Risk Assessment of Buildings due to Lightning Impulses: A Case Study at College of Science and Technology

Namgay Tenzin

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Abstract

Lightning Impulse protection has become important aspect of any electrical installation due to its destructive impacts. Due to changing weather patterns the intensity of lightning has been increasing over the years. The impacts due to lightning impulses usually in domestic installations are destructive and often the electrical supply lines are damaged with service interruptions. College of Science and Technology (CST), is located at foothills of the Himalayas with sub-tropical climate and it experiences minimum of 12-16 lightning events per square kilometers per year. Therefore, the region experiences severe lightning events especially in the late spring, summer and early autumn seasons. In this research a risk assessment of building electrical installations is being analyzed to manage and mitigate the impacts due to lightning impulses by using IEEE 62305 standard to evaluate the risks. The risk assessment for case study location at College of Science and Technology, shows that the earth resistance is beyond the permissible limit as per national and international standards and lightning protection systems are being proposed at various locations in the campus. The current study does not include all the buildings of the CST campus but only selected buildings are assessed for impacts due to lightning impulses.

Key words – *Lightning Impulse, Lightning Protection System, risk assessment*

Introduction

The phenomenon of lightning is a natural event and the density and intensity of lightning is not uniformly distributed around the world. Lightning waveforms are short time impulses with very high magnitudes of millions of volts and temperatures 53,500 °F (Holle & Zhang, 2017). Globally, literature reveals that there was around 2 billion lighting strikes in 2021 and there are reports of numerous damages to human livelihood and loss of property due to it (Vaisala, 2021). The insurance claim in United States of America in the first quarter of 2017 was $5.7 Billion from disasters related to lightning alone (Maryville, 2019), which was highest in USA till that time. Therefore, lightning has become one of the natural hazards around the world. The World Meteorological Organization reports that due to the change in weather patterns and extreme weather events, the occurrence of lightning is increasing over the years. For instance, in India there was an increase of about 34% in lightning strikes in 2020-2021 compared to that of 2019-2020 (LRIC, 2022).

Bhutan is a landlocked country which experiences many natural hazards including lightning. Although the literature on impact of lightning is scarce for Bhutan, it has been reported that lightning has been recognized as one of the natural disasters in Bhutan. It has been reported that, due to lightning a 9 year old boy was electrocuted in Dagana (Delma, 2018), and 5 cows were killed by lightning in 2020 and for a rural households in Bhutan where people are dependent on the agriculture and livestock for livelihood the losses are immeasurable (Rai, 2021). The frequency of lighting and density also differs around the country with southern parts of the country receiving more lightning strokes per year compared to other parts of the world as shown in Figure 1.

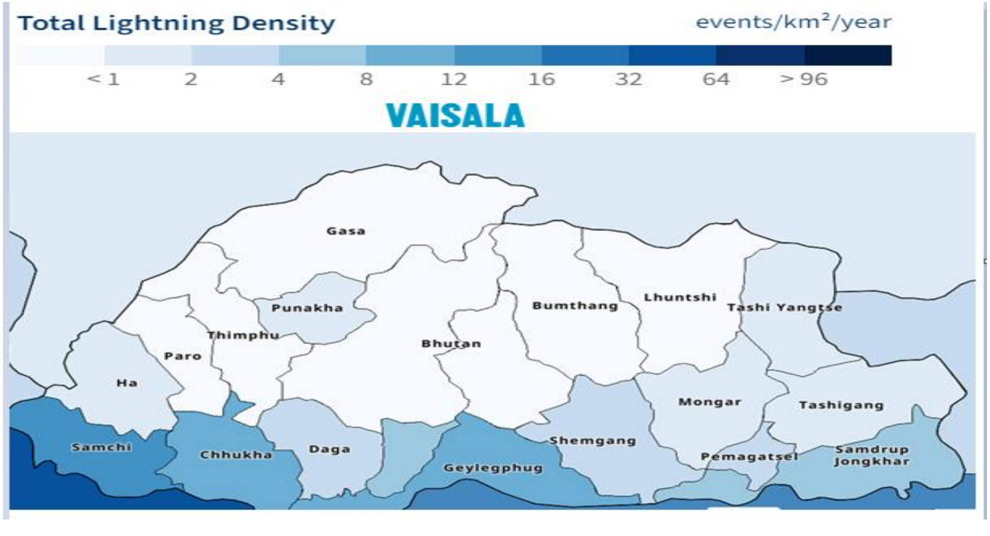

Fig 1. *Total Lighting Density for Bhutan (Vaisala, 2022)*.

The literature reveals that for distribution system of voltage less than 1000 volts the grounding resistance should be less than 4 Ω to safely discharge the energy from lighting impulses (Sestasombut & Ngaopitakkul, 2021) and most of the standards (International Electrotechnical Commission., 2010a) and (BIS, 2006) recommend ground resistance of less than 5 Ω. The impacts of lightning depends upon the type of lightning waveform, type of materials used in electrical installation and topographical features of the area (Sestasombut & Ngaopitakkul, 2021). The effect of lightning on concrete buildings considering risk to human life by (Kasza & Kovacs, 2019) showed that both direct and indirect lightning waves have impact on the human life as well as loss of economy. The research suggests installing LPS systems for protection against direct lightning and using surge protective devices for indirect waves (Yutthagowith et al., 2021). The cases of damage to electrical and electronic equipment have been increasing over the years especially due to sensitive nature of the devices and increased incidences of secondary lightning impulse waves (FPA, 2021).

College of Science and Technology is located in Chukha, one of the southern districts of Bhutan, and it receives about 14.5 lightning events/km2/year as per Figure 1. The impact of lightning on the physical infrastructure has been increasing over the years. The incidents of increasing number of network switches getting burned due to lightning has been observed. In 2019 to 2021 alone, 20 numbers of network switches for internet connectivity were damaged. There has been damage to inverter of roof top solar photovoltaic system, where in spite of numerous air termination units, surge protective devices the inverter switch was damaged in 2019. In Bhutan all the building drawings are approved by relevant authorities including electrical designs as per Bhutan Building Regulations 2018 and Specification of Electrical Works 2022 of Ministry of Works and Human Settlement, Royal Government of Bhutan.

Although the building designs have been prepared as per the existing regulations, accidents due to lightning impulses continues to occur at CST. Therefore, this paper envisages to study the gap identified using case study as a method of study. The study will address the root causes of the accidents and remedial measures that may be adopted to prevent hazards due to lightning impulses in buildings.

Methodology

The aim of the study is to find the root causes of the damage due to lightning impulses and to suggest the remedial measures. The objectives of the study are to study the current practice of designing lightning protection and earthing systems, review the existing guidelines, risk assessment due to lightning and propose remedial measures according to standards and internationally accepted best practices.

The study was implemented in three steps: 1) Review on the current Lightning Protection System Design and Relevant Standards, the LPS design methods, and existing guidelines. The threats to the building were then identified and risk score was being assigned according to IEC standard IEC 62305-2 Protection against lightning. 2) Risk management (International Electrotechnical Commission., 2010a) followed by data collection on earthing resistance, LPS system installed in the CST campus and development of risk matrix. 3) Risk assessment due to lightning impulse as per IEC62305-2 and proposed remedial measures. The study also reviewed the existing regulations and made critical comments. Figure 2 illustrates the methodology used for the study.

Results and Observations

a) Identification of Risks and Threats

The density of lightning and intensity is not uniform, it varies throughout the region with varying severity and impacts. The identification of risks and threats, and assignment of risk score is carried out as per IEC 62305-2. For assessment of risks, a probability-based method where damage due to lightning strokes are being calculated. The lightning risk is based on the lightning density of the selected area (Ng). Danger for people (h), Occupancy coefficient of structure (Lf1), Relative location of site (Cd), Fire Risk (rf), Associated services (Lf2), Electrical Lines (Ai), Lightning Protection Level (Pd), Surge Arrestor (Pi) and dimensions of installation are considered as potential risks as per IEC 62305-2.

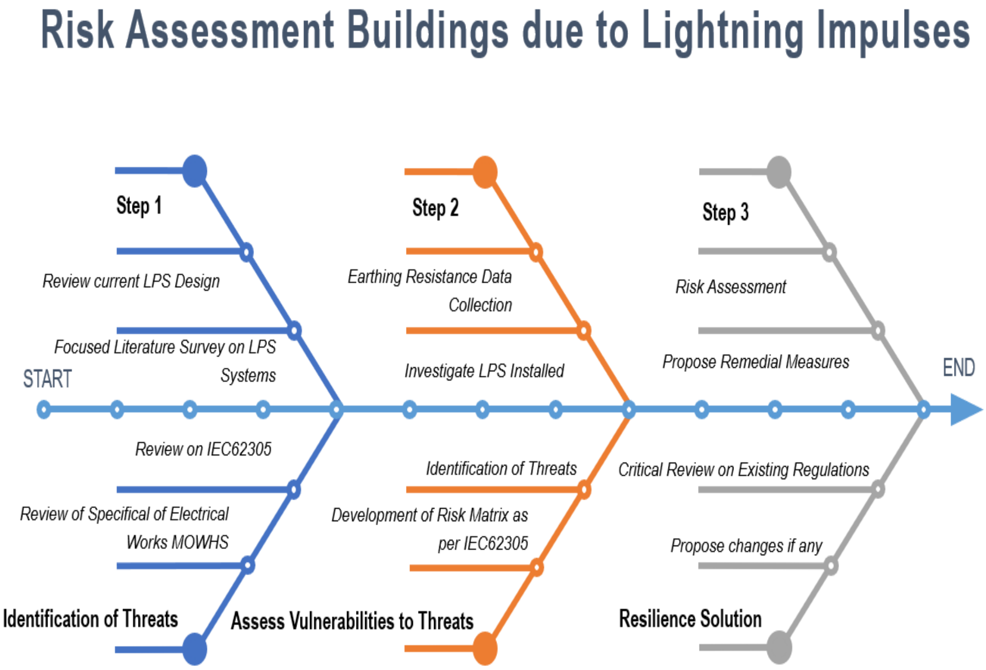

***Fig 2**. Schematic Methodology Used for Study.*

The risk score for Danger to People ranges from 1 to 50; 1 being no danger and 50 for dangers resulting in contamination of environment and for occupancy coefficient it is either 0.1 for structure unoccupied or 0.01 for occupied structure. The risk factor for relative location of site with nearby trees or objects ranges from 0.025 to 2 and fire risk factor which determines the presence of inflammable materials in the building ranges from 0.001 to 1. The risk factor on associated services due to lightning on other services like TV, Gas, Internet, water etc. ranges from 0 to 0.1. The presence of electrical lines increases the probability of building being exposed to lightning; whereby the risk score varies from 0 to 14400. Similarly, the installation of lightning protection system and surge arrestors are also taken into account as per IEC 62305-2. Detailed risk scores with description are given in the appendix.

The tolerable risks are then computed to assess risk to human life, services and cultural heritage shown in Table 1

Table 1 *Tolerable Risks as per IEC62305-2.*

Sr.		Type of Loss	Tolerable Risk
1	RT1	Loss of human life	10^{-5} Risk of 1 in 100,000
2	RT2	Loss of service to public	10^{-3} Risk of 1 in 1,000
3	RT3	Loss of cultural Heritage	10^{-3} Risk of 1 in 1,000

The specification of electrical works 2022 (MOWHS, 2022) outlines that there should be adequate protection in terms of lightning protection systems installed along with proper earth termination units. The guideline mentions that the earthing resistance should be less than 5 Ω and should not exceed 10 Ω. The same is being reflected in IEC 62305 and IS 3043.

b) Data Collection and Field Observations

The study focused on the impact of lightning on the buildings. Therefore, residential units, academic blocks and student hostel areas were included in this research. From the preliminary data collection, it was observed that at CST, network switches were frequently damaged by the lightning, where a total of 22 network switches were damaged in 2019-2021. The location of the damaged switches is depicted in Figure 3. A surge protective device installed on a rooftop solar photovoltaic system on the roof of library building was also destroyed in 2019 which is shown in Figure 4. In June 2022, a sub main distribution board was damaged and control gear (RCCB) was burned beyond recognition due to lightning impulse, which is shown in Figure 5.

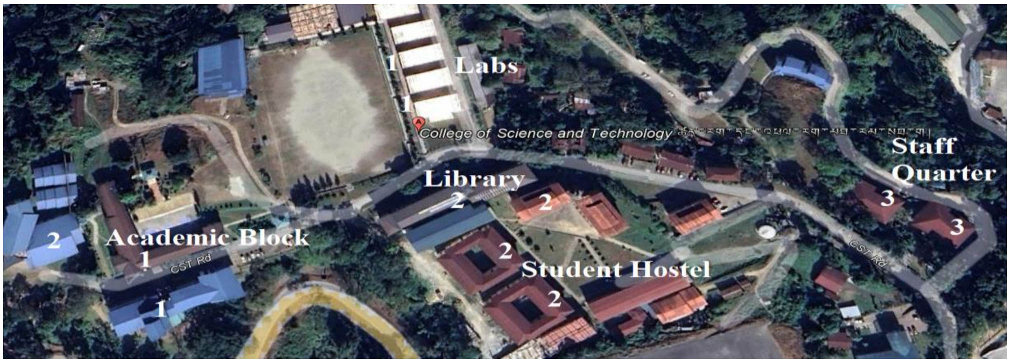

Fig 3. *Location and Network Switches Damaged by Lightning Impulse.*

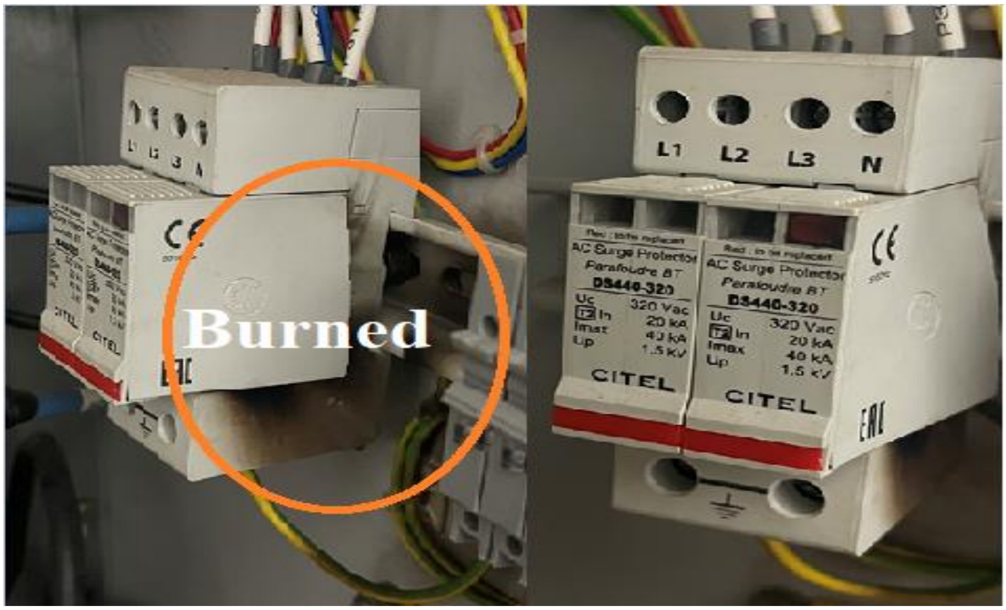

Fig 4. *Surge Protective Device Burned due to Lightning Impulse.*

Fig 5. *SMDB Burned due to Lightning Impulse.*

The lightning protection system installed in the buildings indicated that most of the buildings either do not have LPS system installed or if it is present, it is not connected to the earth pit. Table 2 gives the details of the LPS systems installed as shown below

***Table 2**. LPS Installed in selected Buildings of CST.*

Sl.No	Building	LPS System Installed	Remarks
1.	Library Building	Air Termination Unit (LA)	4 LA's Installed
2.	RK Hostel	No LPS	Height of RK is higher than Library Building
3.	Staff Quarter Block A & B	Air Termination Unit (LA)	One in each (Block B, LA has fallen on the roof)
4.	IT Building	NO LPS	
5.	Student Hostel Block D	Air Termination Unit (LA)	No down conductors

***Fig 6.** Earth Resistance Value (in Ohms) of Different Buildings at CST.*

The earth resistance was surveyed using four pin Weener Method and 3 pin fall of potential method. Figure 6 describes the earth resistance of various buildings in CST campus. The measurements were noted in October 2021.

Table 3. Risk Assessment as per IEC 62305-2.

Sl.No	Building	Risk to Human Loss	Risk of Loss of Service
1.	Library Building	Not Acceptable	Acceptable
2.	RK Hostel	Not Acceptable	Not Acceptable
3.	Staff Quarter Block A & B	Not Acceptable	Acceptable
4.	IT Building	Not Acceptable	Acceptable
5.	Student Hostel Block D	Not Acceptable	Not Acceptable

***Fig 7**. Measurement of Earth Resistance.*

c) Risk Assessment

The risk assessment of selected buildings was carried out as per IEC 62305 -2 which is presented in Table 3. The lightning density was taken as 14 as derived from Figure 1. The risk assessment methodology is illustrated in Fig 9. The threats to the structure are being identified along with losses to human, services and economy. For each type of loss, risk assessments are made using risk score matrix, followed by evaluation of risk tolerance. Based on the risk tolerance the need for LPS, SPDs and other protection measures are analyzed.

In most of the buildings the air termination units in the form of lightning arrestors are being installed but many does not have down conductors, thereby, rendering the LA useless (Fig.8). The buildings under study had LAs installed except for IT building and RK building. Some observations made during the field survey were incorrect operation of control gears. It was observed that in the main distribution board of Administrative Building where SMDB was damaged, the Molded Case Circuit Breaker (MCCB) lever was not discharged properly, meaning the lever was in the middle which meant that the circuit was not interrupted. This might have resulted in continuous flow of current in the circuit. It was also observed that the SMDBs in that very building lacked TPN MCBs for secondary isolation. Generally, each SMDB is controlled by TPN MCB and RCCB.

Fig 8. (a) Missing Down Conductors. (b). LA installed.

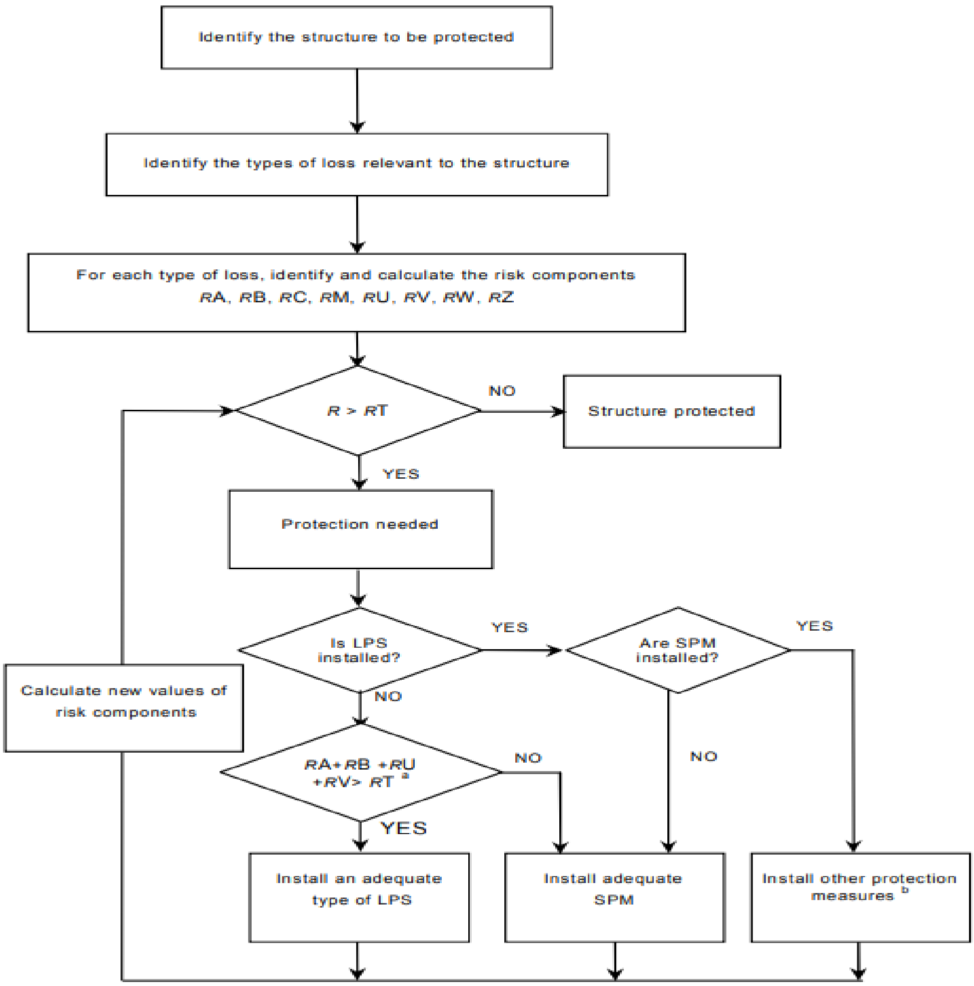

Fig 9. *Risk Assessment Flow Chart (International Electrotechnical Commission., 2010a).*

d) Discussion

The risk assessment of building to human loss and services reveals that current LPS system installation is not adequate. There are numerous methods of LPS proposed, namely, rolling sphere method which is applicable in all setups, protection angle method which is simple in application and mesh method (International Electrotechnical Commission., 2010). In most of the buildings considered in our study, simple air termination unit based on protection angle method has been implemented.

It was observed that, at numerous locations including Staff Quarter B, Lightning Arrestor (LA) is not fixed properly, at Academic Block, LA is missing down conductors, and similar incidents are observed throughout the CST campus. In order to safely discharge the energy content in lightning impulse standards; IEC 62305 and IS 3043; specification of electrical works by DES, MoWHS, the recommended ground or earth resistance should be lower than 5 Ω. This is not present at all the measurement sites as per the earth resistance data presented in Figure 5. This might be one of the main causes of the accidents related to the lightning impulses.

The student hostel blocks A and D have LAs installed but down conductors are missing and in RK building there are no LAs being installed. Analyzing the height of different structure nearby, it was observed that RK building was tallest structure in the area. So, there is high probability that lightning would first strike the roof structure of the RK building. Hence, our study necessitates the installation of air termination lightning arrestors in both wings of RK hostels. Similarly, in IT building too, LAs are missing because IT building occupies a sufficient area and there are no tall structures nearby. Due to this, LAs are required in IT building premises.

The overall earth resistance profile of campus is not as per standard and required guidelines. Moreover, an important electrical installations like network switches for ICT services should be protected with surge protective devices which will shield an indirect and secondary lightning wave. Along with it, the earth resistance should be within the permissible limit or lower to provide an alternate path for high energy content lightning impulse to discharge to the ground.

Building electrical installations are critical components and design of installation with adequate control and protection is important. It was observed that in SMDBs there were no TPN MCBs, which is one of the important protection gears for secondary isolation of the circuits and also MCCB lever which is spring controlled needs to be charged and discharged to operate systematically.

Conclusion and Recommendations

Lightning strokes are natural events which is increasing every year due to change in climate and weather patterns. The current research focused on the risk assessment of the buildings at CST campus due to lightning strokes by using IEEE 62305 standard. Some of the major findings were; the earth resistance of the buildings is beyond the permissible limit; the standard value of earth resistance should be below 5Ω for domestic installations. It was also observed that the lightning protection systems installed needs to be relooked, even if the LPS system was being installed the down conductors were missing and, in most buildings, there was no LPS installed. The control gears design in the buildings needs to be reviewed since some important isolation gears like TPN MCBs in SMDBs are missing.

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About the author

Mr. Namgay Tenzin is currently working as a Lecturer, Electrical Engineering Department and is also a Centre Coordinator, Centre for Renewable and Sustainable Energy Development, College of Science and Technology; Royal University of Bhutan, Rinchending, Phuentsholing, Bhutan. He obtained his Bachelor of Engineering degree in Electrical Engineering from College of Science and Technology (CST), Royal University of Bhutan (RUB), Bhutan in 2015; Master of Technology Degree in Alternate Hydro Energy Systems from Department of Hydro and Renewable Energy (Formerly known as Alternate Hydro Energy Centre), Indian Institute of Technology Roorkee, Uttarakhand, India in 2019. He also has a Post Graduate Certificate in Higher Education from the Royal University of Bhutan. His research area includes integrated renewable energy grid, small hydropower, smart grid, solar and wind power system along with integrated solutions to address human-wildlife conflicts.