



EVALUATION OF LIGHTNING PROTECTION OF A SOUTH WEST NIGERIA UNIVERSITY LIBRARY EDIFICE

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Abstract

Lightning Protective System (LPS) is the most proficient way to protect edifices and properties from direct and indirect lightning stroke damages. This research work concentrates on Cloud-Ground (CG) lightning strike negatives effects and its protection. Data were collected on library building in real time physical measurement using measuring tape, steel ladder and university archives (architectural drawings). Also, existing standards and theories were used in evaluation of the existing LPS and a new LPS was re-designed. Results show that the installed lightning arrester, LA, is Faraday type which are LA 1, LA 2, and LA 3 respectively. LA 1 has the least Protective Zone (PZ) of 0.02%, follow by LA 2 with 0.06% and LA 3 with 0.13%. The total PZ is 0.21; the total area of the researched Library is 99.79% unprotected. The proposed designed for 100% protective coverage is achieved in this work. The installed Down Conductor (DC), and Earthing Conductor, (EC) are solid rod copper materials and conformed to existing standards. This research result revealed that the existing installed air terminal, DC and EC is 75 mm² and do not conform to standard of 161 mm² – 200 mm² for solid iron air terminal. One of the existing surge protectors for the library (40 kA) is below standard and should be replaced with 70 kA Metal-oxide Varistor. Adequate PZ should be designed for a library building in this work for prevention of lives and properties against direct and indirect lightning strikes. Also, there should be a discipline coordination with lightning designer and civil Engineer when designing building roof.

Keywords: *Lightning, air-terminal, down-conductor, surge, earthing*

Introduction

Lightning, a natural phenomenon, is a transient high current discharge which occurs between clouds (intracloud) and cloud-ground (Cooray, 2015). Such discharges can be mainly categorized into two types namely cloud-to-cloud (CC) flashes and cloud-to-ground (CG) flashes. Lightning is an unpredictable event that can strike anywhere on earth. When the faulty currents are not effectively discharged to the ground, malfunction of valuable equipment or systems, equipment damage and life loss are experienced (Oyeleye, 2019). Both humans and living animals may suffer severe harm from the latter, which can result in serious injuries and occasionally even death also can harm man-made structures and other key items on Earth. The electrical discharge heats the atmosphere during CG flashes, a rumbling sound is produced along the lightning path (Rash, 2010). Lightning strikes can have a wide range of negative effects on materials used in construction, such as concrete, stone, wood, steel, and the like. These effects can range from melting because of the formation of hot spots on metal to complete disintegration of the granular

internal structure of cement, concrete, wood, and the like.

A lightning strike is a lightning event in which the electric discharge takes place between the atmosphere and the ground or lightning is a discharge of electricity that occur in the atmosphere and it can be thought of as high current (Webster, 2015; Hoole et al., 2022). Most CG lightning strikes start in a cumulonimbus cloud and end on the ground. These lightning strikes on structures weaken the structure's mechanical energy by causing cracks in the walls and beams. A multitude of cultural and heritage structures that must be preserved for future generations may suffer irreversible damage as a result of these strikes, including damage to idols, deterioration of heritage properties, defacement of rare sculptures, and disfigurement of wall murals.

It is interesting to observe that tall buildings are typically more susceptible to lightning strikes because of the higher electric field caused by the decreased breakdown potential between the ground and clouds. Researchers have shown that large

structures, buildings, and monuments are more vulnerable to lightning strikes globally, according to a number of studies (Srisailan and Venkatesh, 2018; Kongnok et al., 2021). The first step in designing an external lightning protection system is identifying the most vulnerable places on the structure to be struck by lightning. It is clear that lightning strikes on tall structures will create a path for the current to flow to the ground lest might cause malfunctioning of electric equipment installed inside the building, notwithstanding possible damages to the structure (Ostermann et al., 2023). These strikes can result in loss of life, economic damage to properties, and disruption of power (Melodi and Oyeleye, 2017; Oyeleye, 2019).

The best control measure must be used to limit the negative impact of lightning strikes. LPS are the most effective way to protect electrical installations and buildings from lightning stroke damage. Therefore, controlling lightning discharge requires an effective protective system to reduce or eliminate the negative effects of fatalities, property damage, power outages, and other activities. These days, Lightning Detection System (LDSs) are used in conjunction with circuit breaker, relay, and substation alarm monitoring to enhance electrical utility performance and reduce damage (Cooray, 2015; Oyeleye, 2019). Lightning strike can damage not only a relatively easy-to-replace household appliance such as a TV-set or a vacuum cleaner, but also larger and more expensive appliances such as a heat pump, alarm system. Maintaining a lightning system and making sure that one's house electrical system is resilient to power supply interruptions are crucial for providing sufficient protection for oneself and property during a storm. According to Latvian construction requirements, such a system must be installed in every structure. Generally speaking, it is applicable from the beginning of the building design process, but protection can also be added after the project is finished. According to Vipin et al. (2020) the intensity of lightning current can vary from a few hundred amps to over 200,000 amps. The transient current is transmitted to the structures during the lightning event over a very short period. Symbols of lightning flash are presented in Figure 1.

The researched building has two thousand, three hundred and one (2301) students who have registered for Library usage and have seventy-three (73) staffs who's live is at a risk.

A lightning rod or lightning conductor is a metal rod or overhead ground wire mounted on a structure and intended to protect the structure from a lightning strike. Lightning rods are also called air terminals, or strike termination devices. The protective angle coverage offered by over ground wire (sky wire or spike or both) or the area around a protector which would be reliably protected is called zone of protection (Melodi and Oyeleye, 2017).

Down Conductor System serves as the connection between the earthing electrode and the lightning conductor itself (rod, cage, or wire) (Rahim *et al.*, 2016). Because they are exposed to strong currents, they need to be securely fastened, have a minimum cross-section of 50 mm² copper, and travel the shortest path. They must be free of abrupt angles and elevations.

In order to prevent a voltage, increase in the earthing system and the surrounding ground, it is imperative that all exposed conductive components, which are interconnected, be connected. Additionally, the system must be able to discharge the lightning current. The earthing electrode's shape and size are more significant in terms of the discharge of the high frequency lightning current than its low frequency resistance value, as per IEEE Power and Energy Society (2012, and that the earthing value must adhere to $4 \Omega \geq R \leq 10 \Omega$ (Oyeleye and Ale, 2019).

It is good to note that lightning is a natural phenomenon hence lightning strike cannot be prevented. However, lightning strike effects can be alleviated or removed. There are various methods that can be used to prevent lightning negative effects. There are generally two aspect of lightning protection design. Firstly, for diversion and shielding aimed at structural protection also reduction of lightning electric and magnetic field within the structures. Secondly, limiting of currents and voltages on power, electronics and



Figure 1: Lightning symbol (Oyeleye, 2019)

communication systems using surge protection (Koliushko and Rudenko, 2021). According to Melodi and Oyeleye (2017), there are three main known method of lightning protection namely Rolling Sphere Method (RSM), Protection Angle Method (PAM), and Mesh Method.

This lightning protection method is based on the electro-geometric method (EGM), which makes the assumption that the "striking distance," or the point at which a lightning strike occurs, is reached when the stepped leader approaches a critical point when it is drawn to the ground or a tall building. The electric field produced by the stepped leader, which is based on the charge distribution on the stepped leader channel, determines this distance (Almaazmi, 2023). This approach entails rolling an imaginary sphere with a radius equal to striking distance over and along the airports, enclosing the protected area.

The lightning protection angle (α) is a method which is approved by IEC standard 62305, continuously. Essentially, it can be utilized to determine the protective angle for the tall object above a ground level, for instance, a building, cultural heritage and so on (Singhasathein, 2018).

Furthermore, according to the class of LPS specified for the structure, the protective angle approach is only effective up to heights equal to the rolling sphere's radius. The protective angle approach is typically used in conjunction with the mesh method for structures that have a metallic structure that protrudes. The rolling sphere approach is sometimes simplified mathematically by the protected angle method. The protective angle is calculated so that the additional area under the protective angle and the area that is no longer under the protective angle are equal at the point where the slope crosses the rolling sphere.

Cone of protection has the highest lightning protection level (LPL) and minimum peak lightning current with efficiency of 99% of probability of efficiency (Oyeleye, 2019).

The Mesh Method, which was first proposed by Maxwell in 1898, involves installing a mesh network on top of the roof ceiling of the entire structure and is thought to be the greatest way to protect structures from lightning by surrounding them in a Faraday cage. This approach is among the most widely used and reliable methods, particularly for safeguarding a building's flat surfaces. Lightning protective level, Lightning Current and Related Rolling Sphere Radius, Mesh Width, Protection Angle, and Percentage of probability of lightning strike applied in this work is in Table 1.

Materials and Method
Lightning Protective System: Materials and Dimensions

Air terminals, down conductors, and earthing conductors are the components of lightning protection systems. The materials used for the LPS must have the following primary qualities: proper mechanical strength to withstand the electromagnetic stresses brought on by high peak current values, good resistance to corrosion from the atmospheric environment, and good electrical conductivity to permit current flow.

The materials usually adopted are iron, copper, and aluminum depending on cost, corrosion, soil resistivity and ability to dissipate fault current to ground.

According to Oyeleye and Melodi, (2021), the earth rod is usually 16 mm² and the mat (copper) is usually 600mm x 600mm x 3mm and earthing lead

Table 1: Lightning protective level, Lightning Current and Related Rolling Sphere Radius, Mesh Width, Protection Angle, and Percentage of probability of lightning strike (Oyeleye, 2019)

| Lightning Protection Level | Probability of Lightning Efficiency | Rolling Sphere Radius | MSH Width | Protection Angle Method for Different Heights (M) of Terminals | | | | Minimum Peak Lightning Current |
|----------------------------|-------------------------------------|-----------------------|-----------|--|----|----|----|--------------------------------|
| | | | | 20 | 30 | 45 | 60 | |
| LPL | $p(LE)$ | R, m | D, m | ? (°) | | | | I, kA |
| I | 99% | 20 | 5 | 25 | | | | 3 |
| II | 94% | 30 | 10 | 35 | 25 | | | 5 |
| III | 91% | 45 | 15 | 45 | 35 | 25 | | 10 |
| IV | 84% | 60 | 20 | 55 | 45 | 35 | 25 | 16 |

2.9 mm² min and 70 mm² max. 95mm² down conductor are also in used. Because of its better conductivity, copper (Cu) earthing material is popular. It also has good mechanical efficacy. Cu is employed where cost is less considerate. The materials, configuration and cross sections of air terminal, down conductor, lightning electrode size and corrosion effect is as in Table 2.

Data Collection

Data was collected from library site in real time. The method used in this research work is protection angle method for lightning protection coverage.

Evaluation of Existing Lightning Arrester (LA)

Existing lightning arrester (LA) was compared with the standard LA as shown in Equation 1.

$$\theta_{LA-ex} \geq \theta_{LA-st} \tag{1}$$

where θ_{LA-ex} is the existing lightning arrester conductor size in mm²; θ_{LA-st} is standard lightning arrester conductor size in mm².

The lightning arrester applicable standard used in this work is 161 mm² or 200 mm², Table 2.

Evaluation of Protective Angle

In order to evaluate the protective angle, the best lightning protection method and Lightning Protection Level (LPL), Table 2, was employed for direct and indirect lightning strike outside the library, the protective angle is given by Equation (2).

$$\alpha_{PA} = \alpha_a \tag{2}$$

where α_{PA} is the protective angle (PA); α_a is standard applicable protective angle.

In order to determine α_a conformity, the height of the library shall be measured in real time using a measuring tape as in Figure 2.

Table 2: Materials, Configuration and Cross Sections of Air Terminal (AT), Down Conductor (DC), Lightning Electrode (LE) Size and Corrosion, Adapted from; IEEE Power and Energy (Society (2012); National Fire Protection Association (2017); Oyeleye, 2019)

| S/N | DC/AT | CONFIGURATION | MIN CROSS-SECTION | CORROSION INCREASED BY |
|-----|-----------------|-----------------------------------|-------------------|------------------------|
| 1 | Copper; | Solid tape, solid round, stranded | 50 | Sulphur component |
| | | Solid round (AT/LE rod only)) | 200 | |
| | | Solid round (AT/LE rod only) | 161 | |
| 2 | Aluminum | Solid tape | 70 | Alkaline solution |
| | | Solid tape, solid round, stranded | 50 | |
| 3 | Aluminum alloy | Solid tape, solid round, stranded | 50 | |
| 4 | Steel | Solid tape, solid round, stranded | 50 | High chloride content |
| 5 | Stainless steel | Solid tape, solid round | 50 | High chloride content |



Figure 2: Measurement of library height in real time

LPL and height of the library shall be applied to evaluate the lightning protection of the library. The LPL protective angle α_{PLPPA} is given by Equation (3).

$$LPL_{\alpha_{PLPPA}} = 25^\circ \text{ (Oyeleye, 2019)} \quad (3)$$

where $LPL_{\alpha_{PLPPA}} 25^\circ$ is the protective angle.

Evaluation of Roof Orientation

Roof Orientation is another factor to reckon with. This helps in determining the positioning and installation of the lightning arrester. The intended highest point of the building is below the actual height of the building, Figure 3 and Figure 4.

Evaluation of Surge Protector

Lightning surge within the library adequacy will be examined. This was done by physical inspection of the existing ones in the library installation in term of rated value and best practice. This conforms to Table 2.

Evaluation of Down Conductor

In order to achieve objective II, down conductor (D_c), conductor sizing was examined whether it is conformed to the existing standard-Table 2 as shown in Equation 4.

$$50 < D_c \leq 200 \text{ (mm}^2\text{)} \quad (4)$$



Figure 3: Roof orientation

The lightning conductor sizing used is as in Table 2 which conform to 161 mm² or 200 mm².

Evaluation of Earthing Network

Earthing conductor material and sizing was examined whether it conforms to the existing standard using Table 2 as shown in Equation 5.

$$50 < E_c \leq 200 \text{ mm}^2 \quad (5)$$

where E_c is the earthing conductor.

The E_c sizing shall conform to 161 mm² or 200 mm² (Ravok and Uman, 2005); Cooray (2010) and Oyeleye (2019) -Table 2. The earthing value shall conform to Equation (6).

$$(4 \Omega \geq R \leq 10\Omega) \quad (6)$$

where R is a resistance value.

Also, clamp digital earth resistance meter was used to measure the resistance value.

Results and Analysis

Ground Floor Plan Dimensions

Figure 5 presents ground floor of Library without showing dimensions. From Figure 5, the dimensions lines were deleted to produce Figure 6 for clarity and pave way for Lightning arresters positions.



Figure 4: Roof orientation

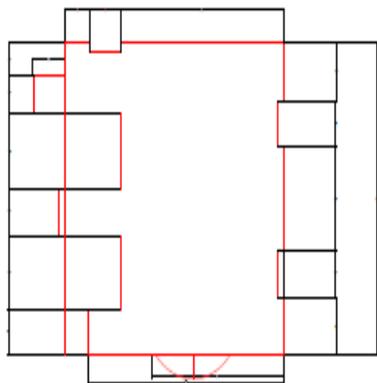


Figure 5: Ground Floor Plan Dimensions
4183.43 mm²

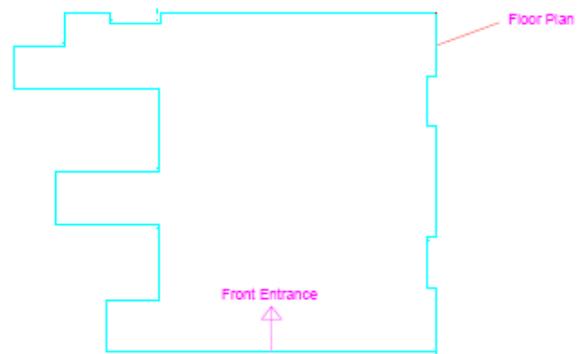


Figure 6: Ground Floor Plan without the dimension
4183.4m²

Roof Plan of library

Roof Plan of library is presented in Figure 8.

There was no as built roof plan. The ground floor plan, Figure 6, was drawn to generate a roof plan of the library, Figure 7. This was used to determine the position of LA, Figure 8. LA positioning is needed to draw the coverage area of each LA.

3.3 Protective Zone of the Installed LAs on the Roof

The protective zone of each LA is presented in Figure 9.

The protective zone of each LA was drawn on the point of each LA position as in Figure 8. The radius of each protective coverage of each LA was measured to find the area protected (protective zone) by each LA.

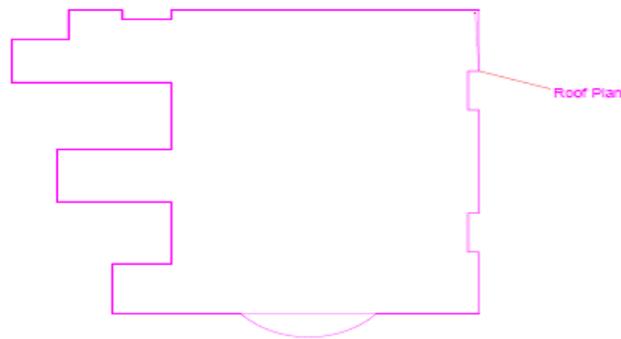


Figure 7: Roof Plan of library, 4482.3mm²

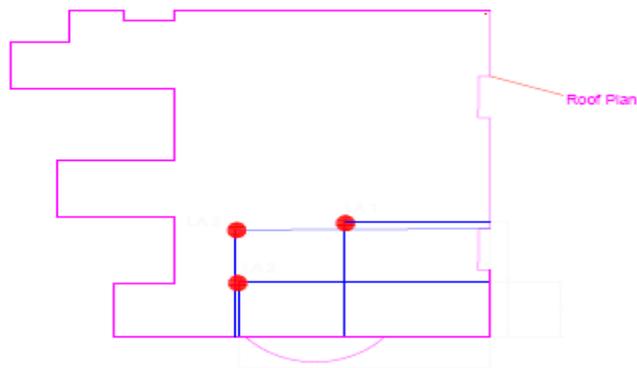


Figure 8: LA Positions on Roof Plan of Library

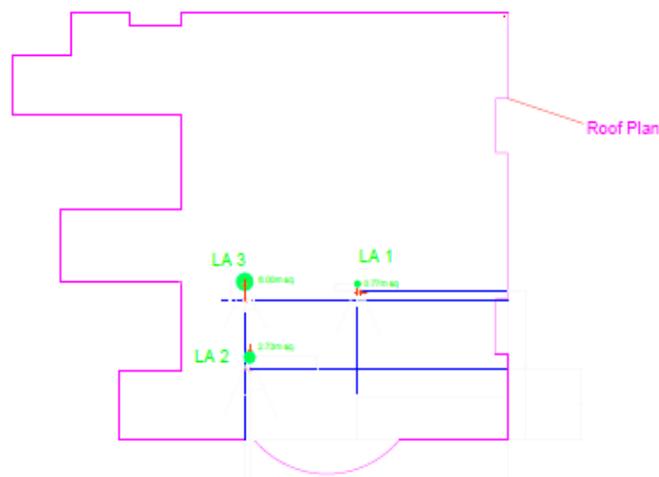


Figure 9: Protective Zone of the library (25 mm² Protective Angle)

Proposed Protective Zone of the Library

Proposed Protective Zone of the Library is presented in Figure 10. The yellow colour is the protective zone (PZ) coverage produced from AutoCAD drawing. The purple colour is the corresponding PZ on the library building. LA 1, LA 2, and LA 3 protective zone covered by the LA, Faraday air terminal.

From Figure 9, Table 3 is produced.

From Table 3, the PZ of LA 1, LA 2 and LA 3 are 0.02%, 0.06%, and 0.13% respectively. The total coverage area is 0.21%. This implies that only 0.21% of the building is protected from the direct lightning strike using (25 mm² Protective Angle, while 99.97% is not protected.

Table 3: Protective Zone Coverage Area

| INSTALLED LA | TYPE | RADIUS (m) | PROTECTED AREA, P _A (m ²) | BUILDING TOTAL AREA, B _T A(m ²) | % P _A (m ²) [x100%] | % PROTECTED [TOTAL %P _A - 100%] |
|--------------|---------|------------|--|--|--|--|
| 1 | Faraday | 0.4934 | 0.77 | 4483 | 0.02 | |
| 2 | Comm. | 0.9319 | 2.73 | 4483 | 0.06 | |
| 3 | Faraday | 1.3826 | 6.01 | 4483 | 0.13 | |
| Total | | | | | 0.21 | 99.79 |

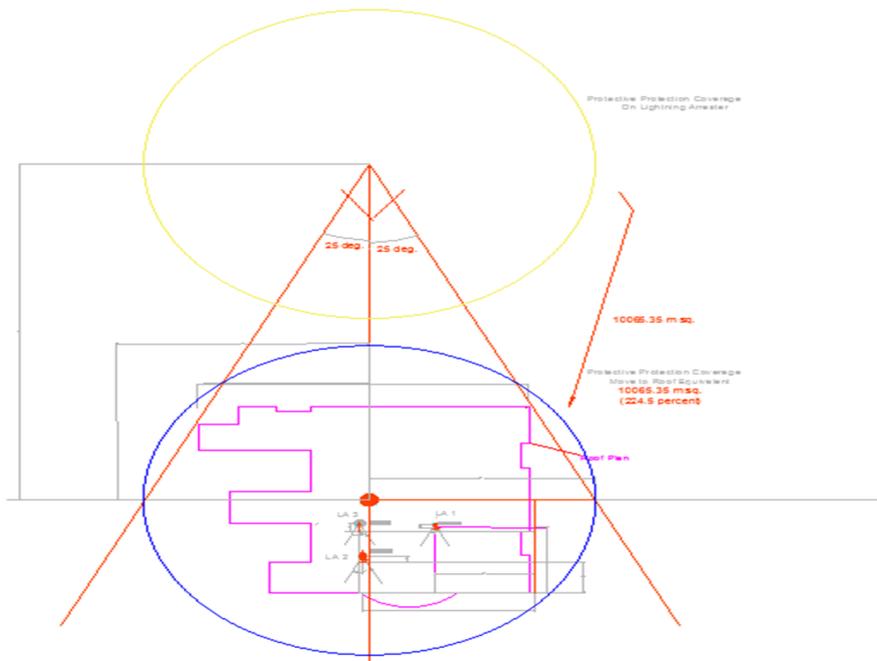


Figure 10: Proposed Protective Coverage Zone of the library (25 mm² Protective Angle)

From Figure 10, Table 4 is produced and presented.

Table 4: Proposed designed Protective Zone

| INSTALLED LA | TYPE | LA HEIGHT (m) | MASK HEIGHT(m) | ROOF HEIGHT(m) | PROTECTED AREA, P _A (m ²) | BUILDING TOTAL AREA, B _T A(m ²) | % PROTECTED AREA [$\frac{B_{TA}}{P_A}$] |
|--------------|---------|---------------|----------------|----------------|--|--|---|
| 1 | Faraday | 3 | 120 | 17 | 10065.34 | 4483 | 224.5 |

From Table 4, the proposed designed protective Zone offered 224.5% protection. It follows that the proposed designed has 100% PZ for the library under consideration.

Conclusions

The evaluation of this research revealed that LA 1, LA 2, and LA 3 protective zone covered by the LA, Faraday air terminal, is 0.02%, 0.06%, and 0.13% respectively. The total coverage area is 0.21%. The library building is not adequately protected from direct and indirect lightning strike effects. The unproductive area of the building is 99.79% and the building proposed protection coverage is 100% . **Sizing** of DC and EC, 75 mm², is not in conformity with existing standards. Hence, adequate sizing of DC, 161 mm², minimum, is designed in this research in conformity with existing standard and theory. The existing SA for the library (40 KVA) is below standard. So, MOV, (70 kA) is recommended as a designed value. The installed *materials* (Copper) used for LAs, DC and EC in this research are in conformity with the existing theory and standards. The ohmic value of the existing earthing system was not allowed to be measured by the concerned authority. However, the ohmic value in this design shall be minimum of 4 Ω and maximum of 10 Ω . The purpose protective zone of protection offers 100% to the research library. Adequate protective zone should be designed for a library building and any other buildings for prevention of lives and properties. Also, there should be a discipline coordination with lightning designer and civil Engineer when designing building roof. This is to ensure adequate siting of the LA.

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