Evaluation Of Substation's Transformer Earthing System, Feeder Panel And Lightning Grounding: Case Study Of A University In Nigeria

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***Abstract*—The earthing-system is an important part of electrical networks at both high and low voltage levels and is fundamental for safety of equipment, building and human beings. It ensures that there is no loss of life and property. The research focus on fourteen numbers of 11/0.415 kV substations and its 33/11 kV injection substation earthing networks in the populated and academic studied area in the event of earth fault. DC earth resistance clamp meter, ETCR 2000 series Earth-Ground –clam- meter was used to measure the earthing resistance value. The measured values were compared to the NESIS system earthing (Transformer) and also with IEC, BIS and Salih. Lightning arrester (LA) and feeder panel were compared with recommended earth effectiveness test for copper/ copper alloy/ aluminum. The result of various substations revealed that the transformers and outgoing feeder panels earthing values vary from 2.3 Ω to open loop (OL), while LA varies from 0.4 Ω to OL. However, 12.5% LA and 6.7% feeder panel met Nigerian standard. Generally, none of the substation under this research meets Nigeria standard (local standard). However, 7% of substation met IEC and BIS while 93% of the Substation failed international standards. Equipment damages, equipment malfunctioning, electric shock and, electrocution of lifes are possible. It is recommended that substation earthing value should conform to both local and international standards for safety of life and property.**

Keywords—Earthing-system, Earth-Ground-clamp-meter, system-earthing, substation, standard.

1. INTRODUCTION

The earthing system is an important part of electrical networks levels and is fundamental for safety of equipment and human beings. It ensures that there is no loss of life and property in the event of earth fault [1], [2], [3], [4], [5]. A well-designed earthing system plays a vital role in any substation [6] Electrical hazards in substations to maintenance personnel and end users are mainly due to poor electrical installation and ineffective earthing system on substations. Earthing of equipment describes the connection of current carrying parts of electrical equipment to the earth. According to [7], earthing system is the total set of measures used to connect an electrically conductive part to earth. Some elements of an earthing system may be provided to fulfil a specific purpose, but are nevertheless part of one single earthing system. Standards require all earthing measures within an installation to be connected together, forming one system [8]. People are usually more or less in contact with earth, so if other parts which are open to touch become charged at a different voltage from earth a shock hazard exists. The process of earthing is to connect all these parts which could become charged to the general mass of earth, to provide a path for fault currents and to hold the parts as close as possible to earth potential. In simple theory this will prevent a potential difference between earth and earthed parts, as well as permitting the flow of fault current which will cause the operation of the protective systems [9]. The evaluation of the earthing system of a distribution substation is necessary to ensure that the personnel at the environs of the earthed facilities are not exposed to electrical shock during fault conditions. In addition, to ensure that a low impedance path to earth for currents are provided for equipment.

This research aimed to protect the transformer, avoidance of its malfunctioning to the end user, protection of life and connected property. The case study is a university with approximately seventeen thousands students and three thousands workers with large infrastructures comprising staff lodges, student hostels and school hospital to mention few. The institution is connected to fourteen numbers of 11/0.415 kV substations from its 33/11 kV injection substation. The university name is deliberately excluded to avoid infringement right. The most expensive equipment in substation is transformer. So, the transformer must be protected against damages and malfunctions. The transformer damage or malfunction can put the students and staff into darkness, equipment malfunctioning, disruption of laboratory meant for practical and research, extension of school academic calendar which will delay students graduation on time, prolong darkness which can cause student protests, damage school property, harassment of staff (often death may results) and storage activities may be affected. It is therefore very crucial to evaluate the university substations earthing as a result of aforementioned problems.

1.2 Effective Earthing System

The main factors which determine the effectiveness of the earthing scheme is the resistivity of the soil and depth of the earth pit wherein the earth rod is fixed [10], [11]. In Nigeria electricity distribution industry today, safety is not practiced as expected [12]. The safety of persons who use electricity has been of great concern to the supply authorities, government, employers of labour, individuals and the general public. Using electricity without being safety conscious could be hazardous due to its irreparable damage to life and property [13]. Hence the reliability, integrity, and safety of any electrical installation, power system, and residential buildings depend on the sensitivity, the effectiveness of protection schemes, safety devices, coordination of relays, circuit breakers depends on the effectiveness of the earthing system in substations [12]. However the overall performance of the earthing system is highly influenced by the soil properties, especially the resistivity. Soil resistivity usually measured in ohms-meter depends on the physical composition of the soil, moisture content, dissolved salts, seasonal variation and current magnitude [7], [14], [15], [16].

1.3 Factors that Affect Earthing System

Several reasons are responsible for the present deplorable condition of the earthing system,
these includes:

1.3.1 Nature of the Soil

Soil is one of the most important natural resources. It is indispensable for the existence of plants and animals. Soils are formed by the combined work of rocks, topography, climate and plants. Soils of different country may be different. Soils are classified based on their colour structure and place where they are found. The wetter the soil, the lesser the resistance it will have [13]. This is the reason buildings have their own earth connection and do not rely on earth point at the distribution transformer [17]. Concisely, soil resistivity is directly proportional to earth resistance, the lower the soil resistivity the lower the resistance [13], [17].

1.3.2 Unskilled Manpower

Good earthing requires good workmanship but where untrained persons lacking in the right knowledge to design, install and maintain earthing systems, non-performance and failure of the system becomes the order[12], [18]

1.3.3 Wrong choice of Earthing Components/ Materials

In order to achieve good earthing, proper materials must be carefully selected and skillfully installed [18].

1.3.4 Economic Situation

Lack of funds sometimes force people to improvise and settle for cheap earthing materials which have adverse effects of the overall performance of the earthing system [12]

1.3.5 Climatic Condition and Seasonal Variations

Earthing systems are installed in widely differing soil types and subject to a range of climatic conditions [19]. The humid climatic condition contributes to the rusting or corrosion of the earthing system and helps to render inefficient and ineffective.

1.3.6 Lack of Proper Maintenance Policy

All forms of installation should be subject to two types of maintenance namely inspection - frequent inspection of all the earthing components which can freely accessible and periodic maintenance -closer arrangement than possible inspection or testing. The recommended period for inspection according to [13], [18], Figure 1, needs to be complied with.

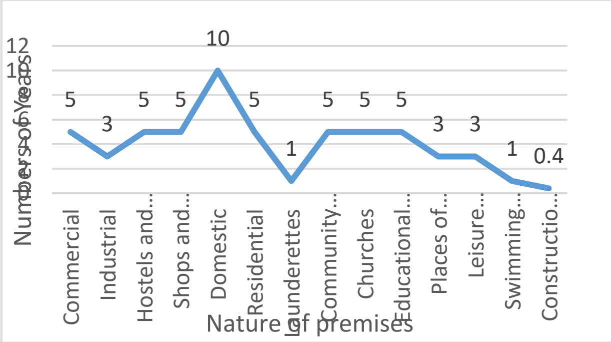

Figure1: Maximum Inspections Time for Different Premises Installation

2. EARTH ROD

Earth rods and their fittings are used to provide the interface to ground in all soil conditions in order to achieve satisfactory earthing systems in overhead and underground electricity distribution and transmission networks providing high fault current capacity on low, medium and high voltage substations, towers and power distribution applications. However, where additional driven earth rods are combined and connected, they should be separated from each other and from any adjacent cables by a distance not less than the depth to which they are driven. Additional earth rods should be connected using copper tape or bare copper cable of the same cross sectional area as the earth electrode conductor. The additional electrodes should be placed so that any necessary separation of the LV and HV earth electrode systems is maintained [9].

2.1 How to Improve Earth Resistance Value

There are various way to improve earth resistance value.

2.1.1 Used of Steel Reinforcement Bar (rebars)

The use of rebars that are either bare or have zinc coating in an earthing system can be used to improve conventional earthing system [20], [21].

For steel reinforcement earthing in a minimum of 55mm of concrete, concrete is in direct contact with earth, located within and near the bottom of a concrete foundation or footing, and be bonded together by the use of steel tie wire [20], [22].

However, [20], emphases that for good continuity of steel reinforcement, steel tie wire is unsuitable for joining the rods. Joining products particularly for the rebars are available in the market. An appropriate connection of the reinforcement steel enhance low resistance path to earth for earth current faults.

2.1.2 Used of Backfills Materials

In high resistive soil, a common method to achieve low soil resistivity is to cover the electrodes with conductivity material also known as backfill materials. The backfill material has the benefit of generating good earth resistance in space-restricted areas with very high soil resistivity by reducing the soil resistivity. [19], [23]

2.1.3 Other Methods of Reducing the Earth Resistance

Increasing of pit depth, increasing of plate area, and increasing number of electrode in parallel. The practice for pit depth is to increase the depth level to 2m [1], [7]. Steel reinforcing is analogical to increasing of plate area since number of steel reinforcement is a function of plate area [20]. .

2.2 Power System Earthing

Generally, earthing is the direct connection to ground of all exposed metallic parts of an electrical appliance or installation for the purpose of limiting voltage buildup relative to ground. Earth provides common return path to earth of electric current through direct physical connection to ground and it is the reference point in an electrical system from which other voltages are measured. [4] The earthing shall minimize electromagnetic interference between power and control/communication equipment and ensure safety to personnel.

2.2.1 Objectives of Earthing

According to [1], [3], [4], [5] the objectives of earthing are to:

i. ensure that no equipment part apart from live has dangerous potential different from that of surroundings,
ii. ensure sufficient current flow safely for proper operation of protective devices,
iii. limit over voltage between neutral or live and ground, and
iv. avoid electric shock, injury to personnel or electrocution of personnel.

2.2.2 Types of Power System Earthing

According to [1], [4] earthing is divided into neutral and equipment earthing.

2.2.2.1 Neutral Earthing

Neutral earthing is the connection of system neutral to the ground for security and protection of the equipment.

2.2.2.2 Equipment Earthing

Equipment earthing is the earthing of the non-current carrying parts of the equipment for personnel safety and protection against lightning.

2.2.2.2.1 Lightning Earthing System (LES)

This is a path created for surge current to effectively discharge to the general mass of the earth. However, in equipment sizing the ground conductor maximum surge current discharge should be put into consideration. In order to achieve effective earthing all the earthing system of the electrical network should be connected together [20]. However, the main difference between an earthing network designed for lightning protection system and that for a power system (Instrument and Electrical) depends on the handling of rate of transfer of energy in term of frequency which is 50Hz and kHz for power system and lightning respectively [3] by the two systems. A lightning protection system consists of air-termination (which intercepts with the downward stepped leader), down conductors (which bring the lightning current to the base of the structures) and earthing system (which safely and quickly disperse lightning energy into earth).

2.2.2.3 Instrument Earthing Systems

[9] accounted for 'Instrument Earthing Systems' in an industrial installation with sophisticated power and electronic equipment, protective measures should be taken to safeguard the instrumentation and the relevant control panels against the sudden high voltages which might hit the earthing system in the event of a fault (short-circuit) in the power circuit of the installation. To achieve this, as a standard design practice, a separate earthing system is necessary in such plants. Technical specification, particularly, the installation of instrument earthing system is quite the same as that of electrical system, described in earlier sections except for that the earthing resistance should not be greater than 1 Ohm throughout the instrument earthing network. Sufficient distance should be maintained between the instrument earth wells and the electrical earth wells. Standard distance is at least twice that of the greatest length of the earth rod driven in either the instrument or the electrical well. Instrument earth wells are installed adjacent to the control building [9].

2.3 Earthing System Testing

The measurement of ground resistance for an earth electrode system is very important. It should be done when the electrode is first installed and then at periodic intervals thereafter. This ensures that the resistance-to-ground does not increase over time. There are two methods for testing an existing earth electrode system. The first is the 3-point or Fall-of- Potential method and the second is the Induced Frequency test or Clamp-on method. The 3-point test requires complete isolation from the power utility. Not just power isolation, but also removal of any neutral or other such ground connections extending outside the grounding system. This test is the most suitable test for large grounding systems and is also suitable for small electrodes. The induced frequency test can be performed while power is on and actually requires the utility to be connected to the grounding system under test.

2.3.1 Fall-of-Potential Method or 3-Point Test

The 3-point or fall-of-potential method is used to measure the resistance-to ground of existing grounding systems. The two primary requirements to successfully complete this test are the ability to isolate the grounding system from the utility neutral and knowledge of the diagonal length of the grounding system. In this test, a short probe, referred to as probe Z, is driven into the earth at a distance of ten times (10X) the diagonal length of the grounding system (rod X). A second probe (Y) is placed in-line at a distance from rod X equal to the diagonal length of the grounding system [9], [21].

2.3.2 Induced Frequency / D.C Earth Resistance Tester

The Induced Frequency tester or D.C Earth Resistance Tester is a Clamp-On tester. It is one of the newest test methods for measuring the resistance-to-ground of a grounding system or electrode. This test uses a special transformer to induce an oscillating voltage (often 1.7 kHz) into the grounding system. Unlike the 3- point Test which requires the grounding system to be completely disconnected and isolated before testing, this method requires that the grounding system under test be connected to the electric utilities (or other large grounding system such as from the telephone company) grounding system (typically via the neutral return wire) to provide the return path for the signal. This test is the only test that can be used on live or ‘hot” systems. Practically, it is not advisable to use it on earthing of life substation [4] Also not advisable to clamp during lightning. However, the limitation includes but not limited to the amount of amperage to be tested should not be greater than the rated value of the Meter [9].

2.3.3 Earth Resistance Value

There are different standards for earthing resistance value as presented in Table 1.

Table1 1: Recommended Earth Resistance Value [4],[9], [18], [24]

S/N	Regulations/Literature	Earth Resistance Value (Ω)
1	IEC, Salih	4
2	NESIS	3 (Steel material)
		5 (Copper/Copper Alloy material)
3	BIS	10
4	NESIS	≤ Transmission station
5	NESIS	≤ 2 MV & LV system (System Earthing)
6	Salih	1 max (instrument earthing)
		4 (general other than Instrument earthing
8	Oyeleye, 2017	5

3 METHODOLOGY

DC earth resistance clamp meter, ETCR 2000 series Earth Ground clamp meter, Figure 1, was used to measure the earthing resistance value.

Figure 1: ETCR 2000 Series Earth Ground Clamp Meter

The values were compared to the NESIS system earthing (Transformer) value of 2 Ω maximum as a tradition which is also in conformity with IEC, BIS and Salih. The 5 Ω recommended for earth effectiveness test for copper/ copper alloy/ aluminum material is compared with LA and feeder panel. Its reliability in measurement was as a result of its use on past projects by Nigerian Electricity Management Services Agency (NEMSA), an agency endowed with testing of electrical installations. Access was grounded into all the university substations. The transformers, feeder panels and lightning arrester (LA) grounding were clamped as in Figure 2 and earthing values recorded accordingly.

4. RESULTS AND ANALYSIS

The result of various substations is presented in Table 1. Figure 3 illustrates a typical substation.

Figure 2: Clamping of Earthing Conductor Using ETCR 2000 Series Earth Ground Meter

Table 2: Transformer earthing, outgoing feeder panel and LA Earthing Values

S/N	LOCATION (SUBSTATION NAME)	TRANSFORMER	OUTGOING FEEDER (Ω)	LIGHTNING ARRESTER (Ω)
1	Main Power 7.5MVA 33/11 kV	OPEN LOOP	36.7	12.2 and 0.4
2	Senate 500 KVA 11/0.415 kV Subsation	2.3	2.3	2.3
3	Jibowu 500KVA 11/0.415 kV	OPEN LOOP	Open Loop	Open Loop
4	IDD 300KVA 11/0.415 kV	138	Not Bonded To Earth	138
5	Works 500KVA 11/0.415 kV	127	17.8	Open Loop
6	2,500 Capacity Auditorium 500KVA 11/0.415 kV substation	OPEN LOOP	Open Loop	Open Loop
7	SOS 500KVA 11/0.415 kV Subsation	OPEN LOOP	12.7	Open Loop
8	Science 500KVA 11/0.415 kV	OPEN LOOP	Open Loop	Open Loop
9	Obanla Quarters 500KVA 11/0.415 kV subsation	OPEN LOOP	Open Loop	Open Loop
10	Farm 500KVA 11/0.415 kV Subsation	OPEN LOOP	Open Loop	Open Loop
11	V.C Lodge 300KVA 11/0.415 kV Subsation	OPEN LOOP	Open Loop	Open Loop
12	PG Hostel 500KVA 11/0.415 kV	OPEN LOOP	Open Loop	Open Loop
13	New Hostel 500KVA 11/0.415 kV	OPEN LOOP	Open Loop	Open Loop
14	SEMS 500KVA 11/0.415 kV	OPEN LOOP	Open Loop	Open Loop
15	SERAJ 200KVA 11/0.415 kV Substation	55.5	10.9	96.5

Figure 3: Typical substation in the study Area

From Table 1, the transformers earthing values vary from 2.3 Ω to open loop, outgoing feeder panels vary from 2.3 Ω to open Loop (OL) while LA varies from 0.4 Ω to open loop. Only 0.4 Ω conforms to NESIS, IEC and BIS Standards. Since the study area location is Nigeria, NESIS in adopted firstly for the purpose of commission of the project. However, one of the LA in substation 1 and LA in substation 2 (12.5%) conformed to standard of 2 Ω for system earthing. Also, substation 2 feeder panel (6.7%) conformed to standard of 5 Ω. Generally, it means that none of the substation earthing is satisfactorily protected. It also means that equipment damages, equipment malfunctioning, electric shock and, electrocution of lifes are possible. Even, only one substation, 2, adequately meets international standards.

5. CONCLUSIONS

i. None of the substation under this research meets local standard.
ii. 7% substation is in conformity with IEC and BIS.
iii. 93% of the Substation failed international standards.

6. RECOMMENDATIONS

Substation earthing value should conformed to both local and international standards for safety of life and properties.

7. ACKNOWLEDGEMENT

I appreciate Mr. Agboola, Ebenezer Adeola, a student of Electrical and Electronics Engineering Federal university of Technology, Akure (FUTA) and Staff of Nigerian electricity management services Agency (NEMSA) for preliminary information.

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