THE INADEQUACY OF EARTHING IN BUILDING STRUCTURES IN ZARIA

BY

MU'AZU, HASSANA ASPITA
M.Sc/ENG/32961/2002-03

A THESIS SUBMITTED TO THE DEPARTMENT OF ELECTRICAL
ENGINEERING, AHMADU BELLO UNIVERSITY, ZARIA IN PARTIAL
FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF A
MASTER OF SCIENCE (M. SC) DEGREE IN ELECTRICAL
ENGINEERING.

OCTOBER 2007

DECLARATION

I, MU'AZU, Hassana Aspita, hereby declare that this thesis titled "**The Inadequacy of Earthing in Building Structures in Zaria**" presented to the Department of Electrical Engineering, Ahmadu Bello University, Zaria is the result of my own research and that it has not been presented in any form, anywhere for the award of a degree.

All literature herein referenced and cited have been duly acknowledged. All shortcomings in this work are entirely my responsibility.

……………………………………………….	………………………………………
MU'AZU, Hassana Aspita	Date

CERTIFICATION

The thesis titled “**The Inadequacy of Earthing in Building Structures in Zaria**” satisfies one of the requirements for the award of a Master of Science (M. Sc) degree in Electrical Engineering and has been approved by the Department of Electrical Engineering, Ahmadu Bello University, Zaria.

……………………………………………….. ………………………………
Prof. B. G. Bajoga Date
(Supervisory Committee)

……………………………………………….. ………………………………
Dr. D. D. Dajab Date
(Supervisory Committee)

……………………………………………….. ………………………………
Dr. M. B. Mu’azu Date
(Head of Department)

……………………………………………….. ………………………………
Prof. S. Nkom Date
(Dean, Postgraduate School)

DEDICATION

This work is dedicated to my Children, Hameed B. Mu’azu and Nabeelah B. Mu’azu for their love and support.

ACKNOWLEDGEMENTS

Firstly, I wish to thank Almighty Allah for his protection over me and my family.

With profound gratitude, I wish to acknowledge the tremendous efforts of Prof. B. G. Bajoga for his encouragement, guidance, fatherly love and thoroughness in searching and presenting ideas which contributed to making this work a reality. I am also grateful to my other supervisor, Dr. D. D. Dajab for all his contributions.

I am grateful to the entire academic and non-academic staff especially Mr. Fatai O. Sadiku of Electrical Engineering Department, Ahmadu Bello University, Zaria for their relentless support.

I wish to thank the management and staff of NITEL Zaria Exchange and that of FAAN/NAMA Zaria Aerodrome for their assistance during the course of field measurements.

My sincere appreciation goes to my in-laws, parents, siblings, friends, colleagues in the office and well wishers who have one way or the other contributed to making this thesis a reality.

Finally, I wish to thank my husband for his understanding, love and financial supports.

Mu’azu, Hassana Aspita
March 2007

TABLE OF CONTENTS

CHAPTER ONE: INTRODUCTION

CHAPTER TWO: THEORETICAL BACKGROUND

CHAPTER THREE: METHODOLOGY

CHAPTER FOUR: RESULTS AND ANALYSIS

CHAPTER FIVE: CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS

DVB :	Digital Video Broadcasting
EMC:	Electromagnetic Compatibility
EMP:	Electromagnetic Pulse.
FAAN:	Federal Airport Authority of Nigeria
IACC:	Iya Abubakar Computer Centre
IEEE:	Institute of Electrical and Electronics Engineers
ILS:	Instrument Landing System
Ltd:	Limited
LIS:	Lightning Imaging Sensor
LNB:	Low Noise Block
LPS:	Lightning Protection System
MDF:	Main Distribution Frame.
NAMA:	National Airspace Management Agency
NASA:	National Aeronautic and Space Agency
NITEL:	Nigerian Telecommunications Limited
NTA:	Nigerian Television Authority
PHCN:	Power Holding Company of Nigeria
SPD:	Surge Protection Device

ABSTRACT

Earthing and lightning protection systems protect people from the danger of electrocution and equipment from over-voltages by dissipating the excess energy into the earth, and at the same time reducing the potential difference between equipment and earth. This study investigated the effect of lightning strikes on people, buildings, communication towers and equipment by determining the number of lightning strikes on the structures depending on their location and height as well as the earthing resistances. With the aid of data obtained from April 1995 to February 2003, from the National Aeronautic and Space Agency (NASA), Lightning Imaging Sensor (LIS) Science Team and from NASA's Optical Transient Detector and colour coded onto a map, the annual flash rate for Zaria was obtained. Based on this, the number of lightning strikes on two structures; the control tower of the Zaria Aerodrome and the communication tower of the Zaria Nitel Exchange; were determined. The Fall-of-Potential Method (also referred to as Earth-Spike Method) was method used for the earth resistance measurement. The null-balance analogue type Megger Earth Tester was used as the test instrument to determine the earth resistance of the following locations within Zaria: Department of Electrical Engineering**,** Zaria Aerodrome Control Tower**,** Commercial Complex, No. 8 Sokoto Road and Nitel Exchange Communication Tower. The earth resistance measurements taken for the various locations were in conformity with the general standards: "The resistance to earth of the earth electrode subsystem should not exceed **10Ω** at fixed permanent facilities". All the earthing resistances measured around the ring earth of the Nitel Communication Tower were within NITEL recommended resistance of less than **1Ω**.

CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTION

Electricity today is playing an ever increasing role in the lives of everyone in the civilized world. The high in demand on use of electricity has resulted in the increased danger to human beings and their properties. Not only defects at consumer's premises, but even at supply authority's premises can electrocute a customer at his own premises. Proper earthing protects humans from this danger of electrocution [1].

Lightning is one of nature's most unpredictable events. It strikes at random, damaging buildings, endangering lives, corrupting data, creating expensive repairs and costly down time . Lightning strikes the earth, on average, one hundred times per second (as there are over eight million lightning strikes per day around the world [2]). The tallest structures (communications towers and masts) in cities across the world are most vulnerable to lightning strikes due to the induction effect between a charged cloud and them. Many of the world's historic and heritage rated buildings, like the Eiffel Tower as shown in Figure 1.1, are at risk because of their construction methods and the lack of sophisticated fire protection systems [2].

Proper earthing provides return paths for large number of electronic equipment or radio frequency (RF) antennas, etc. Earthing is necessary for proper functioning and protection of certain equipment. Some of the equipment suffer physical damages caused by induced transients on service wiring running inside or entering the structure. Engineers, designers, consultants and managers have a responsibility to provide a safe environment for employees, patrons and microelectronic computer and communication systems as a correctly designed and installed earthing system will safeguard both lives and equipment [3].

Figure 1.1: Lightning Striking the Eiffel Tower

1.2 MOTIVATION FOR STUDY

Rainstorms with high thunderstorm activities have been known to have caused the losses of lives, electrical gadgets damage, total failure of electrical and/or telecommunications installations in Nigeria.

According to the Daily Trust of 24th of September, 2006, a residential building located at Kontagora town of Niger State was hit by a lightning strike as a result of which the building caught fire killing the occupants of the building (a woman and her six children).

The server room of the Ahmadu Bello University Zaria Network located at the seventh floor of the Senate building in which digital video broadcasting (DVB) satellite receiver, low noise block (LNB), Satellite transmitter and other equipment worth over two million Naira (N2,000,000) were lost as a result of lightning strike in 2006. This was attributed to poor earthing of the VSAT equipment

Several cases of electronic gadgets have been reported damaged and/or lost due to lightning strikes. Catastrophic failures of telecommunications equipment are particularly common in regions of high thunderstorm activities. A typical example is the case of the Nigerian Telecommunications Limited (NITEL) Digital Exchange in Jos in which the AXE-10 Ericsson equipment and most of its components got damaged on the 13th of September, 1997. The cause of the failure was a lightning strike that hit the tower which was believed to have been poorly earthed. Because the poor earthing system was not immediately identified and corrected, there was a repeat incidence at the Exchange in July, 1998 [4].

All the electronic printed cards inside the Motorola Base Radio Communication equipment at the Power Holding Company of Nigeria (PHCN) Mubi got burnt after the tower was hit by lightning on 21st October 2004. Another case is that of the Nigeria Television Authority (NTA) Yola transmission tower, which was hit by thunderstorm and lightning on 6th April 1992. The tower was damaged along with some vital transmission equipment [4].

In August 1995, during the intermediate approach in a thunderstorm into an airport in Denmark, an A320Airbus was hit by lightning strike - according to the crew, no aircraft systems were affected. However, the approach had to be interrupted with a subsequent diversion to Copenhagen because the destination airport was hit by lightning as well, which caused a complete electricity supply outage including loss of Instrument Landing System (ILS) and communication [5].

These examples emphasize the need for buildings, towers and equipment to be properly earthed by professionals according to standard practices in order to minimize damage and loss of lives and properties as a result of lightning strikes during thunderstorms.

1.3 EARTHING

Earthing may be defined as a system of electrical connections to the general mass of earth [6]. Earthing a building, tower or equipment implies connecting it to general mass of earth by means of a metal plate or rod or electrical conductor. Earthing protects human beings from danger of electrocution by dissipating the excess energy into the earth and at the same time reduces the potential difference between equipment and earth. A correctly designed and installed earthing system will safeguard both lives and equipment [4, 7]

1.3.1 Objectives of Earthing

The objectives of an earthing system include the following:

i) To provide safety to personnel during normal and fault conditions by limiting step and touch potential;

ii) To guarantee correct operation of electrical and electronics devices;

iii) To prevent damage to electrical and electronic apparatus;

iv) To dissipate lightning strikes;

v) To stabilize voltage during transient conditions; and

vi) To divert stray radio frequency (RF) energy from sensitive audio, video, control and computer equipment [8].

The Institute of Electrical and Electronic Engineer (IEEE) Guide for Safety in Substation Earthing [8] states that a safe grounding design has two objectives:

i) To provide means to carry currents in to the earth under normal and fault conditions without exceeding any operating and equipment limits or adversely affecting the Main Distribution Frame (MDF) [8]. However, the path followed by these diverted currents (within the grounding system) can cause dangerous over-voltages capable of damaging existing equipment, depending on the exact discharge path and the parameters of the lightning strike. Consequently, Surge Protection Devices (SPDs) should always divert the current to the same reference of the protected current and should do so through the most direct path to avoid potential difference within the circuit.

ii) To assure that a person in the vicinity of grounded facilities is not exposed to the danger of critical electric shock.

1.4 LITERATURE REVIEW

There are more than a thousand thunderstorms around the Earth causing some 6,000 flashes of lightning strikes every minute and each large thunderstorm has more total energy than that of an atomic bomb. Even an individual lightning charge may contain 30 million volts at 100,000 amperes and can cause serious damage to properties and even loss of lives [9].

According to Conroy et al [9], a study was carried out in 1996 to determine the most effective method of installing low resistance earth grounding. It was determined that deep-driven ground rods would offer the best solution, if full rod contact could be maintained. By 1998, a new process was developed for installing deep-driven ground rods. This new process helped in overcoming the problems associated with installing deep ground rods.

Schmitt et al [10] carried out a study on the simulation of lightning over-voltages in electrical power systems. Lightning strikes which directly strike towers were found to increase the potential of the towers affected and can, dependent on the level of the tower footing resistance and the electric strength of the overhead line insulators, lead to backward flashovers from the tower to an overhead line conductor. These backward flashovers cause traveling waves which propagate via the overhead line towards the switchgear where they cause over-voltages which can pose a risk to any items of equipment connected, such as cables or transformers. They concluded that with the use of metal-oxide arresters, these over-voltages are reduced to values that are within an adequate safety margin.

Dzara [4] carried out a study to determine the soil resistivity and earth resistance for the Nigeria Telecommunications Limited (NITEL) Digital Exchange Mubi and concluded that the earthing plan had been implemented according to NITEL specifications. Average earth resistance values obtained ranged from 0.23Ω to 0.56Ω. These values lie within the Nitel recommended value being less than 1Ω.

This work is aimed at investigating the effect of lightning strikes on people, buildings, communication towers and equipment as a consequence of the earthing standard employed. This is based on the fact that most buildings do not adhere to standard building and electrical installation practices as non professionals are involved in the building construction, electrical earthing and lightning protection systems. The investigation involved the use of questionnaire, determining the number of lightning strikes and the earthing resistance of certain locations around Zaria.

1.5 RESEARCH OBJECTIVES AND METHODOLOGY

Electricity and Electronics play a vital role in the life of everyone. Modern electronic systems, such as computers, radar and telecommunication equipment and/or installations are highly sensitive and susceptible to lightning and electrical surges and other transient pulses received through power or signal lines. Proper grounding and bonding through low impedance ground is essential to facilitate dissipation of these unwanted signals. The objectives of this study are, among others to:

i) Determine the extent of exposure of electrical and electronics gadgets in buildings and structures and their occupants within Zaria to the danger of direct hit by lightning strikes. The possible number of lightning strikes will also be determined;

ii) Determine the earthing resistance of some buildings around Zaria and compare the measured earthing resistance to the standard specified earthing resistance; and

iii) Determine the earthing resistance of Zaria NITEL exchange and compare the value obtained with the standard specified earthing resistance of the industry.

The methodology adopted in carrying out this work involves the following:

i) Use of questionnaire (Appendix A1) to determine the extent of damage caused by lightning strikes on such persons, equipment, buildings and towers within and outside the Ahmadu Bello University Main Campus;

ii) Measurement of earth resistance using the Megger equipment on some buildings and towers earthing points. Some of these buildings and towers include NITEL Exchange Zaria, Control Tower at the Zaria Aerodrome, Electrical Engineering Department building etc; and

iii) Comparison of the measured earthing resistance of the various earthing points taken in ii) to the recommended earthing resistance for such buildings and/or towers.

1.6 THESIS OUTLINE

The thesis consists of five chapters. Chapter one contains the introductory material together with the literature review. Chapter two contains the theoretical background of the work. Chapter three describes the methodology used in carrying out the study while Chapter four describes the analysis of the results obtained. Chapter five presents the conclusions and recommendations for further work.

CHAPTER TWO

THEORETICAL BACKGROUND

2.1 EARTHING

An effective earthing system, which is a fundamental requirement of any modern structure or system, is indispensable for operational and/or safety reasons. Without such a system, the safety of the structure and its occupants as well as the equipment contained within it is compromised [7, 11, 12].

Earthing Systems typically fall into (but are not limited to) one of the following categories:

i) Lightning protection
ii) Electrostatically induced overvoltage of a charged cloud
iii) Telecommunications.

A good earth connection should have:

i) Low electrical resistance to earth
ii) Good corrosion resistance
iii) Ability to carry high currents repeatedly
iv) A reliable life of at least 30 years [13, 14].

The crucial factors that determine the resistance to earth of an electrode are:

i) **Soil Resistivity:** The following factors affect the soil resistivity:

- **Physical composition:** Different soil compositions give different average resistivities as in Table 2.1 [13, 15].

Table 2.1: Effect of Soil Type on Resistivity

Soil type	**Typical resistivity Ohm-m**
Marshy ground	2 - 2.7
Loam and clay	4 – 150
Chalk	60 – 400
Sand	90 – 8,000
Peat	200 upwards
Sandy gravel	300 – 500
Rock	1,000 upwards

- **Moisture:** Increased moisture content of the ground can rapidly decrease its resistivity. It is especially important to consider moisture content in areas of high seasonal variation in rainfall. Wherever possible the earth electrode should be installed deep enough to reach the "water table" or "permanent moisture level" [13].
- **Chemical Composition:** Certain minerals and salts can affect soil resistivity as in Table 2.2. Their levels can vary with time due to rainfall or flowing water. Note that although the addition of salts can lower soil resistivity, they are not recommended due to corrosion and leaching [13]. The treatment is limited to the area in the neighbourhood of earth electrode as in Figure 2.1. The earth electrode should be buried at least 3m into the ground with charcoal and coke powder mixed with salts [16]

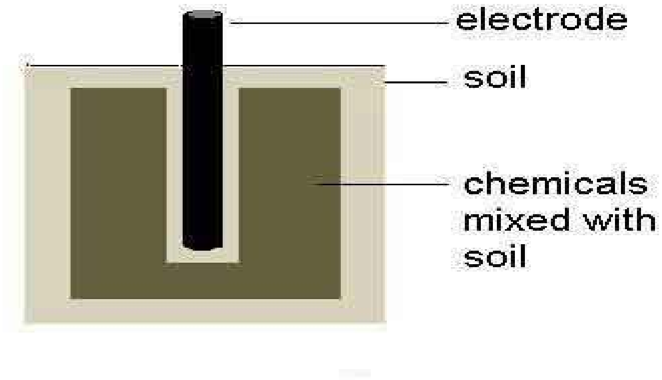


Figure 2.1: Salt Treatment Setup

Table 2.2: Effect of Salt on Resistivity for Sandy Loam (15.2% Moisture)

Added salt (% by weight of moisture)	**Resistivity (Ω-m)**
0.0	107.0
0.1	18.0
1.0	4.6
5.0	1.9
10.0	1.3
20.0	1.0

- **Temperature:** The effect of temperature is more prevalent in temperate regions. When the ground becomes frozen, its resistivity rises dramatically. An earth that may be effective during temperate weather may become ineffective in winter. In Nigeria, the effect of temperature on soil resistivity is negligible [7, 13].

ii) **Electrode Dimensions:** The most important dimension to consider when designing an earth electrode is its length. The greater the length of an electrode the lower the density of the current in soil in the immediate vicinity of that electrode. For this reason a rod or strip type electrode will have a much lower resistance to earth than a plate type electrode of the same surface area. By reaching permanent moisture and frost free soil levels, low resistance should be achieved. Often these levels are some meters below the surface and the most economical way of reaching them is by extensible deep driven earth rod electrodes. The use of deep driven earth rod electrodes is recommended wherever conditions allow. Where rocks lie just below the surface and deep driving is not possible, parallel driven shorter rods, plates, mats and buried conductors, or a combination of these can be used. However, these conductors should still be buried as deep as possible to avoid seasonal variations, damage from constructional and agricultural machinery etc [13].

iii) **Area Available:** Often a single earth rod, strip or plate will not achieve the desired resistance alone. If a number of electrodes can be installed in parallel the combined resistance is then practically proportional to the reciprocal of the number employed. This is true so long as each electrode is situated outside the resistance area of any other electrode. For rod electrodes this separation distance is considered to be equal to the driven depth as in Figure 2.2. When an earth electrode must be composed of multiple parallel electrodes the area available for earthing becomes of major importance [13].

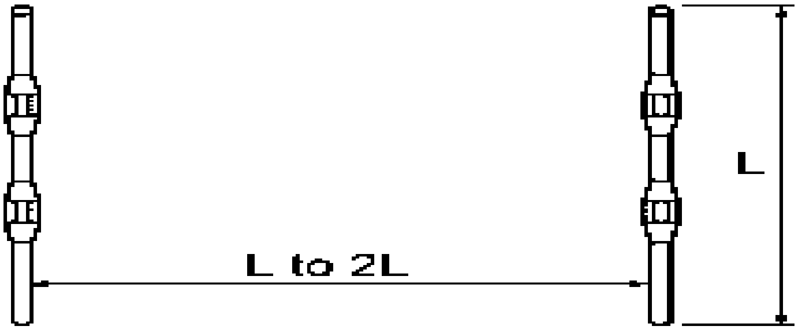


Figure 2.2: Separation Distance for Multiple Electrodes

iv) **Earth Electrode Materials**: Quality earth rods are commonly made from either solid copper, stainless steel or copper-bonded steel. The copper-bonded steel cored rod is by far the most popular, due to its combination of strength, corrosion resistance, and comparatively low cost. Solid copper and stainless steel rods offer a very high level of corrosion resistance at the expense of lower strength and higher cost [13].

2.1.1 The Role of the Earthing System

The earthing (grounding) system plays a crucial overall role in achieving electromagnetic compatibility (EMC) and in providing lightning protection [4]. Electromagnetic disturbances are coupled into electronic circuitry via three basic mechanisms:

i) Capacitive coupling (electric field)

ii) Inductive coupling (magnetic fields) and

iii) Common impedance coupling (electromagnetic fields).

Essentially all the techniques used to mitigate these instances of coupling relate to the grounding system. For example, a shield might be used to deflect unwanted noise along the loop to the ground. In any case, an effectively designed earthing system remains the primary source of lightning protection for electrical and telecommunications systems. This ground system must prevent both high levels of electromagnetic disturbances and dangerous over-voltages or over-currents from being coupled into the circuitry [8].

2.1.2 Earth Resistance Measurement

A typical diagram representing the earthing system is shown in Figure 2.3. When current is injected into an earthing system at a point, it will leave the system through another path and will cause a voltage change on any point connected to it to a reference datum. If only the change in voltage is the focus of attention then the datum point could be ignored and will not change the inference [4].

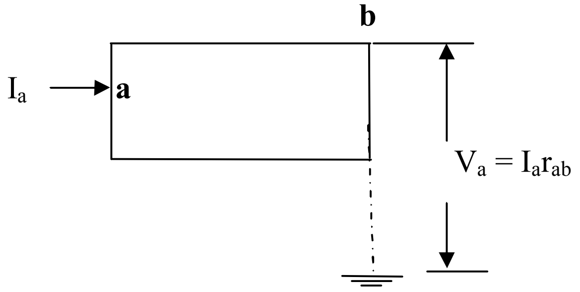


Figure 2.3: Representation of Earthing System

If a current I_a flows to earth at a point a, there will be a change in potential of all the conductors connected to this earth, and the change in potential V_b at any point b, ignoring the sense of the current, in the earthing system can be expressed as:

$$V_b = I_a r_{ab} \quad \Rightarrow \quad r_{ab} = \frac{V_b}{I_a} \qquad 2.1$$

If the conditions were now reversed such that current I_a now flows to earth through point b and the change in potential is monitored at point a, the potential V_a will be;

$$V_a = I_b r_{ba} \quad \Rightarrow \quad r_{ba} = \frac{V_a}{I_b} \qquad 2.2$$

But,

$$I_a = -I_b$$

$$and \qquad 2.3$$

$$r_{ab} = r_{ba}$$

However, the voltages at these respective points are:

$$V_a = I_a r_{aa} + I_b r_{ab} \qquad 2.4$$

and

$$V_b = I_b r_{bb} + I_a r_{ba} \qquad 2.5$$

Using equations 2.3, 2.4 and 2.5, the potential difference between the two points is:

$$V_a - V_b = I_a \left(r_{aa} - 2r_{ab} + r_{bb} \right) \qquad 2.6$$

From which the earthing resistance between the two points is calculated to be

$$R_{ab} = \frac{\left(V_a - V_b \right)}{I_a} = r_{aa} - 2r_{ab} + r_{bb} \qquad 2.7$$

The quantities r_{aa}, r_{bb} and $2r_{ab}$ are resistance coefficients for earth electrodes at points a and b, and the proximity resistance coefficient since the two electrodes are in the region of influence of each other. This is the principle behind the process of measuring the earthing parameters [4].

2.2 LIGHTNING

Lightning is a powerful natural electrostatic discharge produced during a thunderstorm. This abrupt electric discharge is accompanied by the emission of visible light and other forms of electromagnetic radiation. The electric current passing through the discharge channels rapidly heats and expands the air into plasma producing acoustic shock waves (thunder) in the atmosphere. A typical lightning strike is shown in Figure 2.4 [2].

Figure 2.4: A Typical Lightning Strike As Seen in Arlington

Lightning causes thunder because a strike of lightning is incredibly hot. A typical bolt of lightning can immediately heat the air to between 15,000 to 60,000°F (degrees Fahrenheit). This is hotter than the sun! [17]

A lightning strike can heat the air in a fraction of a second. When air is heated so quickly, it expands violently and then contracts, like an explosion that happens in the blink of an eye. It is the explosion of air that creates sound waves, which we hear and call thunder. When lightning strikes very close by, the thunder is heard as a loud and short bang. When lightning occurs but the thunder is not heard, the lightning is too far away [18].

Light and sound will always move at different speeds. And lightning will always produce thunder because of the strike's high temperature. And a flash of lightning will always be seen before the thunder is heard. The first process in the generation of lightning is still a matter of debate [17]. One common idea is that lightning forms from the ejection of charged particles from the sun, which reaches the earth through the solar wind. These charged particles cause the Earth to acquire an electric charge in its outer atmospheric layers, especially the ionosphere. Large quantities of ice in the clouds have also been scientifically proven to enhance lightning development [18].

This charge will neutralize itself through any available path. This may assist in the forcible separation of positive and negative charge carriers within a cloud or air, and thus help in the formation of lightning. A single lightning flash may be in order of 30kA, $200\text{x}10^6$V and will take place within 30 millionth of a second [17, 18]

2.2.1 Occurrence of Lightning

When a thunderstorm occurs, lightning also exists. This is because a thunderstorm is classified by lightning. In order for either of the two to be present in the atmosphere, clouds must first form. The clouds form when the air near the earth's surface is warm, causing it to rise since warm air rises. When air heats up it expands and this expanding air has to go towards the ground. This usually occurs miles ahead of the main storm and will strike without warning on a sunny day [18].

However, lightning does not occur uniformly around the globe. In equatorial regions, the warm and humid weather conditions lead to the highest incidence of lightning. Further away from the tropics, the number of lightning storms decreases to as low as less than one day per year in Polar Regions. Recorded extremes have been as high as 242 thunderstorm days in one year in Uganda to 1 day in 10 years at the poles as in Figure 2.5. Table 2.3 shows a typical relationship between number of thunderstorms and lightning strikes [19].

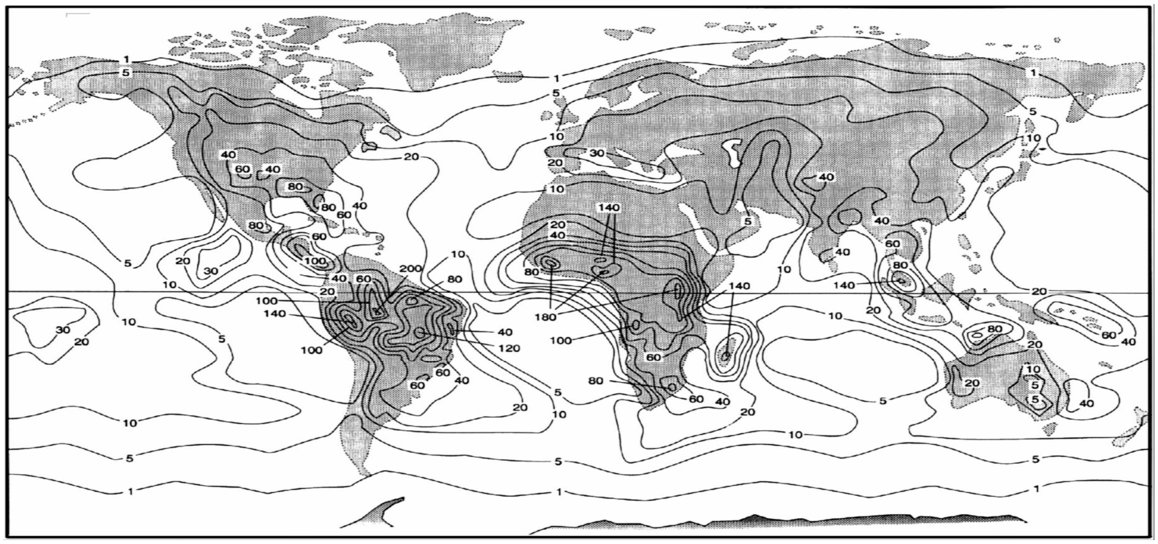


Figure 2.5: World Thunderstorm Zones

Table 2.3: Typical Relationship Between Thunderstorms and Lightning Strikes

Thunderstorm days per year	Flashes per sq. km/year	
	Mean	Limits
5	0.2	0.1 to 0.5
10	0.5	0.15 to 1
20	1.1	0.3 to 3
30	1.9	0.6 to 5
40	2.8	0.8 to 8
50	3.7	1.2 to 10
60	4.7	1.8 to 12
80	6.9	3 to 17
100	9.2	4 to 20

The following are factors that influence the possibility of lightning striking any structure:

i) Height of the structure

ii) Location of the structure

iii) Local level of lightning activity.

Given the local level of lightning activity at a site and the height of the structure under consideration, the number of lightning strikes directly hitting the structure per year is approximately estimated as:

$$N_d = N_g . A_e . 10^{-6} \qquad 2.8$$

Where:

- N_g is the average annual ground flash per square kilometre
- A_e is the equivalent collection area of the structure being assessed in m^2.
- N_d is the number of direct lightning strike to structure per annum [4, 20]

Direct lightning strikes present several types of hazards in addition to the direct strike.

These include the following:

i) The direct strikes - physical damage

ii) Secondary arcing phenomenon – fire or explosion

iii) Traveling wave – electrical damage

iv) Power line surges – electrical damage

v) Electromagnetic pulse – electrical damage

It should be noted that lightning is a probabilistic phenomenon and as such, the number of lightning strikes terminating within an area may vary drastically from year to year, or over short periods of a few years. With a direct strike to or near any area, there are a possible series of secondary effects that can be expected [21]

The secondary effects can influence areas as large as several square kilometers. These effects are as follows:

i) **Earth Current Induced Transients**: The charge within the storm cell induces an equal and opposite charge on the earth beneath it. Everything takes on the charge because the charging rate is slow. When a strike terminates, all of the charge travels to the termination point within about 20 microseconds. Any conductors buried within the surrounding earth will act as the preferred conductors for this charge, thereby inducing transients within those conductors.

ii) **Secondary Arcing and the Bound Charge:** With reference to i) (Earth Current Induced Transients), conductors that are isolated from earth or largely insulated materials such as flammables will take on a charge. The charge is unable to be released within the strike neutralization period (less than 100 microseconds) and is "bound" on the material as a result. When the surroundings are neutralized, the difference of potential between them results in an arc, called the "secondary arc". This is a major cause of flammables related fires.

iii) **Atmospheric Induced Transients:** The varying electrostatic field between the storm cell and earth causes atmospheric transients. The varying electric field induces high voltage transients on any wires immersed in that field. The higher the elevation of these wires, the higher the induced voltage sometimes referred to as "Electrostatic Pulse".

iv) **Electromagnetic Pulse (EMP)**: Lightning creates a large electromagnetic pulse. The EMP within that magnetic field will induce voltages on any nearby conductors. The ***dv/dt*** can reach up to 500 kV/micro-second. The induced voltages can be in the millions of volts, but low energy [22]

2.2.2 Ground-to-Cloud Lightning

Ground-to-cloud lightning is a discharge between the ground and a cumulonimbus cloud, as in Figure 2.6 [22], from an upward-moving strike. Thunderstorm clouds are formed wherever there is enough upward motion and moisture to produce a deep cloud that reaches up to levels somewhat colder than freezing. These conditions are most often met in summer. Lightning occurs less frequently in the winter because there is not as much instability and moisture in the atmosphere as there is in the summer. These two ingredients work together to make convective storms that can produce lightning. Without instability and moisture, strong thunderstorms are unlikely [21].

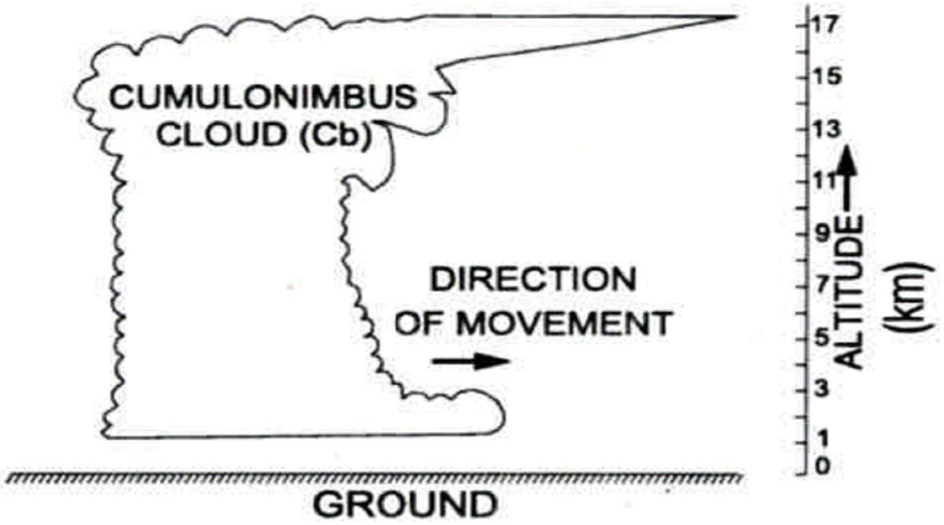


Figure 2.6: A Typical Cumulonimbus Cloud

Lightning originates around 15,000 to 25,000 feet above sea level when raindrops are carried upward until some of them convert to ice. For reasons that are not widely agreed upon, a cloud-to-ground lightning flash originates in this mixed water and ice region [21]. The charge then moves downward in 50 yard sections called step leaders. It keeps moving toward the ground in these steps and produces a channel along which charge is deposited. Eventually it encounters something on the ground that is a good connection. The circuit is complete at that time, and the charge is lowered from cloud-to-ground. The return stroke is a flow of charge (current) which produces luminosity much brighter than the part that came down. This entire event usually takes less than half a second [3, 22].

2.2.3 Effects of Lightning

Nearly 2000 people per year in the world are injured by lightning strikes, and between 25 to 33% of those struck die [23]. Lightning injuries result from three factors:

i) Electrical damage;
ii) Intense heat; and
iii) Mechanical energy which i) and ii) generate.

While sudden death is common because of the huge voltage of a lightning strike, survivors often fare better than victims of other electrical injuries caused by a more prolonged application of lesser voltage. Lightning can incapacitate humans in four different ways:

i) Direct strike;
ii) ‘Splash’ from nearby objects struck;

iii) Ground strike near victim causing a difference of potential in the ground itself (due to resistance to current in the earth), amounting to several thousand volts per foot, depending upon the composition of the earth that makes up the ground at that location (sand being a fair insulator and wet, salty and spongy earth being more conductive); and

iv) Electromagnetic Pulse (EMP) from close strikes especially during positive lightning discharges [22]

The most critical injuries are to the circulatory system: the lungs, and the central nervous system. Many victims suffer immediate cardiac arrest and will not survive without prompt emergency care, which is safe to administer because the victim will not return any electrical charge after the lightning has struck (of course, the helper could be struck by a separate bolt of lightening in vicinity). Others incur myocardial infarction and various cardiac arrhythmias, either of which can be rapidly fatal as well. There is sometimes spectacular and unconventional lightning damage. Hot lightning (high – current lightning) which lasts for more than a second can deposit immense energy, melting or carbonizing large objects [22]

2.3 LIGHTNING PROTECTION

Thunderstorms are the primary source of lightning. As people have been struck many miles away from a storm, an important safety procedure is seeking immediate and effective shelter when thunderstorms approach [22, 24].

Several different types of devices, including lightning rods and electrical charge dissipators, are used to prevent lightning damage and safely redirect lightning strikes. A properly designed and installed lightning protection system will protect lives and property against lightning damage. Such a system is designed to safely carry lightning currents to ground without damage to the protected structure. A typical system will consist of air terminals (lightning rods) and ground terminals which are connected together with low resistance conductors. These conductors are usually copper or aluminium. These metals and their alloys are specified not only for their electrical conductivity, but also for their corrosion resistance qualities [22, 24]

In addition to these basic items, lightning protection codes require separately grounded systems to be bonded together as well as other metallic items that may provide a short circuit path between grounded items [22].

A properly designed lightning protection system will also take into consideration the myriad of electronic devices found in today's homes and businesses. Transient voltage surge protection should be provided to guard against unwanted electrical disturbances from entering the structure via the electrical cables, television telephone or data lines [24].

2.4 SURGE PROTECTION DEVICES AND THE GROUNDING SYSTEM

Surge Protection Devices (SPDs) play a crucial role in averting catastrophic damage when over-voltage does enter the system. Even with careful system configuration, including circuit design, cable usage, and an overall grounding system, nature can still play havoc with lightning volts far in excess of the capacity of the cabling and connected equipment [8]. Normally, Surge Protection Devices (SPDs), the last vital point of defense, are installed near the equipment to be protected; alternatively, Surge Protection Devices (SPDs) can be installed along the communication cable thus splitting the cable length and reducing the amplitude of the coupled over-voltage or over-currents [8].

Clearly, with such vital protection at stake, careful installation of SPDs is vital. Currents diverted do not simply disappear; they must be channeled to the grounding system. For example, lightning–induced currents on metallic cables connected to a telecommunication system can be diverted to ground by Surge Protection Devices (SPDs)(momentary ground connection) installed at the telecommunications system entrance, normally at the Main Distribution Frame (MDF) [8]. However, the path followed by these diverted currents (within the grounding system) can cause dangerous over-voltages capable of damaging existing equipment, depending on the exact discharge path and the parameters of the lightning strike. Consequently, Surge Protection Devices (SPDs) should always divert the current to the same reference of the protected current and should do so through the most direct path to avoid different potentials within the circuit [24].

CHAPTER THREE

METHODOLOGY

3.1 INTRODUCTION

This research is an empirical investigation of the effect of lightning strikes on buildings, structures and equipments within Zaria as a result of the type and quality of the earthing system. The earthing system is an essential element for the electrical system security and it is required to:

i) Allow for protective devices activation when there is an insulation fault;
ii) Equalize the potential of conductive parts that can be accessed simultaneously, with the potential in the surrounding soil in order to prevent people from being exposed to hazardous voltages;
iii) Allow the lightning strike energy to be safely dissipated; and
iv) Reduce electromagnetic interferences [26].

The Institute of Electrical and Electronics Engineers Standard 142, Recommended Practice for Grounding of Industrial and Commercial Power Systems states: "The most elaborate grounding system that can be designed may prove to be inadequate unless the connection of the system to the earth is adequate and has a low resistance. It follows, therefore, that the earth connection is one of the most important parts of the whole grounding system. It is also the most difficult part to design and to obtain..."[27]. In general the earth resistance is defined as the resistance of the earth to the passage of electric current [27] but in practice, it is the resistance existing between the electrically accessible part of a buried electrode and another point of the earth, which is 'far away'[26].

The earth resistance of the electrode has three components:

i) The resistance of the electrode conductor;

ii) The electrode/soil contact resistance; and

iii) The resistance of the soil surrounding the electrode.

Typically, i) and ii) are negligible compared to iii). As a result, most analytical formulae for the earth electrode resistance usually account for the resistance of the soil only [28, 29].

The recent spread of lightning protection systems (LPS) has emphasized the fact that an electrical earth is not, in most of the cases, a suitable lightning earth. The lightning earth must be interconnected with the other earthing systems and especially the electrical earth. But the dedicated lightning earthing system need to be checked when built and also after some years in a maintenance program. So measurement means are needed and so far all standards refer to "usual" ohmmeters which are working at low frequencies. Lightning is a high frequency phenomenon with frequency content up to 1 MHz. Experience has shown that the high frequency part is misunderstood and lead sometimes to false assumptions and poor results. This may explain failures encountered in building without lightning protection systems (LPS) or with lightning protection systems (LPS) badly installed [30].

Based on the methodology stated in Section 1.5, the following will be described in the following sections:

i) Determination of number of lightning strikes;

ii) Measurement of earth resistance; and

iii) Summary of the findings from the survey based on the questionnaire.

3.2 DETERMINATION OF NUMBER OF LIGHTNING STRIKES

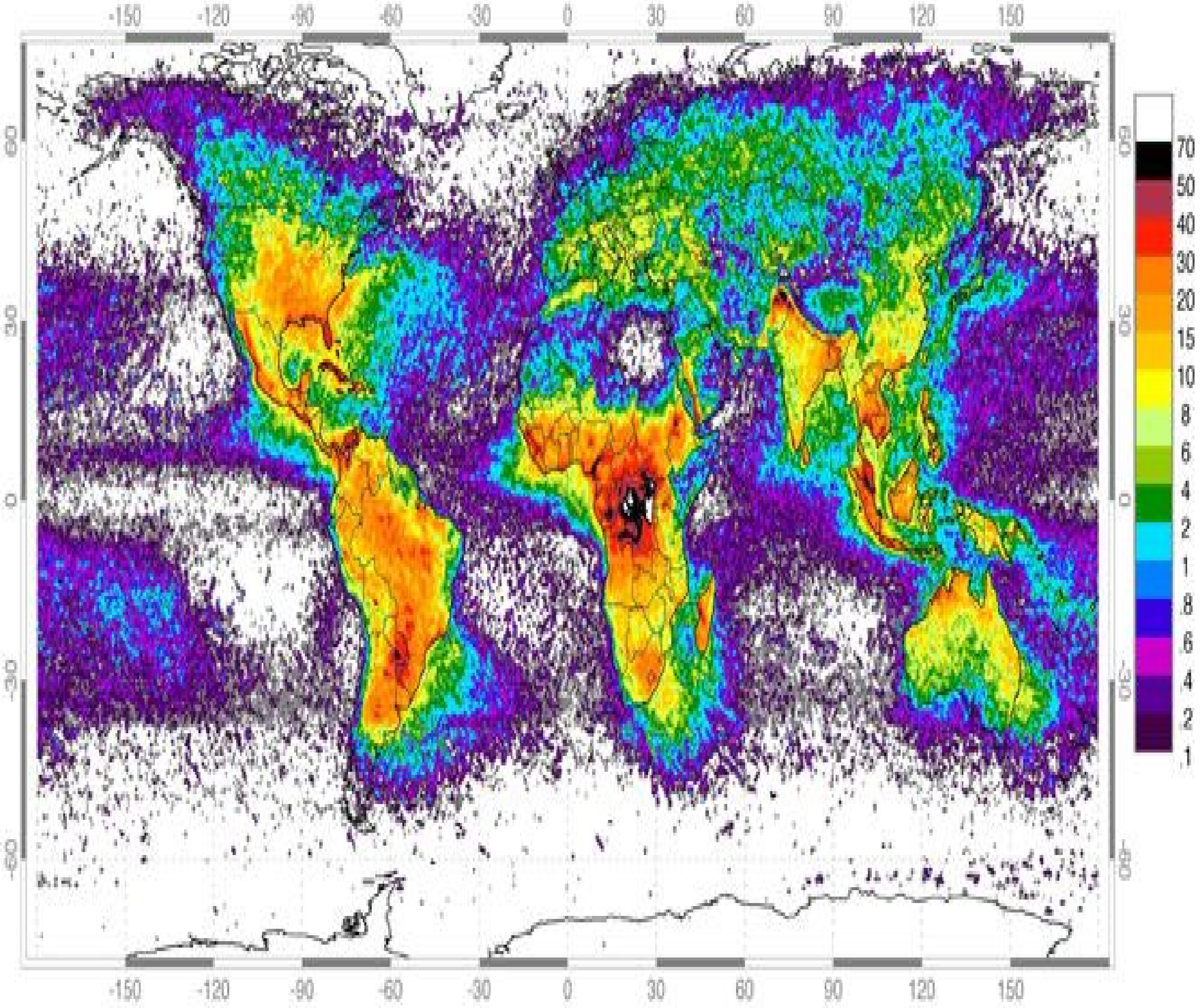
Map from space-based optical sensors reveal the uneven distribution of worldwide lightning strikes, with color variations indicating the average annual number of lightning flashes per square kilometer. The map, from the National Aeronautic and Space Agency (NASA) Lightning Imaging Sensor (LIS) Science Team, Fig 3.1, includes data obtained from April 1995 to February 2003 from NASA's Optical Transient Detector; and from January 1998 to February 2003 from NASA's Lightning Imaging Sensor (LIS) [25]. From the map (Fig. 3.1) the annual flash rate for Zaria is about 15 strikes per square kilometre.

The expression for estimating the number of lightning strikes to structures given an annual flash rate has been given in Equation 2.8. Two cases are being considered:

i) **Zaria Aerodrome:** The height of the mast on the Control Tower of the Zaria Aerodrome premises where the lightning arrestor has been mounted is about 50m. The collection area for the lightning protection system installed on the mast is a circular area on the ground with a radius three times the height of the tower as in Figure 3.2. This implies a collection area of radius of 150m and centre at the vertical axis of the mast. Thus the number of direct lightning strikes, N_d, from Equation 2.8 is: $N_d = N_g A_e x 10^{-6}$

$$A_e = \Pi r^2 = 70695 m^2$$

$N_d = 15 x 70695 x 10^{-6}$ **= 1.1 strike per year.**



High Resolution Full Climatology Annual Flash Rate

Global distribution of lightning April 1995-February 2003 from the combined observations of the NASA OTD (4/95-3/00) and LIS (1/98-2/03) instruments

Figure 3.1: Global Distribution of Lightning (Courtesy: National Aeronautic and Space Agency (NASA)

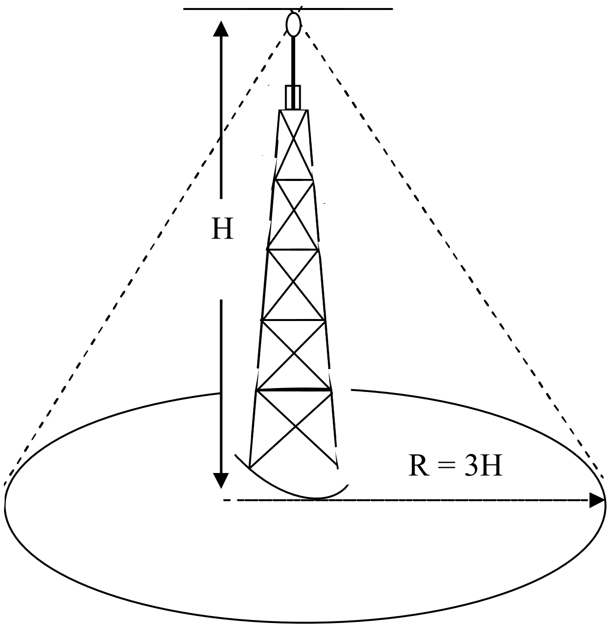


Figure 3.2: Communication Tower Equivalent Lightning Collection Area

ii) **ii) Zaria Nitel Exchange:** The height of the Tower of the Zaria Nitel Exchange where the lightning arrestor has been mounted is about 133m. This implies a collection area of radius of 399m and centre at the vertical axis of the mast. Thus the number of direct lightning strikes, N_d, from Equation 2.8 is: $N_d = N_g A_e x 10^{-6}$

This equation can also be expressed in terms of height, H since $A_e = \Pi r^2$ and $r = 3H$. Then equation 2.8 becomes $N_d = 9 \Pi H^2 N_g x 10^{-6}$

$$N_d = 9 x 3.142 x (133)^2 x 15 x 10^{-6}$$

= 7.5 strikes per year.

This implies that if the installed lightning protection system were absent or ineffective there would be about 1 and 8 lightning strikes hitting the Control Tower at the Zaria Aerodrome and the tower at the Zaria Nitel Exchange every year respectively. This can have a serious implication such as total failure of the communication system of the Aerodrome and Exchange and even exposing the personnel operating and maintaining the systems to the danger of electrocution resulting from high voltage.

Figure 3.3 is a plot of N_d versus H for three locations - Port Harcourt, Zaria and Maiduguri showing uneven distribution of lightning strikes.

Local level of lightning activities for Port Harcourt, Zaria and Maiduguri were obtained from Figure 3.1 to be 40, 15 and 10 respectively. Also, the number of direct lightning strike, N_d to the mast per annum for each location was calculated using equation 2.8

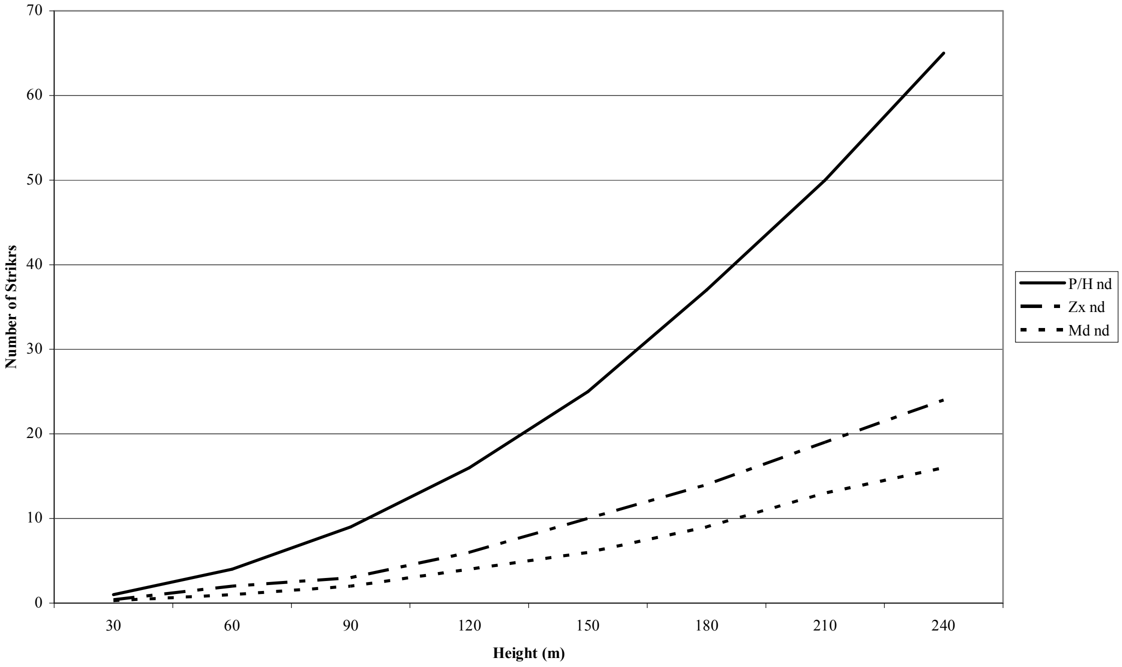


Fig 3.3: Graph of Height, H versus number of direct lighting strike, N_d to a Mast

3.3 EARTHING RESISTANCE MEASUREMENT

In order to measure the resistance, a voltage is applied across the terminals of a null-balance analogue type Megger earth tester (since resistors have two terminals) that cause the circulation of current through it. One of the terminals is the earth system accessible contact. The second one, according to the definition, is any other point of the earth that is really far away from the first. In order to carry out the measurement, an auxiliary electrode should be placed at that point. The second electrode will inevitably have its own earth resistance and resistance area. A third electrode is used in order to avoid the error introduced by the earth resistance of the second electrode. The third electrode is placed at any point outside the first and second electrodes influence zones [26, 30].

This arrangement, as in Figure 3.4, is known as Fall-of-Potential Method (also referred to as Earth-Spike Method) and it is the most commonly used for the earth resistance measurement in small or medium dimension systems, in which the separation of the resistance areas is obtained with reasonable distances between electrodes. The current circulates through the earth system and the auxiliary electrode, and the voltage is measured between the earth system and the third electrode. This voltage is the fall of potential that the test current produces in the earth system resistance, which in this way can be measured without being affected by the earth resistance of the third rod [26, 30].

With reference to Figure 3.3, the current is injected at E and monitored at electrode 2. Based on the principle as described above (and also in Section 2.1.2), the potential difference between the earth E and point 1 is given as:

$$V_e - V_1 = I_e r_{ee} + I_1 r_{e1} + I_2 r_{e2} - \left(I_1 r_{11} + I_e r_{e1} + I_2 r_{12}\right) \quad 3.2$$

The experiment is then arranged in such a way that electrode 1 is on the voltage coil of the instrument so that $I_1 r_{11}$ is negligibly small, and making the spikes 1 and 2 to be quite far apart from E and from each other ensures that r_{e1}, r_{e2} and r_{12} are very small. Thus eventually

$$\begin{aligned} V_e - V_1 &= I_e r_{ee} \\ \Rightarrow R_E &= \frac{(V_e - V_1)}{I_e} \end{aligned} \qquad 3.3$$

It is very nearly so even if r_{11} and r_{22} are quite large [4].

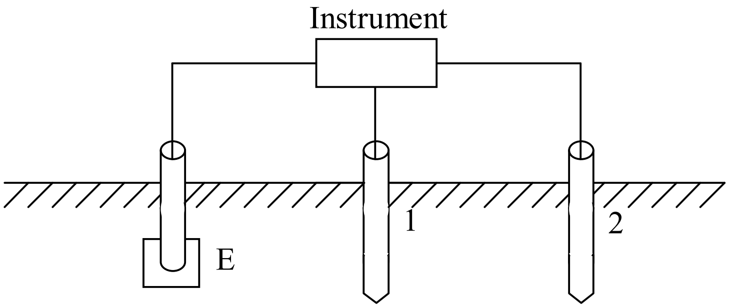


Figure 3.4: Earthing Resistance Measurement Using Fall-of-Potential Method

Two assumptions were adopted in using this method.

- The first assumption is that in Figure 3.3 the electrode 1 should have zero current to ground. Thus to satisfy this requirement electrode 1 is put on the voltage coil of the measurement instrument (Megger). Furthermore the current through it is adjusted using the centre zero-deflection galvanometer to zero value.
- The second assumption is that the electrodes 1 and 2 in Figure 3.4 should be driven to earth quite far away from the earth electrode being measured. Here, too, as long as the separation between the earth electrode and the measuring electrode

is more than 2.5 times the combined lengths of the two electrodes, the measurement will be a correct representation of the estimate of the parameter. What is true for the distance of separation between the earth electrode and the measuring intermediate electrode is also true for the separation between the auxiliary electrode and the measuring intermediate electrode [4].

The null-balance analogue type Megger Earth Tester, made in England by Evershed & Vignoles Ltd with registered design number 690326 and serial number 1680536 was used as the test instrument to fulfill the objectives set out for the investigation. The earth resistance measurements were carried out for the following locations within Zaria

i) **Electrical Engineering Department, Ahmadu Bello University, Zaria:** The complex comprises Laboratories, Workshop, Offices and classrooms. The earth resistance measurement circuit is shown in Figure 3.5. In the setup, **X** is the earth electrode under test, **Y** is the auxiliary earth electrode and **Z** is the second auxiliary earth electrode. $\mathbf{Z_1}$ and $\mathbf{Z_2}$ are alternative positions of **Z** used for cross-checking measurements.

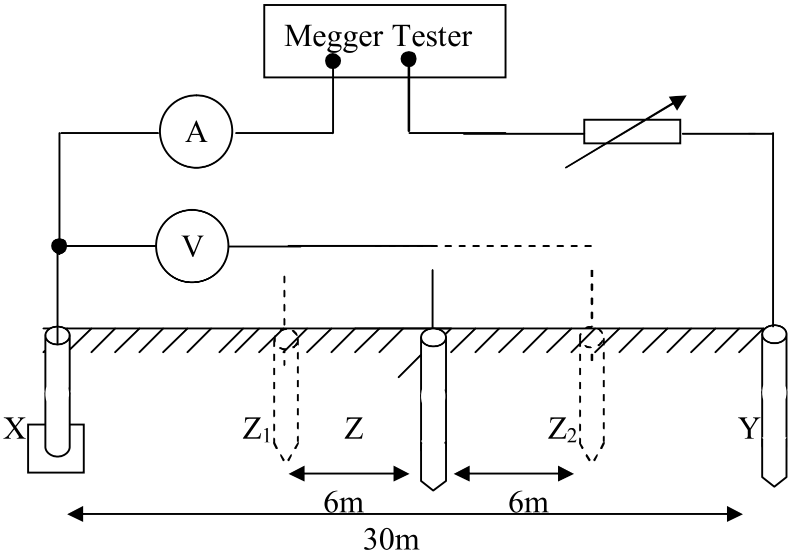


Figure 3.5: Earthing Resistance Measurement Circuit

For each measurement point a test signal ($500V_{dc}$ from the hand driven generator earth tester (Megger)) was injected into the earthing conductor and the auxiliary electrode (**Y**) was driven to ground 30m from the earthing point. Measurements were then taken, using the intermediate electrode, at 8m (**Z_1**), 14m **(Z)**, and 20m (**Z_2**) from the earthing point in a straight line with the auxiliary electrode and the earthing point. The measurements are shown in Table 3.1.

Table 3.1: Earth Resistance Measurements for Electrical Engineering Department

Measurement at Z	Measurement at Z_1	Measurement at Z_2	**Average Resistance**
0.38Ω	0.37Ω	0.38Ω	**0.38Ω**

The average earth resistance measurement taken is **0.38Ω.**

ii) **Zaria Aerodrome, Nigerian College of Aviation, Zaria:** This complex comprises the Control Room and Tower and Offices. The earth resistance measurement circuit is same as in Figure 3.5 and the procedure adopted is same as described in i) above. The measurements are shown in Table 3.2.

Table 3.2: Earth Resistance Measurements for Zaria Aerodrome Control Tower

Measurement at Z	Measurement at Z_1	Measurement at Z_2	**Average Resistance**
0.74Ω	0.75Ω	0.76Ω	**0.75Ω**

The average earth resistance measurement taken is **0.75Ω.**

iii) **Nitel Exchange, Zaria:** The communication tower at the Exchange is the structure of interest at the Zaria Nitel Exchange. The tower consists of the mast, lightning protection system, tower footing earth ring amongst other things as shown in Figure 3.6. The earth resistance measurements were taken with respect to the tower footing, that is, between tower footings **A** and **B, B** and **C** and **C** and **A.**

The earth resistance measurement circuit is same as in Figure 3.5 and the procedure adopted was the same as was described in i) above. However, for taking the measurement between **A** and **B,** as an example, **A (X)** is the earth electrode under test, **B (Y)** is the auxiliary earth electrode and **Z** is the second auxiliary earth electrode. Z_1 and Z_2 are alternative positions of **Z** used for cross-checking measurements. This is adopted in determining the earth resistance between **B** and **C** and between **C** and **A** respectively. The measurements are shown in Table 3.3

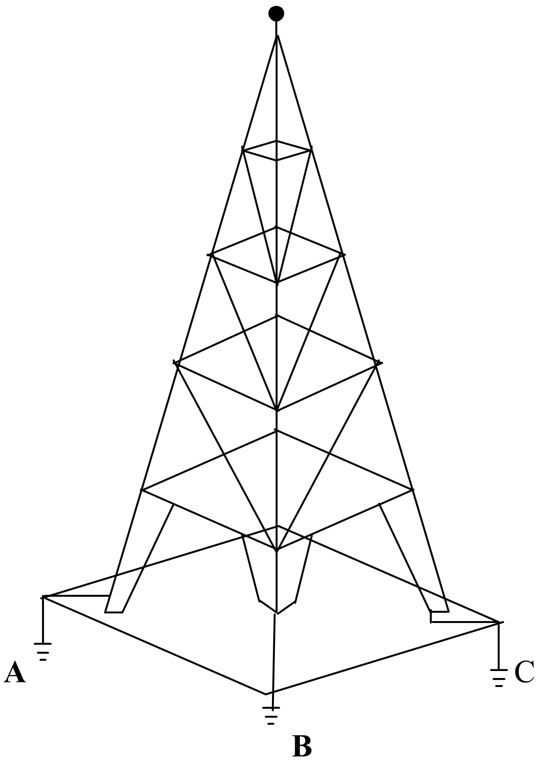


Figure 3.6: Typical Three-Footing Tower as at Zaria Nitel Exchange

Table 3.3: Earth Resistance Measurements for Zaria Nitel Exchange Tower

Between A and B			
Measurement at Z	Measurement at Z_1	Measurement at Z_2	**Average Resistance**
0.30Ω	0.31Ω	0.31Ω	**0.31Ω**
Between B and C			
Measurement at Z	Measurement at Z_1	Measurement at Z_2	**Average Resistance**
0.29Ω	0.29Ω	0.32Ω	**0.30Ω**
Between C and A			
Measurement at Z	Measurement at Z_1	Measurement at Z_2	**Average Resistance**
0.34Ω	0.33Ω	0.32Ω	**0.33Ω**

The average earth resistance measurements taken are **0.31Ω** between **A** and **B,** **0.30Ω** between **B** and **C** and **0.33Ω** between **C** and **A.** These values obtained fall within the NITEL recommended earth resistance of less than 1**Ω.**

iv) Commercial Complex, No. 8 Sokoto Road, Samaru: This complex, which is a storey building, situated besides Union Bank, Samaru originally comprised of a restaurant (Top Chef), a photo studio and beer parlour (Capitol) was converted to its present form in 2004 by the present owner via direct labour. The complex comprises an Internet Café, Restaurant, Hair Salons amongst others. The earth resistance measurement circuit is same as in Figure 3.5 and the procedure adopted is same as described in i) above. The measurements are shown in Table 3.4.

Table 3.4: Earth Resistance Measurements for Commercial Complex, No. 8 Sokoto Road

Measurement at Z	Measurement at Z_1	Measurement at Z_2	**Average Resistance**
1.6Ω	1.5Ω	1.5Ω	**1.5Ω**

The average earth resistance measurement taken is **1.5Ω.**

The plumbing and electrical services designed were completely overhauled but by non-professionals which explains the high value of the earth resistance. This indicates that the complex is not ideal for use as an internet café or any such establishment with such sensitive electronic equipment.

This explains why during the raining season of 2005, the data on all the systems in the internet café were lost as a result of lightning strike. This can be attributed to poor earthing system.

3.4 SUMMARY OF THE SURVEY BASED ON QUESTIONAIRE

The questionnaire was administered in such a way that the respondents were made to understand what lightning arrestors and earthing system meant as well as the need for them to know if their buildings have these facilities.

Table 3.5: Result of the Questionnaire Administered

No of Respondents within Campus	No of Respondents with the knowledge of Earthing System (within Campus)	No of Respondents outside Campus	No of Respondents with the knowledge of Earthing System (outside Campus)
300	61	200	10

Most respondents that are occupants and landlords do not know where their earthing points are located within their premises due to the simple fact that most of them do not know the importance of these systems; the contractors used for some of these buildings are non professionals and as such did not adhere to standard building and electrical services design. Only about 25% of the respondents knew what lightning arrestors and earthing systems means. Out of this percentage, 20% were within A.B.U. campus while the remaining 5% were those living outside the campus.

It was also discovered that over five million naira had been spent to replace equipments lost due to lightning strikes and about two hundred thousand been spent on repairs of electrical/electronics gadgets within the period of two years (2004 – 2006) in Zaria.

CHAPTER FOUR

RESULTS AND ANALYSIS

4.1 INTRODUCTION

This study investigated the effect of lightning strikes on people, buildings, communication towers and equipment by determining the number of lightning strikes on certain structures depending on the location and height of the structures and also the earthing resistances of some of the structures within Zaria.

The results obtained from these investigations are presented in this Chapter with the analysis and implications of the results.

4.2 DETERMINATION OF LIGHTNING STRIKES

Lightning strikes which directly strike towers increase the potential of the towers affected and can, depending on the level of the tower footing resistance, lead to backward flashovers from the tower to the transmission cables. These backward flashovers cause traveling waves which propagate via the transmission cables towards the transmitter where they cause over-voltages which can pose a risk to any items of equipment connected [10]. With the use of lightning arrestors, these over-voltages are reduced to values which, taking into account an adequate safety margin, are below the electric strength of the electrical devices applied.

Lightning arrestor is a conductive metal device mounted at the highest point on the structure, be it building or tower. This lightening arrestor or air electrode is connected to earth electrode through a conducting wire or strip to allow the lightning strike energy to be safely dissipated to the ground.

Two towers were considered as case studies in this investigation: the Nitel Exchange communication tower and the Zaria Aerodrome control tower in order to determine the number of lightning strikes that they can be subjected to with the aid of a map obtained from National Aeronautic and Space Agency (NASA) for the period from April 1995 to February 2003. From the map, with color variations indicating the average annual number of lightning flashes per square kilometer, the annual flash rate for Zaria is about 15 strikes per square kilometre.

Based on this and Equation 2.8, the number of lightning strikes was determined as in Table 4.1.

Table 4.1: Determination of Number of Lightning Strikes

S/N	LOCATION	ANNUAL FLASH RATE/km^2	HEIGHT OF TOWER (m)	COLLECTION AREA (m^2)	LIGHTNING STRIKES
1	Zaria Aerodrome	15	50	150	**1**
2	Nitel Exchange	15	133	339	**8**

The implication of this is that if the installed lightning protection system were absent or ineffective there would be about **1** and **8** lightning strikes hitting the Control Tower at the Zaria Aerodrome and the Communication Tower at the Zaria Nitel Exchange every year respectively. This can cause total failure of the communication system(s) of the Aerodrome and Nitel Exchange and even expose the personnel operating and maintaining the systems to danger of electrocution. This is taking into consideration the fact that a single lightning flash may be in order of 20-30kA, 200x10^{6}V and will take place within

30 millionth of a second [17, 18] and this can cause catastrophic damages if a proper protection system is not put in place.

4.3 EARTHING RESISTANCE MEASUREMENT

Fall-of-potential method, also referred to as Earth-Spike Method, was used for the earthing resistance measurement.

The principles used in the measurement of resistance to earth are essentially the same as those used for measuring other type of electrical resistances. The null-balance analogue type Megger Earth Tester was used as the test instrument and instruments, such as the Megger, designed for measuring earth resistance negate the resistance of auxiliary electrodes and provide sufficient voltage to make the current flow in the measuring setup. It is also important to note that precision in measuring the earth resistance is difficult to obtain and is usually not required. Normally an accuracy of ±25% is sufficient in view of many variables [31].

The earth resistance measurements obtained for the following locations within Zaria are summarized as follows:

- Department of Electrical Engineering: **0.38Ω**
- Zaria Aerodrome Control Tower: **0.75Ω**
- Commercial Complex, No. 8 Sokoto Road: **1.5Ω**
- Nitel Exchange Communication Tower: **0.31Ω (**AB); **0.30Ω** (BC); **0.33Ω** (CA)

4.4 ANALYSIS OF RESULTS

The results obtained from determining the number of lightning strikes on certain structures and their earth resistances are important in emphasizing the importance of incorporating a well designed earthing system. According to IEEE Standards 1100-1992 (Powering and Grounding Sensitive Electronic Equipment) “It is important to ensure that low-impedance grounding and bonding connections exist among the telephone and data equipment, the ac power system's electrical safety-grounding system, and the building grounding electrode system. This recommendation is in addition to any made grounding electrodes, such as the lightning ground ring. Failure to observe any part of this grounding requirement may result in hazardous potential being developed between the telephone (data) equipment and other grounded items that personnel may be near or might simultaneously contact" [32].

Considering the case of the Zaria Aerodrome, where the Control Tower is indispensable in its operations, it has been determined that the tower can be subjected to at least **one (1)** lightning strike per year. A typical lightning strike of **20,000A** striking the tower with earth resistance **0.75Ω** means that the earth electrode will sink to earth **15,000V.** In the case of poorly designed earthing and lightning protection systems or failure of the systems, equipment and personnel within or in the vicinity of the tower are susceptible to this dangerously high voltage.

According to Hasse [33], 'Complete lightning protection potential equalization is the fundamental basis for the realization of internal lightning protection; that is the lightning over-voltage protection for the electrical and also the electronic data transmission facilities and devices in buildings. In the event of a lightning stroke, the potential of all installations in the affected building (including live conductors in the electrical systems with arrestors) will be increased to a value equivalent to that arising in the earthing system -- no dangerous over-voltages will be generated in the system…"

Lightning protection potential equalization ensures the connection of all metal supply lines entering a building, including power and communication cables, to the lightning protection and earthing system and for lightning protection of a structure it is of greater importance than the earthing resistance [33]. The best way for equalization of potentials utilizes a suitable earthing system in the form of a ring or foundation earth, whereby the down conductors are bonded to such a ring earth, as in the case of the Nitel Exchange Communication Tower (as in Figure 3.5).

In the case of the Nitel Exchange Communication Tower, the average earth resistance of each earth electrode on the ring earth is about **0.3Ω**, which means that if the tower is struck by lightning (it can be struck about **eight (8)** times per year) of about **20,000A,** each electrode can sink about **6000V** to earth. As has been reported earlier on, the Nitel Exchanges that have been destroyed due to lightning and thunderstorms was a result of breakdown of the earthing and lightning protection systems.

According to British Standard BS 6651 [30], International Standard IEC 1024-1 (Protection of Structures Against Lightning) by the International Electro-Technical Commission, Geneva and MIL-STD-188-124B (Grounding, Bonding and Shielding) by

Department of Defense, Washington DC, "The resistance to earth of the earth electrode subsystem should not exceed **10Ω** at fixed permanent facilities" [32]. In view of this, the earth resistance measurements taken for the various locations are in conformity with general standards. However, in the case of the Nitel Exchange, there is a specific requirement set by Nitel, that is, the earthing resistance of their structures must be **≤ 1Ω**. All the earthing resistances measured around the ring earth of the communication tower are within NITEL recommended resistance of less than **1Ω** [8].

The high earth resistance of the commercial building shows that the earthing system of the building is poorly designed being a commercial complex. And as such, the building is not suitable for sensitive electronics equipments such as computers. During the raining season, the thunderstorm is usually very high, thereby causing failure of the sensitive electronics systems within or in the vicinity of the building. If computers were contained in this building, the computers are bound to loose the information contained in their memory during lightning strikes. This was the case of the cyber café contained within the building.

In the case of the questionnaire, it was discovered that about 75% of the people living in storey buildings do not know whether the buildings have lightning arrestors/earthing system. Some do not even know what is meant by lightning arrestors or and earthing systems. About 50% of the Landlords of some of the buildings outside A.B.U. Zaria do not know the location of earthing point of their buildings and no building plans. This means that those buildings without lightning arrestors/ poorly designed earthing system and those with inactive lightning arrestors also with poorly designed earthing systems could be destroyed together with their occupants if hit by lightning strikes. In the case of voltage surge, most electronic gadgets contained in these buildings could be damaged beyond repairs. In case of electrical fault, the occupants are at risks of shock; etc.

If there were standard building plans, it will be easy for anyone who can interpret such plans to locate the earthing points and to maintain the lightning arrestors / earthing systems of such buildings.

CHAPTER FIVE

CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK

5.1 INTRODUCTION

The risks involved in failing to comprehensively address the issue of lightning and over-voltage protection include the following:

- Physical damage to equipment resulting in replacement costs;
- Danger to residents or staff and other personnel from the effects of lightning discharges; and
- Partial or complete loss of operations and system downtime resulting in lost revenue.

This study determined the number of lightning strikes on certain structures depending on the location and height of the structures and also the earthing resistances of some of the structures within Zaria with a view to determining the consequence of poor earthing and lightning protection on the structures. It is worth noting that single lightning flash may be in order of 20-30kA, $200x10^6$V and will take place within 30 millionth of a second [17, 18] and this can cause catastrophic damages and even loss of lives if a proper protection system is not put in place

A dedicated low resistance lightning earth is required for the safe dissipation of the lightning energy into the ground mass. Each earthing system (lightning, electrical, communications and equipment room) must be bonded together so that all earths present an equipotential plain ensuring that under transient conditions no hazardous potential differences occur. It is essential for all earths that the resistance of the ground itself is minimized and that all earthing connections are kept as short and direct as possible to minimize inductance. For a typical telecommunications site an earth ring should be installed surrounding the tower footing with the lightning earth directly bonded to the tower earth ring.

5.2 CONCLUSIONS

It can be concluded that most building contractors in Zaria do not adhere to standard building and electrical installation practices because non professionals are involved in the building construction, electrical earthing and lightning protection systems, there have been several reports of loss of properties due to the breakdown or absence of earthing and lightning protection systems.

The earth resistance of the electrode has three components, out of which the resistance of the electrode conductor and that of the electrode/soil contact are negligible compared to the resistance of the soil surrounding the electrode. As a result, most analytical formulae for the earth electrode resistance usually account for the resistance of the soil only [28, 29].

In this study, the null-balance analogue type Megger Earth Tester was used to determine the earth resistance of some locations in Zaria and the following results obtained;

- Department of Electrical Engineering: **0.38Ω**
- Zaria Aerodrome Control Tower: **0.75Ω**
- Commercial Complex, No. 8 Sokoto Road: **1.5Ω**

- Nitel Exchange Communication Tower: **0.31Ω (**AB); **0.30Ω** (BC); **0.33Ω** (CA)

The earth resistance measurement results obtained for the various locations are in conformity with general standards: "The resistance to earth of the earth electrode subsystem should not exceed **10Ω** at fixed permanent facilities" [32]. All the earthing resistances measured around the ring earth of the Nitel Communication Tower are within NITEL recommended resistance of less than **1Ω**.

It has also been shown that the earth electrode of the earthing system of the Zaria Aerodrome Control Tower will sink to earth **15000V** while that of the Zaria Nitel Exchange Tower will sink to earth **6000V.** In the case of poorly designed earthing and lightning protection systems or failure of the systems, equipment and personnel within or in the vicinity of the towers are susceptible to this dangerously high voltage.

5.3 LIMITATIONS

The Megger was the only instrument used in this study to take all measurements of the earth resistance. There was no alternative set of equipment so it was necessary to rely on the accuracy of the Megger for the accuracy of the measurement. And this point is critical because of the analogue nature of the Megger. It would have been preferable to have used more than one type of equipment in order to be able to establish the accuracy of the measurements obtained. This was not possible because there was no alternative equipment available.

In studies like this, the co-operation of owners of buildings or towers is very important. This is because of the need to identify the earthing point and give permission for measurements to be taken. One of the limitations faced was the fact that in some places, like the Iya Abubakar Computer Centre (IACC) and other buildings outside campus, no one could locate the point of the earth electrode.

5.4 SUGGESTIONS FOR FURTHER WORK

The issue of earthing and lightning protection systems is very important, moreso to the communication sectors. Apart from loss of equipment with the resultant replacement costs but downtime also means loss of revenue and customer confidence. In a view to improve upon this work, the following are recommended:

- Standard measurement equipment, especially digital equipment, can be used to take these measurement and compare them with those obtained using the Megger.
- More measurements should be taken, as such the locations and structures should be increased and be more widespread within Zaria. This is to be able to have a very comprehensive overview of the extent of the problem of poor or absent earthing and lightning protection systems.
- A study of the effect of soil type (physical and chemical composition) and electrode type and how these affect the earthing resistance should be carried out. This will be useful in ascertaining how these issues influence the integrity or otherwise of the earthing system.

- The map from NASA and LIS is based on the data obtained from United States of America. The accuracy of the climates based on it can be determined only if

Actual investigation on this average annual number of lightning flashes per square kilometre is carried out. Accordingly there is need to carry out this study as soon as practicable.

REFERENCES

1) "Earthing Systems" (From Wikipedia, The Free Encyclopedia) **http://en.wikipedia.org/wiki/Earthing_system.htm**

2) "Lightning" (From Wikipedia, The Free Encyclopedia) **http://en.wikipedia.org/wiki/lightning.htm**

3) **Airport Authority of India [2006],** "Lightning and Surge Protection and Earthing System of CNS Installations", Communication, Navigation and Surveillance (CNS) Manual Vol. V, 1.ed., pp1-34.

4) **Dzara, A.D. [2006],** Determining The Soil Resistivity and Effective Earthing Resistance For The Nigerian Telecommunications Limited Digital Exchange, Mubi, Unpublished M.Sc Thesis, Department of Electrical Engineering, A.B.U. Zaria.

5) **Krahe, C. [1998],** "Lightning Strikes and Airbus Fly-By-Wire Aircraft" **www.content.airbusworld.com/SITES/Customer_services/html/acrobat/fast_22_p24_27.pdf**

6) **RFI Pty [2004],** "Earthing" **www.rfi-ind.com/au/download/earthing%20rev2%200700.pdf**

7) **Nweze, N. [1995]**, "Better Earthing (Grounding) Techniques" Nigerian Telecommunications Limited, Lagos. (Unpublished Report).

8) **Nigerian Telecommunication Limited, [1995]**, "Draft Specification 0001, Earthing Systems for Telecommunications Plants".

9) **Conroy, M. D., and Richard, P. G. [2002]**, "Deep Earth Grounding", Computer Power and Consulting. **www.cpccorp.com/deep.htm**

10) **Schmitt, H. and Winter, W. [2000],** "Simulation of Lightning Over-Voltages in Electrical Power Systems" **www.ipst.org/TechPapers/2001/IPST01Paper030.pdf**

11) **Siemens AG [2006],** "Earthing" **www.industry.siemens.com/Water/en/solutions/infrastructure_earthing.htm**

12) **ABB [2000],** “Plant Engineering: Electrical Infrastructure Systems” www.abb.com/Plant_Engineering_Electrical_Infrastructiure-Systems_02_03.pdf

13) **Furse [2005],** “Earthing and Lightning Protection” www.furse.com/elp/elp.htm

14) **CIRRONET [2005],** “Application Note: Lightning and Surge Protection” www.cirronet.com/brochure_lightning.pdf

15) **Laver, J. A. and Griffiths, H. [2001],** “The Variability of Soils in Earthing Measurements and Earthing System Performance”, Rev. Energy. Ren: Power Engineering, pp57-61

16) **Polyqual [2004],** “Why Earthing or Grounding” www.polyqual.com/pages/relTopics/earthing/earthingMain.html

17) **CIPCO [2000],** “Lightning: Thunder” http://weathereye.kgan.com/cadet/lightning/thunder.htm

18) **Wozniak, A. [2004],** “Lightning” http://ellerbruch.nmu.edu/classes/cs255w03/cs255students/awozniak/p6/lightningMain.html

19) **Moonraker Antenna Systems[2005],** “When Negative Meets Positive” www.moonraker.com.au/techni/techni.htm#techni

20) **Sowa, A. W. and Okafor, F. [2005]** “Lightning Protection in GSM Base Stations”. International Engineering Conference, Lagos.

21) **Acme [2006],** “Telepower: External Lightning Protection” www.acme.in/telepower.html

22) **Kitsil, R. [2005],** “Fundamentals of Lightning Protection”, National Lightning Safety Institute [NLSI]. www.lightningsafety.com/nlsi_lhm/lpts.html

23) **Centre for Earth Science Studies (CESS) [2002],** “Lightning: Phenomenon and Precautions” www.cessind.org/images/LIGHTNING-BROCHURE.pdf

24) **Revere Transducers (RT) [2001],** “Lightning Protection” www.rt.com/9%20Lightningprotection.pdf

25) **NASA [2003],** “NASA Research Helps Highlight Lightning Safety Week” www.nasa.gov/centers/goddard/news/topstory/2003/0619lightning.html

26) **Leibovich, M. J. [2006],** “Earth Resistance Measurement” www.duncaninstr.com/Gr_article.htm

27) **Cascio, R. L. [1992],** “Safe Measurement of Ground Resistance” www.msha.gov/S&HINFO/TECHRPT/GROUND/SAFEMEAS.pdf

28) **Okyere, P. Y., and Eduful, G. [2006],** “Reducing Earth Electrode Resistance By Replacing Soil in Critical Resistance Area” IJME, Vol. 6, No. 2, Spring 2006. www.ijme.us/issues/spring2006/p33.htm

29) **Fluke® [2006],** “Earth Ground Resistance” www.newark.com/pdfs/techarticles/Earth_Ground_Resistance.pdf

30) **Rousseau, A. and Gruet, P. [2002],** “What is a Suitable Lightning Earth?” www.ineris.fr/WeD-004-226_Rousseau.pdf

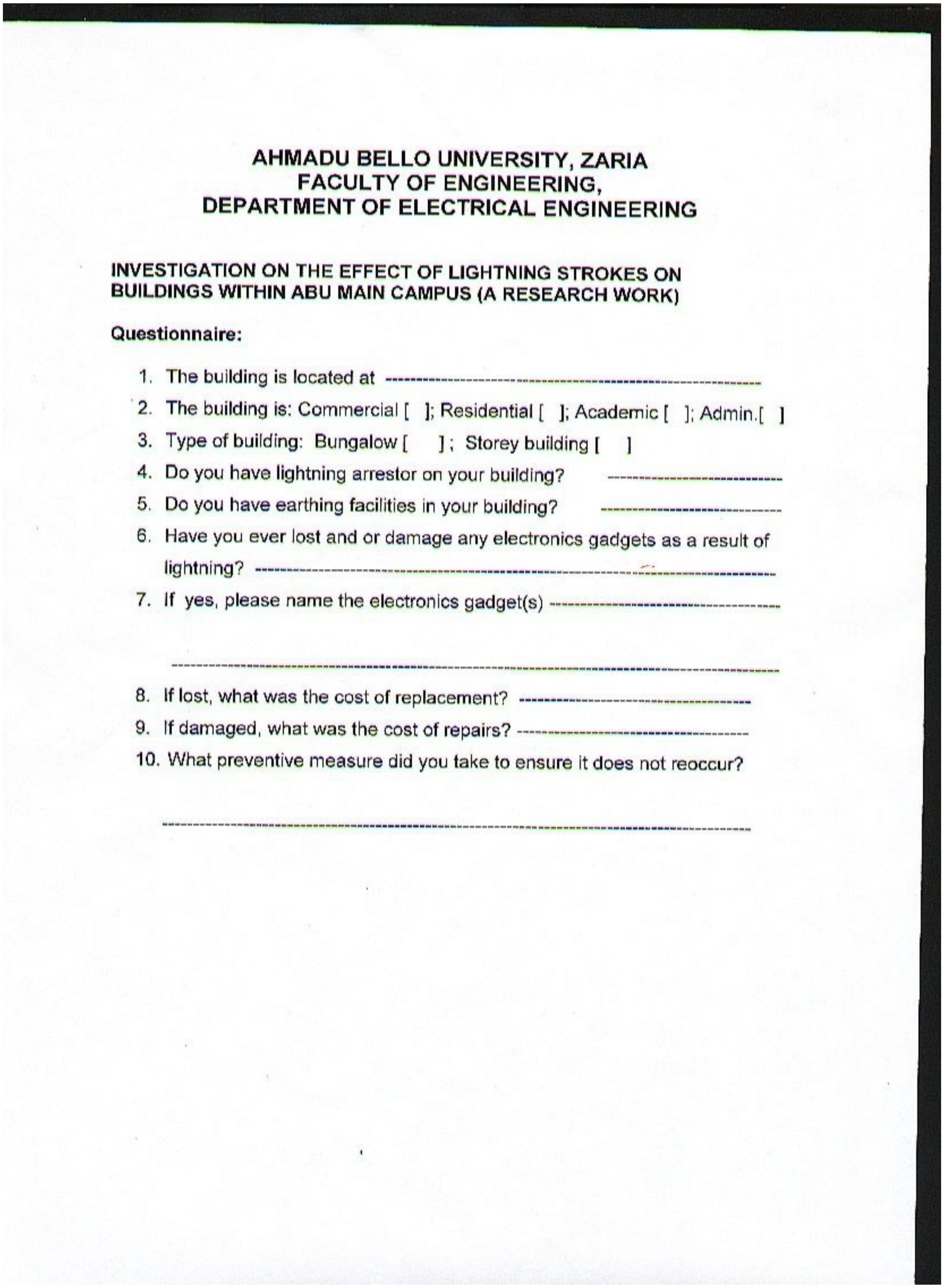
31) **Polyqual [2004],** “Determining Earth Resistance for Tower Earth Systems” www.polyqual.com/pages/relTopics/earthing/measureResis.html

32) **National Lightning Safety Institute (NLSI) [2006],** “Recommended Grounding Guidelines” www.lightningsafety.com/nlsi_lhm/rtaf3.html

33) **Hasse, J. [1992],** Over-Voltage Protection of Low Voltage Systems, Peter Peregrinus Press London, pp56

APPENDIX A

SAMPLE QUESTIONNAIRE



AHMADU BELLO UNIVERSITY, ZARIA
FACULTY OF ENGINEERING,
DEPARTMENT OF ELECTRICAL ENGINEERING

INVESTIGATION ON THE EFFECT OF LIGHTNING STROKES ON BUILDINGS WITHIN ABU MAIN CAMPUS (A RESEARCH WORK)

Questionnaire:

1. The building is located at --
2. The building is: Commercial [ ]; Residential [ ]; Academic [ ]; Admin.[ ]
3. Type of building: Bungalow [ ] ; Storey building [ ]
4. Do you have lightning arrestor on your building? --------------------
5. Do you have earthing facilities in your building? --------------------
6. Have you ever lost and or damage any electronics gadgets as a result of lightning? --
7. If yes, please name the electronics gadget(s) --------------------

   ----
8. If lost, what was the cost of replacement? --------------------
9. If damaged, what was the cost of repairs? --------------------
10. What preventive measure did you take to ensure it does not reoccur?
