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Performance of 150kV RTV SIR coated substation insulators under extreme marine pollution conditions

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SUMMARY

Pollution of high voltage insulators is a problem experienced by many utilities world wide. A method to improve the performance of outdoor high voltage installations is the use of composite insulators instead of ceramic. However there are applications where the use of composite insulation is not possible or requires a considerable financial investment. A typical example is the already installed equipment in high voltage substations. In this case the cost of replacement is considerable and in addition the limited availability for some types of equipment is also an issue. Room Temperature Vulcanized (RTV) Silicone Rubber coatings can be employed in such cases. In this paper a large application of RTV SIR coatings in a 150kV substation is presented and evaluated. The application started in 1996 and in a three years period the total number of the substation insulators were coated.
In order to evaluate the performance of the coated insulators and investigate the influence of the ambient conditions, a leakage current monitoring system was installed. The measurements performed, on the non coated insulators, indicated that in this case the problem of pollution is confined in a three months period, starting from August until October, due to the unique combination of the environmental conditions and especially wind, precipitation and surface condensation. During this period the performance of the coated insulators was remarkably better. On the other hand the continuous insulator monitoring revealed that in the case of light rain the insulator performance (coated and non coated) becomes comparable. At the present stage the levels of activity observed do not indicate a possible flashover risk in the case of the coatings, nevertheless aging is an issue to be considered and thus further investigation is required.

KEYWORDS

RTV SIR Coatings, marine environment, leakage current measurements

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1. INTRODUCTION

The use of composite insulators in outdoor high voltage installations is probably the most efficient solution, in order to suppress the influence of pollution. Many long term applications have been reported worldwide, demonstrating the performance improvement achieved in comparison to their ceramic counterparts [1, 2]. However there are applications where the substitution of ceramic insulators with composites is not technically or financially in profit for the electrical utility. A typical example is the already installed equipment in high voltage substations. In this case the replacement cost of the ceramic insulators is considerable. In addition the limited availability of composite housings, for some types of equipment, especially old, such as transformer bushings, is also an issue. In such applications the use of room temperature vulcanized (RTV) silicone rubber coatings can provide an alternative. Coatings are applied on the surface of the already installed ceramic insulators, imparting a hydrophobic surface behavior, similar to the one demonstrated in the case of composite insulators [3-6]. As a result an improved pollution performance is achieved [4-9].
In this paper the performance of RTV SIR coatings in a 150kV high voltage substation, is evaluated after a nine years time period. In this direction continuous leakage current monitoring in field conditions, by a specially designed for this purpose data acquisition system, has been employed. The results are compared to measurements on porcelain insulators, performed simultaneously in the same substation.

2. APPLICATION OF RTV SIR COATINGS

2.1 APPLICATION SITE

Crete is the biggest island in the Aegean Sea, Greece. Due to its coastal development the majority of the 150kV installations are located in a proximity to the sea coast. Consequently intense pollution problems have been experienced, usually resulting to long duration power outages. In order to suppress the influence of pollution high pressure washing has been employed as the primary maintenance method, achieving after years of experience a remarkable decrease of the pollution related flashovers. However for substations an improved maintenance method was required, since the financial cost for washing is considerable, not only due to the man hours spent, but also considering that in the case of substations, live washing is not permitted in Greece by law, thus power interruptions were necessary. In addition in the case of step up substations, the problem is even more intense since the maintenance procedures sometimes require some of the steam power generators to be stopped.
The first application took place in 1996 at the Linoperamata substation, which is one of the two 150kV step up substations in Crete. Being located in a distance of less than 500m from the sea coast, is exposed to the action of the sea and as a result intense pollution problems had been experienced, although the creepage distance of the insulators used had been appropriately selected according to IEC815. In a three years period the total number of 2700 ceramic insulators had been covered, employing a material amount of 4100kg, provided by three manufactures. It must be mentioned that since the application no other maintenance method has been employed up to today.

2.2 MATERIAL MONITORING

For the selection of the appropriate monitoring method special requirements must be considered. At first the monitored insulators are part of the substation and therefore off line (out of voltage) measurements have limited application. Secondly the insulators are exposed to the field conditions, thus continuous monitoring is necessary in order to evaluate their performance. Thirdly comparative measurements must be provided, not only in respect of the ceramic insulators but also between the coated insulators. Finally the measurements must be performed in the conditions of a high voltage substation.
Among the methods usually employed [10], leakage current monitoring is probably the most suitable in this case, fulfilling the above requirements. It has been applied by many researchers worldwide both in field and laboratory conditions [11-15], both on ceramic and composite materials and in addition

can provide information for the total electrical activity observed (from the onset until a possible flashover).

2.3 MEASUREMENTS SETUP

Leakage current is distributed on the surface of the insulator. In order to be recorded it has to be collected and then driven through a current sensor. Usually this is achieved by inserting the current sensor between the grounded side of the insulator and the system ground electrode. In this case however due to the insulators supporting infrastructure, this was not possible and instead a collection ring was installed at the bottom side of the insulator. Further the ring was connected though the current sensor to ground. In order to enforce the conduction of current through the new path formed, a small part of the insulator leakage distance was excluded (left after the collection ring).For the measurements Hall current sensors were employed. The selection of this type relied on the provided bandwidth, starting from DC up to 20kHz, the remarkably low input impedance and the galvanic isolation of the electronic measuring system from the high voltage side.
The acquired from the sensor data are then transmitted to a central data acquisition system, which is capable of monitoring nine current channels. Sampling is performed continuously and simultaneously for all insulators, at a rate of 2kHz for each and a resolution of 12bit. Then due to the amount of the measured data (continuous monitoring), further processing is performed and values such as min/max current, average etc over user defined intervals are stored. In addition the current waveform is also recorded in the case of intense activity. Finally, the system is capable of synchronized (with the current) measurements of a three phase voltage system through voltage transformers and meteorological data i.e. temperature, relative humidity, precipitation and wind. A schematic diagram of the measurements setup is illustrated in figure 1.

3. LEAKAGE CURRENT MEASUREMENTS

3.1 PORCELAIN INSULATORS

The performance of porcelain insulators is considered as a reference for the RTV SIR coatings evaluation. In this direction two out of a group of nine simultaneously monitored insulators, were not coated but instead the regular washing maintenance was employed. For these two the monthly distribution of the accumulated charge, given as the average value in the nine years monitoring period, is illustrated in figure 2.
The measurements indicate that the problem is confined in a three months period, starting from August until October, while during the rest of the year the activity intensity is remarkably lower. The measurements of leakage current come is agreement with the observed surface activity, as illustrated figure 3, where the monthly frequency distribution of power outages (total and pollution related), since 1969, when the first 66kV Transmission line was put in service, is shown. It is worth noticing however that although confined in a two months period, the number of pollution related outages is remarkable, coming up to 43% of the total number of outages observed.

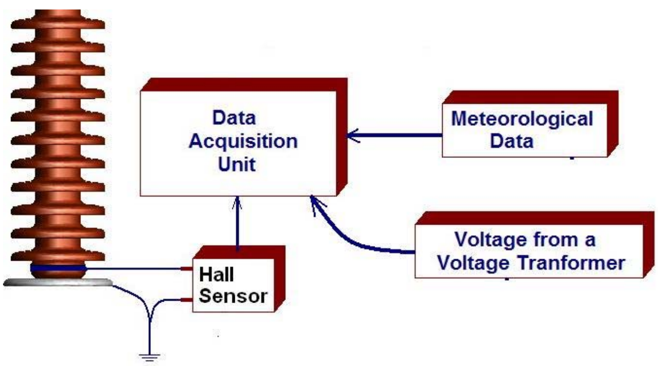

Figure 1. A schematic diagram of the data acquisition system employed for the material monitoring

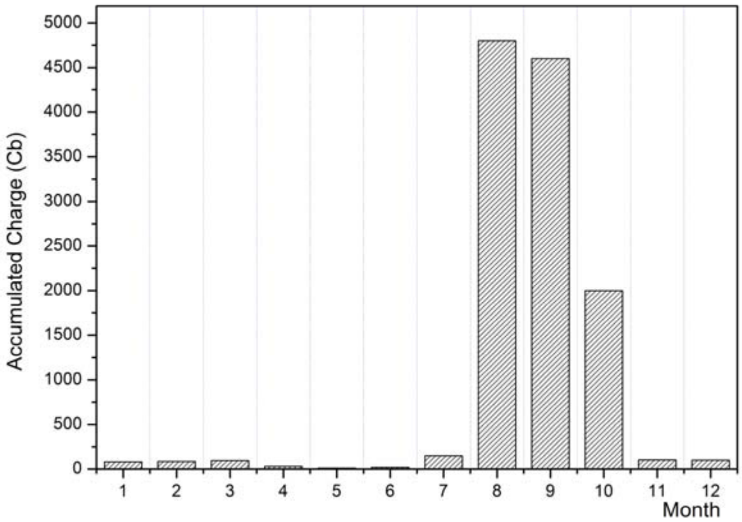

Figure 2. Monthly distribution of the accumulated charge, given as the average value in the nine years monitoring period, for the porcelain non coated insulators.

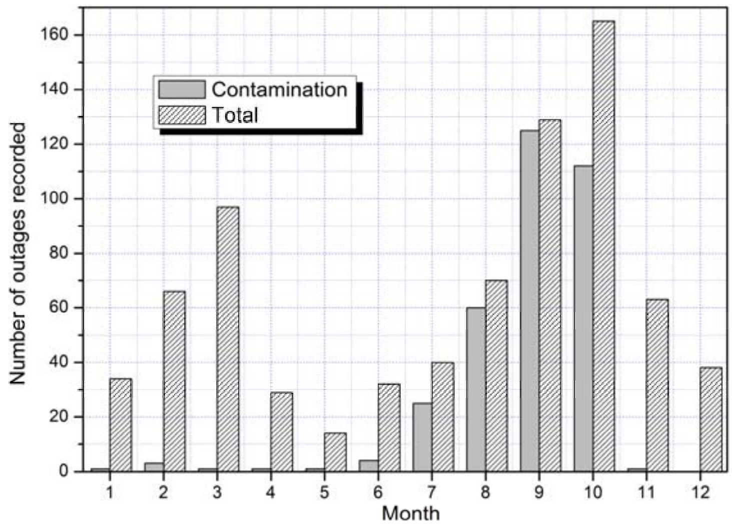

Figure 3. Monthly frequency distribution of power outages, total and pollution related, in the Transmission System of Crete, from 1696 up to today.

3.2 CORRELATION TO THE ENVIRONMENTAL PARAMETERS

The intensity of the pollution problem is strongly correlated to the environmental conditions observed, especially on the wind activity, which is the primary contamination transfer mechanism and precipitation which on the other hand is the primary cleaning mechanism.

In figure 4 the frequency distribution of wind forces per month for five typical months, including the period from July to September, during the nine years monitoring period are illustrated. The distributions indicate that during July and August the number of calm days is decreased, thus the wind activity is more intense. Also higher wind speeds are observed during this period. Therefore the amount of contamination transferred is increased during these two months. However the range of wind speeds observed indicate that there is a progressive contaminants accumulation up to the critical value. Practically an average period of eighteen days is considered necessary for a critical amount to be formed, considering that washing during this period is necessary every two to three weeks.

At the time of deposition the transferred contamination is already humid since the sea is the primary source. However the amount of water transferred by the wind is not enough to support the formation of a conductive surface film. In addition due to the increased ambient temperatures observed during this period the humid contamination is dried upon deposition on the insulation surface. Consequently surface wetting is required for the phenomenon development.

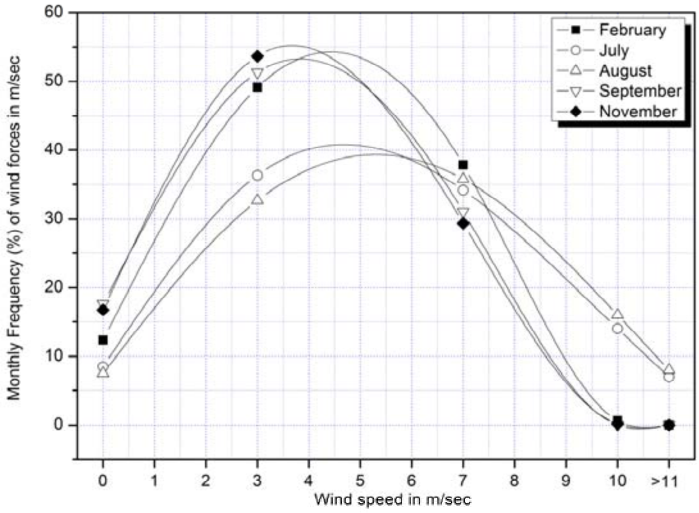

Figure 4. Monthly frequency distribution of wind forces for five typical months, including the period from July to September, during the nine years monitoring period.

Precipitation is one of the wetting mechanisms observed, however as illustrated in figure 5 during the period of intense activity the values of precipitation observed are remarkably low. Therefore there is an increase of the accumulated contamination since the degree of insulator cleaning is limited; however an additional wetting mechanism is required for the phenomenon development. This mechanism is condensation.

Due to the radiation of heat, observed during clam and cloudless nights, the condensation of the ambient humidity occurs and wetting of the insulators surface is possible. As a result during August and September, the probability for RH to exceed 75% which is the threshold for condensation, considering the phase transition of Sodium chloride particles [16] is increased, although precipitation is low, the values of the relative humidity observed are increased, as also illustrated in figure 5.

Consequently the problem of pollution in the case of Crete is the result of the limited insulators cleaning during a dry period and the development of an additional wetting mechanism, which is condensation. The problem is enhanced by the wind activity which is also increased during the considered period. It is worth noticing however that due to wind forces observed the accumulation of contaminants is progressive and due to the features of the condensation mechanism, wetting and contaminants deposition cannot develop simultaneously, since condensation is observed during calm nights. Therefore in the most severe case there is a time gap in the range of six to ten hours from deposition to wetting.

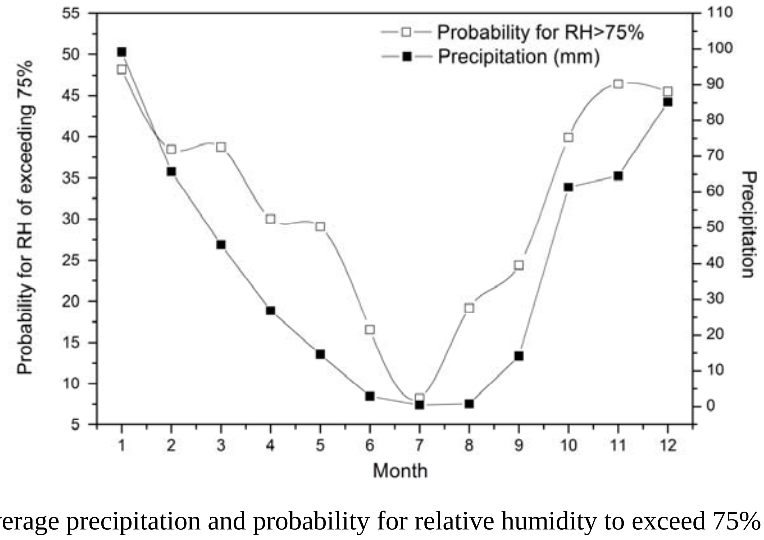

Figure 5.Average precipitation and probability for relative humidity to exceed 75% per month (data available after a 20 years monitoring period).

3.3 RTV SIR COATED INSULATORS

In figure 7 the monthly distribution of the accumulated charge, given as the average value for the porcelain insulators (figure 2) and the maximum value for the coated insulators, in the nine years monitoring period, is illustrated.

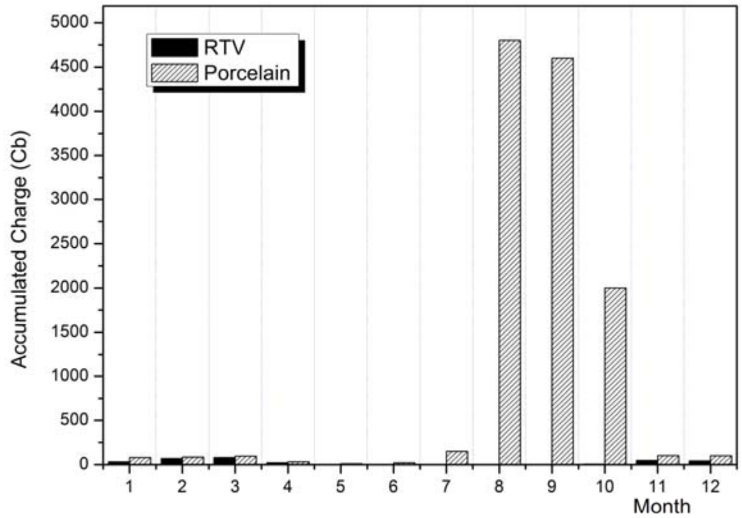

Figure 7.Monthly distribution of the accumulated charge, given as the maximum value in the nine years monitoring period, for the RTV SIR coated porcelain coated insulators.

The improvement achieved by the application of the coatings is evident from the values presented especially during the period of intense activity. However it can be seen that the surface activity on the surface of the RTV SIR coatings becomes comparable to the activity observed on the surface of uncoated insulators, in the period from December to April and especially in March. During this period, in addition to condensation, light rain is also a wetting mechanism that can support the development of surface activity, in both coated and non coated insulators. The important feature in this case is that the amount of water deposited on the insulators surface is higher in comparison to the condensation mechanism, but it is not enough to completely clean the insulator surface.

The correlation between light rain and surface activity is evident from the recordings of figure 8, where the simultaneous surface activity on a porcelain insulator and a coated porcelain insulator in respect to precipitation are illustrated. The activity in the case of the porcelain insulator is higher; however it is comparable to the activity recorded on the coated insulator.

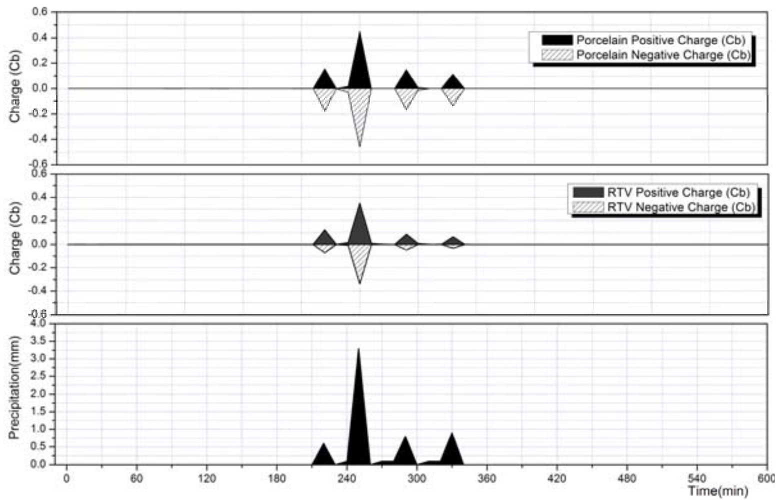

Figure 8.Simultaneous measurements of the surface charge observed on a RTV SIR coated insulator and on a similar non coated, under light rain.

4. EVALUATION OF THE COATED INSULATORS PERFORMANCE

The measurements of leakage current reveal the influence of the environmental conditions and especially of the wetting mechanism to the performance of both coated and non-coated insulators. In the case of porcelain intense surface activity and increased flashover risk have been recorded for the period from late July until October. This period is characterized by remarkably low precipitation, which in combination to the wind activity observed correspond to increased contaminants transfer rates, in comparison to the rest of the year. However the difference is not significant and for the increased amount accumulated, the fact that condensation is not capable of cleaning the insulation surface, although it can support the development of the surface conductive film, must also be considered.

For this period, which is characterized by increased flashover risk due to pollution, the performance of the RTV SIR coated insulators was remarkably superior to the corresponding performance of the non-coated insulators, although neither washing nor any other maintenance procedure has been performed to the coated insulators since the coatings application. The reason is the hydrophobic surface behavior and especially the SIR capability to transfer the hydrophobic behavior to the accumulated contamination. The progressive accumulation that occurs (an average period of eighteen days for a critical amount to be formed) and the time gap that exists between deposition and wetting permits the recovery of hydrophobicity on the coating surface, as a result of the LMW molecules migration [17-23]. Thus leakage current activity is suppressed.

On the other hand, in the case of light rain the levels of surface activity observed are at comparable levels for both coated and non coated insulators. The reason is the larger amount of water supplied on the insulator surface in this case. As a result two different surface activity mechanisms can develop, i.e. discharges between or along droplets in hydrophobic areas and dry band arcing in the case of a hydrophobicity loss. Both can enhance the stress applied and can accelerate material aging.

It is worth noting however that at the present stage, the levels of surface activity recorded are still limited, indicating the material suppressing capability. Nevertheless continuous monitoring throughout the year and further investigation of the influence of light rain are required.

5. CONCLUSIONS

RTV SIR coatings can be used in order to improve the pollution performance of ceramic insulators. In this case, after a nine years service period, such an improvement has been achieved, as it has been verified by continuous leakage current measurements. The measurements also revealed the importance of the wetting mechanism present in each application. Condensation wetting appears to have limited effect on the performance of the coated insulators. A possible reason is the limited amount of water formed on the surface. In addition the progressive contaminants accumulation and the time gap that exists between deposition and wetting are also in favor of the coatings performance.

On the other hand light rain can supply larger amounts of water which can support the formation of conductive areas, where a loss of hydrophobicity has taken place or enhance the surface electrical field due to the water droplets formed, which are more in number in this case. As a result the surface activity observed in the case of light rain is in comparable levels as in non coated insulators.

In conclusion the coatings performance after nine years of service can be considered successful for the specific conditions. However the need for further investigation of the possible material aging is an issue that rises considering the performance in the case of light rain.

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