DEVELOPMENT OF AC FLASHOVER VOLTAGE MODEL FOR HYDROPHOBIC CYCLOALIPHATIC EPOXY RESIN INSULATOR

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Abstract: In this paper, a mathematical model describes the relationship between the flashover voltage (FOV) and Equivalent Salt Deposit Density (ESDD) of epoxy resin insulator under high voltage AC using Dimensional Analysis method is presented. The Dimensional Analysis method has been applied in many applications to study experimental data. In this paper, five salinity levels are introduced to the insulators. The insulators under test are housed in a fog chamber specifically designed in accordance to IEC507 standard. Critical flashover voltages were recorded at each salinity level. The experimental results are presented together with the mathematical model developed using Dimensional Analysis method. As the use of epoxy resin insulator is becoming wide spread in the power distribution networks around the world, the results presented in this paper will be important in gaining better understanding of the performance of epoxy resin insulators under various polluted conditions.

1 INTRODUCTION

The common failure modes of polymer insulators include brittle fracture, surface tracking, surface contamination and mechanical failure [1-4]. Polymer insulators deteriorate over time due to constant exposure to rain, pollution, heat and ultraviolet radiation. With the severe weather pattern in Australia over recent years, the polymer insulators in our power systems are severely stressed. Since the 80s, large number of polymer insulators was installed in the transmission and distribution network. Therefore, the performance of the polymer insulators becomes the main concern for the power utilities. It was reported that failing polymer insulators have caused several recent power blackouts around the world [5-6].

Many studies of insulators performance under normal and various outdoor weather have be carried out in the past. Different flashover voltage models were presented. The dry band arc model based on arc voltage and resistance of the pollution layer was first presented in [7]-[8] and was known as the Obenaus's model for polluted insulators. Many variations of the model were later developed taking into consideration the non-linearity and non-uniform distribution of the pollution layer [9-12]. In other works, more sophisticated techniques such as Generic Algorithm [13] and Artificial Neural Network [14] are applied.

In this paper, a mathematical model describes the relationship between the flashover voltage (FOV) and Equivalent Salt Deposit Density (ESDD) of epoxy resin insulator under high voltage AC is presented. The relationship between critical flashover voltage and ESDD is formulated using Dimensional Analysis method. The Dimensional Analysis method has been applied in many applications to study experimental data. The basis of Dimensional Analysis method is the Buckingham π Theorem. The fundamental dimensions of length, mass, time and current are used in developing the model.

The polymer-based insulators under study are 22KV permanent hydrophobic cycloaliphatic (PH-CEP) epoxy resin insulators. The epoxy resin insulators possess excellent hydrophobic property due to the introduction of the nano-size silica filler. In this paper, five salinity levels vary between 0 Kg/m^3 and 170 Kg/m^3 are introduced to the insulators. The insulators under test are housed in a fog chamber specifically designed in accordance to IEC507 standard [15]. Critical flashover voltages were recorded at each salinity level. The experimental results will be presented together with the mathematical model developed using Dimensional Analysis method. As the use of epoxy resin insulator is becoming wide spread in the power distribution networks around the world, the results presented in this paper will be important in gaining better understanding of the performance of epoxy resin insulators under various polluted conditions.

2 THEORECTICAL MODEL BASED ON DIMENSIONAL ANALYSIS

Dimensional Analysis technique has been used widely in various applications of physical sciences and engineering [16]. The application of Dimensional analysis to flashover voltage value is based on the hypothesis that the solution is expressible by means of dimensionally homogenous equations in terms of specified variables.

We consider the mean affect for flashover voltage in the insulators as a combination factor of ESDD, insulator leakage distance (L), charging time (t_c) and static arc constant (N)

$$N = E * I^n \quad (1)$$

where: E = electric field intensity (V/m)
I = current (A)
n = arc constant

The four fundamental dimensions namely length (ℓ), Mass (M), time (T) and current (I) are used throughout the derivation of our model.

The relation between flashover voltage (V) can be expressed in (2)

$$V = f(\text{ESDD, L, N, } t_c) \quad (2)$$

The dimensional matrix of the respective variables can write as shown in the Table 1.

	V	ESDD	L	N	t_c
ℓ	2	-2	1	1	0
M	1	1	0	1	0
T	-3	0	0	-3	1
I	-1	0	0	n-1	0

Table 1: Dimensional Matrix

The rank for the above matrix is 4 (the number of rows). According to the Dimensional Analysis theory, there will be one dimensionless product in a complete set.

The dimensional matrix with respective variables can re-write as shown below:

		A	B	C	D
	V	ESDD	L	N	t_c
ℓ	2	-2	1	1	0
M	1	1	0	1	0
T	-3	0	0	-3	1
I	-1	0	0	n-1	0

Table 2: Dimensional Matrix Solution

where A,B,C,D are exponent of ESDD, ESDD, insulator leakage distance, charging time and static arc constant.

The homogeneous linear algebraic equations can be written :

$$\ell^2 = \ell^{-2A+B+C} \quad (3)$$

$$M = M^{C+A} \quad (4)$$

$$T^{-3} = T^{-3C+D} \quad (5)$$

$$I^{-1} = I^{(n-1)C} \quad (6)$$

The values of A, B, C, D in terms of V can be derived from equations (3) to (6).

$$A = \frac{n}{n-1} \quad (7)$$

$$B = \frac{4n-1}{n-1} \quad (8)$$

$$C = \frac{-1}{n-1} \quad (9)$$

$$D = \frac{-3n}{n-1} \quad (10)$$

It easy to write the dimensional equation as shown in (11) where

$$\Pi = V \cdot (ESDD)^{-\frac{n}{n-1}} \cdot \ell^{-\frac{4n-1}{n-1}} \cdot N^{\frac{1}{n-1}} \cdot t_c^{\frac{3n}{n-1}} \quad (11)$$

By applying the Buckingham's Π theorem, the above equation can be written as:

$$\alpha = V \cdot (ESDD)^{-\frac{n}{n-1}} \cdot \ell^{-\frac{4n-1}{n-1}} \cdot N^{\frac{1}{n-1}} \cdot t_c^{\frac{3n}{n-1}} \quad (12)$$

where $\alpha = \Pi$, a dimensional constant

It can be re-write the dimensional equation as shown:

$$V = \alpha (ESDD)^{\frac{n}{n-1}} \cdot \ell^{\frac{4n-1}{n-1}} \cdot N^{\frac{-1}{n-1}} \cdot t_c^{\frac{-3n}{n-1}} \quad (13)$$

To highlight the relationship between the flashover voltage and ESDD, we consider that ℓ, t_c and N will be constants. Therefore, the final expression describing the flashover voltage (FOV)can be written as:

$$V = \alpha (ESDD)^{\frac{n}{n-1}} \quad (14)$$

3 EXPERIMENTAL PROCEDURE

3.1 Experimental Set Up

In this paper, the 11KV pin-post type hydrophobic epoxy resin insulators were selected as the test specimens. This particular type of insulator is widely used in Australia and it has an impulse withstand voltage of 150kV and dry/wet power frequency withstand voltage of 90kV/73KV. The insulator is designed for outdoor installation in areas experiencing light to very heavy pollution. The creepage distance of the insulator is 600mm with a total height and weight of 280mm and 4kg respectively.

The pin-post insulator was energized with a 50kVA 100KV high voltage transformer via a bare aluminium conductor. The insulators are housed inside a fog chamber completed with fog nozzles, temperature and humidity sensors. The overall dimension of the chamber is 2m (width) x 4m (length) x 3.5m (height). The fog chamber is depicted in Fig.1. The vertical precipitation rate is 1.0 mm/min.

Figure 1: Fog Chamber at RMIT University

The artificial pollution is prepared by mixing *NaCl* with distilled water. In this paper, the test specimens are subjected to five different pollution levels as shown in Table 3. The solution are prepared inside small tank that can carry 40 litres of solution, the salt-solution pump and air compressor are switched on after the insulator is cleaned in accordance to procedure specified in the IEC 507 [15]. The insulator is energized after the compressed air has reached the normal operating pressure at the nozzles.

Starting with a solution with no salt, the insulator is subjected to the test voltage for 10 min until the insulator flash over. If the insulator does not flash over, the voltage is raised in steps of 10% of the test voltage every 5 min until flashover occurs.

Pollution Levels	Salinity (Kg/m^3)
No Salt	0.09555
Light	11.636
Medium	32.39
Heavy	87.88
Very Heavy	169.75

Table 3: Pollution levels in accordance to IEC standard

After flashover, the voltage is reapplied and raised as quickly as possible to 90% of the previously obtained flashover voltage and thereafter increased in steps of 5% of the initial flashover voltage every 5 min until flashover and this process repeated for six further times. The results obtained from the no-salt test are shown in Fig. 2. The flashover tests were repeated for four other pollution levels by increasing the salinity level of the solution. All of the flashover test results are plotted in Figure 3 and tabulated in Table 4.

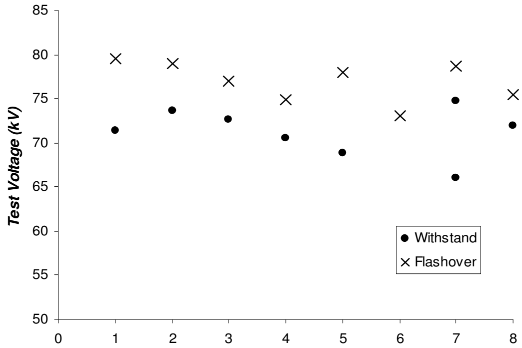

Figure 2: Results from eight consecutive flashovers test under no salt condition

Pollution Level	Flashover Voltage (kV)							
NO Salt	79.5	79	77	74.9	78	73	78.7	75.5
Light	69.5	69.4	70.1	69.4	68.6	67.1	67.4	68.3
Medium	67.6	66	67.9	64.9	66.5	65.9	66.4	64
Heavy	66.9	66.7	67.4	62.6	62.8	62.5	63.4	65.7
Very Heavy	65.4	62.1	61.4	62.6	62.4	63	62.9	62.6

Table 4: FOV versus pollution level

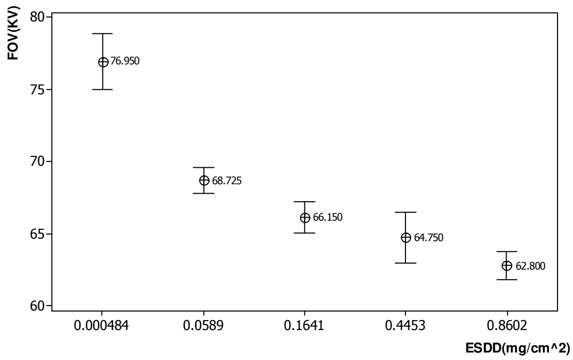

Figure 3: Flashover voltages (max, min and average) collected from experiments

4 RESULTS

In order to compare the experimental results with the theoretical results based on the flashover voltage model developed using Dimensional Analysis method, the mean of the flashover voltages measured at the five different pollution levels were calculated and tabulated in Table 5. Subsequently, the experimental results and flashover voltage calculated using equation (14) derived using Dimensional Analysis are plotted in Figure 4. The value of α and n are 63kV and 0.026 respectively.

Salinity (Kg/m^3)	ESDD (mg/cm^2)	Average FOV (kV)
0.09555	0.000484	76.95
11.636	0.0589	68.725
32.39	0.1614	66.15
87.88	0.4453	64.75
169.75	0.8602	62.8

Table 5: Average FOV derived from results in Table 4

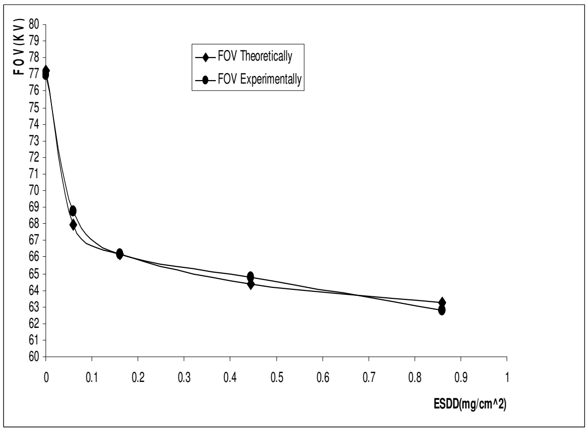

Figure 4: Theoretical and Experimental Results

5 CONCLUSION

The close match between the theoretical and experimental results clearly show that the theoretical model developed using the Dimensional Analysis method provides a good mathematical relationship between flashover voltage of epoxy resin insulator and ESDD levels.

The author will further explore the Dimensional Analysis method to study the effect of temperature and precipitation rate on flashover voltage of hydrophobic cycloaliphatic epoxy resin insulator in future works.

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