greek utility has therefore issued several R&D projects to investigate and battle the phenomenon through the years, often in cooperation with various HV labs and academic institutions. Different maintenance techniques have been applied over the years and the current situation is characterized by the extended use of polymer insulators in transmission lines and coatings in substations. As a result, current research is mainly focused on the performance of polymer materials. In this paper, the experience from Crete is described and further data are provided for the latest research steps: the construction and operation of TALOS High Voltage Test Station in Iraklion, Crete and a currently running project (POLYDIAGNO) aiming to assess the life time (aging) of polymer insulators.

Key-Words: - High Voltage; Insulator; Pollution; Test Station; Polymer; Aging; Field; Power System; Reliability; Fault

1 Introduction

The fault free performance of outdoor insulators is a matter of great importance for power utilities, considering that insulators are used throughout the network and a single insulator fault may lead to an excessive outage. Several factors related to operation conditions affect the performance of outdoor insulators with the experienced pollution being a dominant one [1-5]. Coastal areas are generally considered heavily polluted areas due to marine pollution, i.e. the deposition of sea salt on the insulators' surface. When this deposited salt is diluted in water through the presence of a wetting agent (humidity, drizzle, fog, light rain etc), a conductive solution is created and leakage current flows on the surface [1]. Under favorable conditions activity may advance and reach a flashover [1]. Therefore, local weather and climate are considered important factors for the determination of a site's pollution severity (SPS) class (e.g. strong winds carry more salt, frequent rains may provide natural cleaning etc) [1-5].

The most common method to cope with the problem is the use of silicone based materials that suppress the phenomenon by not allowing the formation of a conductive film on the surface, and thus the flow of leakage current, due to their hydrophobic surface [1-10]. Room Temperature Vulcanized Silicone Rubber (RTV SIR) is widely used for the fabrication of coatings [6-8] whereas High Temperature Vulcanized Silicone Rubber (HTV SIR) is widely used for the fabrication of composite insulators [8-10]. The usual case is the application of RTV SIR coatings on substations' ceramic insulators [6-8] (which are usually hard to replace) and the installation of HTV SIR in Transmission Lines [8-10]. However, coated ceramic insulators are also used in Transmission Lines when a combination of features is required [11]. In any case, the use of such polymer materials brings forth new issues, as these materials portray hydrophobicity loss and recovery cycles and their general performance is connected to their aging [4-12]. Further, other issues concerning the different characteristics of each insulation path that may be followed (e.g. weight, endurance, ease of locating a fault etc) should also be considered. As there is not one perfect solution to be followed, utilities around the word participate in several research and monitoring projects, usually along with research centers and academic institutions, e.g. [13-16]. As the phenomenon is strongly correlated to the weather, high voltage open air test station are constructed in order to test the performance of outdoor insulators under actual service conditions [15-17].

The Greek island of Crete provides a rather interesting case study. The heavy pollution experienced in combination with specific local factors has led the Greek utility to apply several measures over the years to cope with the problem, cut costs and boost reliability. The latest step is the construction of TALOS High Voltage Test Station in Iraklion, an open air test station mainly focused on insulator research [18]. This paper provides an insight to the case of Crete and to the latest research steps that are mainly focused in TALOS and to a current research project related to the performance of polymer insulators

2 The case of Crete

Crete is a Greek island located in the Mediterranean Sea, at the southern end of Europe. The island has a rather elongated shape (260 km long and 15-60 km wide) and has a coastline of 1046 km, mostly rocky. Three large mountain formations cover the center part of the island from east to west. The development of the island is mostly coastal with the four largest cities (Iraklion, Rethimnon, Chania, Ierapetra, Agios Nikolaos with a descending order, population wise) being located next to the coast. The power system of Crete is shown in Figure 1. A substation located in the premise of a city is usually named after this city, and therefore the location of all major cities can also be deducted from Figure 1. Crete's climate is characterized by prolonged dry periods (usually from April to October) and generally strong north winds that also reach their peak during this time, followed by increased humidity [19-21]. This creates a nearly worst case scenario regarding the pollution impact. Recently published pollution measurements [22] agree with past experience [19-21], describing a medium-to-light pollution on the western side and a medium-to-heavy pollution on the eastern side. Generally the severity increases near pollution sources (sea, cities) and therefore coastal areas in the eastern part of the island should be considered heavily polluted. The diversity between the east and west side of the island should be attribute to the increased natural cleaning occurring at the west because of the more frequent and heavier rains [19-21].

Fig. 1. The power system of Crete. Squares denote step-up substation/power plants and triangles denote step-down substation

3 Transmission Lines

Pollution problems were recorded as soon as the first transmission line was constructed, as the upper parts of the wooden poles used for the then 66 kV line, occasionally caught fire [21]. Pretty soon after the operation of the first 150 kV lines (1976 to 1979), pollution problems were recorded at the eastern part of the island [19, 23]. Pollution was historically the single factor responsible for more faults in the 80s (32.5%) and 90s (19.6%) [19]. The decrease from one decade to the next is attributed to the employment of different pollution maintenance techniques over the years such as pressurized washing by a ground crew (started in 1985) and pressurized washing with the use of helicopters (started in 1995) [19-21, 23]. The gradual installation of HTV composite insulators in transmission lines started in 1993 in a small scale/trial basis (only 33 towers were equipped from 1993 to 1998). Large scale installation was initiated in 2004, at the Linoperamata-Agios Nikolaos-Ierapetra-Atherinolakos route and also the line connecting the Iraklion 2 S/S with the rest of the system (denoted with a black line in Figure 1). In 2006, the Atherinolakos-Sitia line (far east of the island, red line in Figure 1) was fully equipped with HTVs and the Ierapetra-Sitia line (east coastal part of the line in Figure 1) followed in 2010. The installation of HTV SIR insulators in the Linoperamata-Mires line and the Linoperamata-Chania line started in 2013 and is expected to be concluded by 2015. The refurbishment of the Mires-Ierapetra line started in 2014 and is also scheduled to be fully refurbished by 2015. A look up table can be found in Table I. The priority followed, hints to the severity of the pollution problem for each route.

It should also be noted that in some special cases coated ceramic insulators have been installed in a small number of towers in certain lines, an issue to be thoroughly presented and discussed in [24]. Until rather recently not a single pollution fault had been recorded on HTV insulators (the first two were recorded in the past few months but were related with birds nesting and droppings, and thus not related to the material). The improved performance is reflected to the total number of faults per 100 km recorded in the Cretan network which has fallen from 75 in the 80's to 51 in the 90's and 24 in the 00's [22]. In regards to the economic benefit, it has been shown that the yearly cost of washing was slightly larger than the 1/5 of the cost of replacing (i.e. the cost of replacement is paid back in 4.7 years of washing) [25].

Table 1 Insulators in transmission lines (by 2015)

TL	Ins. Type	Year of large scale installation of HTVs
Linoperamata-Agios Nikolaos-Ierapetra-Atherinolakos	HTV SIR	2004
Atherinolakos-Sitia	HTV SIR	2006
Ierapetra-Sitia	HTV SIR	2010
Linoperamata-Mires	HTV SIR	2013
Linoperamata-Chania	HTV SIR	2013
Mires-Ierapetra	HTV SIR	2014
Chania-Kasteli	Porcelain	-

4 Substations

As shown in Figure 1, the majority of all substations is located near the coast. Historically, high pressure water washing was mostly employed to clear the insulators and suppress the pollution problem [8, 19-23, 26]. It should be noted that as live washing is prohibited under Greek law, that meant an added cost during the substations' design and construction in order to be possible to wash all insulators without power interruptions [8, 19-23, 26]. An added issue was the cleaning schedule: if washing was scheduled late, a high risk occurred. If washing was scheduled early a new washing could be required before the end of the dry period which meant a significant added cost. Considerable costs also occurred due to the fact that the island's system is isolated. This meant that when a part of a substation was put out of service, supply interruptions could occur [8, 19-23, 26]. Further, in some cases (e.g. Linoperamata) when cheap base units were turned off, expensive gas turbines had to be used in their place [19-23, 26]. These problems resulted to the introduction of polymer coatings (RTV SIR) for the substations' insulators. The first installation took place in the Linoperamata substation in 1998, again in a small testing/trial basis. As results were encouraging, the station was fully coated some years later [21] and today the majority of open air substations in Crete are fully coated with RTV SIR [8, 19-23, 26-27]. It should be noted that although no washing or any other maintenance technique is applied in general, no problems have been reported since the initial installation. Regarding the achieved cost saving, it should be noted that just for Linoperamata it has been calculated that the installation cost was lower than the cost of washing for that year and, most importantly, that almost a quarter of million Euros is save each year thereafter [25].

5 TALOS High Voltage Test Station

As described in the previous paragraphs, the extended use of polymer materials boosted the reliability of the network and resulted to significant cost saving. However, it also created the need of further research in the direction of aging and performance of these materials. Therefore, back in the 90s, two specially designed leakage current monitoring devices were installed, initially in Iraklion 2 and Linoperamata, capable of constantly monitoring eighteen 150 kV post insulators [28]. Both these devices were moved to Linoperamata some time later [28]. Further, the construction of an Open Air Test Station in the premise of the Linoperamata substation was decided, where insulators could be tested and monitored under certain scenarios but yet subjected in actual service conditions (and, in fact, following a worst case scenario, as the test station is constructed right next to the coast). TALOS High Voltage Test Station aims to aid network protection and reliability by providing a controllable testing and monitoring facility mainly for insulators, where new insulators as well as insulators removed from the network can be monitored and tested under real service conditions and where custom made research scenarios can be arranged [18]. Further, a clamp testing set up has also been arranged capable of providing high current (over 1000 A) [18].

5.1 Location and installations

The initial installations in TALOS included only 150kV suspension insulators [28]. Later, the test station was expanded to the point that it is now consisted of three bays: one for 150kV post insulators, one for 150kV suspension insulators and one for 21kV suspension and post insulators (Figure 2). TALOS is also equipped with a dedicated facility capable of operating at variable heights where non energized insulators are suspended in order to acquire comparative pollution measurements between insulators of different type, material and profile. A 3D model of the Test Station is shown in Figure 3 whereas photos of the arch used for comparative pollution measurements are shown in Figure 4. A dedicated weather station has been installed on top of the pollution measurements arch (Figure 5) capable of recording temperature, wind, humidity, rain and UV radiation readings.

The leakage current measurement is acquired by using a stand-off insulator to lead the current to a hall sensor. Currently a DATAQ DI-722-32 DAQ is installed capable of monitoring 32 samples with a burst sampling rate of 50kHz. Added DAQs to be installed will provide the capability of monitoring over 100 insulators. An explosive fuse is used to protect the leakage current monitoring equipment and to enable the disconnection of a particular insulator, e.g. in case of a flashover, without interrupting the supply to the other insulators. Sensors and measuring devices are housed in a cabinet for protection and ease of access. Drawing and photos regarding the leakage current set-up are shown in Figure 6. All measuring devices (DAQs and weather station) are connected via LAN to a PC housed in the control room. The position of the control room is at the center of the test station as shown in Figure 3.Additional photos and data along with a list of related published material and a live weather report can be found in the station's site [18].

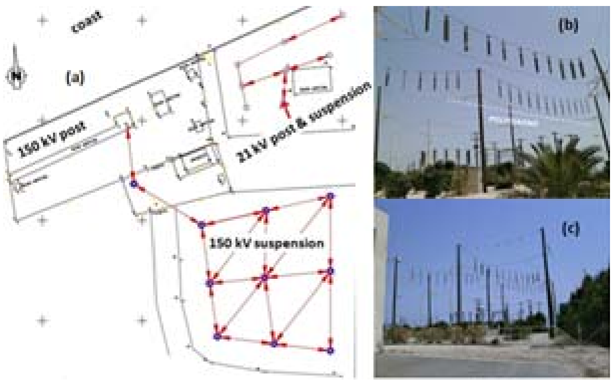

Fig. 2. (a) A drawing of TALOS (b) a picture from inside TALOS (POLYDIAGNO insulators noted) (c) a view of TALOS entrance

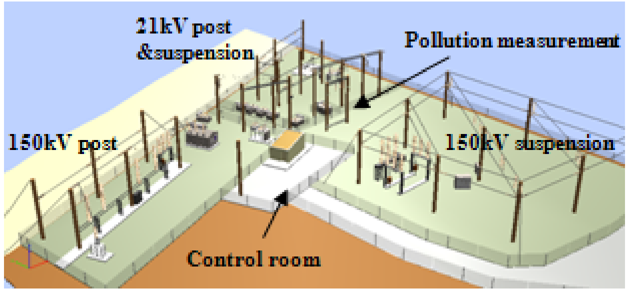

Fig. 3. 3D model of TALOS

Fig. 4. Photos from the pollution measurement arch (upper and lower position of insulators)

Fig. 5. Installation of the weather station on top of the pollution measurement arch

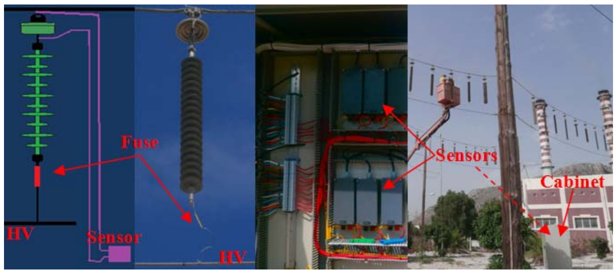

Fig. 6. A drawing of the basic leakage current measuring installation and photos from the actual installation in TALOS High Voltage Test Station

5.2 Research & collaborations

The Greek power utility has participated in several research schemes over the years and, with the construction of TALOS, aims to establish permanent R&D activities and collaborations with all interested parties (HV labs, academic institutions, manufacturers, other utilities etc). Up to now, TALOS has collaborated (through various schemes and in various levels) with the High

Voltage Lab of the Technological Educational Institute of Crete, the High Voltage Lab and the Pattern Recognition Lab of the University of Patras, the Power Systems Lab of the Democritus University of Thrace, the High Voltage Lab of the National Technical University of Athens and the Foundation for Research and Technology-Hellas (FORTH). The several R&D projects include, among other, the construction and installation of pollution measurement kits, comparative pollution measurements on dead insulators, leakage current monitoring and signal processing/pattern recognition techniques employed on leakage current waveforms, software development, simultaneous monitoring and performance assessment of insulators of different materials, clamp testing etc. A full list of related published material can be found in the Research/Publications page of [18].

5.3 The "POLYDIAGNO" research project

TALOS is currently participating in POLYDIAGNO (project code 11SYN-7-1503), which is a research project focused on the monitoring and diagnosis of polymer based outdoor insulators used in high voltage applications, with a budget of about 0.5 M E [22]. The research partners are the Hellenic Electricity Distribution Network Operator (HEDNO), the Technological Educational Institute of Crete (TEI of Crete), the Foundation for Research and Technology-Hellas (FORTH) and ENTEC Green Economy Consultants. The aim of the project is to propose a standard procedure and a diagnostic technique that could be used to assess the aging of polymer insulators and thus their performance. The collaborating labs of TEI of Crete and FORTH will contribute several material analysis techniques (Electron Microscopy, X-Ray Diffraction, FTIR) along with other measurements (wettability, contact angle, recovery time etc) on insulators and specimens that have been submitted to field (TALOS) and lab stress (e.g. inclined plane, corona, dynamic drop).

As a first step, polymer insulators was decided to be removed from the network and be treated as research specimens. To decide the location of the towers, prior experience along with practical issues was to be considered. Previous pollution measurements performed in various network locations were also considered. The pollution measurements were conducted on offline insulators hanged from the metal structures of 150 kV towers (or from other available structures in Substation) for a three years time span [22]. The insulators were hanged from a lower height in order to be easily accessible, as shown in Figure 7. As these measurements were performed on various types of insulators (similar to the ones used at the location at the time), the correlation factors derived from the comparative measurements performed in TALOS were used to unify the data. A detailed report on the results is under publication.

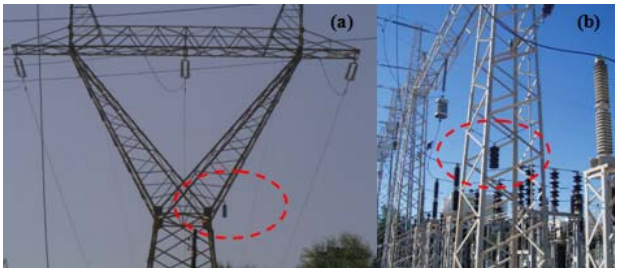

Fig. 7. Unenergized strings for pollution measurements (a) in a Transmission Line (b) in a substation

The pollution measurements throughout the island showed good agreement with service experience but also underlined the fact that cities should also be considered as a primary pollution source [22]. As more measurements are incorporated, the pollution map is expected to be updated. The current version of the pollution map is shown in Figure 8(a). The years in service are a major factor to be considered and therefore it was decided to remove some of the insulators that were first installed during the initial/testing stage of installing HTV SIR insulators in Transmission Lines. The location of the thirty-three 150 kV towers where polymer insulators were first installed during the testing/trial stage (1993-1998) is shown in Figure 8(b).

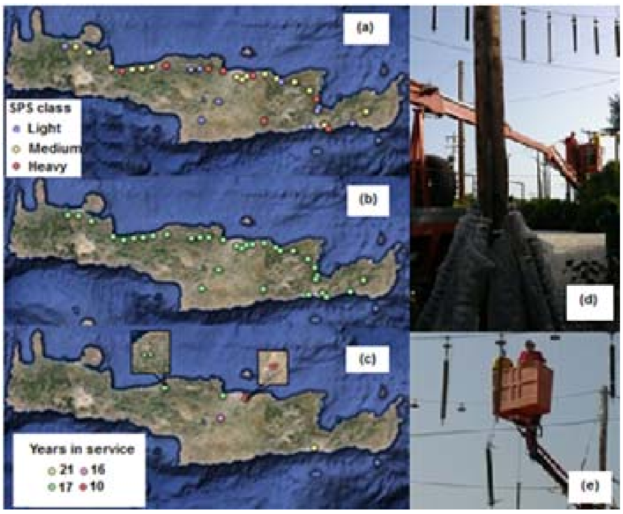

Fig. 8. The current version of Crete's pollution map (b) the 33 towers were the first polymer insulators were installed in a trial basis in 1993-1998 (c) the 7 towers

from which insulators were removed (d)-(e) pictures during the installation of the insulators in TALOS

After the consideration of all data (years in service, network experience, pollution measurement, practical issues etc), seven 150 kV towers were selected (Figure 8(c)) and three polymer insulators where removed from each one. Two of the removed insulators were then installed in TALOS, whereas the third one was sent for lab tests to the collaborating labs [29-30]. The final arrangement of the POLYDIAGNO related insulators in TALOS is shown in Figure 2(b). Pictures taken during their installation are shown in Figures 8(d) and 8(e).

At a later stage, the insulators installed at TALOS will be removed at different intervals and be sent for lab tests and analysis. Meanwhile, leakage current monitoring along with weather and pollution measurements will provide a complete profile of the stress that these insulators were subjected to at TALOS. First results hint that the ratio of Si-O/Si-CH3 bonds may provide an aging indication for polymer insulators [29-30].

6. Conclusion

Investigating the performance of outdoor insulators is a matter of significant interest for power utilities as insulators are scatted throughout the network and a single insulator fault can cause an excessive outage. The performance of outdoor insulators is strongly correlated to highly localized service conditions such as the location, the site's pollution severity and the experienced weather and climate. Modern polymer insulators provide superior characteristics especially in terms of pollution problems, but aging and hydrophobicity loss and recovery cycles appear as added factors of consideration. The Greek island of Crete provides a rather interesting case study as its isolated power network is subjected to sever marine pollution and the Greek utility has employed several techniques to cope with the problem over the years. The Greek utility has issued the construction of TALOS High Voltage Test Station in Iraklion, Crete as an R&D facility. Research is currently mostly focused on the assessment of aging and performance of polymer insulators installed in Transmission Lines in collaboration with other research partners. A basic description of TALOS and of the current research activities is presented in this paper.

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