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Prediction And Analysis Of Flashover Voltage On A Polluted Insulator

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Abstract: *The flashover performance of polluted insulators in high-voltage transmission systems is critically influenced by multiple factors, including leakage current, surface conductivity, creepage distance, and contamination severity. This study investigates the interplay between these parameters through Mathematical model using the leakage current of the polluted insulator to predict the voltage flashover. The results demonstrate that Flashover voltage exhibits an inverse exponential relationship with leakage current, showing a reduction in flashover as leakage current increases. The study further compared the mathematical model results with the experimental results. The results shows over 90% correlation between the mathematical prediction model with experimental test results The mathematical model based approach can be utilized to predict the voltage flashover characteristics of sea salt polluted insulators.*

Keywords— porcelain Insulator; voltage flashover; prediction, pollution

1. INTRODUCTION

The electric power network is design to transmit electrical energy from generation to load center through the transmission and distribution network. The return on investment of the power system network is dependent on the reliability of the network. The reliability of the the network is largely dependent on the protective devices and the proper function of the insulators. The transmission and distribution networks transvers through coastal and industrial areas, and the outdoor insulators are exposed to sea salt, dust, emission from vehicles and industries [1]. The effectiveness of the outdoor insulator is based on two parameters such as humidity and environmental pollution [2]. Over time, salt particles accumulate on the surface of the outdoor insulators of a transmission or distribution lines infrastructure on the coastal areas and the salt layers do not cause any harm on the power system when they are dry. However, with light rain or high humidity, a conductive path is established for current to flow on the dirty surface of the outdoor insulator which can result to network failures due to the reduction of the dielectric properties of the insulator [3],[4]. The current flowing through the conductive part of the insulator to the ground point of the tower is called the leakage current. This leakage current creates a dry band by dissipating its energy causing flashover [5][6] and can lead to blackout, loss of sale and increased maintenance. It has been reported that several power interruptions in Egyptian power network as at 2010 was caused by polluted insulators [7]. According to [8], marine and saline pollution are prone in the coastal areas. The reliability and efficiency of electrical power transmission networks largely depend on the performance of outdoor insulators. These insulators serve as critical components in transmission lines, ensuring electrical isolation between conductors and supporting structures. However, their performance is significantly affected by environmental pollution, which can lead to flashover, a phenomenon that compromises the integrity of the power system and leads to outages, equipment damage, and financial losses. Flashover occur when a contaminated insulator surface becomes conductive due to the deposition of pollutants, such as dust, salt, industrial emissions, and organic materials. When moisture is present, these contaminants form a conductive layer, reducing the insulation strength and leading to partial discharges and eventual breakdown. Numerous studies have highlighted the adverse effects of pollution-induced flashover on power transmission systems and predicting the flashover effect using different predicting strategies [9][10][11], emphasizing the need for effective mitigation strategies. Various solutions, including periodic washing, application of hydrophobic coatings, and improved insulator designs, have been proposed to enhance insulation reliability. Advanced technologies such as artificial intelligence and predictive maintenance systems are also being explored to minimize the occurrence of flashover and optimize maintenance schedules. This study focuses on analyses, and investigating of a mathematical model for predicting the flashover voltage of a polluted porcelain insulator and results compared with an experimental investigation by [12]. The findings from this study will contribute to improving the sustainability and efficiency of power transmission networks, particularly in regions prone to high levels of environmental contamination

2. METHODOLOGY

The flashover voltage and several other key parameters were thoroughly evaluated using a combination of theoretical (Mathematical model) to analyze the performance of a porcelain insulator, specifically the XP-70 model. The detailed parameters for this insulator are presented in Table 1, which includes essential physical and electrical properties critical for the analysis. These properties play a pivotal role in understanding how the insulator behaves under various environmental conditions, particularly in the presence of contamination.

To investigate the effect of pollution on the insulator's flashover behavior, experimental data of the leakage current was incorporated into the mathematical model. The ESDD and leakage current values used in this study were sourced from [12] as outlined in Table 2.

Table 1: The parameter of the Porcelain insulator used for the analysis

Insulator Type (Model)	**Porcelain Xp -70**
Diameter/Creepage (mm)	255
Length (mm)	295
Height (mm)	146
Form Factor (F)	0.736

Table 2: Experimental test result used for the study [12]

ESDD (mg/cm^2	0.0790	0.1280	0.1859	0.2350	0.3540
Leakage current (I) mA	0.88	1.02	1.16	1.22	1.29
Flashover Voltage (kV)	57	52	47	41	37.5

Mathematical model-based prediction method applied the following steps to predict the flashover voltage of a polluted porcelain insulator. The applied steps are as follows [13];

Step 1: The first step in the analysis is to calculate the minimum surface resistivity of the insulator by using the applied voltage and the leakage current measured on the polluted surface. By determining this minimum surface resistivity, we can better understand the insulator's behavior under extreme contamination levels and predict the risk of flashover in such scenarios.

The minimum Surface resistivity of insulator string can be calculated using equation 1

$$R = \frac{U_d}{I_m} \quad (1)$$

R was minimum surface resistivity. Ud was applied voltage. Im was saturated, leakage current of insulators.

Step 2: After calculating the surface resistance, the surface resistivity could be calculated using equation 2 and it is regarded as the relationship between surface resistance and length of insulator string.

$$r = \frac{R}{F} \quad (2)$$

Where R is the surface resistance and F is the form factor or shape factor of the porcelain insulator.

Step 3: The equivalent cylinder and the insulator are assumed to have identical geometrical properties, including the same equivalent diameter, creepage distance, and form factor. These parameters are critical in determining the insulator's performance, as they influence the electric field distribution and the path of leakage currents along the surface. This uniformity in surface resistivity is an important assumption for modeling and predicting the insulator's performance under polluted conditions.

The equivalent diameter D of the polluted insulator could be calculated using equation 3.

$$P_{Deq} = \frac{L}{nF} \quad (3)$$

L is the creepage distance, n is the empirical arc constants

Step 4: The resistance of the residual contaminated layer can be calculated using equations 4

The resistance of the residual contaminated layer

$$R(x) = r.\frac{L-x}{P_{Deq}} \quad (4)$$

Where x is the arc length

Step 5: The pollution flashover voltage of the porcelain insulator can be determined using the Obenaus Model, which provides a mathematical framework for calculating the flashover voltage under polluted conditions. This model takes into account various factors such as the leakage current, creepage distance, arc length, a and surface resistivity. By applying the specific parameters related to the insulator and the contaminant characteristics, equations 3.5 or 3.6 can be used to predict the voltage at which flashover occurs. This approach helps in understanding the insulator's behavior when exposed to contamination

$$U_{pf} = A.I^{-n} + r.\frac{L-x}{P_{Deq}}.I \quad (5)$$

Where A and n are the empirical arc constants. The values used for A and n are 68 and 0.1655 respectively.

The arc length of the polluted insulator could be calculated using equations 6

$$x = \frac{L}{n+1} \quad (6)$$

The mathematical algorithm/ flowchart for predicting the possible flashover using the leakage current is depicted in Fig 1

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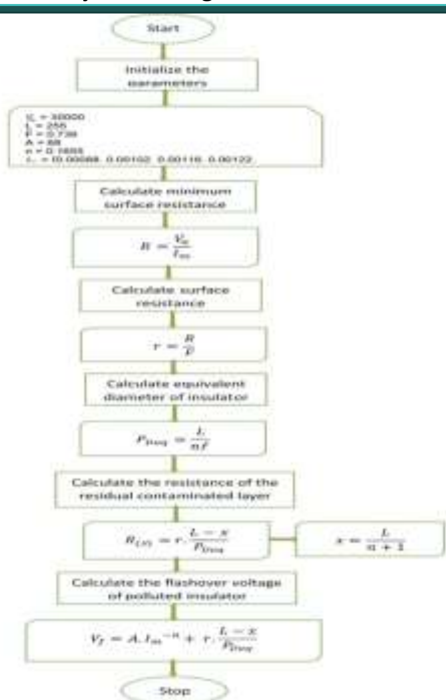

Figure 1: Flowchart of the Mathematical model approach for predicting polluted insulator flashover voltage

3. Result and Discussion

The flashover voltages were predicted with an applied voltage of 30kV.. During this evaluation, the values of flashover voltages were obtained using the leakage current obtained from the polluted insulator. It shows that the flashover voltage of the insulator reduces with increase in the leakage current. Fig 2 shows that with a leakage current of 0.88 mA, 1.02mA, 1.16mA, 1.22mA, and 1.29mA, a flashover voltage of 59.9kV, 52.2kV, 46.4kV, 44.3kV and 42.1 kV respectively was obtained with an applied voltage of 30kV. The results depict the influence of leakage current and ESDD on the flashover voltage. These findings highlight a strong inverse relationship between leakage current and flashover voltage. A higher leakage current leads to lower flashover voltages, while lower conductivity results in higher withstand levels. This trend re-enforce the critical role of leakage current in determining insulation performance under arcing conditions. Table 3 shows the comparison between the experimental evaluation of flashover voltage and theoretical based prediction technique. Table 3 depicts a good prediction which shows above 90% correlation.

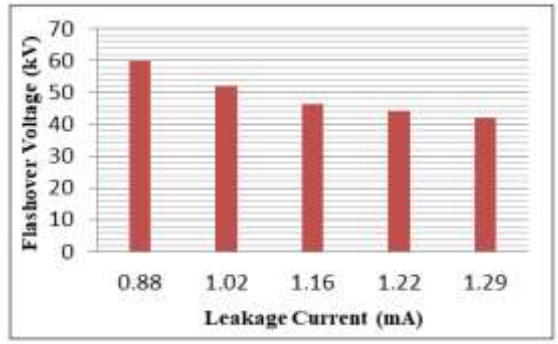

Figure 2: Mathematical model based Prediction of Flashover Voltage with an applied voltage of 30kV

Table 3: Comparison between Experimental test result and Theoretical based prediction

Experiment test (Banik, *et al.*, 2015)	Mathematical model based Prediction	Error
57	59.987	-2.987
52	52.28	-0.28
47	46.43	0.57
41	44.3	-3.3
37.5	42.12	-4.62

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4. Conclusion

The increasing frequency of insulator flashovers in high-voltage transmission lines, primarily due to environmental pollution, has become a major concern for the reliability and longevity of power systems, particularly in coastal areas and industrial zones. In these regions, pollutants such as sea salt, industrial particles and biological contaminants can accumulate on the surfaces of transmission line insulators, significantly affecting their performance. These pollutants degrade the insulating properties of the materials, leading to increased risks of flashover events, which can cause power outages, equipment damage, and costly repairs. As transmission networks grow and age, ensuring their resilience to environmental factors becomes increasingly crucial. The objective of this study is to analyze and predict the flashover voltage of insulators exposed to various types of pollution using mathematical model. This research seeks to understand the mechanisms by which contaminants influence insulator performance, providing predictive models that can guide maintenance practices, and operational decisions.

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