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Improved Lightning Protection Reliability Assessment for Substation Grounded Electrode

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ABSTRACT--Lightning is a phenomenon that occurs during thunderstorm between regions of cloud that are electrically charged. Causing destruction of electrical facilities/equipment, insulation breakdown, endangering the lives of personnel within the stations. Essentially, earthing system for transmission substation must be designed to match the incidence of the occurrence of lightning strikes or any form of faults scenario in order to maintain the statutory limits of touch and step potentials within the desired permissible level of the code of practice. This paper is aimed to improve the existing condition of the earthing system of 132/33kV transmission station Port Harcourt main, zone-2, Trans-Amadi, Rivers state. The paper updated soil variable of the existing case used to improve state of the soil derating factor to 0.8 which is characterized from an exponential transient growing behaviour to linear description of an improved adequate earthing condition for better interactions to the lightning surges in the event of fault occurrence. The improved values of the ground potential rise (GPR) and thickness of thin layer crushed rock (100mm, 4500□m) materials are adequate to allow permissible limits of touch and step potential in the events of natural faults occurrence

Index Terms—DisCos, GenCos, NERT Act 2005, ground protection rise, lighting protection, 132/32kV, port Harcourt transmission station, TranCos, VIMs, NIPPs.

I. INTRODUCTION

Lightning is a natural phenomenon which development applied to the upper atmosphere becomes unstable due to the convergence of warm, solar heated, vertical air column on the cooler upper air mass. These rising air currents carry water vapor which, on meeting the cooler air, usually condense, giving rise to convective storm activity such that the vertical air movement becomes self-sustaining, forming the basis of a cumulonimbus cloud formation with its center core capable of rising to more than 15,000 meters (Gayar, & Abdul-Malek, 2016). This means that Effective earthing/lightning design are considered to be of great importance.

The system of earthing adopted in power generation, transmission and distribution stations is of primary importance particularly to the Substation earthing system (Afa&Anaele, (2010), which is essential not only to provide protection to human beings working within the vicinity of earthed facility. This paper present an improved step-by-step approach on earthing system design for 33/1IKV substation necessary parameters for satisfactory performance, a case study on RSU 2×7.5MVA, 33/1IKV injection substation and four (4) associated feeder locations in Port Harcourt, Rivers State.

1.1.1The Mechanism of Lightning Strike

The cloud and the ground form two plates of a gigantic capacitor and the dielectric medium is air. The lower part of the cloud plate is negatively charged and the earth plate is positively charged by induction. The charge on the base of the cloud induces an opposite charge on the surface of the earth beneath it.

As the storm cloud builds, it increases the potential difference between the cloud base charge and the ground charge, the insulating capacity of the air breaks down with the cloud base charge trying to pull the ground charge off the surface of the earth. Stepped leaders start to develop when charge differences in the cloud become too large.

As the charged storm cloud travels through the atmosphere, it drags its ground charge along beneath it. When the ground charge reaches a structure, the attraction of the cloud charge pulls it up onto the structure, and concentrates the ground charge on the structure, it moves away the charge on the cloud base manages to concentrate enough ground charge potential on and around the structure beneath it to overcome the dielectric of the intervening air an arc or lightning strike, occurs.

When the dielectric of the air is overcome and lightning is going to strike, the process begins with the formation of stepped leaders branching down from the cloud.

1.1.2The Mechanism of Grounding

Earthing systems are otherwise known as grounding. To reach good grounding system depend on a number of factors:
(i)Soil resistivity
(ii) Stratification (Soil Layering)
(iii) Size and type of electrode used
(iv) Depth to which the electrode is buried
(v) Moisture and chemical content of the soil
(vi) Temperature
(vii) Texture

These factors will affect the earth resistance which are a function of the soil constituents. Hence this paper investigated into the class of soil constituents on how they affect the earth resistance and optimal constituents that provide the lowest minimum earth resistance.

1.2 Statement of the Problem

Considering several factors affecting reliable earthing condition and the tendency of lightning occurrence on power systems operations which influence performance particularly, the lightning-surges impinging on system components such as (substation – transformer, outgoing /incoming feeders, and buses, grounding wire).

However, inadequate and poor earthing conditions in the study case (RSU 2×7.5MVA injection substation supply to three (3) outgoing feeder locations: Ojoto, Federal, Wokoma feeders respectively) this strongly necessitated the determination of soil parameters (soil resistance, conductivity, soil-resistivity, touch, potential/touch voltage, step potential/step voltage, soil layering, soil resistivity materials etc) for purpose of standard statutory limits and operating conditions for system violations.

This means that adequate earthing design parameters must be obtained to the desirable design values in order to achieve reliable and functional system operations for power quality and steady voltage supply.

Essentially, this paper is aimed to monitor the design to optimize the soil parameters in line with statutory–code of practice on the view to avoid system collapse due to system interruptions, in order to allow strong compliance.

The outage/black-out activities in the study zone under investigation due to inadequate lightning protection scheme have tremendously influence effective performance to the power system reliability. This is due to:
(i)Aging /poor earthing design conditions.
(ii) Soil earthing parameters are not capable of arresting lightning surges to the ground in the event of fault scenarios.
(iii) Poor compliance between soil resistances, soil-resistivity conductivity to lightning incidence due to fault occurrence to power system.
(iv) Poor discrimination time for isolation between circuit breaker and relay setting for system protections.
(v) Violations of soil parameter, soil-laying, soil-resistance, soil resistivity, electrode/mesh-mat used and general design conditions) for optimal system operations/performance.

1.3 Aim of the paper

The aim of the study is to investigate strongly and evaluate an improved lightning protection reliability assessment scheme for RSU 2×7.5MVA injection substation electrode to three (3) outgoing feeders' locations at: Ojoto, Federal, Wokoma feeders respectively

1.4 Objectives of the paper

The specific objectives of the study are;
I. Determine the status of the existing system using Finite Element Method.
II. Determine the behaviour of associated feeders using CONSOL Multiphysics
III. To formulate governing equations that represent the matching section for lightning surge incidence.
IV. To adopt using the existing parameters to determine the protection reliability of the particular grounded electrode using backward propagation.
V.To represent the Nzimiro power supply feeder with a single line diagram in other to provides low earth resistance in line with standard practices.
VI. Conduct validation test for purpose of improvements and stability

1.5 Scope of this paper

The study is limited to the investigation of the performance of an earthing system in a substation

II. MATERIAL AND METHOD

The major consideration of this paper is to collect numerical data in the study case under investigation in order to determine the existing condition for purpose of improved performance. The Rivers State University injection substation consisted of (2×7.5 MVA,

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33/11kV) in conjunction with three (3) feeder locations (Ojoto, Federal and Wokoma feeders) respectively are examined. The supply system to Rivers State University (RSU) is linked from Port-Harcourt zone-4 (Amadi Junction, Nzimiro) with injection capacity of 132/33kV.

2.1 Materials used for this paper

Materials used for improving earthing of RSU injection and associated three feeder locations sub transmission station was chosen carefully by taking account of the physical and chemical composition of the soil. The determined value of each of this details are earth grid resistance, computation of mesh potential, step potential, touch potential and ground potential rise. The following materials are details as follows:

(i)The earthen area to be determined include using measurement tape (short and long).

(ii) Digital earth meter (mastech Ms2302) for resistance testing, resistivity testing measurements, using the technique of three/four pin (fall-of-potential method)

(iii) Representation of a single line diagram using Etap version 19.0.1 of the steady case are geared to determine soil parameters etc.

Engage experimental set-up for the study case in order to improve existing condition

2.2 Method used for the Study

The method used for improving earthing of RSU injection substation and its associated three (3) feeders locations was chosen carefully to take account for physical and chemical compositions of the soil.

The determined value of each of these parameters including earth grid resistances, computation of mesh potential, step potential, touch potential and ground potential rise are taken into strong considerations.

This paper looked at Wenner four pin probe Ground-grid Techniques (touch and step voltage) with associated earth measurement design parameters. The supply system from Amadi junction by Nzimiro (with capacity 132/33kv) to the paper case RSU injection substation capacity (33/11kv with associated feeder location Ojoto, federal and Wokoma Feeders) respectively.

Essentially, representation of the study case from supply system are presented in a single-line diagram using Electrical Transient Analysis Tool (Etap-version 19.0.1)

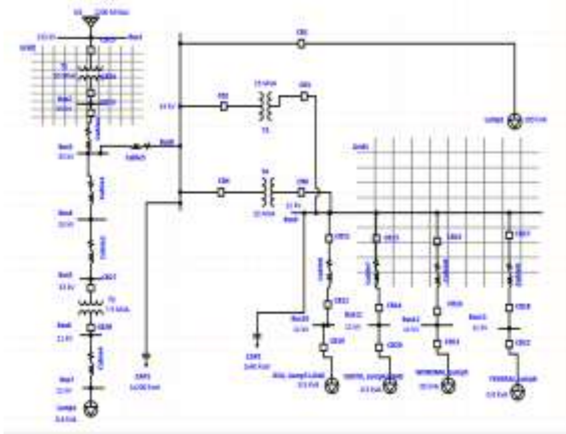

Figure1: Showing the single-line representation of the study case (Amadi by Nzimiro to RSU and its associated feeder locations. (Not simulated)

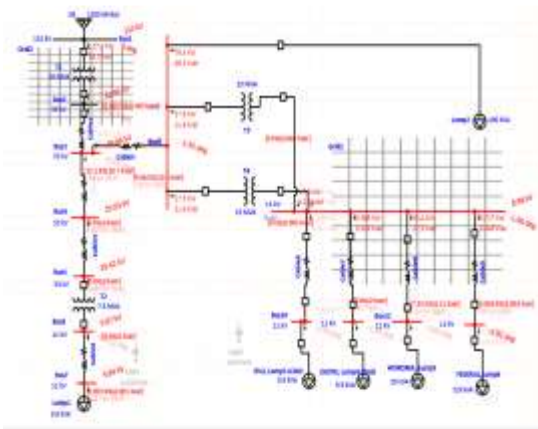

Figure 2: Showing the single-line representation of the study case (Amadi by Nzimiro to RSU and its associated feeder locations (Simulated)

2.3 Data Collected for the Study Case under Investigation for the substation –site and its associated feeder location for earth resistance values of pit measurement

Presentation of earth measurement value for various pits (pit 1 – pit 6) respectively

Table 1: The Distance and the Earth Resistance Values of Pit 1

S/No.	Distance (M)	Resistance (Ω)
1.	4	1.17
2.	8	1.24
3.	12	1.39
Actual earth resistance for pit 1		**1.17**

Table 2: The Distance and the Earth Resistance Value of Pit 2

S/No.	Distance (M)	Resistance (Ω)
1.	4	1.21
2.	8	0.57
3.	12	0.64
Actual earth resistance for pit 2 0.57		

Table 3: The Distance and the Earth Resistance Values of Pit 3

S/No.	Distance (M)	Resistance (Ω)
1.	4	1.21
2.	8	0.57
3.	12	0.64
Actual earth resistance for pit 3 0.57		

Table 4: The Distance and the Earth Resistance Values of Pit 4

S/No.	Distance (M)	Resistance (Ω)
1.	4	0.69
2.	8	0.45
3.	12	0.34
Actual earth resistance for pit 4 0.34		

Table 5: The Distance and the Earth Resistance Values of Pit 5

S/No.	Distance (M)	Resistance (Ω)
1.	4	4.49
2.	8	3.22
3.	12	2.73
Actual earth resistance for pit 56 2.73		

Table 6: The Distance and the Earth Resistance Values of Pit 6

S/No.	Distance (M)	Resistance (Ω)
1.	4	0.24
2.	8	0.55
3.	12	0.72
Actual earth resistance for pit 6 0.24		

Table 7: The Earth Resistance Rating of each of Pit

S/No.	Earth Resistance for each Pit	Resistance (Ω)
1.	1	1.17
2.	2	0.57
3.	3	1.25
4.	4	0.34
5.	5	2.73
6.	6	0.24

The earth resistance value of each pit and its resistance total average
Initial Design from 132kV OHL substation grounding case study parameters are given as follows:
Slope Coefficient, U = 0.55
Potential Probe Distance, DPT = 10.97M
Actual Resistance, R = 0.59Ω
2×60 MVA 132/33KV Transformer = 0.20Ω
Lighting Arresters = 0.20Ω
Line Gantry = 0.20Ω
7.5 MVA,33/11KV Earthing Transformer = 0.20Ω
Transformer Body = 0.43Ω

Table 8: Continuity Checks of Equipment to Earthing Grid System

S/No.	Equipment	Status
1.	All Panels in Switchgear Room	Continuous
2.	All Panels in Battery Room	Continuous
3.	All Panels in Communication Room	Continuous
4.	132KV Lightning Arresters	Continuous
5.	Perimeter Lighting	Continuous
6.	Perimeter Fencing	Continuous
7.	Control Room	Continuous
8.	All Gantry	Continuous

2.4 Resistivity of Soil and Surface Layer

Soil resistivity is usually done in order to determine the soil structure at a particular site as it can vary greatly depending on the type of terrain.

For example, resistivity value of local area includes silt on a river bank may have resistivity of 1.5 ohms-meters, while dry sand or granite may have values of 10,000 ohm-meters. However, Table 3.9 shows the soil resistivity of the earth conductor (electrode) which are buried at the following depth.

Table 9: The Depth of Earth Conductor

Table Sr. No.	2.	Soil Resistivity in Economical Depth ohms/meter	Buried in meters
(1)		50 – 100	0.5
(2)		100 – 400	1.0
(3)		400 – 1000	1.5

III. RESULTS AND DISCUSSION

During the conceptual phase of this study, qualitative data was collected. The data collected during the phases was included as part of the literature review, material and methods. Therefore they will not be discussed here. Only the results and its emphasis will be followed

First Case Study Representation of the Amadi by Nzimiro to RSU and its associated feeder locations, Existing state without compensation of capacitor not simulated as shown in Figure 3

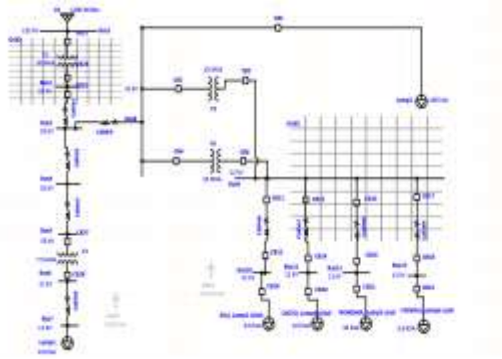

Figure 3: Showing the single-line injection feeder for Amadi by Nzimiro to RSU and its associated feeder locations. Existing state without compensation of capacitor not simulated

Second Case Study Representation of the Amadi by Nzimiro to RSU and its associated feeder locations Existing State with Capacitor Not Simulated shown in Figure 4

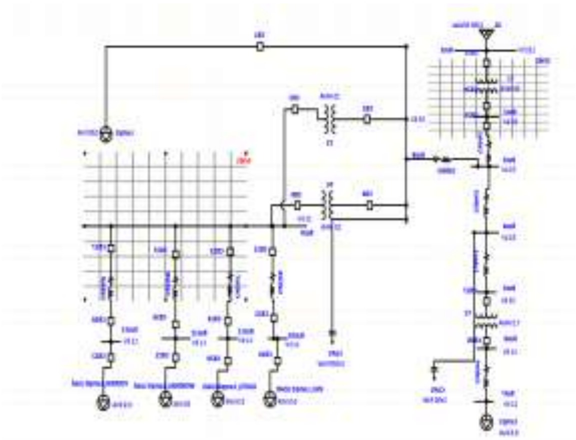

Figure 4: Showing the Single-Line Representation of the Study Case (Amadi by Nzimiro to RSU and its Associated Feeder Locations), Existing State with Capacitor Not Simulated

Third Case Study Representation of the Amadi by Nzimiro to RSU and its Associated Feeder Locations), Existing State without Compensation Simulated as shown in figure 5

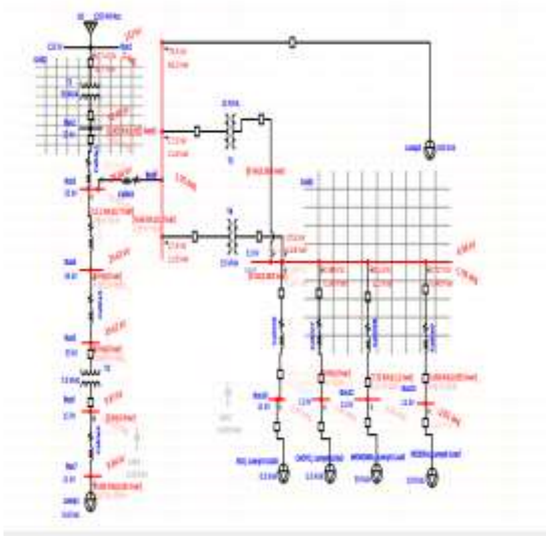

Figure 5: Showing the Single-Line Representation of the Study Case (Amadi by Nzimiro to RSU and its Associated Feeder Locations), Existing State Without Compensation Simulated

Fourth Case Study Representation of the Amadi by Nzimiro to RSU and its associated feeder locations), Existing State compensated and Simulated as shown in figure 6

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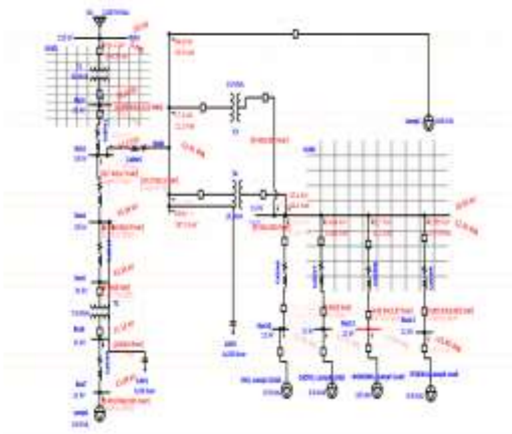

Figure 6: Showing the Single-Line Representation of the Study Case (Amadi by Nzimiro to RSU and its associated feeder locations), Existing State compensated and Simulated

The results from measurement for the three main soil location were taken and presented in Table 10

Table 10: Depth of electrode and Resistivity values at different depth $\Omega - m$

Depth of electrode in meters	Resistivity values at different depth $\Omega - m$					
	Ojoto feeder		Wokoma feeder		Federal feeder	
	Feb.	Sept.	Feb.	Sept.	Feb.	Sept.
0.5	90	23	180	62	242	52
0.8	32	22	100	35	102	35
1.2	22	21	45	25	42	23
1.5	20	18	32	22	32	21
pH value	5.1	5.8	4.85	5.0	4.91	5.2
Ambient Tem. ℃	37	31	35.8	29.4	38.1	29.0
Humidity in mmHg	71	82	70	79	77	812

From table 4.1 the graphs were drawn for each soil division indicating the resistivity variation for the seasons as shown in below.

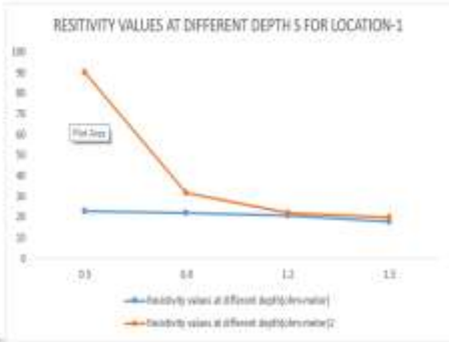

Figure 7: Resistivity values at different depth (Ojoto feeder)

Table 11: Depth of Electrode in Meter, Resistivity Values at Different Depth

Depth of electrode in meter (m)	Resistivity value at different depth (ohm-meter)	Resistivity values at different depth (ohm-meter)2
0.5	23	90
0.8	22	32
1.2	21	22
1.5	18	20

4.6 Analysis of Resistivity and Assessment Depth for System Performance Location-2

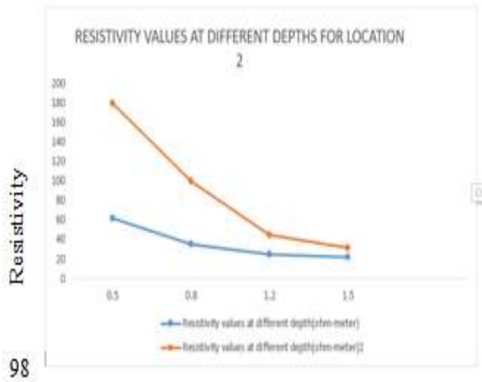

Figure 8: Resistivity values at Different Depths for location 2

Table 12: Depth of Electrode versus Resistivity Values at different Depth

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Depth of electrode in meter (m)	Resistivity value at different depth (ohm-meter)	Resistivity values at different depth (ohm-meter)2
0.5	62	180
0.8	35	100
1.2	25	45
1.5	22	32

4.7 Analysis and assessment of Resistivity and Depth Locations-3

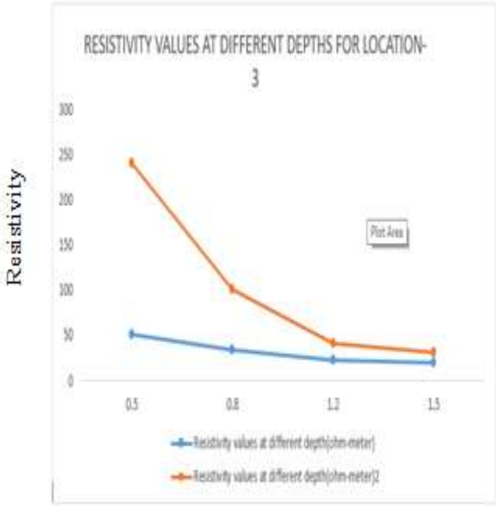

Figure 9: Resistivity Values at Different Depths for Location 3

Figure 9 shows the graphical representation of resistivity value at different depth.

Table 12: Depth of electrode versus Resistivity values at different depth

Depth of electrode in meter (m)	Resistivity value at different depth (ohm-meter)	Resistivity values at different depth (ohm-meter)2
0.5	52	242
0.8	35	102
1.2	23	45
1.5	21	32

Table 13: Seasonal Variation of Soil Condition for the Study Case

Depth of electrode in meters	Coefficient of Seasonal Variation		
	Ojoto feeder	Wokoma feeder	Federal feeder
0.5	3.9	2.9	4.6
0.8	1.5	2.8	2.9
1.2	1.05	1.8	1.8
1.5	1.11	1.45	1.6

Table 14: Soil Resistivity and Corrosion Allowance

Range of soil resistivity Ω – m	Class	Corrosion Allowance
Less than 25	Severely corrosion	+ 30 percent
25 – 50	Moderate corrosion	+ 15 percent
51- 100	Mildly corrosive	+ 15 percent
Above 100	Very mildly corrosion	No addition

Case 1: Location Point 1 (Ojoto feeder) for Transverse Measurements and Analysis

Table 15: Resistance of transverse 1 and 2 with distance, location-1

Distance	Transverse1, resistance	Transverse2, resistance2
1	54	1
2	50	3
3	32	6
4	31	9
5	24	11
6	20	12
7	19	15
8	18	18
9	16	21
10	14	24
11	13	27
12	15	30
13	16	33
14	17	36
15	18	39
16	10	42
17	9	45

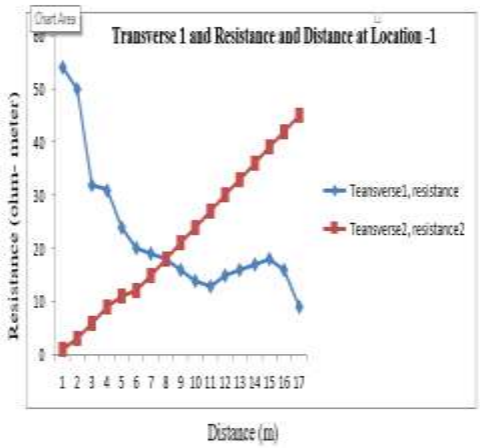

Figure 10: The graph showing the behaviour of resistance of transverse 1 and 2 with respect to distance (m)

IV. CONCLUSION AND RECOMMENDATION

The reliability of electric power supply from one level to another required efficient protection of power system equipment to the consumers. This means that continuous improvement of lighting performance in line with soil parameters (resistances, resistivity, conducting etc.) in terms of conduction or resistance of any form of fault current to the earth considered in order to avoid huge equipment failures and damage during lightning strike, resulted into financial losses to the transmission companies etc. Since the power system facilities are exposed to lightning incidence surges and changing system of overload this variability necessitated strong attention

Therefore this work have provided the substation with a good reference report to rely and engage regular monitoring procedure in order to avoid unsafe, unreliable and loss of revenue in terms of cost, following the existing soil earth condition and the improved state to match the incidence of fault occurrence.

Essentially, better result of ground potential rise (GPR) for soil parameter were also achieved for system validation and improvement on the view to control system behaviour, in the transmission substation of 33KV for reliable and efficient electricity power supply

Contribution to knowledge

This work is a good references to the transmission substation at 33KV, which are presented as;

i. The data used and determined for this study are real data gotten from it serves as reference materials for electricity utility and future related work.

ii. This work is a valuable guide for the Electricity Distribution Company (Disco) Transmission Company (Transco) and Generation Company (Genco) for system planning and operation.

iii. The Electrical Transient Analyser tool (ETAP) simulation software and MATLAB was used to accomplish the desired results for the earthing soil condition of soil resistivity, resistivity of surface layer material and thickness of surface layer materials. Also the soil derating factor was determined and achieved with better improvement from existing data which characterized adequate earthing condition that can match interactions of lightning strike occurrence that would have caused danger to lives and property.

iv. The improved state of Ground Potential Rise (GPR), step and touch potential, voltage level and mesh potential are determined which governed and control the activities of the substation earthing parameters.

5.3 Recommendation

The activities of electrical transmission substation have multivariable parameters in nature, that is power system are generated, transmitted and distributed from one level to another using transformers, switchyard electronic devices, protective scheme for the isolation and discriminatory of faults occurrence with the support of adequate earthing arrangement. Soil resistivity are essentially determined to evaluate the soil structure at a particular site, because of the variability of soil terrain, during wet and dry condition. It is necessary to enhance the effectiveness of the earthing condition to support the incidences of lightning strike which must rely strongly on the several properties of soil formation on the view to provide adequate alternative part of the lightning strike or any other faults occurrence to the ground without serious damage to the electrical equipment/apparatus and facilities etc.

Therefore the following recommendations are considered:

(i)Periodically check the soil structure information to avoid poor diversion of faults current and lightning strike.

(ii) The determined improved parameters for soil investigation can be employed in the prediction of faults occurrence interactions with lightning strike.

(iii) Particularly, Soil Derating Factor (c_s) and Ground Potential Rise (GPR) must continuously be monitored for the purpose of control performance.

(iv) Protective smart electronics devices should be installed to interacts within few seconds of operation on the view to protect the transmission station, machinery and appliances under faults conditions.

(v) Regularly monitor, to ensure that all exposed conductive part do not reach dangerous potential.

To create and provide safe path to dissipate lightning and short-circuit currents during faults occurrence

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