

# A Study of the Cleansing Effect of Precipitation and Wind on Polluted Outdoor High Voltage Glass Cap and Pin Insulator

CHIBUIKE ILOMUANYA<sup>1</sup>, AZAM NEKAHI<sup>1</sup>, AND SHAHAB FAROKHI

Department of Electrical and Electronic Engineering, Glasgow Caledonian University, Glasgow G4 0BA, U.K.

Corresponding author: Azam Nekahi (azam.nekahi@gcu.ac.uk)

**ABSTRACT** In this work, the extent of natural cleansing effect of rainfall, wind and fog or a combination of these on an insulator string were investigated. Results showed that pollution losses progress with time, with a considerable fraction of losses occurring within 15 minutes of testing. While wind alone played little or no role in surface cleansing, it increases the extent of cleansing by rainfall. The topsides of insulators were found to be more affected by natural cleansing compared to the underside. Equivalent Salt Deposit Density (ESDD) and Non-Soluble Deposit Density (NSDD) measurements were carried out. ESDD was found to be higher in the lower disc irrespective of the weather condition the insulator string has been subjected to. NSDD measurements established no pattern on how natural cleansing was impacted by disc position on a string, demonstrating the random nature of pollution-cleansing cycle of outdoor insulators. Insulator performance was assessed by high voltage AC tests and monitoring of partial discharge events using Radio Frequency antennas and a High Frequency Current Transformer (HFCT). Measured output by the HFCT showed that leakage current decreases uniformly with time, and the speed at which this occurs is an indication of the intensity of natural cleansing activity.

**INDEX TERMS** Flashover, insulators, partial discharges, pollution.

## I. INTRODUCTION

Pollution is a major cause of insulation breakdown and increases the likelihood of a flashover incidence in affected insulators. According to [1], consideration for pollution flashover in design and construction of HV transmission systems has assumed priority in recent times. The circumstances surrounding a high voltage insulator culminating in the contamination deposition and accumulation, and the fluctuating wetting and cleansing of the insulator, are a result of interaction of several meteorological characters with each other and with the dielectric surface. The nature and constituents of insulator pollution is not solely dependent on anthropogenic elements but is greatly affected by the transport flow characteristics of pollutants [2]–[4].

The severity of pollution of electrical equipment is classified by “pollution degree” according to the quantity of condensation and dry pollutants present in each environment [5] and ranges from pollution degree 1 to pollution

degree 4. Pollution degrees 3 and 4 are more prevalent in the work environments of interest in this study and includes conductive pollution and dry non-conductive pollution that becomes conductive when exposed to condensation, as well as persistent conductivity caused by conductive dust, rain, fog or snow [6]. These are typical of industrial areas, construction sites and outdoor electrical equipment.

Pollutants range from inorganic matter (dust, smoke, fumes) and organic matter (such as bacteria, pollens, plant spores) to water forms (fog, mist, rain) [7]. Water is considered a pollutant as without it, most solid pollutants will not be conductive. A typical sample of rainwater is slightly acidic, due to the presence of carbon dioxide in the atmosphere. Hence, acidity, in addition to the quantity of dissolved salts, determine the conductivity of rainwater [8]. But water also play a significant role in limiting pollution accumulation by providing natural washing/ cleansing of insulators through rainfall [9]. Pollution particles are of two types – solid pollution with non-soluble component and pollution with soluble component. Severity of pollution can be estimated by calculating the NSDD and the ESDD respectively.

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This is a standard method that offers an efficient offline pollution monitoring technique. The two variables combined provide information on the site pollution severity which is a classification of the extent of pollution of a region under investigation as described in the International Electrotechnical Commission (IEC) and International Council on Large Electric Systems (CIGRE) technical specifications [10], [11]. Soluble particle contamination has a higher impact on an insulator's performance when compared to contamination from non-soluble particles.

Pollution on insulator surface is known to cause a drop in resistance, increase in leakage current (LC) and partial discharges (PD) which is a reliable indication of imminent insulator failure (flashover) [12], [13]. PD monitoring therefore offers a reliable method of assessing pollution severity in real time and have been widely used in insulator pollution level monitoring in various research works. PDs emit light, heat, sound waves and radio waves and may be characterized by the flow of leakage current along the surface of the insulator. Based on these, PD detection can be achieved through different measurement techniques ranging from the use of High Frequency Current Transformers (HFCT), electro-optical sensors, Infra-red camera, ultrasonic sensors, Radio Frequency (RF) antennas and superficial resistance measurement [14]–[19].

In this work, a non-standard method is used in calculating surface pollution losses to better understand the extent of natural cleansing undergone by the test insulator when exposed to precipitation and wind elements. This method, though crude (simple), is novel and our review of previous work did not reveal its use anywhere. The concept of measuring pollution losses by volume as presented in this article is also unconventional and new. This method requires the use of a precision balance to weigh a polluted insulator before and after exposure to simulated rain, fog and wind. The precision balance used in this work has a readability of 0.01g and a measurement capacity of 4200g. Simultaneously, partial discharges monitoring is carried out using standard online monitoring techniques – radio frequency antennas to monitor RF signals and HFCT to monitor leakage current on the ground conductor. A combination of these methods will help better understand the relationship between emitted radio frequency signals and leakage current from the same PD event. Overall, with this test setup, it is possible to identify the transition from reduced surface conductivity due to moisture absence to the critical point of maximum conductivity and probable flashover due to precipitation and finally to minimal conductivity due to surface cleansing.

## II. TEST INSULATOR, SETUP AND PROCEDURE

### A. CAP AND PIN INSULATOR

Toughened glass cap and pin insulators predominate in overhead line tension and suspension sets above 33kV. Their biggest advantage is the tendency to achieve nearly any creepage distance by putting together the required number

of single units to form a string [20]. This, coupled with the superiority of glass over porcelain, including its ability to easily detect any flaws in molding/ production and lower cost of material, bolsters the choice for this very design. Typical surface incline greater than 5 degrees enhances self-cleansing of the pollution accumulation resistant smooth hard top surface, coupled with undersides which varies considerably in shape, subject to leakage distance and aerodynamic requirements [21]. Cap and pin insulators fall into the cemented cap type construction of suspension type insulators and are more widely deployed even though it has been argued that the Hewlett type of design offers far superior reliability as compared to the cemented cap disc type [22].

### B. PARTIAL DISCHARGE MONITORING

Two types of transducers were employed in this work – a high frequency current transformer (HFCT) and radio frequency antennas. The current transformer selection was relatively straightforward. The major factors considered were frequency range, cost and availability. Since this work aims at capturing PDs in the VHF range (30MHz – 300MHz) of the electromagnetic spectrum, the ETS-Lindgren model 93686-8 current transformer was chosen. This is a versatile clamp-on probe capable of accurate measurement of common mode radio frequency current on a wire in the frequency range of 10kHz to 250MHz. While the maximum frequency measurable is less than the maximum VHF frequency, this probe was nonetheless chosen for its availability and robustness. Thus, our measurement range in this work is redefined as 30MHz to 250MHz. The technical specifications for the HFCT are presented in Table 1.

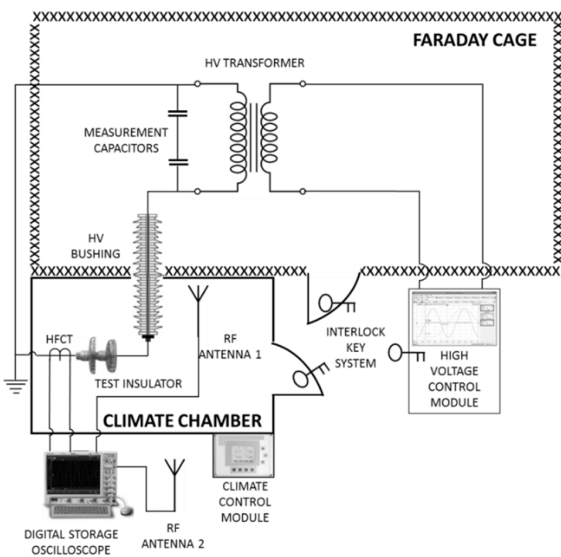
TABLE 1. Current transformer specifications.

| Electrical Specifications       |                                       |
|---------------------------------|---------------------------------------|
| Minimum frequency               | 10kHz                                 |
| Maximum frequency               | 200MHz                                |
| Load impedance                  | 50Ω +/- j0                            |
| Maximum power current (400Hz)   | 300A                                  |
| Maximum power current (DC-60Hz) | 300A                                  |
| RF current range (RF CW)        | 0A – 62A                              |
| RF current range (Pulse)        | 62A                                   |
| Transfer impedance              | 8Ω + 3dB                              |
| Sensitivity under rated load    | 0.125μA with 1μV sensitivity receiver |

In selecting an antenna to accurately measure electromagnetic emissions from PD activity, fundamental parameters of bandwidth, gain and directivity were top considerations [23], [24]. Other considerations were economical – cost versus availability. The Watson W-881 super gainer which was readily available in the laboratory was chosen for this work. It offers an ergonomic design and has a frequency range of 25MHz to 1900MHz. It measures 41cm in length and is connected to the data acquisition and signal processing unit through its BNC connector.

**C. TEST SETUP**

The experimental setup is shown in Figure 1. The test insulator string of two standard glass disc cap and pin insulator is pre-contaminated with sulphuric acid and kaolin mix before being mounted in a specially made wooden stand in an environment chamber. The transformer is secured in an earthed enclosure and an interlock key provides access to the gated enclosure. This ensures that the HV area is inaccessible when the transformer is energized and the supply from the control panel is switched off when the enclosure gate is open. The same applies to the environment chamber. The HV terminal of the transformer secondary is passed into the environment chamber through an oil impregnated HV bushing. The terminal is connected to the pin of the test insulator using specially made cables and bolts, ensuring that the minimum clearance distance is maintained between component parts at high voltage and the metal walls of the environment chamber. The ground wire is connected to the cap of the insulator with the assistance of the insulator stand. The HFCT is clamped over the ground wire to measure the leakage current. One RF antenna is positioned inside the environment chamber, 1 meter from the test insulator with the aid of a tripod stand and clamps. Another RF antenna is positioned at the same distance from the test insulator but outside the chamber. All sensors are connected to dedicated channels of a digital storage oscilloscope (DSO) with the aid of coaxial cables. Protective circuits are placed between the measurement devices and the DSO to protect it from flashover induced damage.



**FIGURE 1.** Experimental setup.

**D. ARTIFICIAL POLLUTION**

The pollution substance is prepared by mixing a 100% concentration of sulphuric acid with water and kaolin as shown in Table 2 below. The pollution is then meticulously applied to the insulators by completely immersing the insulator in

**TABLE 2.** Pollution mixture formulation.

| 100% H <sub>2</sub> SO <sub>4</sub><br>(Part) | Water<br>(Part) | Resultant acid<br>concentration (%) | Resultant acid<br>quantity (g) | Kaolin quantity<br>(g) | Pollution<br>severity | Conductivity<br>(µS/cm) |
|---|-----------------|-------------------------------------|--------------------------------|------------------------|-----------------------|-------------------------|
| 1   | 10000           | 0.01                                | 100                            | 4                      | Very light            | 100                     |
| 1   | 2000            | 0.05                                | 100                            | 4                      | Light                 | 165                     |
| 1   | 1000            | 0.1                                 | 100                            | 4                      | Medium                | 485                     |
| 1   | 500             | 0.2                                 | 100                            | 4                      | Heavy                 | 837                     |

a bowl containing the acid-kaolin suspension for at least 1 minute after which it is brought out and left for as much time as required to dry. Prior to the application, the insulators were thoroughly washed to remove any impurities present.

**E. STUDY OF NATURAL CLEANSING EFFECT**

An investigation is carried out on the effect of natural cleansing due to fog, rain and combined rain and wind. This is achieved by comparing the pollutant weight before and after test. To calculate the pollutant weight before test, the insulator is weighed before contamination and weighed again after contamination and drying using a precision balance. The contaminated insulator weight is then subtracted from its pre-contamination weight to give the pollutant weight before test. In this case the top and bottom surfaces are added together.

The insulator string is then mounted in the chamber and the temperature of the chamber brought to 27°C±5%. The test voltage is applied instantaneously to the test piece. Rainfall or rainfall plus wind is introduced within 5 secs and allowed to run for 15 minutes. If a flashover occurred within this time, the electrical characteristics are recorded. After this, the test insulator is left to dry at ambient for 12 hours, physically examined and weighed again. The ESDD and NSDD are measured and recorded as described in BS EN 60507: 2014 standard [25]. The percentage pollutant loss is calculated by subtracting the measured weight (sum of top and bottom measurements) from the deposit weight before test (difference of clean insulator weight and polluted insulator weight).

$$\frac{\text{pollutant weight} - \text{residue weight}}{\text{pollutant weight}} \times 100 \quad (1)$$

The chamber is left to return to ambient conditions. In these cases, the insulators are used only once. The time to failure and pollution weight loss are recorded.

The cleansing effect of fog is investigated by the same process at 27°C temperature, and 100% relative humidity and results compared to rainfall and rainfall plus wind effects. In the case of fog wetting, there is no pollutant abrasion from contact as in the incident of rain and wind. However, the considerable exposure to fog and resultant saturation and condensation on the outer surface of the polluted insulator causes moisture to trickle down the insulator sheds, leading to a progressive washing of some pollution materials off the surface.

A test to investigate total surface cleansing was carried out by subjecting a string of heavily polluted test insulator to

8 hours of wetting under fog, rainfall and combined rainfall and wind.

### F. ESDD AND NSDD MEASUREMENTS

The pollution severity of our insulator was determined by measuring the equivalent salt deposit density (ESDD) and the non-soluble deposit density (NSDD) of materials present. This was done by thoroughly washing the polluted insulator with distilled water and collecting contents into a beaker, while ensuring that no further contamination is caused in the process. The conductivity of the water containing contaminants is measured and guidelines of BS EN standard 60507 followed to calculate the ESDD. The non-soluble contents are then retrieved through filtration and weighed to calculate the NSDD.

For each pollution category (degree), 8 insulator discs were contaminated to form 4 strings of two insulators. The ESDD of the first string was calculated. The second string was subjected to rain and ESDD/ NSDD measured afterwards. Following on, the third and fourth string underwent the same process but under rain plus wind and fog weather conditions, respectively. From these, the percentage pollution weight loss is calculated.

### G. DISCHARGE CHARACTERISTICS STUDY

To study the relationship between discharge phenomenon and leakage current, the insulator string was subjected to prolonged testing at 22kV for 8 hours under saturated fog condition and the leakage current measured using a HFCT.

## III. RESULTS AND ANALYSIS

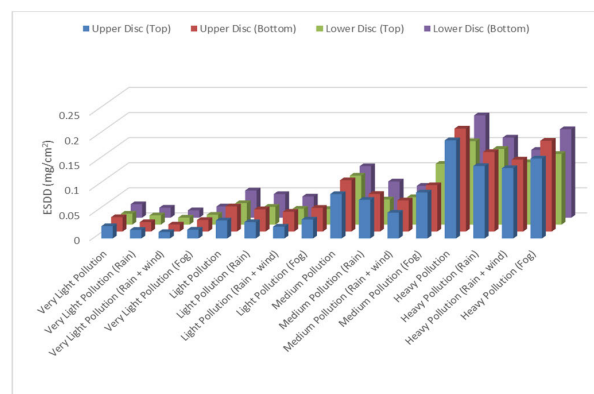
The insulator surfaces were physically examined after contamination and after subjection to various weather conditions. In general, whilst the top and bottom sides of both upper and lower discs were found to be uniformly polluted after the application of the pollution layer, the top side of the discs were observed to be in cleaner condition than the underside after exposure to elements in the natural cleansing simulations. This is typical of disc insulator strings in the field after rain with disparity increasing as the rainy season progresses. It is basically due to the orientation of the insulator string and direction of rain and supports results of previous research work in our literature review.

With respect to the relationship between disc position on the string and pollution losses due to natural cleansing, the results were considered inconclusive even though for most of the test, the lower discs experienced more pollution losses. This is because our string was limited to 2 discs and to best investigate this, a minimum of 3 disc will be required. However, the permissible clearance distance for assembly in our chamber would not allow for this. But on the contrary, it is expected that for vertically aligned discs exposed to rain in the field, the topmost disc would be relatively cleaner than the rest. The discrepancy between experimental results and likely field results could be attributed to further limitations of

nozzle number, position, and direction of precipitation as it strikes the insulator surfaces.

### A. ESDD RESULT

The ESDD results from studying the effects of rainfall, combined rain and wind, and fog on the polluted insulator are presented in Figure 2. It can be observed that irrespective of the weather condition the insulator was exposed to in the environment chamber, ESDD is majorly higher in the lower disc. This is true for 97.5% of 80 measurements. Furthermore, the ESDD is even higher on the bottom surfaces of both the upper and lower insulator discs with only 5% of cases differing. It could be observed that the combined action of rainfall and wind has higher cleansing effect than rainfall alone while fog exposure has the least impact on washing of pollutants from the equipment surface. After subjection to rainfall and wind, the pollution severity is reduced to the next level of severity in most cases or remains in the same pollution category in other cases. For instance, a heavily polluted insulator subjected to rainfall or rainfall plus wind is found to either be of medium pollution level after exposure or remained heavily polluted.



**FIGURE 2.** ESDD results of top and bottom surface of both upper and lower discs in a two-disc string.

When the insulator was subjected to prolonged exposure, more significant cleansing of pollutants was observed. Rainfall and wind effect very nearly washed all pollutants off as noted from the ESDD calculations, while fog brought about a three-quarter reduction of ESDD. This is shown in Figure 3 below.

### B. NSDD RESULT

The calculated non-soluble deposit density for various pollution severities under different environmental conditions are shown in Figure 4. Similar to the ESDD results, the NSDD measured for rainfall and wind together is less than the measurement for rainfall only. Both are significantly less than NSDD measured for fog effect. It goes a long way to show that whilst the cleansing effect of wind alone at 3m/s speed may not compare to its role in pollution accumulation, it plays a huge part in cleansing when combined with rain. This is

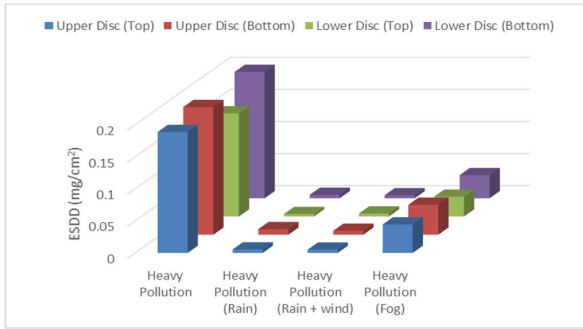


FIGURE 3. ESDD results of top and bottom surface of both upper and lower discs for prolonged exposure of a two-disc string.

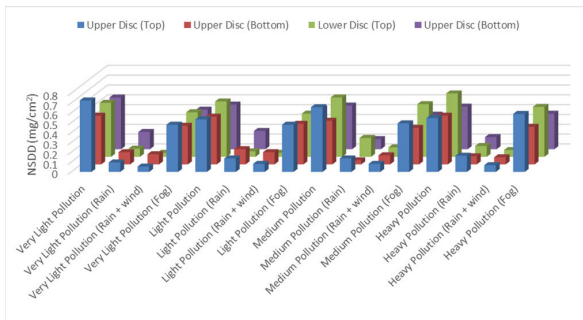


FIGURE 4. NSDD results of top and bottom surface of both upper and lower discs in a two-disc string.

because it increases the velocity of raindrops in motion and consequently the force at impact with the insulator surface, which results in more abrasion. However, the extent of cleansing between the top and bottom surfaces in this case is random as compared to ESDD measurements. Also, in contrast to ESDD measurement, the degree of cleansing between upper and lower discs were random in all cases of weather effect and pollution severity. This very well demonstrates the random nature of pollution-cleansing cycle of outdoor insulators in harsh environments.

Again, when the equipment was subjected to prolonged exposure to weather elements, the NSDD reduced more significantly but in similar proportions as shown in Figure 5.

Similar to ESDD, rainfall and wind were highly impactfully and brought about, near-total cleansing of the equipment

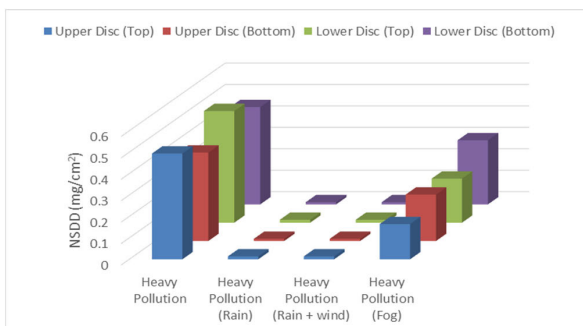


FIGURE 5. NSDD results of top and bottom surface of both upper and lower discs for prolonged exposure of a two-disc string.

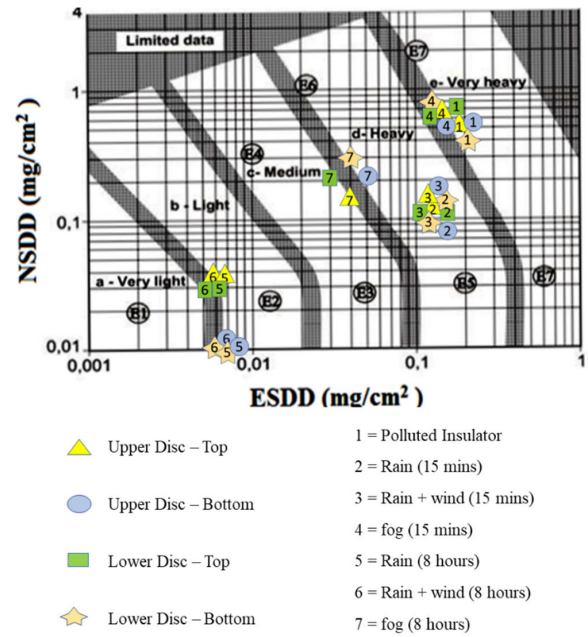


FIGURE 6. Relationship between ESDD and NSDD for heavy pollution (very heavy pollution) under various precipitation conditions.

surface contaminants while fog halved the contamination severity.

Figure 6 presents a simultaneous illustration of ESDD and NSDD on a standard pollution severity chart calculated for heavy pollution under minimal exposure and prolonged exposure to weather elements. From the chart, five clusters can be observed. The difference in severity between a minimal and a prolonged exposure of insulators to rain, wind, and fog is obvious at first glance. The cluster with 1's and 4's depicts the slight impact of fog on surface cleaning when exposure is minimal.

The cluster with 2's and 3's shows the additional washing of pollutants brought about by the presence of wind in addition to rain when tested for 15 minutes. The group of 7's shows the result of prolonged exposure to fog on the top and bottom surfaces of both upper and lower insulator disc. Comparing this to grouping for 4's, it is clear that the prolonged exposure has reduced pollution severity from heavy/ very heavy to medium. The two clusters of 5's and 6's show the distribution of pollution severity for tops and bottom surfaces of the upper and lower discs respectively after prolonged exposure. While ESDD is higher for bottom surfaces, NSDD is less. In summary, the test clearly demonstrates the random nature of surface cleansing if under controlled environmental conditions.

### C. POLLUTION LOSS

The graph of percentage pollutant losses for upper and lower insulator discs are shown in Figure 7.

In general, lower discs lost more pollution. This results from the combined effect of weather elements and trickling down from the upper disc to the lower disc causing more

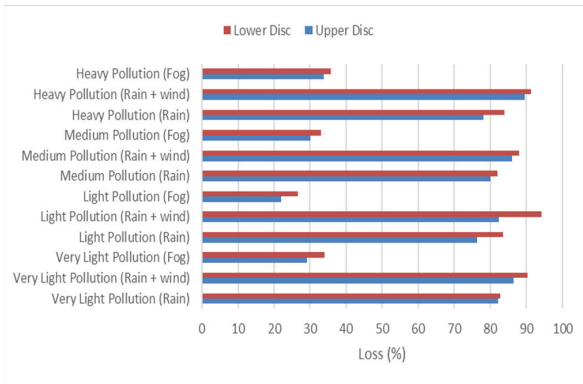


FIGURE 7. Percentage pollutant loss upper and lower discs.

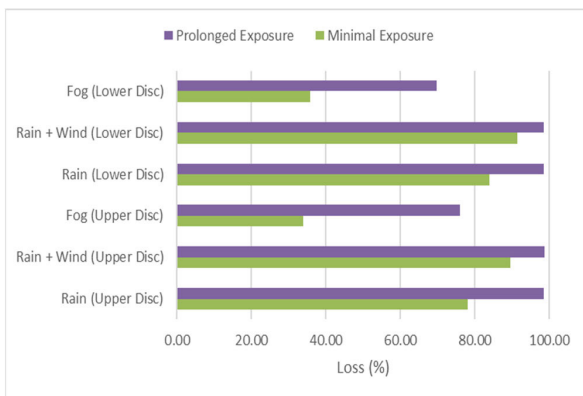


FIGURE 8. Comparison of prolonged exposure to minimum exposure of insulators to weather element in natural cleansing study.

severe natural cleansing. If the string were to be horizontally or obliquely aligned, the dripping effect will not be felt on the lower disc and depending on the angle of inclination, pollution loss may be more or less in the lower disc. Another observation that can be made is that the cleansing effect by the various weather elements are approximately the same irrespective of the pollution severity. While the constituents of pollutants may vary in field conditions, results here have shown that if a polluted insulator is subjected to these weather conditions, the surface cleansing experienced will follow the pattern established here with fog having the least impact. This in no way predicts the electrical characteristics of the equipment.

Figure 8 compares pollutant losses between insulators subjected to minimal exposure and those subjected to prolonged exposure. Prolonged exposure brought about more losses with the most significant being under fog conditions where it more than doubled. Again, it can be observed that a combination of rainfall and wind led to a near-total surface cleansing.

**D. TIME FACTOR OF POLLUTION LOSS**

To determine the relationship between pollution losses and time under the external influence of rain, wind and fog, test times were varied, and pollution losses calculated. Each test was repeated 3 times and the average of the 3 taken. In these cases, ESDD and NSDD were not measured. A time interval

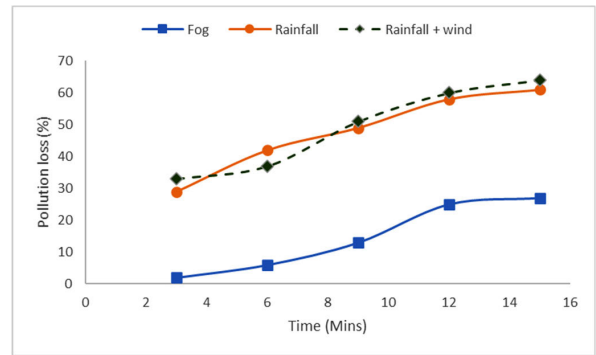


FIGURE 9. Percentage pollution loss as a function of time.

of 3 minutes was chosen for this. It was ensured that in each case, the string maintained approximately the same position to ensure the three measures of representivity, repeatability and reproducibility. The result is shown in Figure 9.

It is observed that losses progress with time and under the test condition, a significant proportion of losses occur within 15 minutes of testing. This is dependent on the flow rate of precipitation, its direction of travel and the glutinous property of the pollutant.

**E. EFFECT OF VARYING THE POLLUTION MIXTURE**

The adherence of pollutant to the test equipment for our pollution mix is highly dependent on the constituents of the pollutant. To determine the extent to which the quantity of kaolin affects our test results, different ratios of acid to kaolin mixture were tested. These are shown in Table 3 below.

As shown in the table, the quantity of acid was kept constant while the amount of kaolin was varied. This had little or no influence on the conductivity of the pollutant which demonstrated that conductive properties of our mixture in this study is mostly dependent on its soluble components. The percentage pollutant losses for the various mixtures are shown in Figure 10.

From the graph, it is evident that the extent of natural cleansing is inversely proportional to the quantity of kaolin in the pollution mixture. This is simply because the more the grammage of kaolin in the mixture, the better the pollutant adheres to the surface of the insulator making it more resistant to weather elements and tougher to be washed off. An important confirmation from this as observed from the graph, is that wind indeed, heightens the severity of cleansing brought about by rainfall.

TABLE 3. Measured conductivity for various pollution mix.

| H <sub>2</sub> SO <sub>4</sub> (0.1ltr) | RATIO |            | Conductivity (μS/cm) |
|---|-------|------------|----------------------|
|   |       | Kaolin (g) |                      |
| 100                                     | 2     |            | 172                  |
| 100                                     | 4     |            | 169                  |
| 100                                     | 6     |            | 175                  |
| 100                                     | 8     |            | 179                  |
| 100                                     | 10    |            | 171                  |

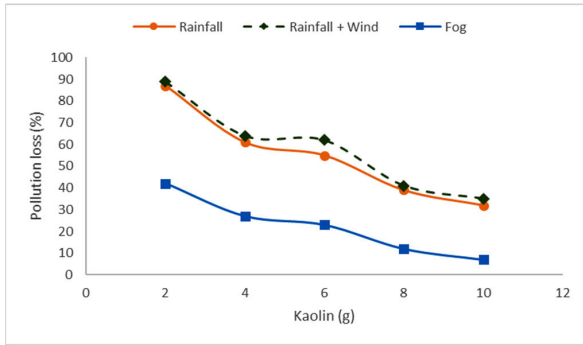


FIGURE 10. Percentage pollution loss as a function of kaolin.

F. DISCHARGE CHARACTERISTICS RESULT

The result of the test is shown in Figure 11. A steady leakage current can be observed for the unpolluted insulator. In the case of polluted insulators, it can be observed that leakage current decreases uniformly with time in both cases. This is an indication of the natural cleansing effect of fog on insulators. The discharge characteristics for the 3 states of insulator pollution tested are presented in Table 4.

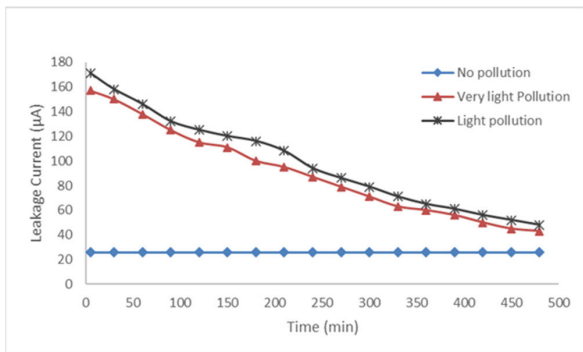


FIGURE 11. Leakage current as a function of time.

TABLE 4. Discharge characteristics for unpolluted and polluted insulators.

| Pollution severity   | Maximum leakage current (µA) | Discharge event                   |
|----------------------|------------------------------|-----------------------------------|
| Unpolluted           | 26                           | Corona effect at HV end           |
| Very light pollution | 157                          | Moving discharge on glass surface |
| Light pollution      | 171                          | Moving discharge on glass surface |

G. LEAKAGE CURRENT WAVEFORM ANALYSIS

When a polluted insulator string was subjected to flashover test at 22kV, PD activities were observed. These PD activities occurred both in the negative and positive half cycles close to the applied voltage peak value. Figure 12 below shows the time domain scope of the signal which contain some discrete PD components together with a relatively high level of background noise, as captured by our three measurement devices.

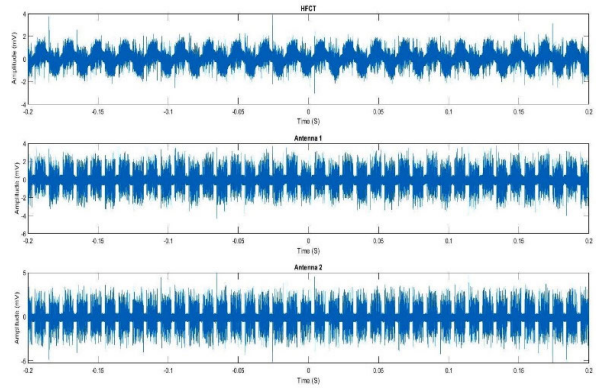


FIGURE 12. Waveform of signal with discrete PD and background noise.

The magnitude of strong discharge waveform measured ranged from ~2mV to 5mV. The continuous partial discharge activities witnessed at a sustained test voltage of 22kV neither resulted to a damage to our test insulator nor lead to flashover of the equipment even when left to run for over 3 hours.

Comparing signals from the three devices, the waveforms of the two antennas are very similar as compared to that of the HFCT. The magnitude of the measure PD signals was within the same approximate range across all three devices.

IV. CONCLUSION

The natural cleansing activity of precipitation and wind has been identified in this work as a highly crucial and economically important process in insulator pollution accumulation and monitoring. While this process is not within human control, it helps reduce human intervention in the form of manual cleaning of polluted equipment. Through laboratory simulations and experience, this research work studied natural cleansing activities to improve our knowledge of how this event affects insulators based on their position on a string and based on the face (side) of the insulator. ESDD and NSDD measurements were also carried out to understand how natural surface washing affects these components of pollution.

Test results showed that regardless of the weather elements the insulator string was exposed to in the environment chamber, ESDD remained higher in the lower disc. Also, ESDD was found to be higher on the bottom surfaces of both the upper and lower insulator discs. It was observed that the combined actions of rainfall and wind had higher cleansing effect than rainfall alone while fog exposure has the least impact on washing off pollutants from the equipment surface. Again, it was revealed that the degree of natural cleansing is inversely proportional to the quantity of kaolin in the pollution mixture while pollution losses progressed uniformly with time.

A study the relationship between discharge phenomenon and leakage current revealed that for polluted insulators, LC decreases uniformly with time irrespective of the severity of pollution. This confirms that subjecting the insulator to prolonged fog exposure results in surface cleansing.

The study of natural cleansing effect in this work therefore demonstrates how accumulated pollution diminishes with time under the influence of weather elements. This will aid asset owners estimate times for artificial cleaning of insulators in the field.

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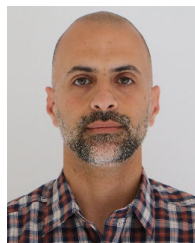
**CHIBUIKE ILOMUANYA** received the B.Eng. degree in electrical and electronic engineering from the Federal University of Technology Owerri, Nigeria, in 2008, and the M.Sc. degree in applied instrumentation and control, and the PgCert degree in research methods from Glasgow Caledonian University, U.K., in 2012 and 2016, respectively. He joined as a Lecturer at the Faculty of Engineering, Imo State University, in 2013. He is currently a Ph.D. Researcher and a Graduate

Teaching Assistant with the Electrical Power Engineering Department, Glasgow Caledonian University. He is a member of the Institution of Engineering and Technology and a Chartered Engineer of the U.K. Engineering Council. His research interests include outdoor high-voltage insulators under pollution conditions and partial discharge monitoring techniques.



**AZAM NEKAHI** received the B.Sc. degree in electrical engineering from the Amirkabir University of Technology (Tehran's Polytechnic), in 2004, and the master's and Ph.D. degrees from the Université du Québec, Canada, in 2007 and 2011, respectively, within the NSERC/Hydro-Québec/UQAC Industrial Chair on Atmospheric Icing of Power Network Equipment (CIGELE). She worked as a Research Fellow at Glasgow Caledonian University (GCU), from 2012 to 2014.

Since 2014, she has been a Lecturer with the School of Computing, Engineering and Built Environment, GCU. Her main research interests include outdoor insulation, partial discharge, and spectroscopy. She is an active member of IEEE-DEIS and WIE. In 2012, she was appointed as a Liaison between IEEE Dielectrics and Electrical Insulation Society (DEIS) and IEEE Women in Engineering (WIE) Committee.



**SHAHAB FAROKHI** received the B.Eng. and master's degrees in electrical engineering from the Amirkabir University of Technology (Tehran Polytechnic) and the Ph.D. degree from the Université du Québec, Canada. After a Post-doctoral Fellowship with the NSERC/Hydro-Québec/UQAC Industrial Chair on Atmospheric Icing of Power Network Equipment and a Lectureship with the same university, he joined the Faculty Member of Glasgow Caledonian University, in 2012. He has authored or coauthored several scientific contributions, including a book. His current research interests include insulation coordination, outdoor insulators under icing and polluted conditions, and electromagnetic transients in power systems. He is an active member of IEEE-DEIS and the IEEE Insulators Working Group for selection of transmission and distribution insulators with respect to icing.

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