Evaluation of the pollution performance of SIR materials in the Cretan Transmission System in correlation to the pollution model of Crete

K. SIDERAKIS, D. AGORIS
High Voltage Laboratory
Electrical and Computer Engineering Dept, University of Patras, Rio, Patras 26500
GREECE
sidkir@ieee.org, tel. 0030 810 303235

E. THALASSINAKIS, J. STEFANAKIS
Public Power Corporation S.A.
Kastorias Str., Katsambas, Heraklion 71307 Crete,
GREECE

ABSTRACT: Contamination performance of Outdoor Insulation is among others a material influenced phenomenon. Silicone Rubber is considered an effective and reliable composite material for such applications where contamination flashovers are common. The main advantage is the hydrophobic surface together with its capability to recover hydrophobicity when it is covered by a hydrophilic layer of contaminants. The recovery mechanism and its interaction with the environmental conditions are key factors for the pollution performance of the material.
In Crete the contamination phenomenon contributes significantly to the total number of power outages. The main reason is the marine influence in combination with environmental factors (humidity, precipitation etc). Silicone Rubber materials have been used in the Cretan Transmission System for the improvement of the Insulation performance, mainly in the form of Room Temperature Vulcanized SIR for High Voltage Substations and the last two years in the form of High Temperature Vulcanized SIR for Transmission Lines.
In this paper, a study is presented concerning the behavior of SIR materials in correlation with the pollution model of Crete.

Keywords: High Voltage Transmission, Outdoor Insulation, Crete, RTV, Silicone Rubber, Hydrophobicity marine model.

I. HYDROPHOBIC MATERIALS

Hydrophobicity is a surface characteristic directly correlated to the internal structure of a material. It is a result of an imbalance of intermolecular forces near the surface, where molecules are attracted only from molecules inside the material volume, in contrast to molecules away from the surface, which are subjected to symmetrical attractions.[1][2]

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Therefore there is energy on the surface (surface tension γ) and the amount of it is a function of the structure strength.
When water droplets occur on the surface, water molecules are subjected to the surface energy and the result depends on the amount of the surface energy in comparison to the cohesion energy of water. If the surface energy is enough then the droplet will spread and form a film. If not it will remain in the form of droplets.[2]

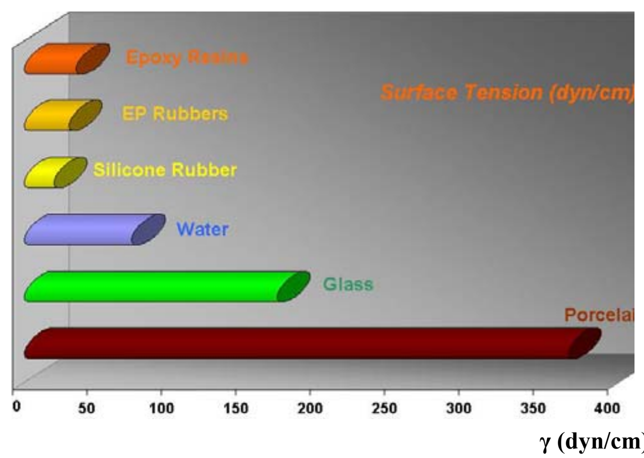

Figure 1 Surface tension γ of materials used for outdoor insulation in comparison with water

In the case of porcelain and glass, materials that have been used for Outdoor Insulation since the establishment of such systems, the surface appears to be hydrophilic and therefore their performance is unsatisfactory in the case of contamination. On the other hand due to their powerful structure, as it is reflected to their surface tension (fig.1), they are remarkably resistant to aging.
Consequently, hydrophobicity is a characteristic of materials with lower strength, such as polymers. This type of materials has already been used in Outdoor Insulation, especially in Systems with pollution problems. However the main disadvantage in this case is aging, not only because of the

electrical stress but also because of the environmental influence. [3]

A Silicone Rubber Hydrophobicity

Silicone Rubber belongs to the family of inorganic polymers. In other words it is a material with polymer structure, but with the difference, that Carbon at the main chain of the macromolecule is replaced by Silicon.[4]
Silicone Rubber is a hydrophobic material like its organic ancestors, even though the very strong Silicon – Oxygen bond exists in the main chain of the macromolecule. It is worth mentioned that the Silicon – Oxygen bond is the main structure element of the hydrophobic ceramic materials. The difference in the case of SIR is the existence of the methyl side groups, which are oriented to the surface, keeping the main chain away (figure 2).[3]

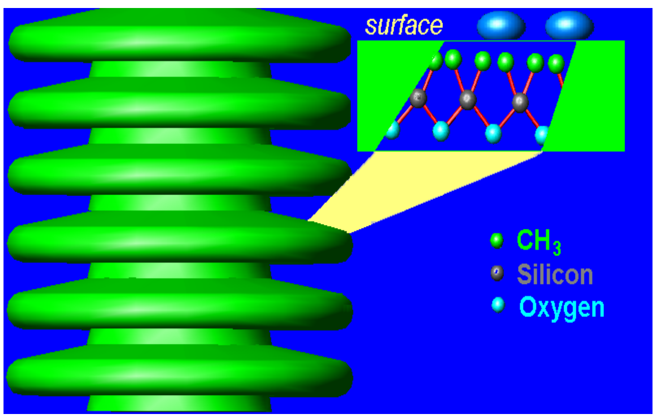

Figure 2 Influence of the side methyl groups orientation to surface hydrophobicity

On the other hand the Silicon – Oxygen bond gives remarkable strength to the molecule, which is reflected to it's superior aging resistance in comparison with other composite materials.

B. Transfer of Hydrophobicity to the surface contaminants layer [3][5-11]

Even when the surface of Insulation is hydrophobic, the accumulation of a hydrophilic, water absorbing, contaminant is enough to eliminate the hydrophobic advantage. Therefore it is necessary to impart hydrophobicity to the contaminants layer too. Silicone Rubber is a material capable to interact with the contaminants layer, due to a migration mechanism of SIR molecules from the bulk of the material to the surface.
The main component of the above mechanism is a population of Low Molecular Weight molecules (LMW), which exists in the bulk of the material. These molecules are not part of the cross linked network and they are free to move between the large chains of the material. The force of this movement is the difference of molecules concentration from the bulk to the surface.
Furthermore, the mechanism is affected by the composition of the material and the temperature. Various additives, used to improve the material properties, may decrease the recovery rate, since they increase the movement friction of LMW molecules. For example ATH filer, used to improve the tracking and erosion performance of the material, acts unfavorably to the recovery mechanism in two ways. At first due to the movement friction phenomenon referred above and secondly because in a certain quantity of material, increase of the ATH concentration results to decrease of the LMW molecules population.
On the other hand temperature acts in favor of the mechanism, since the mobility of the molecules is increased.

C. Importance of the hydrophobicity transfers mechanism to the effectiveness of the material.

Recovery of hydrophobicity is possible mainly due to the migration mechanism described above and also due to the reorientation of the side methyl groups to the surface.
Since the main mechanism is based on the movement of molecules, there is a time interval between the accumulation of contaminants and the complete transfer of hydrophobicity to them. During this time interval the surface remains hydrophilic and if the material doesn't recover in time and the conditions are favorable, the pollution phenomenon can develop leading to dry band arcing and possible flashover.
Therefore, in order to evaluate the effectiveness of SIR for a particular environment, it is necessary to correlate the pollution model to the recovery mechanism and the factors affecting it.[11-13]

II. POLLUTION PHENOMENON AT THE CRETAN TRANSMISSION SYSTEM

Pollution of high voltage insulators is an environmentally affected phenomenon. Therefore, parameters such as climatic conditions, weather and geographical location of the insulation system play a very important role.

D. Influence of Wind and Precipitation

In Crete, the Transmission System is located mainly near the coastline because of the consumer's geographical distribution. Therefore it is subjected to the marine influence or in other words to the combination of sea salinity and wind.
Wind is the transfer medium and therefore months with intense wind activity correspond to months with high contamination transfer rate. The minimum wind speed that can create waves and consequently transfer salinity to the atmosphere is 5m/sec.[14][15]

On the other hand precipitation is a cleaning factor. So it must be taken into account in order to determine the accumulation of contaminants on the insulation surface.[16]
Thereby a factor A_C is introduced. This factor is calculated from the relative frequency of wind speeds over 5m/sec and precipitation, in order to point the months with higher accumulation rate.

$$A_C = RelF_{wind}\,(100 - Av(p)) \quad \mathbf{(1)}$$

Where $\mathbf{A_c}$ the accumulation factor, $RelF_{wind}$ the rel. frequency of wind speed greater than 5m/sec and **p** the average precipitation.

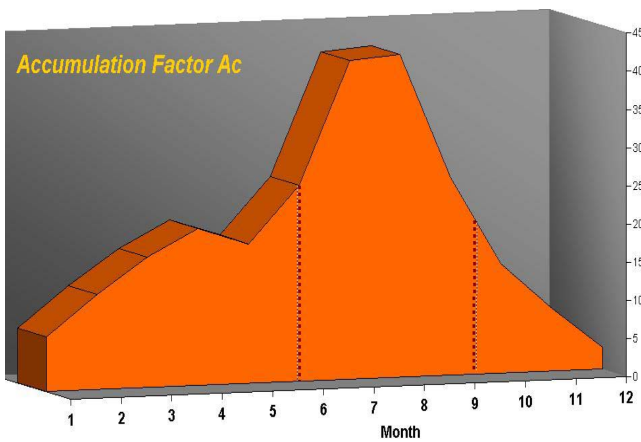

Figure 3 Accumulation factor Ac during the year

As it can be seen from figure 3, the higher accumulation rate takes place from June to early September. This is because of the often and strong winds in combination with a dry period (low precipitation) starting from April. Thus this period is considered to be very critical regarding pollution Accumulation.

E. Influence of temperature and humidity

Usually marine contamination is already humid when it is deposited on the insulation surface and therefore it is conductive. However in the case of Crete and during the above critical period when humid contaminants are deposited on the surface, they are dried out. This is because wind is blowing mainly during the day, when environment temperature, especially this time of year as it can be seen from figure 4, is high.
Therefore the development of the dry band activity to flashover is unlikely to occur without another humidifying parameter that would increase surface conductivity.
This parameter is atmosphere humidity, which in this case can contribute to the wetting of the insulation surface through the condensation mechanism.

In Crete high humidity is noted at the end of the above-mentioned dry period and especially from August to October. Additionally the most favorable time in a 24h clock round for humidity condensation on insulation surface is during the night and early in the morning when temperature is low and there is no wind.

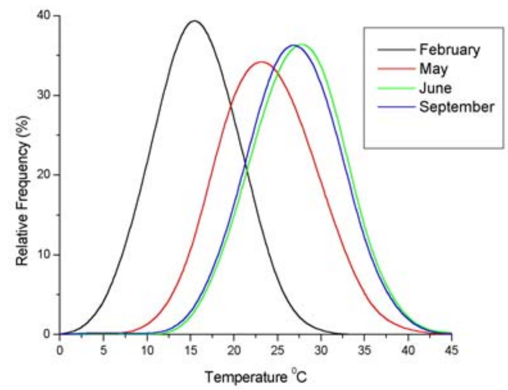

Figure 4 Temperature variations from February to September [13]

Combining the effect of wind and precipitation (accumulation factor) with temperature and humidity, it seems that in Crete the insulation pollution model is constituted by two time periods. The first (period **A**) starts from late April until June. During period A precipitation is low but on the other hand the accumulation rate is not enough to support surface activity. Therefore period A is a long accumulation period.
The second period (period **B**) that follows period A, starts from August until October. During period B the accumulation rate, is less than period B as declined from the curve in figure 3 but humidity is present especially during the night and early in the morning. Therefore the conditions are favorable to the development of surface activity, which may lead to flashover.

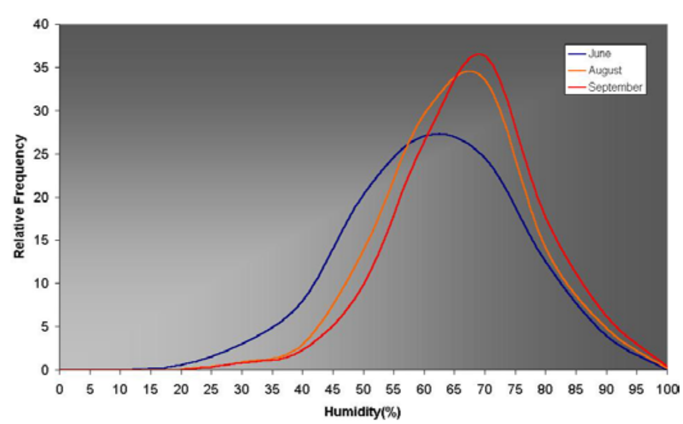

Figure 5 Humidity variation from June to September[13]

The combination of the above factors influence the insulators pollution performance something that has been verified by measurements of leakage current activity and also statistical data regarding power outages due to pollution.

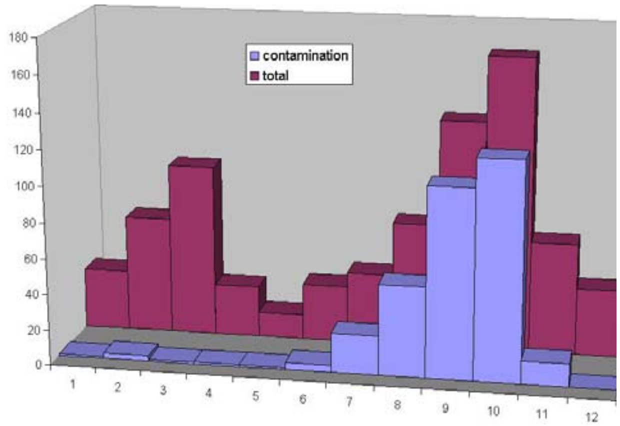

Figure 6 Number of contamination faults in comparison to the total number of faults since 1969

As it can be seen from figure 6 the majority of outages due to insulator contamination takes place mainly during the above-mentioned period B and especially during September and October.

Additionally as it can be seen from figure 7, during a day of period B the most intensive activity takes place during the night and early in the morning. This results to the dissipation of energy due to leakage current and dry band arcing as illustrated in figure 7.

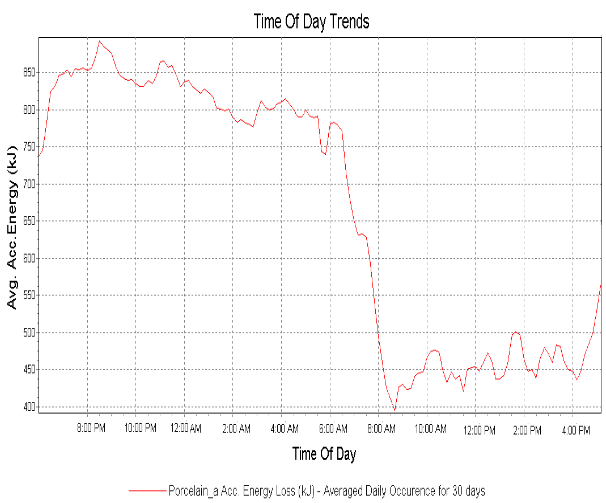

Figure 7 Accumulated Energy during a typical Period B day

It is worth mentioning that this is also verified by statistical data of power outages, where the majority of contamination faults takes place during the night and early in the morning (fig 8).

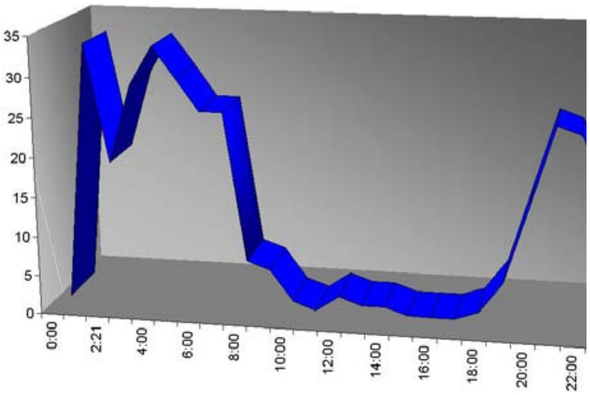

Figure 8 Time occurrences of contamination faults

III. APPLICATION OF COMPOSITES MATERIALS FOR OUTDOOR INSULATION IN CRETE

F. Transmission Lines

The first application of composite materials for outdoor insulation in Crete took place in 1979, when a number of insulators arising to 320, with TEFLON housing, was installed on the most pollution heavy Transmission Line. The performance of these insulators regarding pollution was satisfactory, since none of them flashed over because of contamination. However their good performance was limited due to brittle fracture. After 23 years of service, 12 faults have been registered out of 320 insulators (3,7%) and the signs of brittle fracture were obvious in all of them.

Today the same Transmission Line is the first in Greece that is upgraded to High Temperature Vulcanized Silicon Rubber Insulation.

G. Substations

In the case of substations, Room Temperature Vulcanized SIR seems to be a good solution. This is because it is installed in liquid form and becomes solid through the vulcanization process at Room Temperature. Therefore it can be used on already installed equipment or when composite housings are not available in the market. At the moment RTV SIR has been installed in four Substations of the Cretan Transmission System.

The first application took place in 1998 at Linoperamata Substation, where the pollution problems were severe, due to the small distance of the installation from the coast line and the difficulty of insulators washing since Linoperamata is the step up substation of a nearby Power Plant.

The performance of the material was satisfactory. Thus in the following years until 2001, together with the completion of Linoperamata Substation, two more High Voltage substations at the Eastern Crete were fully covered. Finally today four High Voltage Substations are fully covered with RTV SIR

Coatings in Crete and 50% of Soroni Substation in Rhodes, an island eastern of Crete. The performance in all cases is satisfactory until today.

H. Leakage Current measurements of porcelain post insulators with and without coatings

When hydrophobicity is lost, there is space for leakage current and dry band arcing to develop. Leakage current is a good fingerprint of the surface condition, especially for ceramic insulators but also for composite ones. Thus through leakage current and the dissipated energy it is possible to evaluate the recovery capability.

Figure 9 Coated Porcelain insulators at Linoperamata Substation

Therefore a data acquisition system is used to monitor leakage current on 150kV insulators. Among them there are four, coated post insulators and two uncoated of the same type. In figure 10 it is shown the maximum value of the accumulated energy (kJoule) of the coated insulators, in comparison with the uncoated, for four different months.
As it can be seen, the leakage current activity on porcelain insulators during August and September is 22 times more than the corresponding activity during March. This is in agreement to the above regarding periods A and B. Additionally it must be mentioned that during August and September porcelain insulators are washed at least two times. Washing is also the reason why in figure 8, the accumulated energy during September is less than August, although as it was mentioned above flashovers are statistically more often during September.

I. Evaluation of the application of RTV coatings in Crete

As it was mentioned above period A is a long accumulating period with low accumulation rate and almost no humidity. Therefore there is enough time for the material to recover and the relative stress is low. So at the end of period A and the beginning of period B, hydrophobicity has recovered, supported also by the high day temperatures. This is verified by the energy dissipated on the insulation surface as it can be seen in figures 10 and 11.

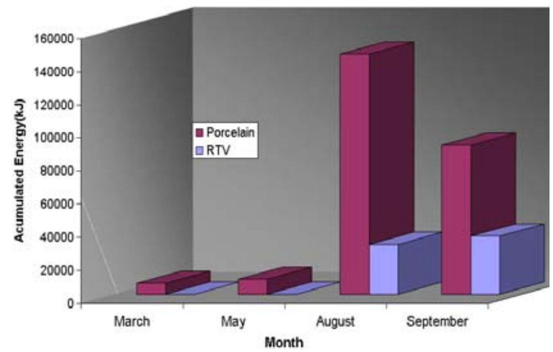

Figure 10 Accumulated energy on coated and uncoated porcelain 150kV post insulators

On the other hand period B is a period of high material stress. This is because during the day, contamination is accumulated on the insulation surface and humidity appears after a time gap of some hours. Therefore the available time for the hydrophobicity recovery is remarkably less. This results to a major increase of the surface activity as it is reflected on the accumulated energy in figure 10.

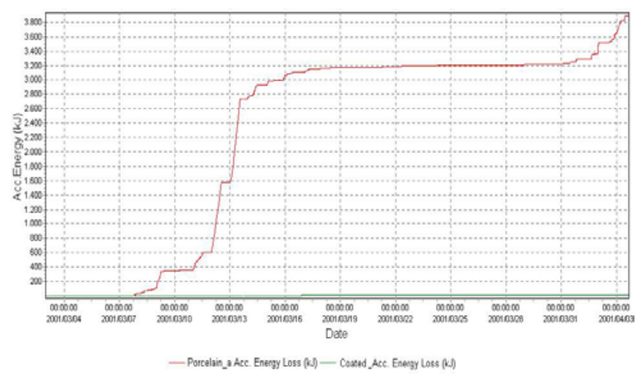

Figure 11 Accumulated energy on coated and uncoated porcelain 150kV post insulators during March

Undoubtedly even during this period the performance of the coated insulators is superior to the un-coated. However this stands as long as the material remains in good condition and can recover in time. In this specific application the material seems to be in good condition and therefore surface activity is restricted. This is also verified when comparing the dissipated energy during August and September (fig 10). As it can be seen, there is a little increase from August to September, although there is a larger amount of contaminants on the surface since the coated insulators are not washed (in contrast to the porcelain insulators).

IV. CONCLUSIONS

Composite materials seem to be an efficient solution for the Pollution of High Voltage Insulation. The advantage in this case is hydrophobicity, which on the other hand is a characteristic of low strength materials. Therefore the disadvantage is aging.

Silicone Rubber is a material that combines hydrophobicity and aging resistance due to the material structure, which is between strong but hydrophilic ceramic materials (Si-O bond) and composite hydrophobic (methyl side groups). Additionally it is capable to transfer hydrophobicity to the contaminants layer.

In Crete the application of composite materials started at the late seventies. Today a large-scale application of RTV SIR to High Voltage Substations has taken place. The performance of the material is considered as satisfactory for the time being, something that depends on correlation of the hydrophobicity recovery mechanism to the pollution model in Crete.

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VI.BIOGRAPHIES

Kiriakos Siderakis obtained a Diploma in Electrical and Computer Engineering from the University of Patras in 2000. Presently he is a PhD student at the High Voltage Laboratory of the School of Electrical and Computer Engineering at the University of Patras. His research field is contamination of High Voltage Insulators and composite materials. He is an IEEE student member and a CIGRE member.

D. Agoris was born in the island of Chios, Greece, on Nov. 8, 1952. He received his diploma degree in Electrical & Mechanical Engineering and a PhD degree from the NTUA. Since 1980 he is with the Public Power Corporation, as project engineer (1980-1987), Head of the HV Laboratory (1988-1992), member of the board of directors (1992-1996) and from 1996 director in the General Management for Development. Since 1996 he is Ass. Professor, Director of the HV Laboratory in the Electrical and Computer Engineering Dept of the University of Patras. From 2000 he is the President of the Centre for Renewable Energy Sources. His research activities involve HV networks and equipment, energy management, renewable energy sources, lightning, transients, insulating materials, reliability and environmental aspects.

Emmanuel Thalassinakis received a Diploma in Electrical Engineering from the National Technical University of Athens and he is currently working on his PhD. He works in the Public Power Corporation of Greece as head of Subsection of High Voltage Substations in the Cretan Power System. His professional and research interests are reliability, high voltage technology, power system operation and contamination of the high voltage insulators.

John Stefanakis received a diploma in electrical and mechanical engineering from the National Technical University of Athens. He works in the Public Power Corporation of Greece as head of Transmission Grids / Crete and Rohdes Section. His professional and research interests are reliability, high-voltage technology, power system operation, contamination of high-voltage insulators, and renewable energy sources.