Assessing Pollution of Outdoor Insulators in the Cretan Power System

D. Pylarinos, K. Siderakis, I. Pellas, E. Thalassinakis

***Abstract*—**Insulators are key components of power systems as a single insulator fault may lead to an excessive outage. Insulators' performance is strongly linked with local conditions and especially with the experienced pollution. Therefore pollution mapping is an important procedure for power utilities that can be used for insulator maintenance, selection and replacement. For this purpose, several approaches can be followed considering the severity of the problem and also the available time and funds. These include the consideration of geographical and environmental data, human expertise/experience, fault analysis and specially designed measurements such as ESDD, NSDD and DDDG. In this paper, the experience from pollution mapping in the Mediterranean Island of Crete, is presented. The Cretan power network bears a significant interest due to its unique characteristics which are also briefly described. Results and future research perspectives are discussed and conclusions are drawn.

***Keywords*—**insulator, lab, field, high voltage, monitoring

I. Introduction

HIGH voltage insulators are important components of power systems and their performance strongly reflects to the system's performance and reliability [1]. A single insulator fault may result to excessive outages and therefore insulator research is of significant importance for power utilities. One of the main factors affecting insulators' performance is the experienced pollution, which is highly localized [2-3]. Deposited pollutants allow leakage current to flow on the surface, which in turn may cause the formation of dry bands, discharges and may even result to a complete flashover [1-3]. To suppress the problem several remedies can be employed, such as extending the creepage distance, using specially designed profiles and using hydrophobic materials to manufacture insulators or to coat their surface [1-7].

Assessing a Site's Pollution Severity (SPS) class is a complex task which is strongly related to available funds and time [3]. Depending on the case, some or all of the following may be employed: laboratory tests, field tests, pollution measurements, past experience, fault analysis, weather and geographical data [3]. The distance from pollution sources is mostly considered when referring to geographical data with the addition of altitude when it is high enough to bring about extreme conditions (icing, snow) [8].

The Greek island of Crete is located in the Mediterranean Sea and its power system suffers mainly from severe marine pollution due to local weather conditions and its coastal development [9]. The Greek utility (now the Hellenic Electricity Distribution Network Operator S.A., a former part of the Public Power Corporation S.A.) has issued several different remedies to cope with the problem over the years [10-12]. Further, significant efforts have been made towards mapping the island's pollution and its impact on outdoor insulators. In this paper, the different data related to the assessment of the experienced pollution are presented. The island's morphology, the climate, the network's geography, the recorded faults on different parts of the network and finally the results from pollution measurements conducted in different locations throughout the island's network are presented.

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II. Local Conditions & Power Network

A. *Island's morphology and location*

Crete is a Greek island located in the Mediterranean Sea, at the Southern end of Europe as shown in Figure 1a. Crete has a rather elongated shape (it is 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 as shown in Figure 1b. The development of the island is mostly coastal with the four largest cities (Iraklion, Rethimnon, Chania, Ierapetra, Agios Nikolaos with a descending order) being located next to the coast as shown in Figure 1b.

B. *Weather and Climate*

Crete's climate is characterized by prolonged periods of dry and then wet weather. The dry period usually starts in April and lasts until the end of October. Although the amount of rainfall is significant, most occurs only between November and March. Crete also experiences strong winds mainly of north-northwest direction. Wind reaches its strongest during the summer. Strong winds combined with the rocky coasts result

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to increased salt deposition on outdoor insulators. Further, towards the end of August increased precipitation (and relative humidity) is observed [9-11]. As a result of the above, pollution builds up during the dry period and results to an increased risk when wetting occurs. In addition, a significantly diverse behavior is observed between the eastern and the western part of the island. Strongest winds are recorded on the east side of the island whereas the west part receives almost twice the rainfall compared to the east [9-11].

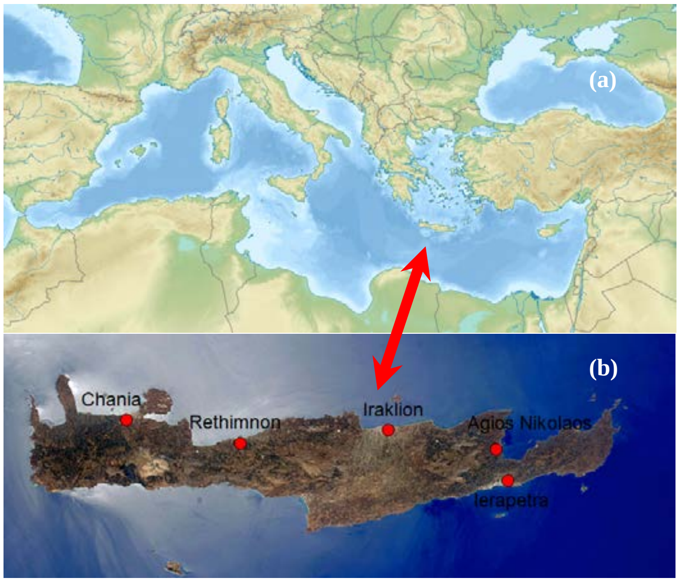

Fig. 1. (a) Crete located in the Mediterranean Sea (b) the island of Crete

C. Network Development and Past Experience

The location of all 150 kV towers of the transmission system, and thus the route of the transmission lines, is shown in Figure 2.

Fig. 2. The location of the 150 kV Transmission Towers

As it can be seen from this figure, the network is mainly coastal, which exaggerates the marine influence. In fact, pollution was responsible for a large percentage of faults that was gradually diminished as more maintenance experience was gained and further reduced as more Transmission Lines were equipped with composite insulators [9, 13]. Historically, pollution problems were recorded as soon as the first transmission line (from Iraklion to Chania) was constructed in the early 60's. The voltage level was then only 66 kV, wooden poles were used and pollution resulted to the burning of the upper parts of several poles [11]. The 150 kV Transmission Lines were gradually installed from 1976 to 1979 and pretty soon the first problems were recorded at the eastern part of the island. It should be noted that from 1978 until 1993 the faults per km where ten times more in the east compared to the west, even though the eastern side was overinsulated and was also washed clean occasionally [9, 14]. Limited installation of composite insulators started in the 90's in order to monitor their performance and as results we encouraging, extended installation started after 2000. As shown in Figure 3, composite insulators was only the 3% of installed insulators in 2000 and their percentage reached 52% in 2010 [13] and keeps increasing.

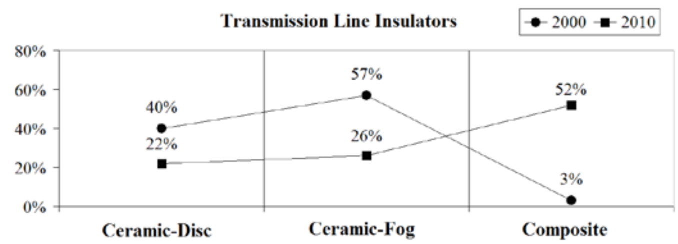

Fig. 3. Transmission line insulator percentage from 2000 to 2010

The total number of faults per 100 km for the years 1980-2010 is shown in Figure 4. The Cretan network has expanded about 36,000 km over these 30 years and therefore the faults per 100 km have been considered in this Figure. As shown in Figure 4 the number of faults per 100 km shows a significant decrease from a decade to next which can be largely attributed to pollution maintenance procedures. For example, from 1978 to 1981 sponge washing was applied. Then, from 1982 to 1985 no washing was applied which led to the increased number of faults in 1985, when pollution was combined with suitable weather conditions [9-11]. As a reaction, washing using pressurized water was introduced as a pollution maintenance procedure, which prevented similar "breakouts" in the following years [9-11]. The gradual installation of composite insulators in the 00's led to a significant decrease in the total number of faults as shown in Figure 4. It should be noted that no flashover has been recorded on any SIR composite insulator in the Cretan power system since their installation.

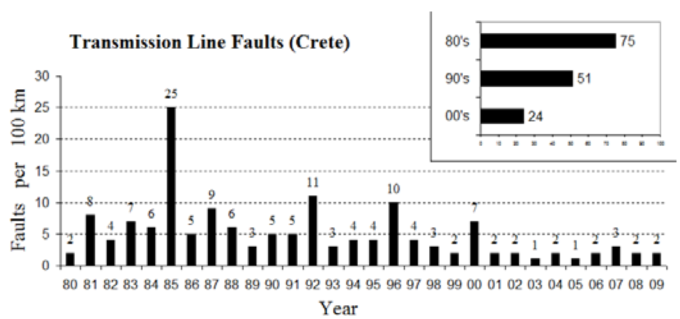

Fig. 4. Transmission Line faults (1980-2010) per 100 km

III. POLLUTION MEASUREMENTS

A. Introduction, Set-Up and Location

Three basic procedures have been standardized in order to measure pollution: the Equivalent Salt Deposit Density (ESDD), the Non-Soluble Deposit Density (NSDD) and the Directional Dust Deposit Gauge (DDDG) [3]. ESDD relies on collecting the pollution deposited on the surface of off-line insulators in certain intervals, diluting it in water and measuring the conductivity and temperature of the solution in order to define the equivalent amount of salt in mg per cm^2 of the insulator's surface. To acquire the NSDD measurement the solution is filtered, the filter is dried and weighted to calculate the weight of non-soluble deposits. The DDDG measurement relies on the installation of special kits of cylindrical design that collect pollution from four directions (East, West, South, North).

Each procedure has its prons and cons. ESDD is considered a low cost technique that considers the insulator's profile and can be conducted on site but requires frequent mounting and unmounting of insulators. NSDD is especially needed when non-soluble deposits are present (e.g. sand) but requires special equipment (a drying oven, a dessicator, a laboratory weighing scale) and therefore may be costly and can not be conducted on site. DDDG is an easily implemented procedure which is considered as an easy alternative for large area mapping but has the disadvantage of not considering the insulator's profile which is strongly related to the amount of deposits that actually stays on the insulator's surface and also to the cleaning effect of rainfalls. In fact, it should be mentioned that some 400 kV insulators where installed in one Transmission Line of the Cretan network when the line was first upgraded from 66 kV to 150 kV, but their performance was rather poor [9, 11]. Indeed a 55% of them was damaged (and replaced) due to flashovers from 1985 to 1994 [11]. At the same time, only 0.7% of the 150 kV insulators installed at the same line had to be replaced. This was largely attributed to the difference of their profile, as the 400 kV insulators exposed only 36% of their surface to the cleaning effect of rain whereas the 150 kV insulators exposed the 53% [11]. Therefore, it became obvious to PPC engineers that what mattered was not merely the amount of salt that is carried from the sea, but the actual amount that stays on the insulators' surface.

Considering the above, it was decided that ESDD measurements were conducted on various locations throughout the island. A number of 35 towers of 150 kV lines were selected considering past network experience, as shown in Figure 5. Most selected towers belong to eastern coastal lines and especially the line connecting Iraklion (starting at the Linoperamata Substation) with Ierapetra, due to the experienced problems recorded on this line and also considering the line's importance. Further, multiple towers were selected near the larger cities as these were areas also exposed to other pollution types (industrial, domestic etc). Strings of insulators were hanged from the metal structure of towers as shown in Figure 6. These dead strings were hanged from a lower height compared to live ones in order to be easily and safely accessible by the crew.

Although small intervals are proposed for ESDD measurements, this was not practical in this case due to the number of the measuring points and also considering local weather conditions. In fact, conducting multiple measurements during the dry period would be redundant as pollution kept concentrating on the insulators' surface whereas further measurements after the rainfall period starts would result to lesser pollution due to the cleaning effect. Therefore, and also considering the man hours needed, it was decided that a single measurement was conducted yearly at each tower in the months September and/or October (at the end of the dry period and before rainfalls start). To cut costs, measurements were conducted on site by the line crew with the opportunity of other works in the area. To make sure that a credible measurement was taken, the procedure was repeated for three years in a row to minimize the risk of a local rain before the measurement. The maximum of the 3 measurements was then considered as the ESDD value for the location.

Fig. 5. The location of the ESDD measurement spots

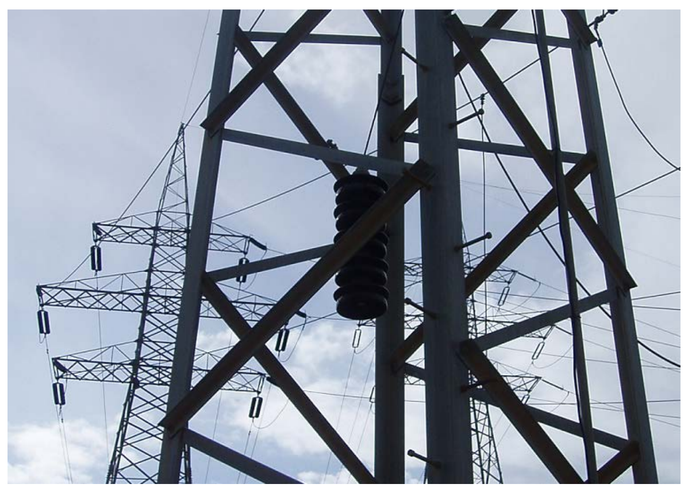

Fig. 6 Offline installation of an insulator string for ESDD measurements

In order to calculate the area of the insulators' surface, computer aided design was implemented using Autocad as shown in Figure 7. Further, as both fog and disc profile insulators were used to conduct measurements a correction factor should be applied in order to correlate measurements as proposed in [15]. However, the exact value of the correction factor is not specified, as a value in the range of (0.8 ± 0.3) is proposed. In order to follow the worst case scenario the maximum value of 1.1 was selected in this paper. However, further research is needed for the exact determination of this factor. PPC (and now HEDNO) have constructed and operate an outdoor High Voltage Test Station in Iraklion Crete [16], where a series of comparative measurements have been scheduled in order to define this factor with further accuracy.

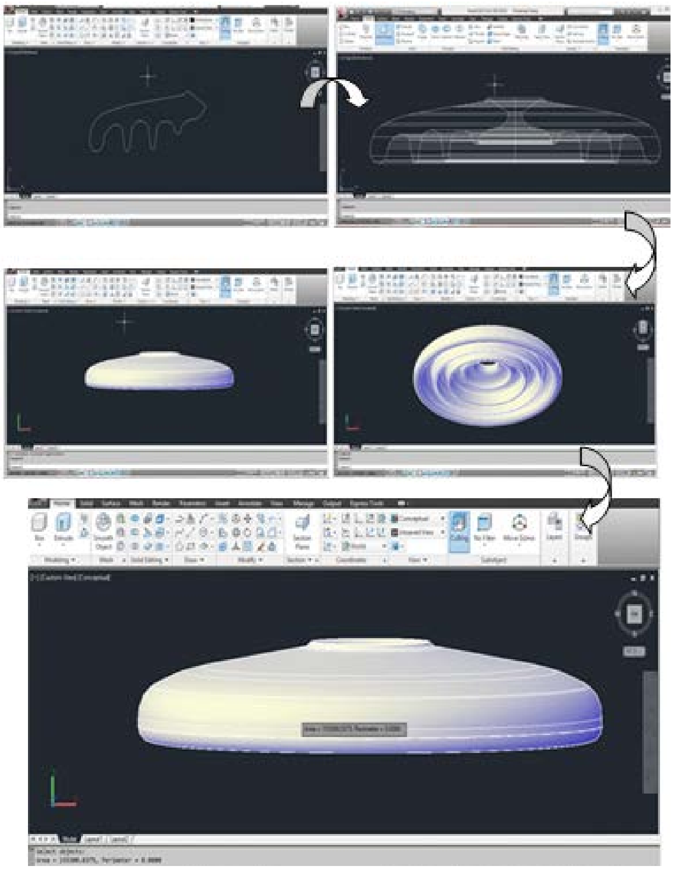

Fig. 7. Calculating an insulator's surface area using Autocad

B. Results

In order to classify a Site's Pollution Severity (SPS) to the three basic classes (light, medium, heavy), slightly different ranges of ESDD measurements have been proposed by IEC [3], IEEE [17] and CIGRE [18]. The IEC values are given through an ESDD-NSDD diagram and have relatively large cross-areas, therefore the more specific IEEE [17] and CIGRE [18] values shown in Table I are used in this paper. Results are shown in Figures 8a and 8b for IEEE and CIGRE limits respectively. It should be noted that further splitting up of the three basic classes (e.g. using a "very light" [3] or a "very heavy" SPS class [18]) has been avoided, in order to produce easily comparable results. Further, IEC [3] has suggested that the distance from the sea (or other pollution sources) could be considered as an indication, especially when there are no other measurements. Since the actual distance can not be conducted from the images and the size of the marker icon may be misleading, the minimum distance of each tower from the sea is presented in Figure 8c. Further, the altitude for each tower is shown in Figure 8d.

Coastal towers of low altitude are mainly selected. As shown in Figure 8, 27 of 35 towers have a distance of less than 5 km from the sea and 28 of 35 have an altitude of less than 200 m.

Table I. SPS and ESDD values

SPS	ESDD value (mg/cm^2) (IEEE) [17]	ESDD value (mg/cm^2) (CIGRE) [18]
light	<0.06	<0.06
medium	0.06-0.10	0.06-0.12
heavy	>0.10	>0.12

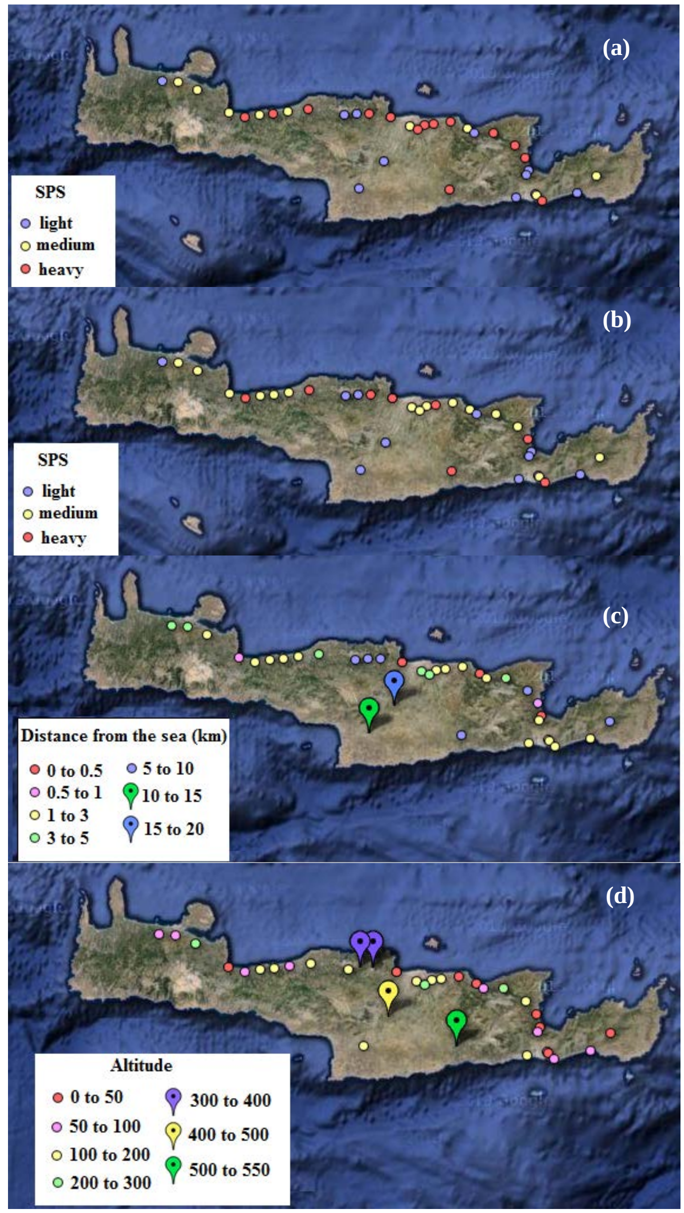

Fig 8. (a) SPS classes according to IEEE (b) SPS classes according to CIGRE (c) the minimum distance from the sea for each tower (d) the altitude of each tower

As shown in Figure 8 some locations changes classes when moving from IEEE to CIGRE limits. This shows that a more tolerant approach as the one proposed by IEC [3] is probably closer to reality, even though a strict definition is usually preferred by utility engineers. Further, it shows that added measurements such as NSDD and DDDG could prove helpful in providing a more accurate classification. In addition it should be noted that the highest tower (529 m) also shows increased pollution severity (falls in the "heavy" SPS class) even though it is in a relatively long distance from the sea (6.7 km). Although additional research is required to define the impact of lower altitude variations on pollution deposition, nevertheless this result may be an indication of the multivariate procedure behind SPS definition.

An added strong conclusion is best portrayed in Figure 8b. As shown the proximity to pollution sources, mainly the coast and large cities, is proven to be a key factor for heavier pollution. However, rainfall patterns and wind direction is also to be considered. As shown in Figure 8b, heavy pollution has been recorded next to Iraklion, Rethimnon, Agios Nikolaos and Ierapetra. However, not near Chania even though Chania is larger than Agios Nikolaos and Ierapetra. This verifies the different conditions experienced on the west part of the island as described earlier in this paper. Further, the measurements conducted on coastal towers located in the south part of the island shows a lighter pollution image which should be largely attributed to the direction of the experienced winds which is mostly north-west.

IV. Conclusion

Assessing the pollution of outdoor high voltage insulators is an important piece of information for power utilities. Several approaches can be followed to map the experienced pollution depending on the available time and funds. Crete is a Greek island located in the Mediterranean which offers a valuable case study for pollution of outdoor insulators due to its location, shape, climate and power network design. Marine pollution is the dominant pollution form experienced by the island's power network. The Greek power utility has employed several remedies to cope with the problem and has also participated in several research schemes that investigate the phenomenon's various different aspects, including pollution mapping. Various factors are considered and presented in this paper: the island's morphology and location, the experienced weather and climate, the network's development, past fault and maintenance experience as well as pollution measurements conducted on 35 different spots throughout the island. The island's pollution profile is portrayed through the use of descriptive maps. The overall conclusion is that pollution mapping is a rather complex procedure and even though the distance from the sea is a strong indication, additional data such as the distance from other pollution sources as well as wind strength, wind direction and rainfall patterns should also be considered.

V. Future Work

As mentioned in paragraph III, the exact definition of a correlation factor should be established in order to define SPS classes when ESDD measurements are conducted on fog profile insulators (instead of the reference disc profile). In this paper, we have followed the worst case scenario described in [15] by setting the correlation factor equal to 1.1. However, further research should be conducting toward this direction in order for the correlation factor to be more accurately defined. Therefore, a specially designed arc has been installed in TALOS High Voltage Test Station where parallel ESDD measurements can be conducted on different insulators and the first series of measurements will be initiated in 2014. Further, setting up and initiating a series of NSDD and DDDG measurements is also a goal set for 2014.

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