RECOMMENDATIONS FOR INSULATOR-POLLUTION-FLASHOVERS IN SRI LANKA WITH SPECIAL EMPHASIS ON A STUDY OF COMPOSITE INSULATORS

by

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Abstract

This paper presents the performances of 33 kV high voltage insulators consisting of composite, porcelain, and coated porcelain insulators exposed to polluted and clean environmental conditions in Sri Lanka. Seven different types of insulators (four composite, one coated, one porcelain long rod and one porcelain cap & pin string) have been installed in 33 kV distribution lines. The insulators were periodically tested for more than three and half years and their performances were investigated by means of visual inspection, hydrophobicity classification, salt deposit density, surface conductivity, leakage current and flashover voltage value. Composite and coated insulators performed well without having any flashover during this period whereas porcelain insulators had frequent flashovers under polluted conditions. Based on the overall performance, it is recommended that the silicone rubber composite and coated insulators be used to reduce the power outages due to insulator-pollution-flashovers in polluted areas in Sri Lanka.

1. Introduction

The electrical power generated at the generating stations is transmitted to the load centres by means of outdoor transmission lines. From there, the distribution of power to industries, commercial and residential customers is done by both outdoor distribution lines and underground cables. Outdoor transmission and distribution lines need to be insulated from their supporting structures for safety and to avoid short circuiting of the power source. Therefore, the reliability of electric power depends on the insulation used with outdoor lines.

Porcelain has been used as the oldest material for outdoor insulation, and it is still widely used around the world. The other main insulating material is glass. However, when the insulation is exposed to environmental stresses such as pollution (salt, industrial) and weather (humidity, rain) together with the electric stresses, a leakage current (LC) flows along the surface of the insulator. The development of LC causes flashover by short circuiting across the insulation. This is a vast problem in the transmission and distribution lines exposed to polluted areas. Some of the methods presently used to overcome these problems require insulator replacement at regular intervals, increasing the creepage distances, insulator washing, and greasing or coating. Another method is to replace the traditional insulators by composite insulators.

A composite insulator, referred to also as non-ceramic and polymeric insulator, consists of three parts, namely metal fittings for the connection to the power conductors and the supporting structure, a fiber glass rod for mechanical strength of the insulator and a housing material for protection of the fibre glass rod and for using as the insulation. The main advantages of composite insulators are light weight, resistance to damage and good pollution performance, when new. The first two reasons provide low cost of transportation and installation of insulators. The latter provides reliability in the polluted environments. However, the main drawback of the composite insulators is the surface aging. Under difficult service stresses such as corona discharge, UV exposure, chemical attacks etc., chemical reactions can occur on or inside the composite material. This may result in hydrophobicity loss and other surface degradations for example tracking and erosion. Another limitation is the high cost of raw materials which may result in a higher market price for the insulator. However considering the costs ap-

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plicable to consumers due to "power outages" and low cost for transportation and installation, the high price of the composite insulators may not be considered as a disadvantage.

Going back to history, the first composite insulators were used on outdoor lines during the mid 1960 period. Since then, there have been many changes in the material composition and design of insulators. Now composite insulators are being used in significant quantities in Australia, Canada, Europe, South Africa and the USA. Today, the majority of the composite insulator users are in the USA.

The most common materials used today for composite insulators are silicone rubber (SIR) and ethylene propylene diene monomer (EPDM). The SIR is used in two forms: room temperature vulcanized (RTV) and high temperature vulcanized (HTV). Another type of insulators called coated insulators are also presently used by spraying a SIR coating on porcelain insulators. Usually, RTV is used for those coatings whereas HTV is used for composite housings.

A lot of information about the performance of composite insulators in the field and under laboratory conditions has been collected around the world over past decades [1-13] and overall experiences have been good. The same refers to RTV coatings on porcelain insulators. However, the material deterioration due to aging was the most common cause if failures appeared. Based on a survey among the United States Utilities Schneider et. al. [1] reported that 64 % of the nonceramic insulator failures originated in consequence of material degradation. Similar conclusions were presented in some of the CIGRÈ and IEEE publications describing world-wide experience [2-5]. For example, In a broad survey of field performance of non-ceramic insulators in the United Kingdom, France and Italy [6,7] revealed that such surface defects, i.e. erosion, splits, cracks, holes, broken rods etc. occured due to material deterioration. Burnham et. al [8] has reported that EPDM insulators frequently fail under high humidity conditions in Florida.

According to world experience, the EPDM insulators when new, show good surface properties and better pollution performance than the traditional porcelain and glass insulators [4,5, 14-18]. However under severe environmental and electric stresses the EPDM surfaces can deteriorate rapidly [19,20]. Then they perform worse than porcelain and glass insulators [6 - 9, 14, 16]. On the other hand, the SIR insulator is believed to be the best insulator concerning its overall performance [9,14,16,18]. It has also been found that the use of RTV coating improved the contamination performance of porcelain and glass insulators [21,22].

Among the currently available data, most information concerning the performance of nonceramic insulators and RTV coatings is related to field experiences gained under temperate, desert and sub-tropical climatic conditions. On the other hand, information about performance in tropical climate is rather limited. In comparison with other environments, the tropics are characterized by high humidity, rainfall, temperature and sun irradiation. All these factors may significantly influence insulator performance. High humidity makes a polluted insulator surface conductive. In contrast, heavy rainfall washes the contaminants away. Intensive UV irradiation and high temperature leads to a rapid aging of the polymeric housing. Both, high humidity and elevated temperature also create a favourable environment for the growth of biological contaminants. It is, therefore, interesting to see how these conditions affect the performance of nonceramic insulators and coatings. On the other hand, in Sri Lanka, one of the main reasons for power outages in the 33 kV distribution system is insulator pollution [23].

A joint research program between, the University of Peradeniya (UP), Chalmers University of Technology (CTH), Sweden, and Ceylon Electricity Board (CEB) started a project under a Sida/SAREC funds. Some of the technical aims are to obtain a better understanding of the composite insulator performance in tropical environments and to check whether the application is useful to solve the existing pollution problem in the power distribution system in Sri Lanka. Accordingly, different types of insulators have been installed in different locations in Sri Lanka, and their performances were periodically tested.

2. Details of the Insulators

Six different insulators originating from different manufactures were used for the performance testing. These comprised four composite (three SIR and one EPDM), one RTV coated porcelain, and one porcelain insulator. The parameters of the insulators are given in Table 1 given as the code names of #1 - #6. Three or four cap & pin porcelain insulators are presently used on 33 kV distribution lines respectively in clean and polluted areas. One such cap & pin insulator string was selected as the reference insulator and dimensions of one insulator are shown in the Table 1 as code name #7.

3. Test Sites

According to the presently available statistics on power outages in grid substations (GSS), higher number of trippings were found in Puttalam, Kurunegala, Habarana, Anuradhapura, and Badulla

GSSs [23]. The latter four GSSs are located in relatively clean environments and the most possible reason for power outages was the lack of leave clearance closer to the distribution lines [23]. However, majority of the power outages in Puttalam GSS are caused by insulator pollution. Thus two test sites were selected in Puttalam area representing marine pollution and industrial pollution. Apart from that, a third site was selected at the University of Peradeniya. The pollution classes according to IEC 815 [24] are shown in Table 2.

Table 1 Insulator parameters

Insulator code name		#1	#2	#3	#4	#5	#6	#7
Material		SIR	SIR	SIR	EPDM	Porcelain	RTV coated	Porcelain
Arcing distance	[mm]	345	400	345	345	260	260	172
Creepage distance one unit	[mm]	790	853	840	840	500	500	272
Total specific creepage distance	[mm/kV]	23.9	25.8	25.5	25.5	15.2	15.2	24.7 or33.0
No of sheds large/small		4	4/3	6	6	5	5	1
Distance between sheds	[mm]	62	40	50	50	45	45	-
Shed diameter large/small	[mm]	160	122/81	126	126	105	105	127
Core diameter	[mm]	22	27	26	26	45	45	-

Table 2 Pollution classification at the test sites (Acc. to IEC 815 [24])

Site name	Puttalam cement factory	Puttalam coastal line	University of Peradeniya
Site No.	Site I	Site II	Site III
Pollution classification	very heavy	very heavy	light
Pollution type	thick cement deposit	very close to sea and exposed to sea spray	low density of houses, frequent rain & wind

I. Industrial Site - Puttalam Cement Factory

This site is located at the premises of the cement factory about 8 km from Puttalam. A solidified layer of cement dust is a typical contaminant at this location. New insulators become covered with the cement layer and there is a need for their frequent replacement. Here, the insulators have been installed horizontally.

II. Coastal Site - Puttalam Coastal Line

This site is situated on the coast about 2 km from Puttalam. This place is located in the vicinity of a lagoon (~200 m), where salt is produced. The Indian Ocean coast is about 5 km away across the lagoon. Salt is the main contaminant in this location. It is brought from the ocean and the lagoon by the prevailing south-west winds. Frequent discharges and sometimes flashovers take place during the rainy periods and some of the insulators are damaged due to the increased discharge activity. The insulators have been installed horizontally.

III. Clean Site - University of Peradeniya

At this site, the insulators were hung vertically on a balcony of one of the University buildings at the University of Peradeniya. A high intensity of rainfall and sun irradiation appear at this location. The main aim of this installation is to see how the local atmosphere affects the insulator performance. For easier observation the insulators were not energized. Past experience has revealed that no difference in insulator performance was found independently whether the insulators were energized or not [9].

4. Experimental Procedure

The insulators were installed during September/October period in 1995. After the installation, the insulator performance at the cement factory and the coastal line was tested a few times. The time schedule for testing, indicating the moments when the insulators were scrutinized in the field or disconnected for laboratory investigations, is illustrated in Fig. 1. The insulators installed at the University of Peradeniya were tested more frequently, i.e. once a month. In all the cases, the insulators, were carefully inspected for any presence of possible defects and then photographs were also taken of them. Then the surfaces of the insulators tested for hydrophobicity, salt deposit density, surface conductivity, current leakage and flashover voltage value. The details of the series of tests are summarized in table 3. Since mostly rain and the wind affect the amount of contaminants on the insulators, the table provides information on the relationship between the test times and the rainy season and the predominant wind direction.

the flow of LC and increases the FOV or reduces the risk of flashover incidence. Thus a hydrophobic surface is one way of evaluating a good insulator.

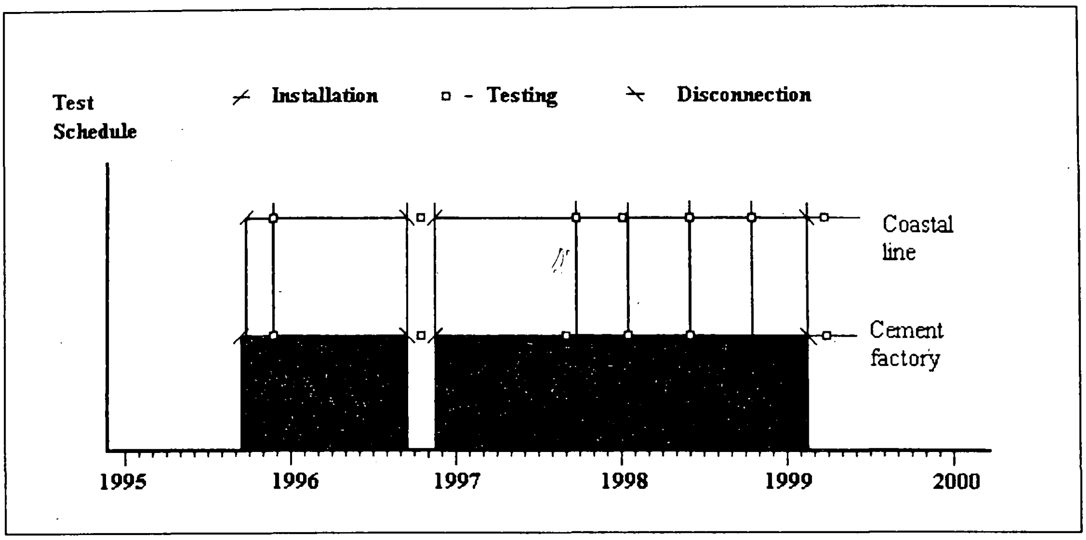

Fig.1. Test Schedule

Table 3 Test procedure of insulator investigation at Puttalam sites

Test time	Site	Tested parameters	Relation to rainy season	Wind direction/ expected pollution
Nov. 95	cement factory, coastal line	SDD, HC	after	SW/low
Nov. 96	cement factory, coastal line	SDD, k, HC, LC	before	SW/high
Sep. 97	cement factory, coastal line	k, HC	before	SW/high
Jan. 98	cement factory, coastal line	k, HC	after	NE/low
May 98	cement factory, coastal line	k, HC	during	SW/low
Oct. 98	coastal line	k, HC	during	SW/low
Feb. 99	cement factory, coastal line	SDD, k, HC, LC, FOV	after	NE/low

The first installation of insulators (#1 - #4) took place at the industrial site on 11 th September 1995. Similarly, the same insulators (#1 - #4) were installed at the coastal site on 20 th September 1995. The installation at the clean site started on 12 th October 1995 and insulators (#1 - #5) were installed there. After installation, seven testings over three and a half years were done periodically to check.

I. Hydrophobicity Classification (HC)

The surface hydrophobicity is one of the important parameters describing the insulator performance. The term "hydrophobicity" is fundamentally classified as either hydrophobic or hydrophilic. On a hydrophobic surface, water appears in droplet form whereas a hydrophilic surface is easily wetted. In principle, composite insulators when they are new are hydrophobic which provides high surface resistance on the weather-shed surfaces of the insulators. This reduces

The standard method of measuring the hydrophobicity is the use of contact angle [25]. The contact angles usually referred are static and dynamic (receding [θ_r], advancing [θ_a]). However, the past experience showed that the most important angle was the receding angle [26]. The measurements of the receding angle provides precise evaluation of the hydrophobicity, but its applicability in the field is sometimes inconvenient. The Swedish Transmission Research Institute (STRI) proposed a simple method [27] especially usable in the field application. This method was followed in investigating the insulator hydrophobicity.

In this method, the hydrophobicity is divided into seven classes (see Table 4) depending on the receding angle of the surface. In this classification HC = 1 refers to a completely hydrophobic surface while HC = 7 to a completely hydrophilic surface. In this procedure, first the surface is sprayed with de-ionized water until the surface is completely wetted (20-30 seconds). Then HC evaluation is judged by comparing typical pictures illustrating these different hydrophobicities with the water droplet behavior on the surface. Usually the evaluation is made about 10 seconds after the spraying is finished.

at a voltage 2 1/2 steps below the last FO value (One step was equal to 3 1/2 to 4 1/2 % of the last FO value). After the FO, the test was continued from a voltage below 2 1/2 steps of the FO voltage. Then the voltage was increased by one step at three-minute intervals until FO. This sequence was repeated until the FOV values were reduced to a minimum and then rose well above the minimum. The FOV value was the minimum value.

Table 4 Criteria for hydrophobicity classification in [27]

HC	Description
1	Only desecrate droplets are formed $\theta_R \approx 80^0$ or greater for the majority of droplets
2	Only desecrate droplets are formed $50^0 < \theta_R < 80^0$ for majority of droplets.
3	Only desecrate droplets are formed $20^0 < \theta_R < 50^0$ for majority of droplets. Usually they are no longer circular
4	Both desecrate droplets and wetted traces from the water runnels are observed (i.e. $\theta_R = 0^0$. Completely wetted areas < 2 cm^2. Together they cover < 90% of the tested data
5	Some completely wetted areas > 2 cm^2, which cover < 90% of the tested area
6	Wetted areas covered > 90%, i.e., small unwetted areas (spots/traces) are still observed
7	Continuous water film over the whole tested area

II. Salt Deposit Density (SDD) [28]

In this procedure, the contaminants were removed and carefully collected from a defined area of the insulator with a cotton swab. The contaminants were then desolved in a known quantity of de-ionized water and stirred for at least two minutes. The volume conductivity of the contaminant was measured by using a volume conductivity meter. The conductivity value was corrected to a room temperature 20^{0}C. Then salinity of the solution was determined. Finally the SDD value was estimated from the volume and the salinity of the solution, and the area of the clean surface.

III. Surface Conductivity (k) [29]

In this method, a 1 cm^2 paper strip was first fixed between the probes of a layer conductivity meter. The paper strip was dipped in de-ionized water in order to become wet. Then, it was placed on the dry pollution layer. The k value was noted once it became stable.

IV. Leakage Current (LC)

The LC is measured buy means of a built data acquisition system. More details of the test system can be found in [31-32].

V. Flashover Voltage Value (FOV)[33]

In this procedure, the insulators were energized at a voltage estimated at 20% or more above the nominal FOV value. If there was no FO within 25 minutes, the voltage was increased by 5% at one minute intervals until FO. After the FO, the insulator was re-energized

Two months after the installation of insulators in November 1995 there was a torrential shower at Puttalam. Two weeks after the shower on 26 November 1995, insulators were disconnected from the cement factory and the coastal line for a first scrutiny.

On 14 August 1996 (before the second rainy season of the year) all the insulators were removed and brought to the high voltage laboratory at the University of Peradeniya for a second laboratory testing. After testing of HC, SDD, k and LC the insulators were cleaned and installed again in the same places on 14th November 1996.

On 30 August 1997, the insulators at the coastal line were tested for a third time before the second rainy season of the year. The measurements at the cement factory had to be postponed until 27 September 1997, due to the impossibility of disconnecting the power supply. However, the total rainfall that appeared between 30 August to 27 September was not large (~60mm) and, therefore, the results could still be compared.

During the period between October 1997 and the end of December 1997, the insulators were exposed to unusually heavy rains. It rained almost every day during the evenings and nights whereas it was sunny during the day time. When these, continuous intensive rains had finished, field investigations were performed for a fourth time on 10 January 1998 and 17

January 1998 on the coastal line and the cement factory, respectively.

A fifth testing was performed on 30 May 1998 at both locations.

The insulator performance at the coastal line was checked for the sixth time on 10 October 1998. The insulators at the cement factory could not be tested due to heavy rains.

The intensive rains lasted until January 1999. The insulators at the cement factory and on the coastal line were removed on 14 February 1999, respectively. Then they were brought to the University of Peradeniya for final laboratory measurements of LC and flashover voltage value. One week later SDD, k and HC measurements were performed in March 1999.

5. Results

I. Weather Details at the Test Sites

The weather parameters were collected from the meteorological departments located at Puttalam and Kandy respectively for industrial and coastal sites at Puttalam and clean site at University of Peradeniya.

According to the weather statistics, the rain mainly appears in both Puttalam and Peradeniya (Kandy) during the rainy seasons (April/May and August/September). The annual rainfalls in Puttalam and Kandy one year prior to the investigations are ~1300 mm and ~2000 mm respectively. The other characteristics of the climate are high humidity, high temperature, high sun irradiation and moderate winds. The average temperatures in Puttalam and Kandy are 28°C and 25°C respectively. The average values of relative humidities are 82% and 84% respectively for Puttalam and Kandy. The average wind speed in Puttalam is 4 km/hr. The direction changes to north-west during November to March whereas it is in the South-West direction during the remaining period. The south-west winds are responsible for deposition of contamination in both polluted sites. Usually, during the other period, less pollution accumulation is expected on the insulator surfaces. The average period of the daily sun irradiation in Kandy is 5.5 hours therefore, the insulators are exposed to high amount of UV irradiation. Unfortunately the meteorological department has no information about the sun irradiation in Puttalam. However, the average value of sun irradiation in Puttalam must be higher than that in the Kandy area.

The main weather parameters influencing the insulator performance are rainfall, temperature, humidity, and sun irradiation [4, 14, 16].

Figs. 2 and 3 respectively show the time variations of rainfall intensity and wind details during the registered periods in Puttalam. According to Fig. 2, the South-West monsoons made the main contribution to the rainfall. On the other hand, in Puttalam the rainfalls during one or two days contributed mainly to the total monthly rain intensity. On four occasions, during the testing period the daily maximum rain intensities exceeded 100 mm. On one occasion, the insulators were not energized. The other occasions were

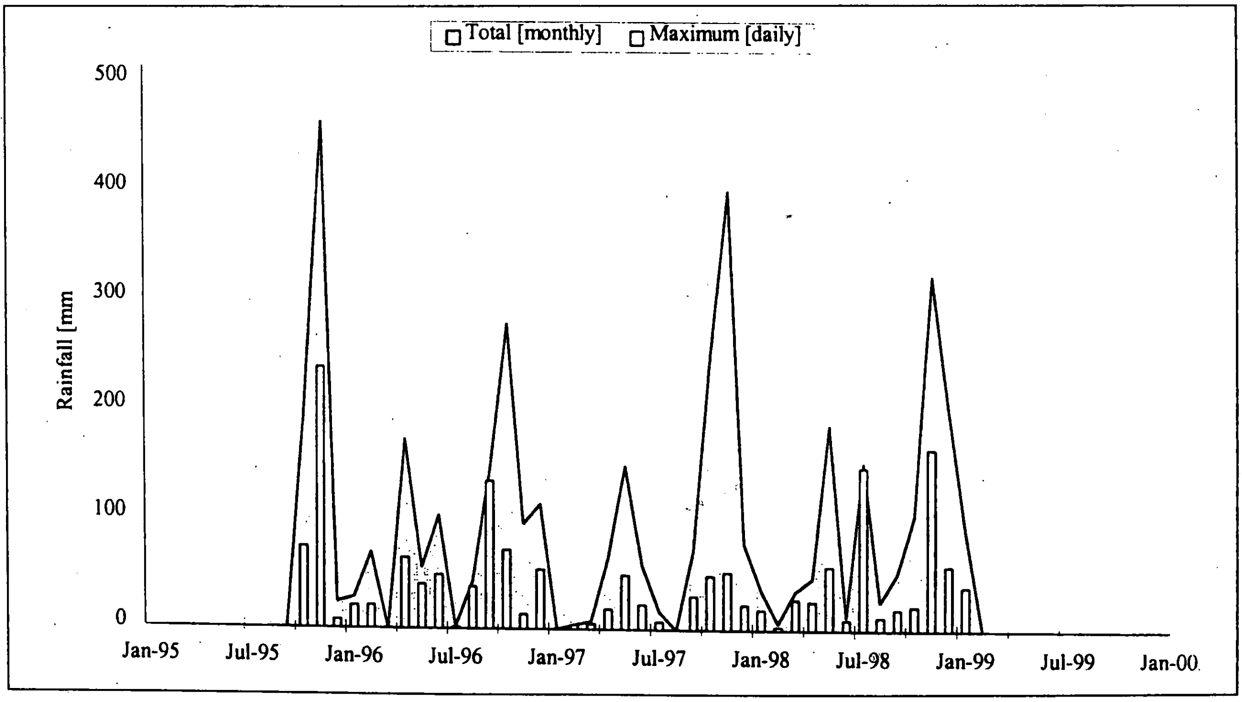

Fig. 2. Maximum daily and total monthly rain intensity values at Puttalam

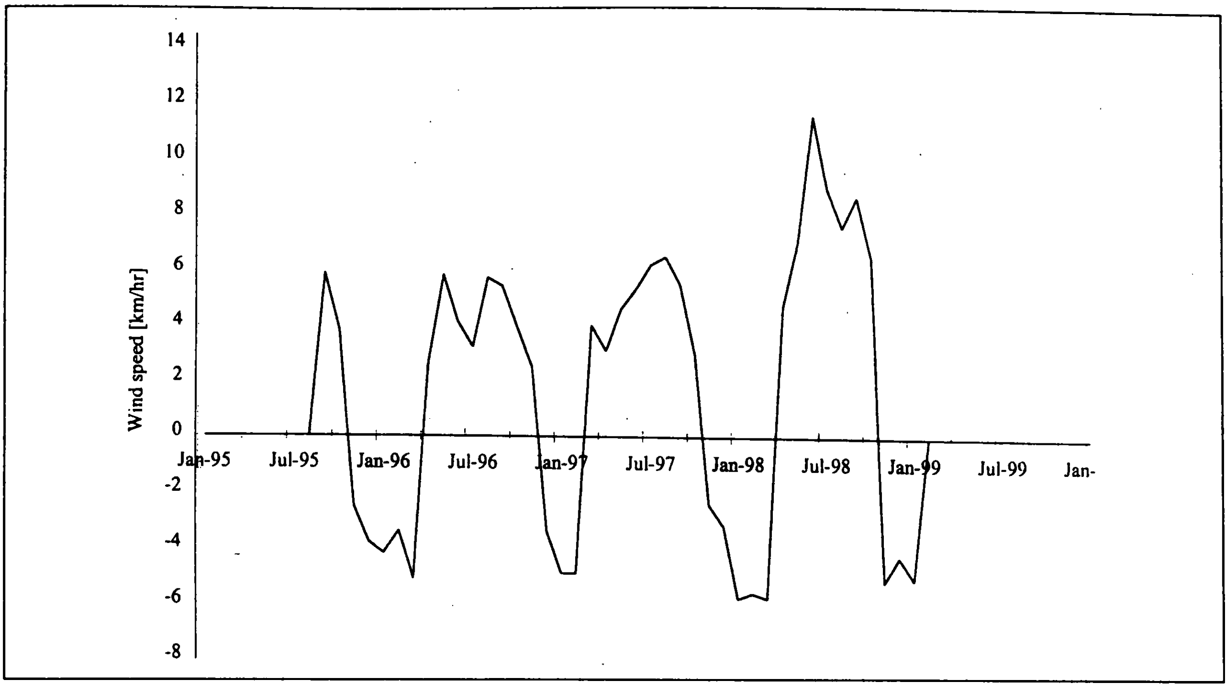

Fig. 3. Wind direction annd speed at Puttalam (positive-from south-west direction, negative-from north-east direction)

(i) 5th November 1995 (period I) about 237.9 mm (ii) 18th July 1998 (period VI) about 147.6 mm and (iii) 28th November 1998 (period VII) about 164.1 mm. One could expect a high removal of pollutants during these periods. In Kandy the rain intensity values were slightly higher than Puttalam. At the same time, monthly total rain intensity consisted of rainfalls during several days. The daily rain intensity exceeded 100 mm only on one occasion (i.e. 28 November 1996 (period III) about 160.6 mm).

In Puttalam the wind direction was usually from South-West during April - October while the direction was from North-East during rest of the time In general, the wind speed was moderate though there was slightly higher wind speed during 1998.

The other weather parameters such as temperature and relative humidity values were mostly constant throughout the study. Considering the temperature values, the insulators in Peradeniya and Puttalam were respectively exposed to the temperature ranges of 15 - 35°C and 20 - 40°C. This means the insulator surfaces had high possibility of aging and hydrophobicity recovery.

The average values of humidity in both places were around 80%. This reported that the insulators were exposed to high humidity most of the time. The maximum monthly humidity percentage was always above 90 % and in Kandy it was always at or just below 100%. This indicated that at least on one day each month the insulators had been exposed to very high humidity levels.

According to the overall weather data, one year period can be classified into four durations: January to March, April/May, June to August and September to December. During January to March, the weather conditions were characterized by lower rainfall, higher temperature and sun irradiation, and wind from North-East direction. Thus less accumulation of pollutants could be expected. In addition, higher aging and hydrophobicity recovery could take place. Flashovers might occur during this period. During April and May, the wind was from South-West and the rain intensity was higher. Higher pollution accumulation can be expected and, at the same time, they could be washed away. Again flashovers might occur. During July to August, the wind blew from South - West direction, the monthly rainfall was lower and the humidity level was higher. Thus flashovers could take place during this period due to highly deposition of contaminants by South-West winds and wettability by high humidity and light rain. According to the CEB observations, flashovers mainly occurred in Puttalam during these months. During the last duration (September - December), the rain intensity was in general very high. Thus the possibility of having flashovers is low.

II. Visual Scrutiny of the Insulators

During the investigated period the insulator surfaces were carefully inspected in order to identify any surface defects or changes. The main observations are presented in Table 5.

Table 5 Main observations on newly installed insulators

Insulator No.	Puttalam cement factory	Puttalam coastal line	University of Peradeniya
#1	Contaminated by thick removable cement layer	Part of the insulator shed covered by brownish dust	Darkening of the upper sides of the sheds
#2	Contaminated by thick removable cement layer	Whole insulator surface darker	Darkening of the upper sides of the sheds
#3	Contaminated by thick removable cement layer	Part of the insulator shed covered by brownish dust, partly corroded metal fittings	Darkening of the upper sides of the sheds
#4	Contaminated by thick hardly removable cement layer, deterioration of sealing material between core and fitting,	Completely chalked partly corroded metal fittings deterioration of sealing material between core and fittings	Chalked areas exposed to direct sun light
#5	Contaminated by thick hardly removable cement layer	Severely eroded material surface close to the metal fittings melting spots on the fittings	No visible surface changes
#6	Contaminated by thick removable cement layer	Part of the insulator shed covered by brownish dust, erosion signs due to discharges	Part of the coating damaged by birds

Pollution:

During the first period itself, thick cement dust was observed on all the insulators at the industrial site. The cement layer was not solidified and was easily removable on SIR insulators. However, the dust was not easily removable from EPDM insulator.

From the second period onwards, the deposition of cement dust was even thicker on all of the insulators. In general, higher content of dust was observed on insulators #1, #5 and #6. The dust was easily removable on SIR surfaces. Oppositely, hardly removable and partly solidified dust was observed on the other two (porcelain and EPDM) insulators. A contaminated porcelain cap & pin insulator is shown in Fig. 4.

In general, no visual pollution appeared on the insulators at the other sites.

Surface Erosions:

Erosion is defined as an irreversible and non-conducting deterioration of the insulator surface that occurs from electrical dry-band arcing and results in a loss of housing material. During the first two months after installation, branch-like surface erosions occurred on the EPDM insulator surface at coastal site. These structures were lighter (white) in colour, however, no such erosions appeared on the other two sites.

Surface Discolourations and Chalking:

The colour of the EPDM insulator surface changed from original dark gray to white colour. This was very clear at the clean site. These surface discolourations were caused by UV rays from sun irradiation.

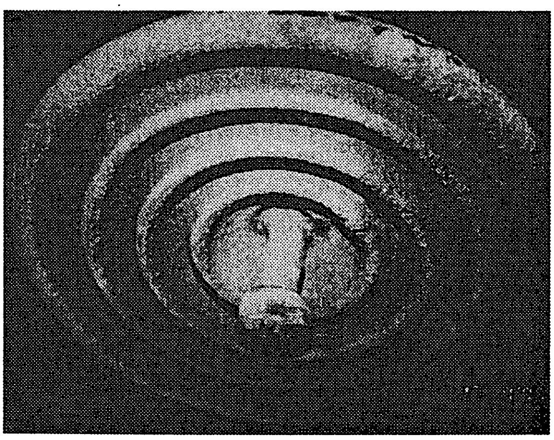

Fig. 4. Polluted porcelain insulator from the cement factory

Furthermore, the discoloured areas appeared as a powder called chalking. This was most probably due to the appearance of filler particles of the housing material on the surface of the insulator. Similar observations were found at the coastal site as well.

Opposite to the EPDM insulators, some SIR surfaces were darker during the investigations. Likewise the upper side of the top shed was the darkest.

Insulator Burning:

The porcelain insulator at the coastal site had been exposed to severe dry band arcing. These discharges were clearly visible at night during rainy seasons. These resulted in severe surface erosions on the insulators surfaces closer to the metal fittings. Part of the surface had burnt out. This effect is illustrated in Fig. 5.

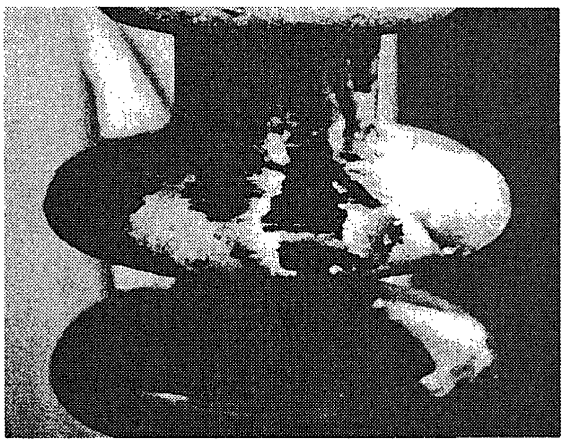

Fig. 5. Damaged porcelain insulator due to heavy dry band arcing at the coastal site

Apart from the above mentioned change of surface properties, some of the minor surface changes were open sealing (see Table 5), corrosion, and removal of the RTV coating.

None of the newly installed composite insulators had flashed over during the registered period. On the other hand, the reference porcelain insulators flashed regularly during the June - August period every year. The porcelain insulator #5 flashed over in one occasion at the coastal line.

III. Hydrophobicity Classification

In this investigation, the hydrophobicities were tested on upper and under sides of the sheds and the sheath. It was observed that the HC values varied among sheds and sheath parts. In addition, the HCs differed even within the shed itself due to either non-uniform distribution of pollutants or dissimilar surface hydrophobicity. The average HC values are shown in Table 6.

Out of all the main insulating materials such as SIR, EPDM and porcelain, the porcelain insulators exhibited hydrophilic properties throughout the study.

In addition, it seemed that the EPDM insulators had lost their hydrophobicities permanently in all sites. The insulator indicated hydrophilic property during the first period of exposure to cement dust. On the other two sites, the hydrophobicity had been lost during a one year period.

In general, the SIR insulators and coatings preserved the hydrophobicity except in some special cases.

The industrial site exhibited a thick pollution layer with lower conductivity. On the contrary, the coastal site displayed an invisible pollution layer with comparatively high conductivity. Apart from those two cases, the clean site does not show any visual pollution. At the coastal site there was a general tendency of loosing hydrophobicity on SIR surfaces. However, such variation was not observed at the other two sites. This indicated that the hydrophobicity could be lost even on SIR surfaces when they have been exposed to high conductive pollutants such as salt.

Usually, the pollutants are brought by the prevailing winds and the intensive rainfall washes out the pollutants. Comparisons were made on HCs before and after the rainy seasons. One such example was the testings on September 1997 and January 1998. The results revealed that HCs in some of the SIR insulators have improved after the rainy season.

IV. Pollution Severity Measurements

Pollution severity levels of the insulators were estimated by SDD and k measurements. Table 7 and 8 show the variation of SDD and k values at the cement factory and the coastal line. The SDD values were relatively low and sometimes negligible. The k values were also low. In November 1996, the SDD values on the coastal line were relatively high since the tests were made before the rainy season. Higher k values were also obtained on some of the insulators when tested in November 1996 and September 1997. In February 1999, the SDD became very low despite that the insulators had remained exposed to natural conditions for 2.5 years between the measurements. The k values were relatively low during the periodical tests after September 1997. It seems obvious that heavy rains efficiently washed the salt contaminants from the insulator surface.

Table 6 Hydrophobicity classes of the insulators from Puttalam cement factory, Puttalam coastal line University of Peradeniya.

Test time	Nov. 1995	Nov. 1996	Sep. 1997	Jan. 1998	May 1998	Oct. 1998	Feb. 1999
Time to testing [months]	2	14	23	28	32	37	42
Puttalam cement factory							
Insulator #1	5	3	2	1	2	NA	5
Insulator #2	3	2	1	1	1	NA	2
Insulator #3	1	1	1	1	1	NA	2
Insulator #4	6	6	7	7	7	NA	7
Insulator #5	NA	6	7	7	7	NA	7
Insulator #6	NA	1	1	1	1	NA	3
Puttalam coastal line							
Insulator #1	2	3	5	5	4	3	5
Insulator #2	1	2	3	1	1	1	1
Insulator #3	1	2	3	3	4	3	4
Insulator #4	2	6	7	7	7	7	7
Insulator #5	NA	6	7	7	7	7	7
Insulator #6	NA	2	5	2	1	1	1
University of Peradeniya							
Insulator #1	1	1	3	2	2	3	3
Insulator #2	1	1	2	1	1	1	1
Insulator #3	1	1	2	2	2	2	1
Insulator #4	2	6	7	7	7	7	7
Insulator #5	NA	6	7	7	7	7	7
Insulator #6	NA	1	2	2	1	1	1

Table 7 Variation of the SDD at the polluted sites [μg/cm²]

Site	Puttalam cement factory		Puttalam coastal line	
Time	Nov. 1996	Feb. 1999	Nov. 1996	Feb. 1999
Period [month]	12	28	12	28
Relation to rain	before rains	after rains	before rains	after rains
#1	30	5	70	20
#2	35	10	50	10
#3	35	10	40	10
#4	45	10	60	10
#5	80	10	75	15
#6	25	10	30	15

Table 8 Variation of the k at the polluted sites [μS/cm]

Time	Nov. 1996	Sep. 1997	Jan. 1998	May 1998	Oct. 1998	Feb. 1999
Relation to rain	before rains	before rains	after rains	during rains	during rains	after rains
Puttalam cement factory						
#1	5.1	9.9	7.7	7.7	NA	6.2
#2	4.7	10.6	5.7	7.9	NA	8.8
#3	5.3	14.1	7.9	7.6	NA	7.3
#4	4.8	10.6	10.1	9.4	NA	8.6
#5	11.1	9.1	6.7	5.2	NA	7.2
#6	5.1	10.2	7.6	9.3	NA	8.6
Puttalam coastal line						
#1	47.0	24.1	5.8	5.4	5.5	5.3
#2	8.1	39.1	6.0	6.0	5.9	10.8
#3	7.6	18.8	5.8	6.8	6.2	8.1
#4	15.9	85.1	5.8	4.5	4.4	7.4
#5	33.8	39.8	6.0	4.9	4.7	7.0
#6	6.7	59.2	5.6	5.3	5.5	8.7

V. Leakage Current and Flashover Voltage Value

The measured LC levels at the end of testing were in micro amperes range. Maximum levels were below 50 μA. When the insulators were removed in 1999, the surfaces had been merely washed by the previous rains. Thus the LC levels were low. The FOV values obtained at the end of the test were all above 60 kV confirming the washing of the pollutant from the insulator surface. The both LC and FOV results indicated that the insulators were still in the good condition.

6. Discussion

In this study, composite and coated insulators despite some slight surface property changes, performed well without having any evident flashovers. However, the reference porcelain insulators having higher creepage distance (about 30% higher than composite) flashed over frequently. The tested porcelain insulator (#5) flashed over in one occasion. One may argue that the creepage distance of the porcelain insulator is lower than that of composite insulators. However, composite coated insulator (#6) having similar insulator dimensions performed well. By taking into account the flashovers in outdoor conditions, composite insulators and coated ones can be ranked as the best. It is, therefore, this paper suggests that the application of composite insulators could be used to reduce the power outages in the distribution system due to insulator pollution. This application must be compared with other solutions as well as their relative advantages and disadvantages.

In the present Sri Lankan distribution system, the power outages are minimized by the extension of creepage distance (i.e. adding one more insulator) or decreasing the distribution voltage (i.e. 33 kV to 11 kV) [23]. These methods are not the best solutions from the technical point of view. Extension of creepage distance will make the insulator bulky so that the installation and maintenance works are difficult. The latter solution provides higher losses and voltage drops in the distribution system. Application of composite insulators provides low maintenance cost as well as good insulator performance under polluted conditions.

One important fact is the price of the insulator. In cost comparison, the price of the porcelain insulator is less than that of the composite insulator. Unfortunately we can not give any fix price for the comparison because the cost for the composite insulator varies vastly depending on the supplier, supplying quantity and the demand. At the same time, it is not the best way to just compare the figures of the prices. In addition, attention must be paid to the problems encounted for the domestic and industrial power consumers due to the power failures using traditional insulators. Thus relevant cost should also be added. On the other hand, in favour of composite insulators, the transportation and installation costs are lower. In addition, the present utilities in the world, are moving towards the composite insulators and, therefore, this provides a price reduction for composite insulators in future. By taking into account of all these factors, the effective cost for porcelain and composite insulators are the same. Recently, an extensive survey conducted by a Japanese group among different groups of insulator manufacturers, utilities and research and maintenance groups in the world, also reported a similar price level for composite and traditional insulators [15].

I. Industrial Pollution - Cement Dust

The main insulator problem in Sri Lanka due to industrial pollution is the cement dust. Thick cement dust deposits on any type of insulators independent of the insulating material and the dust is so thick that it is not significantly washed by natural rains. Thus this can only be eliminated by replacing the insulators. However, SIR surfaces, despite the thick cement layer, preserved the hydrophobicity (see Table 6). Good hydrophobicity reduces the risk of flashover incident by having lower surface leakage current. Thus SIR housings (insulators) or coatings (on porcelain) can be used for cement pollution.

II. Marine Pollution

In this study, porcelain insulators flashed over under marine pollution. Similarly the surface properties have changed on EPDM insulator especially the hydrophobicity (see Tables 5 and 6). Therefore, the SIR housings or coatings can also be used to avoid flashovers. The prevailing rain improves the hydrophobic properties of SIR surfaces (see Table 6) so that the life-time of the SIR insulators could be high.

III. Clean Environments

In a clean environment, flashover due to pollution is a rare occurrence. Thus porcelain or glass insulators are still usable. According to IEC 815 [24], the specific creepage distance of the insulators should be above 16 mm/kV (light pollution). However, composite insulator can be used with high electric stress because of good surface properties. Thus composite insulators can be used with lower specific creepage distance (less than 16 mm/kV).

7. Conclusions and Recommendations

Since their installation in 1995 under marine and industrial pollution conditions in Sri Lanka the composite and RTV coated porcelain insulators have performed well. No flashovers have been reported on them, despite the heavy service conditions. Simultaneously, flashover events have taken place on porcelain cap & pin insulators, acting as references and tested porcelain insulators at locations with high concentration of salt pollution. Based on this extensive study and by taking into account the other relevant factors, it is recommended that silicone rubber composite and coated insulators be used to reduce the power outages due to insulator-pollution-flashovers in polluted areas in Sri Lanka.

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