Behaviour of porcelain insulator with polymer coatings under high voltage application

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The effect of the polymer coated layer thickness on porcelain insulators under the ac and dc flashover voltage is presented. A comparative study of the performance of three types of polymer coatings (epoxy, silicone rubber, polyester) is introduced in this paper. The paper elaborates that the use of polymer material coating on porcelain insulator provides water or contamination repellence and this has been reflected on flashover voltage. This work concludes that the polyester coating register the best performance under the most severe contaminated conditions.

هذا البحث يلقى الضوء على أختيار وأداء العازلات السيراميكية عند طلائها بالراتنجيات – تحت تطبيقات الجهد العالى فى الظروف البيئية المختلفة. وتم دراسة تأثير سمك طبقة الطلاء الراتنجى على جهد أنهيار العازلات سواء الجهد المستمر أو الجهد المتردد. تم عرض المقارنة بين أداء ثلاثة أنواع من الراتنجيات المختلفة (أيبوكسى - السيليكون المطاطى – البولي أستر) تحت تأثير الجهد العالى خلال هذه الدراسة. النتائج المستنتجة من التجارب العملية أظهرت أن العازلات السيراميكية المطلية بالراتنجيات قد أصبحت نازعة للمياه والتلوث – وبذلك حسنت من أداء أسطح العازلات – وبالتالى أثرت على قيمة جهد الأنهيار بالزيادة. ولخصت النتائج المعملية أنه تحت أسوء ظروف للتلوث البيئي – وجد أن الطلاء بالبولي أستر يعطى أفضل أداء كهربى لأسطح العازلات السيراميكية.

Key words: Porcelain insulator, Epoxy, Silicone rubber, Polyester, Flashover voltage

1. Introduction

High Voltage outdoor insulators used on transmission lines and substations are subjected to various forms of contamination. When contaminated insulators are wetted, water filming was produced on insulator surface. This water filming leads to develop surface leakage currents which may lead to reduce flashover voltage. Porcelain and glass have been used in outdoor insulators for a long time. These materials can take a substantial amount of arcing without serious surface degradation because they have high electric strength, and they can withstand the heat of dry band discharges. However, these materials are highly wettable due to their high surface energy [1].

On ungrounded wood structures, leakage currents can cause cross-arm and pole top burn-offs, while on steel structures, uncontrolled leakage currents can develop into flashover. In either event, disruptions of the power system can occur [2]. The evaluation of water-repellent coatings on existing insulators using polymer material is of prime interest to prolong the life of insulator. Polymer materials provide the initial water repellency which suppresses the development of leakage current. It provides an arc-resistant path with a long term ability to limit leakage current and prevent flashover [3]. Polymer coatings can be applied to porcelain insulators by dipping, brushing, or spraying. Polymer coating's ability to suppress leakage current activity and therefore flashover is its hydrophobicity. This property causes water to bead up rather than form a continuous film of moisture [4-6]. Although the contamination build-up on coated or uncoated porcelain insulators is the same, the water repellence of the coating surface. To use polymeric insulating materials as coatings in contaminated environments for long terms, the aging of the material becomes the main consideration. The main environmental conditions leading to dry-band arcing which must be considered are humidity, pollution and voltage stress [7-9]. The transmission line designer must start his design by assessing the environment and contamination along the proposed route.

This study was undertaken to provide the best type of polymeric material coatings of porcelain insulators to withstand the flashover for both ac (50Hz) and dc voltage. Three different types of polymer coating on porcelain insulator are used, epoxy, silicone rubber and polyester. Various environmental conditions have been introduced on the surface of coated porcelain insulator, such as dry condition, wet by water condition and contaminated with salted water condition.

2. Properties of coatings

Tests were made to study the performance of three different types of polymer coating on Pin type porcelain insulator. These types of polymer coatings are Epoxy (E), Silicone Rubber (SR) and Polyester (P).

Table 1 shows the coating adhesion (No. of layers, coating thickness, and coating weight) of different polymer types to surface of porcelain insulator. The coatings were applied by brushing on the surface of porcelain insulators. After brushing, the specimens were removed to normal atmosphere for curing. The average coating thickness is 0.5 ± 0.05 mm, measured by ZYGO optical interference microscope.

3. Set-up the test

3.1. HVAC (50 Hz) test

The high voltage arrangement for ac test consisted mainly of a Siemens single phase high voltage testing transformer (150 kV – 15 kVA). The output voltage of the transformer is smoothly controlled by a (0-250V) variac regulating the voltage applied to its primary winding. A water limiting resistor is connected between the high voltage electrode and high voltage transformer. The high voltage set up has been enclosed in an earthed cage.

Table 1
Coating adhesion

Type of polymer	No. of layer coating	Coating thickness (mm)	Coating weight (g.)
Epoxy (E)	1	0.50	1.01
	2	1.02	2.02
	3	1.53	4.27
	4	2.04	6.09
Silicone Rubber (SR)	1	0.51	1.11
	2	1.03	2.27
	3	1.54	4.90
	4	2.03	6.92
Polyester (P)	1	0.49	0.91
	2	1.01	1.92
	3	1.50	3.31
	4	2.02	4.81

3.2. HVDC test

The dc high voltage is obtained from a 60 kV, 1 mA, Brandenburg dc power supply. The high voltage set-up has been enclosed in an earthed cage. The high voltage supplies were calibrated first against sphere gap of 25 cm diameter.

3.3. Test procedure

Three samples (Pin type porcelain) are used in each test to check the reproducibility of the results. The voltage was gradually increased at an almost constant rate of 2 kV/sec until the breakdown occurs. The flashover voltage is defined as the maximum voltage that the insulating gap withstands just prior to its collapse to a very low voltage accompanied with a large arc current. The reported flashover voltage is the average of 10-15 tests and these readings were corrected to normal pressure and temperature which is commonly used.

4. Results and discussion

The ac (50 Hz) and dc flashover voltages have been measured for various polymer layer coatings on porcelain insulator under different testing conditions such as; dry, wet and wet with salt conditions.

Fig. 1-a, shows the ac (50 Hz) flashover voltage of different layers of three type of polymer coatings E, SR and P under dry condition.

It can be observed from this figure that, the flashover voltage of porcelain insulator without any type of polymer coating is 38 kV. This value records the lowest value of flashover voltage, compared with other values of porcelain coated with polymer. Fig. 1 presents the trend of increasing the number of polymer coating layers with flashover. The increase of the number of polymer coating layers, increases the flashover voltage values. This trend applies till a certain number of layers, above which the increase of the number of polymer coating layers, the lower the flashover voltage values. This can be attributed to the unglazed and non-homogeneity of repetitive coatings. Epoxy and Polyester follow the same trend, which records the highest values of flashover voltage at the third layer coating. The highest flashover voltage was 50 kV with Epoxy coating, and 45 kV with polyester coating. Silicone Rubber records the same trend as that recorded with Epoxy and Polyester but the highest flashover voltage of 45 kV was at the second coating layer. This can be attributed due to the surface roughness. The more polymer coated layers on the porcelain the more surface roughness conditions on the surface. The coated material surface adhesion is less above the second layer for Silicone Rubber, and less above the third layer for Epoxy and Polyester.

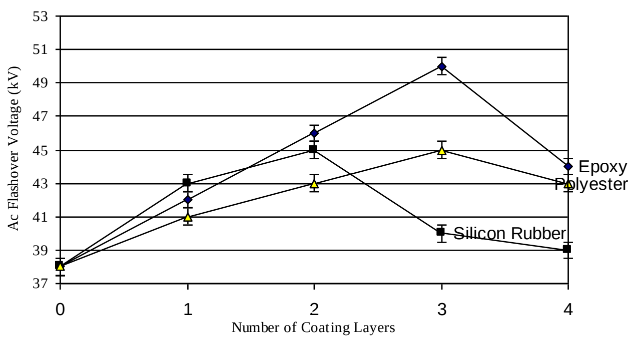

Fig. 1-a. The ac flashover voltage for different coating layers of three types of polymer under dry condition.

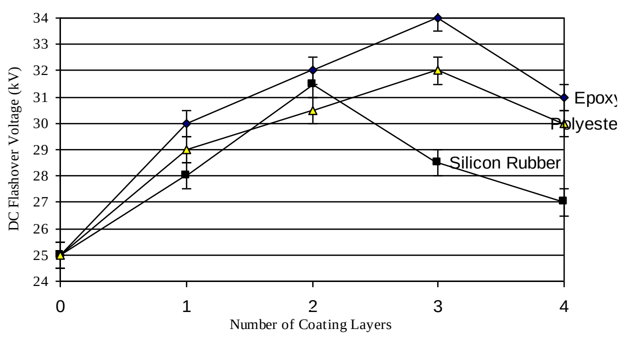

Fig. 1-b. The dc flashover voltage for different coating layers of three types of polymer under dry condition.

Surface roughness causes higher electric field at the surface, which in turn increases the surface leakage current and therefore a more rapid material degradation occurs. It can be also seen from fig. 1, that the fourth layer of E, P and SR records the lower flashover voltage for each type. Even the lower flashover voltage at the forth level was higher than that of bare porcelain.

The dc flashover voltage of different number of coating layers of E, P and SR under dry condition is shown in fig. 1-b. It can be seen from this figure that, the number of polymer coating layers against flashover voltage under dc high voltage follow the same trend as that obtained under ac flashover voltage. The dc flashover voltage records lower values than that obtained under ac flashover voltage. It can be observed from this figure that, the flashover voltage of porcelain insulator under dc high voltage without any type of polymer coating is 25 kV. The highest flashover voltage was 34 kV with Epoxy coating, and 32 kV with polyester coating.

Silicone Rubber records the same trend as that recorded with Epoxy and Polyester but the highest flashover voltage of 31.4 kV was at the second coating layer. This can be attributed also for the surface roughness (same reason applies for the case of ac application).

4.1. Flashover voltage performance of epoxy coating adhesion

The relationship between Epoxy coating layers versus ac (50 Hz) and dc flashover

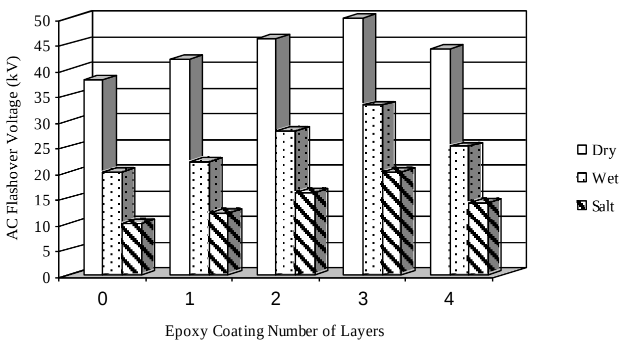

Fig. 2-a. Epoxy coating layers versus ac flashover voltage under dry, wet, and salt conditions.

voltages, under dry, wet and salty condition are shown in figs. 2-a and 2-b. From these figs., it can be seen that the flashover voltage decreases with the insulator contaminated surfaces. Porcelain insulator without Epoxy coating records 38, 20 and 10 ac kV at dry, wet and salt condition respectively. The values of ac flashover voltage increase with the thickness of E coating increases from first layer 0.5 mm to third layer 1.53 mm. At the third layer of E coating, the values of ac flashover voltages are 50, 33 and 20 KV under dry, wet and salt condition respectively. Above the thickness of 1.53 mm, the ac flashover voltage decreases under different contaminated conditions.

The dc flashover voltage versus Epoxy coating layers, under dry, wet and salt condition are shown in figs. 2-b. It can be seen from this figure that, the number of Epoxy coating layers against flashover voltage under dc high voltage follow the same trend as that obtained under ac flashover voltage. The dc flashover voltage records lower values than that obtained under ac flashover voltage. For porcelain without E coating, the flashover voltages are 25, 15 and 4 KV under dry, wet and salt condition respectively. The highest value of dc flashover voltage, under each contamination condition was recorded at the third layer of E coating, these values are 34, 27.5 and 8 KV under dry, wet and salt conditions respectively.

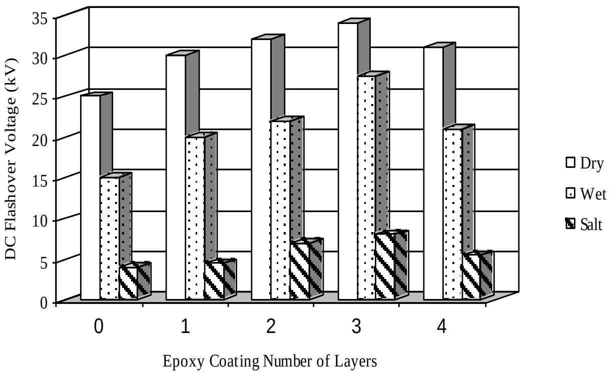

Fig. 2-b. Epoxy coating layers versus dc flashover voltage under dry, wet, and salt conditions.

4.2. Flashover voltage performance of silicone rubber coating adhesion

Figs. 3-a and 3-b illustrate the ac and dc flashover voltages for Silicone Rubber coating layers under dry, wet and salt conditions.

By increasing the number of SR coating layer the flashover voltage performance improved, till the second layer of SR coating, above which the increase of SR coating layer decreases the flashover voltage.

The highest values of ac flashover voltage were 45, 40 and 15 KV under dry, wet and salt conditions respectively, at the second layer. The ac flashover voltage is improved at the second layer coating of SR (1.03 mm thickness) than those obtained of bare porcelain without coating with 18% for dry, 100% for wet and 50% for salt conditions. While, the highest value of dc flashover

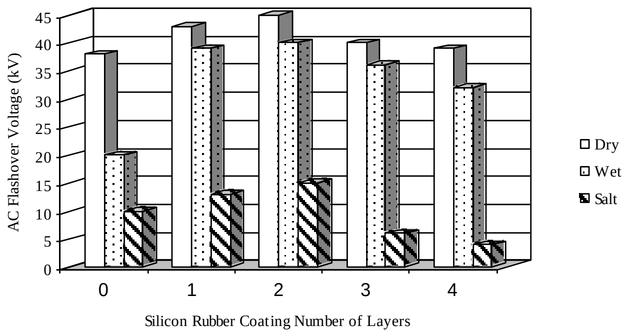

Fig. 3-a. Silicone Rubber coating layers versus ac flashover voltage under dry, wet, and salt conditions.

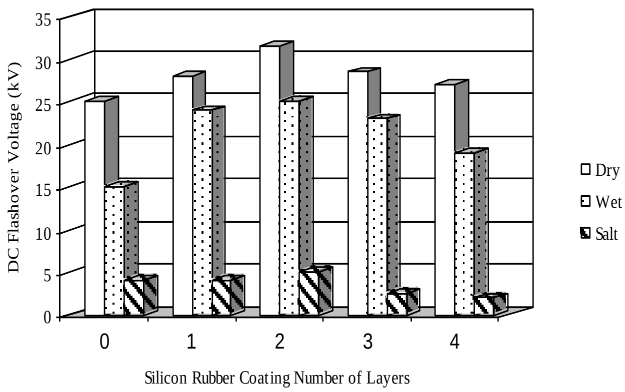

Fig. 3-b. Silicone Rubber coating layers versus dc flashover voltage under dry, wet, and salt conditions.

voltage were 31.5, 25 and 5 KV under dry, wet and salt conditions respectively, at the second layer of SR coating. Also, dc flashover voltage is improved at the second layer coating of SR than those obtained of bare porcelain without coating with 26% for dry, 66% for wet and 25% for salt conditions.

4.3. Flashover voltage performance of polyester coating adhesion

The ac and dc flashover voltages of polyester coating layer under dry, wet and salt conditions are shown in figs 4-a and 4-b. It can be seen from the two figures that, the third layer register the highest flashover voltage under the application of ac voltage in dry, wet, and salt conditions (45, 40, 26 kV, respectively).

The same trend has been introduced under the application of dc voltage in dry, wet, and salt conditions (32, 25, 16 kV, respectively).

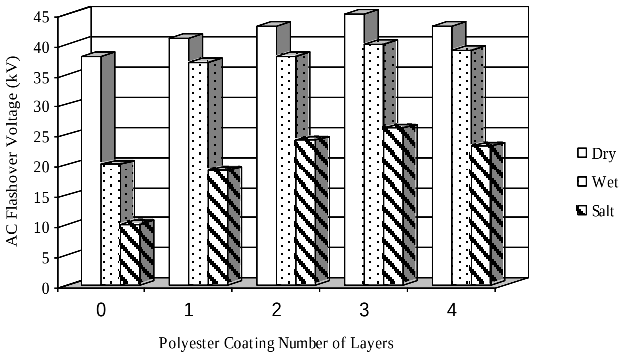

Fig. 4-a. Polyester coating layers versus ac flashover voltage under dry, wet, and salt conditions.

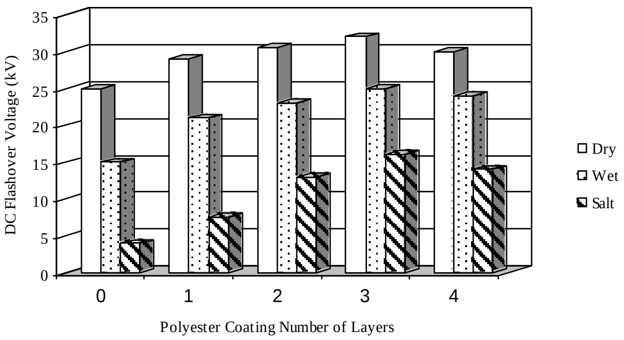

Fig. 4-b. Polyester coating layers versus dc flashover voltage under dry, wet, and salt conditions.

4.4. Effect of Polymer type on flashover voltage

A comparison has been made between the flashover voltage values of a porcelain insulator coated by three layers of different polymers, under dry, wet and salt conditions. The results were presented in fig. 5-a for ac (50 Hz) flashover voltage, and fig. 5-b for dc flashover voltage.

It can be noticed from these figures that, the values of flashover voltages (kV) for E are higher than that for P and SR under dry condition, for both ac and dc flashover voltages. But the values of flashover voltages at wet, and salty conditions are higher for P coatings than that of SR and E for both ac and dc voltages.

Generally, the obtained results under ac flashover voltage are higher than that obtained under dc flashover voltage. This can be attributed due to the more effective accumulation of contamination and surface charge on the coated insulator surface by electrostatic forces [9]. The great deposition of contamination results in a higher leakage current and therefore a more rapid material degradation with ac and dc application.

From the obtained results, it can be observed that the flashover voltage under ac and dc in dry condition, is higher than that of wet and salt conditions. This can be explained due to polymer hydrophobicity. Generally, it can be observed that, Epoxy coating is hydrophilic to the water with or without salt. This means that all values of flashover voltages decrease at wet or salt conditions. Where, polyester coating is more hydrophobic than silicone rubber coating. But, the observed reduction in the flashover voltage under salted condition than that of wet condition, may be explained due to hydrolysis of sodium chloride content in salted water. This results in the formation of sodium hydroxide and the evolution of hydrogen-chloride gas, which is further dissolved in water.

5. Conclusions

The conclusion of the presented experimental results can be summarized as follows:

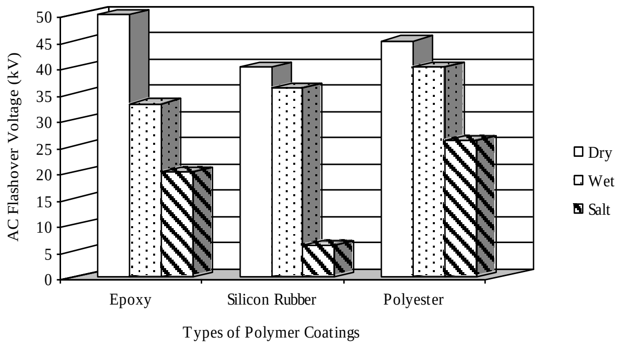

Fig. 5-a. Comparison between three different types of polymers, with three coating layers versus ac flashover voltage under dry, wet, and salt conditions.

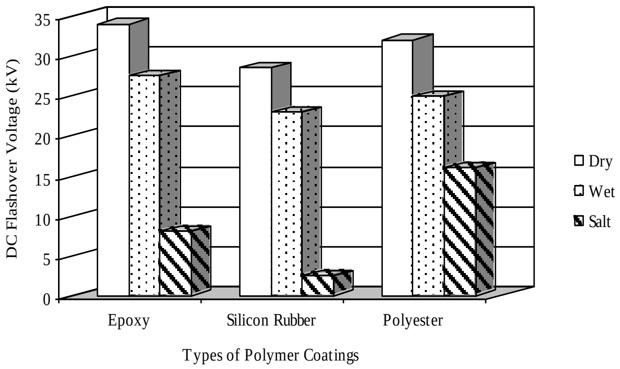

Fig. 5-b. Comparison between three different types of polymers, with three coating layers versus dc flashover voltage under dry, wet, and salt conditions.

1- The type of polymer layer coating has pronounced effects on the flashover voltages of porcelain coating.
2- The development of flashover voltage has been considerably increased by more brushing of polymer coating on porcelain insulator until certain thickness of layers. This has been attributed to the surface roughness.
3- Polyester coating is preferred than silicone rubber coating, for its capability of withstanding under various weather conditions.
4- Epoxy coating is hydrophilic material under contaminated and wet condition.

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Received September 22, 2005
Accepted May 30, 2006