Techniques Used by ACLENet in Protection of Schools in Rural Uganda

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***Abstract*—A primary objective of ACLENet is to provide a lightning-safe environment for as many schools in Uganda as funding levels allow. The baseline for this protection is the IEC 62305 series of standards. However, ACLENet faces the same problem faced by many developing countries that a lightning protection system meeting the letter of the standard can be cost prohibitive. This paper discusses how ACLENet is addressing this problem in the protection of schools in rural Uganda using lightning safety awareness in conjunction with lightning protection measures. We use Mongoyo Primary School, which experienced a lightning event that killed three children and injured dozens in October 2018, as an example in this discussion.**

Keywords—lightning safety, lightning protection, lightning in Africa, schools.

I. INTRODUCTION

This paper primarily focuses on the technical aspects of the design and installation of lightning protection systems used by the African Centres for Lightning and Electromagnetics Network (ACLENet) for schools in Uganda. As the program moves forward, it continues to evolve and the scope of the lightning safety effort has expanded to include more than only classrooms, and in some cases, more than only schools.

Other than for a small staff in Uganda, ACLENet relies completely on volunteers and donations to protect these schools. There are 33,000 public and private, primary and secondary schools in Uganda, many with histories of recurrent lightning strikes and injuries [1-3]. In October 2018, one lightning strike at Mongoyo Primary School killed three children and seventy two [4, 5]. When a donor stepped forward to protect a school, ACLENet assigned Mongoyo because of the recent deaths.

Mongoyo Primary School is the 4th school protected by ACLENet designed by the Lightning Protection Working Group (LPWG) and the 7th overall protected by ACLENet. Each of the previous three schools designed by the LPWG introduced new challenges. Mongoyo consists not only of classroom blocks, but also teachers' quarters that have thatch roofs, a church, and administration buildings. This paper addresses how ACLENet addressed these challenges, focusing specifically on examples at Mongoyo.

The cost of protection of a lightning protection system meeting the letter of international standards such as IEC 62305 is generally more than the replacement cost of the structure and its contents. However, other factors such as the risk of injury and death and a lack of resources for education of the children in the region are important considerations that need to be addressed in a lightning risk assessment for these applications. In order to safely protect the maximum number of schools practicable by maximizing the resources available, ACLENet would also have to take on the challenge faced by most developing nations in determining how to provide effective protection that meets the intent of IEC 62305; the minimum resources that are available. Risk assessment considerations are discussed in Section IV and associated design considerations are provided in Section V.

II. LIGHTNING PROTECTION WORKING GROUP (LPWG)

The initial challenge in providing lightning protection for at-risk schools in Uganda was to develop and implement an overall plan to provide a safe environment for the children from the threat of lightning. The Executive Committee of ACLENet assembled an initial group of volunteers from the United States, South Africa, and Uganda that meet weekly to discuss how best to meet this goal. Another 2 members from Europe were added at the start of the Mongoyo project. The multi-continental group of volunteer lightning protection professionals with diverse backgrounds supplement one another to address the technical and logistical issues associated with protecting schools, providing efficient lightning protection systems, while maximizing the resources available.

Prior to the initial LPWG meeting, a group of lightning protection experts from the United States and South Africa had informal discussions on the ACLENet project while attending an IEC TC 81 meeting in Chengdu. It was agreed that the use of natural lightning protection system components must be considered for ACLENet to be able to protect a relevant number of structures. It was also agreed that the logical choice would be to use the IEC 62305 series of standards as guidance in the protection of the schools.

The strategy agreed by the LPWG confirmed the lightning protection system designs should reflect the intent of IEC 62305, Part 3 [6]. The team would consist of South African and US representatives on IEC Technical Committee on Lightning Protection TC 81 Working Group, Maintenance Team, Task Force and Ad Hoc Groups; with others having experience in Africa with local knowledge and hands-on experience. The US delegation volunteered to develop lightning protection system (LPS) designs and drawings based on survey data provided by the team in Uganda. Uganda members provide other data and in-country support as needed, including system installations. South African members provide review of the LPS designs with valuable African experience and took the lead in negotiating imports, shipping logistics, and discount pricing when possible. Academic support is provided by the University of Witwatersrand in discussions of technical issues and where deviations to the IEC standard are proposed.

Mongoyo Primary is in the final stages of installation. At the last 2 schools (Mongoyo and Rock View), a total of 37 structures were protected. Designs of 2 additional schools are in discussion. ACLENet has also received requests for consultation from Kenya. Tanzania, Madagascar, and the Democratic Republic of the Congo; concerning lightning safety at schools, medical facilities, and a church.

III. CHALLENGES

A major challenge for ACLENet is that all its funding is provided through donations. With the exception of a small paid staff in Uganda, the work of the LPWG is performed by part-time volunteers with other full-time jobs. This leads to longer design and installation times than would be necessary for organizations with paid staff and workers.

Primary communications among LPWG volunteers are via email and weekly virtual meetings. In addition to the normal issues associated with virtual meetings between participants stretching across ten time zones, there is often poor connectivity somewhere, intermittent internet service, and the occasional lack of electricity. There is sometimes difficulty understanding native regional accents. Issues with different meanings of words and terminology were initial challenges, but over time have generally resolved themselves.

Early in the process, it was acknowledged that there are effectively no sources of components certified to IEC 62561 available within Uganda, so, with few exceptions, all materials used in the installations must be imported, adding to time and cost of installations. Most of the school structures are of simple construction and contain few items that can be used as a natural LPS component.

Since ACLENet relies on donations, it is necessary to reduce the cost of lightning protection systems where possible, including the use of natural components. This must not reduce the efficiency nor long-term reliability of the system. An example of the use of local materials to reduce costs and support the local economy is the mast-type LPS discussed in Section VI.

Another challenge was to ensure accurate lightning protection system design data. Initially, the users of the data had no input on the initial survey data collected, but as the process progressed there was a better understanding of what was needed. ACLENet developed a data collection form and now provides a good opportunity to discuss details that may not be included in the form. The current challenge is to add more detailed information on internal metallic conductors that can be inductively coupled to LEMP from a lightning event. Very little information was available on the contents of the structure other than electrical and communications systems when they are installed.

A particularly difficult challenge to resolve is how to protect against the threat presented by metallic poles used on the verandas of the typical classroom designs in Uganda. A lightning strike near the structure will create a resulting voltage on the metal poles due to the lightning electromagnetic pulse created by the event. School children often congregate on the verandas either touching or is in close proximity to the metal poles (see discussion in Section VI).

IV. LIGHTNING RISK ASSESSMENT

The primary tool for the assessment of lightning risk is IEC 62305-2 [7]. Its purpose is to assess the lightning risk of the application and determine the associated protection levels needed when the risk exceeds the tolerable level. Most schools considered by ACLENet are of simple constructions and not considered to be of cultural significance. In these cases, risk R_3, will not be considered as a part of the lightning risk assessment.

The incentive of ACLENet in the protection of schools in Africa is the reduction of injuries and deaths in the schools by providing a safe haven where children will feel safe to stay during thunderstorms. While not downplaying the loss of a structure, such as a classroom, and the effort it takes for the community to replace the structure, the risk of loss of economic value, R_4, is not a primary factor considered in the Lightning Risk Assessments for the schools. It is also noted that a large percentage of structures at the schools have no incoming lines and none have had the level of internal electrical and electronic systems that warrant the consideration of electrical and electronic system protection (SPM) described in IEC 62305-4 [8]. Where applicable, IEC 62305-4 and economic loss will be considered.

Even though the schools may provide the villages with a place to meet and hold community events, or provide other services, the risk of loss of the service to the public, R_2, is not a primary factor in ACLENet's consideration of the need for protection. It can be considered in the lightning risk assessment but often is not. To reiterate, the primary goal is the reduction of injuries and deaths in the schools. This is manifested in risk, R_1, (risk of loss of human life and permanent injury). As many structures have no incoming lines, the primary risk factors considered are electric shock due to touch and step voltages inside the structure and outside in zones up to 3 meters around down conductors (R_{A1}) and physical damage caused by dangerous sparking inside the structure triggering fire or explosion (R_{B1}).

A lightning risk assessment was performed for Mongoyo Primary School considering the six classroom blocks located around a common courtyard [9]. At the time of the assessment only the classroom blocks were being considered for protection. The result of the assessment indicated protection would be required to meet the tolerable level of risk indicated in IEC 62305-2 [7] and that a Lightning Protection Level (LPL) IV lightning protection system (LPS) would be sufficient to meet the tolerable level of risk specified in the standard. The LPL IV LPS installation is consistent with other assessments performed for classroom blocks in Uganda.

V. LIGHTNING PROTECTION SYSTEM DESIGN

As discussed in II, LPS designs developed by ACLENet for schools and associated structures are based on the requirements of IEC 62305. Where concessions must be made in some applications, the intent of the standard must be met or justified otherwise.

For the initial effort in 2019, the ACLENet Executive Committee selected a small accessible school with three simple rectangular classroom blocks and symmetrical pitched roofs. This allowed the LPWG to focus on the design processes and plans of action to best accomplish these goals. The next 3 schools, including Mongoyo, were progressively more complex, challenging, and involved.

The initial goal in the design of the lightning protection systems for the schools is to simplify the design to reduce the influence of variables between sites and types of structures. Type B earthing systems (IEC 62305-3, 5.4.2.2) are installed to reduce the influence of earth resistivity in designs, maximize current division in the earthing systems and reduce issues related to unknown rocky conditions.

Investigations of incidents in schools in Uganda have identified a susceptibility to inductive coupling onto internal conductive items inside a structure. Mud-brick construction for exterior walls provide little electromagnetic shielding between the exterior lightning protection zone (LPZ) LPZ 0 and the interior LPZ 1. The LPWG considered this threat in conjunction with the propensity for multiple deaths at these sites with no evidence of a direct strike (see Section VI). It concluded that an interim solution could be to specify that lightning protection systems be designed to a Lightning Protection Level (LPL) II versus an LPL IV identified from the lightning risk assessments. This decision takes advantage of the increased shielding that would be provided by the decreased down conductor spacing from 20 meters required for LPL IV to 10 meters required in a LPL II design (IEC 62305-3, Clause 5.3.3, Table 4). The decision also provides a more stringent earthing system requirement without an impact on cost because of the initial decision to use Type B earthing electrodes.

Another effect of the decision to design to LPL II for the school structures is the more stringent requirements on the air termination system. This has at times resulted in the addition of extra or taller air terminals than would be required in a LPL III design. Because cost of material and time required for installations are factors, the effect of overdesign must be considered. A detailed review of existing data should be performed to determine the prevalence of information suggesting a direct strike, but it is suggested that a reduction of the air termination requirements from a LPL II to a LPL III design would have a minimal effect on the safety of the children. The dominant threat appears to be touch and step potential (internal and external), with perhaps sideflash from isolated conductive items and in rare cases metal roofs.

Cost is a factor that dominates the number of structures that can be protected. This means the use of natural components is necessary when safe to use. The baseline policy to address where natural components could be considered is based on the ability to develop a surveillance program that could be implemented to confirm the components continue to fulfill IEC 62305-3 requirements. This includes the electrical and physical properties of natural components in Clause E.4.2.3.1. The confirmation should include visual monitoring of the components at the sites by individuals identified by ACLENet at the time of commissioning of the system, as well as electrical testing during the periodic inspection of the systems by ACLENet.

In the design at Shone School, a relatively new school and the first design by the LPWG, a continuous sheet of metal roofing was used as a natural roof conductor to provide the current path between ridge and down conductors. A review of Quality Control program pictures from the Shone School later provided by the on-site monitor showed the aging (rust) associated with the quality of the roofing material used. The decision was made not to use roofing material as a part of the LPS at Mongoyo and instead use conductors and connectors certified to IEC 62561 Parts 1 and 2 [10, 11] through the entire primary current path. Associated actions to be taken at Shone, Palabek, and Rock View schools [3] are discussed in Sections VI and VII.

A cost saving method implemented is the use of in-country materials where available. An example is the use of local aluminum poles used for power and lighting as the mast-type LPS currently being installed to protect thatched roof teachers' quarters at Mongoyo Primary School. One such structure is shown below in Figure 1.

Figure 1 - Thatched roof teacher's quarters at Mongoyo

VI. DISCUSSION

A. Electromagnetic Coupling

A summary from Holle [1] reports 121 events with lightning casualties totaling 212 deaths and 824 injuries in Uganda from 2007-2020. It is estimated that 15 to 20 percent of the events occurred inside structures. Reviewing casualties relating to schools, we find 23 of the 43 reported were identified as being inside a structure and 2 were standing on the veranda.

Examining specific reports of deaths and injuries due to lightning events at schools in Africa, there is rarely evidence of a direct strike to the structure and yet an excessive number of injuries and deaths are often reported due to a single event. The source data from reports in developing countries are not often as detailed as required for a good forensic analysis. To gain additional details that may lead to a better understanding of specific lightning threat mechanisms involved in injuries and deaths inside (as well as outside) structures, ACLENet has participated in follow-up studies of the Mongoyo [5] and Arua [12] incidents. These and future efforts will provide greater knowledge of specific threats for which future protection will be required.

Many of the school events reported occur in structures with no incoming power lines. This infers that the greatest threat to children inside the structures are step and touch potentials (or sideflash) associated with inductive coupling. A review of incident reports [1, 2, 4, 5] suggests typical structures provide little attenuation of lightning electromagnetic pulses (LEMP) produced by nearby lightning. Tushemereirwe [5] reported that the ACLENet response team did not find evidence of a direct strike to any of the classroom buildings at Mongoyo Primary School during their October 2018 investigation. A witness reported seeing lightning strike just outside the ring of classrooms. At least one of the students reported feeling the electrical shock come from the metal legs of his desk. There were at least two other reports of students feeling as if their legs were on fire. Figure 2 is a picture of desks that were in the classroom at the time of the event. The blue frame of the desk is metallic and the floor is concrete. It is reasonable to assume that isolated metal bodies of various types not currently identified in surveys could exist capable of coupling LEMP from nearby strikes. School survey forms addressed only incoming lines at the time of the survey with little other internal details. The survey process continues to evolve and future surveys will include identification of the material of floors, walls and roof, as well as internal metal conductors.

Figure 2 - Metal framed desks in Mongoyo

An additional electromagnetic coupling threat is the metal veranda poles mentioned in Section III. The typical design of classroom blocks in Uganda is a rectangular footprint that will include 2 to 3 classrooms per block with a veranda running the entire length of the front of the block. The roof of the veranda is supported by metal poles at the front of the veranda. The classrooms can be built at earth level or elevated by a typically block foundation. Figure 3 is an example of one at earth level.

In addressing the challenge presented by the metal veranda poles, the LPWG explored several options. The 3 primary options were: (1) connect them to earth at their base, (2) provide insulating material around them equivalent to 3 mm or thicker cross-linked polyethylene (PEX), and (3) implement lightning safety education and signage. There are issues with each of these options. Method (1) will require a significant amount of material that is not available in-country, and the installation is labor intensive because all trenching required must be dug by hand. It is the most expensive of the options and correspondingly requires the greatest amount of assets available. Method (2) is an interesting option that could reduce the touch potential threat but its effectiveness against a possible step potential issue on a veranda wet from rain would need to be assessed on a site-by-site basis. It could not be confirmed that PEX, or other variants such as XPE or XLPE, was available in-country. There are versions of polyvinyl chloride (PVC) pipes available, but it could not be confirmed they meet the 100 kV, 1,2/50 μs impulse withstand voltage specified in IEC 62305-3, 8.1. The logistics of an installation method that would withstand the ambient environment would also have to be resolved. In the end, Method (3) was selected until further study of other options or the resolution of existing problems are found. The implementation of Method (3) will require that lightning safety be taught in the schools, that drills be performed to address proper separation from the metal poles and that each teacher be responsible for clearing the veranda in front of their classroom when lightning could become a threat.

Figure 3. Veranda poles on Mongoyo Classroom Block C

B. Use of Natural and Locally Available Components

One of the challenges identified earlier was the lack of available components certified to IEC 62561 in Uganda, increasing the cost and time associated with the logistics associated with the import of the components. These costs increase the level of donations that are required to protect the school and correspondingly reduces the number of structures that can be protected.

This creates an emphasis on the use of natural components where practical, but the schools typically are not constructed of materials that meet the requirements. For the first three schools designed by the LPWG, it was decided to use new iron roofing sheets as part of the roof conductor system on classroom blocks, where practicable. After reviewing surveillance photographs of the roofs about a year later, it appears the metal sheets are already starting to rust [13]. The design for Mongoyo Primary and future schools will incorporate conductors certified to IEC 62561-2 [11] to serve as roof conductors. Electrical testing will be performed during the upcoming inspection of the 3 earlier installations to assess the ability of the roofing material to continue to perform the function of a made conductor. If necessary, additional conductors will be installed to interconnect the ridge conductor to the down conductor.

ACLENet has expanded its use of natural lightning protection system components to cut costs where reasonable. A mast-type LPS was selected as the lowest cost solution for protection of thatched-roof teacher's quarters in Mongoyo. The mast materials are aluminum power and lighting poles fabricated in Uganda. These poles meet IEC 62305 requirements for a lightning mast and have the advantage of being provided with an internal earthing lug that is used in the design of the LPS earthing system. Another advantage is that the base necessary to support the poles is a proven design used with these poles throughout Uganda. The base includes reinforcing steel in the design that is used to create a concrete encased electrode, resulting in a redundant (dual) LPS earthing system (see Figure 4). The mast is bolted through a base plate directly to the reinforcing steel in the base. The earthing connections include a conductor connecting the earthing lug on the mast directly to the earth electrode, routed through the base in an insulative sleeve. Two other earthing connections are made to opposite corners of the reinforcing steel in the base. IEC 62561-1 [10] certified connectors provide access connections on the exterior of the concrete base for the interconnection between the connectors and the earthing electrode at a point circa 1.5 m on each side of the center connection, for a total of three earthing connections at a spacing of approximately 3 m centered on the mast. The earthing electrodes are ring earth electrodes (Type B) for most of the structures. Three of the mast installations involve structures where rock does not allow the installation of a ring earth electrode. In these three cases, a Type A horizontal earth electrode is installed, centered at the mast.

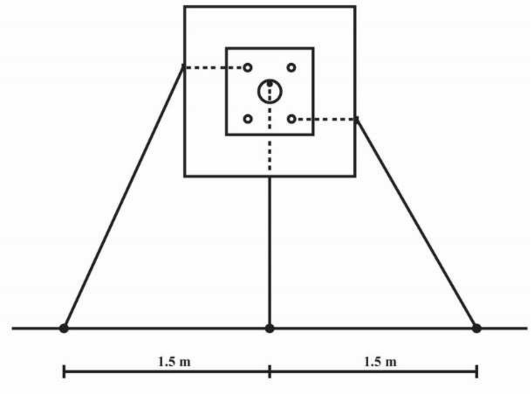

Figure 4 - Earthing details for masts

C. LPS Quality Control

The LPS Quality Control Program at ACLENet functions at several levels. These include the monitoring of natural components used in lieu of components certified to IEC 62561, as well as the maintenance and inspection program to ensure they will continue to function as intended. The Quality Control program for natural LPS components is simple: if you cannot see how it is aging and quantify it meets the necessary electrical characteristics required, it shall not be used. This means anything that is buried or not accessible should meet the applicable requirements of IEC 62561. Where there are natural components in use, the ACLENet point-of-contact for the school will be requested to periodically provide photographs of the material as a gauge to see how it is aging. When necessary, electrical testing may be required and a member of ACLENet will be dispatched to perform the required testing for analysis. To the extent possible, this will be coordinated with the Maintenance and Inspection cycle for the school.

Details of the ACLENet LPS Maintenance and Inspection (M&I) Plan are under consideration, although there is a draft currently available for use. ACLENet's funding, based on donations, has no sponsor to date. By design, the schools are located across Uganda to provide regional models. There are limited numbers of personnel in country qualified to perform the inspections and make the necessary repairs, as well as little material available for the repairs.

Given the restrictions on manpower and hardware, the M&I will be simple and focused on information that is necessary to ascertain the status of the system. The LPS system designs are simple, with consideration given to minimizing the complexity and time required for the inspections. With few exceptions where required by rocks or other impediments, Type B earthing systems are used for each structure. Where there are structures in close proximity, such as classroom blocks and teacher's quarters, the ring earth electrodes are interconnected; increasing the surface area contact with earth and lowering the resistance to earth for the system. It will not be necessary to disconnect each down conductor to perform testing so fewer and quicker tests will be required. As additional inspections are performed, the plan will be improved to be more effective and efficient.

Local representatives at the school will serve as ACLENet's eyes on the ground. The goal is to have a person at each school to monitor the status of the lightning protection systems and notify ACLENet at least bimonthly if any damage is noted or if the system looks different. If so, pictures and any supporting material will be sent to ACLENet for review and any necessary action by the LPWG.

D. ACLENet Technical Advisory Group

Section II describes the origin and makeup of the LPWG. Not all of the members support the day-to-day efforts of the group, nor do they all attend the weekly meetings. However, they are all valuable members because of the skill set they provide when needed.

The need for an ACLENet Technical Advisory Group (TAG) is currently under discussion. The proposal is that the core of the TAG be a subset of the LPWG populated by South African and United States representatives with membership on IEC TC 81 Working Groups, representatives from the University of Witwatersrand, and technical members of the LPWG that participate in the weekly meetings.

The specific scope of the TAG is still under discussion. ACLENet focuses most of its work in protecting schools in Uganda but its scope is an African Center for Lightning Safety. In addition to Uganda, ACLENet currently has worked or is working with organizations in Kenya, Tanzania, Madagascar, and the Democratic Republic of the Congo. As the jurisdiction for these various applications are not clearly defined and may not exist in some countries, ACLENet may have to act as an Authority Having Jurisdiction (AHJ) to resolve some applications. The ACLENet TAG could provide the technical expertise associated this function, working in conjunction with the Executive Committee.

VII. CONCLUSIONS

In developing countries, it is often necessary to pair lightning safety awareness with protection measures to provide affordable lightning protection. An example is the use of awareness in the context of "When thunder roars, go indoors" to address the threat of lightning coupling to veranda poles. Lightning protection alone cannot eliminate the deaths and injuries seen across rural Africa, but it is an important element to reduce the number of incidents and foster the education of children in Uganda by removing the perception that the school is cursed by the gods.

The risk assessment drivers for the protection of schools in Africa are most often those associated with the risk of a direct strike, especially for the large number of structures that have no incoming lines. However, a review of lightning incident data suggests step and touch potentials resulting from LEMP coupling on conductive items on and inside the structure could be significant causes of injuries and possibly deaths. Additional data should be reviewed, and more detailed reporting should be encouraged in future incident investigations to help assess the specific threat associated with an injury. Consideration can also be made of other measures such as providing insulation on concrete floors to reduce the severity of potential step voltages. Resurfacing a floor can be cost prohibitive for poor rural communities. Andrews [14] has suggested that the use of shoes or flip- flops could provide protection inside structures, depending on the surface resistivity of the floor.

The establishment of an ACLENet Technical Advisory Group would be a step forward in tackling the more complex technical issues that arise, especially where considering implementation of practices that are not well defined by the standards or difficult to implement in developing countries. Specific items mentioned in this paper that could be addressed by the TAG are:

- Review the feasibility of tailoring LPLs for each LPS subsystem (air termination, down conductors, earthing, etc.)
- Review of benefit in shielding effectiveness from reduction of down conductor spacing
- Provide guidance on the implementation of IEC standards where the application is not clearly addressed in the standard
- Generate proposals for revision of standards for developing countries where applicable.

Other conclusions to be considered are:

Cost is a major challenge in providing lightning safe havens at schools in developing countries when trying to meet the letter of the requirements of IEC 62305. The cost of materials certified to IEC 62561 and the logistics of importing the components and transporting them to remote locations where many of the vulnerable schools are located make them much more expensive than industrialized areas.

Data packages for future designs should include details on internal metallic objects onto which inductive coupling of nearby LEMP could produce dangerous voltages. Types of walls, floors and roofs are also important.

A source of funding to support the Maintenance and Inspection program must be developed for the long-term success of the program. Consideration of long-term funding sources for on-going M&I must be addressed.

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