Implementing a Lightning Protection Solution for Multi-Structure Orphanage in Haiti

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***Abstract*—This paper discusses the response of the United States lightning protection industry to a request for help from an orphanage in Haiti that addresses the educational and social needs of the poorest of the poor. The methodology used in this response can be applied to other applications to provide lightning-safe structures protected in accordance with national and/or international lightning protection standards. From the perspective of a developing nation, there is a benefit to working with non-profit organizations involved in lightning safety as they can provide the contacts necessary to properly assess the needs of the organization and implement the solutions required.**

Keywords - lightning, lightning protection, trees, lightning-safe communities, developing nations, personal lightning safety, Haiti

I. Background

In late 2012 St. Helene's Home, a school and orphanage operated by NPH International in the Kenscoff Mountains of Haiti, contacted the Lightning Protection Institute (LPI) seeking advice on protection of the children and property at the orphanage against the damaging effects of lightning [1]. The facility is home to over 400 orphans as well as 30 children and adults with neurological conditions and special needs. Another 350 children from the Kenscoff community attend the onsite schools [2].

Ste. Helen's Home reported that each year they suffer damage to electrical equipment at the site as a result of lightning activity. The operating budget for the orphanage relies primarily on donations and fund raising efforts such as the sale of Christmas cards designed by the children. Funds to replace the damaged equipment is not often available in the budget so replacement of damaged equipment is performed only when absolutely necessary because if the impact on funds available for children's programs.

The request from Ste. Helen's Home was brought to the attention of the NOAA Lightning Safety Awareness Team. Team members from the Lightning Safety Alliance (LSA), a US lightning protection industry group, decided to investigate whether it was feasible to provide some level of support. Through a partnership with LPI and the NOAA Lightning Team, a social media effort was launched and awareness of the opportunity was highlighted at industry conferences and organizational web sites. When leaders in the lightning protection industry began to pledge their support, it became apparent that some level of support could be provided and the Haiti Project Coordination Team was formed. Contact was made with the orphanage and a data package with pictures and additional information was provided for review.

II. Introduction

The site is located approximately 40 kilometers southeast of Port-au-Prince in the Ouest Department of Haiti and sits on the highest point in the Kenscoff Mountains, at an elevation of over 1500 meters. The 13-acre (0.05 km^2) site contains 29 structures including an elementary and secondary school, clinic, nursery, special needs facility, bakery and housing. It is heavily wooded and has an on-site garden to provide fresh vegetables and greens for the children.

Long-term volunteers at Ste. Helen's Home indicate that storms often appear with little warning. Their primary lightning warning technique available is flash-to-bang and reports by volunteers are that they rarely experience more than a 2 second delay between seeing the flash and hearing the thunder. This leaves little time for implementation of lightning safety procedures but establishing a number of lightning safe structures across the campus will help to decrease the vulnerability to storms that appear without notice.

Haiti does not have a national lightning detection network. An estimate of the average flash density at the orphanage was determined by satellite data available from the NASA Lightning Team from various sources. Driscoll [3] provides a map developed from the EOS Optical Transient Detector (OTD) showing total lightning flash density observed by the OTD September 1995-August 1996. The total lightning flash density for Haiti is given as 6 to 15 flashes/km^2/year. The World Lightning Map, based on data collected by NASA's Lightning Imaging Sensor on the Tropical Rainfall Measuring Mission satellite between 1995 and 2002, indicates a lightning flash density of somewhere between 30 and 40 flashes/km^2/year [4]. This tracks with the value of 30.7 flashes/km^2/year reported by Christian [5] for Manzanillo, Cuba. These data include both cloud-cloud and cloud-ground flashes. IEEE Standard 1410-2010 [6] recommends that where satellite observations are used, the lightning ground flash density be assumed to be equal to one-third of the total flash density; resulting in an estimate of 10 to 13 flashes/km^2/year estimated for Ste. Helen' Home.

Damaged equipment identified by the orphanage includes radios, computers, modems, wireless routers, power inverters, dryers, ovens, and. light bulbs. Of greatest concern was recurring damage to the kitchen equipment, which is relied upon daily to feed the children, the loss of charger/inverters and the loss of communication equipment (radios and internet access). There were also reports of strikes to trees in the heavily wooded complex and a report of lightning damage to one of the houses where the children reside.

The remote isolation of the orphanage and minimal operating budget are key contributors to the lightning susceptibility of electrical equipment at Ste. Helen's Home. Haiti's infrastructure has suffered numerous environmental challenges over the last 10 years. This includes frequent hurricanes, including 4 separate storms in 2008 alone. It experienced a magnitude 7.0 and magnitude 6.1 earthquake within a 10-day period in January 2010 with numerous aftershocks in the 5.0 to 5.9 magnitude range. The recovery was hampered by additional damage from Hurricane Tomas in November 2010. The Western Hemisphere's poorest country has struggled to rebuild its infrastructure due to lack of funds for capital investments. The recovery of public utility Electricité d'Haïti (EDH) has been affected by the lack of capital as well as theft of services, which has also hampered the ability to perform necessary system maintenance [7]. Power from EDH is often available for just a few hours a day so it is primarily used to charge batteries, which then power the structures through inverters. The loss of inverters reduces the number of structures that have continuous electrical service. Ste. Helen's Home has two generators which were donated to provide power to critical structures such as the Special Needs Facility, Bakery and Laundry when needed. However, the cost of gasoline and diesel fuel prohibits the use of the generators except where necessary. A patron of the orphanage donates a finite amount of gasoline that must last the orphanage the entire year. The diesel generator and a larger, less efficient gasoline generator are generally not used due to lack of fuel.

III. Implementation

A. *Assessment*

The initial phase of the effort was to review an information provided by the orphanage and assess what level of support could be provided. Much of the literature on lightning safety schemes for low-income and developing nations has focused on the lack of awareness and lack of lightning-safe structures in which to take refuge [8-11]. This was also the case in the Haiti application. Gomes, Ab Kadir, and Cooper [8] suggest that one of the main reasons for failure in promoting lightning safety in developing countries is the impracticality of many recommendations given in lightning protection standards originally formulated in developed countries. The Haiti Project Coordination Team sought to address this failure mode by involving accredited lightning protection system designers and installers.

The Haiti Project Coordination Team consulted with Ste. Helen's Home staff to establish priorities for the effort. It was agreed that the establishment of lightning-safe locations for the children of the orphanage was a priority but the operating budget would not allow the orphanage to continually lose critical assets. A reduction of losses of electrical resources associated with lightning activity at the site was also assigned a high priority. The installation of lightning protection systems in accordance with national and international lightning protection systems for priority structures would address both goals.

After a thorough review of the data packages provided and additional discussions with the orphanage, it was decided that an advance team should be dispatched to Haiti to properly assess the level of effort that would be required to mitigate the threats. From this, an estimated level of effort and the logistics associated with getting people, tools, and material to the site could be developed. The advance team met with the staff of the orphanage to discuss specific problems encountered, to identify priority structures, and to get a better idea of the layout and function of the campus. They also performed measurements and provided documentation required to complete a design of lightning protection systems, including earth resistivity testing to determine any restrictions on earth electrodes used at the site. The team spent 2 days on-site and one member spent a third day to try to sort out the power distribution system at the site and assess what improvements could be made during the installation phase.

Given an estimated ground flash density for the site of 15 flashes/km^2/year and the area of the campus to be 0.05 km^2, the estimated number of ground flashes to the campus is calculated to be 0.8 each year. It was clear that the installation of proper earthing arrangements and surge protection would be necessary to resolve the critical losses of electrical equipment and services and the anecdotal evidence discussed in the Introduction suggests that the threat against direct strikes presents a real risk. Considering the above information, it was determined that a formal risk assessment in accordance with IEC 62305-2 [22] for the entire campus would not be cost effective. A risk assessment is not required to define design parameters when using NFPA 780 [12] as the primary design standard. It was agreed that the design could be supplemented by IEC 62305-3 [13] where justified to minimize resources required and make use of natural components available on the structures. The decision was reinforced by the fact that the Installation Team is composed primarily of members of the lightning protection community in the United States and they are most familiar with such designs.

B. *Design*

Based on the information gathered by the advance team, a lightning protection system (LPS) for each structure was designed. The NFPA 780-based design is similar in many aspects to a LPS Class III design as described in IEC 62305-3.

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The protected volume of the air termination devices are based on a rolling sphere radius of 45 meters (150 feet) but there are some differences in the definition of the protection angle. The protection angle in IEC 62305-3 varies based on height while NFPA 780 allows a 60-degree angle for heights up to 7.6 meters (25 ft) and 45-degrees from 7.6 to 15 meter heights. There are also slight differences in the thickness required for natural air-termination requirements but all natural air-termination components used in the Haiti project met both standards.

Most of the structures are of steel reinforced concrete construction but there is no documentation to confirm that the reinforcing steel is electrically continuous and there is minimal to no access to the reinforcing steel at the earth level. For this reason, lightning protection system designs incorporate “made” down conductors.

The design of the earth termination system for the structures meets the requirements of a Type A arrangement of vertical electrodes in accordance with IEC 62305-3, 5.4.2.1. A 16 mm diameter by 3-meter long copper-clad steel ground rod is installed at the base of each down conductor. Equipotential bonding is installed as applicable. Surge protection and power panel grounding was provided on electrical service entry for 23 of the structures, all inverter sites, and all switch houses.

Fig. 1 provides an example structure to discuss a typical design. The roofs of most structures are accessible for normal human traffic. All water used at the site is captured from rain water or trucked up the mountain from Port au Prince. For this reason, most of the structures contain at least one rain barrel such as the one seen on the right rear of the roof. To minimize the amount of material required to be transported to the site, maximum use of natural air-termination components is used. In this example, the hand rails around the perimeter of the roof served as the perimeter air-termination, supplemented by an air terminal mounted on the hand rail at the right-front electrical box and at the water barrel to provide a protected zone for these elements not protected by the hand rails. Steel reinforcing bars protrude through numerous roofs. The individual reinforcing bars are interconnected and tied into roof system to also serve as natural air-termination components.

C. Logistics

Once the designs were complete, a materials list was developed. It was also necessary to identify all tools needed to complete the installation since every tool and component used would have to be shipped to the site. An estimate of the number of man-hours required to implement the plan was also developed, taking into consideration that most of the labor saving conveniences would not be available.

At this time the scope of the required support was established and a call went out to the industry to assess the level of available support. It was thus determined that the project should aim to provide protection for all of the structures identified instead of the few priority structures previously thought.

The logistics of getting the hardware and tools on the mountain were eased by the location of an NPH affiliate Friends of the Orphans in Miami, FL. In order to expedite the hardware and tools through Haitian customs, humanitarian aid (such as medicine, clothing, etc.) was included in the shipment. The shipment included 4156 kg of material and tools, including 100 ground rods, 235 air terminals, and over 2.7 km of cable. Two surge protection manufacturers donated the 28 SPDs required to implement the designs. Total transit time for the staging and shipping of the required supplies was just under four months.

D. Installation

In order to provide protection for all of the structures identified by the orphanage, it was determined that a team of 10 volunteer installers was needed. The team consisted of lightning protection system installers from across the United States, two of whom were licensed electricians to address the grounding and surge protection issues noted by the advance team. A briefing to address the LPS design and electrical system improvement issues was provided to the installation team prior to departure for Haiti. The briefing identified logistics for the trip, made sure the installation team was aware of the priorities and answered team member’s questions about their mission.

Once in country, the installation team was met by representatives of Ste. Helen’s Home at the Port-au-Prince airport and taken to the site. Upon arrival, they unpacked the crates shipped to the orphanage and pre-staged tools and materials. In the following 4 days, 26 structures were provided with a lightning protection system, inverter sites were provided with proper grounding and surge protection and equipotential bonding was provided for incoming lines to each protected structure. From the time of inception of the Building Lightning Safe Communities – Haiti Project to the completion of the installation was 2.5 years.

Fig. 2 and Fig.3 show examples of the installation of roof-top lightning protection and earth electrodes employed at the orphanage.

Figure 1. St. Helene’s Home Bakery

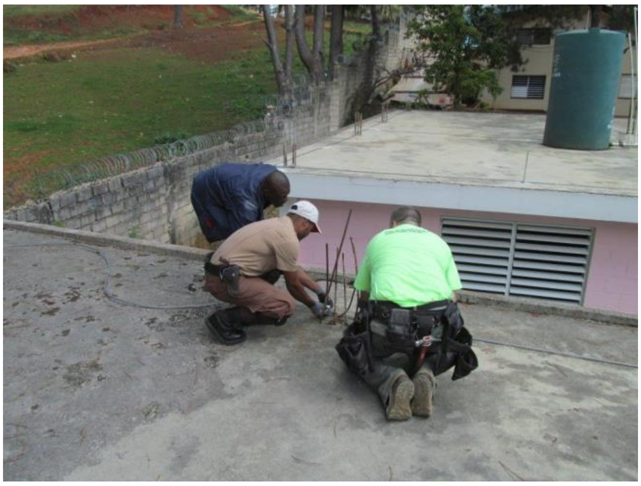

Figure 2. Installers making interconnection with reinforcing steel for use as air termination with completed structure in background

IV. DISCUSSION

The St. Helene's Home Installation Project provides an example of how lightning safety programs can be implemented in developing countries on a large scale while respecting the requirements of national and international lightning protection standards. It is suggested that this model could be adopted to provide lightning safe locations in rural communities and developing nations as long as there is a local contact to provide logistics support.

The model could also be applied to locations where substandard construction makes the installation of standards-compliant systems impractical, impossible, or cost-prohibitive as long as one key substantial structure (or two depending upon the population of the community) can be identified. These could be equipped with an LPS meeting national or international standards and designated as a "lightning safe structure." Of course, this would also have to be supplemented by lightning safety awareness education.

Each application will present a unique set of problems to be resolved. In the case of St. Helene's Home, financial support was provided wholly within the US lightning protection community but the social media effort at the start of the program identified a number of organizations that offered funding, services, logistics or other types of support. These sources may be revisited as follow-up efforts are considered.

While the program to date has satisfied the initial priorities of providing lightning safe locations for the children at school and at home, as well as protecting critical assets such as the bakery, laundry, clinic, and special needs facility; there are some additional steps under consideration. These are addressed in Section V. Among these are a lightning safety awareness program for the children (and staff) to ensure they are aware of how and when to use the lightning-safe structures.

V. FOLLOW-UP EFFORTS

A. Trees

An additional item for follow-up consideration is the threat presented by the numerous trees at the site. These trees present a hazard to the children that may be playing outside at the approach of a thunderstorm. There is currently no organized method to warn the children to seek shelter when lightning may be imminent. As identified in Section II, the only method used by the orphanage to track a storm is flash-to-bang and this warning often provides a first warning when the strike location is as near as 0.6 km away. The threat presented by a tree is typically limited to sideflash, touch and step potentials, as well as the damaging effects associated with projectiles from some trees being struck [14-15]. However, at St. Helene's Home electrical distribution wiring is strung through the trees in some locations, which could further complicate the problem.

NOAA reported 26 lightning-related fatalities in the United States in 2015 and 8 of 26 (31%) were characterized as under or near tree [16]. Holle [17] reports that people aged between 11 and 20 are the most frequent casualties around trees in both the US and non-US areas. The risk of a lightning related event is enhanced at the orphanage by the density of population at the orphanage, the density of the trees, the exposure of the site atop the mountain, and the amount of time spent outside playing with friends (see Fig. 4 and Fig. 5 for examples of forestation at the site). Roeder [18] reports on an analysis using a model considering the lightning casualty mechanisms associated with exposure in an open field with a similar model associated with exposure in a dense forest and concluded that exposure in a wide flat field is slightly safer than a large dense forest. While the difference is not statistically significant, it suggests that the heavily treed orphanage should not be considered to be safer than if it were a large open field at the top of the mountain.

Figure 3. Earthing electrode showing aluminum to copper transition at down conductor

Figure 4. Installation of air terminal base on parapet wall on primary school

The above discussion would suggest the protection of the trees should be considered. However, this could be much more problematic than the protection of a structure. There are a small number of LPS installation professionals that specialize in protection of trees in the US. Most such installations are performed by arborists. The typical technique for protection of a tree is given in NFPA 780 [12], Annex F and ANSI A300 Part 4 [19]. Protection of trees is generally expensive, time consuming and require non-standard tooling. ANSI A300 explicitly states that tree lightning protection systems are intended to safeguard trees against damage caused by lightning and do not provide safe havens from lightning.

Meilleur [20] indicates the results of a 33-year study at the University of Pennsylvania concluded that the protective zone of a lightning protection system for a tree was less than 20 meters. It is concluded that it would not be practical to protect a sufficient number of trees to have an effect on the safety of the children that may be outside when lightning is in the area. The better solution appears to be the implementation of a lightning safety awareness program that stresses the children go indoors when lightning is in the area.

B. Lightning Safety Awareness Program

The efforts to date have provided lightning-safe structures but have not addressed scenarios to ensure that children are protected against a lightning strike to the many trees on the campus unless they are inside the protected structures. The development of lightning safety awareness information for the staff and children at the orphanage will be one of the follow-up efforts to consider. Lightning safety materials developed by the NOAA Lightning Safety Awareness program as implemented by the Lightning Safety Alliance will be the basis for this educational effort. The safety awareness information will identify the threats presented by the trees and other outdoor areas at the orphanage and propose procedures to mitigate such threats. Many have credited lightning safety awareness programs for the reductions in lightning fatalities in the United States from a 30-year average of 49 deaths per year to a relatively steady rate of 26 deaths per year since 2011 [21] [16].

Simple messaging such as the "When Thunder Roars, Go Indoors" slogan commonly used now in the US along with pictures and games have proven popular means for teaching children lightning safety procedures. The training program should focus on training the staff (train-the-trainer) and the children; and should encourage the incorporation of lightning safety into the school curriculum. Curriculum material can be augmented from time to time through electronic media. Signs identifying individual structures as a "lightning safe" location can provide constant reinforcement of the lightning safety message.

C. Power Distribution System

An additional follow-up effort under consideration is to assess additional reduction of the vulnerability of the electrical equipment at the orphanage. The electrical distribution procedures within the campus incorporates both above ground and buried conductors. The electrical distribution system uses undersized wiring in some cases the routing techniques for the wiring maximizes the susceptibility to electromagnetic coupling. An assessment of the expected effectiveness of the improvements made by the installation team will be conducted to determine whether any addition support is warranted and can be implemented by the support team with available resources. Given that the orphanage owns the distribution wiring within the complex, numerous options such as those given in IEC 62305-4 [23] to reduce the coupling of electromagnetic fields and the magnitude of induced internal surges are available. Possible considerations are replacing existing external wiring consisting of undersized independent wires with sufficiently-sized shielded distribution cable with grounds and/or cleaning up the routing of internal cables to minimize the size of induction loops.

D. Maintenance and Inspection

The final follow-up effort under consideration is to return to the orphanage after a year to conduct a physical inspection and electrical testing of the installations. This will provide some indication of the damage the installations have experienced (either from climatic conditions or physical abuse) and provide a baseline for the development of a maintenance plan for the lightning protection systems. Training of the local electrical team on the basic principles of lightning protection systems will be considered to determine whether they can perform long term maintenance on the systems.

Figure 5. Example of density of trees on campus

From the perspective of the developing nation, there is a benefit to working directly with someone in the industry. The entity seeking assistance will likely not be well versed in lightning susceptibility or have the expertise to identity an appropriate solution to their problem. It is important to establish a dialog and gather information to assess the situation to ensure that any actions taken will resolve the problem. An additional benefit of connecting with experts from the industry, especially a non-profit involved in lightning safety, is direct access to lightning protection system designers and component manufacturers who can potentially negotiate reduced rates for material or possibly donations.

Social media is a valuable tool in gaining support for humanitarian projects. In addition to heightening awareness, social media is inexpensive and efficiently reaches multiple parties. Direct benefits from social media can range from raising funds to providing services and providing equipment that will be required to support the effort. Indirect benefits can include additional donations beyond the scope of the specific request. In this case, donations of appliances, clothing, toys and treats for the children at the orphanage were also obtained and included in the shipment to the site.

There is significant benefit to sending an advance team to assess the scope of the effort. This advance team will generally require more time than is normally allocated to assess a lightning protection project because unknowns will arise regardless of the amount of advance information and preliminary discussions provided. Being on-site allows discovery of unknowns that can be resolved prior to arrival of the installation team, saving time, reducing costs and improving the level of support that can be provided. A lesson learned in this instance is that it would be helpful to provide on-site continuity between the advance/design team and installation team to address any problems or questions that arise. Between the time the advance team was on-site and the installation team was dispatched there was an additional structure added and solar panels were installed on the primary school to assist in their electrical power issues. Neither of these were anticipated nor identified by St. Helene's Home prior to the arrival of the installation team. These issues were able to be addressed by the installation team but greater awareness by each party would reduce the effects of unanticipated surprises.

VI. Summary and Conclusions

This paper demonstrates how a request for help in resolving lightning susceptibility issues in developing countries can be answered. It is also possible to provide solutions that meet national and international standards. An important part of a successful endeavor is to have a local point of contact in the developing nation or rural area to provide support with logistics and to help the responding organization accurately define the specific threat requiring resolution.

The model utilized for this project could be followed to provide similar relief from damaging lightning effects in other lightning vulnerable locations. The key areas of focus include:

- involving industry experts,
- using social media to raise awareness, identify possible funding resources, and build industry support,
- sending an advance team to analyze the situation and design the solution,
- providing an adequate number of trained technicians to complete the required work,
- including a certified designer / inspector with the installation team to provide a lint to the advance team, to address issues that have arisen since the design, and to provide real-time certification so any required changes can be made prior to departure from the site.

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