Polymer Insulators and Coatings in the Cretan Power System. The Transmission Line Case

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***Abstract*—The reliability of Transmission Systems largely depends on the performance of the HV insulators used in Substations and Transmission Lines, and thus, insulation coordination and research is a rather important issue for power utilities. This paper's focus is on the Transmission Line case of the power network of Crete. The Cretan network faces severe pollution problems and the Greek utility has employed several remedies over the years. Ceramic insulators have been gradually replaced with polymer (HTV SIR) composite insulators in most Transmission Lines but polymer coatings have also been used in some special cases. The current state of the network (insulator-wise) is presented in this paper, along with past experience, the pollution profile of the island and the latest research steps, focused on monitoring and testing of polymer insulators removed from the network, in TALOS High Voltage Test Station and in collaborating labs.**

***Index Terms*—insulators, polymers, transmission lines, pollution, coatings**

I. Introduction

The reliability of Transmission Systems largely depends on the fault-free operation of high voltage insulators used in Transmission Lines (TLs) and Substations. Strongly localized conditions such as the proximity to pollution sources (e.g. the sea, cities, plants etc) as well as the experienced weather, play an important role regarding the performance of outdoor insulators [1]-[3]. Coastal areas are generally considered heavily polluted due to the deposition of sea salt on the insulators' surface, which when diluted in water through the presence of a wetting agent (humidity, drizzle, fog, light rain etc), creates a conductive solution. Leakage current then flows on the surface and under favorable conditions activity may advance to a flashover [1]. Therefore, local weather and climate are also considered important factors for the determination of a site's pollution severity (SPS) (e.g. strong winds carry more salt, frequent rains may provide natural cleaning etc) [1-5].

The Transmission System of Crete provides a rather interesting case study, as it is mostly coastal and experiences severe pollution problems [4]-[5]. To cope with the problem, the Greek utility (originally PPC and now HEDNO) has issued several remedies over the years [6].

The current paper mainly focuses on the use of polymer insulators and coatings in TLs. Traditional ceramic insulators (glass, porcelain) have been largely replaced with composites having a hydrophobic surface due to the High Temperature Vulcanized Silicone Rubber (HTV SIR) used [1]-[7]. Further, Room Temperature Vulcanized Silicone Rubber (RTV SIR) coatings have also been used in TLs in certain special cases. As the performance of these materials is strongly connected to the experienced conditions and their aging [1]-[8], further research is conducted in collaboration with academic institutions and labs. The current network status (insulator-wise) along with past experience, the island's pollution profile and latest research steps are presented in this paper.

II. Cretan Power Network and TLs

Crete is a rather elongated Mediterranean island (260 km long and 15-60 km wide) and has a mostly rocky coastline of 1046 km. The transmission voltage level used is 150 kV. The development of the network has followed the general scheme of coastal development met in the island, as shown in Figure 1. As shown, the majority of all substation and TLs routes are in proximity to the coast and this fact combined with local weather conditions (prolonged dry period, strong winds etc) results to severe pollution problems [4]-[6], [9]. In fact, pollution was historically the single factor responsible for more faults in the 80s (32.5%) and 90s (19.6%) [9].

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

III. Pollution Profile and Fault Analysis

Network experience along with recently published measurements [4] has illustrated the island's pollution profile as such: pollution should be considered medium-to-heavy in coastal areas (severity related to the distance from the coast and cities) in the central and eastern coastal areas. In western areas however (west of Chania) pollution should be considered medium-to-light even in coastal areas and next to large cities (e.g. Chania) [4], [9]. This diversity is mainly attributed to the more frequent and heavier rains occurring at the western side [4]-[9]. The usual wind direction met in the island is north-west [4]-[9].

It should be noted that from 1978 to 1993, 216 faults took place in eastern Crete and just 1 fault (not pollution related) in western Crete, although extensive cleaning activities were performed only at the eastern side [10]. Further research in recorded faults data from 1994 to 2013 shows a similar picture as shown in Table I. The majority of faults have been recorded eastern of Iraklion (246 out of 307, i.e. 86%), with only 41 (13.35%) recorded in the TL connecting Iraklion to Chania and just 2 (0.65%) west of Chania. It should be noted that these are all the recorded faults (not only the pollution related ones) and also that the eastern routes include a double circuit (gradually upgraded in 2000-2004) in the Linoperamata-Agios Nikolaos-Atherinolakos route, denoted with a black line in Figure 1.

TABLE I. Recorded Faults in TLs Routes (1994-2013)

Chania-Kasteli	2
Linoperamata-Chania	41
Linoperamata-Agios Nikolaos-Ierapetra	117
Linoperamata-Mires-Ierapetra	72
Linoperamata-Iraklion 2	31
Ierapetra-Atherinolakos-Sitia	44

IV. TLs and Insulators

Historically, ceramic insulators (both glass and porcelain) were used in 150kV TLs with fog profiles being used in areas where pollution was considered heavier. The number of discs in insulator strings also differed according to the pollution severity of the area. The distance from the coast was the decisive factor at this stage.

Pollution problems were recorded as soon as the first transmission line was constructed with fires occurring on the upper parts of the wooden poles of the 66 kV line used at that time. Not long after the operation of the first 150 kV lines (1976 to 1979), pollution problems were recorded at the eastern part of the island. Pollution was historically the single factor responsible for more faults in the 80s (32.5%) and 90s (19.6%) [9]. The decrease from one decade to the next should be 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) [9]-[12].

The installation of HTV SIR composite insulators started in 1993, in a small scale/trial basis. Large scale installation was initiated in 2004, at the Iraklion-Agios Nikolaos-Atherinolakos route. The Atherinolakos-Sitia TL was fully refurbished in 2006 and the Ierapetra-Sitia line followed in 2010. The installation of HTV SIR insulators in the Iraklion-Mires TL and the Iraklion-Chania TL started in 2013 and is expected to be fully concluded for both by 2015. The Mires-Ierapetra line is also scheduled to be fully equipped with polymer composite insulators by 2015. Traditional ceramic (porcelain) insulators are installed west of Chania (Chania-Kasteli) and there has not been a replacement scheduled for them as this TL faces minimal problems. The priority followed, also hints to the severity of the pollution problem for each route.

Table I: TLs and Insulators (Summer 2014)

TL	**Ins. Type (in general)**	**Year of large scale installation of HTVs**
Linoperamata-Agios Nikolaos-Atherinolakos	HTV SIR	2004
Atherinolakos-Sitia	HTV SIR	2006
Ierapetra-Sitia	HTV SIR	2010
Iraklion-Mires (*)	HTV SIR, Glass, Porcelain	2013
Iraklion-Chania (*)	HTV SIR, Glass, Porcelain	2013
Mires-Ierapetra (*)	Glass	-
Chania-Kasteli	Porcelain	-

(*) to be fully equipped with HTV SIRs by 2015

It should be noted that not a single pollution related fault had been recorded at lines equipped with HTV SIR. In 2014, two faults were recorded that were related with bird droppings and nesting and even though such faults (especially the one caused by bird droppings) may be considered as pollution related, the insulator material can hardly be considered responsible. It should also be noted that certain insulator batches seemed to be rather attractive to big birds as shown in Figure 2. This was dealt with following a trial/error method using different batches (hardness and color seemed to play a major role in the bird's liking) and also through the use of ceramic coated strings, thoroughly presented later in the manuscript. In regards to the economic benefit, it has been calculated that the yearly cost of washing is 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) [11].

Figure 2. Polymer insulators attacked by birds

RTV SIR coated insulators have also been used in certain 150 kV towers when special conditions are met [13]. These insulators were coated by PPC/HEDNO personnel (e.g. Figure 3) and the first coating took place in 2004. The metal parts were also coated in order to avoid corrosion problems. RTV coated glass strings have been used in the upper phase of certain towers of the Ierapetra-Atherinolakos TL where clearance issues did not allow the use of the available composites. They were also used near the archeological site of Knossos and near the Iraklion 2 substation. In both these cases it was decided to use metal posts instead of towers mostly to avoid visual pollution complaints (especially in the case of Knosos) and also due to space limitations (especially in the case of Iraklion 2 premises that fall in the city grid of Iraklion). Originally ceramic insulators were installed in these posts but complaints for noise pollution were made, as the hollow metal posts magnified the buzzing noise related to minor activity. Most importantly, a high failure rate was observed (47 shattered units out of 1300 in 3 years) [12]. Therefore, the ceramic insulators installed in these poles (glass strings and long rod porcelain) were coated on site, which resulted to both these problems being solved.

Figure 3. HEDNO personnel coating suspension insulators with RTV SIR

RTV coatings have also been used in the Atherinolakos-Sitia TL (mainly in terminal and tension towers). The strong winds in certain parts of this area combined with the low weight of the HTV SIR insulators initially installed, resulted to tripping as the conductors got too close to the cross arms. Therefore, RTV coated strings were installed in the bridging parts of certain towers and weights were also installed in some cases. Also, as mentioned above, coated strings have been used to solve the bird attacks problems observed in certain areas.

In general, it should be noted that although some imperfections could be spotted right after the coating and although parts of the coatings have been found to peel off after several years of installation, still there has been no problems reported regarding the RTV coated insulators installed in TLs of the Transmission System of Crete.

V. Research

The extended use of polymer materials, especially RTV SIRs in substations [6]-[12], [14] boosted the reliability of the network and resulted to significant cost savings. However, it also created the need of further research in the direction of aging and performance of these materials. Leakage current monitoring devices were purchased and installed in substations back in the 90s. Initially post insulators (porcelain, coated and HTV SIR) were monitored. The latest research step was the construction of TALOS High Voltage Test Station in the premise of the Linoperamata substation [15]. At first, TALOS had only one bay where 150 kV post and suspension insulators could be tested. Later (in 2011) the station was expanded and is now equipped with three bays where 21 kV and 150 kV post and suspension insulators can be monitored and tested.

As shown in Table I, almost the entire Cretan network (with the exception of the Chania-Kasteli TL) will soon be fully equipped with HTV SIRs and therefore the research has gradually focused in such insulators. HEDNO (and TALOS) participate in POLYDIAGNO, a research project focused on the monitoring and diagnosis of polymer based outdoor insulators used in high voltage applications, along with the Technological Educational Institute of Crete and the Foundation for Research and Technology-Hellas. The aim of the project is to describe a standard procedure/diagnostic technique that could be used to assess the aging and performance of polymer insulators.

For the purposes of the POLYDIAGNO research project, composite insulators were to be removed from certain network towers, some of them to be installed in TALOS and others to be sent for lab evaluation. To decide the location of the towers, prior experience along with previous pollution measurements (Figure 4) [4] were considered. The years in service and also some practical issues (tower location, ease of removing etc) were also considered. It should be noted that the considered ESDD measurements were conducted on site using dead insulator strings hanged from the metal structure of 150 kV towers [4]. However, as glass and porcelain strings of fog and disc profile were used to acquire the measurements, a correlation factor has to be defined in order to provide a unified image. Currently the worst-case-scenario value proposed in the literature has been used [4] but comparative ESDD measurements have been conducted in a specially designed arch in TALOS, shown in Figure 5, which will provide a more accurate value when published.

Figure 4. SPS classes as acquired via ESDD measurements

Figure 5. The ESDD arch in TALOS

After all data had been considered, seven 150 kV towers were selected and three insulators where removed from each one [5]. The exact location and the years in service for each insulator are shown in Figure 6. Two out of the three insulators removed from each tower were installed in TALOS, whereas the third one was sent for lab tests which include chemical and material analysis (FTIR, SEM, LIBS, etc) and HV tests (e.g. inclined plane, dynamic drop etc), e.g. [16], [17]. At a later stage, the insulators installed at TALOS will be removed at different intervals and be sent for lab evaluation.

The monitored leakage current, weather and pollution will provide a complete profile of the stress that these insulators were subjected at. A stand-alone weather station has been suitably installed in top of the ESDD arch as shown in Figure 7 and an online weather report is currently publicly available in the station's site [15]. The leakage current measurement is acquired by using a stand-off insulator to lead the current to a hall sensor. An explosive fuse is used to protect the 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 are shown in Figure 8.

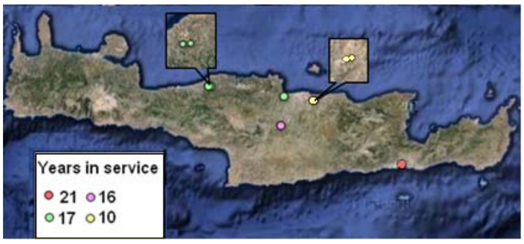

Figure 6. The seven selected 150kV towers and the years in service for the insulators removed from each insulator

Figure 7. Installation of the weather station in top of the ESDD arch

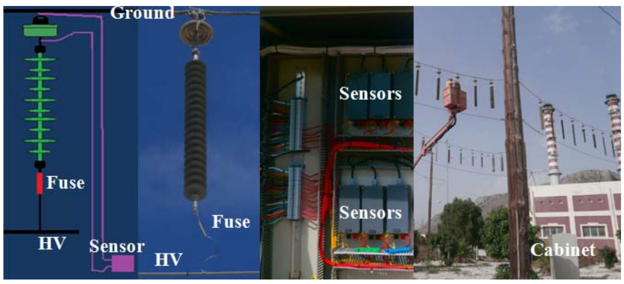

Figure 8. A drawing of the basic leakage current measuring installation and photos from the actual installation in TALOS High Voltage Test Station

Figure 9 shows the location of TALOS and also a 3D model of it. The exact location of the POLYDIAGNO insulators has been noted in these pictures and a photo of the POLYDIAGNO insulators installed is also shown. The location of the ESDD arch is denoted in the 3D model whereas the proximity to the coast is made obvious in the top view image. Further, the location of the control room, connected to all measuring devices via LAN, is also shown. More pictures along with additional info and published material can be found in [15].

An NSDD measurement set up has also been established in the recently refurbished chemistry lab of HEDNO in Iraklion 2 substation. ESDD measurements are conducted in TALOS and the acquired solutions are then carried in bottles to the chemistry lab in Iraklion 2, as shown in Figure 10. Further, as a future step, it was decided to fabricate DDDG measurement kits and a photo of a first prototype is also shown in Figure 10. For the exact procedure followed for ESDD, NSDD and DDDG measurements see [2].

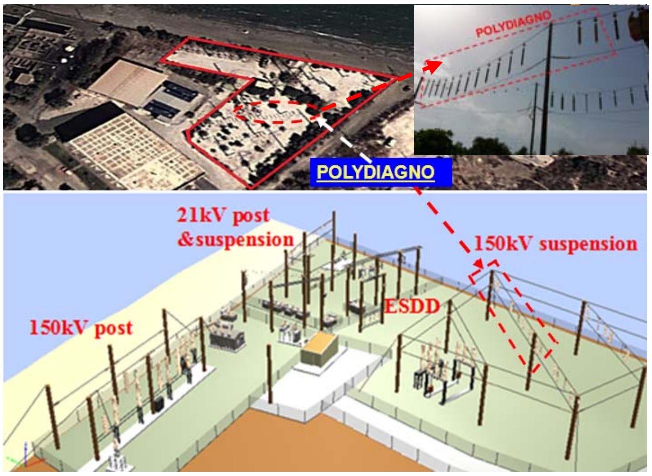

Figure 9. Top view, 3D-model and a photo of TALOS showing the station and also the exact location of the POLYDIAGNO insulators in the test station.

Figure 10. Labeled bottled with the remaining solution after ESDD measurements, the precision scale in HEDNO's chemistry lab weighing a dried filter, and the result of a first attempt to fabricate a DDDG measuring kit

VI. CONCLUSION

The fault free operation of high voltage insulators is a matter of great importance for power utilities. However, the performance of outdoor insulators is strongly influenced by the local service conditions (experienced weather and location). Traditional ceramic insulators have been proved to face severe problems in coastal areas due to sea salt deposited on their surface. Polymer insulators and coatings may provide superior performance in such heavily polluted areas due to their hydrophobicity which suppress the pollution problem by not allowing the formation of conductive films on the insulators' surface. The Mediterranean island of Crete provides a rather interesting case study due to the specific local conditions met there. The Greek utility has employed several remedies to cope with the insulator pollution problem over the years. This paper focuses on the transmission lines case and to the related research. The utility's strategy is briefly presented along with the latest research steps that include TALOS High Voltage Test Station and the POLYDIAGNO research project. Current research aims to describe a standard procedure/diagnostic technique that could be used to assess the aging and performance of polymer insulators. Further, the infrastructure provided by TALOS and the collaborating labs can offer significant research and testing services to academia, power utilities and insulator manufacturers.

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