Substation Pollution Maintenance using RTV SIR Coatings

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1. Introduction

Pollution of high voltage insulators is a problem experienced by many utilities worldwide. It originates from the environment and is capable of deteriorating the performance of outdoor insulation, under the nominal voltage stress. The problem features and intensity may vary from place to place, even within the same transmission or distribution system. Different pollutants, transfer mechanisms and transfer rate can be experienced, resulting sometimes to a unique combination, when also the insulation properties are considered.

Usually the problem is more intense in the Transmission Lines of a power system. This is due to the variety of conditions that can be experienced along their routing. Even from tower to tower, differences can be detected, comparing from example two towers one at the top of a hill and the next in the valley that follows. The group of conditions experienced in each case, can be described as a “micro environment”, which in the same time but in different locations may or may not support the development of surface activity.

Therefore, in an effort to maintain an outdoor installation operative, many methods have been proposed, which however most of the times deal with the pollution problem from the transmission line point of view. In this paper the problem of pollution maintenance in the case of substations is investigated, considering the experience gained in the case of Crete.

2. High voltage substations

A high voltage substation is a node in a transmission system. Therefore a possible outage in a substation usually corresponds to a more severe impact to the power system, in comparison to a corresponding incident in a transmission line. Therefore, from the reliability point of view, substation maintenance has a considerable importance, which increases with the corresponding increase of the correlated transmission circuits' number.

As far as the pollution problem is concerned, in this case there are two considerable advantages. Firstly a substation is an installation geographically concentrated and therefore the conditions variety is limited. Secondly the majority of the substations is supervised or can be easily supervised either locally by personnel or remotely, by an appropriate Closed Circuit TV (CCTV) system. Consequently the problem development can be detected and remedy measures can be applied in time. This is one of the reasons why the pollution related outages in substations are limited in comparison to the corresponding number in transmission lines.

However, there are problems in the case of substations that can complicate an effort to a possible permanent solution. At first in a substation there is a large number of insulators, serving different needs (CTs, VTs, Bushings, post insulators, lightning arresters) and further having different geometries. This corresponds to a considerably increased replacement cost and also complicates geometry related maintenance methods. Further, until some years ago, the availability of composite housings was rather limited.

3. The pollution problem within the design process

In the case of a new installation and if pollution problems are due to appear, there are methods and solutions capable of restricting or even eliminating the possible influence of the environment. The aspects usually considered within the design process are presented in table 1.

Table 1. Design remedies in the case of new substations

Design guideline		Problem intensity	Comments
Insulator selection	Leakage distance	Low	IEC60815
	Geometry	Low	Physical cleaning mechanisms
	Material	Medium	Hydrophobicity Resistive Glazed
Substation scheme	Multiple bus systems, sectionalizing CBs or isolators, automatic washing systems	Medium	Capability of Live washing
Enclosed substations	Partially enclosed in Air	Increased	Medium Voltage Side
	Fully enclosed in Air	Increased	Both MV and HV side
	Fully enclosed in SF_6 (Gas Insulated Systems)	Extreme	Sophisticated systems, maintenance, cost

The first step is the selection of the insulation parameters. Usually, the leakage distance is the first parameter evaluated. The required value can be determined according IEC60815, depending on the experienced problem intensity. However the insulator geometry is also considerably important. An appropriate profile selection must take advantage of the self cleaning mechanisms present. Otherwise, problems may be experienced, although the leakage distance criterion is satisfied. Such a case has been experienced in Crete and is presented in reference [2].

Finally the use of composite materials that provide a hydrophobic surface is also an improvement that can be considered. However the material lifetime is an issue, considering that the replacement cost is remarkable and availability is also an issue. Further, in this case also the insulator geometry must be evaluated. An example is the post insulators illustrated in the picture of figure 1a. They have been installed in the 150kV Linoperamata Substation and since installation are monitored by a leakage current measuring system and it is evident from the measurements that they demonstrated a satisfactory performance. However in the case of rain, probably due to their geometry, increased activity has been recorded. A typical leakage current waveform in such a case is illustrated in figure 1b.

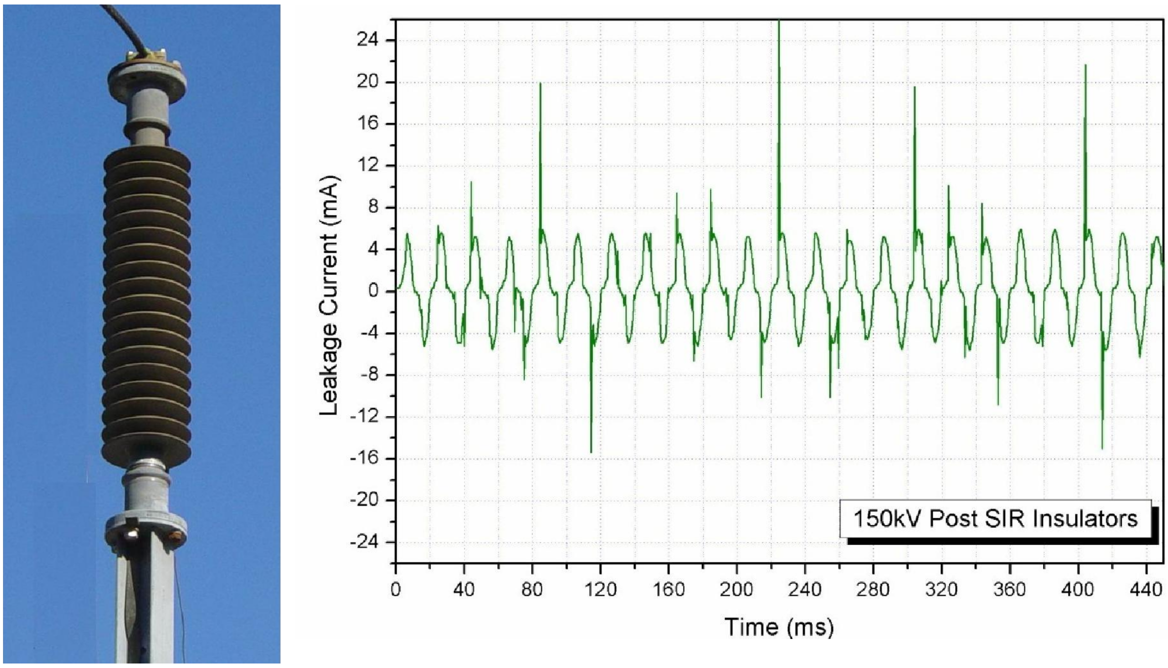


Figure 1. (a) 150kV post SIR insulator installed at Linoperamata Substation
(b) Leakage current measurement on the insulator of figure 1(a) during rain

The substation scheme is also an issue considering the possibility maintenance. Especially if live water washing is not possible, as in the case of Greece, different supply schemes must be available, in an effort to avoid power interrupts and thus maintain high levels of quality. The scheme usually implemented contains multiple bus systems and sectionalizing circuit breakers.

Finally, if severe pollution problems are due to appear, then the construction of enclosed substations should be considered. In the case of Crete, the majority of the 150kV /20kV substations are partially enclosed, thus only the 150kV side is exposed to the environment. In addition there is one 66kV air insulated substation that is fully enclosed, a view of which is illustrated in figure 2. In both cases, the environmental oriented problems are restricted, however a control of the inner atmosphere is necessary considering that phenomena such as condensation may appear.

Figure 2. View of the 66kV **enclosed air substation** at Linoperamata

Finally, the substation scheme that totally encounters pollution problems is a GIS installation, thus a substation enclosed in SF_6. In this case the possibility of a pollution related problem is totally eliminated and the save of space achieved is an advantage. However there are issues to consider, concerning the maintenance means and procedures and the installation cost. In Crete at the moment there is one GIS 150kV substation at the Atherinolakos Power Plant and a second is under construction.

4. Pollution maintenance methods in substations

In the case of the already installed equipment, the financial investment required in order to apply any of the remedies reported in table 1 is considerable. Therefore the performance of the existing insulation must be improved. This is the reason why the case of substations is different.

The first action usually taken is cleaning of the insulators exposed to the problem. There are many different cleaning methods, which are selected according to parameters such as the number of insulators to be cleaned, the pollutant type, the possible by-products and the corresponding application cost. It is worth mentioning that the application of such methods is easier in the case of substations, since the considered equipment is geographically confined.

Some of these methods are summarized in table 2.

Table 2. Insulator Cleaning methods

Cleaning Method		Medium	Deposit	Comments
Insulator Washing	High Pressure Washing	Water	Deposits with poor adhesion	1. Time of Washing 2. Live Washing? 3. Work hours 4. Cost if power interruptions are required
Insulator Cleaning	Dry Cleaning	Dry Abrasive Cleaner	Cement Fertilizers	1. Time of cleaning 2. Dry material deposits 3. Cost 4. Glaze damage and insulator shattering
	Hand Cleaning		Cement Fertilizers Greases	1. Time of cleaning 2. Work hours 3. Power interruption
	Dry Ice	Solid Carbon Dioxide		1. Cost of equipment and material 2. There are no by-products deposits 3. Environment

In any of the methods included in table 2, the primary problem is the selection of the optimum cleaning time. This is an exclusively experience oriented parameter, which depends on various factors regarding the locally experienced service conditions. If cleaning is performed earlier than required then a critical build up of contaminants is possible to develop in short time and thus the problem still remains. On the other hand the more the cleaning is delayed the higher is the possibility of an outage due to pollution.

Further, there is also a considerable financial cost related to the cleaning procedures, especially in if they cannot be applied on live equipment. In the latter case a supply interruption is required, which corresponds to a deterioration of the system reliability, since a part of a substation is set out of service and to an additional financial loss since it may be required to interrupt the power supply to a number of consumers.

It is worth mentioning that this financial loss can be increased in the case of step up substations, if due to the supply interruption one or more power units are put out of operation for some hours. Then, the probable problems related to the power units operation can result to an additional cost, quite considerable. Such a case is the Linoperamata Substation, in Crete, GREECE, were it was required to clean the substation in two parts, at least twice in each summer.

In addition, the necessary man-hours, considering that insulator cleaning is performed during hours of low power load, thus during the night and early on the morning, must also be considered.

Consequently, insulator cleaning is a method that can be applied in order to ensure the insulation performance under pollution conditions, but there are two significant parameters that must be considered. The first is the selection of the optimum cleaning time, since it is a rather suppressive method (not preventive) and the second is the correlated financial cost, especially if it cannot be applied live.

In a more advance case, instead of cleaning the insulator, an effort to improve the corresponding surface performance is possible by the use of coatings. Different types of coatings can be found, however the two types mainly used are the Silicone Grease and RTV Silicone Rubber coatings. The improvement achieved is the application of a preventive method (instead of suppressing), since the coating can be installed at a time convenient for the utility and within its operational lifetime is capable of suppressing the pollution influence at any time.

In both cases, the phenomenon suppression is possible by proving a water repellant surface, which as a result does not permit the formation of a surface conductive contaminants film. The difference between these two types is the method employed in order to maintain the water repellency feature, while contaminants are deposited on the surface, mainly by the wind.

In the case of Silicone Grease, the deposited contamination is encapsulated within the material volume and as a result the surface is maintained clean. This indicates that there is a saturation point, when the maximum contaminants amount that can be encapsulated is achieved. At this point the end of the coating service lifetime is achieved and the material must be removed. Otherwise, a performance even worse than an insulator without Silicone Grease, is probable to be experienced.

In the case of Crete, the average lifetime of silicone grease coatings is six months. Therefore such a coating must be applied and further removed twice each year, something that limits a possible large scale application and it may only be applied on critical equipment. Furthermore, this limited coating service lifetime and the required man-hours for replacing the coating are the two primary drawbacks that limit the possible use of Silicone Grease.

The water repellant surface is also the primary feature of RTV SIR Coatings. However, there is no encapsulation feature in this case but instead a hydrophobicity transfer capability is evident, sufficient to change the initial hydrophilic behavior of the deposited contamination film to hydrophobic. As a result, although the deposited contaminants remain on the surface (no encapsulation), the surface behavior is hydrophobic, thus suspending the phenomenon development. This is a considerable improvement in comparison to Silicone Grease, since the accumulated contamination is still exposed to various cleaning mechanisms such as rain and therefore there is no saturation behavior in this case. Further the application lifetime is elongated and can exceed a period of 5 years, achieving in some cases a lifetime of more than 10 years.

Therefore RTV SIR Coatings can be considered as a preventive measure that can provide an efficient solution in the case of substations. They can be applied on any insulator type, regardless of material, use and geometry. The application can take place at a time convenient for the utility and remain active for a period that most of the times exceed 5 years. Also large scale application is possible, due to the elongated material lifetime, at a reasonable cost. It is worth mentioning that in the case of Crete, the application cost for the application of the total amount of RTV SIR Coatings that have been installed is less than the corresponding cost of washing at Linoperamata Substation, for a period of three years.

Of course in this case also there are drawbacks that must be considered. Aging for example, maintenance, the optimum time of replacement and the corresponding cost (labour and financial) are concerns that must be answered. However the preventive feature and the large scale application capability are considerable advantages that distinguish this method from the rest.

However, it is worth mentioning that coatings cannot fully counterbalance the lack of the required creepage distance. If the later is not sufficient then the use of elastomeric creepage extenders is obligatory. These extenders can be applied in any insulator type. But they must be specifically designed for the considered insulator geometry, something that limits the possibility of a large scale application and further corresponds to an increased application cost (too sophisticated). Therefore it is a method usually adopted in special conditions, when the methods already mentioned are not sufficient.

Finally, the pollution maintenance methods usually employed in the case of substations are summarized in table 3.

5. Application of RTV SIR coatings in 150kV substations in Crete

The first application of RTV SIR Coatings in Crete started in 1998 at Linoperamata 150kV step up substation, which was fully coated a few years later. In addition, more substations were coated and today, eleven years later, more than 7500kg have been installed in 66kV and 150kV substations, in Crete and Rhodes, as illustrated in figure 3.

Since application, the surface activity due to pollution has been remarkably suppressed and no flashovers have been experienced, although washing procedures have been suspended on the coated insulators. Therefore up to today the coatings application can be considered successful. However, having coatings that exceed a lifetime of five years, and in many cases reaching ten, there are concerns regarding the material reliability, evaluation and the necessary maintenance actions.

In service conditions, the coatings evaluation was based mainly on empirical observations, such as surface discharges noise and visual effects during the night. Leakage current measurements were also performed and verified the improvement achieved by the coatings application. A comparison is possible by comparing the graphs of figure 4.

Table 3. Maintenance methods in the case of substations

Maintenance Method		Problem intensity	Comments
Insulator Washing	Automatic or Manual systems	Any	1. Live Washing? 2. Time of Washing 3. Work hours 4. Cost if power interruptions are required
Insulator Coatings	Silicone Grease	Medium	1. Method of Preventive Maintenance 2. Limited lifetime (encapsulation) 3. Necessary coating replacement 4. Power interruptions are required (replacement) 5. Work hours
	RTV Silicone Rubber	Medium	1. Method of Preventive Maintenance 2. Extended lifetime (Hydrophobicity) 3. Aging and replacement are issues
Creepage Extenders	Elastomeric	High	1. Method of Preventive Maintenance 2. Specific Design for each insulator geometry 3. Application Cost

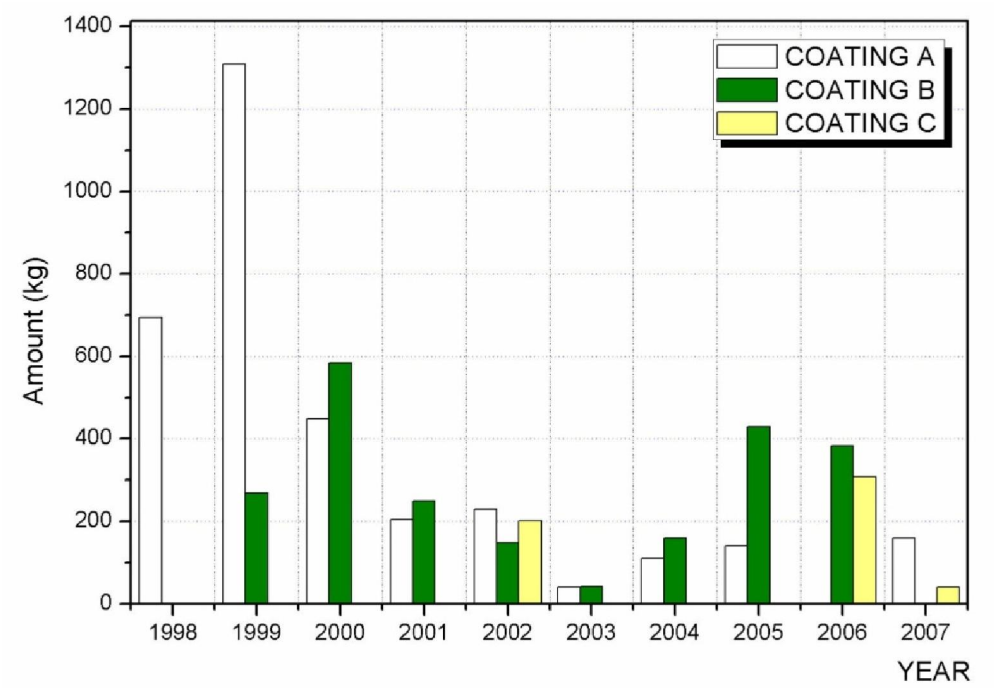


Figure 3. Amount of installed RTV SIR Coatings per year in Crete, Greece

In the first (figure 4a) the monthly distribution of the accumulated charge recorded on the surface of the monitored 150kV porcelain post insulators (average behavior) is illustrated. It is evident that the surface activity is observed during the summer period and especially from August to October, as expected. In the second (figure 4b) the same distribution is illustrated, in the case of RTV SIR coated insulators, of the same geometry, for the same time period and installed at the same location. The values of the accumulated charge (vertical axis) are indicative of the improvement achieved.

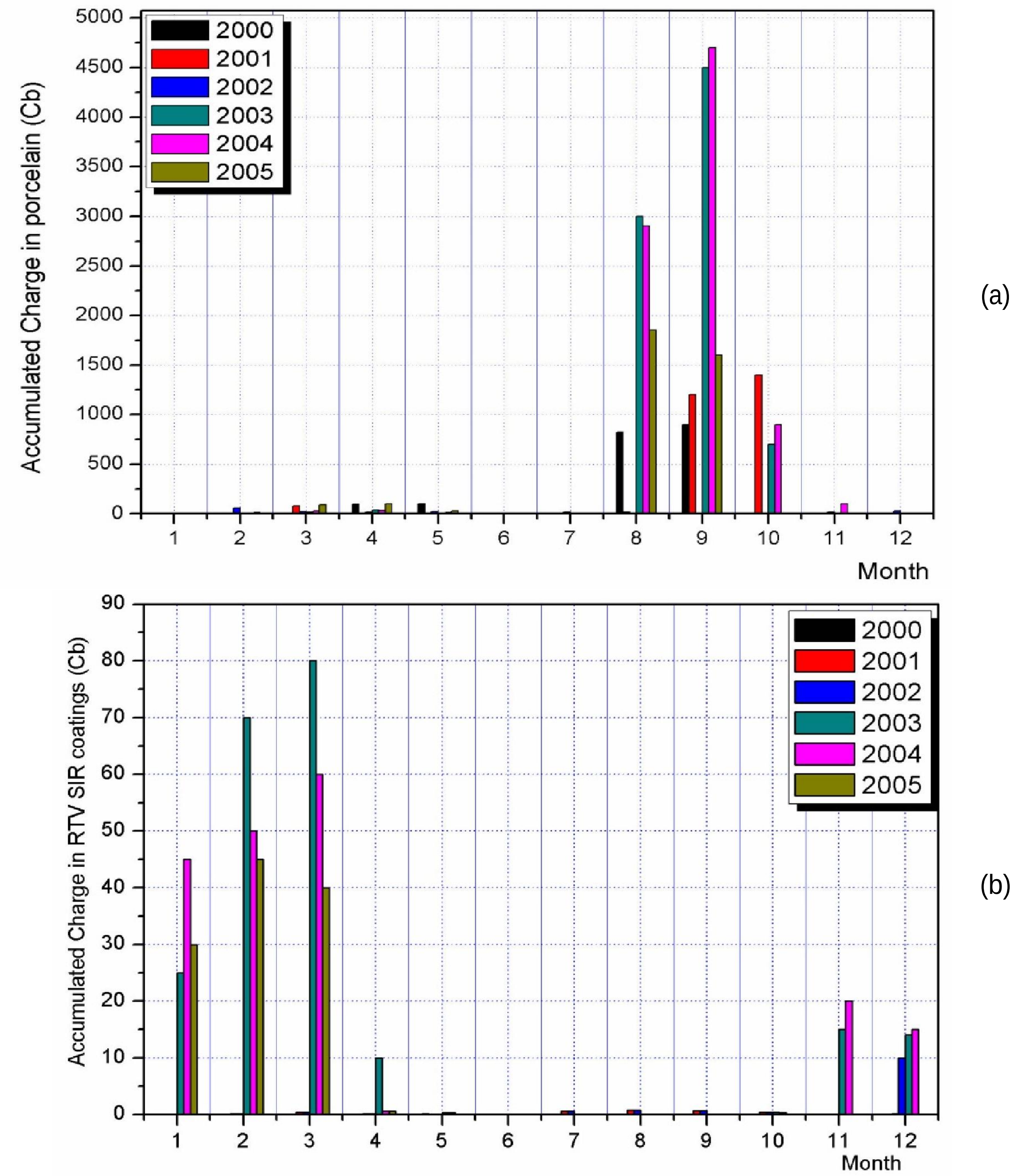
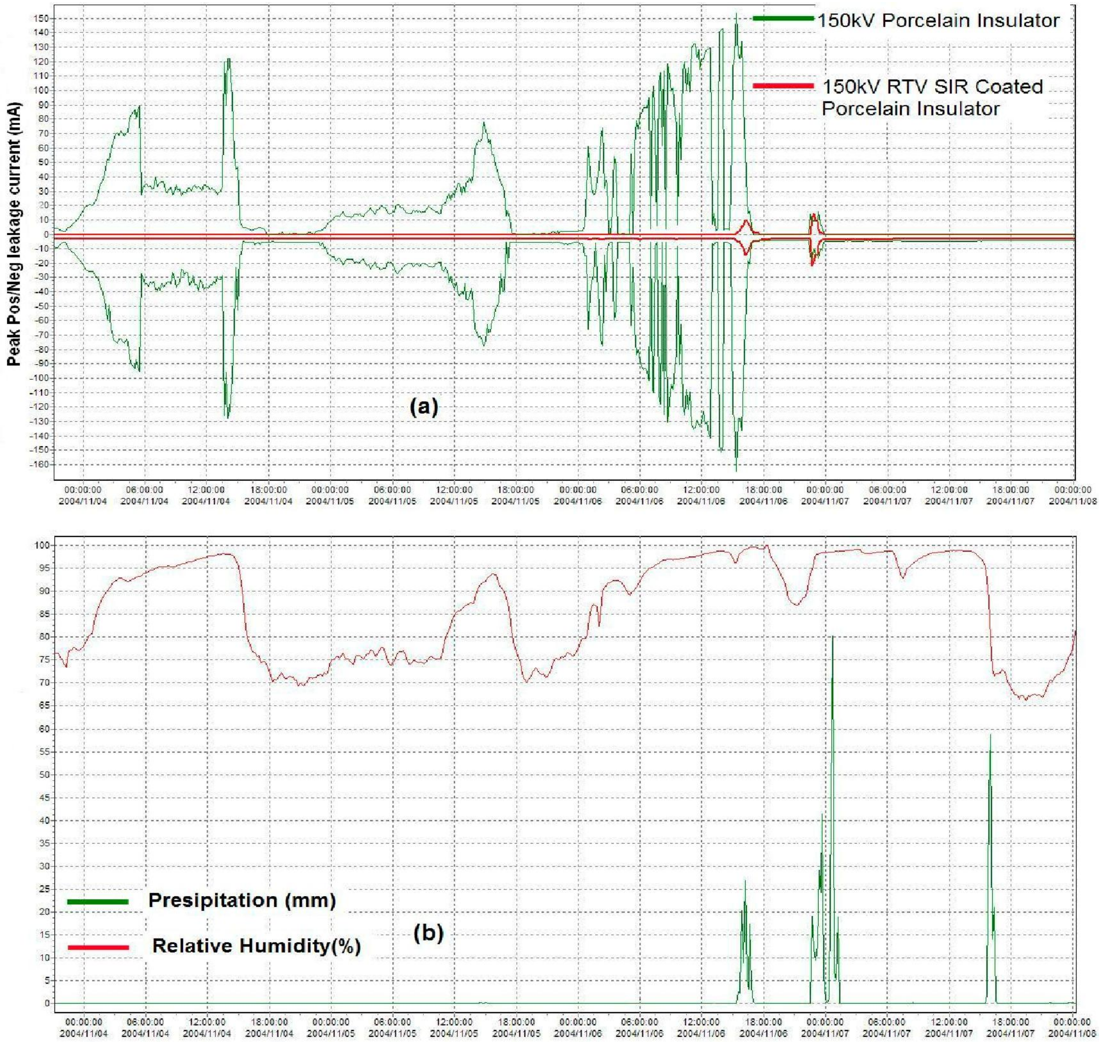


Figure 4. Accumulated charge for the same time period in the case of 150kV post insulators of identical geometry, installed at the same location
(a) In the case of porcelain
(b) In the case of RTV SIR coated porcelain

In addition, it is worth noticing that the period of activity is different in each case. Although the main pollution problem is experienced during the summer, for RTV SIR Coatings the surface activity is increased during the winter and especially from November to March. This has been correlated to the influence of the wetting mechanism, which is different in each case. During the summer, the mechanism observed is condensation and during the winter is precipitation.

A typical example of the influence of the two mechanisms on the two different insulation surfaces is illustrated in figure 5. As it can be seen in the case of condensation, activity is observed only on the porcelain insulator. On the other hand during rain on both insulators surface activity is present. At the first incident the activity on the coated insulator is considerably less that on the porcelain. At the second incident of rain, the same levels of activity are observed and finally at the third incident, no activity is present.



(a)

(b)

Figure 5. The impact of condensation and light rain on the surface behavior of both surface types (coated and not) in the case of two identical insulators, at the same place and time.
(a) simultaneous measurements of the maximum and minimum surface leakage current observed on both insulators,
(b) precipitation and relative humidity at the same place and time

The measurement of leakage current is a valuable tool in understanding the behavior of the RTV SIR coatings in these specific service conditions. However it is not sufficient to support an evaluation process of the installed coatings. We do have verified the performance improvement, but we haven't been able to detect the action of the experienced aging mechanisms.

Firstly, the application of this method is limited to a small number of insulators, due to the relevant financial cost. Further it is not possible to monitor the full range of currents with the required accuracy. In this case currents less than 1mA could not be recorded and this is one of the reasons why we do not have reliable data to compare the coatings from different manufactures. Finally, the property of great interest in this case is surface hydrophobicity and the corresponding recovery mechanism, which are strongly correlated to the material properties and through leakage current can be evaluated only in a macroscopic scale.

In an effort to improve the available information of the coatings condition, hydrophobicity measurements using the STRI Guide 92/1, have been carried out. The results indicated that even for the oldest coatings a hydrophobic surface behavior could be expected. However these measurements evaluated a constant surface condition and no information regarding the loss and recovery cycle of hydrophobicity (stability) could be deduced. In addition it is a rather subjective method resulting sometimes to measurements that disprove each other.

Consequently, the application of RTV SIR coatings in Crete is successful until today, considering also that the corresponding investment has been paid off in a period less than three years. However, now we have entered a different era and various concerns regarding the required coatings evaluation and maintenance come forward.

6. Concerns regarding the application of RTV SIR Coatings

The first concern is the material selection. Today there are many manufactures worldwide and more appear every year. Therefore, from the utility point of view there is a need for standards were methods and criteria will be available, in order to evaluate the coating quality in laboratory conditions, before application.

After application, the required monitoring is an issue. The measurement of leakage current and hydrophobicity can be applied. However, the experience gained from the application of these methods in Crete, indicates that they are not enough. It is evident that material related analysis is required and the question that rises is which parameters must be evaluated and what methods should be employed. Further is it possible to establish criteria in this case also.

If aging is detected, which are the remedies required in order to protect the coating and probably elongate its lifetime. Insulator cleaning or high pressure washing (figure 6) could probably employed or even recoating. However which should be employed and when, in order to achieve an improvement of the coating performance and not a probable deterioration.

Figure 6. High pressure water washing of a 150kV RTV SIR coated VT at Linoperamata Substation

Finally, an establishment of an end of life criterion is necessary in order to select the optimum replacement or recoating time. In this case the development of methods that could be employed in order to remove the aged coating is necessary, considering that recoating is a temporary remedy.

Consequently, a monitoring and maintenance strategy must be established since the coating selection, in order to be able to evaluate the coating condition when it is required and further determine the necessary actions.

7. Conclusions

Pollution maintenance of high voltage substations is an issue for every utility worldwide. The feature that distinguishes the case of substations from transmission lines is the service features and the corresponding financial cost of the equipment included in such an installation. Especially in the case of already installed equipment, the employed remedies have to improve the performance of the existing insulation, since the cost of replacement is considerable. Many methods can be employed in this direction. Among them RTV SIR Coatings can be proved to be the most promising, since they provide a predictive remedy and a long lifetime.

In Crete, a large scale application has taken place and coatings that exceed a service period of 5 to 10 years are still in operation. The insulation performance has been improved, as it has been verified by leakage current measurements and considering also that since application no other remedy has been applied. However there are concerns, regarding the coating selection, the necessary monitoring and maintenance and finally the optimum replacement time and method.

8. References

[1]. R.S. Gorur, Accomplishments and future challenges for outdoor insulating systems under contaminated conditions, International Symposium on High Voltage Engineering, India 2001

[2]. R.S. Gorur, E.A. Cherney, J.T.Burnham, Outdoor Insulators, R.S.Gorur Inc, Phoenix, Arizona, USA

[3]. R. Hackam, Outdoor Composite Insulators, IEEE Transactions on DEIS, Vol 6, No 5, October 1999

[4]. S.M.Gubanski, Modern Outdoor Insulation - Concerns and challenges. Electrical Insulation Magazine, 2005. 21(6): p. 5-110p

[5]. J.S.T. Looms, Insulators for high voltage, IEE Power Engineering Series 7.

[6]. CIGRE WG 33-04, TF 01, A Review of current knowledge: Polluted Insulators, Cigre Publications, 1998

[7]. IEEE Std 1523 – 2002, IEEE Guide for the application, maintenance and evaluation of RTV SIR Coatings for outdoor ceramic insulators, IEEE Outdoor Service Environment Committee, 2002

[8]. E.A. Cherney, R.S. Gorur, RTV SIR Coatings for Outdoor Insulators, IEEE Transactions on DEIS, Vol 6, No 5, October 1999

[9]. E.A. Cherney, RTV Silicone – A high tech solution for a dirty insulator problem, IEEE Electrical insulation Magazine, Vol. 11, No. 6, November/December 1995

[10]. J. Hall, T. Orbeck, RTV protecting coating for porcelain insulators, IEEE PES 1982 Summer Meeting, July 18 – 23 , 1982

[11]. R.E. Carberry, H.M. Shneider, Evaluation of RTV Coating for station insulators subjected to coastal contamination, IEEE Transactions on Power Delivery, Vol. 4, No. 1, January 1989

[12]. IEEE DEIS Outdoor Service environment committee S-32-3, Protective coatings for improving contamination performance of outdoor high voltage ceramic insulators, IEEE Transactions on Power Delivery, Vol. 10, No. 2, April 1995

[13]. CIGRE WG 33-04, The measurement of site pollution severity and its application to insulator dimensioning for a.c. systems, Electra No.64 pp. 101-116

[14]. Sorqvist T., Polymeric Outdoor Insulators, A Long-term Study, PhD, Technical report No. 313, Chalmers University of Technology, Goteborg, SWEDEN 1997

[15]. Vosloo W.L., Holtzhausen J.P., Roediger A.H.A., Leakage current performance of naturally aged non ceramic insulators under a severe marine environment, Afficon Conference, South Africa 1996

[16]. Munteanu R., Use of Leakage Current Monitoring System for maintenance of insulators on a HV Network, World Conf. on Insulators, Arresters and Bushings, Malaga, Spain, 2003

9. Biographies

Kiriakos Siderakis received a diploma degree in Electrical and Computer Engineering in 2000 and a PhD Degree in 2006 from the University of Patras. Presently, he is working as a consultant with Public Power Corporation in Crete and also teaches High Voltage Engineering at the Technical Institute of Crete. His research activities include high voltage insulation, composite materials and performance of insulators in polluted areas. Dr Siderakis is a member of CIGRE and the Technical Chamber of Greece.

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