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Effect of Environmental Pollution on Performance of Rivers State University Injection Substation, Port Harcourt.

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***ABSTRACT**: This research work examined the effect of environmental pollution on performance of Rivers State University injection substation. The effect of environmental pollution in the insulators is one of the main factors threatening the safe operation of the injection substation worldwide, which can lead to shutdown of the power line and equipment failures. An existing data were collected from Port Harcourt Electricity Distribution Company (PHEDC) and were formulated to determine the critical voltage and critical current equation for the purpose of simulation. The critical arc length was reduced to 1.9 cm and the leakage current was also reduced to 0.013 A for the plate position of the glass insulator. The pollution resistance per unit length value was reduced to 756.04 Ω and the leakage length was also reduced to 3.0 cm for the plate position of the glass insulator, this show that the pollution resistance per unit length depends on the leakage length. Furthermore, the results of the experiments show that the Equivalent Salt Deposit Density (ESDD) and salinity of the solution has a positive significant impact for contributing the severity level of salt deposit in the substations, the result of the improved case study shows that the ESDD value was reduced to 0.025 mg/cm^2 which shows that the ESDD and salinity of the solution were categorized under light pollution level according to International Council on Large Electric Systems (CIGRE) pollution for the first to the sixth plate positions of the glass insulators respectively. It is highly recommended that critical remedial measures should be implemented in order to overcome problems due to pollution such as manual cleaning of insulators, washing the insulator on a regular basis to prevent build-up of pollutants, corn blasting (dry cleaning) and application of silicon grease.*

***KEYWORDS**: Equivalent Salt Deposit Density (ESDD), critical arc length, leakage length, salinity of the solution, critical current, pollution resistance per unit length*

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I. INTRODUCTION

The flashover insulators are constantly subjected to environmental stress cause by environmental conditions such as weather, ambient temperature and moisture that directly affect the performance of injection substation. For instance, moisture components like rain, dew, and fog etc, significantly causes arcing and lower the surface resistance of the insulators. According to [1], with the presence of pollution, the insulator surface resistance is reduced drastically. Moreover, the reduction of surface resistance may cause increased leakage current to flow on the surface and dry band arcing to take place. The insulator begins to fail when the pollutants that exist in the surface of the insulator and combine with the humidity of the rain, dew or fog. However, the mixture of the pollutants, plus the humidity form a layer that can become conductor and allow the flow of currents that will facilitate the conditions of short circuit which led to negative effect on the insulation system of power lines and substations. These effect is due to a decrease of the resistance of the insulator surface for a long period of time causes degradation of the insulator surface that could eventually lead to flashover and consequently failure of line [2]. Unless there is a natural cleaning or an adequate maintenance, the electrical activity will be affected by a possible flashover in the insulator.

Recently, Engineers, researchers, and manufacturers have profound and tried to solve possible problem which lead to pollution in the substation using mathematical models such as Obenaus's model to predict the critical voltage, arc resistance, critical current, surface conductivity, voltage gradient, maximum voltage etc.

A possible outage in a high voltage substation usually corresponds to a severe impact to the power system [3]. Therefore, from the reliability point of view, substation maintenance has a considerable importance, which increases with the corresponding increase of the correlated transmission circuits' number. Pollution of high voltage insulators is a problem experienced by many utilities worldwide. It originates from the environment and is capable of deteriorating the performance of outdoor insulation, under the nominal voltage stress.

The first step of the pollution phenomenon is the accumulation of contaminants on the insulation surface [4]. In the case of hydrophilic insulation (e.g. porcelain), the presence of a wetting mechanism (e.g. rain, fog, humidity) transforms the contaminants layer into a conductive film which permits the flow of leakage current through it. The flow of current heats up the surface and localized changes in the surface conductivity occur. Areas of higher resistance are formed, called dry bands, and discharges may appear (dry band arcs) which can ultimately lead to a complete flashover of the insulator surface [4].

Several methods have been applied to cope with the pollution problem [5]. The most usual suppressing method is the cleaning of insulators. Other methods employ different insulator and substations design. Polymer insulators and coatings can also be employed in order to prevent film formation, by retaining moisture in the form of droplets.

However, periods of hydrophobicity loss and recovery are observed [6]. In addition, discharges may appear from and between scattered water droplets. One of the polymer materials frequently used as coating is the Room Temperature Vulcanized Silicone Rubber (RTV SIR).

The power system in Rivers State University suffers from intense pollution problems due to several factors [7]. Several techniques have been employed to cope with the problem [8]. The use of RTV SIR coatings is thoroughly investigated since a large scale application of such coatings has been issued by the RSU Power Systems. In addition, data from a field leakage current monitoring system that has been installed in a 33/11KV Substation are presented and the performance of coated insulators is further investigated.

1.2 Problem Statement

Pollution of outdoor high voltage insulators is a common problem for utilities, with a considerable impact to power system reliability. Pollution resources combined with moisture provide undesirable conductive paths on insulations that result in faults and economic losses. Types and degree specification of pollution seems to be vital for efficient operation and proper choice of insulation. At present, there is no data available regarding the pollution level in the various regions. Pollution falling on the insulators produces a conductive film on the surface which causes the surface leakage current to increase, eventually resulting in flashover / local arcing on insulators. Flashovers occur mainly on transmission lines when, in combination with condensation, light rain or fog, ash or dust build-up cause arcing across insulators and dips and spikes in power supplies. This weakens the insulators, and repeated arcing can cause the shutdown of the power line. Fires can also impact the insulators of power lines due to the generated ash particles. When these particles are combined with high humidity under foggy conditions, they form a "conductive fog" that can cause transmission network trips. This "conductive fog" is instantaneous and not predictable. Some of the glass insulators used in substations and power lines are not able to withstand this phenomenon, due to the effect of environmental pollution to the injection substation which has led to:

i. Negative effect on the insulation system of power lines and substations.
ii. Shutdown of the power line.
iii. Surface leakage current to be increased.
iv. Causing widespread flashovers, which initiate tripping of lines and other facilities.
v. System collapse.
vi. Equipment failures.

1.3 Aim of the Study

The aim of this study tends to establish the effect of environmental pollution on performance of Rivers State University injection substation.

1.4 Objectives of the Study

The objectives of this research work are:

i. Collect data from the injection substation for purpose of analyzing.
ii. Analyze the severity of the pollution, in order to establish "zones of pollution".
iii. Implement the data into the critical voltage, critical current equations.
iv. Validate the numerical value calculated using the existing International Council on Large Electric Systems (CIGRE) pollution guide.

1.5 Scope of the Study

The scope of this work considered the analysis effect of environmental pollution on performance at Rivers State University injection substation, for a flat plate insulator of 10cm x 1cm cross-section.

II. LITERATURE REVIEWS

Pollution is a major criteria for the design of transmission line insulators. Pollution has a negative effect on the insulation system of power lines and substations, which could occur in the shutdown of the power line. At present, there is no data available regarding the pollution level in the various regions [9]. Pollution falling on the insulators produces a conductive film on the surface which causes the surface leakage current to increase, eventually resulting in flashover / local arcing on insulators. According to [10], flashovers occur mainly on transmission lines when, in combination with condensation, light rain or fog, ash or dust build-up cause arcing across insulators and dips and spikes in power supplies. This weakens the insulators, and repeated arcing can cause the shutdown of the power line. Fires can also impact the insulators of power lines due to the generated ash particles. When these particles are combined with high humidity under foggy conditions, they form a “conductive fog” that can cause transmission network trips.

Environmental and climatic effects on insulator performance have dealt with the effects of choice of insulator material and the consideration of insulator design techniques. Although these material and design aspects may be well coordinated, insulator performance is still found to be affected significantly by a number of environmental and climatic conditions [11]. Some effects instantaneously lead to insulation failure, while others may cause a gradual degradation in the insulating properties of the insulator (often referred to as ageing), thereby eventually leading to insulation failure [12]. A major factor that affects insulator performance is the deposition of contaminants or pollutants that may render the insulator surface to be conductive. Other factors include precipitation, wind speed and direction, bird droppings and streamers and physical surface damages and human vandalism [11].

The exposure of insulators to the environment subjects them to the deposition of pollutants onto their external surfaces [12]. The collection of deposits can either immediately cause a leakage current to flow along the insulator surface or it would require some form of wetting to become conductive on an energized insulator [11]. Therefore, there are two insulator pollution mechanisms: pre-deposited pollution and instantaneous pollution processes [11]. The former collects over a certain time stretch and it requires wetting to form an electrolytic layer depending on the solubility of the pollutants. Pre-deposited pollution can be either active, which contains soluble pollutants that can form a conductive layer when wetted or inert, which contains non-soluble pollutants and no conductive layer may be formed even in the presence of wetting. In contrast, instantaneous pollution contains pollutants that are readily electrically conductive even in the absence of any wetting mechanisms.

III. MATERIALS AND METHODS

Materials Used in the Analysis

I. The power supply network from Afam power generating station, through 132kv transmission line Port Harcourt mains to 33kv injection distribution line at Rivers State University injection substation.
II. The distribution data shall be collected from the Port Harcourt Electricity Distribution Company (PHEDC). The method of analysis in this study is described according to respective cases of the problem formulation.
III. Also the line diagram showing the supply to the RSU injection substation.

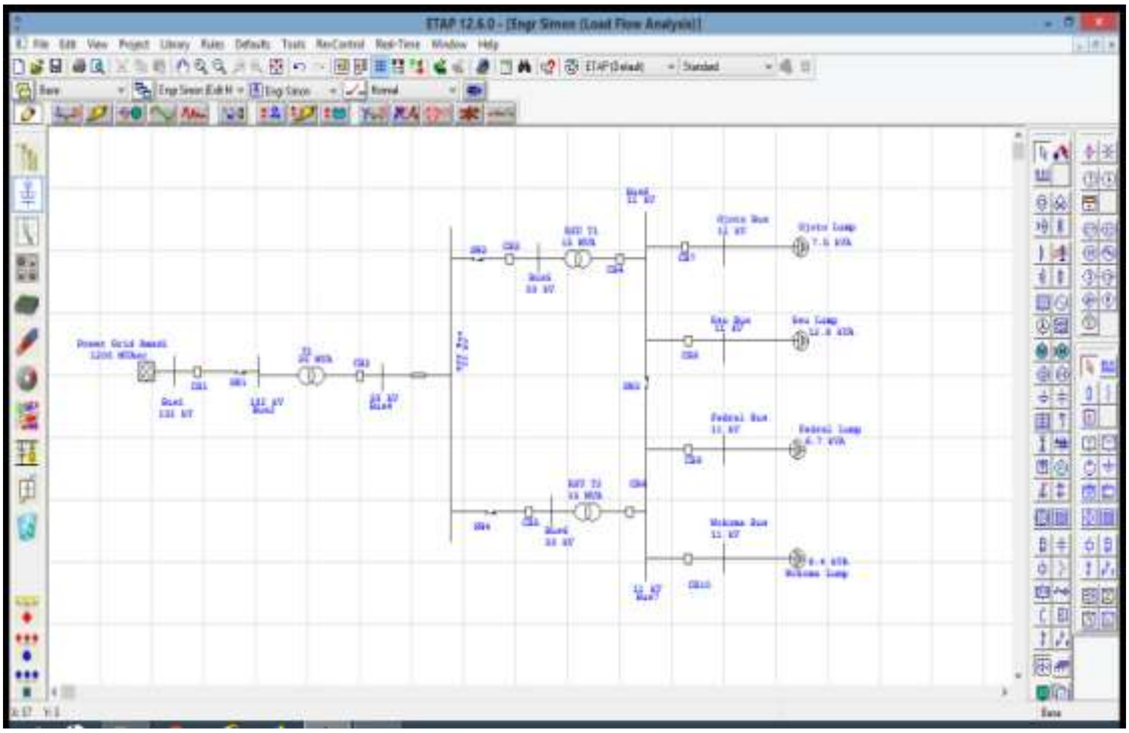

Figure 3.1 Single Line Diagram of RSU 2 X 15MVA, 33/11KV Injection Substation

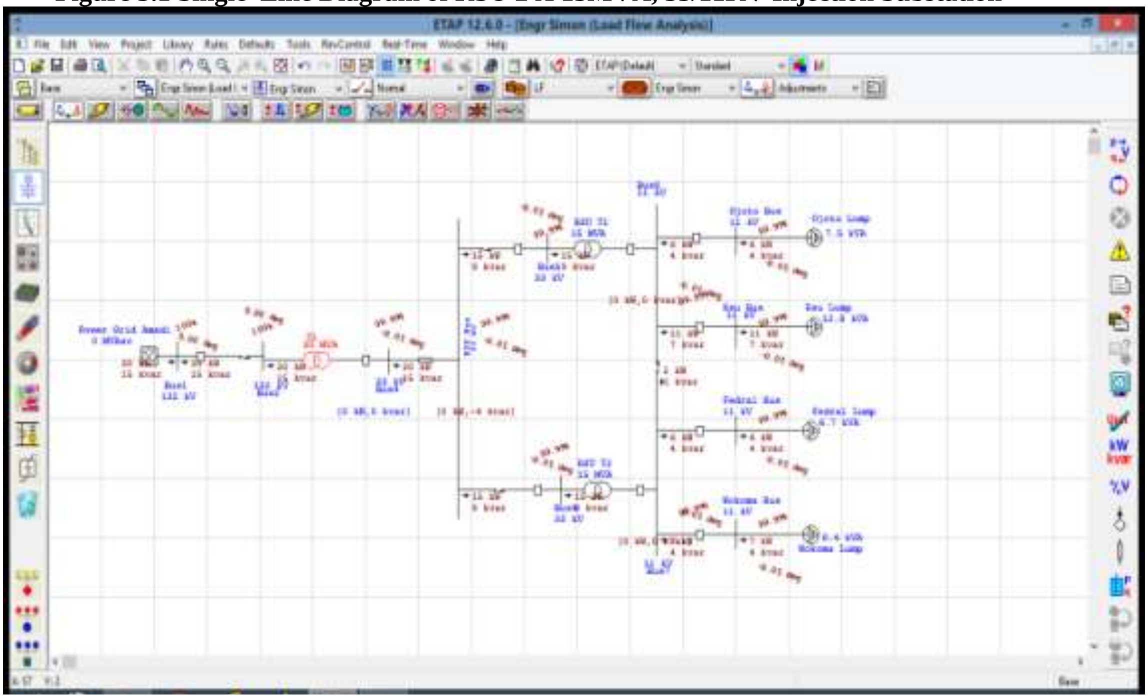

Figure 3.2: Simulated Single Line Diagram of RSU 2 X 15MVA, 33/11KV Injection Substation

Table 3.1: Available Data Used for the Analysis

PARAMETER	VALUE
Nominal rated voltage	33/11 KV
Highest system voltage	36/12 KV
Base MVA	100
Flashover voltage for 33KV, 3units	Approx. 215KV
Frequency	50 Hz
Number of phase	3
T1A Impedance	11.1%
T2A Impedance	10.7%
Maximum Load	1880 KW
Temperature rise Oil/Wind	50/55^{0}C

OFF Load Losses	7099 W
ON Load Losses	53601 W
15MVA Transformer primary ctr	300/5
15MVA Transformer secondary ctr	1200/5
Pollution resistance of wet plate R_p	50,000 Ω
Flat polluted insulator plate	10 cm X 1cm
Volume of the solution	110 cm^3
Area of the cleaned surface	110 cm^3
Arc characteristic constants (N & n)	$N = 63$ and $n = 0.5$
Constant K	26.28
Ambient temperature	50^0C

Source: PHEDC unpublished

3.2 Method used in the Analysis

The method used in this analysis considered the application of Obenaus technique. One of the quantitative analyses of arcs on contaminated surfaces of the injection substation is that due to pollution effect. Due to the effect of environmental pollution of Rivers State University injection substation, the following method were adopted:

I. The method used in this analysis considered the application of Obenaus's technique.
II. Electrical Transient Analyzer Program (ETAP) version 12.6 software for simulation.

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3.3 Determination of the Arc Voltage And Resistance of the Wet Plate

The applied voltage can be related to the arc voltage and resistance of the wet polluted layer is expressed in the following equations as:

$$V = V_{arc} + R_p\ i \tag{3.1}$$

The arc burning voltage is expressed as,

$$V_{arc} = \chi . N . i^{-n} \tag{3.2}$$

Therefore equation 3.1 and 3.2 becomes,

$$V = \chi . N .\ i^{-n} + R_p\ i \tag{3.3}$$

Where the following parameters is expressed as;

V_{arc} = arc voltage
$V =$ applied voltage
$\chi =$ arc length
i = leakage current
R_p = pollution resistance
n = exponent of static arc characteristic
$N =$ static arc constant

3.4 Determination of Leakage Length and Critical Value of Current

From equation (3.3) the value of leakage length χ is expressed as,

$$\chi = \frac{i^n}{N} . (V - i\ R_P) \tag{3.4}$$

The maximum arc length in cm is obtained by differentiating x with respect to i and equating it to zero, hence,

$$\frac{n.\ i^{n-1}}{N} . V - \frac{(n+1)\ i^{-n}}{N} . R_P = 0$$

$$i = \frac{V.\ n}{(n+1) . R_p} \tag{3.5}$$

This expression " i " is known as the critical value of current and is denoted as i_c

Therefore,

$$i_c = \frac{V.\ n}{(n+1) . R_p} \tag{3.6}$$

3.5 Determination of Pollution Resistance Per Unit Length

In Obenaus technique a slight modification is applied, instead of a resistance R_P, representing the pollution layer connected in series with the arc, a uniform pollution resistance per unit length is assumed for the wet portion.

Therefore, pollution resistance is expressed as,

$$R_P = r_p \ (L - \chi) \quad (3.7)$$

$$r_p = \frac{R_p}{L-X} \quad (3.8)$$

Where;

r_p = pollution resistance per unit length.

X= X_c= critical arc length of the insulator

L = leakage length of the insulator

And L is expressed as

$$L = \frac{3\,X_c}{2} \quad (3.9)$$

And the applied voltage V is given as,

$$V = \chi N i^{-n} + i\, r_p (L - \chi) \quad (3.10)$$

3.6 Determination of the Salinity of the Solution

The salinity of the solution is determined by the use of the following formula:

$$S_a = (5.7.\ \sigma_{20})^{1.03} \quad (3.11)$$

Where:

S_a = salinity (kg/m^3)

σ_{20} = normalized conductivity (S/m)

3.7 Determination of the Equivalent Salt Deposit Density (ESDD)

The ESDD in mg/cm^2 can then be calculated by the using the following formula:

$$ESDD = \frac{S_a.V}{A} \quad (3.12)$$

Where:

V = volume of the solution (cm^3) (110 cm^3)

A = area of the cleaned surface (cm^2) (10cm x 1cm = 10 cm^2)

3.8 Problem Formulation

This model is applied to a given flat polluted insulator plate, 10 cm long and 1 cm wide as shown in the figure below:

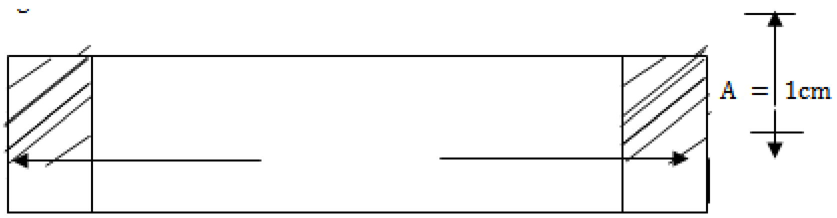

Figure: Flat plate insulator: 10 x I cm.

Pollution resistance of wet plate R_p = 50,000 ohm.

Voltage applied = 11KV.

The values of N = 63 and n = 0.5 is used in this analysis which are the arc characteristic constants (N).

3.8.1 The relationship between critical arc length and critical current

The critical arc length is given by:

$$\chi_c = \frac{i^n}{N}.(V - i_c R_P)$$

From the above equation, the critical value of current is denoted as i_c and it is given by

$$i_c = \frac{V.\ n}{(n+1).R_p}$$

Where;

χ_c = Critical Arc Length of the Insulator
V = Applied Voltage
i_c = Critical (Leakage) Current
R_p = Pollution Resistance of the Wet Plate
n = Exponent of Static Arc Characteristic

3.8.2 Relationship between pollution resistance per unit length and leakage length of the insulator

The pollution resistance per unit length (r_p) is given by;

$$R_p = r_p (L - x_c)$$

$$r_p = \frac{R_p}{L - X_c}$$

where:

X_c = Critical arc length
L = Leakage length $L = \frac{3\ X_c}{2}$

3.8.3 Relationship between equivalent salt deposit density and salinity of the solution

The t ESDD in mg/cm^2 can then be calculated by the using the following formula:

$$ESDD = \frac{S_a.V}{A}$$

Where:

V = volume of the solution (cm^3) (110 cm^3)
A = area of the cleaned surface (cm^2) (10cm x 1cm = 10 cm^2)

IV. RESULTS AND DISCUSSION

Based on the results obtained from the existing case study, the following tables and results discussion were allotted based on the flashover parameters such as critical arc length, critical (leakage) current, pollution resistance per unit length, leakage length, ESDD and the severity of the solution etc.

Case Study 1: Result Presentation of Critical Arc Length and Critical (Leakage) Current for the Existing and Improved Case Study

Plate Position	Existing case study		Improved case study	
	Critical Arc Length (cm)	Critical (Leakage) Current (A)	Critical Arc Length (cm)	Critical (Leakage) Current (A)
1	31.52	0.0609	28.78	0.0603
2	33.23	0.0614	29.14	0.0606
3	35.24	0.0615	29.52	0.0610
4	37.68	0.0600	29.92	0.0614
5	40.69	0.0564	30.33	0.0617
6	44.58	0.0479	30.76	0.0620

The table above shows the values of critical arc length and critical current for the existing and Improved case study, the values of the critical arc length increases as well as the values of the critical current increases from the first to third plate position whereas from the fourth to sixth plate position the values of the critical current decreases respectively.

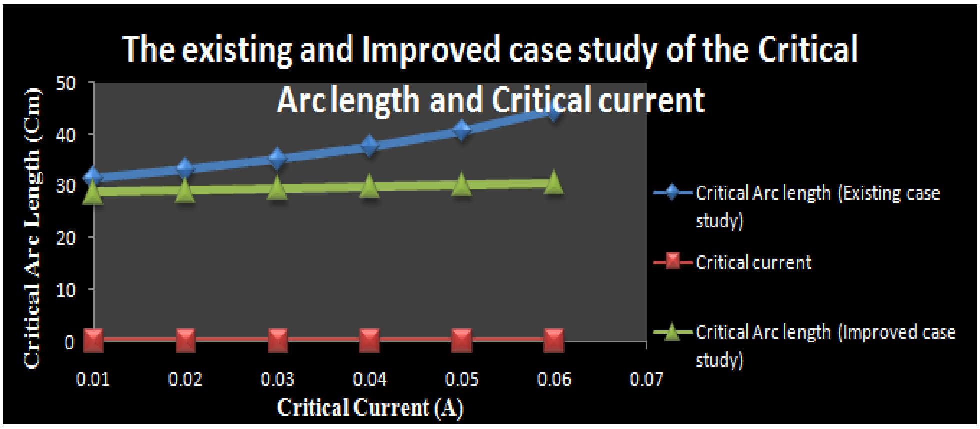

Figure 4.1: Graph of Critical Arc Length and Critical Current of the Existing and Improved Case Study

The result obtained from the existing case study shows that the critical arc length value for the first and sixth plate insulator is 31.52 cm and 44.58cm. On the other hand, the results for the critical (leakage) current shows that the first and sixth plate insulator value is 0.0609 A and 0.0479 A respectively. Moreover, the result obtained from the improved case study shows that critical arc length value for the first and sixth plate insulator is 28.78 cm and 30.76cm. On the other hand, the results for the critical (leakage) current shows that the first and sixth plate insulator value is 0.0609 A and 0.0479 A respectively.

Therefore, the results obtained from the improved case study shows that the critical arc length value were reduced to 1.98 cm and the critical current value were also reduced to 0.013 A. The results indicates that the critical arc length strongly depends on the critical current and the high magnitude of the Leakage Current caused the heating effect which leads to rapid dry band formation in the insulator.

Case Study 2: Result Presentation of Pollution Resistance Per Unit Length and Leakage Length of the Insulator for the existing and improved case study

Plate Position	Existing case study		Improved case study	
	Pollution Resistance Per Unit Length (Ω)	Leakage Length (cm)	Pollution Resistance Per Unit Length (Ω)	Leakage Length (cm
1	3172.59	47.28	4169.56	43.17
2	2707.58	49.85	4015.09	43.71
3	2270.15	52.86	3861.79	44.28
4	1857.75	56.52	3709.89	44.88
5	1474.20	61.04	3559.66	45.50
6	1121.58	66.87	3413.52	46.14

The table shows the values of pollution resistance per unit length and leakage length for the existing and improved case study, in the existing case study the values of the pollution resistance per unit length decreases while the values of the leakage length increases respectively. Moreover, the improved case study show that the values of the pollution resistance per unit length decreases from the first plate to the sixth plate position of the insulator whereas as the values of the leakage length increases.

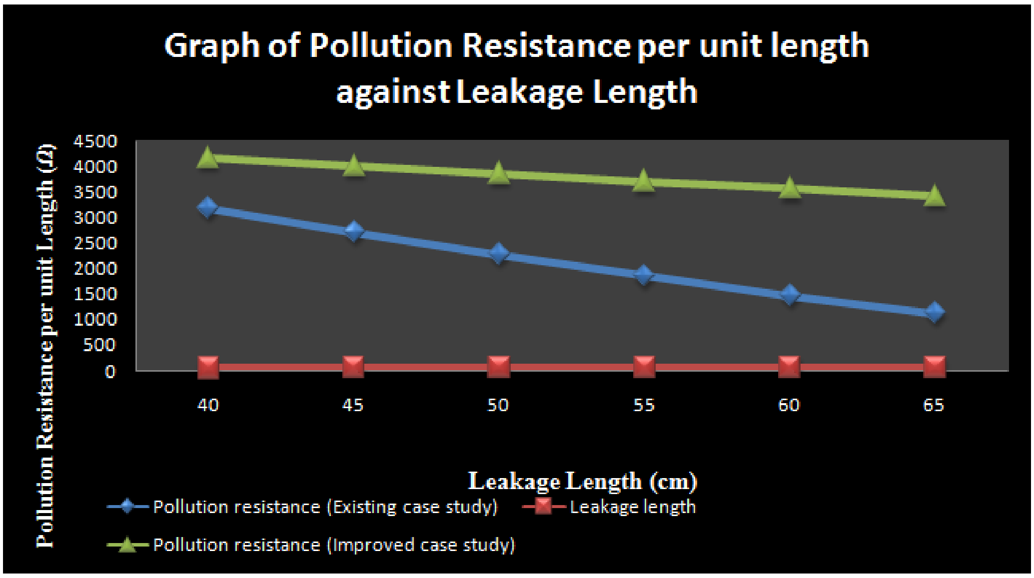

Figure 4.2: Bar Chart of Pollution Resistance Per Unit Length and Leakage Length Showing the Existing and Improved Case Study

The result obtained from the existing case study shows that the pollution resistance per unit length value for the first and sixth plate insulator is 3172.59 *Ω* and 1121.58 *Ω*. On the other hand, the results for the leakage length value shows that the first and sixth plate insulator value is 47.28 cm and 66.87cm respectively. Moreover, the result obtained from the improved case study shows that the pollution resistance per unit length value for the first and sixth plate insulator is 4169.56 *Ω* and 3413.52 *Ω*. On the other hand, the results for the leakage length value shows that the first and sixth plate insulator value is 43.17 cm and 46.17 cm respectively. Therefore, the results obtained from the improved case study shows that the pollution resistance per unit length value were reduced to 756.04 *Ω* and the leakage length value were also reduced to 3 cm. Therefore, the results show that the Pollution Resistance per unit Length depends on the Leakage Length.

Case Study 3: Result Presentation of Equivalent Salt Deposit Density and Salinity of the Solution for the existing and improved case study

Plate Position	Existing case study		Improved case study	
	ESDD (mg/cm^2)	Salinity of the Solution (S_a) kg/m^3	ESDD (mg/cm^2)	Salinity of the Solution (S_a) kg/m^3
1	0.05	0.0045	0.015	0.0136
2	0.10	0.0091	0.020	0.0182
3	0.15	0.0136	0.025	0.0227
4	0.20	0.0182	0.030	0.0273
5	0.25	0.0227	0.035	0.0318
6	0.30	0.0273	0.040	0.0364

The table show the values of the Equivalent Salt Deposit Density (ESDD) and Salinity of the Solution for the existing and improved case study, for the existing case study the ESDD values was measured in magnitude of 0.05 mg/cm^2 for all the plate position of the insulator, while the values of the Salinity of the Solution increases respectively. Moreover, the improved case study show that the ESDD values was also increase with magnitude of 0.05 mg/cm^2 respectively from the first plate to the sixth plate position of the insulator. Similarly, values of the Salinity of the Solution was increased respectively.

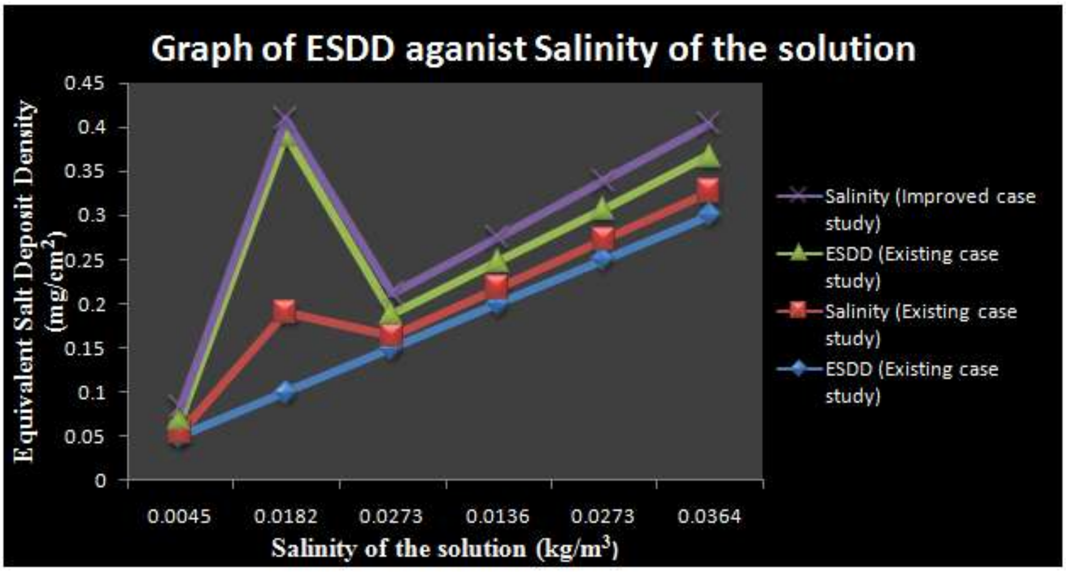

Figure 4.3: Graph of ESDD and Salinity of the Solution showing the Existing and Improved Case Study

The result obtained from the existing case study shows that the ESDD value for the first and sixth plate insulator is 0.05 mg/cm^2 and 0.30 mg/cm^2. On the other hand, the results for the salinity of the solution value shows that the first and sixth plate insulator value is 0.0045 kg/m^3 and 0.0273 kg/m^3 respectively. Moreover, the result obtained from the improved case study shows that the ESDD value for the first and sixth plate insulator is 0.015 mg/cm^2 and 0.040 mg/cm^2. On the other hand, the results for the salinity of the solution value shows that the first and sixth plate insulator value is 0.0136 kg/m^3 and 0.0364 kg/m^3 respectively.
Therefore, the results obtained from the improved case study shows that the ESDD value were reduced to 0.025 mg/cm^2 and the salinity of the solution value were also reduced to 0.0228 kg/m^3.

However, our results show that ESDD and Salinity of the solution values has a positive significant relationship for contributing the severity level of the salt deposit in the insulator. The ESDD and Salinity of the solution were categorized under light pollution level according to CIGRE pollution guide for the first and sixth plate position of the glass insulator respectively.

V. CONCLUSION AND RECOMMENDATIONS

Conclusion

The research work examined the effect of environmental pollution on performance of Rivers State University injection substation. The distribution data were collected from the Port Harcourt Electricity Distribution Company (PHEDC), the method of analysis were described according to respective cases of the problem formulation.

The result obtained shows that the critical arc length value was reduced to 1.90 cm and the critical current value was also reduced to 0.013 A. The results show that the arc length depends strongly on the leakage current, thereby allowing the leakage currents to increase over the surface of the insulator and causes the heating effect which leads to rapid dry band formation.

Moreover, the result obtained shows that the pollution resistance per unit length value for the existing case study was reduced to 756.04 *Ω* and the leakage length value was also reduced to 3.0 cm. Therefore, the results show that the pollution resistance per unit length depends on the leakage length.

However, our results show that ESDD and Salinity of the solution values has a positive significant relationship for contributing the severity level of the salt deposit in the insulator. The results show the relationship between the existing and improved case study, the ESDD value was reduced to 0.025 mg/cm^2 while the salinity of the solution value was also reduced to 0.0228 kg/m^3 respectively. The ESDD and Salinity of the solution were categorized under light pollution level according to CIGRE pollution guide for the first and sixth plate position of the glass insulator respectively.

Recommendations

The pollution flashover is still a major problem that influences the performance of power system operations in the substation. Studies on pollution flashover considers the prediction of critical flashover voltage. Generally, this is used to develop the insulator design and insulation variety. Recently, studies has been conducted to predict the critical flashover voltage could be applied to engineering practice. Basis on the experimental results and analysis the following recommendations were drawn:

1. In order to allow for future progress in experimental work to determine the effect of environmental pollution on the substation, it is necessary to see that deficiencies are remedied that lead to assumptions due to lack of data.
2. Some of the glass insulators used in substations and power lines are not able to withstand the flashover phenomenon, therefore causing widespread flashovers which initiate tripping of lines and shutdown of the systems. To avoid these problems, it is necessary to perform pollution measurements to assess whether pollution deposits are within or beyond limits.
3. The contamination flashover implementation of an insulator relies upon the kind of contamination found in the substation, therefore the properties of the insulator materials and the wetting states of the environment should be study carefully in order to avoid loss of energy supplied and may harm equipment which may produce destruction of the insulator itself due to the effect of pollution.

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