Comparative Analysis of Flashover by Measuring Leakage Current in Composite Insulation

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Abstract. The insulators located outdoors are subjected to external environmental factors such as humidity, temperature and pollution. The surface of the insulators may be subjected to high flow of leakage current during wet and polluted conditions. Due to this, a dry band arching occurs and when it extends for a longer duration it may degrade the insulator and ultimately lead to failure of the lines by initiating the insulator flash over. By conducting detailed study of the characteristics of the surface deposition layers contaminating the insulators The phenomenon of occurrence flash over in insulators that are polluted has been done by the study of the characteristics of layers of contamination deposited on the insulator surface in high voltage laboratories. This paper presents the simulation results of the epoxy coating on ceramic insulators. It was discovered that the magnitude of leakage current was significantly suppressed the coating. The flash over voltage is significantly enhanced by this coating. It was evident in the simulation there was a notable improvement of surface resistance of insulator after coating epoxy layer under a wide variety of environmental conditions in comparison with that of uncoated insulators. Overall experimental results indicated significant enhancement of insulator performance by applying epoxy coating. MATLAB Simulink is utilized for simulation studies and result comparison. ANSOFT SV2D Software is utilized for simulation studies and result comparison.

1. Introduction

In general the insulators are subjected to outdoor environmental contaminations as they are used in outdoor electric power transmission lines. Chances of flashover are more likely upon the contamination of the outdoor insulators. A build-up of a dry layer on the insulator surface is dependent on the duration and nature of exposure by industrial, sea and dust contaminations. The path of leakage current through a layer of dry contaminants on the surface of the insulator is capacitive with the amplitude of current being small and sinusoidal in nature. Upon exposure to moist environment the layer of dry contaminants becomes conductive.

Due to the progress of wetting, the path of leakage current changes from capacitive to resistive along with a marginal raise in current. Dry bands are formed around the areas with high current density as a result of increase in leakage current that dries the conducting layer. These dry bands leads to an interrupt in flow of current and majority of the applied voltages are impressed across the thin dry bands. In case if the dry bands cannot withstand the voltage, the dry bands will be spanned by discharges due to localized arcing. The surface flashover is triggered as the arcs combine together to form a single arc [1].

The severity of contamination determines the probability of flashover in terms of frequency and intensity of arcing. In desirable conditions when the contamination level is low, layer has high resistance and arcing prolongs until the wind or sun dries the layer and the arc ceases. Ceramic insulators are not harmed by continuous. Contamination in dry conditions is less harmful compared to wet conditions.

The distribution of voltage along the polluted, moist surface of a flat insulating strip is based on the method of dry band formation, continued with growth of discharges on the surface that is polluted [2]. It was found from the experiments that an arc rooted on a cylinder having constant resistivity would propagate along the surface if the voltage gradient in the column of arc is comparatively lesser than that along the cylinder. In addition, an arc propagating with the surface of water burns in an atmosphere of steam, and measurements showed that the arc gradient in the steam is considerably higher than a similar arc burning in an atmosphere of air. However, the arc behavior which is rooted on a wet, polluted surface is complicated by the rapid changes in surface resistances which occur during a surge of current; hence, further research was warranted to determine the conditions for flashover.

In [1] an insulator of moist, conducting layer of pollution the flashover occurs due to bridging and formation of a dry band due to a partial arc pre-discharge was suggested. The electric field over the dry band falls as the partial arc current decreases. A new model is developed to represent the spark properties rather arc properties. Both models were tested in laboratories. For mild contamination, the dry-band spark model suits the test data better than the partial-arc model.

In [3] the methodology for improving the insulator performance under polluted condition, RTV silicone coating is done on the insulators under polluted conditions. The coating effectively suppresses the amount of leakage current, corona, reduces the temperature at the surface, eliminated the harmonic content and increased the flashover voltage of insulator. Analysis and simulation of the leakage currents showed significant enhancement of surface resistance of insulator. Several contributions have been made in the past decade to address the issues with insulators [4-10].

This paper proposes a method to suppress the leakage current effectively. The rest of this manuscript is organized as follows: An introduction to ANSOFT SV2D is presented in Section 2. Simulation of dielectric combination algorithm are elaborated in Section 3. Section 4 presents a comparison of substrate materials Section 5discusses the simulation results Section 6and 7 discusses the hardware set up and results. In Section 8 the epoxy coated insulator and its and its applications are presented and section 9 exemplifies the significance of the work.

2. Formatting your Paper

The Maxwell 2D Student Version 9.0 (SV) is a software package used for analyses of electromagnetic fields in cross-sections of various structures. It uses finite element analysis (FEA) in solving two-dimensional (2D) electromagnetic problems.

To analyse a problem, it is necessary to have the specifications of the appropriate geometry, properties pertaining to that material, and excitations for a system of devices. The Maxwell software then does the following:

- The finite element mesh is created automatically as per requirement.
- Force, torque, capacitance, inductance or any loss of power that serves as a key quantities of special interest along with the magnetic or electric field solution is calculated desirably.
- Manipulation analyses and display of the field solution is possible.

2.1 General Procedure for Creating and Solving A 2D Model

The general procedure to follow when using the software to create and solve a 2D problem is given below:

Step 1: Use the Solver command to specify which of the following electric or magnetic field quantities to compute:

Electrostatic
Magneto static
Eddy Current
DC Conduction

Step 2: The drawing command can be used to select one of the following model plans:

XY plane: Cartesian models appear to sweep perpendicularly to the cross section.

RZ plane: Axis symmetric models appear to revolve around an axis of symmetry in the cross section.

Step 3: Use the define model commands to create the geometric model. Upon clicking define model, the following menu appears:

Draw Model: Allows accessing the 2D modeller and building the objects that make up the geometric model.

Group Objects: Allows you to group discrete objects that are actually one electrical object. For example, two terminations of a conductor that are drawn as separate objects in the cross-section can be grouped to represent one conductor.

Step 4: Use the Setup Materials command to assign materials to all objects in the geometric model.

Step 5: Use the Setup boundaries/sources command to define the boundaries and sources for the problem. This determines the electromagnetic excitations and field behaviour for the model.

Step 6: Use the Setup Executive Parameters command to instruct the simulator to compute one or more of the following special quantities during the solution process:

- ➢ Matrix (Capacitance, inductance, admittance, impedance, or conductance matrix, depending on the selected solver). Force, Torque, Flux lines, Post Processor macros, Core loss, Current flow.

Step 7: Use the Setup Solution Options command to enter parameters that affect how the solution is computed.

Step 8: Use the Solve command to solve for the appropriate field quantities.

Step 9: Post Process Command can be used to analyse the solution.

These commands must be chosen in the sequence in which they appear. The geometric model must be created initially using the Define model command before you specify material characteristic for objects using the Setup Materials command. A check mark appears on the menu next to each step which has been completed.

2.2 Flowchart

Fig. 1. Flowchart for drawing insulator model using ANSOFT MAXWELL 2D.

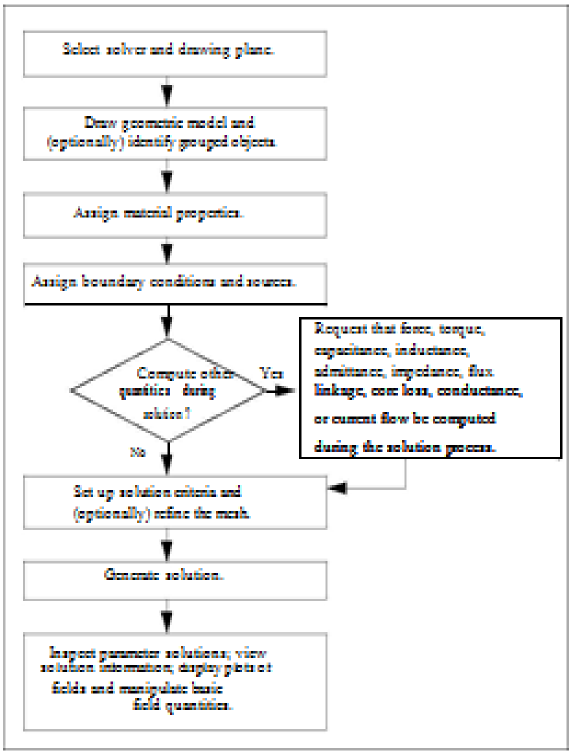

Fig 1. Flowchart for Drawing Insulator Model

3. Simulation of Dielectric Combination

This subdivision deals with the various possible arrangements and combinations of dielectrics such as FR4 epoxy, Mica, Teflon and Silicon di oxide. These models are simulated using the ANSOFT Maxwell SV2D Software and from the obtained results the best combination is chosen for the experiment.

3.1Dielectric Arrangement

There are two types of dielectric arrangements. They are

1) Transverse Arrangement
2) Longitudinal Arrangement

In both arrangement of dielectric combination there are two electrodes (i.e., hv electrode and ground electrode) and an interface is formed between the dielectric materials.

3.1.1Transverse Arrangement

This is also known as horizontal arrangement. The dielectric material and the porcelain are arranged parallel to the electrodes. The voltage is applied tangentially to the dielectric materials between the electrodes.

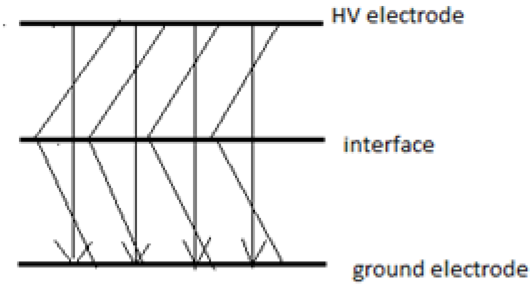

Fig.2. Transverse arrangement

3.1.2 Longitudinal Arrangement

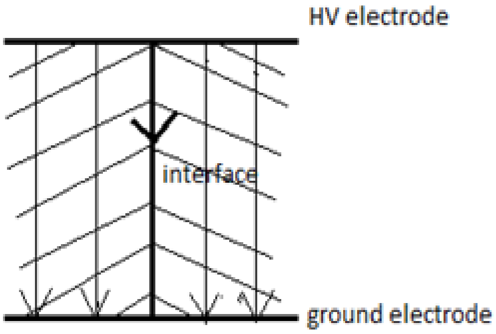

Fig. 3.Longitudinal arrangement

This is also known as vertical arrangement. The dielectric material and the porcelain are arranged perpendicular to the electrodes. The voltage is applied along the interface of the dielectric materials.

3.1.3 Why transverse Arrangement?

In longitudinal arrangement the porcelain, dielectric material and the interface are subjected to the applied voltage separately so, it won’t give appropriate results. Whereas in case of transverse arrangement the combination of both the dielectrics along with the interface is experience the applied voltage normally. Hence the transverse arrangement is preferred for this particular testing of dielectric combination in ANSOFT MAXWELL 2D SOFTWARE.

3.2 Dielectric Combination

Various materials which can be coated over the existing porcelain pin type insulator are preferred based on the properties of the dielectric materials.
The materials preferred for simulation are:

- FR4 EPOXY
- TEFLON
- SILICON-DI-OXIDE
- MICA

4. Comparison of Substrate Materials

Table 1. Comparison of Substrate Materials

Properties	**Teflon**	**Mica**	**Modified Epoxy**	**Silicon dioxide**	**FR4 Epoxy**
Density	2.16 gm/cm^3	2.7 gm/cm^3	2 – 11 gm/cm^3	2.648 gm/cm^3	1.850 gm/cm^3
Dielectric Strength	60 kV/mm	80 kV/mm	15KV/mm	10^4Kv/mm	2000 Kv/mm
Melting Point	327^0 C	1250 – 1300^0 C	150^{0}C	1600 – 1725 ^{0}C	140 ^{0}C

Relative permittivity	2	2.5 – 7	3 – 6	4.2	4.8

The various combinations of dielectric materials which are simulated using ANSOFT Maxwell SV2D Software are,

- Dielectric-Porcelain (2:8)
- Dielectric-Porcelain (8:2)
- Dielectric-Porcelain (5:5) and vice versa of all the above combination.

4.1 Dielectric-Porcelain (2:8)

This combination involves **80%** of **Porcelain** and **20%** of **dielectric material** .The corresponding dielectric material, boundaries, applied voltage are assigned and the model is solved using the software package and simulation results are recorded.

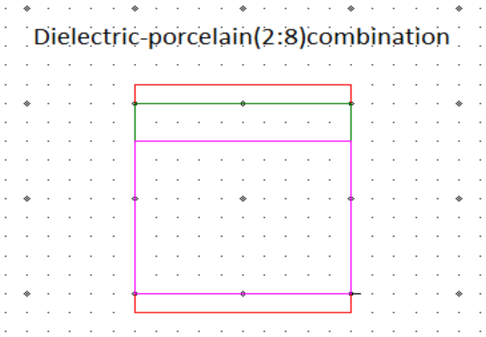

Fig. 4. Dielectric-porcelain (2:8) combination

4.2 Dielectric-Porcelain (8:2)

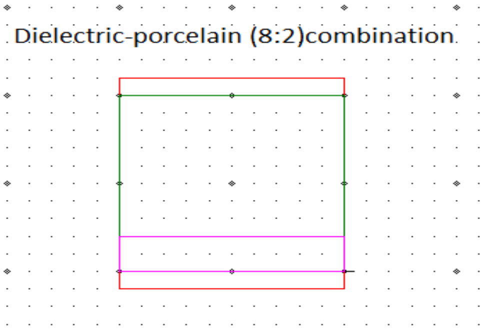

Fig.5. Dielectric-porcelain (8:2) combination

This combination involves **20%** of **Porcelain** and **80%** of **dielectric material** .The corresponding dielectric material, boundaries, applied voltage are assigned and the model is solved using the software package and simulation results are recorded.

4.3 Dielectric-Porcelain (5:5)

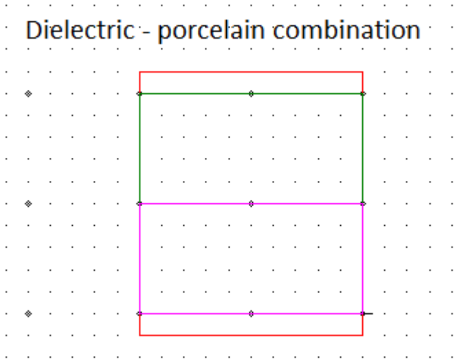

Fig. 6. Dielectric-Porcelain (5:5) combination

This combination involves **50%** of **Porcelain** and **50%** of **dielectric material** .The corresponding dielectric material, boundaries, applied voltage are assigned and the model is solved using the software package and simulation results are recorded.

Table.2 Comparison of various dielectric combinations

Combinations	**Capacitance Value**	**Total Energy**
Epoxy Porcelain	5.7682E-011	1.5256E-006
Porcelain Epoxy	5.787E-011	1.53066E-006
Epoxy Porcelain (2:8)	6.1241E-011	1.61982E-006
Epoxy Porcelain(8:2)	5.4646E-011	1.44540E-006
Teflon Porcelain	4.2095E-011	1.11340E-006
Porcelain Teflon	4.2712E-011	1.12974E-006
Teflon Porcelain (2:8)	5.1703E-011	1.3675E-006
Teflon Porcelain (8:2)	3.6203E-011	9.57561E-007
Modified Epoxy-Porcelain	5.6537E-011	1.49541E-006
Porcelain – Modified Epoxy	5.6752E-011	1.50109E-006
Modified Epoxy-Porcelain(2:8)	6.0661E-011	1.60448E-006
Modified Epoxy-Porcelain (8:2)	5.3091E-011	1.40427E-006

Silicon dioxide-Porcelain	5.5339E-011	1.46370E-006
Porcelain-Silicon dioxide	5.5587E-011	1.47028E-006
Silicon dioxide-Porcelain(2:8)	6.0044E-011	1.58816E-006
Silicon dioxide-Porcelain(8:2)	5.1509E-011	1.36240E-006

From the simulation results the values such as capacitance value and total energy values are compared for various combinations of materials which include various proportions of the materials such as Dielectric-Porcelain (2:8), Dielectric – Porcelain (8:2),Dielectric – Porcelain (5:5) and vice versa. The values are given in the following table 3.2, from which values are compared and best combination is chosen.

4.4 Best Combination

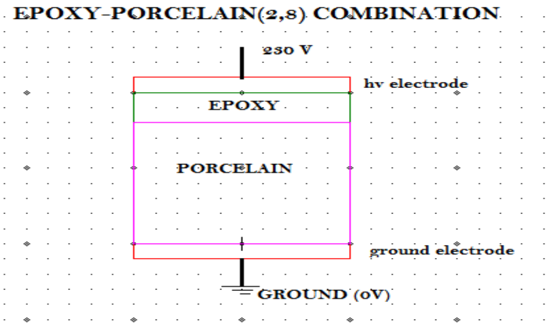

Fig.7.Best Combination

The **EPOXY-PORCELAIN (2:8)** combination is found to be the best combination from various dielectric combinations by comparing the capacitance and total energy values. From the simulation result we concluded that to coat the Fr4 epoxy over the existing pin type porcelain insulator in transmission lines below 33kv.

5. Simulation Results

5.1 Energy Line

This graph is plotted between energy lines versus distance between two electrodes. It gives the energy value for the dielectric combination. In that the epoxy can withstand for a maximum value of energy of 0.004 and porcelain can withstand for the maximum energy value of 0.003. The difference between both the dielectric is 0.001 which is less compared to other combination.

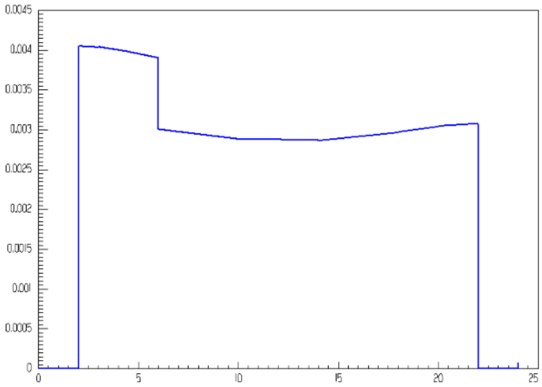

Fig. 8.Energy Line

5.2 Mag E Energy Line

This graph is plotted between MAG E energy lines versus distance between the two electrodes. It gives the magnitude value for the dielectric combination. In that the epoxy can withstand for a maximum value of 14500 and porcelain can withstand for 11000. The difference between both the dielectric is 3500 which is less compared to other combination.

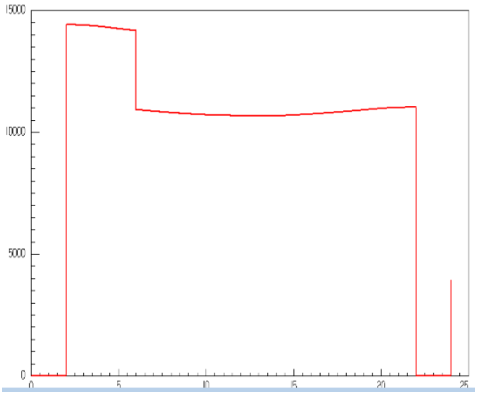

Fig. 9. Mag E line

5.3 Mag D Line

This graph is plotted between Magnetic density Vs the distance between the electrodes. It gives the magnetic density value for the dielectric combination. In this both the dielectrics withstand for the same value of 5.8E-007.

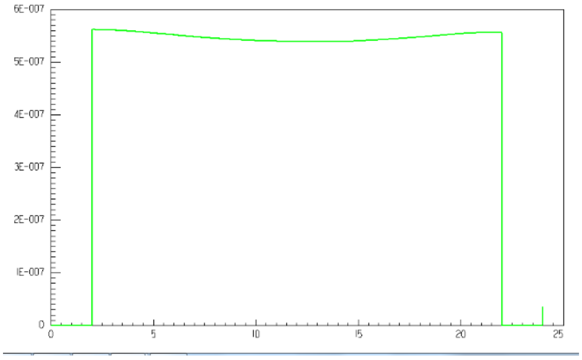

Fig.10. Mag D line

5.4 PHI Line

This graph is plotted between the various flux values. It gives the energy value for the dielectric combination. In that the epoxy can withstand for a maximum value of 13600 and porcelain can withstand for 10000. The difference between both the dielectric is 3600 which is less compared to other combination.

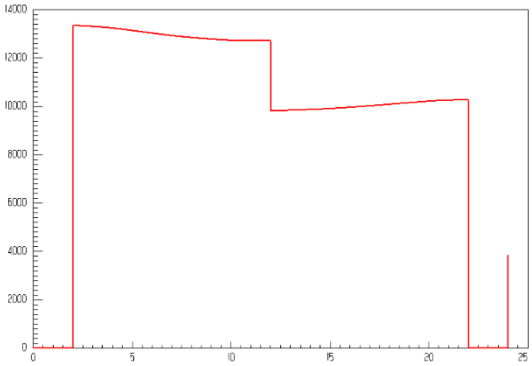

Fig.11. PHI line

5.5 Energy Surface All

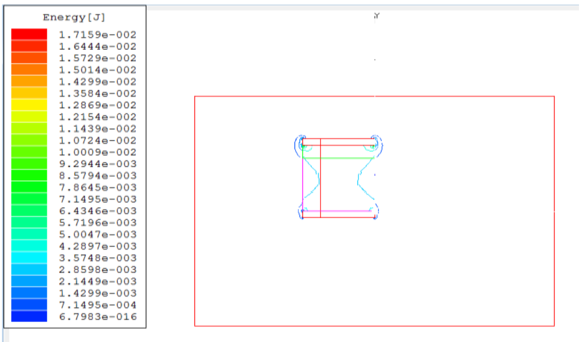

Fig.12. Energy Surface all

This graph gives the flux lines throughout the dielectric combination. In that the maximum flux value is 1.7159E-002 and the minimum value is 6.7983E-016.Each color in the model represents the values as mentioned in the tabular column.

5.6 PHI Surface All

This graph gives the flux lines throughout the dielectric combination. In that the maximum flux value is 1.7159E-002 and the minimum value is 6.7983E-016.Each color in the model represents the values as mentioned in the tabular column. From the figure it is clear that the maximum flux occurs in the epoxy than the porcelain.

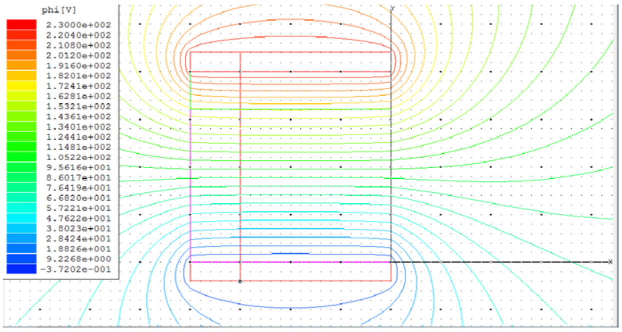

Fig.13. PHI Surface all

6. Hardware Setup

A proposed pin type insulator model is used for contaminating experiments of flashover. Here the contaminant mixture is substituted by dissolved mixture of an inert-binder Kaolin and NaCl salt. For the contamination flashover testing, Kaolin and various quantities of NaCl were mixed and the mixture is dissolved in distilled water which is then thoroughly mixed as per the standard. The slurry is coated upon the insulator and subjected to pollution testing under AC voltage. The leakage current is measured by the ammeter and the voltage waveforms are monitored through the DSO-025C2 Digital Storage Oscilloscope.

6.1 Pollution Test

The various environmental pollution like dust, smoke, salt layer deposition on the surfaces, deposition of sand, ice and fog deposition on the insulator cause corrosion, non-uniform gradient along the insulator surface and also cause deterioration of the material.

6.2 Salt Test

6.2.1 Solution Preparation

240gram of **kaolin** is equally weighed in to 40gram each. Different **NaCl** concentrations such as 20g, 30g,50g,70g,100g,120g, and weighed separately. For every concentration of NaCl, 40g of kaolin is mixed up and then the mixture is dissolved in one litre of distilled water, which is known as slurry.

Fig.14. Solution Preparation

6.2.2 Methods of Coating

The slurry is coated on the insulator and this coating can be done in two ways. They are

i. Dipping

The insulator is immersed in the slurry for 30 seconds approximately.

Fig. 15. Dipping

ii. Spraying

The slurry is filled in the spray bottle and it is sprayed uniformly on the surface of the insulator at an inclination of 45^0 to the vertical.

Fig.16.Spraying

6.3 Experimental Setup

Phase of the supply terminal is connected to one end of the coated insulator and the other end of the coated insulator is connected to the positive of the ammeter and the negative of the ammeter is connected to the positive of the DRB (**Decade Resistance Box)**, negative of DRB is connected to the neutral of the supply. The DSO (**Digital Storage Oscilloscope**) is connected across the DRB. The DRB is adjusted to a value of 100 ohms.

Fig. 17. Experimental Setup

Fig.18. Pin type insulator model

7. Result Analysis

The experimental results in Table 3 shows that the amplitude of the leakage current increases with increase in NaCl content.

Table. 3 Experimental Values of Leakage Current

Various NaCl concentrations	**Leakage current value**
20	24
30	34
50	41
70	53
100	61
120	100

The waveforms of the Kaolin coated with different NaCl concentration such as 20g, 30g, 50g, 70g, 100g, and 120g for 0th minute and 15th minute are shown in figure 18-23.

7.1 Waveform Output For 0th Minute

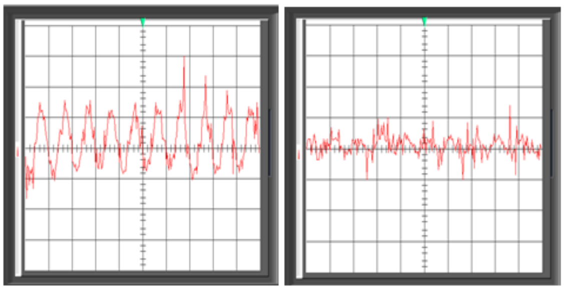

Fig.19. 20g of Nacl&30g of Nacl

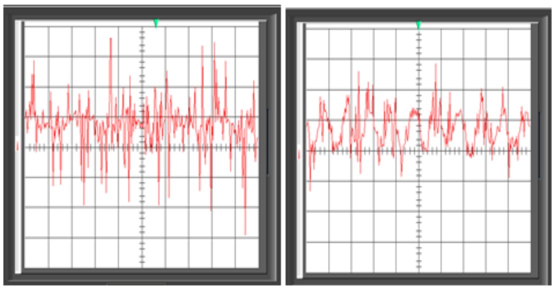

Fig.20. 50g of Nacl & 70g of Nacl

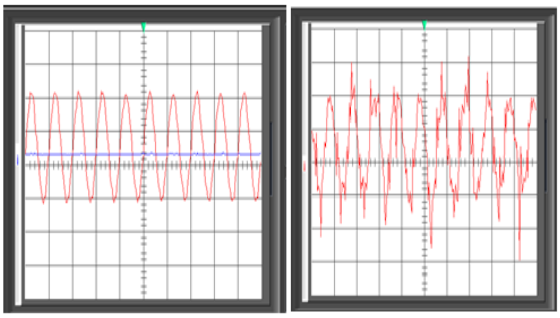

Fig.21. 100g of Nacl & 120g of Nacl

7.2 Output Waveform For 15th Minute

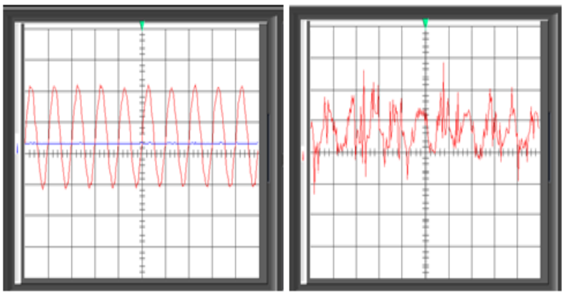

Fig.22.20g of Nacl & 30g of Nacl

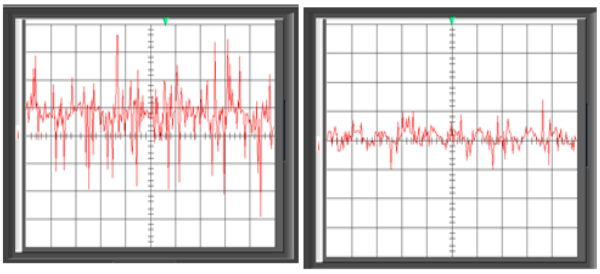

Fig.23. 50g of Nacl & 70g of Nacl

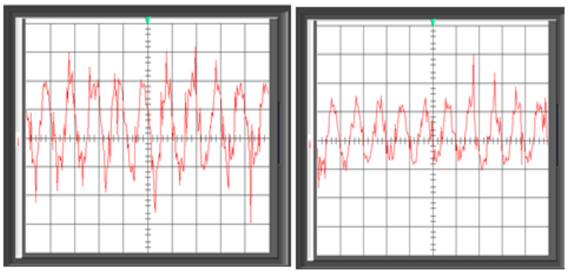

Fig. 24.100g of Nacl & 100g of Nacl

8. Epoxy Coated Insulator and Its Applications

The pin type insulator is permanently coated with epoxy layer by the heating process. The slurry which was prepared with various concentrations of NaCl and Kaolin is coated upon the epoxy coated insulator and subjected to pollution testing under AC voltage. The leakage current is measured using the ammeter and the voltage waveforms are monitored through the digital storage oscilloscope. Then the leakage current values of the uncoated and epoxy coated insulator are tabulated and compared.

8.1 Procedure For Epoxy Coating

Step 1: 100ml of epoxy resin is mixed with 10ml of hardener (10:1)
Step 2: The insulator is coated using the prepared epoxy mixture.
Step 3: The epoxy coated insulator is cured in the oven, which is maintained at 150^0c for 1 hour for complete polymerization to take place.
Step 4: The epoxy coated insulator was then cooled to room temperature.

Fig.25. Epoxy coated insulator

8.2 Pollution Test

The various environmental pollution like dust, smoke, salt layer deposition on the surfaces, deposition of sand, ice and fog deposition on the insulator cause corrosion, non-uniform gradient along the insulator surface and also cause deterioration of the material.

8.2.1 Solution Preparation

240gram of **kaolin** is equally weighed in to 40gram each. Different **NaCl** concentrations such as 20g, 30g,50g,70g,100g,120g, and weighed separately. For every concentration of NaCl, 40g of kaolin is mixed up and then the mixture is dissolved in one litre of distilled water, which is known as slurry.

8.3 Experimental Setup

The above epoxy coated insulator is dipped in the slurry made of 240gram of kaolin which is equally weighed in to 40gram each with different NaCl concentrations such as 20g, 30g, 50g, 70g, 100g and 120g. For every concentration of NaCl, 40g of kaolin is mixed up and then the mixture is dissolved in one liter of distilled water, which is known as slurry.

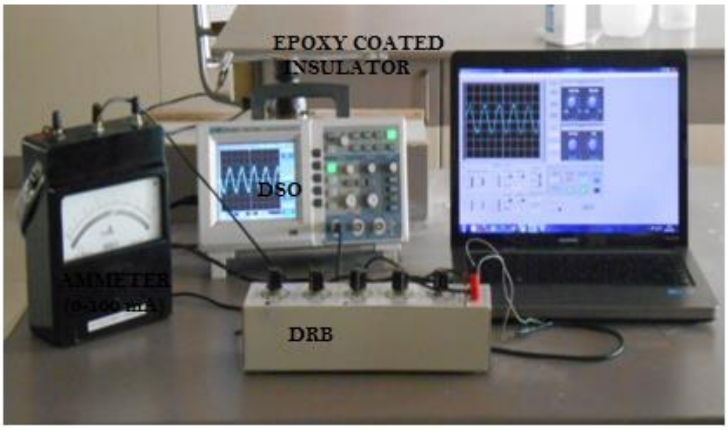

Fig.26. Experimental setup for Epoxy coating

8.4 Measurement Of Leakage Current

When the supply is switched ON, current passes through the transmission line model, due to the slurry solution over the insulator, leakage current flows on the surface of the insulator. It is measured using ammeter.

Table. 4. Experimental Values of Leakage Current with Epoxy Coating

NaCl content in solution (g)	**Maximum leakage current(mA)**
20	15
30	21
50	32
70	41
100	51
120	83

8.5 Comparison of Leakage Current

The experimental results in Table 5 shows that the amplitude of the leakage current increases with increase in NaCl content.

Table 5. Comparison of Leakage Current Values

Various NaCl concentrations	**Uncoated insulator**	**Epoxy coated insulator**
20	24	15
30	34	21
50	41	32
70	53	41
100	61	51
120	100	83

The waveforms of the Kaolin coated with different NaCl concentration such as 20g, 30g, 50g, 70g, 100g, and 120g on the epoxy coated insulator for 0th minute and 20th minute are shown in figure 26-31.

8.6 Output Waveform For 0th Minute (Epoxy Coated Insulator)

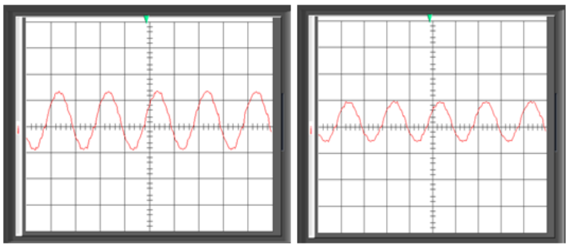

Fig.27. 20g of Nacl & 30g of Nacl

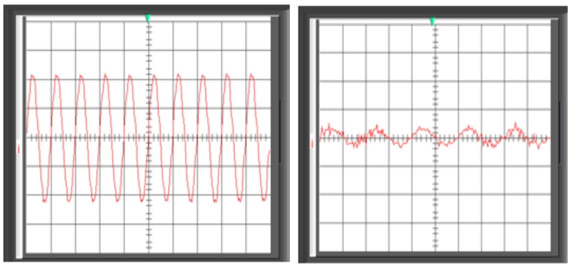

Fig.28. 50g of Nacl & 70g of Nacl

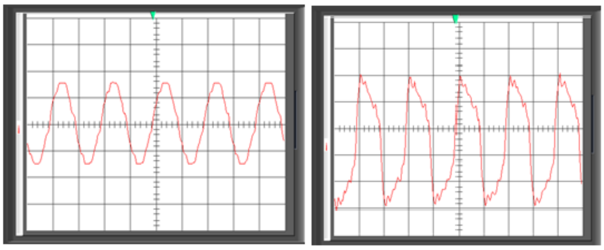

Fig.29. 100g of Nacl & 120g of Nacl

8.7 Output Waveform For 20th Minute (Epoxy Coated Insulator)

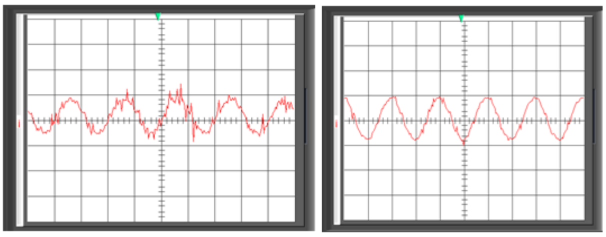

Fig.30. 20g of Nacl & 30g of Nacl

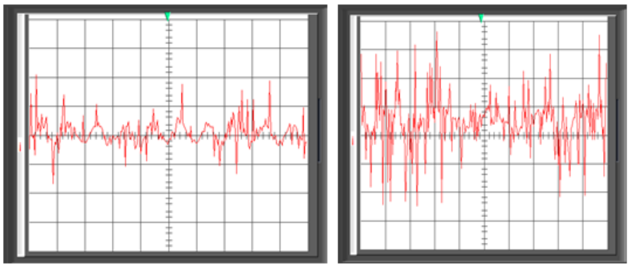

Fig.31. 50g of Nacl & 70g of Nacl

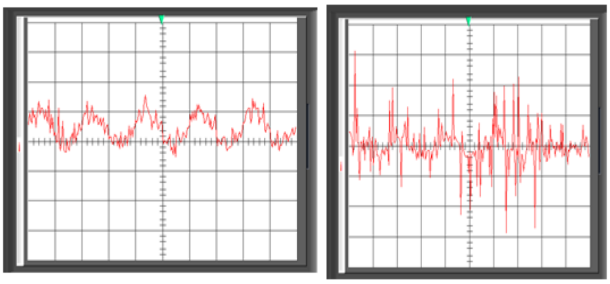

Fig.32. 100g of Nacl & 120g of Nacl

From the comparison table 5.2 and the graphs obtained by the experimental result we found an average of 10 mA of leakage current is reduced in the insulator.

9. Conclusion

This study provides an approach to reduce the leakage current of a pin type porcelain insulator used for 230 V applications. The implementation was done using epoxy coating on the available porcelain insulator. Experimental results show that, for the epoxy coated porcelain insulator, the leakage current is reduced to an average of 10 mA.

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10. References

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