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Reliability of Lightning Protection Systems of Residential Buildings in Waterlogged Areas in Eastern Nigeria

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ABSTRACT

There have been reported cases of structural damage, especially in buildings in Eastern parts of Nigerian States such as Enugu State, Nigeria due to lightning strikes in waterlogged areas or during heavy rainfall. This necessitated investigations into reasons for such disasters, hence this study. The study aims to investigate the reliability of lightning protection systems in selected residential buildings in waterlogged areas in Nigeria. To achieve this aim, the study adopted a mixed research design (empirical and analytical research designs). Visual inspections and calculations were done according to the specifications of BS EN 62305 for earthing and lightning protection system design. Computations were performed using software developed by the G.M. Krzhizhanovsky Energy Institute, JSC ENIN, OJSC. An Advanced Lightning Direction Finder (ALDF) was adopted to detect cloud-to-ground lightning strikes and determine their location by triangulation of two or more bearing lines. The results were corroborated with the ones obtained using the Dead Earth Method (as stipulated in BS 6651), and their means were recorded for every three measurements. The study concluded that buildings with poor lightning protection are prone to lightning strikes causing excessive vibrations that lead to building collapse; buildings located in waterlogged areas without adequate lightning protection suffer from higher impacts of lightning strikes because of the electro-hydraulic effects and have greater failure and mortality rates.

Keywords:
Electro-Hydraulic,
Lightning,
Building Collapse,
Prevention.

INTRODUCTION

Structural failures are sadly a numerously recurring, worldwide problem. There exist a number of different natural causes of structural failures, namely earthquakes, volcanoes, hurricanes, tornadoes, high winds, flash floods and floods, landslides, thunderstorms and lightning, hail, winter storms, fire, erosion, land subsidence, and corrosion. The number of documented cases is vast and many of these instances have led to devastating consequences, such as loss of life and large-scale physical destruction which amounts to billions of dollars' worth of damage yearly (Chahar *et al.*, 2023). Since everyone is a potential victim of structural failure, this phenomenon has for some time received widespread attention, not only in the form of academic journal papers, but also through discussions at conferences, reports in the media, and even congressional hearings. However, much research on predictive models and preventative technologies for structural failures still remains to be done. The issue of lightning becomes crucial in this respect.

Lightning protection is a system that is put in place to protect a structure or a building from lightning damages, and to protect either persons or livestock inside or around the buildings (Commission, 2010). Lightning strikes are highly unpredictable and can cause damage to buildings and even loss of life. They can result in large impulse currents up to 200kA, creating electrical arcs resulting in huge amounts of heat (Kuan *et al.*, 2019). Lightning protection is done using lightning rods. A lightning rod or lightning conductor (British English) is a metal rod mounted on a structure and intended to protect the structure from a lightning strike. If lightning hits the structure, it is most likely to strike the rod and be conducted to ground through a wire, rather than passing through the structure, where it could start a fire or cause electrocution. Lightning rods are also called finials, air terminals, or strike termination devices (Kumar *et al.,* 2018).

The lightning rod requires a connection to the earth to perform its protective function. Lightning rods come in many different forms, including hollow, solid, pointed, rounded, flat strips, or even bristle brush-like. The main attribute common to all lightning rods is that they are all made of conductive materials, such as copper and aluminum (Basholli and Daberdini, 2023). Copper and its alloys are the most common materials used in lightning protection (Kumar *et al.,* 2018). Precautions must be taken to prevent side-flashes between conductive objects on or in the structure and the lightning protection system. The surge of lightning current through a lightning protection conductor will create a voltage difference between it and any conductive objects that are near it. This voltage difference can be large enough to cause a dangerous side-flash (spark) between the two that can cause significant damage, especially on structures housing flammable or explosive materials (Basholli *et al.,* 2022). The most effective way to prevent this potential damage is to ensure the electrical continuity between the lightning protection system and any objects susceptible to a side-flash. Effective bonding will allow the voltage potential of the two objects to rise and fall simultaneously, thereby eliminating any risk of a side-flash (Kuan *et al.,* 2019). Structures may be protected from lightning by either channeling the current along the outside of the building and into the ground or by shielding the building against damage from transient currents and voltages caused by a strike (Basholli and Daberdini, 2022). Many buildings constrain the path of lightning currents and voltages through use of lightning rods, or air terminals, and conductors that route the current down into a grounding system. When a lightning leader comes near the building, the lightning rod initiates a discharge that travels upward and connects with it, thus controlling the point of attachment of lightning to the building (Bibri *et al.,* 2024). However, a lightning rod functions only when a lightning strike in the immediate vicinity is already immanent and so does not attract significantly more lighting to the building (Stefanescu and Botezan, 2016). The down conductors and grounding system function to guide the current into the ground while minimizing damage to the structure. To minimize side-flashes, the grounding resistance should be kept as low as possible, and the geometry should be arranged so as to minimize surface breakdown (Stefanescu and Botezan, 2016). Overhead wires and grounded vertical cones may also be used to provide a cone-shaped area of lightning protection. Such systems are most efficient when their height is 30 metres or less (Suryadi and Sudjono, 2020).

Protection of the contents of a structure can be enhanced by using lightning arresters to reduce any transient currents and voltages that might be caused by the discharge and that might propagate into the structure as traveling waves on any electric power or telephone wires exposed to the outside environment (Bibri *et al.,* 2024). The most effective protection for complex structures is provided by topological shielding. This form of protection reduces amounts of voltage and power at each level of a system of successive nested shields. The partial metallic shields are isolated, and the inside surface of each is grounded to the outside surface of the next. Power surges along wires coming into the structure are deflected by arrestors, or transient protectors, to the outside surface of each shield as they travel through the series, and are thus incrementally attenuated (Stefanescu & Botezan, 2016).

Lightning must reach the ground. Lightning uses ground as its whole conductor. A lightning protection system means that it gets to the ground and the current is dispersed safely. No part of the system will work without the other. The grounding system is integral to a modern electrical lightning protection system. Without it, lightning can cause danger and damage including ground faults, loud electrical noises, damage to buildings, fire and personal injury (Zhang *et al.,* 2019). Earthing is fundamental to a lightning protection system. It is the part of the system that terminates the current and transfers it safely to the ground.

In some instances a more complex earthing system is required. For example, where there are hazardous areas in a building, a perimeter earth electrode that surrounds the structure should be used and this consists of horizontal buried electrodes. When lightning occurs on a waterlogged area, electro hydraulic effects are observed. However, the Eastern part of Nigeria has recorded numerous losses due to this lightning activities. This has raised serious concern among the residents of the region. Thus, the need for the investigation on the protection measures against lightning strike on buildings in the region. Therefore, this paper investigates the reliability of lightning protection systems in selected residential buildings in waterlogged areas in Nigeria

MATERIALS AND METHODS

This study adopted a mix research design. Empirical and analytical research designs were necessary to achieve the objectives of this study. Five residential buildings were strategically selected and numbered (A-E) using direct counting in the study area. The selection criterion was exhibition of structural distresses (vertical, horizontal and longitudinal cracks on walls; roof failures and at least 6-12m high) and location in waterlogged areas. Visual inspections and calculations were done in accordance with the specifications of BS EN 62305-2, BS EN 62305-3 and BS EN 62305-4 for earthing and lightning protection system design. Computations were carried out using software developed by the G.M. Krzhizhanovsky Energy Institute, JSC ENIN, OJSC. An Advanced Lightning Direction Finder (ALDF) was adopted in the detection of cloud-to-ground lightning strikes and determining their location by triangulation of two or more lines of bearing. An ALDF automatically detects more than 90% of all cloud-to-ground lightning occurring within a range of 100 km. The results were corroborated with the ones obtained using the Dead Earth Method (as stipulated in BS 6651) and their means were recorded for every three measurements.

Method of Calculation

The occurrence of lightning strikes into the ground is 4 strikes/sq. km per year

The total number of strikes into the system is 0.043 (once every 23 years).

Total number of blowouts is 0.0031 (once per 323 years).

System reliability is 0.929.

The probability of breakout into all facilities of the system is 0.071.

Ground terminal resistance calculation:

Vertical electrode resistance

$$R = \rho_{eq}\,(2\Pi L)^{-1}\left[\left(\ln\frac{2L}{d}\right) + \left(0.5\ln\frac{4T+L}{4T} - L\right)\right] = 34.25\ \mathrm{Ohm} \quad (1)$$

here ρ_{eq} is equivalent soil resistivity, 100 Ohm·m;

L vertical electrode length, 3m;

d is diameter of the vertical electrode, 0.014m;

T deepening - is the distance from the ground surface to the ground electrode, 2m;

$$T = \left(\frac{L}{2}\right) + t = 2\mathrm{Ohm} \quad (2)$$

where t is electrode top depth, 0.5m.

Horizontal electrode resistance

$$R_{rop} = \left(\frac{\rho}{2\pi L_{rop}}\right)\ln\left[\frac{(2L_{rop})^2}{bh}\right] = 4.31\mathrm{Ohm} \quad (3)$$

where ρ is soil resistivity, 100 Ohm·m;

b is horizontal electrode width, 0.03m;

h is horizontal electrode depth, 0.5m;

L_{rop} is horizontal electrode length, 45m.

Electrical impedance of the grounding arrangement

$$R_{3y} = K_{util} - \sum_j^n n_i / R_i = 3.86 \quad (4)$$

Where n is a number of sets, vertical grounding arrangements - 3 pcs, horizontal grounding arrangement - 1 pc;

K_{util} is utilization rate, 0.81.

The rated resistance of the grounding arrangement is 3.86 Ohms.

RESULTS AND DISCUSSION

The following results were obtained as recorded on Table 1 below.

Table 1: Summary of Test Results of the Selected Buildings

S/N	Test	Buildings				
		A	B	C	D	E
1	Size and Spacing of Air Terminals	250x4.5 c-c	375x5.2 c-c	750x6.5 c-c	820x5.8 c-c	860x5.4 c-c
2	Type/Condition of Conduits	Al / good	Cu/ good	Al /good	Cu /good	Al /poor
3	Length and Diameter of Ground Contactor	3.0x12 mm dia	3.0x11 mm dia	3.0x12 mm dia	3.0x12 mm dia	3.0x11 mm dia
4	Condition of Interconnectors	Okay	Okay	Okay	Okay	Okay
5	Condition of Lightning Diverters	Okay	Okay	Okay	Okay	Okay
6	Vertical Electrode Resistance	5.30 Ohm	27.25 Ohm	31.78 Ohm	36.70 Ohm	23.52 Ohm
7	Horizontal Electrode Resistance	4.40 Ohm	12.73 Ohm	3.90 Ohm	4.25 Ohm	12.60 Ohm
8	Electrical Impedance of Grounding Arrangements	2.20 Ohm	12.26 Ohm	2.80 Ohm	2.92 Ohm	12.20 Ohm
9	Electro-hydraulic Effects	Nil	Seen	Nil	Nil	Seen
10	Reliability	0.91	0.35	0.62	0.74	0.32

Discussion

Lightning activity is a frequent occurrence during the rainy season, which typically lasts six months in the Eastern region of Nigeria, from April to September. It is frequently accompanied by wind and sand storms that seriously harm residential buildings (rooftops) and valuable trees, resulting in significant financial loss. Human lives and livestock are occasionally lost in these instances (Sani, 2012). Due to a lack of knowledge about lightning safety training and reporting protocols, the majority of lightning incident cases go unreported and undocumented. However, buildings are equally affected in great measures by these lightening activities. According to Chandima and Zainal (2015), the amount of damage caused by direct lightning strikes to buildings with steel reinforcement is negligible when compared to the impacts of lightning on structures without such reinforcement. Since small-scale damages are only seen at sites of impact, the only danger to people and property is harm or damage from falling objects. These overview and resolutions are equally supported by the findings of this paper.

The results of our findings as shown in Table 1, above, indicated that there were inadequate spacing of the air terminals in buildings C, D and E since 7.5m is the minimum recommended. Also, Building E has poor conduits. Some external fractures were observed on the conduits and may have poor connection of lightning flashes from the air terminals to the ground, without dispersing them deep into the earth, harmlessly. Buildings B and E have inadequate diameters of electrodes since the recommended diameter is 12mm. However, they were made of standard materials (aluminum or copper). Conditions of interconnectors and lightning diverters were observed to be good. Buildings B, C, D and E have inadequate vertical electrode resistance (>10 Ohms) while building A has adequate vertical electrode resistance. Buildings A, C and D have adequate horizontal electrode resistance (<10 Ohms) but B and E have inadequate horizontal electrode resistance (>10 Ohms). Buildings A, C and D have adequate electrical impedance of the grounding arrangements (<10 Ohms) but B and E have inadequate electrical impedance of the grounding arrangements (>10 Ohms). Buildings B, C, D and E are prone to electro-hydraulic effects. Buildings B and E have poor reliability (<0.50) while buildings A, C and D have good reliability (>0.50).

CONCLUSION

In this research, it has been found that buildings with poor lightning protection are prone to lightning strikes which cause excessive vibrations that lead to building collapse; buildings located in waterlogged areas without adequate lightning protection suffer from higher impacts of lightning strikes because of the electro-hydraulic effects and have greater failure and mortality rates.

REFERENCES

Basholli, F., and Daberdini, A. (2023). Monitoring and assessment of the quality of electricity in a building. *Engineering Applications*, 2(1), 32-48. https://www.researchgate.net/deref/https%3A%2F%2Fpublish.mersin.edu.tr%2Findex.php%2Fenap?_tp=eyJjb250ZXh0Ijp7ImZpcnN0UGFnZSI6InB1YmxpY2F0aW9uIiwicGFnZSI6InB1YmxpY2F0aW9uIiwicG9zaXRpb24iOiJwYWdlQ29udGVudCJ9fQ

Basholli, F., Merkuri, L., and Daberdini, A. (2024). Magnetic and electric fields in high - voltage power transmission lines, impact on the environment. *Optime, XIV Year of Publication*, 2, 232-249. http://dx.doi.org/10.13140/RG.2.2.24702.15681

Basholli, F., and Daberdini, A. (2022). Monitoring and evaluation of the quality of electricity in a building. *Advanced Engineering Days (AED)*, 5, 77-80. https://www.researchgate.net/deref/http%3A%2F%2Faed.mersin.edu.tr%2F?_tp=eyJjb250ZXh0Ijp7ImZpcnN0UGFnZSI6InB1YmxpY2F0aW9uIiwicGFnZSI6InB1YmxpY2F0aW9uIiwicG9zaXRpb24iOiJwYWdlQ29udGVudCJ9fQ

Bibri, S. E., Krogstie, J., Kaboli, A., and Alahi, A. (2024). Smarter eco-cities and their leading-edge artificial intelligence of things solutions for environmental sustainability: A comprehensive systematic review. *Environmental Science and Ecotechnology*, 19, 100330. https://doi.org/10.1016/j.ese.2023.100330

Chahar, R. S., Lee, J., and Mukhopadhyay, T. (2023). On quantifying uncertainty in lightning strike damage of composite laminates: A hybrid stochastic framework of coupled transient thermal-electrical simulations. *Aerospace Science and Technology*, 142, 108597. https://doi.org/10.1016/j.ast.2023.108597

Commission, I. E. (2010). Protection against lightning– Part 3: Physical damage to structures and life hazard. IEC 62305-3, Switzerland. https://webstore.iec.ch/en/publication/6795

EN 62305-2 Lightning Protection – Part 2. Risk Management. https://ifsm.org.uk/wp-content/uploads/2-DEHN-UK-Lightning-prot-Risk-Management-IFSM.pdf

EN 62305-3 Lightning Protection – Part 3. Protection Against Damage to Buildings and Danger to Life).

https://ifsm.org.uk/wp-content/uploads/3-DEHN-UK-Lightning-prot-Physical-damage-to-structures-IFSM.pdf

EN 62305-4 Lightning Protection – Part 4. Electrical and Electronic Systems Installed in Constructions). https://ifsm.org.uk/wp-content/uploads/4-DEHN-UK-Lightning-prot-Electrical-and-Electronic-systems-IFSM.pdf

Kuan, T. H., Chew, K. W., and Chua, K. H. (2019). Practical approach on surge protection device for Ex application. 2019 1st International Conference on Electrical, Control and Instrumentation Engineering (ICECIE), 1–7. http://dx.doi.org/10.1109/ICECIE47765.2019.8974781

Kumar, V., Yokozeki, T., Okada, T., Hirano, Y., Goto, T., Takahashi, T., and Ogasawara, T. (2018). Effect of through-thickness electrical conductivity of CFRPs on lightning strike damages. *Composites Part A: Applied Science and Manufacturing*, 114, 429–438. https://doi.org/10.1016/j.compositesa.2018.09.007

Stefanescu, S., and Botezan, A. (2016). Overview of the protection lightning standards suite EN/IEC 62305. 2016 International Conference and Exposition on Electrical and Power Engineering (EPE), 504–509. http://dx.doi.org/10.1109/ICEPE.2016.7781391

Suryadi, A., and Sudjono, D. (2020). Evaluation of Parameters in the Development of a Building Protection System. *International Journal of Electrical Engineering and Applied Sciences (IJEEAS)*, 3(2), 7–13. https://ijeeas.utem.edu.my/ijeeas/article/view/5865

Yousefpour, K., Lin, W., Wang, Y., and Park, C. (2020). Discharge and ground electrode design considerations for the lightning strike damage tolerance assessment of CFRP matrix composite laminates. *Composites Part B: Engineering*, 198, 108226. https://doi.org/10.1016/j.compositesb.2020.108226

Zhang, J., Zhang, X., Cheng, X., Hei, Y., Xing, L., and Li, Z. (2019). Lightning strike damage on the composite laminates with carbon nanotube films: Protection effect and damage mechanism. *Composites Part B: Engineering*, 198, 108210. http://dx.doi.org/10.1016/j.compositesb.2019.03.054