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POWER LOSS REDUCTION OF DISTRIBUTION NETWORK IN DENSELY INDUSTRIALIZED COASTAL BELT BY DEVELOPMENT OF HYDROPHOBIC COATING APPLYING ACCELERATED AGING FOR CERAMIC INSULATOR

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Graphical abstract

Abstract

This paper aims to reduce the power losses by improving the hydrophobic strength of ceramic insulators for densely industrialized coastal areas to save them from flashover due to contamination. The hydrophobic strength of ceramic insulators must increase to resolve the contamination occurrence and power losses problem. The system progresses by creating an artificial chamber to provide five different environmental conditions heat, rain, fog, dust, and humidity. The testing part of the system includes taking readings for rain happened, temperature, humidity, and pH for five years using data from reliable sources and creating acidic rain, temperature, dust, and fog artificially to obtain results more accurately. The Coating includes nitrocellulose material dissolved in a solvent mixture of diacetone alcohol, Hexa hydro phenol, ethyl acetate, benzol, and toluene in a spray form to apply on the insulators. The coated insulator was tested in an artificial aging chamber by applying all the environmental effects of the coastal areas for five years using accelerated testing. After performing tests, the results show a 7% decrease in contamination development on the ceramic insulator surface. Hence improving its hydrophobic strength and losses of the power system minimized.

Keywords: Ceramic Insulators, Hydrophobic Coatings, Nitrocellulose, Artificial Aging, Power Loss

1.0 INTRODUCTION

Insulators are one of the basic building blocks of transmission and distribution systems for electric power. They manufacture using ceramic and polymer materials. With the rise in the range of transmission voltage, the pollution severity at the site becomes the most significant factor in determining the insulation level of the system [1, 2]. Outdoor insulators play a vital role in power system accuracy maintenance. For longer times, insulators worked to their fullest in power transmission and distribution lines. A pollution layer is formed on the surface of the insulator when airborne particles and other environmental factors deposit on the surface of insulators installed in different areas such as coastal, industrial and agricultural [3]. Hence, it allows the leakage current flow in wet weather conditions like fog or drizzle [16].

The accumulation of contamination on the outer surface of the insulator on their exposure to marine or coastal environments can make them conduct electricity. In areas nearby the coast, in the morning time, the salt dew deposits on the insulator surface created this contaminated layer [4]. The deposited layer then dries out due to the temperature rise and, it strengthens on the surface. The pollutants deposited on the surface of the insulator are not harmful in a dry climate. On the other hand, the same matter the most in wet weather conditions such as rainfall the high humid climate during which the deposited layer makes the insulator surface the conductor [18,19]. The weather conditions play a vital part in the deposit rate of pollutants and contaminants and the action of insulators as they differ from nearby sea areas to the interior lands [5]. The evaporated salt already present in the environment deposits on the surface of the insulator due to extreme winds. As time passes, other salts and pollutants layers will become thick and strengthened on the insulator's surface [6].

The contamination threat on the insulator depends on the nature of pollutants and the condition of the exterior area. Therefore, examining the causes of contamination and the way the contamination deposits is the foremost priority[20]. Atmospheric pollutants are the key carriers of contamination they; act as a direct lead to contamination and pollutants accumulation on the insulator. Equivalent salt deposit density (ESDD) defines the hardness of the contamination measured in mg/cm.

Possessing strong mechanical and electrical characteristics, the ceramic insulator as an outdoor insulator has some deficiency gaps in specific climatic conditions and factors which weaken its resistance to surface contamination [7]. This decrease in resistance to surface contamination might enhance the flow of leakage current on the surface of outdoor ceramic insulators [16]. Ceramic insulators offer resistance against chemical incursions. Due to their specification, they are easily prone to losses. Also, glass insulator endures more from discharge assaults as compared to porcelain insulators. In tropical surroundings, where climatic conditions are defined by referring to high relative humidity, around 80% of erosion can make its way to damage ceramic insulators [8].

The mechanisms that lead to outdoor insulators aging are complicated. The damages expected from the insulators aging cannot eliminate [9]. Inspecting the factors of leakage current of HV insulators has resulted in many successful paths in the aging analysis. More inspections on the frequency factors of leakage current are allowable to invigilate and diagnose aging of insulators in networked mode [10]. Different salt contamination experiments are conducted on porcelain and silicone rubber insulators to inspect the pollution harshness on their surfaces. These insulators are experimented with and examined at various contamination levels. The voltage applied during the testing is used to propose a wet percentage of the area of the insulator [11]. These factors make it possible to differ the insulation level on insulators in one line as the contamination conditions may vary for all lines [12]. The climatic factors affect the rise of contamination percentage in a field. The application of the silicone-based hydrophobic coating on the surface of the insulator resulted better in comparison to other corrective measures for the avoidance of flashovers due to contamination [17]. RTV silicone rubber coating fusing on strengthened glass insulators is tremendous in later discharge actions and voltage flashover inspection tests [13, 14]. Leakage current is minimum in climatic conditions testing. It indicates the high term action of RTV coated insulators in comparison with the field ceramic insulators [15].

2.0 EXPERIMENTAL CHAMBER DESIGN

The aging analysis proceeds by designing an experimental chamber using an acrylic sheet with 5 mm thickness and a temperature strength of 90 °C. The dimensions are 2x2x2 ft. The reason to use the acrylic sheet is that it has excellent optical clarity, weather ability, and heat resistance. Figure 1 shows the experimental chamber.

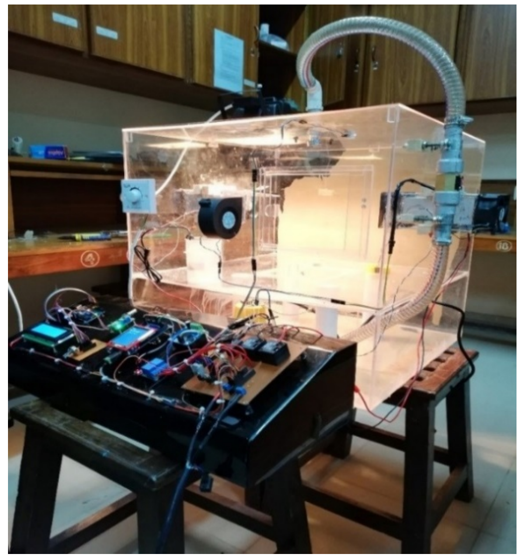

Figure 1 Experimental Test Bench

2.1 Heat And Cold Effect On Ceramic Insulator

Artificially created heat and cold effects performed accelerated aging on the insulator. Installation of two Peltier modules along with heat sinks and fans was performed on the left and right sides of the designed chamber. Also, a 500 W halogen light was installed on the top of the chamber, facing in a downward direction, for boosting the heat effect in the chamber. For measuring temperature values, the DHT22 sensor is used. This temperature affect system is a closed-loop system where one can change the input value of the required temperature using a TFT touch screen and observe changes in the system.

2.2 Raining Effect On Ceramic Insulator

The rainfall effect on ceramic insulator-contaminated surfaces was observed by an artificially designed and tested rainfall setup. A water storage compartment at the bottom of the chamber is present in which a DC submersible pump delivers the water up to the shower. To determine the flow rate of the water flow sensor is used and with this flow rate, we can set the rain rate value in mm/hr. One can change the rain rate by shifting the speed of the pump by using a BTS7960 motor driver with the same. The rain rate input value can be provided by the TFT touch screen. Due to the presence of different salts in rainwater, a pH sensor is measuring the pH values.

2.3 Effect Of Fog On Ceramic Insulator

The artificial fog effect was created by using the Ultrasonic Humidifier mist maker (Air Humidifier Fogger), which utilizes water to create fog and, the DHT22 sensor measures the amount of humidity.

2.4 Effect Of Dust And Ash On Ceramic Insulator

A blower mounted in front of the insulator creates a dust effect in the chamber by throwing it straight on the insulator. The TFT screen containing the input panel controls the amount of dust thrown at the insulator. Figure 2 shows the experimental chamber with control panel's all components are labeled and, Figure 3 shows an accelerated aging chamber depicting weather conditions.

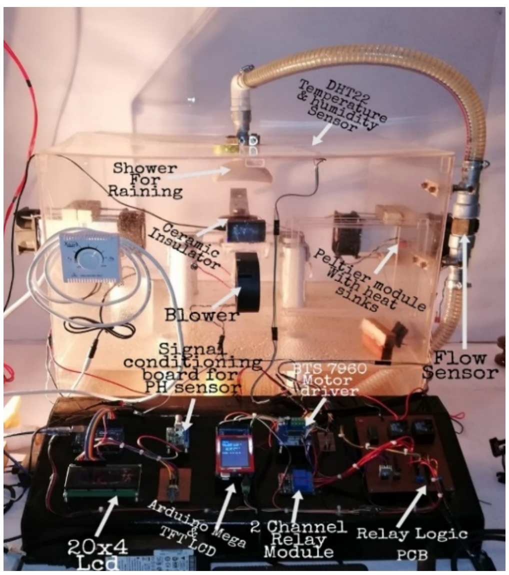

Figure 2 Control Panel Description

Figure 3 Artificial Environmental effects description

3.0 METHODOLOGY

To perform accelerated aging referencing, one of the periods of 5 years (2015-2019) on an insulator sample modeled for an industrialized coastal area, the team designed an experimental chamber. The block diagram shows the complete flow of the experiment. Based on acquired data of rainfall area and minerals present in the rainwater salts has been added. Salts description and quantity are mentioned below in Table 1.

Table 1 Salts for Artificial Raining

Salts	Quantity (in grams)
$MgCl_2$	134.47
KCl	118
$CaCl_2$	94.02

pH of the water is measured using a sensor installed in an experimental chamber. Noted and observed every referenced year temperature, rain rate, and dust deposition alongside humidity. It will repeat itself in three cycles for each year. After performing the aging analysis on five years of collected contamination from the surface of the insulator, its weight will measure the contamination for observation and analysis. Alongside the experiment, the camera will be recording the whole process from inside the chamber. The same will repeat by applying hydrophobic coating on the sample of the insulator. A camera installed in the experimental setup recorded all the steps, alongside the sensors working automatically on the input reading provided. Figure 4 depicts the complete block diagram of the system.

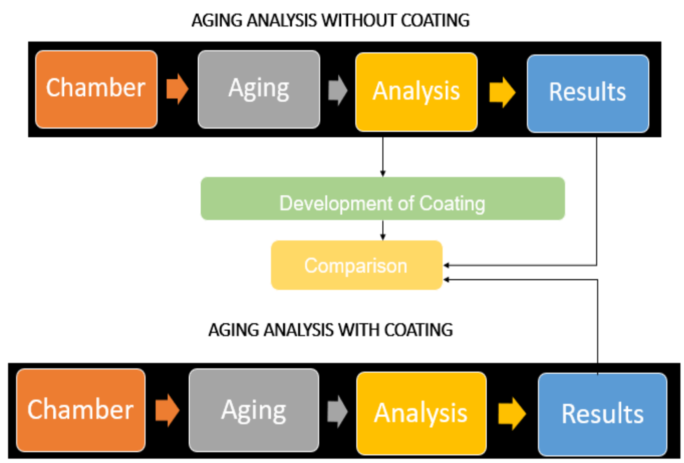

Figure 4 Block Diagram of the System

3.1 Testing

The testing is performed in an experimental chamber on coated and uncoated ceramic insulators for accelerated aging.

3.2 Accelerated Aging Of Uncoated Insulator For Five Years

The accelerated aging process is executed for an uncoated insulator for five years in the experimental chamber within the given data of rain, temperature, humidity, fog, and dust. The feedback sensors controlled and monitored the complete process. Table 2 shows the weather conditions set for an accelerated aging process for each year. Also, figure 5 will be showing images for each year of aging.

Table 2 Weather Input For Accelerated Aging (Uncoated Insulators 2015-2019)

Accelerated Aging for year 2015				
Cycle	**Temperature**	**Rain**	**Humidity**	**pH**
	°C	**mm**	**%**	
1	28°	61	82.6	6.79
2	28°	61	94.6	5.88
3	28°	61	90.6	5.59
Accelerated Aging for year 2016				
1	29°	60	91.5	6.79
2	29°	60	94.1	6.79
3	29°	60	94.6	6.79
Accelerated Aging for year 2017				
1	28°	74	85.1	6.65
2	28°	74	93.4	6.65
3	28°	74	92.6	6.65
Accelerated Aging for year 2018				
1	29°	36	75.9	6.46
2	29°	36	90.2	6.46
3	29°	36	96.2	6.46
Accelerated Aging for year 2019				
1	29°	87	95.7	5.82
2	29°	87	93.5	5.82
3	29°	87	95.2	5.82

Figure 5 Accelerated aging of uncoated insulator as per coastal area weather condition

3.3 Accelerated Aging Of Coated Insulator For Five Years

The Hydrophobic coating containing nitrocellulose dissolved in a solvent mixture of hydrocarbons applied on the insulator sample was kept aside for 16 hours to dry. Figure 6 shows the coated insulator sample.

Figure 6 Insulator after applying Hydrophobic coating

After the aging process on an uncoated insulator, the accelerated aging process for a coated insulator will be done for five years in the experimental chamber on the given weather data of rain, temperature, humidity, fog, and dust. Feedback sensors control and monitor the complete process. Weather conditions set for an accelerated aging process for each year have shown in Table 3. Figure 7 shows the images for each year of the accelerated aging processes.

Table 3 Weather Input for Accelerated Aging (Coated Insulators 2015-2019)

Cycle	Temperature °C	Rain Mm	Humidity %	pH
Accelerated Aging for year 2015				
1	28°	61	84.2	6.52
2	28°	61	94.2	6.52
3	28°	61	95.6	6.52
Accelerated Aging for year 2016				
1	29°	60	90.1	5.77
2	29°	60	92.2	5.77
3	29°	60	93.4	5.77
Accelerated Aging for year 2017				
1	28°	74	85.3	5.58
2	28°	74	90.4	5.58
3	28°	74	94.6	5.58
Accelerated Aging for year 2018				
1	29°	36	94.9	5.34
2	29°	36	94.8	5.34
3	29°	36	96.9	5.34
Accelerated Aging for year 2019				
1	29°	87	94.8	5.21
2	29°	87	96.2	5.21
3	29°	87	93.8	5.21

Figure 7 Accelerated aging of coated insulator as per coastal area weather condition

4.0 RESULTS AND DISCUSSION

An extensive contrast of coated and non-coated insulators finalizes the conclusion. Further details are provided as under:

4.1 Comparision Between Coated and Uncoated Insulators

Water drop test containing minerals ($MgCl_2$, KCl, $CaCl_2$) was performed on coated and uncoated insulators and kept under the same for 10 minutes and dry under artificial sunlight in the aging chamber. The water on the coated insulator vanishes out quickly as compared to the uncoated insulator sample. The ease in water flow helps limit the contamination layer formation eventually, resulting in fewer power losses due to the coating applied. Figure 8 shows the comparison results.

Figure 8 Water drop test on coated and uncoated insulators

After performing the complete analysis for the aging of coated and uncoated insulators, figure 9 shows the contamination collected from both insulator's surfaces. Afterward, weighing contamination and obtaining the difference in the tray weight from the total weight of tray (i.e., including contamination), the contamination weight is 0.14 gm for coated insulators and 0.21 gm for uncoated insulators.

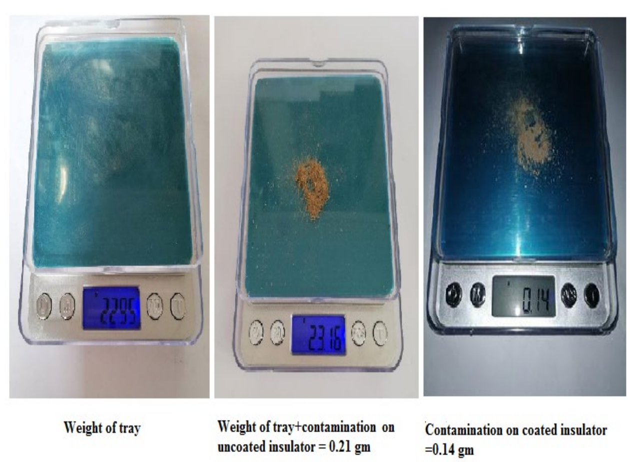

Figure 9 Weight of contamination collected from coated and uncoated insulators after aging

Table 4 shows the weight of contamination collected from coated and uncoated insulator samples. Showing the contamination weight difference for uncoated samples proves the strong possibility of strengthening the hydrophobicity of the insulator sample and helps in reducing power loss in the coastal area power distribution network.

Table 4 Comparison of Results

Insulator Samples	Contamination Weight (gm)
Uncoated Insulator	0.21
Coating Insulator Sample	0.14
Difference for Coating	0.07

5.0 CONCLUSION

This analysis depicts the power losses reduction of ceramic insulators in polluted conditions in the coastal areas. An experimental chamber designing initiated to perform tests on ceramic insulators in five artificial environments setups like rain, temperature, humidity, fog, and dust conditions. Coated and uncoated ceramic insulators undergo different aging tests by implementing artificial environments. The accelerated aging analysis tests on ceramic insulators have depicted how much the application of the hydrophobic coating on the insulator sample can decrease its power loss and leakage current flow. Afterward, noting readings for the tests in three cycle data for each year from 2015 till 2019, all the values listed down. After careful observation of results, conclusions can state as power losses reduction processes on the application of the hydrophobic coating on the insulator's surface will easily let go water, dust, and other contaminants flow off the surface, progressing to the reduction in leakage current and losses. Also, it extends the lifetime of the insulator and increases the reliability of the power distribution network in densely industrialized coastal areas.

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