Case Studies of Lightning Related Injuries and Property Damage in Zambia

Foster Chileshe Lubasi
National Institute for Scientific and Industrial Research, Zambia
fclubasi@yahoo.com

Mohd Zainal Abidin Ab Kadir
CELP, Electrical & Electronic Engineering Dept
University Putra Malaysia
Serdang, Malaysia
mzainal@eng.upm.edu.my

Chandima Gomes
CELP, Electrical & Electronic Engineering Dept
University Putra Malaysia
Serdang, Malaysia
chandima@eng.upm.edu.my

Mary Ann Cooper
University of Illinois, Chicago
USA
macooper@uic.edu

***Abstract*— This is the first investigation and analysis of lightning related incidents in Zambia. Two case studies on both human injuries and equipment damage at five sites are reported. Lightning injuries were mostly attributed to the lack of proper structural protection systems, although lack of awareness among the public may also contribute to the situation. Many injury mechanisms, including unsuccessful upward streamers, may cause injuries. Design of lightning protection schemes should take social structures and affordability by the affected public into account. Losses in the power sector are excessively high in the region and seriously affect the operation of both business and domestic life. Replacement cost incurred by the power companies can be prohibitive. Lightning density and pattern in the localized areas, grounding systems of the installations, and specification and installation techniques of lightning arresters should be revisited in giving proper solutions to transformer and power line failures.**

Keywords-lightning injury; Zambia; step potential; direct strikes; transformer failure, insulation breakdown

I. INTRODUCTION

Situated at approximately 15° S and 28° E, Zambia is a land locked country in the Southern part of African continent. The country is surrounded by eight countries: Democratic Republic of Congo, Tanzania, Malawi, Mozambique, Zimbabwe, Botswana, Namibia. Fig-1 is the map of Africa with Zambia and it's neighboring countries highlighted.

The elevation of the great plateau on which Zambia is located, is typically between 1000 m and 1,300 m above sea level. Isolated mountain ridges are scattered over the country which peaks above 3000 m. Most parts of the country are generally flat and characterized by small hills formed by the erosion of crystalline rocks over millions of years. The area of the country is estimated to be 752,618 km^2. The population is nearly 14 million of which the majority leads rural life.

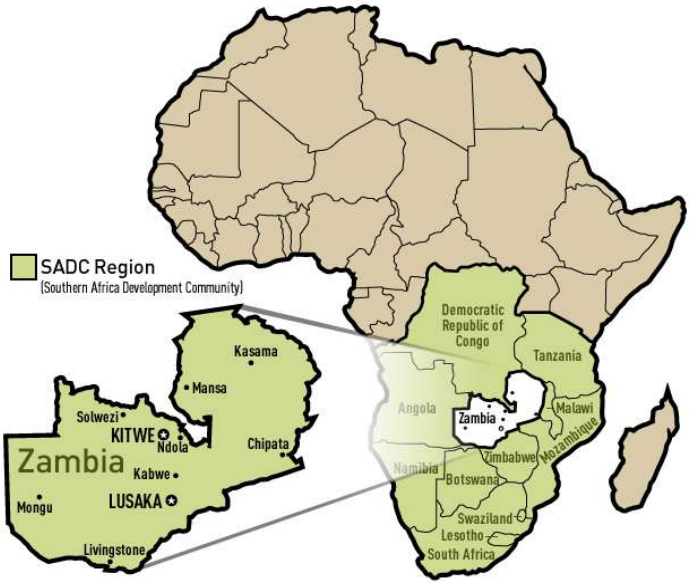

Figure 1. Map of Africa highlighting Zambia and its neighbourhood.

Due to its latitude, longitude and altitude, the climate is a combination of tropical and sub-tropical features. The rainy season starts at the end of October and ends in early April. The altitude modifies mean temperatures to lower values than that of coastal areas at the same latitude. The mean winter temperature in Zambia may reach as low as 0^oC at night whereas the summer temperature may be as high as 38^oC. The rainfall varies over a range of 500 to 1,400 mm per year with most areas recording between 700 to 1200 mm per annum.

The distinction between rainy and dry seasons is marked, with almost zero rainfall in the months of June, July and August. The rains are due to Inter-tropical Convergence Zone (ITCZ) and are characterized by severe thunderstorms rich with lightning and sometimes hail. The ITCZ is located north

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of Zambia in the dry season. It moves southwards in the second half of the year and northwards in the first half of the year. In some years, it moves south of Zambia leading to a somewhat dry season in the north of the country for three or four weeks in December.

According to the NASA map for lightning flashes, Zambia is rated quite high. It lies in the region of 10 to 20 lightning flashes per km^2 per annum. By the empirical formula that relates the ground flash density and isokeraunic level (IEC 62305-2, 2010 [1]), such ground flash density yields 100 to 200 thunder days per year. However, due to errors in discriminating ground flashes from cloud flashes in NASA data and to the reliability of related empirical formulae [2], the actual isokeraunic level in any area may have large deviation from the given range.

Zambia, as well as many other neighboring countries, is known for having a high occurrence of lightning accidents [3]. During the rainy season in the recent past, , it was not uncommon to observe many news items on human deaths and injuries, outages in power and telecommunication facilities, equipment and structural damage and other incidents due to lightning. Most accidents are reported in the public media several days after the incident, especially if they happen in remote areas. Due to the lack of scientific knowledge, many of these reports contain grossly distorted explanations of the causes of the incidents and their aftermath.

Since no scientific literature is available to determine the extent to which lightning affects the nation, it is difficult to quantify the losses and analyze the types of losses. Research is essential to develop appropriate protection and safety models for the country. This study is an effort to begin to fill the void between currently recorded accident information with scientific analysis.

The main objective of the research is to develop a database on human and livestock casualties and equipment and infrastructure damage / losses with the view of identifying lightning effects on society in Zambia and trends of occurrences during the last few years. The secondary objective is to propose safety and protection models to suit the socio-economic aspects of Zambia based on our analyses.

II. METHODOLOGY

Site visits were done by a team of experts (TOE) under the Materials Engineering and Technical Services Program of National Institute for Scientific and Industrial Research, Zambia, during the period of 2011-2012. The investigations have been carried out under the guidance of the Center of Excellence on Lightning Protection, University Putra Malaysia.

Sites for investigation were selected by considering the convenience of access, rather than any scientific criteria. Being a country of large span with many areas inaccessible to outsiders by direct means, selecting sites in Zambia for lightning injury/damage investigation was not an easy task especially since the number of reported incidents per year is usually quite high. Hence, the expert team visited whenever and wherever possible to collect data. Pre-information regarding the incidents was collected either from media reports or by personal correspondence.

During the visits, survivors, eye witnesses, neighbors and relatives of affected people and buildings were interviewed. Photographs of affected buildings, survivors and eye witnesses were also taken. The information gathered has been cross-examined through various other sources such as media reports, records maintained by any authority or evidence given by a reliable involved third party.

III. RESULTS

CASE 1: Nakonde town incident near Zambia Revenue Authority, ZRA

The incident took place in Nakonde in the northern part of Zambia in Muchinga province. Radio Phoenix, a private radio station in Zambia, on Friday, 10th December, 2011, reported during the lunch time news that a number of people had been struck by lightning in Nakonde near the Zambia Revenue Authority offices at the border with Tanzania. Two people were reported dead and several injured were admitted to Nakonde General Hospital.

However, when the TOE reached Nakonde, it was discovered that there were many more lightning incidents in the township than that had been reported. Unfortunately, The TOE could only investigate three incidents due to funding and time constraints.

a. Site-1 was a shelter erected under tall trees behind several shops and bars at the town centre. The shelter is a basic structure comprising a roof supported by wooden poles. It is roughly 5m long and 1 ½ m wide. The roof is made of a mixture of iron sheets, grass, paper and plastic. Several people, mostly young men, usually play pool on pool tables under the shelter. On the fateful day, many people were taking shelter in the pool shed to seek cover from the heavy rain. According to the people in the locality, rain is usually accompanied by lightning and thunder in this area. However, on that particular day, when the rainfall reduced drastically, there was a sudden fierce lightning flash with a loud explosion. For a moment, everyone in the shelter thought they had been struck by lightning as most of them said they felt like something had exploded on them. Some people at a distance said they saw fire on top of one of the trees. Those who recovered first said they saw fire and sparks of fire from the pools of water by the shed. Seven people including a twelve year old boy were affected so critically that they were thought to be dead by the onlookers. However, before the police arrived, five regained consciousness. The remaining two were pronounced dead at Nakonde Hospital. According to the police report and eye witnesses, the two young men who were in their early thirties looked as though they had been cut by razor blades on the exposed parts of their bodies, mainly their arms. No post-mortem examination was conducted and the bodies were released to the relatives of the deceased.

b. Site 2 was at a United Church of Zambia building in Itindi village in Nakonde. Eight ladies, one with a baby on her back were practicing choir inside the church building at the time of the incident. Mr Bwalya the choir master stood facing the window as he led the ladies in the singing. They had been in a smaller building outside the main building before but had decided to continue their singing practice in the main church building when the rain became heavy.

Mr Bwalya said that he saw a blinding red light in the window. Instinctively, he turned and looked in the other direction. He could not remember how long it took him to look back in the direction of the choir members but, when he did, all of them were on the ground looking as though they were dead. He decided to phone the pastor who rushed to the scene and began to pray for the fainted or dead choir members. As the pastor was praying, the choir members started regaining consciousness until all of them were conscious except for the baby who only regained consciousness after being administered a drip at the hospital. She is well and has not experienced anything unusual since the incident.

Ms Linda Nsofu, 36, one of the ladies interviewed, said that during the incident she felt as though her chest was expanding before she fell down. Afterwards she reported feeling "hot in the chest" for almost a week. Although she tried to drink a lot of cold water, the feeling of hot smoke coming out of her chest persisted.

Ms Agness Mwila, 30, another lady interviewed, said that during the incident she had no idea what had happened. She realized she had fallen from the chair and was about one and a half meters from the place where she had been seated. She recalled that she had been screaming. Although she attempted to stand up she was unable to due to a feeling of extreme tiredness and numbness in her left leg and arm. She also complained that she now occasionally feels pain in the ankle.

Mr. John Bwalya, one of the gentleman interviewed complained that he has been suffering from a shoulder pain since the incident. The pain becomes severe after a few minutes of heavy work. He had not experienced such pain before the lightning incident.

Ms. Linda Nsofu, another lady interviewed has chest pain from time to time and sometimes experiences pain in the legs. She has received no medical attention and usually goes to the pastor for prayers when she experiences the pains. She feels better after being prayed for.

c. Site-3 belongs to Zambia Electricity Company (ZESCO) According to the officers on duty on the day of the TOE visit, ZESCO poles and transformers are regularly struck by lightning (almost one incident per week). In the latest incident, a transformer in Zanga Quary area and two poles in the Chozi area had been struck two weeks prior to the TOE visit. In the transformer incident, the lightning arrester an MV surge protective device, had been damaged with insulation breakdown. Although repair of the damage was attempted, the transformer caught fire as soon as it was energized.

On 2nd April, 2012, lightning struck the poles in Chozi area causing insulation failure and physical termination of the power lines. The line fell to the ground and ignited part of the corn field over which the power cables ran overhead. A visit to the site revealed that the area is fairly open with no tall trees but with the electric poles which are 100 m apart. The poles are fitted with earth aerials and the earth resistance of zero ohms was measured by a two pole earth resistance meter, a Metrel, model M12124

Several police officers, who were present near the site when lightning struck the ZESCO pole, said they saw sparks of fire on the pole and later the field under the pole caught fire.

According to the officer in charge of the site, damaged poles are usually replaced nearly immediately following the incident. The downtime in such case is around 24 hours. Unfortunately, it takes considerably longer to replace a damaged transformer.

The town supplied by the damaged transformer was temporarily connected to a transformer in the neighboring village. The sharing of the transformer had resulted in long hours of load shedding in both areas affecting all the businesses and households in the two villages. It was difficult to assess the financial loss to ZESCO, as the technicians simply replace damaged parts without proper documentation.

CASE 2: Mkushi town incident

Mkushi is part of the central province. Two sites were visited in the area. One site was at Kasansama village and the other was the Zambia Electricity Company.

a. Site1: Reports by many Zambian newspapers as well as the internet related that a house in Kasansama village in Mkushi had been struck by lightning, killing five members of the same family. Fig.-2 shows the affected house reported in case under consideration.

According to the neighbors, it appeared that the father and an 18 month old baby were in the bedroom while the mother and three children were in the sitting room when the lightning struck. It seems that lightning struck the roof near the bedroom which immediately caught fire. The father and the baby were severely burned while the mother and two of the three children, a girl and a boy, were found dead in the kitchen. All three bodies looked grayish in color and white froth appeared to be coming out of the mother's mouth. The third child, a little boy estimated to be around three years old, was found alive standing in the corner of the kitchen. According to eye witnesses, he looked quite oblivious to what was going on around him

Mr Siame, an eye witness, saw very bright and sharp/fierce lightning followed by an explosion. A few minutes later, he saw smoke at his neighbors' house and rushed there. He found that the mother and two children were dead in the kitchen and the three year old boy was standing in the corner of the house, near the door. The eye witness managed to get the three out before fire destroyed the sitting room and kitchen.

b

Figure 2 a. Remnants of the affected house after it was burnt by fire caused by lightning
b. Police officers shows the place where they found the bodies after they were pulled out by Mr Siame
c The affected house was very similar to this before being burnt by fire

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b. Site 2: A visit to ZESCO, Mkushi revealed that the company loses transformers regularly in the rainy season from lightning strikes which cost them nearly USD 8000 per week.
Since transformers are usually imported to Zambia from Europe it may take up to six months to replace a damaged transformer. The loses are unbearable with companies in the region making regular complaints regarding loss of business due to power downtime. At the domestic level a major problem is loss of perishable food in cold storage. Fig.3 show transformers which were affected within a period of two months in the area and the parts affected.
As per the ZESCO officers, transformers are damaged despite good grounding systems and also in the presence of lightning arresters. Lightning arresters are also damaged in most cases.

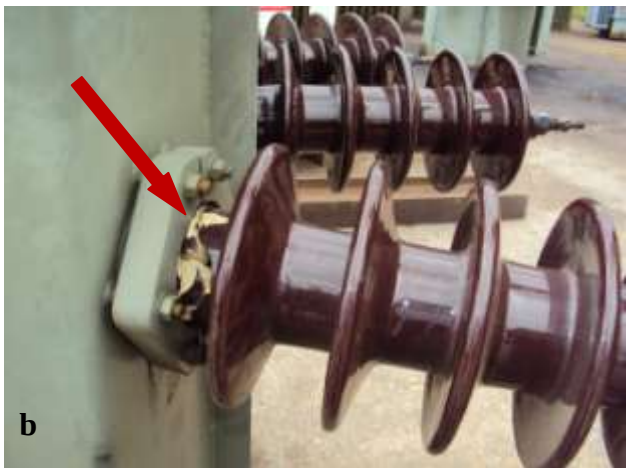

Figure 3 a. Damaged transformers in the ZESCO yard in Mkushi
b. Damaged part of the transformer

IV. DISCUSSION

The two case studies presented in this paper showed damage/injury in all cases to be due to the lack of proper lightning protection schemes for the structures and systems although lack of awareness on lightning safety may also be a contributing factor.

Case 1/site 1 is a typical example of side flash and step potential injuries due to a strike to a nearby tree. It can be assumed that the two dead people have been subjected to side flash as they had visible injuries to their arms. The rest may have been subjected to step potential. Unfortunately the TOE was not able to collect the exact locations of the victims with respect to the affected tree.

The incident described in Case 1/Site 2 is more difficult to explain with the available information. As the ladies were seated at the time of the incident and there was no evidence either by the choir master's testimony or by physical marks for side flash, either step potential or arc current injection is highly improbable. This leaves the cause of injury and temporary paralysis as due to unsuccessful upward leaders from the bodies of the victims.

The incident reported in Case 2/Site 1 is most likely due to a direct strike to the unprotected thatched roofed house. However, as per the details given by the eye witness it seems that the victims succumbed to their lightning injuries rather than the consequent house fire. A probable explanation for the cause of death is side flashing from the roof or walls after the structure is attached with the stepped leader. The three-year old child may have been spared due to his lower elevation which reduced the possibility of side flashing from the roof.

Due to the low per capita income of the public any expensive protection system will not be practically viable in most parts of Zambia. Safety and protection schemes need to be designed to be affordable, easily installed, easily maintained, and effective in lightning dense areas. Several less expensive lightning protection schemes for the low-income societies in Asia and Africa have been proposed [5].

Case 1/Site 3 and case 2/Site 2 indicate the seriousness of property damage to the power sector in Zambia due to lightning. Similar situations may prevail in many nearby countries as lightning density and occurrence patterns are similar throughout the region.

We basically focused our attention on two important observations in these cases. Transformers and poles are frequently damaged despite seeming to have good grounding systems and surge arresters.

It will be of interest to find how "good" these grounding systems are. Interviews done with root level engineers in many African countries revealed that the acceptability of the grounding system (both design and implementation) is based on individual perceptions rather than scientific information or guidelines given in standards. The TOE expects to conduct further investigations in this regard.

Ratings, specifications and installation details of lightning arresters have not been recorded by the TOE due to the unavailability of this data during the visits made in this study. Solid conclusions on the failure of such devices will be drawn once such information is available.

V. CONCLUSSIONS

Case studies conducted in Zambia on lightning injuries and damage shows that the situation is a serious problem in the country which needs urgent attention. The human injuries recorded were basically due to the lack of proper building protection systems. Once protection systems are formulated, extra attention should be paid to the cost effectiveness of such systems in a low-income society.

It is likely that many types of lightning injury mechanisms accounted for the reported cases. More study and evidence is required to draw more concrete conclusions on mechanisms.

Lightning damage to power system related devices is of serious concern due to both direct financial losses and indirect downtime losses. More studies are required to find the root causes of equipment and system damage in order to formulate proper solutions to the lightning related problems.

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