STUDIES ON POLLUTION PERFORMANCE OF OUTDOOR PORCELAIN DISC INSULATORS

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***ABSTRACT*- Flashover of a polluted insulator can occur when surface is wet due to fog, dew or rain. Despite extensive research, the basic mechanism of pollution flashover has not been understood fully. This is because of large number of parameters associated with the phenomenon and makes the study more complicated. Theoretical models that predetermine the flashover voltage of polluted insulators for wide range of field conditions are useful and reduce the number of laboratory experiments. Most of existing theoretical models are static in nature i.e. they does not taken into account the instantaneous changes in the arc parameters and are called dynamic models more appropriate than static models. In the present work two models based on dynamic concept has been selected to evaluate their capabilities in predicting flashover voltages of insulators. In the first phase of our work the flashover voltages were determined experimentally using solid layer method for selected porcelain disc type insulators for different pollution severities. In the second phase, the flashover voltages were calculated using Gorur and Dixit models MATLAB software. These models are applied to our selected insulator models and flashover voltages are calculated. The calculated flashover voltages are compared with each other and with experimental results to check the validation of the models.**

Keywords – DISC INSULATOR, GORUR MODEL, DIXIT MODEL

1. INTRODUCTION

Insulator and flashover

Insulators are the material which does not allow the flow of current through it. A perfect insulator is the one where there is no availability of free electron for conduction but practically such type of materials are not exist, thus a material with high dielectric strength is considered as good insulator. Insulators are usually employed in electrical isolation of two current carrying conductors and also to kept current flow intact. Insulators play the prominent role in high voltage transportation system. High voltage insulation provides isolation paths in transmission and distribution networks.

The insulation of overhead transmission line and substations is subjected to several basic types of abnormal conditions. They are (i) Over voltage due to lightning, (ii) Over voltage due to switching and (iii) Abnormal voltage gradient due to pollutants. High voltage insulators are exposed to various climates. Due to the rapid rise of transmission voltages and growth of pollution, the problem of flash over has drawn more attention in recent years. The efficiency of the system is based mainly on the continuity of the service, avoiding faults that suppose economic losses for companies and users. To maintain this continuity, one of the main problems that have been found is the effect produced by pollution on the insulators of electric lines. Contamination monitoring is required in order to determine the proper design and choice of insulation type and level.

In both AC and DC transmission systems, the pollution flashover cause line interruptions and the fault will be repeated many times on closing the lines. As the level of transmission voltage is increased, the design of external insulation under polluted condition becomes the main criterion for design, since switching over voltage level can be properly controlled with good protective devices. Thus performance of the insulators under polluted condition is to be carefully looked into for EHV/UHV systems.

2. EXPERIMENTAL SET-UP

A schematic of the experimental test set- up used in the present work is shown in fig.1. The test arrangement consists of a plastic (synthetic) tent of dimension 2.75m×2.75m×2.75m, which is supported by a metallic frame. From the center of the tent provision was made for the arrangement of the suspension string consists of three disc insulators of which top two insulators are dummy. The bottom of the insulators was connected to conductor clamp. The high voltage lead consisting of rubber cable was taken through FRP tube. The steam was generated by boiling the water in a boiler. The power was supplied from a 60kV, 60kVA transformer with a primary voltage of 230/415V and a rated continuous current of 1A.

A. Experimental setup to determine the flashover voltage under different polluted conditions

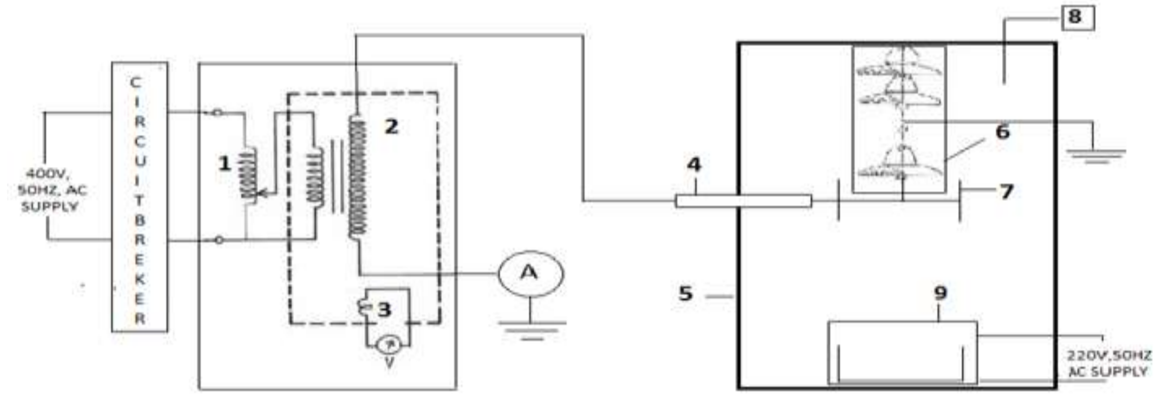

Figure 1: Experimental setup to determine the flashover voltage under different polluted conditions 1. Auto transformer 2. High voltage winding 3.Measuring winding 4 High voltage bushing 5.Pollution tent (2.75m×2.75m×2.75m) 6. Test insulator 7. Corona rings 8. Humidity sensor 9. Steam generator

2.1 Theoretical Measurement of Pollution Resistance

In this work, the pollution resistance is measured using the IEC60507 recommended form factor concept. According to the IEC standard, the pollution resistance (R_{pol}) is given by R_{pol} =FF/Ks. Where FF is the form factor of the insulator and Ks is the layer conductivity in µS. The form factor is determined from the insulator dimensions. For graphical estimation of the form factor, the reciprocal value of the insulator circumference is plotted versus the partial creepage distance (l) counted from theend of the insulator upto the point reckoned. The form factor is given by the area under the curve and calculated according to the formula.

$$FF = \int_{L_{arc}}^{L} \frac{dl}{\rho(l)} = \int_{L_{arc}}^{L} \frac{dl}{2\Pi r}$$

Where L is the leakage length of the insulator, dl is the incremental leakage length and r is the radius at distance dl.
To calculate the FF the profile of the insulator is taken using a lead wire. The wire is ribbed along the surface of insulator starting from the pin to the cap. The profile is traced on to the graph as shown in fig.1 The incremental distances dl equal to 2mm length are marked along the length of the profile and then the radial distances are measured from the axis of the insulator and are tabulated. Then the form factor is calculated by using a program developed on MATLAB. The layer conductivity Ks is calculated for the given pollution severity expressed in mg/cm^2 using the equation

$$K_s=90.13*(ESDD)^{0.92} \text{ in } \mu S$$

Three Porcelain disc insulators were selected for experimentation. They are named as A1, A2 and A3. Insulators A1 (90kN) and A2 (160kN) were standard porcelain disc insulators and A3 was Antifog type.

2.2 Artificial pollution of the insulators.

Artificial pollution was employed for the proposed work. In this method, the pollution layer is deposited on the insulator by dipping the insulator in water-based pollutant slurry and then drying it. And that insulator looks as shown in the fig.1 (a). This method consists of five steps. (i) Cleaning (ii) Drying (iii) Polluting (iv) Washing and (v) ESDD measurement.
The pollutant slurry is prepared by dissolving a known quantity of salt (NaCl, commercial purity) in a known volume of deionized water whose conductivity is less than 0.05 µS. To this solution 40 g/l of Kaolin is also added and mixed thoroughly to get the pollutant slurry.

2.3 Experimental Procedure

The test sample (insulator) was washed and cleaned thoroughly with clean water and dried. The test sample was dipped in the prepared contaminating suspension for about 30 sec and was artificially dried using a hand drier. Slurry suspension was sprayed over the test sample to attain the uniformity of contamination. This test sample with the pollution layer was then mounted in the experimental chamber. The steam-fog was allowed for a period of 15 minutes, after which the required humidity (90% - 95%) was reached. Now, the high voltage is applied through a high voltage transformer at a very low level and increased gradually till the flashover occurred. The flashover voltage during the arc initiation and at the end of flashover process was recorded. The leakage current was also noted down. Then immediately the test sample was taken out of the steam chamber and is washed with a known volume of de-mineralized water whose conductivity (σ_1) is initially measured. After washing the test sample cleanly with limited volume of de-mineralized water, the suspension was stirred thoroughly for about 2min and conductivity of the suspension (σ_2) and temperature (t_2) were measured using conductivity meter. Hence ESDD is calculated using the IEC 507 recommended procedure shown below.
ESDD is measured by washing the contaminants on the surface of the insulators, using deionized water of Volume V without losing any minute quantity and then measuring the conductivity of this water. The conductivity of the solution is then calculated using the formula

$$\sigma_{20} = (\sigma_1 - \sigma_2)[1 - b(t_2 - 20)]$$

Where, t_2 is the solution temperature in °C
σ_2 is the volume conductivity at a temperature of t_2 °C (S/m)

σ_1 is the volume conductivity at a temperature of 20 °C (S/m)
b is the factor depending on temperature t_2□as given by the equation
b □□0.0353 □□0.00080θ □□8.629x10^{-06} t_2□^{2}
The salinity Sa (kg/m3) of the suspension is then calculated, when σ_{20} is within the range 0.004-0.4 S/m, by the use of the following equation Sa= (5.7*σ_{20}) 1.03 kg/m3
The Equivalent Salt Deposit Density (ESDD) in mg/cm2 is now obtained from the equation:

$$\text{ESDD} = \frac{S_a V}{A} \quad \text{mg/cm2}$$

Where, V is the volume of the suspension (cm3) and A is the area of the cleaned surface (cm2).
The experiment was repeated atleast three times for the same pollution severity and same insulator to verify the repeatability of the ESDD value and flashover voltage. The same procedure was repeated, for different values of ESDD of chosen insulators A1 (90kN standard type), A2 (160kN standard type) and A3 (120kN standard antifog).
This method is known to be good for measuring ESDD for porcelain and glass insulators, as these are completely wettable and hence adopted here.

3. ANALYSIS OF ANALYTICAL MODELS

The physical dimensions of the insulators are given in Table 1

Name of Insulator	Insulator Type	Height in cm	Diameter in cm	Creepage length in cm	Surface area in sq. cm	Form factor (FF)
A1 (90kN)	Standard Porcelain disc	16.5	25.12	31	1624.5	0.5804
A2 (160kN)	Standard Porcelain disc	19.9	28.8	38.4	2333.1	0.6928
A3 (120kN)	Standard antifog disc	20.6	30.5	48.6	3217.8	0.8009

3.1 Model of R.S.Gorur and R.Sundararajan

In the analysis of this model, a dynamic model that computes the flashover voltages of polluted insulators energized with dc voltage is presented. The salient feature of this model is that it takes into account the configuration of the insulator profile at every instant, which plays an important role in the flashover process of the dc polluted insulators.
It has been observed that the flashover voltage depends upon the polarity of voltage, type and nature of the polluted, practical size, non-uniform wetting, surface conductivity, washing, wind, length, orientation, diameter, and profile of the insulator etc. In laboratory experiments, additional factors, such as the rate of voltage applications, power supply characteristics, method of fog generation and the application of contaminant, dimensions of the laboratory etc., will affect the results. The polluted insulator along with its dry band arc, shown in above fig.is modeled as a discharge in series with a high resistance as shown in fig, based on the concept of Obenaus, who was the first to initiate a theoretical study of flashover of polluted insulators (Extinction Theory). The discharge represents the dry band arc and the resistance, the pollution layer of the unbridged portion. Obenaus outlined the steps for the flashover voltage, establishing the importance of surface resistivity and dry band formation. This was completed by Neumark, who assumed a uniform pollution resistance per unit length for the pollution layer, which was followed in present model. However, the effect of non-uniform pollution distribution on the flashover voltage has been investigated in this model.

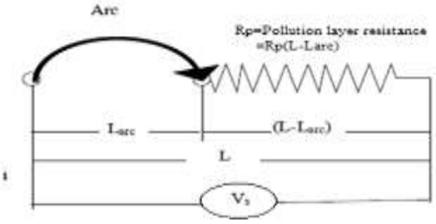

Fig.2 Electrical Equivalent Circuit of pollution flashover phenomenon

3.2 Dixit model

The author developed a mathematical model has been developed to calculate flashover voltage of polluted ceramic insulators. This includes the geometrical parameters of the insulators, pollution severity and ambient conditions.

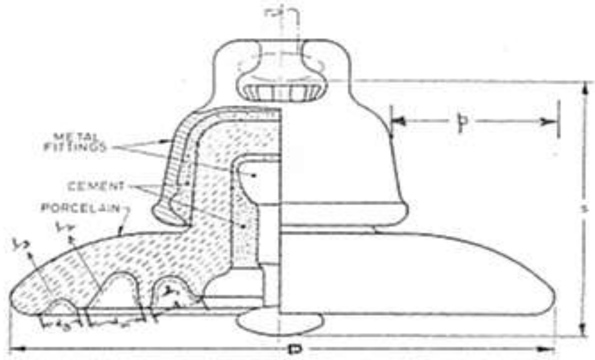

Fig 3 Cross-section of a standard suspension insulator

In this model, all the geometrical parameters ie; the ratio of creepage distance to clearance (l/d) undesirable of the insulator is considered and discussed in detail. Where 'd' is the straight or arc distance measured between two corresponding points situated on successive ribs and 'l' is the creepage path measured between the above two points along the surface as shown in the fig 3.The ratio l/d as a prominent role on the critical leakage current. The profiles of the rest of ribs/sheds will also influence on the voltage. There the author defined a new factor known as modified profile factor which includes the profile of the rest of the sheds of the insulator and is defined as

$$K_{mpf} = \frac{L_B + L_T}{L^1{}_p}$$

Where, L_T=length of the top surface measured from the edge of the top to the tip of the last rib counted from the pin.
L_B=the air distance/ the shortest distance from the tip of the last rib to the tip of the first rib measured from the pin.
$L^1{}_p$=protected creepage distance from the tip of the last rib to the tip of the first rib.
The flashover voltages given by this model is

$$V_{F0} = 68\,[\{K_{mpf}\left(\frac{l}{d}\right)_{min} e^{-0.03K_s}\}\,K_s\,(L_{arc})_c^2\, p^{3/2}h^{-1/2}\,]^{-0.65}\,(L_{arc})_c + [\{K_{mpf}\left(\frac{l}{d}\right)_{min} e^{-0.03K_s}\}\,K_s\,(L_{arc})_c^2\, p^{3/2}h^{-1/2}\,]\,R_p\,(L-(L_{arc})_c)$$

For the given geometry of an insulator K_{mpf} and $\left(\frac{l}{d}\right)_{min}$ are constant and both are dependent on geometry of the insulator hence the author named the product as geometrical factor $K_G=K_{mpf}\left(\frac{l}{d}\right)_{min}$. With this new factor flashover is given by

$$V_{F0} = 68\,[K_G\; e^{-0.03K_s}\,K_s\,(L_{arc})_c^2\, p^{3/2}h^{-1/2}\,]^{-0.65}\,(L_{arc})_c + [K_G\; e^{-0.03K_s}\;K_s\,(L_{arc})_c^2\, p^{3/2}h^{-1/2}\,]\,R_p\,(L-(L_{arc})_c)$$

In the present study three standard disc insulators (Type A1, A2 & A3) were considered. In this model, the insulator has been considered as a two-dimensional (2D) surface. However, the pollution resistance in series with the arc has been obtained after calculating the Form Factor (FF) for a given pollution severity.

4. RESULTS AND DISCUSSION

The voltage was gradually applied till the flashover occurred for the give pollution severity. The experiment was repeated atleast three times for the same pollution severity and same insulator to verify the repeatability of the results. The same procedure was adopted for the selected 3 insulator types and for different pollution severities. The results obtained were tabulated in table 2

Table 2: experimental flashover voltages for type A1, A2, A3 insulators.

SL.no	ESDD mg/cm^2	K_s (μs)	Experimental results		
			A1	**A2**	**A3**
1	0.07	7			21
2	0.08	8			17.5
3	0.09	9	11.5		18
4	0.1	10	16	17	22
5	0.11	11	14	15	20.5
6	0.13	13	12	16	
7	0.14	14			20
8	0.16	16		16	17
9	0.17	17	10	18	17
10	0.18	18	12	16	18
11	0.19	19	10.5		

12	0.2	20	10	18	
13	0.21	21		18	16
14	0.22	22		17	14
15	0.23	23			16.5
16	0.24	24		16	
17	0.25	25	12		
18	0.26	26	14	16	
19	0.27	27	12	16	

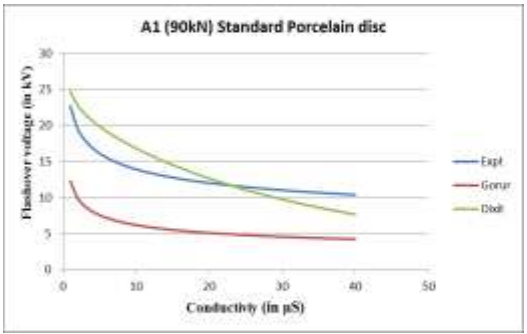

Fig.4 Comparison of flashover voltages of experimental, Gorur and Dixit model for A2

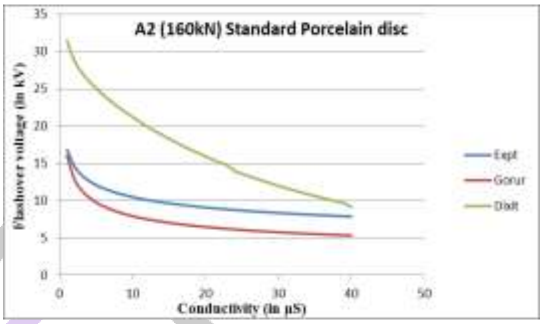

Fig. 5 Comparison of flashover voltages of experimental, Gorur and Dixit model for insulator insulator A1

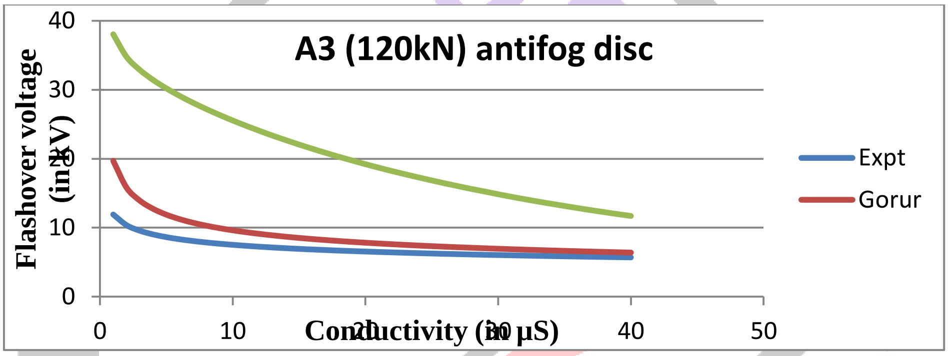

Fig. 6 Comparison of flashover voltages of experimental, Gorur and Dixit model for insulator A3

5. CONCLUSION

The flashover voltages were predetermined for different pollution severities varying from 1µS to 40µS for the selected tested insulators (A1, A2, and A3). In the second phase of the present work, the flashover voltages are determined experimentally for the same insulators for different pollution severities. The simulated flashover voltages of the Gorur and Dixit were compared with each other and with experimentally obtained flashover voltages. With detailed analysis and discussion we can draw the following conclusions.

•Both models discussed in this result show better accuracy.

•Flashover voltages predetermined using Gorur model results were always below the experimental values and hence the results are optimistic.

•Prediction of flashover voltages using Dixit model are agreed with the experimental results in the medium pollution level range (i.e., from 17µS to 29µS layer conductivity). However the percentage error for lower and higher level pollution severities lie within permissible range.

In general all the models compared are in one way or the other are the improvement of the earlier model of Obenaus. There is no single model which will be good for all insulators and which could be applied easily.

6. REFERENCE

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