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Effect Of Industrial Pollution On Different Types Of High Voltage Insulators

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Abstract

High voltage insulators is essential part of the high voltage electric power transmission line . This paper investigate the electrical performance of two types of insulator (porcelain and silicon rubber) used in service and subjected to pollution condition from Baiji Refinery and thermal power station of Baiji for more than(10) years .

The test data of flashover voltage measurements, surface resistance measurements and the insulators hydrophobicity are evaluated. The test result show that the silicon rubber insulator has a better performance compare with porcelain insulator.

Key Word: Porcelain insulator , silicon rubber insulator , flashover voltage, pollution insulator

الخلاصة

عوازل الضغط العالي عنصر أساسي من مكونات خطوط الضغط العالي . هذا البحث تناول الخصائص الكهربائية لنوعين من العوازل (البورسلين و مطاط السيلكون) مستخدمين في الخدمة ومعرضين إلى التلوث الصادر من مصفى بيجي و محطة بيجي الحرارية لأكثر من عشرة سنوات .

النتائج المختبرية لقياس فولتية الشرر ، ومقاومة السطح ومقاومة العازل للماء تم حسابها . النتائج المختبرية أظهرت أن عوازل مطاط السيلكون لها الخصائص الأفضل مقارنة مع عوازل البورسلين .

1. Introduction

The performance of insulators under polluted environment is one of the guiding factors in the insulation coordination of high voltage transmission lines. The flashover of polluted insulators can cause transmission line outage of long duration and over a large area. Flashover of polluted insulators is still a serious threat to the safe operation of a power transmission system. It is generally considered that pollution flashover is becoming ever more important in the design of high voltage transmission lines [1].

The flashover of polluted high voltage insulators constitutes one of the most important high voltage energy transmission problem. Due to rapid rise of transmission voltages and growth of pollution, this problem has drawn more attention in recent years [2]. The environment in which an insulator is installed can have a significant impact on the unit's performance. When insulators are situated in areas where they are exposed to polluted , their performance can deteriorate significantly. This is likely the single greatest challenge encountered in the design and operation of substation insulation. Although the problem of polluted of insulators has been recognized for over 50 years most studies have been carried out within the last three decades. polluted flashover has become the most important and of the limiting factor in the design of high-voltage outdoor insulation and hence became a subject of extensive studies.

Polluted flashover (PFO) requires both soluble salts and moisture. To a large extent differences in insulator behavior arise due to the variety of environments and complex wetting mechanisms. The various sources of pollution that affect power system insulation include[3]:

- Sea salt – salt from sea water is carried by winds up to 15–30 km inland or further.
- Industrial products which contain soluble salts.
- Road salts.
- Bird excrement.
- Desert sands.

2. Flashover Mechanism Of Polluted Insulators Under A.C. And D.C.

Insulators in service become covered with a layer of pollution. When the surface is dry the contaminants are non-conducting; however, when the insulator surface is wetted by light rain, fog, or mist, the pollution layer becomes conducting with the following sequence of events:

- conducting layer build-up,
- dry band formation,
- partial arcing,
- arc elongation,
- eventual arc spanning the whole insulator followed by flashover.

The pollution layer in general is not uniform. When conduction starts, the currents are in the order of several milliamps, resulting in heating of the electrolyte solution on the insulator surface.

The leakage current begins to dry the pollution layer and the resistivity of the layer rises in certain areas. This leads to dry band formation, usually in areas where the current density is highest. The dry band supports most of the applied voltage. The air gap flashes over, with the arc spanning the dry band gap which is in series with the wet portion of the insulator.

The arc may extinguish at current zero and the insulator may return to working conditions. Dry band formation and rewetting may continue for many hours. The current coinciding with the occurrence of dry band breakdown is in the order of 250 mA. The current at this stage is in surges, and the voltage is unaffected[4].

2.1 Model For Flashover Of Polluted Insulators

Let us assume a uniform pollution layer with resistance r kΩ/mm as shown in Fig. (1). When the arc is burning in series with the pollution layer, the voltage across the insulator with an arc partially bridging the insulator will be given by[5]:

$$V = V_{arc}(I, x) + I(L - x)r \qquad \text{............(1)}$$

where the function Varc(I, x) relates the arc voltage to the current I and the arc length x. In general, for a given resistance r the curve relating V to x/L has the form shown in Fig. (2).

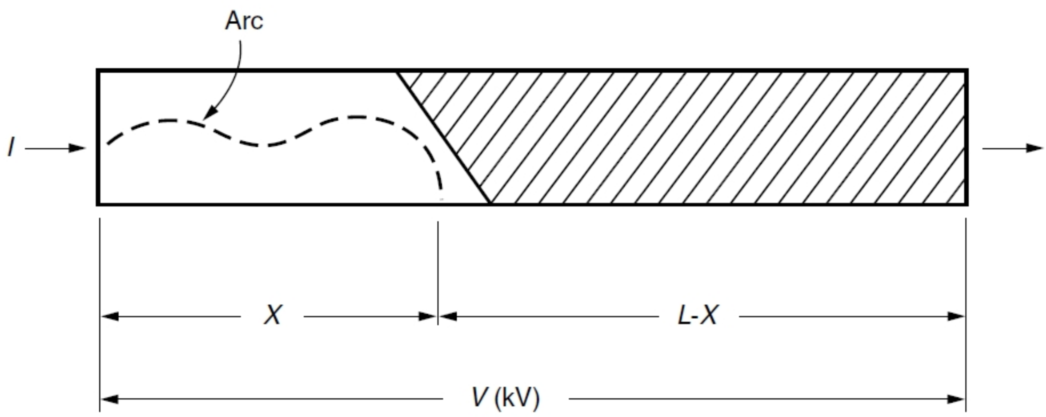


Figure (1) Model Of A Single Arc Developing On A Polluted Surface (Uniform Pollution Layer R, KΩ/Mm)

For an applied voltage Va, x/L may have values no greater than x/La. The curve has a maximum critical voltage Vc, and for voltages equal to or greater than Vc, x/L may have values up to unity.

When the applied voltage Va is less than Vc, x/L cannot increase to unity and flashover cannot occur. Numerous empirical relations have been proposed to solve eqn (1). For example, for voltage 33 kV and above:

$$V_c = 0.067 r^{\frac{1}{3}} L_a^{\frac{2}{3}} L_s^{\frac{1}{3}} \quad kV(r.m.s.) \qquad \text{...........(2)}$$

where La is the minimum arc length (mm) to the bridge insulator and Ls is the leakage path (mm) on the insulator surface[6].

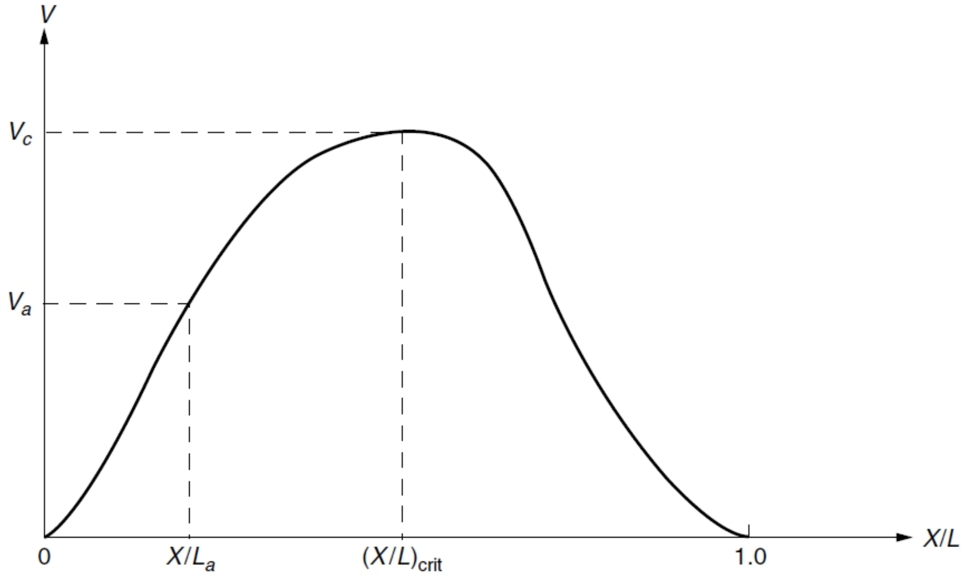


Figure (2) Voltage Versus X/L For An Arc In Series With A Pollution Layer Of A Fixed Resistance Per Unit Length

For a cap and pin type insulator string,

$$V_c = 0.67^{\frac{1}{3}} N r^{\frac{1}{3}} L_s^{\frac{2}{3}} \lambda^{-\frac{1}{3}} \quad kV(r.m.s.) \qquad \text{...............(3)}$$

where λ is a constant and N is the number of insulators in the string.

For a given insulator type

$L_s \propto L_A$

Or

$L_a = kL_s$ with k=constant

Therefore eqn (2) can be written as

$$V_c = 0.067 r^{\frac{1}{3}} k^{\frac{2}{3}} L_s \qquad \text{...............(4)}$$

3. Measurements and tests

Assessments of the performance of insulators is based on laboratory and field tests which include:

3.1 Measurement Of Insulator Dimensions:

In order to effectively assess the degree of contamination present on an insulator surface the dimensions of the insulator must be taken into account. The relevant dimensions include the leakage path Ls, and the surface gradient expressed in kV/Ls (Ls in mm). For a definition of Ls see Fig. (3) . The indentations X and Y are assumed filled with a conducting material.

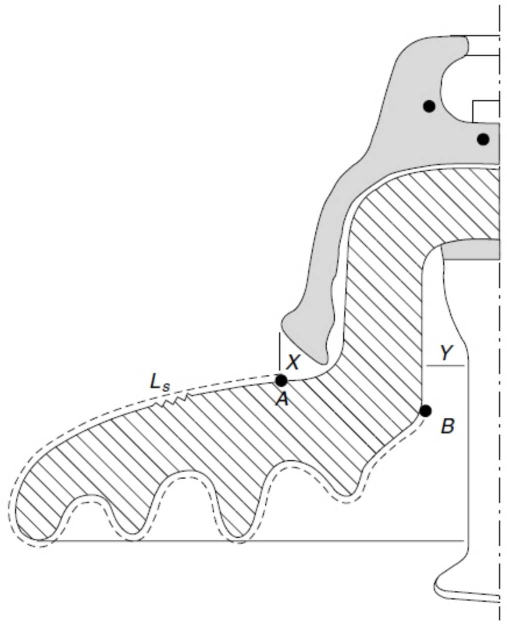


Figure (3) Evaluation Of Insulator Dimensions For A Typical Shape.Ls = Leakage Path Length.

The parameter relating resistance R of a polluted insulator in air to the surface resistivity σ is known as the form factor F, defined as[7]:

$$F = \frac{R}{\sigma} \qquad \text{.........(5)}$$

$$F = \int_0^{L_S} \frac{dL_S}{2\pi a} \qquad \text{..........(6)}$$

where a is the radius corresponding to the path element dLs. In the laboratory, the resistance R can be measured with a low-voltage bridge and the average resistivity σ is determined from eqns (5) and (6).

The average value of r is obtained from:

$$r = \frac{R}{L_S} \qquad \text{..........(7)}$$

Therefore σ can be related to the minimum flashover voltage. The insulator surface area is required to determine the Equivalent Salt Density Deposit (ESDD) in mg/cm2 (usually mean area based on maximum and minimum areas). The ESDD in (mg/cm2) is calculated using the following expression[8] :

$$ESDD = \frac{0.42\,(vol.in\ ml)}{Area\ in\ cm^2}\left(\sigma_{20^0C}\right)^{1.039} \qquad \text{...........(8)}$$

3.2 Measurement Of Flashover Voltage:

The insulator is subjected to 80% of the probable flashover voltage for 20 minutes after the relative humidity has reached 100%. If there is no flashover the voltage is raised in 10%, and each step is maintained for 5 minutes until flashover is obtained [9]. This process is repeated for different levels of ESDD. The flashover voltage reported is the average of three measurements for the same ESDD. The flashover voltage was produce by a transformer rated 40kVA/100kV.

3.3 Measurement Of Surface Resistance :

Surface resistance of the polluted insulators in fog or dews differs according to the kind of pollution whether the pollutions is dust from sand or ashes resulting from factories[10].

Surface resistances of the polluted insulators in the artificial fog chamber (porcelain and silicone rubber insulators) were measured by applying 50 Hz voltage periodically at 5 minutes interval. The applied voltage had the various values for both insulators due to the leakage distance for each insulator .

3.4 Hydrophobicity Classification (HC)

The surface hydrophobicity is one of the important parameters describing insulator performance. The term ‘hydrophobicity classifies the interaction between the housing material and water.

On a hydrophobic surface, water appears in droplet form, whereas a hydrophilic surface is easily wetted by a water layer.

The hydrophobicity is usually evaluated by using the measurements of the contact angle between water droplets and the surface [11].

4. Result and Discussion:

The main characteristics of porcelain insulators as well as silicone rubber (SR) long rod insulators which were used in this investigation are shown in fig (4).

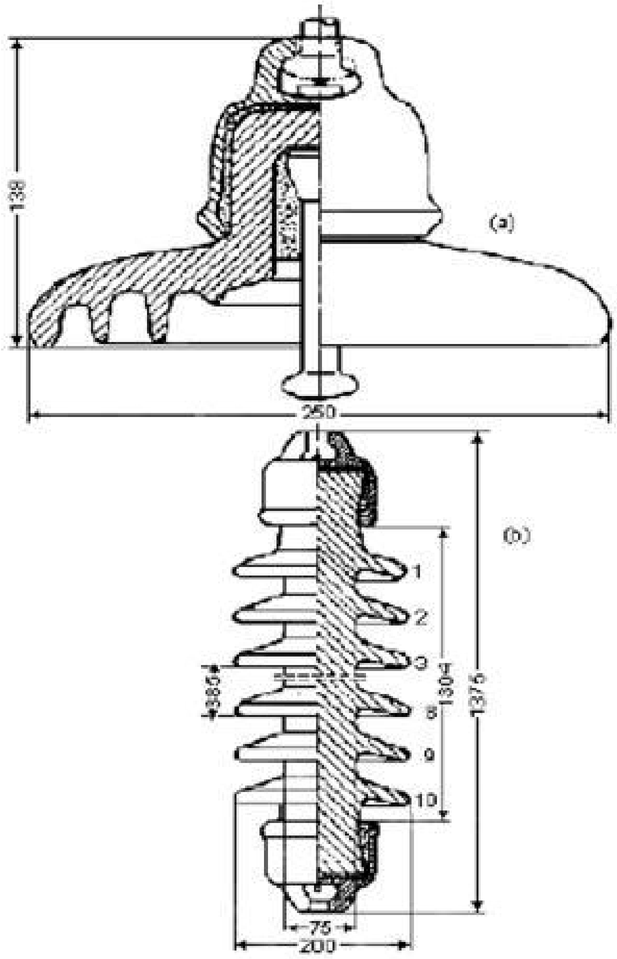
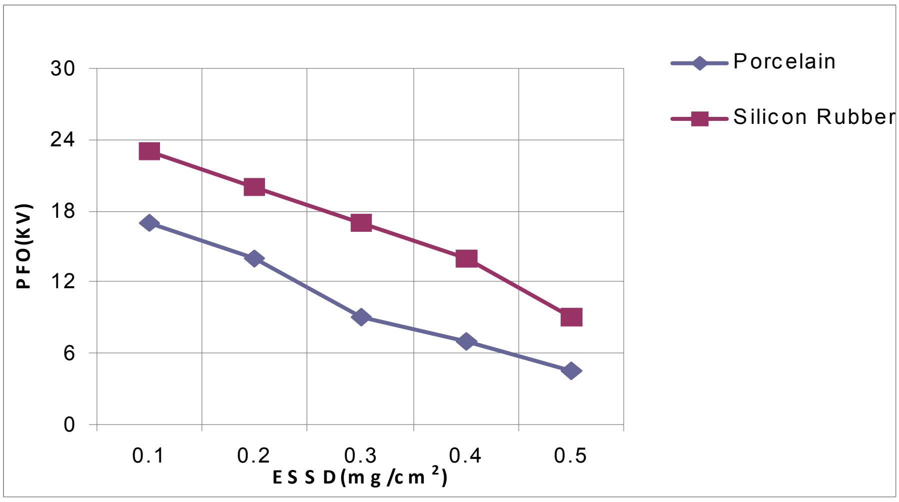


Figure (4) Profiles Of The Insulators Tested. (A) Porcelain (Cap-Pin) Type, Leakage Path 292 Mm. (B) Silicone Rubber (Long Rod Type), Leakage Path 465 Mm And Number Of Sheds 10.

4.1 Flashover Voltage Measurement:

The experiments were performed for a wide range of ESDD from 0.1 - 0.5 mg/cm2. Figure (5) shows the variation of ESDD with flashover voltage for all the different samples.

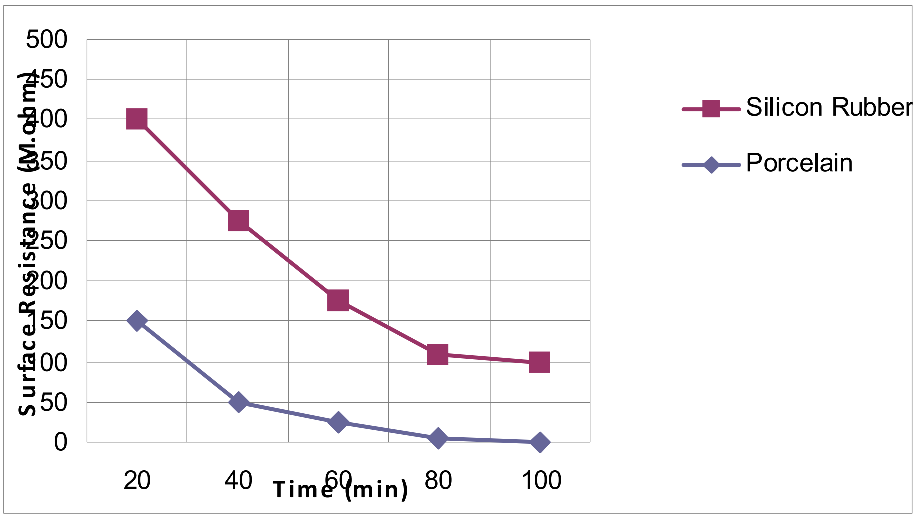
It can be seen that for the same level of ESDD the flashover voltage for ceramic insulator is about 14 % less compared to silicone rubber. These different in the flashover voltage are indicative of inherent difference in the materials ability to resist water filming.



Fig(5) Flashover Voltage To ESSD For Porcelain And Silicone Rubber

4.2 Surface Resistance Measurement:

Surface resistances of the polluted insulators in the artificial fog chamber (porcelain and silicone rubber insulators) were measured by applying 50 Hz voltage periodically at 5 minutes interval. The applied voltage had the same value for both insulators .The leakage distance for porcelain is (29cm)while for silicon rubber is (46 cm). Time variation of surface resistance is shown in Fig.(6). From the figure. it can be noticed that the surface resistance of the polluted insulators in clean fog decreased rapidly within (20 min.) after application of fog generation. This can be attributed to the high deposit solubility (95%) of the pollution layer. Moreover, it can be noticed that silicone rubber insulators have higher surface resistance compared with porcelain ones. The surface resistance of silicone rubber insulators decreases slowly with time and does not reach a minimum value even after 90 minutes of fog generation.



Fig(6) Surface Resistance To Time For The Insulator

4.3 Hydrophobicity Classification (HC)

Fig(7) shows that for silicon rubber the dynamics of the hydrophobic surface result in a much higher value of surface resistance than porcelain , Under pollution, ceramic insulators almost lost of their hydrophobicity (very small contact angle, 3 - 0).

In such condition, under high humidity of about 90 %, the trapped water was high and a leakage current of about 600μA was developed. However, silicone rubber insulators still maintained their contact angle even under pollutions. These results indicated that the silicon rubber is significantly increased hydrophobicity even in polluted condition.

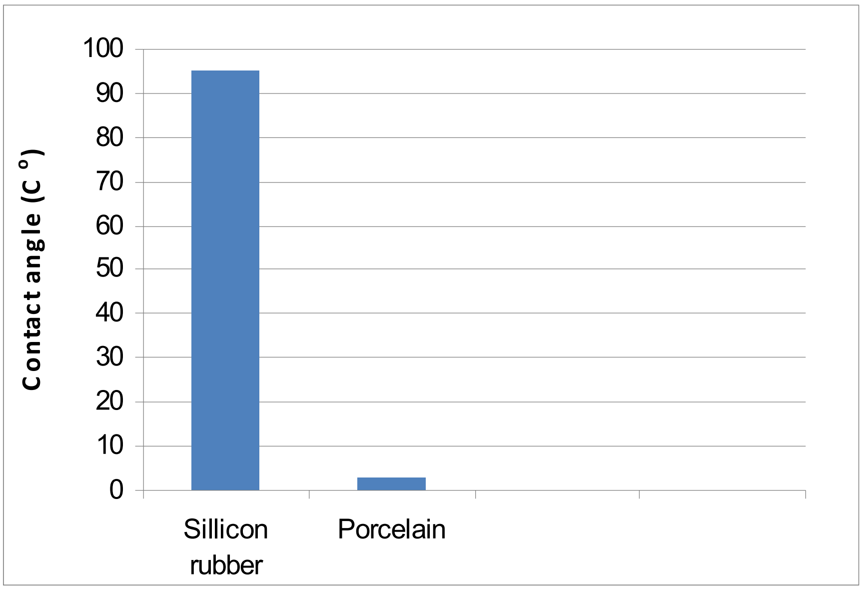


Fig (7) The Contact Angle For The Insulator (Silicone Rubber And Porcelain)

5. Conclusion :

The flashover voltage , surface resistance and hydrophobicity was experimentally investigated for both porcelain and silicon rubber insulators .

The result show that the silicon rubber is has better insulating ability under pollution condition compared with porcelain insulator .

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