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A Comprehensive Study of Silicone Rubber Insulators with Different Creepage Distances

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Abstract: Composite insulators with polymeric housing have become an alternative to ceramic insulators during last four decades. Out of different composite insulators, silicone rubber (SIR) insulators have usually exhibited better performance under polluted conditions. In a previous research during 1994-1999, 33 kV SIR insulators with similar creepage distances with ceramic insulators have shown good performance under polluted and clean conditions in Sri Lanka. This paper presents the extension of that study aiming to check whether SIR insulators with shorter creepage distances (Short insulators compared to porcelain insulators) could perform well even under polluted conditions. In 2001 three sets of nine 33 kV SIR insulators with different creepages and two ceramic insulators were installed in two test sites exposed to marine and clean conditions in Sri Lanka. Their performances had been investigated in the field for more than 5 years by visual inspection and hydrophobicity evaluation. After 5 years, they were tested under laboratory conditions by leakage current, time variation of dc resistance and wet flashover measurements. In parallel, a separate set of SIR insulators were aged for 1000 hours under salt fog conditions and the leakage current was continuously monitored. It was found that the housing material influence the insulator performance rather than its creapage distance. Further there is a possibility of stressing the SIR insulators higher than ordinary ceramic insulators.

Keywords: Insulators, composite, Silicone rubber, Creapage distance

1. Introduction

Composite insulators with polymeric housing have become an alternative to ceramic insulators. Their water repellent (hydrophobic) properties, although not understood to its fullest potential yet, are the main reason for the usage. In addition, the low weight of composite insulators contributes to reduction of transportation and maintenance costs. Therefore, composite insulators are specified nowadays more often by power utilities and by manufacturers of high voltage equipment. This situation follows the positive outcomes of tests performed in field and laboratory conditions over the last four decades [1-4]. Today, the most common housing materials used for housings of composite insulators are ethylene-propylene rubbers (EPM and EPDM), silicone rubbers as well as their mixtures. However, silicone rubber (SIR) insulators have usually exhibited better performance under polluted conditions [2].

In Sri Lanka, the insulator failure due to the natural pollution in the 33 kV distribution lines, causes severe problems. In these lines, porcelain or glass cap&pin insulators (three or four in a string) are mainly used. In the coastal areas and areas around the industries insulators get contaminated and pollutants produce heavy discharges and flashovers during rainy and high humid conditions. In 1994, a collaborative project among University of Peradeniya, Chalmers University of Technology Sweden and Ceylon Electricity Board (CEB) was initiated to understand the performance of composite insulators under polluted and clean conditions. Under this project several set of 33 kV composite insulators (SIR, EPDM) with similar creepage distance to that of porcelain insulators were installed in three sites exposed to marine and industrial pollution and clean conditions. Their performances were tested over 4 years and it was found that SIR insulators performed well [5-7].

In 2001, a separate project was started to extend

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the above study aiming to see whether SIR insulators with shorter creapage distances (Short insulators compared to porcelain insulators) could perform well even under polluted conditions. Thus the outcome of the project may help to reduce the recommended minimum creapage distance (for heavily polluted site and low polluted site are 31 mm/kV and 16 mm/kV respectively [IEC 60815]) so that utility may be benefited in saving money by installing short insulators both in polluted and clean areas. In this work, 33 kV silicone rubber insulators with different creepages were installed under marine and clean environments and their performance were checked under field and laboratory conditions. In parallel, a set of SIR insulators were aged under laboratory conditions.

2. Details of the insulators

Different manufacturers of SIR insulator were requested to send test insulators for the study. The details of the insulators are given in Table 1. Three set of each insulator type was used for the investigation.

The insulators comprised of 8 SIR insulators (#A-#H), and one hybrid insulator having silicone rubber shed and ceramic core (#I). The insulators were from five manufactures (insulators #A-#C from manufacturer 1, #D and #E from manufacture 2, #F and #G from manufacturer 3, insulators #H, and #I from manufacturers 4 and 5 respectively). The reference insulators were porcelain cap & pin (No. #K) and glass cap&pin (No. #L). The specific creepage distances varied between 9 mm/kV to 25 mm/kV. (The electric stresses varied between 94% and 287% of the stress for the reference insulators).

3. Overall Test Procedure

Two sets of insulators were installed and energized to 33 kV system voltage in Sri Lanka. The insulators were exposed to marine pollution and clean condition more than over 5 years. Their performances were periodically checked and at the end, the field aged insulators were tested in the high voltage laboratory in University of Peradeniya. Another set of insulators (five) were aged inside the salt fog chamber for about 1000 hours in Chalmers University of Technology and their performances were checked. The detail of the test procedure is illustrated in Table 2.

Table 1 – details of the insulators

Details		Insulators										
		#A	#B	#C	#D	#E	#F	#G	#H	#I	#K	#L
Country of origin		Sweizerland			USA		Korea		Poland			
Material		SIR	SIR	SIR	SIR	SIR	SIR	SIR	SIR	SIR	Porc.	Glass
Creepage distance [mm]		370	585	570	410	546	645	830	780	305	876	930
Specific creepage distance [mm/kV]		**11.2**	**17.7**	**17.3**	**12.4**	**16.5**	**19.5**	**25.2**	**23.6**	**9.2**	**26.5**	**28,2**
Electric stress [kV/cm]		**0.51**	**0.33**	**0.33**	**0.46**	**0.35**	**0.30**	**0.23**	**0.24**	**0.62**	**0.22**	**0.21**
Arcing distance [mm]		310	320	330	190	250	310	390	340	180	510	525
Distance between fittings [mm]		290	290	290	170	240	275	360	270	140	-	-
Number of sheds	L	1	2	3	5	7	7	7	4	2	3	3
	S	N/A	N/A	N/A	N/A	N/A	N/A	6	3	N/A	N/A	N/A
Distance between sheds [mm]		N/A	100	70	35	35	40	30	35	40	N/A	N/A
Shed diameter [mm]	L	140	140	140	80	80	88	88	140	130	254	260
	S	N/A	N/A	N/A	N/A	N/A	N/A	44	9	N/A	N/A	N/A
Rod diameter [mm]		30	30	30	35	35	30	30	30	40	16	16

The recommended minimum specific creepage distances for heavily polluted site and low polluted site are 31 mm/kV and 16 mm/kV respectively [IEC 60815]. In Sri Lanka used specific creepage distance 26 mm/kV.

Table 2 - Detail of the test procedure

Insulator	#A	#B	#C	#D	#E	#F	#G	#H	#I
Field aged insulators									
Field investigation (Visual inspection, HC, LC)									
Marine environment	x	x	x	x	x	x	x	x	x
Clean environment	x	x	x	x	x	x	x	x	
Laboratory investigation (Resistance, LC FOV)									
Aged in marine conditions	x	x	x	x	x	x	x		x
Aged in clean conditions	x	x	x	x	x	x	x	x	
Laboratory aged insulators (LC)									
Salt fog test	x		x	x		x			x
Clean fog test on aged ones	x		x	x		x			x

4. Field Investigations

4.1 Test sites

Two test sites were selected for the study. One is a polluted site, located at Koggala whereas the other is a relatively clean site located at Peradeniya. The test voltage was selected as 33 kV. The selection of the sites are mainly decided by the general factors of site safety and security for insulators and measuring system, place with shelter, surrounding people for visual inspection of the insulator performance, and environmental conditions such as pollution and cleanness.

Coastal Site (KG site)

The polluted site is located Koggala in Galle district 125 km away from Colombo. This town is more popular for free trade zone of garment and other export-oriented industries. Two boundaries of this site are facing to a river/lake and this river is ending up at sea about 400m toward south of this site, through which salty wind is channeled to this site.

A gantry arrangement had served the demand in this area until 1998. CEB constructed and commissioned a 33/11kV primary substation adjacent to this gantry to cater the growing demand for electricity. The gantry was abandoned and was not removed completely when starting this project. This gantry arrangement was modified for the installation of test insulators.

According to CEB investigations, FOs have been reported during night time with shimmering light prior to the construction of new primary substation. Also severe flashovers have been recorded in the 11/33kV lines running along southern coastal belt. According to IEC 60815, this site can be categorized into "very heavy pollution" class. An air-conditioned control building was used as the indoor part of the test site.

Relatively Clean Site (PG site)

The clean condition site is located in the village called Irriyagama in Peradeniya; Kandy district 115 km away from Colombo. According to IEC 60815, this site can be classified into "light pollution" class.

Earlier 66/33kV-grid substation was located at Irriyagama and after 132kV and 220kV replaced the 66kV transmission system in Sri Lanka this was abandoned. Presently a gantry arrangement operates in 33kV voltage. In the same premises Irriyagama deport office is also situated. Some test insulators were hanged on the abandon steel structure gantry arrangement and were energized. One of the old broken security hut close to this steel gantry was modified to suit the indoor arrangements of the study.

4.2. Test Procedure

The insulators at KG site were installed vertically and energized in November 2001. The insulators were tested in November 2002 (before monsoon), in February 2003 (after monsoon) and in

February 2006 (after monsoon). The insulator surfaces were carefully observed. Hydrophobicities were evaluated.

In February 2006, the insulators (#A, #B, #C, #D, #E, #F, #G and #I) were brought to University of Peradeniya for laboratory investigations. The investigations consisted of a few steps. First, the insulator surfaces were carefully checked and the hydrophobicity was tested on upper sides, under sides and cores of each insulator. Then, time variation of the surface resistance was measured inside a clean fog chamber by means of a megohmmeter. During the resistance measurements the applied voltage was set at 1 kV in order to avoid formation of dry bands. The fog was produced by evaporating water at about 40-50°C at a rate of 0.1-0.2 l/hour. Later, ac leakage current patterns (waveforms) were also measured in the same chamber at 19 kV (phase to ground voltage of 33 kV system voltage). Finally, wet flashover voltage values were obtained. After finishing the tests, the hydrophobicity was again evaluated. The insulators were installed back in the KG site for future investigations.

The insulators in PG site were installed in November 2001. In April 2006, the insulators (#A, #B, #C, #D, #E, #F, #G and #H) were brought to University of Peradeniya for testing. Insulator surfaces were carefully checked and hydrophobicities were evaluated. Later the wet flashover tests were conducted.

4.3 Field Results

No flashovers were recorded on SIR insulators during the service, although the applied electric stress was relatively high. However, sometimes a visible discharge activity could be observed on the reference ceramic insulators during night time. This confirmed that the SIR insulators performed well in the field despite the applied stress was high.

However, when checking the other parameters, the following observations were made. At the first two occasions (November 2002 and February 2003), all insulators were hydrophobic. The maximum leakage current levels (during 12 hour period covering night time) varied between 2 - 5 mA and 1-2 mA, respectively. This confirms that washing of the contaminants took place during the monsoon. The average LC levels were relatively low (below 1 mA) and the waveforms were sinusoidal. During testing in the third occasion (February 2006) following observations were noted.

Visual Scrutiny

Corrosion

At the KG site, the metal connections between the structure and the insulator end fittings corroded due to the intensive salt contamination. The corrosion of fittings was common for all the insulators. This effect is shown in Fig. 1 for insulator #A. The corroded surfaces confirmed the severe pollution in KG site. However the salt pollution was not visible on insulator surfaces.

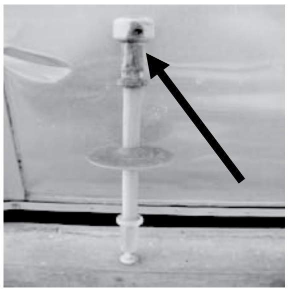

Figure 1 - Corrosion at metal fitting of insulator #A

Discolouration

In KG site, as regards insulator appearance after the exposure, the upper sides of the insulator sheds became darker, while the under sides maintained their original color. Fig. 2 illustrates such discolouration on insulator #A. The top shed was always the darkest. It seems reasonable to believe that the darkening was caused by diffusion of dirt into the near surface layer of the insulator housing or by its encapsulation by the low molecular fraction of rubber polymer. The insulators from PG site showed similar discoloration as in KG site. The upper sides became darker compared to under sides and the top shed was the darkest.

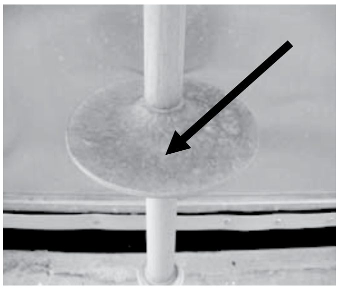

Figure 2 - Discoloration of upper side of insulator #A

Dirt/pollution

In KG site, on some of the insulators, the dirt concentrated to the areas exposed to the prevailing wind direction. It could be found on upper sides, under sides as well as on the cores of the insulator housings, as shown in Fig. 3 for insulator #F. No salt pollution could be visible. In PG site, a common in the area brownish dust collected on under sides of the sheds, predominantly on the bottom sheds. The area under the gantry was dusty due to ongoing excavation works.

Figure 3 - Collected dirt at under side of insulator #F

Surface changes

No significant surface changes (tracking, erosions, etc.) were found on the tested insulators. However, tree-like marks (only on the top shed) could be observed on insulator #I (hybrid insulator). This effect is shown in Fig. 4.

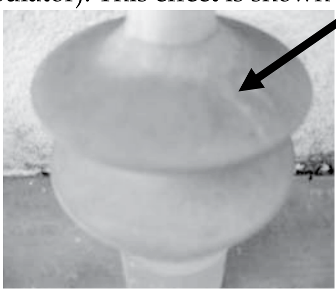

Figure 4 - Tree like discoloration on top shed of insulator #I

Biological Contamination

Biological growth (Algae and fungal) was found on insulators from PG site.

Algae Growth

Out of energized insulators in PG site, some of the insulators (Nos #B, #C, #F, #G, and #H) were severely contaminated by green algae. The contaminants were mainly appeared on upper sides of the sheds except the top one. In most cases, the contaminants almost covered the upper sides as a layer and within the contaminants some areas seemed to be clean. Fig. 5 illustrates this effect on insulator #C. The lengths of the contaminants along the creepage distances were measured and their approximate values to the total creepage distance were 12% for #B, 24% for #C, 25% for #G, 27% for #H and 30% for #F. These percentages were less effective because the under sides and the cores as well as first shed were not covered by such contaminants. Two insulators (#D and #E), identical in material (creepage distance 410 and 546 mm), showed very little contaminants (about 5% along the creapage). No algae contaminants were found on insulator #A due to the fact that the insulator housing was not partially sheded since the insulator has only one shed. It is evident that algae contamination on SIR insulators in clean environment is less effective. This argument is supported by the results obtained from our previous work [5] as well as by others [8].

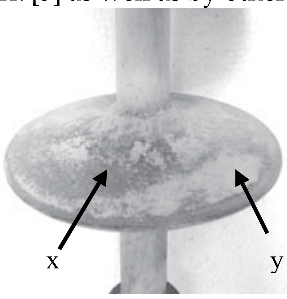

Figure 5 - Green algae on second shed of insulator #C , x- contaminated area, y- contaminated and clean

Fungal Growth

Fungal growth could be observed on the under side of the insulator. Fig. 6 shows such example. No fungal growths were found on other insulators.

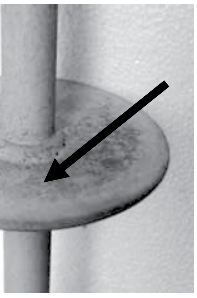

Figure 6 - Fungal growth on underside of the insulator #A

Hydrophobicity evaluation

The results of hydrophobicity classification of the insulators from KG and PG sites are provided in Tables 3 and 4 respectively. As the state of the hydrophobicity can vary for different insulator parts, the evaluation was performed separately for upper shed sides, under shed sides, top shed, core and areas exposed to wind. The reference porcelain insulators were wettable.

Table 3 - Hydrophobicity classification on insulators from KG site.

Insulator	Hydrophobicity				
	TO	UP	UN	CO	WD
#A	1	1	1	1	2,3
#B	1	1	5,6	1	2,3
#C	1,3	1	1,2	1,2	3,4
#D	1,2	1,2	5-7	1,2	3,4
#E	3,4	2,3	7	5-7	6,7
#F	1	1	2-4	1,2	1-4
#G	1	1	1-3	1	1,2
#I	1,2	1,2	1,2	1,2	1,2

Table 4 - Hydrophobicity classification on insulators from PG site.

Insulator	Hydrophobicity			
	UP	UN	CO	BG
#A	1,2, 5-7	6,7	1,2	6,7 (F)
#B	1,2,3	6,7	1,2	6,7 (A)
#C	1,2,3	2,3	1,2	5-7 (A)
#D	1,2,3	5-7	1,2	N/A
#E	1,2	3-7	1,2	N/A
#F	1,2,3	1,2,3	1,2	3, 6,7 (A)
#G	1,2	1-3	1,2	5-7 (A)
#H	1,2,3	1,2,3	1,2	5-7 (A)

(TO - upper side of the top shed, UP - upper sides of the sheds except the top one, UN - under sides of the sheds, CO - core, WD - areas exposed to predominant wind direction, BG – Biological growth)

Almost all SIR insulators in KG site preserved their hydrophobic properties well. However, the areas exposed to prevailing winds became partially wettable due to the fact that salt pollutants deposited in those areas. These areas were only a small part of the whole area of the insulators, however, they were spread between end fittings along one insulator side. This effect might cause a flow of high leakage current.

In PG site, the SIR insulators preserved their hydrophobic properties well. However, the areas covered by biological contamination were wettable.

In both sites the state of hydrophobicity on the upper sides of the insulator sheds was, by average, better than that on the under sides, since the interaction of UV radiation with elevated temperature of the sheds might have activated the hydrophobicity recovery process to become faster. At the same time, the shorter insulators (i.e. insulators #A and # D), despite of their exposure to higher electric stress, preserved hydrophobicity better than one of the longer insulators (#E). The effect is shown in Fig. 7. The other long insulators behaved similarly as the short ones. It therefore seems that it is not the creepage distance but the material composition that is the main factor influencing the ability to preserve and recover the hydrophobicity in the field service.

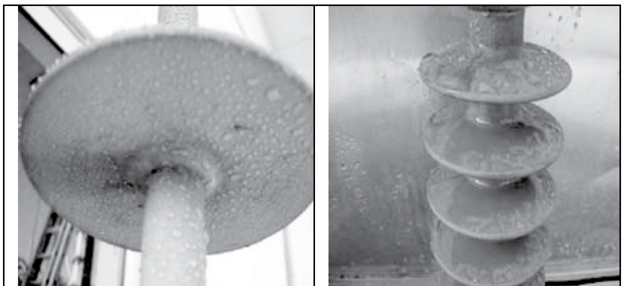

Fig. 7a Under side of insulator #A HC=1	Fig. 7b Upper side of insulator #E HC=6,7

Figure 7 - Comparison of hydrophobic and hydrophilic insulator surfaces.

4.4 Laboratory Results

In the laboratory, the insulators from KG and PG sites were tested.

4.4.1 Dc resistance

The time variation of the dc resistance of the tested insulators from KG site is shown in Fig. 8. The stable values of R and the ratios of dc resistance to the creapage distance (R/l) are indicated in the figure caption. In all cases the dc resistances were initially high and gradually became lower due to the fact that the insulators got wet inside the chamber with the time. Later these values stabilized. Among the insulators, insulator #C had the highest resistance of 400 MΩ, whereas insulator #I showed the lowest one of 60 MΩ. It could be observed that the insulators having a higher ratio of the shed diameter to the distance between sheds (#G-88/30, #F- 88/40, #D and #E- 80/35, #C –140/70 and #B – 140/100) showed higher dc resistance values per unit creepage distance. This higher ratio may therefore provide a better protection against deposition of contaminants on the insulator housing. However, insulator #I (shed diameter to distance between sheds - 130/40) was exceptional by having lower value of R/l, most probably due to the fact that the noticeable surface change (the tree-like marks) could influence the surface resistance.

When considering the values of dc resistance per unit creepage distance (R/l), some of the insulators (#B, #E, #F and #G) showed similar properties. Insulators #E and #G had almost similar R/l values but their hydrophobicities varied significantly. On the other hand insulators #C and #D showed similar hydrophobicity, but their R/l values were different. It should be noted that the correlation between hydrophobicity and dc resistance was not regular.

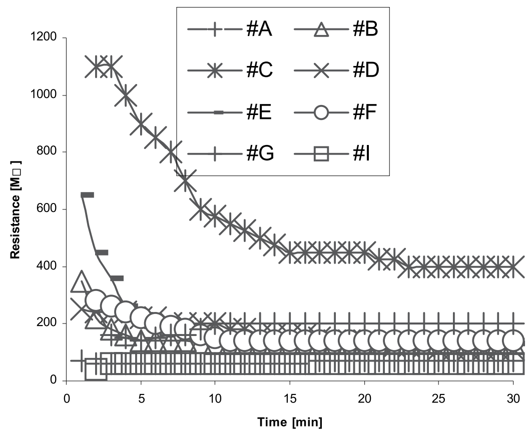

Figure 8. - Time variation of the dc resistance. R values in MΩ are 70 - #A, 130 - #B, 400 - #C, 110 - #D, 130 - #E, 140 - #F, 200 - #G and 60 -#I. The R/l values in MΩ/m are 189 - #A, 222 - #B, 701 - #C, 268 - #D, 238 - #E, 217 - #F, 240 - #G and 197 -#I

Ac leakage currents (LC)

The LC patterns measured under clean fog condition were sinusoidal in shape and low in magnitude for the insulators from both sites. The values varied from 4 μA to 10 μA for all the insulators. The less hydrophobic insulators got slightly higher values. It should be noticed that the insulators were earlier washed in the field by intensive rains appearing in Sri Lanka at the beginning of 2006.

The presence of low level of LCs and their sinusoidal shape confirmed that hydrophobic properties of the insulators surfaces were good. No signs of dry band activity were verified [9,10]. One should point here however the large difference between the levels of measured dc resistance (60-400 MΩ) and the ac resistance (1.9 - 4.75 GΩ), the latter resulting from the ac LCs of 4-10 μA at 19 kV, despite of using the same clean fog conditions.

Flashover voltage (FOV)
The FOV values measured at wet conditions on the insulators from KG and PG sites are shown in Table 5 and 6 respectively. The ratios of FOV to the creepage distance and FOV to the arcing distance are also indicated.

Table 5 - FOV values for insulators from KG site

Insulator	FOV [kV]	FOV/creepage distance [kV/cm]	FOV/arcing distance [kV/cm]
#A	122.4	3.30	3.94
#B	153.0	2.62	4.78
#C	163.2	2.86	4.95
#D	112.5	2.74	5.90
#E	112.5	2.05	4.49
#F	142.8	2.21	4.60
#G	178.5	2.15	4.58
#I	112.5	3.68	6.23

Table 6 - FOV values for insulators from PG site

Insulator	FOV [kV]	FOV/creepage distance [kV/cm]	FOV/arcing distance [kV/cm]
#A	128.5	3.47	4.14
#B	152.4	2.6	4.76
#C	114.2	2	3.46
#D	109.5	2.67	5.76
#E	104.7	1.92	4.18
#F	123.0	1.9	3.96
#G	152.4	1.83	3.9
#H	142.8	1.83	4.2

The recorded FOV values for all insulators were high and well above the recommended wet FOV level (i.e 70 kV) for ceramic insulators in Sri Lanka. The results proved also that the tested insulators remained in good condition after the field exposure. The ratios of FOV to the creepage distance and FOV to the arcing distance were for some types of the insulators similar and different for the others. The respective average values of the ratios were 2.7 kV/cm and 4.93 kV/cm, however, the maximum variation of the ratio of FOV to the creepage distance was 35% whereas it was 26% for the ratio of FOV to the arcing distance.

5. Laboratory Investigations

5.1 Salt Fog Test

The salt fog test was conducted at Chalmers University of Technology, Sweden from 12th August to 30th September 2002 on the set of insulators. Only five insulators could be kept inside the salt fog chamber because of the available space. They were #A, #C, #D, #F and #I. The insulators were energized at 19 kV (The phase to ground voltage of 33 kV system voltage).

The salt fog was initially sprayed about 8 hours continuously every day and the insulators were allowed to rest without salt fog during the rest of 16 hours. The test was usually started at about 8 a.m. The conductivity level in the salt fog was maintained at about 1000 μS/cm by adding required salt and deionized water.

5.2 Leakage Current

The LCs were recorded through a shunt as the potential difference. The selected shunt value was initially 1000 Ω and after seven days, due to the increase of leakage current, it was changed to 500 Ω. The LCs were stored in a personal computer through A/D converter of 16 channels. The maximum and minimum output voltages of A/D converter were +10V and -10V so that the LC maximum and minimum level limits were initially ±10 mA and then it was ±20 mA.

The stored LCs were recorded in two forms. Those were maximum and minimum LC data values and continuous LC data values. Maximum and minimum values of LC were recorded during each testing day for 30 second interval for 16 channels and the maximum and minimum values were saved in excel files. Continuous LC values were taken arbitrarily and were stored for a small time period i.e. 1 to 2 seconds. The sampling frequency for one channel was 2.5 kHz. Thus the number of data points for one cycle of one insulator was 50.

5.3 Results

During salt fog spray of the salt fog testing, the LC levels, analyzed from LC minimum and maximum data, were higher compared to that of resting. The high LC values were due to salt contamination on the surface. The time variation of LC levels increased with respect to test time confirming insulator ageing. When observing the LC patterns, analyzed from the continuous data, the general tendency was the wave forms initially capacitive and resistive then became non-linear and increase discharges appeared on the crest of the wave forms. The formation of dry band caused those change of shapes of the waveforms [9,10].

6. Discussion

Table 7 shows the summery of results obtained on insulators exposed to field ageing and laboratory ageing. The results were based on LCs, hydrophobicity and flashover voltage. In addition, a comparison of values with normalized creepage distance and arcing distance are also included. HC values give average hydrophoobicity at the end of the field investigation.

Table 7 - Summery of insulator performance

Insulator		#A	#B	#C	#D	#E	#F	#G	#H	#I
Description	Parameter									
Field ageing under marine conditions after 5 years										
Field	HC (Average)	1,2	1,2	1,2	1,2	2,3	1,2	1,2		1,2
Laboratory	R (Dc) [MΩ]	70	130	400	110	130	140	200		60
	LC (max) [μA]	10	6	4	6	4	6	4		6
	Wet FOV [kV]	122	153	163	113	113	143	179		113
Field ageing under clean conditions after 5 years										
Field	HC (Average)	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	
Laboratory	LC (max) [μA]	6	4	4	4	4	4	4		4
	Wet FOV [kV]	129	152	114	110	105	123	152	143	
Laboratory ageing under SF condition at 1000 hrs										
Salt spray	LC (max) [mA]	15.3		2.3	0.63		0.77			1.0
Resting	LC (max) [μA]	0.6		0.04	0.1		0.1			0.15
Effect of creapage distance (Normalized values)										
Creapage distance [mm]		370	585	570	410	546	645	830	780	305
Field ageing under marine conditions										
Laboratory R (Dc), [MΩ/m]		189	222	701	268	238	217	240		197
Laboratory ageing under SF condition										
Salt spray	LC (max) [mA*cm]	5.54		1.3	0.25		0.49			0.4
Resting	LC (max) [μA*cm]	0.2		0.02	0.04		0.06			0.03
Effect of arcing distance (Normalized values)										
Field ageing under marine conditions										
Arcing distance [mm]		310	320	330	190	250	310	390	340	180
Laboratory	Wet FOV [kV/cm]	3.9	4.8	5.0	5.9	4.5	4.6	4.6		6.2
Field ageing under clean conditions										
Laboratory	Wet FOV [kV/cm]	4.1	4.8	3.5	5.8	4.2	4.0	3.9	4.2	

Among different parameters, the FOV value provides the indication of occurrence of flashover event in the field. No flashovers were reported in the field. In addition, the wet FOV values were above the recommended level. The variation of LC is also important, because increase LC activity may lead to flashover event. In general, the LCs were within satisfactory levels except some cases. The hydrophobicity also preserved in most of time, which directly relates to pollution severity and wettability. Based on these information, it is clear that the SIR insulators performed well despite the short creapage distances.

In this extensive study, field investigation provides the realistic information about the performance of the insulators. The laboratory investigation on field-aged insulators, provides the information about their surfaces after the field exposure. Although the insulators had been exposed to marine pollution severely, due to natural washing by periodic monsoons, the insulators showed good performance by LC and HC measurements independent of the different creapage distances. On the contrary, during laboratory ageing under salt fog test, the insulators were severely aged so that increased LC activity could be observed on some of the short insulators (i.e. #A). It is clear that when SIR insulators are severely aged, the performance can differ depending on the creapage distance. However, by considering the fact that the insulators exposed to marine pollution in Sri Lanka get monsoon rains periodically, and the natural washing reduces the pollution level on insulator surfaces, and therefore it is less chance of ageing the insulators severely. Thus it is reasonable to state SIR can be stressed by reducing their creapage distances.

7. Summary and Conclusions

- SIR insulators exposed to marine and clean environments performed well independent of the creepage distance. No flashovers were recorded on them. The FOV values of the insulators under laboratory conditions were above the recommended values.
- The field aged insulators preserved the hydrophobicity most of the time. At the same time, the LCs were low and surface resistances were high under clean fog conditions.
- Green algae grow on partially sheded areas on SIR insulators exposed to clean environments. Some fungal growths were also reported. In general, hydrophobicity looses on such growths, but its effect on the insulator performance is limited.
- During laboratory ageing under salt fog test, the LC increases with the salt spray as well as ageing time. However, LC activity significantly reduces during resting period. Some short insulators showed increased LC levels when severely aged.

By considering all the above facts, it can be concluded that the SIR insulators can be stressed below the specific creepage distances recommended for different pollution classes.

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