Insulation Coordination and Pollution Measurements in the island of Crete

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Abstract—**The performance and reliability of outdoor dielectrics used in power systems is strongly linked to local environmental conditions. A major factor affecting their performance is the pollution severity in the area along with local climatic conditions. Sea is considered a major pollution source and therefore coastal installations and islands usually face severe pollution problems. The Mediterranean island of Crete provides a rather interesting case study as the particular conditions met there have resulted to the island being a reference point on both national and global scale. The Greek utility has employed several different remedies to cope with the pollution problem over the years. Pollution measurements have been performed throughout the island in order to acquire a pollution map to assist in insulation coordination and maintenance. Measurements have been performed on un-energized insulators similar to the ones used in each area/tower at that time. However, as both material and profile play an important role on the actual pollution impact, comparative measurements have also been performed in a specially designed High Voltage Test Station in order to derive a suitable correlation factor between different insulator types and designs. The final version of the acquired pollution map is presented in this paper and is correlated to network experience regarding the maintenance and selection strategy of outdoor insulators.**

Keywords—High Voltage Insulators; Pollution Problem; ESDD Measurements; Pollution Map; Maintenance strategy; Insulation Coordination

I. INTRODUCTION

Severe environmental conditions and pollution degree strongly influence outdoor dielectrics performance and reliability. The pollution phenomenon is rather complex in the case of HV insulators of a transmission or distribution network as a single insulator fault may lead to an excessive outage. Pollutants deposited on the insulators' surface allow the flow of leakage current, which in turn may cause dry bands formation, discharges and possibly lead to a complete flashover [1-2].

The Greek island of Crete is located in the Mediterranean Sea and provides a rather interesting case study. The biggest part of the island's network is coastal and subjected to severe marine pollution [3-4]. As a result, it encounters significant insulating problems. The Greek utility has made significant efforts to cope with the problem and has employed a variety of remedies [3-9]. Some of them concern the design stage, such as the selection of the appropriate insulator geometry and material whereas for the already installed equipment, pressurized water washing and RTV SIR coatings are the methods usually employed [3-9]. The vast majority of insulators in coastal HV substations are now coated with RTV SIR [5, 8] and most Transmission lines were recently equipped with HTV SIR composite insulators [7, 9].

Significant efforts have been made towards mapping the island's pollution, and its impact on outdoor insulators, through a series of pollution measurements [10-12]. However, since the results from the comparative measurements were not available at the time, a worst case scenario was used to correlate measurements taken on different insulators according to the values proposed in [13]. In this paper, the correlation factors that derived from a series of comparative pollution measurements [14] were considered in order to acquire a uniform mapping. Further, the latest field measurements were also considered. The measurements presented in this paper took place on TLs throughout the island. The comparative measurements were conducted in TALOS High Voltage Test Station [14-15]. In order to assess the Site's Pollution Severity (SPS) class, two basic methods were used: the Equivalent Salt Deposit Density (ESDD) and the Non-Soluble Deposit Density (NSDD).

II. EXPERIMENTAL METHOD

A. ESDD

In this method the contaminants of an insulator's surface are carefully removed with a cotton swab, excluding any metal parts or assembly materials (Fig. 1). The contaminants are then dissolved in distilled water of 100-300 cm^3, stirred and then the conductivity and the temperature of the solution are measured (Fig. 2). ESDD is finally estimated from the volume of the solution, the area of the cleaned surface and the corrected to room temperature (20^{o}C) conductivity [1, 2, 13]. ESDD is a low cost and relatively easy technique and for that reason it can be conducted on site.

Fig. 1. Measuring ESDD on site

Fig. 2. Measuring the conductivity of the solution

B. NSDD

In order to acquire the NSDD measurement, the ESDD solution shall be filtered by a pre-dried and weighed filter paper. Then, the filter containing the pollutants shall be dried and weighed again to calculate the weight of the non-soluble deposits [1, 2, 8]. NSDD can not be performed on site as it is a time consuming technique that requires special equipment such as a water vacuum pump, a drying oven, a desiccator and a precision scale. The Chemistry Lab of HEDNO (Hellenic Electricity Distribution Network Operator) provided the necessary equipment to perform the NSDD measurements in this case. The solutions used, were carried to the laboratory into labeled bottles as shown in Fig. 3. The drying oven, desiccator and scale used are shown in Fig. 4.

Fig. 3. Solutions into labeled bottles, filtering with water vacuum pump and residuum on the filter paper

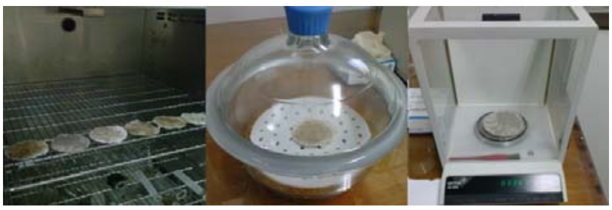

Fig. 4. Filters in the drying oven, desiccator and precision scale

III. POLLUTION MEASUREMENT PROCEDURE

A. Measurements on ceramic insulators

In order to investigate insulators' behavior under natural contamination conditions and the pollution severity along the island, a series of ESDD measurements were conducted throughout the network. Four periodical measurements took place in yearly intervals as the required by [2] monthly visits were rather impractical and time consuming for the line crew. Considering that the measurements took place after the end of summer (September-October) and before any rainfall, they should provide a good approximation to the worst-case pollution scenario (i.e. the SPS). The strings of insulators were hanged from the metal structure of 150 kV towers (Fig. 5) in 35 spots throughout the Cretan power system (Fig. 6). Each dead string was composed of five ceramic (porcelain and glass) discs, hanged from a lower height in order to be easily accessible. Disc and fog profile insulators were used for these measurements. The location of the 35 150kV towers where the specimen insulators were hanged is mainly residential and marine polluted areas, the majority of them being at the central and eastern part of the island, as shown in Fig. 5. The mentioned specimens are shown in Fig. 7 and their characteristics are presented in Table I.

Fig. 5. Dead strings hanged from the metal structure of towers

Fig. 6. Location of the specimen insulators

TABLE I. CERAMIC INSULATORS CHARACTERISTICS

Insulator Profile/Material	Creepage Distance (mm)	Shed Diameter (mm)	Shed Area (mm2)
fog/porcelain	430	267	252,700
disc/porcelain	310	254	164,900
fog/glass	390	255	201,300
disc/glass	310	254	164,900

Fig. 7. 150 kV specimen insulators

B. *Measurements on composite (HTV SIR) insulators*

The largest part of Crete's TLs is coastal and for that reason subjected to intense marine pollution. The pollution problem is rather exaggerated on the eastern side of the island, as the frequent rains on the western side resulted to no particular problems experienced there [3-4]. In order to cope with the problem, the most heavily influenced TLs were equipped over a decade ago with HTVs and most of the rest followed recently [7, 9]. Recently, additional ESDD and NSDD measurements were conducted on polymeric insulators that were removed from TLs after a long time service period. The specific TLs are Linoperamata-Mires, Mires-Ierapetra, Linoperamata-Chania and Linoperamata-Ierapetra and their route can be found in [7, 9]. As the value of an insulator's surface area was not provided by the manufacturer, Computer Aided Design (CAD) had to be employed to design 3D models for each insulator in order to calculate the required values. The characteristics of the mentioned RTV-SIR insulators are shown in Table II. In Fig. 8, the surface pollutants of an HTV-SIR insulator are removed by cotton and a spatula and the different view between the two wiped sheds compared to the others which is shown in the third picture.

Fig. 8. ESDD measurement on a HTV-SIR insulator removed from the network

TABLE II. HTV-SIR INSULATORS CHARACTERISTICS

Designation No.	Creepage distance (mm)	Arcing Distance (mm)	Shed Diameter (mm)	Shed Area (mm2)	Years in service
1	5,711.36	1,600	130/96	44,842.894	17
2	5,711.36	1,600	130/96	44,842.894	16
3	5,555	1,600	136	31,864.500	21
4	5,555	1,600	136	31,864.500	17
5	6,079	1,400	170/130	75,712.130	10
6	5,555	1,600	136	31,864.500	17
7	6,030	1,460	175/135	82,849.961	10

C. *Measurements in TALOS H. V. Test Station*

Comparative ESDD and NSDD measurements were also conducted on insulators of TALOS High Voltage Test Station in Iraklion, Crete [14]. TALOS is a research and testing center west of the city of Iraklion, near a 150 kV substation [6, 15]. As shown in Fig. 9, it is located next to the coast in order to be subjected to maximum marine pollution [6, 15]. TALOS is divided in three different sections: 150 kV post insulators section, 150 kV suspension insulators section and 21 kV post and suspension insulators section. Also, it is equipped with a specially designed arch, where five different types of suspension insulators are hanged offline. The specimens used are: a Teflon long rod insulator, a fog profile glass insulator, a fog profile glass insulator coated with RTV-SIR, a disc profile glass insulator and an HTV-SIR long rod insulator (Fig. 10).

The specimen insulators were exposed to natural contamination under un-energized conditions for more than one year. The measurement period was from March 2014 to May 2014 and the measurements were carried out at monthly intervals in order to give a better understanding of the pollution build-up mechanism [14]. The specific measurements were performed not only for further investigation of the insulators performance under severe contamination conditions, but also for determining an appropriate corrective factor that would correlate the measurements on different profiles. According to [2], SPS classes are related to ESDD values measured on disc profile insulators and for that reason the measurements on other insulators (see previous paragraph) should be corrected in order to acquire a unified image.

Fig. 9. The location of TALOS High Voltage Test Station

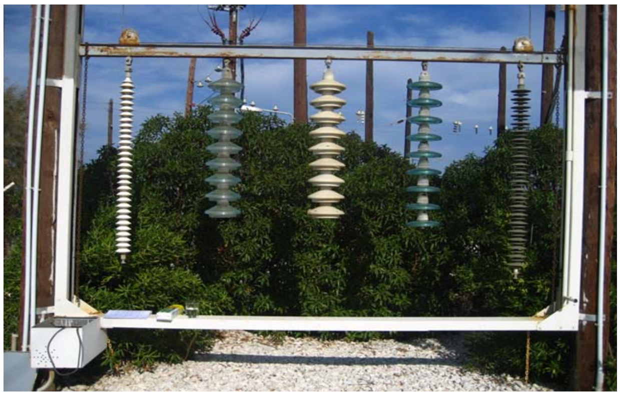

Fig. 10. Specimen insulators in the lowest position of the ESDD arch

IV. MEASUREMENT RESULTS

The maximum ESDD values of the measurements conducted on ceramic insulators throughout Crete's Power System were considered as the final ESDD value for this location. According to [2], the Site Pollution Severity classes are linked with ESDD values measured on disc profile insulators. Therefore, correction of the measurements conducted on the ceramic deep ribbed insulators that are described in paragraph III-A of this paper is necessary. Although a correlation factor of 0.8±0.3 is proposed by [7], the comparative measurements that took place in TALOS HV Test Station gave larger values. The correlation factors calculated for each measurement are in the range of 0.761 to 1.637 [14]. The average value is 1.0251 and if one considers the max ESDD value in both cases then the correlation factor that follows this worst case scenario is 1.143. This is the value that it was finally used in this paper in order to acquire the unified pollution map shown in the next paragraph.

Fig. 11 shows the final pollution map of the island of Crete, according to CIGRE limits, after the described field tests and after the application of the correlation factor calculated through the comparative measurements. As it is obvious, areas near big cities (Iraklion, Rethimnon, Agios Nikolaos and Ierapetra) have high pollution levels, with the results proving that the proximity to pollution sources and coast is a key factor for pollution levels. However, the city of Chania is an exception as the pollution recorded there is milder probably because of the frequent rains, almost twice the rainfall compared to the eastern part [3-4]. Also, the lighter pollution of the coastal sites in the south part should be attributed to the prevailing direction of the wind which is north-west [3-4]. These facts verify the reason why the majority of the remedies employed have always been focused on the eastern side of the island.

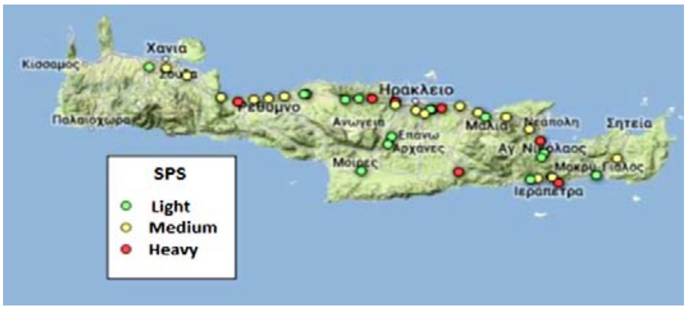

Fig. 11. Pollution map of Crete

V. CONCLUSIONS

The performance of outdoor insulators in power systems is strongly influenced by the deposition of pollutants on their surface in combination with the experienced weather. Coastal installations are subjected to severe pollution due to sea salt deposition. To optimize the selection and maintenance of insulators, power utilities consider weather profiles, location, past experience and pollution measurements, if available. The power system of the Greek island of Crete provides an interesting case study due to its specific characteristics. The Greek utility has performed pollution measurements on several locations throughout the island in order to gain a further insight of the problem. These were conducted on dead strings hanged from the metal structure of transmission towers. The strings used were ceramic (glass and porcelain) of both disc and fog profile. Further, additional measurements were conducted on HTV SIR insulators that were recently removed from the network. To obtain a uniform image of the situation, a series of comparative measurements were recently conducted in a High Voltage Test Station. Correlation factors were determined and were used to provide a unified pollution map.

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