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An Experimental Study on Pollution Flashover: A Review

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Abstract - *This paper reviews on the pollution flashover phenomenon on the insulators used in the high voltage transmission. It focuses on the insulator classifications; factors causing the flashover and proposes various models. This paper describes the impact of conductivity and distribution of pollution on high voltage insulators. A comparative study is presented by testing the influence of pollution on flashover voltage and leakage current of insulators.*

Key Words: Pollution flashover, dynamic modelling, outdoor insulators, 1512L insulator, flashover, leakage current, high voltage.

1. INTRODUCTION

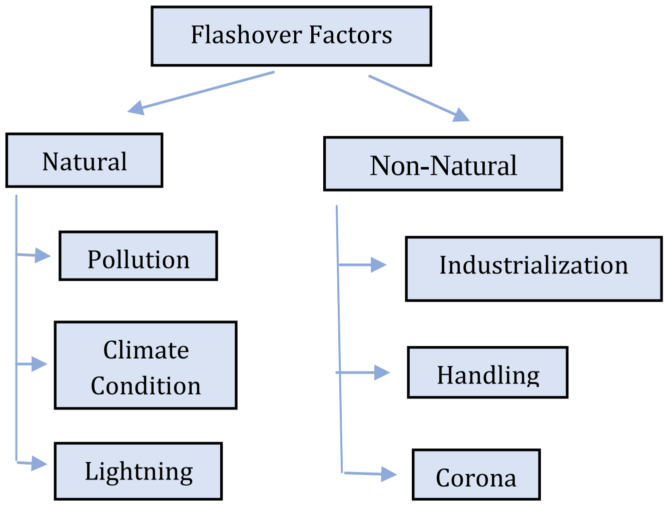
The insulators present in the electric power system are subjected to many stresses. Outdoor environment conditions such as temperature and pressure affect the performance of insulators. Insulator pollution is continuous or intermittent deposition of impurities on the surface of insulators. Moisture such as rain, cold fog and melting ice present on the insulator surface increases the surface conductivity which causes increases in leakage current and leads to the formation of dry bands, initiation of partial discharge and may lead to flashover.

The insulator comprises of three zones parallel with each other, which are air gap, dielectric material and interface air and dielectric material. Flashover voltages of polluted insulator depends on conductivity of pollutant deposits, degree of pollution and distribution of layer on its surface. The flashover voltage of polluted insulator occurs when the leakage current flows through electrolyte. This current heat up the electrolyte due to which conductivity of medium increases and leads to the drying of polluted layer. When the voltages are applied, it gets transferred to the terminals of dry zones and formation of local arcs take place. This is the initiation of discharge process in which the arc finds a more stable position of shortest length and elongates until it reaches the electrode and causes a flashover.

This paper proposes the factors that are responsible for the flashover. The factors could be natural or non-natural. It depicts various dynamic models proposed by the researchers to overcome the problem of flashover.

This paper also presents an experimental study on pollution flashover by creating artificial pollution on an experimental model. An observational study has been done to examine the impact of conductivity and distribution of pollution on 1512L cap and pin insulator and its proposed experimental model.

2. FACTORS INFLUENCING FLASHOVER DISCHARGE



2.1 Natural Flashover Factors

2.1.1 Pollution

A contamination layer is formed when the airborne particles gets deposited on the surface of the insulator. Depending upon the solubility of the pollution layer, different effects will take place on the insulator. Wetting of the pollution layer will lead to the flow of leakage current on the surface of the insulator and will lead to the flashover.

2.1.2 Climate Condition

Variations in climate such as rain, fog, relative humidity and ambient temperature can lead to the increase in the contamination of the insulator's surface. Fog, dew and drizzle can cause flashovers very easily. According to researchers, fog accounted for 65% cases and drizzling accounted for under 10% cases of flashover on high voltage lines.

2.1.3 Lightning

When impulse surges are applied, formation of corona occurs which is followed by the second detonation of corona if the rate of applied voltage is increased. If the voltage is high enough to evolve a leader channel to cross the gap, a flashover will take place.

2.2 Non-Natural Flashover Factors

2.2.1 Industrialization

At the time of manufacturing, defects and damages may occur in insulators due to inadequate quality standards. Factors that could affect this are the diameter, binding stage, pre-heat temperature, moisture, mould temperature etc. These variations should be in the acceptable limits otherwise this would lead insulators to face more electrical stresses and will eventually result into the flashover.

2.2.2 Handling

During the installation, insulators can get damaged due to the tension, incisions, vandalism, tracking and many other several factors. These damages can make insulators vulnerable and let them directly exposed to the contamination and wetting. Regular inspections should be carried out otherwise these factors will lead to the flashover.

2.2.3 Corona

When the number of free electrons accelerates around the insulator, the surrounding air gets ionized. The increase in the electric field on the surface of insulator will lead to the corona discharge. The threshold electric field magnitude for the corona depends on the conditions of the surface (dry or wet) and the type of voltage applied (AC or DC).

3. POLLUTION FLASHOVER MECHANISM

In high voltage transmission lines, the flashover is often lead by contamination. When the surface of insulator gets covered by a wet pollution layer, it tends to lose its insulation property. Due to pollution, the leakage current increases on the insulator's surface and the dry band gets widened which leads to an increase in the voltage and results into the flashover.

Pollution flashover mechanism gets developed in the following manner:

1) Contamination of cumulative pollutants on the surface of the insulator
2) Wet pollution
3) Change of leakage current and voltage
4) Discharge of flashover arc along the polluted area

4. PROPOSED FLASHOVER MODELS

4.1 Obenaus Model

According to Obenaus model, if an arc resistance is estimated in series with the wet polluted layer resistance then the critical voltage required to sustain an arc can be calculated by the following equation

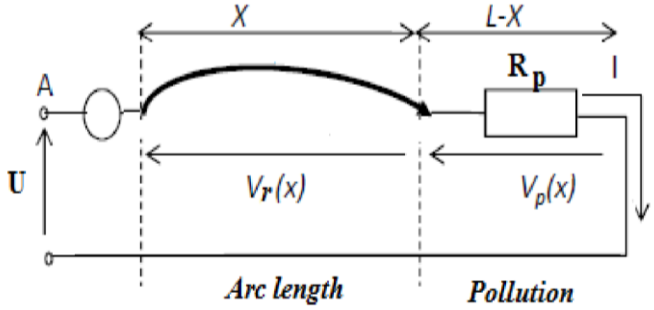


Fig-1: Obenaus Model (Salem, Abd-rahman, Kamarudin, & Othman, 2017)

$U = V_r\,(X) + V_p\,(X)$ -------(1)

$V_r = XNI^{-n}$

Inserting the value of V_r in (1),

$U = XNI^{-n} + R_pI$ -------(2)

Where

V_r = arc voltage, U = supply voltage, X = length of arc, I = leakage current, R_p = pollution layer resistance, n = exponent of static arc characteristic and N = static constant for arc

4.2 Neumarker Model

According to Neumarker, the resistance is uniform per unit length of pollution layer.

$R_p = r_p\,(L-X)$ -------(3)

$U = XNI^{-n} + r_p\,(L-X)$ -------(4)

4.3 Wilkins's Model

Wilkins proposed a model in a rectangular strip in which a resistive pollution layer burns in series with the quasi stable gas discharges which format from pollution.

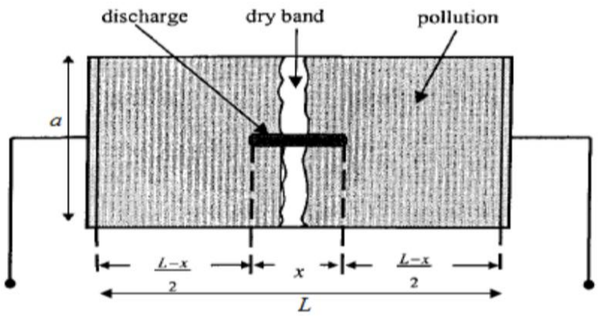


Fig-2: Wilkins model for flashover of a polluted strip (Salem, Abd-rahman, Kamarudin, & Othman, 2017)

The voltage is given by

$U = xNI^{-n} + U_e + 2IR$ -------(5)

Where

R= resistance of pollution layer along ((L-x)/2), U_e = electrode voltage drop, x = arc length

For resistance (R) of pollution layer, Wilkins proposed two cases:

1) a<<L (narrow strip)

$R = \frac{1}{2\pi\sigma} \{ \frac{\pi(L-x)}{a} + \ln(\frac{a}{2\pi r d}) \}$ -------(6)

2) a= 3 times L (wide strip)

$R = \frac{1}{2\pi\sigma} \left\{ \ln\frac{2L}{2\pi r d} - \ln.\tan\left(\frac{\pi x}{2L}\right) \right\}$ -------(7)

where,
σ = conductivity of insulator surface, r_d = channel discharge radius

4.4 Claverie's Model

Claverie used a highspeed camera for the screening of propagation arc. The study was done on the function of the arc root position on porcelain insulator surface in series with arc channel with re-ignition condition of the arc. It also derived critical arc voltage and the voltage re-ignition of arc.

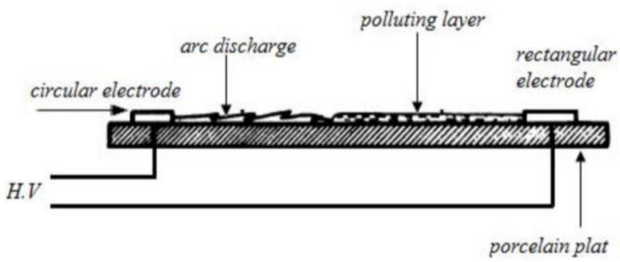


Fig-3: Claverie's Model (Salem, Abd-rahman, Kamarudin, & Othman, 2017)

The applied voltage is given by

$U = \frac{100x}{\sqrt{I}} + R_p(m)\, I = \frac{100x}{\sqrt{I}} + \frac{f(x)!}{\sigma}$ -------(8)

Where

$\frac{100x}{\sqrt{I}}$ = arc voltage (V_{arc}), R_p(m) = resistance of pollution layer at the point (m), I = maximum value of current in rms

For the reignition condition $V > \frac{940x}{\sqrt{I}}$,

Maximum arc length $x_m = \frac{V\sqrt{Im}}{940}$ --------(9)

Applied voltage will be

$U = 100\sqrt[8]{(x_m)^2}\, f^3 \sqrt[8]{x_m}$ -------(10)

Critical flashover voltage is given as,

$U_c = 47.6 \sqrt[8]{r_p} L$ -------(11)

Where

$L = \frac{3xc}{2}$

4.5 Ghosh's Model

This model predicts the flashover voltage by considering the change in the chemical nature of pollution layer over electrolytic surface.

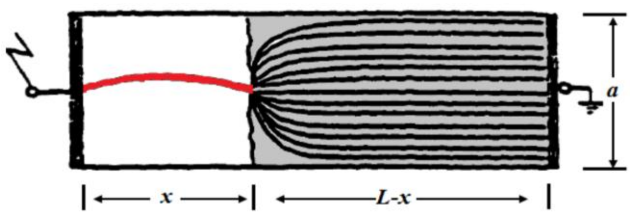


Fig- 4: 2D Model of Ghosh (Salem, Abd-rahman, Kamarudin, & Othman, 2017)

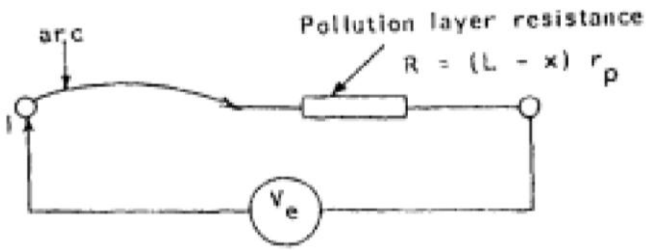


Fig-5: Simplified electrical equivalent circuit (Salem, Abd-rahman, Kamarudin, & Othman, 2017)

Applied rms ac voltage

$V = kxNI^{-n} + r_p (L-x) I + V_c$ -------(12)

$V_c = Lk^{1(n+1)} N^{1/(n+1)} r_p^{n/(n+1)}$ -------(13)

$I_c = [kN/r_p]^{1/(n+1)}$ -------(14)

Where

$k = \left(\frac{\sqrt{2}}{1.3}\right)^{-(n+1)}$

When $x \sim L$ and $I=I_c$

$V_m = kLNI_c^{-n} + V_c$ -------(15)

4.6 Alston's Model

In this model the length of discharge is linked to the voltage required to support the discharge on polluted insulator. If this voltage is greater than the supply voltage then the flashover will not occur.

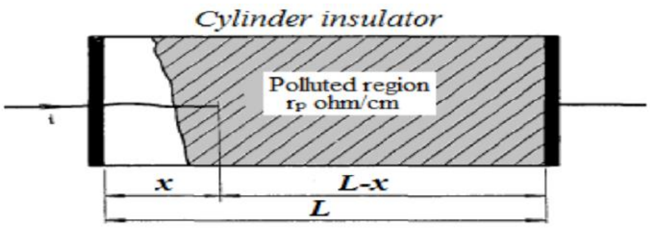


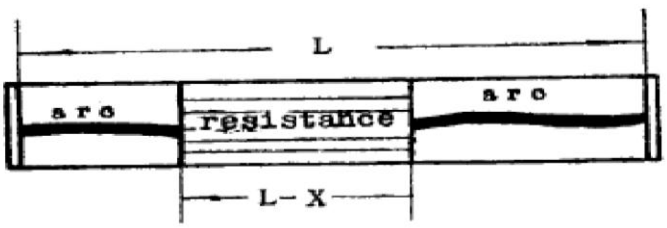
Fig-6: Alston's Model (Salem, Abd-rahman, Kamarudin, & Othman, 2017)

Flashover doesn't take place when

$E < A^{1/(N+1)} r^{n/(n+1)}$ -------(16)

4.7 Renyu's Model

In this model, Renyu recorded the propagation of arc on the surface of the wet polluted layer over cup pin insulator through high speed camera. In this experiment it was observed that the critical distance for the flashover to occur during an arc propagation was equal to 2/3 of the leakage length of the insulator surface.



FFig- 7: DC Flashover Model (Salem, Abd-rahman, Kamarudin, & Othman, 2017)

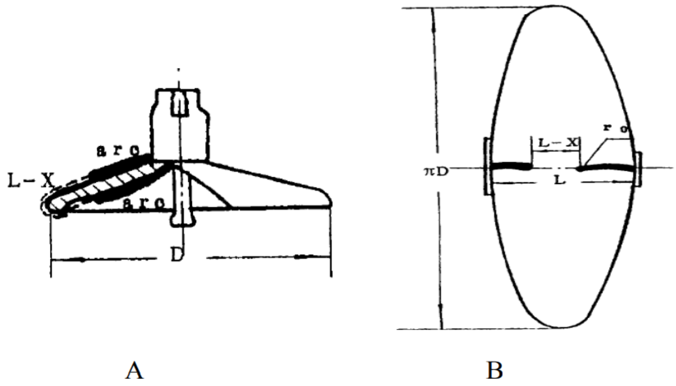


Fig-8: (A) cup-pin insulator, (B) plane model of insulator (Salem, Abd-rahman, Kamarudin, & Othman, 2017)

The critical voltage and current in dc flashover case is given by,

$i_c = \left[\frac{nAxc}{R(xc)}\right]^{1/(n+1)}$ -------(17)

$V_c = \left(1 + \frac{1}{n}\right) (nAx_c)^{1/(n+1)} R(x_c)^{n/(n+1)}$ -------(18)

5. EXPERIMENTAL STUDY

The experimental model 1512L is a disc shaped glass insulator with radius (r) of 200mm and thickness (e) of 5mm and other dimensions are mentioned in the Table-1. The model has a heat resisting property and two electrodes with radius r_1 of 86mm representing the cap and connected to ground. The other electrode has a radius of r_2 of 13mm representing the pin for high voltage supply. Artificial pollution conditions are created by using salt solution having various conductivities and assumed to be distributed in form of circular bands on insulator surface.

Table-1: Dimension of 1512L insulator (Benguesmia, M'ziou, & Boubakeur, 2017)

Dimensions	Values
Leakage distance/mm	292
Cement/mm	14
Air flashover distance/mm	230
Insulator cap/mm	488
Insulator pin/mm	250
Net weight of the insulator/kg	3.75

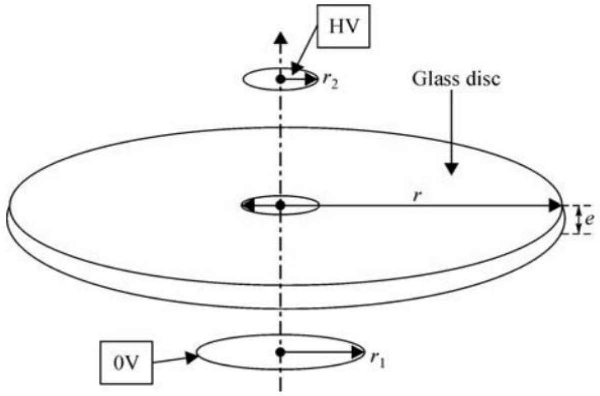


Fig-9: 1512L proposed model (Benguesmia, M'ziou, & Boubakeur, 2017)

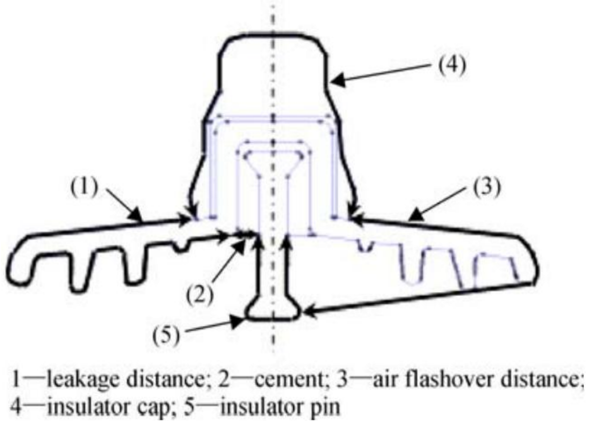


Fig-10: Cap and pin 1512L insulator dimension (Benguesmia, M'ziou, & Boubakeur, 2017)

For the determination of test voltage, a capacitive divider is connected to the secondary of transformer test and primary towards the regulating transformer. On an average 10 tests are performed at different conductivities by varying the salt concentration in salt solution. This pollution is applied on 1512L insulator by filling the different zones by the salt solution with different conductivities to obtain different level of pollutions.

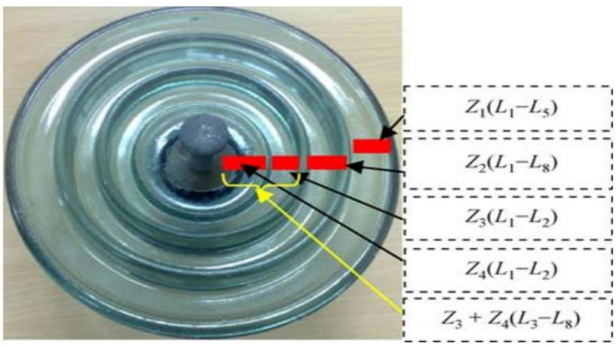


Fig-11: Distribution of polluted zones on the 1512L high voltage insulator (Benguesmia, M'ziou, & Boubakeur, 2017)

5.1 Flashover Process

To determine the effect of pollution on flashover voltage, salt solution (artificial pollution) of any particular conductivity is prepared and applied on the experimental model. Flashover process has to follow these procedures:

- Cleaning of insulator with distilled water and drying it with papers and once again cleaning it with 70° alcohol.
- Filling the zones ($Z_1+Z_2+Z_3+Z_4$) of insulator with L_1 level of pollution.
- Application of high voltage up till flashover condition.
- Measurement of flashover voltage for L_8 levels of pollution.

For better understanding these procedures is repeated for different values of conductivities.

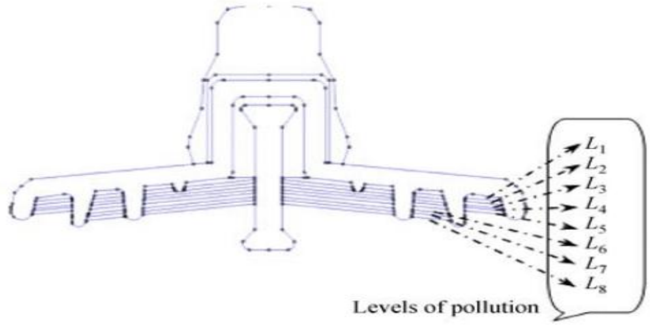
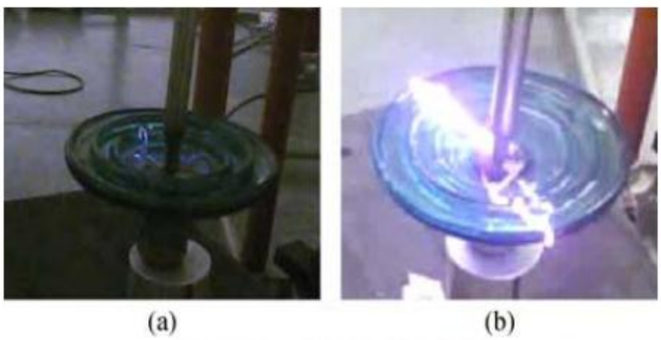


Fig-12: Determination of different levels of pollution for 1512L (Benguesmia, M'ziou, & Boubakeur, 2017)

5.2 Laboratory Observation

The laboratory test observations showed that by application of few kilovolts between the electrodes leads to the generation of leakage current and initiates the formation of arc. Due to high current density salt solution evaporates, by the Joule effect and the surface area becomes dry. Further increase in applied voltage lengthens the arc towards the opposite electrode and reaches a critical value, beyond which further in voltage causes a total flashover.

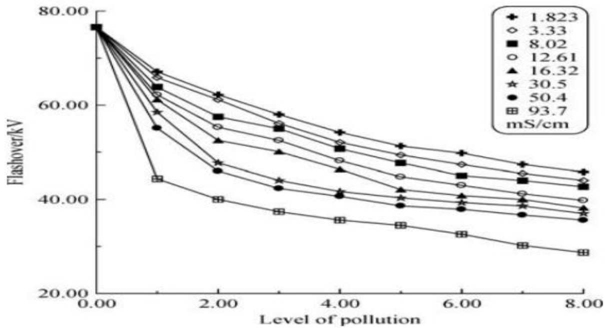


(c)

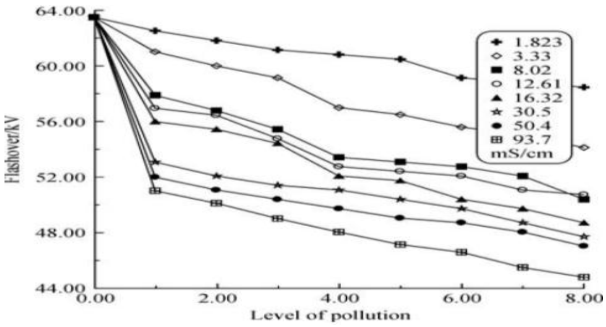
Fig-13: Flashover process observed in laboratory for 1512L polluted insulator
(a) Initialization of the; (b) evolution of the arc;
(c) total flashover
(Benguesmia, M'ziou, & Boubakeur, 2017)

5.3 Effect of Pollution on Flashover Voltage

This section presents the investigation of variation in flashover voltage according to the conductivity. It is expected that with the increase in flashover voltage, there is reduction in level of pollution. The Fig-14 shows the variation of flashover voltage at different levels of pollution for real model and experimental model.



(a)

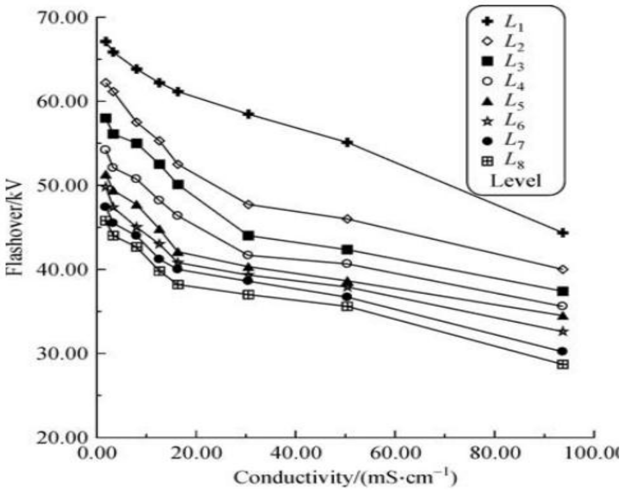


(b)

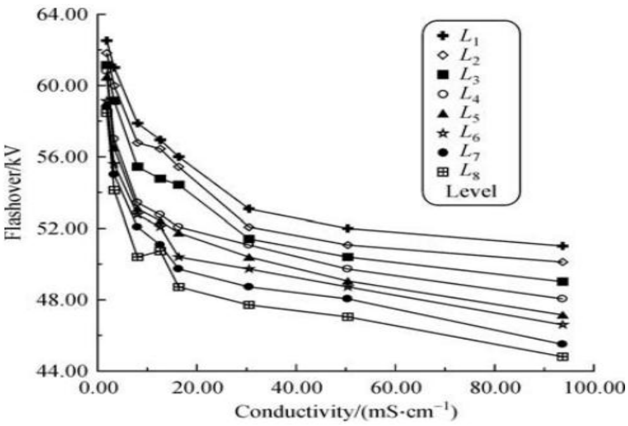
Fig-14: Flashover voltage-level of pollution for different conductivities
(a) real model (b) experimental model
(Benguesmia, M'ziou, & Boubakeur, 2017)

5.4 Effect of Pollution Severity on The Flashover Voltage

The variation of flashover voltage at different conductivities is shown in Fig-15. It is observed that with the increase in flashover voltage there is a remarkable reduction for conductivities lower than 30.5 mS/cm and a gradual decrease beyond this conductivity. It is concluded that insulator is more rigid when conductivity is weak.



(a)



(b)

Fig-15: Flashover voltage-conductivity for different levels of pollution

(a) Real model (b) experimental model

(Benguesmia, M'ziou, & Boubakeur, 2017)

5.5 Leakage Current

The variation of leakage current against the level of pollution for different conductivities are shown in Fig-16. Current increases with the reduction in surface resistivity of clean zones which is temperature dependent. Fig-17 represents the variation of leakage current as a function of conductivity at varying voltages and it is observed that for low conductivities, increase in leakage current is low, for voltages lower than 25% of flashover voltage and there is no intense discharge at the active electrodes. While for voltages greater than 50% of flashover voltage the activity of discharges becomes intense and there is a significant increase in leakage current. With the increase in conductivity pollution the rigidity of insulation decreases.

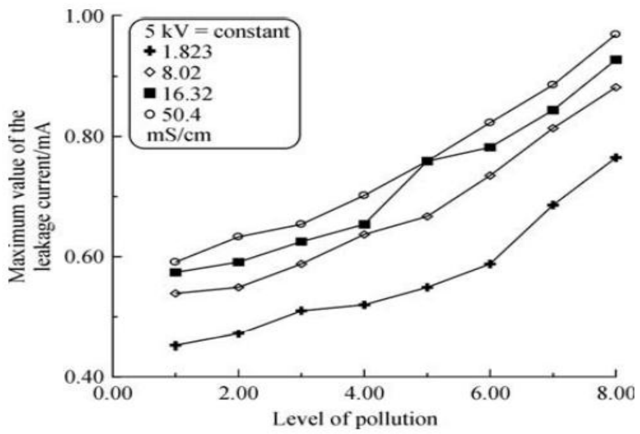


Fig-16: Leakage current-level of pollution for different conductivities for an applied voltage of 5kV (Benguesmia, M'ziou, & Boubakeur, 2017)

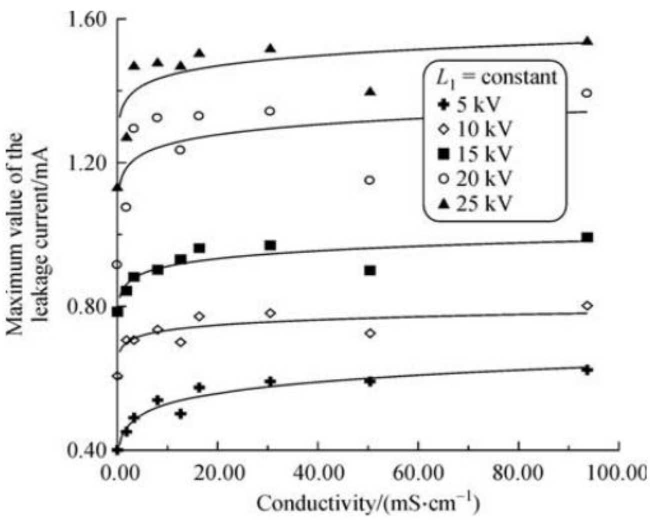


Fig-17: Leakage current- conductivity for various applied voltage for L1 level of pollution (Benguesmia, M'ziou, & Boubakeur, 2017)

6. SUMMARY TABLE

Research paper/ year of publication	**Area of Study on Pollution Flashover**
A Review of the Dynamic Modelling of Pollution Flashover on High Voltage Outdoor Insulators [2017]	Dynamic Modelling on Pollution Flashover for HV Insulators
Probabilistic assessment of insulator failure under contaminated conditions [2020]	Analyzing the failure risks of insulators under contaminated conditions
Lessons to Learn from Post-Installation Pollution Levels Assessment of Some Distribution Insulators [2020]	Impact of environmental pollution on insulator flashover
The pollution flashover on high voltage insulators [2008]	Investigating the insulator modelling for pollution flashover
Prediction of pollution flashover voltages of ceramic string insulators under uniform and non-uniform pollution conditions [2016]	Estimation of contamination flashover voltages of ceramic string insulators
Environmental Effects on HV Dielectric Materials and Related Sensing Technologies [2019]	The influence of environmental factors on high-voltage materials and components
Influence of pollution distribution on insulator surface on flashover characteristics [2014]	Influence of pollution distribution along and around insulator
Experimental study of pollution effect on the behaviour of high voltage insulators under alternative current [2017]	Behaviour of HV insulator under the effect of pollution
Study on Pollution Accumulation Characteristics of Typical Insulators [2015]	Characteristics of pollution accumulation on insulators
Experimental Study on the Pollution Flashover Mechanism of Polymer Insulators [2000]	Pollution flashover mechanism on hydrophobic surfaces
Study on Pollution Flashover Performance of Short Samples of Composite Insulators Intended for ±800 kV UHV DC [2007]	Effect of pollution and high altitude on the flashover performances
Factors and models of pollution flashover on high voltage outdoor insulator	Pollution flashover phenomenon on HV insulators

[2017]	
Dynamic pollution prediction model of insulators based on atmospheric environmental parameters [2020]	Dynamic pollution prediction model
Non- uniform distribution of contamination on composite insulators in HVDC transmission lines [2018]	Field contamination experiments of HVDC transmission lines

7. CONCLUSION

Pollution flashover studies are done to predict the flashover voltages. It is used for developing insulator designs and insulation assortment. The paper reviewed on the characteristics of the electric field, resistance of pollution and insulators, conductivity, leakage currents during the entire pollution flashover stage. It proposed various models and the equations through which the critical voltage and resistance can be determined. This paper presents an experimental study on the behavior of 1512L insulator and experimental model under the effect of pollution and testing under alternating voltage. These experiments were conducted in laboratory for two models at different conductivities and different distributions of pollution. Variation in the behavior of flashover voltage and leakage current were studied against other parameters. It was observed that flashover and leakage current changes with the change in conductivity and width of the polluting layer and also with the increase in surface conductivity of pollution, flashover decreases. During the application of pollution, insulator is less rigid, which ultimately affects the voltage flashover and it becomes even more important in the case of dry state. While the leakage current increases with the increase in applied voltage, pollution conductivity and width of pollution layer. Therefore, it is concluded that experimental model does not reflect the exact behavior of real insulator under the effect of pollution. However, it can be said that, experimental model is helpful in determining the flashover voltage to some extent for a good analysis of physical phenomena of flashover.

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