Proceedings of the Second IASTED International Conference
POWER AND ENERGY SYSTEMS (EuroPES)
June 25-28, 2002, Crete, Greece

MEASURES AND TECHNIQUES AGAINST POLLUTION IN THE CRETAN TRANSMISSION SYSTEM

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ABSTRACT

The morphology, characteristics and climatic conditions of the island of Crete, create an ideal setting for severe marine pollution that generates serious problems to the reliability of the local power system.

This paper presents the wide experience that has been accumulated in dealing with the problem. Techniques, methods and materials are described that have been used to combat the detrimental effects of pollution.

KEY WORDS: pollution, high voltage transmission, coatings, insulators washing, RTV's.

1. INTRODUCTION

The shape and morphology of the island contribute a grate deal to the pollution problem for the high as well as for the medium voltage installations [1].

The island is 260 km long and 15-60 km wide. As a result, it has a relatively long coastline (1046 km), mostly rocky. This fact, coupled with the strong winds, results in the dispersal of atomized seawater droplets and their deposition on the insulators. On the other hand, the interior of the island is quite mountainous with three main mountain ranges with more than 2000 m altitude.

Fig. 1 Dry and wet period.

The variety of morphological features (plenty of hills, valleys and gorges) creates various climatic microenvironments, which results in parts of the Power System being well protected and some others totally exposed to severe marine pollution.

It should be clarified that although salty seawater is not the only polluting agent, it is by far the most important.

Concerning the climate, it should be pointed out that there is a very long dry period usually starting at the end of April and very often terminating at the end of October (fig. 1).

Although the total amount of rainfall on the island is considerable, it is unevenly distributed during the year and throughout the island. The west part of the island has the advantage of receiving almost double rainfalls in comparison with the east part. This is a very important characteristic, which, in combination with the stronger winds in the east, makes the pollution problem by far more severe on the east side.

2. POLLUTION FLASHOVER PROCESS

The pollution flashover process can be divided into four phases, each of which is very important for the final result [8,12,13]:

2.1. Phase one: Pollution deposit

The contamination deposit particles (salt, dust, smoke, etc) are carried by the wind and are concentrated between the ribs and on the upper surface of the insulators.

The accumulation factors are the following:

- nature of deposit, weight and size of the particles
- wind speed
- insulator profile and its ability for self-cleaning
- distance between the insulator and the pollution source
- possible shielding of neighbouring structures
- insulator string orientation (vertical, horizontal, inclined)

The deposit accumulation is continuous and is only affected by the rain and wind. The self-cleaning is more efficient on the top surface of the insulator than on the bottom surface. This makes the bottom surface more polluted, a fact, which is confirmed by our measurements. The deposit accumulation reaches a maximum value between 2 to 5 months.

2.2 Phase two: pollution humidification

Fog, condensation and drizzle gradually humidify the entire polluted insulator surface. Salts in the deposit are dissolved and create a conductive layer on the insulator surface, resulting in a continuous leakage current. This leakage current increases during the humidification cycle to a maximum value but decreases if there is washing out or drying.

2.3 Phase three: dry bands development and arcs ignition

The leakage current density is higher close to the insulator fittings and in the areas, where the pollution is higher. With the thermal heating effect, the temperature increases evaporating some water from the deposit creating "dry bands"[10,11,14]. The current is, in that case, greatly reduced by the presence of dry bands.
The potential distribution on insulator is now governed by these dry bands, which have a higher electrical resistance so that most of the voltage is mainly applied across them. If this voltage exceeds the dielectric strength of the dry band, an arc is formed. (fig. 2).

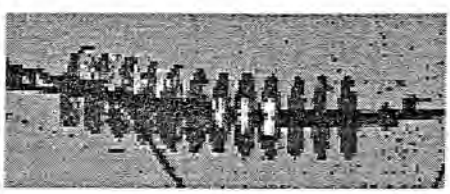

Fig. 2 Arcs developed on an insulator string under pollution conditions.

2.4 Phase four: arc behaviour and final flashover

The wet deposit resistance R is in series with the arc (fig.3), so it limits the arc current [5,14]. If the current is too low, the arc will switch off. The dry band will be humidified again and the mechanism will repeat itself. As long as the leakage current do not exceed a "critical current" corresponding to a "critical length of the arc", this situation is kept stable.

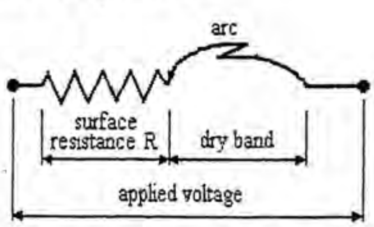

Fig. 3 Model of the polluted insulator in arc conditions

If the wet deposit resistance is low enough and the leakage current increases past the critical current, the length of the arc is increasing up to flashover.

3. CRETAN POWER SYSTEM (CPS)

The CPS includes two Power plants one in Linoperamata and the other in Chania with a total capacity of 529 MW. The total installed Wind Farms (W/Fs) capacity is 67 MW, and an additional number of new W/Fs of total capacity 54 MW will soon start producing.
The Transmission System has two voltage levels. The main part of the System works at 150 kV but there is also a small old part working at 66 kV, which is soon to be upgraded also to 150 kV. There are 12 substations of 150 kV and 2 substations of 66 kV. The total length of Transmission Lines (T.L's) is about 532 km long.
The peak load of the island is always in the summer because of tourism and last year it reached 448 MW (mean hourly peak).

4. SYSTEM CHARACTERISTICS

As it is already apparent, the characteristics of the CPS are the following:

-It's a small system
-It's isolated from the mainland
-It's located mainly near the coast and especially the north coast where the biggest cities and most of the hotels are located. This has to be considered in combination with the more frequent north winds so the marine pollution becomes really very severe.
-The numerous W/Fs installed during the last few years, create a high wind power penetration, sometimes approaching the level of 30%, which is a worldwide record.

The characteristics mentioned above, describe a rather vulnerable and sensitive system.

5. IMPACTS OF THE POLLUTION ON THE CRETAN TRANSMISSION SYSTEM

Among the various impacts of the pollution the more serious ones are the flashovers, the corrosion on the metal parts of the insulators, the burning of the wooden poles, the erosion of the surface of polymer insulators, the acoustic noise, etc.[1,2]
The first 66 kV T.L. from Heraklion to Chania was built in the early 60's. It was a T.L. on wooden structures and from the beginning of its operation the pollution phenomenon made its appearance with the burning of the upper parts of the structures. To solve this problem copper wires were placed along the horizontal wooden crossbeams in order to make the potential equal.
Because of the severe pollution conditions, there were times that the line couldn't be re-energized after being down due to flashovers.
The existing 150 kV Transmission System came into operation gradually from 1976 to 1979 and this brought a new era to the pollution issue.
Fig. 4 shows the total faults on the Transmission System during the last two decades from pollution and other causes.

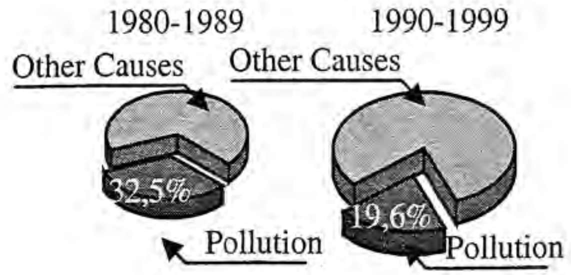

Fig 4 Faults on the Transmission System

The remarkable points here are, first, that pollution is indeed an important source for the System faults and second, it is apparent that there has been some progress in the fight against pollution from one decade to the next.

6. MEASURES AGAINST POLLUTION

The measures that have been taken are distinguished into two categories, the preventive and corrective ones. Preventive measures are all the appropriate actions taken at the phase of design of the System and corrective are the maintenance and refurbishment procedures, necessary for the good operation of the System.

Regarding T.L's. the **preventive** measures consist of:

- increasing the insulation level
- the use of composite insulators

Regarding Substations:

-straight from the beginning the 150 kV Substations were designed with metal cladding at the medium voltage side

-there is one 66 kV building enclosed substation.

-two new G.I.S. substations are also planned for installation.

Corrective measures include dead washing, live washing with helicopter and the use of hydrophobic coatings.

7. INSULATORS

7.1. Insulators types

A great variety of different insulator materials and profiles have been used and tested on the T.L's of the C.P.S. The first insulators, used, were inorganic ones (porcelain and glass, cap and pin type). Although the insulation level was high (between 3.2 kV/cm and 3.9 kV/cm), their performance wasn't ideal under local pollution conditions. The first composite insulators, which were installed in especially selected polluted sites of the T.L's, were from isoflone. These insulators showed a very good performance concerning their dielectric behavior, but they had serious mechanical problems because of the brittle fracture phenomenon. Silicon Rubber insulators have been, broadly used, which are the most reliable for TL's in the areas with heavy pollution according to our own and international experience [2,3,14].

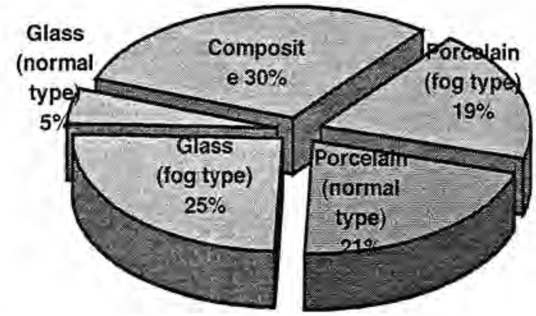

Fig. 5 Insulator map of TL's

After the completion of the new double circuit line, the largest part of which is already constructed, the insulator map of the T.L's has become as depicted in fig 5.

7.2. How important is the profile ?

-Although 400 kV level doesn't exist on Crete, a number of 400 kV insulators were used in a T.L. The performance of these insulators couldn't be worse. From 1985 until the end of 1994, 294 of these insulators out of 531 (percentage 55%) were replaced because of their damage after flashovers.

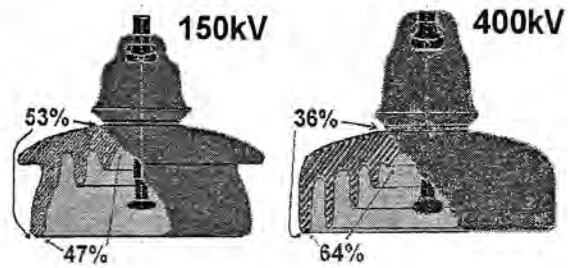

Fig. 6 Two types of insulators used in the CPS (150 kV and 400 kV).

In the same period and in the same line, for the type 150 kV insulators, only 23 pieces out of 3200 were replaced (percentage 0.7 %).

Examining carefully the two different insulator type profiles (fig. 6), we can notice that:

For the 150 kV type the exposed outer surface is 53% of the total surface.

On the other hand, for the 400 kV type, the exposed outer surface is only 36% of the total surface.

This fact leads to a better self-cleaning of the first type.

According to our experience the open (aerodynamic) profiles have better performance against pollution under our special meteorological conditions with the long dry period and the strong winds.

Therefore the design of the insulator profile should take into consideration the specific conditions under which, the insulator is going to operate. For this reason it is necessary that the various types of insulators should be tested under the local environmental conditions in special constructed open air test stations before their general use. It's a practice that many electric Utilities have already adopted.

8. WASHING

The first maintenance work against pollution was dead washing with sponges and buckets, a primitive method

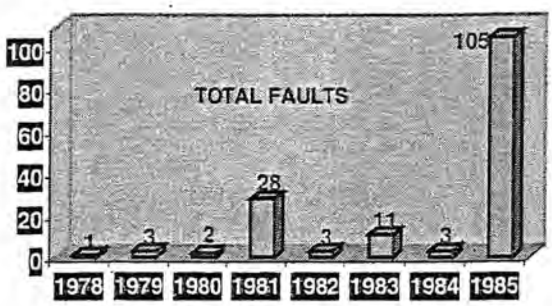

Fig. 7. Faults due to pollution

for cleaning the insulators, which was implemented from 1978 until 1981. On the diagram of the fig. 7, we can see the corresponding faults on the System at that first period. During the following years 82, 83, 84 no washing was done and the favorable meteorological conditions helped so that the System didn't experience many faults. This break was short lived and in 1985 the System experienced 108 flashovers with the corresponding consequences. After that, it was well understood that measures against pollution were of first priority for the stability and reliability of the System and a new method for dead washing with pressurized water (fig. 8) was introduced both in the Substations and the T.L's. as well. This method was initiated in 1985 and it has been in use since then, although it is combined with other methods as well.

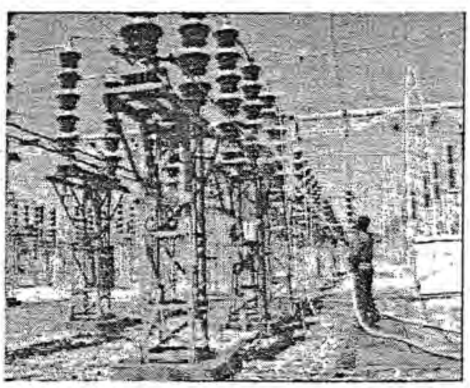

Fig. 8 Pressurized water washing

-In a similar way T.L's insulators are washed. Suitable vehicles with water tanks and high-pressure pumps and water jets are used and the technician climbs up onto the tower to wash the insulators. In the double circuit line, one circuit is being washed, while the other is under voltage.

-After 1995 the Public Power Corporation (PPC) introduced the method of live washing with helicopter for the T.L's (fig. 9).

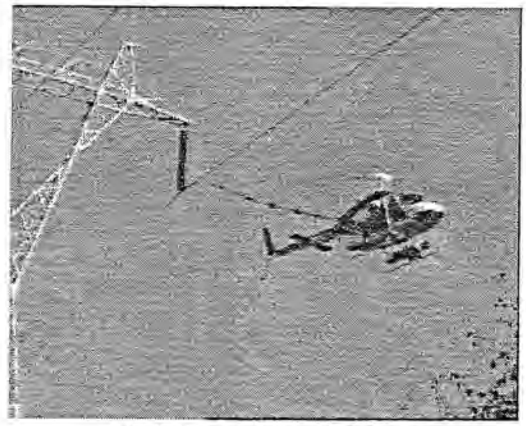

Fig. 9 Live washing with helicopter

This kind of washing is used both in the CPS as well as in some parts of the mainland Power System, which also suffers from some kind of pollution. Its main advantages are that it is a fast method and that there is no need to take the lines out of service. The disadvantages are, that under strong wind conditions, a situation not uncommon to Crete, the helicopter cannot fly and that for lines going parallel in a small distance from each other the access of the inner strings is not possible. In those cases we have to employ our old methods.

9. COATINGS

Another category of corrective measures is the use of coatings. They are organic materials used to cover the inorganic insulators (porcelain or glass) and their effectiveness is based on their strong hydrophobic properties. In particular they don't allow the water from humidity or rain to constitute a conductive film over the surface of the insulators.

9.1 Silicon grease

The first coating that was used was silicon grease. It's a material that needs replacement every 6 months due to saturation and loss of its hydrophobic properties. This method was applied in sensitive elements such as lightning arrestors, bushings, some circuit breakers etc. It is considered a time consuming and expensive method.

9.2 Room Temperature Vulcanized materials (RTV's)

Next, we proceeded with the application of the RTV's. They are materials with a much longer life and superior hydrophobic properties because of their extremely low surface energy. They are applied with brush or gun (in spray) on inorganic insulator surfaces, where a film of 0.5 mm should be formed. As they are exposed to the

atmospheric air they become vulcanized and they are quickly (in some minutes) solidified at room temperature.
The implementation of this method started in 1998 and we have proceeded with a rather fast pace. Since the first application we have never washed the corresponding installation and the results until now are very promising (no flashover occurred).
Up to now we have covered the two substations of the Power Plant in Linoperamata and the substations of Ierapetra and Sitia in eastern Crete, while Soroni in Rhodos is covered by 50%.

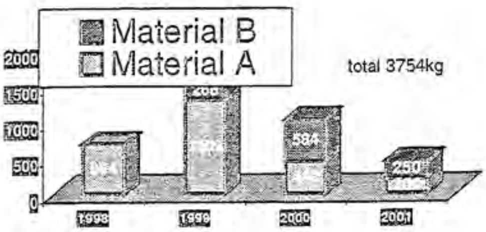

Fig. 10 Quantities of applied RTV's.

A 150 kV gate with about 40 insulators needs on average 70 kg of RTV's and takes about 170 man-hours of expert labor.
The bar diagram of fig. 10 shows the total quantities of RTV's of two different manufacturers that we have used in the last three years, a total of 3 754 Kg.

10. ECONOMICS OF DEAD WASHING VERSUS THE RTV POLICY

As already mentioned in Linoperamata Power Plant there are two substations (one 150 kV and another 66 kV). They are exposed to severe marine as well as to industrial contamination. These substations used to be washed dead, twice a year until the general application of RTV's, which ok place three years ago. It must be stressed that the great savings in this case come from the fact that during the washing, we had to take out of service the inexpensive Base Units and put in operation the very expensive Gas Turbines because the washing is done during the high load season when all the Base Units are already in operation.
The cost of the RTV material and its application to these two substations by our own personnel is about 7600 € for a 150 kV gate and 2900 € for a 66 kV gate. The above two substations include 21 gates of 150 kV and 7 gates of 66 kV. Consequently the total cost of the RTV policy amounted to **179 900 €**.
On the other hand only the additional fuel cost during every washing comes up to 89 500 €, which means 179 000 € per year and **537 000 €** for three years of washing. In other words, the cost of one year washing is about the same as the RTV application (fig.11), while the RTV is expected to last from 5 to 15 years. In our calculations we don't take into consideration the washing labor cost and the cost for the Units start up as being negligible in comparison to the very high fuel cost.
From the above we conclude that, during the last three years, PPC has saved **357 100 €** from the implementation of the RTV policy in Linoperamata.

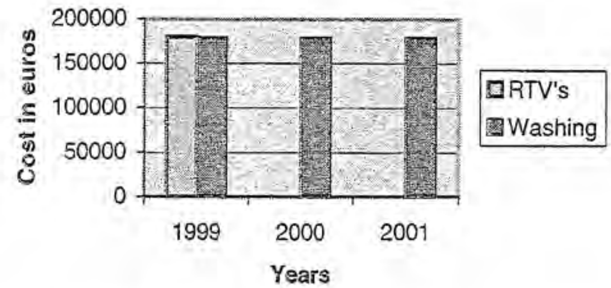

Fig. 11. Costs for the last three years for the two alternative antipollution polices.

11. ACTIONS AND RESULTS

In the combined Gant and bar diagram of fig. 12 the implemented pollution fighting methods and the corresponding faults because of pollution can be seen. It is apparent that the strategy and the variety of measures that have been implemented have borne some fruits.
On the other hand, the exception of the year 92 when the System experienced a lot of faults (50), despite the equally intensive care and effort, shows the real dimensions of the pollution problem, a phenomenon depending on many parameters that always keeps you on alert.

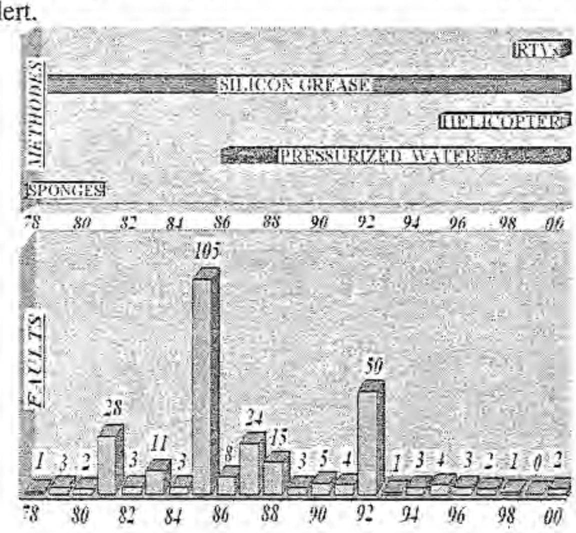

Fig. 12 Actions and results.

12. MEASUREMENTS

For the study of the pollution phenomenon various parameters should be measured and monitored.
We need to draw the meteorological and pollution map of the Cretan System in order to know the crucial places and times related to the phenomenon. Data for the meteorological parameters come either from the National Meteorological Service or from our own measurements.

We conduct regular Equivalent Salt Density Deposition (ESDD) measurements, which help us make significant decisions about when and where to wash.

After the wide application of the RTV's and the abandonment of washing of the corresponding installation we are concerned about the life time of these materials. As it is apparent, RTV's, being organic materials, are subject to deterioration. Ultra violet radiation, acid rain, thermal and dielectric stress, corona phenomenon as well as other environmental parameters degrade these materials and destroy their high hydrophobicity [4,5,6,7].

With a special designed monitoring system we can measure the leakage current on the insulators, gaining valuable information about the performance of various coatings and the aging procedure of the organic materials.

13. CONCLUSION

As the Cretan Transmission System is exposed to severe marine pollution and operates at considerable high voltage level (150 kV), it is ideal for the study of the pollution phenomena and the test of various insulators and techniques. Having lived with the problem for a long time, the gained experience leads us to the conclusion that for our local conditions (subtropical climate and marine pollution), the best way of facing the problem is composite insulators (especially silicon rubber) for the T.L's. and RTV's for the Substations.

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