Need of Low-Cost Lightning Protection Schemes for Small-Scale Applications

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***Abstract*— Designing of lightning protection systems for buildings and many other structures is well-documented in standards, however, the recent studies in Asia and Africa reveal that design and implementation complexities, cost and material theft of these recommended protection systems prevent many building owners, and even government authorities in adopting such systems, especially for small structures. Apart from domestic applications, many outdoor activities such as sports and recreation, mining and construction etc., require either stand-alone protection units or low-cost, easy to implement lightning protection units for temporary shelters, especially in regions with high lightning occurrence density. This paper analyses this issue in detail to find suitable and potential solutions.**

***Index Terms*—lightning protection, structure, low-cost, safety device**

I. Introduction

Although, protection of buildings is well-documented in many international and local standards, a number of factors prevent a sizable percentage of the global community in implementing such systems in small structures, especially in the developing countries, despite the buildings and structures need lightning protection. These factors are the complexities of design and implementation, cost, aesthetic concerns, material theft and some socio-cultural aspects. The need of such protection measures is also felt in outdoor activities such as sports, entertainment and recreation, livestock industry, mining and construction industries, inland fisheries, pilgrimaging and adventure excursions etc. Under such backdrop stand-alone protection units or low-cost, easy to implement lightning protection units for temporary shelters have become essential needs in countries with high lightning occurrence density. The main objective of this paper is to investigate the background for the requirement of such protection systems in realistic situations at present and achieving feasible solutions by following scientifically acceptable methodologies.

II. Need for Feasible Protection Systems

Lightning brings impulsive current from the cloud which has double exponential wave shape at the channel base. The lightning struck object typically experience multiple stroke current pulses of which the first stroke has a peak value of 30 kA on average while subsequent strokes have 50% of that on average. The impulse current most often last for less than about 70 μs [1]. Sometimes the impulse component is followed by a continuing current which has magnitudes in the range of few hundred Amperes and flow for several hundreds of milliseconds [2]. According to the wave profile, the impulse part of the lightning current is categorized into three types; negative first stroke, negative subsequent stroke and positive stroke [1]. Any lightning safety/protection device should be tested for all three types of these lightning currents as they have features unique to each of them.

Since the time of Benjamin Franklin (1706-1790) it has been proposed that a person is safe only inside a sturdily built structure enclosed with a system of metallic strips which has been erroneously referred as a Faraday cage in some literature. The most up-to-date document that comprehensively specifies the design of such protection system is IEC 62305 (2010) [3]. The factors that determine the risk of lightning threats to human beings have broadly been discussed and hypothesized in [4]. The output of research presented in [5] and [6] emphasizes the gravity of lightning risk of public that earn their living by outdoor activities, in low-income societies. Personal communication with Richard Kithil, President, National Lightning Safety Institute, USA reveals that even rich industries such as mining, timber and petrochemical urgently seek suitable protective shelters for their outdoor workers operate in high lightning dense regions. In this backdrop, Gomes et al [7] provided design and implementation techniques of implementing low-cost lightning protection schemes for existing house and boat structures in low-income societies. They also suggested improvement of lightning protection in buildings with reinforced steel structure at a very competitive cost [8].

In the modern times it is not a totally viable recommendation to ask the public to be inside such sturdy protected buildings until a thunderstorm lasts, which may sometimes take 1-2 hours. Many studies conducted in Africa, Asia and Latin America in the recent past reveal that a majority of the public in these parts of the world reside permanently in very unsafe simple structures that may subject the occupants into grave risk of being injured in the event of a lightning strike [6, 9-13].

Work done in Mongolia (paper to be presented at ICLP-2016) reveals that almost 90% of the lightning accidents in the country are pertinent to the cases where victims were at wild areas. These 'wild areas' are referred to grasslands or low grown vegetation in the mountain slopes where shepherds take their livestock for grazing. These landscapes are many hundred hectares in area thus, the workers in the livestock industry that lead the animal have no place to take shelter even if they receive thunderstorm warning well in advance. Similar observations have been made in Uganda, where people in Lake Victoria Basin are compelled to go for fishing even under overcast conditions, due to economic reasons [5]. In the event of an approaching thunderstorm, they are at the mercy of nature as it is almost impossible to abandon their operations abruptly and ride to the shore which may be a couple of hour journey. In such scenario, providing early warning to the boaters may not be as fruitful as one anticipates. Thus, the only option is to give a certain level of protection to their boats at an affordable cost.

Even in developed countries, there are many lightning accidents reported where the victims were campers, golfers, adventure-seekers, boaters etc., who could not access a safe shelter within a reasonable time due to the isolation of their location by the time they have detected the thunderstorm [14, 15].

III. INFORMATION ON ATTEMPTS MADE SO FAR

The above background demands for more feasible and practical solutions to address this issue, rather than demanding the public to seek shelter in sturdy structures whenever there is a thunderstorm in the vicinity. As a remedy to that Wiesinger [16], Darveniza et al. [17] and Darveniza [18], developed concepts of portable lightning safety devices, few of which have been tested under laboratory conditions. However, lack of theoretical approach / testing with different human body models and the consequent retirement of the sole project leader from active research prevented the device being developed to a level of wide scientific acceptance. The other attempt on developing such personal protection system has been vaguely revealed by Prof. Liew Ah Choy of National University Singapore in 2009. During an interview with the Star Newspaper [19], he mentioned that plans are underway to develop a fabric by which lightning current could safely be dissipated into ground when a person or group of people is covered with that. However, no further information on this device is available in the public domain so far.

The concept of personal lightning safety proposed by Darveniza [17] was re-taken for research in 2010/11 as an undergraduate level engineering project at Universiti Putra Malaysia [20] which was completed successfully. The project produced a lightning safety structure which has been theoretically tested for its safe handling of lightning currents. However, the device needed much extensive detailing of electrical, mechanical and thermal behavior under the injection of all possible types of lightning currents (varying their rise time, amplitude and energy content) under model simulation and then validation under HV conditions to re-confirm the acclaimed performance before being recommended for public use.

The research conducted by Mary and Gomes [5, 10] in Africa, Doljinsuren and Gomes [9] in Mongolia, Jayaratne and Gomes [21] in South Asia reveals that in under-privileged societies protection schemes for small structures are more appropriate than personal lightning protection devices due to the high cost per capita that will be incurred in developing such devices. Furthermore, the observations done in South Africa [22] and USA [23, 24] reveal that in the recreational sector, too, protective structures for small groups or protection schemes for already built small structures are more useful due to the burden that recreationalists encounter in carrying personal protective devices and setting them up in a hurry.

IV. INTO THE FUTURE

It should be emphasized that the concept of protection systems to small-structures is based on the fact that the sole objective of the design is to safeguard human or/and animal life. Thus apart from structural damage that may directly affect the human/animal safety (burning or exploding of materials, detachment of heavy structural parts and falling down), the design does not address property damage such as destruction of electronics, data losses and signal corruption etc.

It is noteworthy to give a concise description of the modes of injuries due to lightning to understand the minimum requirement of a protection system to be designed.

To be injured due to lightning one may not essentially encounter a direct lightning strike. Even if the person is in the vicinity of the point of strike he could receive lethal injuries or temporary disabilities that intern may cause even death. Lightning may injure or kill a living being, basically in several primary and secondary mechanisms [25-27].

a. Direct strikes: A person in open field and keeping himself as a high protrusion in the vicinity may be the subject of a direct lightning strike if the answering leader from the person meets lightning stepped leader.

b. Side flashes: A close to a tall object may receive a side flash if the object is hit by lightning. In such case the entire lightning current or a part of it may pass through the victim's body.

c. Step potential: When the feet of a person are separated in the direction of increasing potential, a partial current may pass through the body due to the injection of current into earth from a nearby lightning strike.

d. Touch potential: A partial current may pass through the body of a person, if a part of body comes in contact with a higher elevation of the lightning struck object while the other part remains in contact with ground.

e. Upward Streamers: As the lightning stepped leader reaches ground from the cloud, typically carrying negative charge, it creates an intensive electric field in the vicinity. Hence, many objects in the surrounding starts sending oppositely charged streamers towards the stepped leader. Once one of those answering leaders is successful in meeting the stepped leader, the others vanish. These answering leaders give rise to a small current through the body of the objects that send them. Such current may most often paralyze the person; however, depending on the heart cycle that it passes through, even serious injuries or cardiac failure may result.

f. Proximity to the strike: The shock wave generated by lightning channel due to sudden expansion of air may damage the skin or ear drums when the person is very close to the point of strikes. Furthermore the intense light may cause vision imparity of animals close by.

g. Secondary effects: Falling from higher elevations due to momentary shock, falling of heavy materials from structures (detached due to lightning strike), falling of tree branches and missiling of split-fractions of lightning struck trees, burns and choking hazards due to volatile materials in the surrounding catching fire, shockwave from exploding substances and psychological trauma.

The protection system developed should address each of these mechanisms of injuries to ensure the safety of the protection seeker. The other essential criterion is that the total cost of the system (material, construction, implementation and maintenance) should be well affordable to the target group.

The next step is to streamline the research and feasibility questions to address the major issues as follows

a. In the event of various types of lightning currents injected into a conducting structure that stands alone or encloses a given small building what would be the voltage and current distribution, mechanical stresses and thermal effects in the environment?

b. How can we optimize design parameters and materials of the structure to bring the possibilities of side flashing, step and touch potential, dangerous temperature increments and melting of materials, mechanical instability and failures in the event of a lightning current injection, down to negligibly small levels?

c. Can these optimized designs be re-validated under laboratory conditions (High Voltage/current impulses) and further developed to a level that the schemes can be commercialized?

d. Will the commercialized products be affordable to the target groups; feasible to be implemented in the target fields/areas; durable and reliable under specified weather conditions?

The protection schemes for small structures may have a wide spectrum due to the divergent nature of applicable scenarios. For examples; a domestic house in steppe climate (such as ‘ger’ in Mongolia) may be quite different from thatched-roofed, clay-walled houses in Africa. Protection of both are different from that of fishing boats in inland lakes. Therefore, a single research team better not attempt to address a wide range of structures as the availability of time, physical resources and man-power may be an uphill challenge. Instead, it is advisable to select one or few structures and develop the system for such.

Once the specific targets are decided the next phase is to define the research methodology. The following procedures are proposed for a methodical implementation.

a. Select a certain target group and application scenario for which the protection system should be designed. For an example, a small protective cabin in the field for mine workers in a n isolated place.

b. Design a suitable protection module based on prior knowledge.

c. Determine by means of a suitable EM computational software, the current and potential distribution of the module, during the interception, passage-through and ground dispersion of lightning current.

d. Based on the software design, determine the best design parameters and materials of the module that provides the voltage and current distributions which satisfy the pre-determined thresholds in preventing side flashes, touch and step potentials, excessive heat dissipation and magnetic forces.

e. After obtaining acceptable level of protection against lightning effects, optimize the selected structure for other concerns such as; low-cost implementation, easy- handling, lightweight, portability, mechanical and thermal stability, structural durability and appearance.

f. Construct the optimized structure and subject it to high voltage laboratory testing, mechanical stability and physical durability testing, thermal performance and weather resistance.

g. Further testing under the application of triggered lightning may definitely boost the confidence of the potential end users.

The most significant difference between a standard lightning protection system and those designed for small structures and portable applications (discussed in this study) is the complexity of grounding system. The standard lightning protection system is meant to

intercept with stepped leader without letting it attached to a point in the original structure,

carry the current to the ground level without letting potential gradient or heat generation reaching dangerous levels and

dissipate the excessive charge into earth safely and quickly without letting dangerous step potentials or arcing taking place.

The structures discussed is this study (both external protection systems for small structures and standalone protection structures with portability) may not have a comprehensive earthing component due to both economic and strategic limitations. Instead the system is designed to have equipotential (or nearly equal potential) within the structure, thus it may be called a “Faraday cage at transient stage”. In the absence of an earthing system (or a comprehensive eathing system), large step potentials and surface arcing may take place outside the structure, therefore, the protection is meant only for those who are inside the protective system. Triggered lightning experiments [1] have shown that dangerous potential gradients may develop and arcing may extend up to tens of meters from the strike point. Thus, the product may carry this instruction and warn the positioning of the structure well away from the possible human movement or sores of inflammable/explosive material.

On the other hand in the case of lightning protection system for fixed small structures, at least a single deep driven electrode can be provided to minimize such dangerous situations in the external space. At regular visiting sites (grasslands, hiking and camping sites, construction sites etc.) permanent grounding systems could be implemented with easily reachable earth connection leads.

The next challenge is to promote such structures in the communities that require lightning protection. This phase of a project on lightning protection system for small structures requires much more rigorous strategic planning than the others. The structural design needs final appearance appealing to the socio-cultural norms of the society. For an example in some communities in the Indian sub-continent, certain shapes symbolize bad omens and some symbolize good luck. The designer should be sensitive to such ideologies of the target group. The placement of the structure should always be of concern as the community may opt for convenience rather than protection. As per the personal communication with a team of non-governmental organization revealed the following situation. The NGO has constructed a small concrete structure with lightning protection system for a community in South Asia that has reported several lightning accidents during a few year period. As all accidents of this fisheries industry based community have been reported as happened in river banks the structure has been constructed at a site about 300 meters from one of the accident-prone river bank location. However, as yet another accident has been reported, a team from the NGO has visited the village to investigate the situation. They have found that the community thinks that it is too far to walk into this structure, abandoning their work as a thunderstorm approach. Thus, the structure has been converted to a dried fish storage.

The cost of the system is also of major concern. In most cases of under-privileged rural communities, a government or charity organizations may purchase the systems for the people. In such cases, almost buy-and-install type end product is preferred due to a possible large number of items being acquired. If the target group has the buying power up to some extent would be more appropriate to let the owner do fixing at a reduced cost for the component (compared to the finished product). In industrial cases such as mining, building and highway construction, entertainment and recreational industry etc., the coast may not be a major concern. Thus the quality of the product could be enhanced.

The easy-to-understand written guidelines are also a compulsory item to be included in the product. As the system has to ensure the safety of both users and non-users, the warning signs (such as not to stay close to the structure from outside under thunderstorm conditions) should be embedded in the structure itself. Periodic demonstrations by either manufacturer or a third party on safe usage of the structures are also recommended and encouraged.

V. Conclusions

This paper discusses the need for lightning protection systems for small structures and the way forward for the design, testing and implementation of such systems. The paper also emphasizes the requirements to be fulfilled by both designers and manufactures to ensure the safety and socio-economic acceptance. The need for such structures is enormous, however, the challenges and barriers in making such a venture successful in both business and social welfare points of view are also colossal. A well planned and strategized, collective effort is required from scientists, business community and governmental / non-governmental sectors in making the objectives of such a project reaching planned milestones and goals.

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