Telecom towers under the threat of lightning hazards

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Abstract: Lightning is an extremely complex electrical discharge that occurs within the earth's atmosphere. It is the biggest threat to communication and transmission towers and damages electronic and electrical equipment beyond repair directly or indirectly. Although the protection against the lightning hazards can be achieved with the available technology and knowledge, such measures are largely overlooked in the developing countries in particular. Protecting communication & transmission towers, communication & transmission systems from the direct lightning strikes and saving human lives, livestock and other property damages from indirect lightning is a big challenge to the service providers. Nepal is a lightning prone country where the communication towers and system are often the victims of lightning strikes. In this study, we have made field assessment at the various sites of Nepal Telecom's Base Transceiver Station (BTS) and Repeater towers for investigating their status pertinent to lightning threat and protective measures adopted in those sites. The main objectives of the field assessment were to investigate the effectiveness of the protective measures adopted, identify their inadequacies and hence to provide appropriate solutions as per the international standards (IEC 62305-4), in order to improve the quality of telecom services. The lightning strikes to the towers inside the Kathmandu valley were recorded to be rare, however it was common in the outskirts. Although, severe damage to the towers were not observed neither were recorded, the status of the towers in the perspective of lightning hazards were not found to be in the sound state. Contact resistance of the earthing system, installation of SPDs and equipotential bonding of the system need to be improved. Further, the protective measures against the hazards due to indirect effects of lightning strikes were found to be extremely poor. We recommend the improvements in protective measures against lightning in the neighborhood of the towers for the human as well as equipment safety.

Keywords: Lightning; Lightning protection system; BTS; Communication towers.

Introduction

Lightning is the most spectacular, commonly experienced atmospheric phenomenon which produces the brightest light and the loudest sound commonly occurring on Earth. Most of the lightning is generated in thunderstorms and is characterized by a length of 5-10 km at the extreme over 100 km[1]. All lightning discharges can be divided into two categories (1) those that bridge cloud charge and the earth, and (2) those that do not connect the earth's surface with the clouds. There are 30-100 cloud and cloud to ground lightning discharges per second worldwide making roughly 9 million discharges per day worldwide which is about 90% or more of global cloud-to-ground lightning accounted for by negative downward and other is positive downward, negative upward and positive upward discharges[2]. Of the

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total lightning discharges, 25% are reported to be cloud-to-ground discharges and 75% do not involve in ground[2].

Lightning can be deleterious to the communication towers and system either directly striking on the tower or system or indirectly due to electrical surges produced by its striking elsewhere. Lightning affects the tall tower in different ways through direct strike, side flashing, electromagnetic induction, capacitive reactance and high impedance from a certain nearest distance. Direct strike on the tower, aid in the rise of excessive current and overvoltage damaging the property and threat to the living beings[3].

The type and amount of lightning damage that an object suffers, depends on both the characteristics of the lightning discharge and the properties of the object. The physical characteristics of lightning of most interest are various properties of the current waveform and of the electromagnetic fields. Four distinct properties of the lightning current waveform can be considered important in producing damage[4]: (i) the peak current, (ii) the maximum rate of change of current, (iii) the integral of the current over time of the charge transferred and (iv) the integral of the current squared over time. Hence, general principles of lightning protection apply to all objects and systems[4].

Lightning protection system plays a vital role in mitigating the damages to the communication system and improvement of the quality of the service. It is, therefore a major challenge to the service providers. In order to mitigate the threat to the communication system and improve the quality of the service, continuous research activity is inevitable. Furthermore, owing to the precarious nature of lightning and diverse topography at various geographical locations, protective measures in the desired location may vary from other locations that requires research on the very location.

The need for protection, the economic benefits of installing and the selection of adequate measures should be determined in terms of risk assessment, which is currently the subject for international or national standards related to lightning protection of structures and objects on the ground[11]. There are generally two aspects of lightning design[11]: (i) diversion and shielding, primarily intended for structural protection but also serving to reduce the lightning electric and magnetic fields within the structure and (ii) the limiting of currents and voltages on electronic, power and communication systems via surge protection. The lightning protection system consists of both external and internal lightning protection system. External lightning protection consists of the Air-termination, the down conductor system and the earthing system. Internal lightning protection includes all additional measures to avoid electromagnetic interference, over voltages etc. due to lightning current in the protected volumes[6]. On a building or other structures to be protected, the diversion of lightning currents to ground is accomplished by installing (a) either one or more connected vertical lightning rods or a system of connected horizontal wires intended for the same purpose, that of intercepting the descending lightning leader, (b) down conductor to carry the intercepted lightning current to the ground terminal connections and (c) earth termination system to disperse the lightning current in the soil below the surface of the earth. The protection of electronic, power or communication equipment within a structure must include the control of currents and voltages resulting from direct strikes to the structure containing the equipment as well as from lightning-induced current and voltage surges propagating into the structure on electric-power, communication or other wires and metal types entering the structure on electric-power, communication or other wires and metal pipes entering the structure from outside[4]. In the following, the roles of each component are elaborated.

1) Air-termination system

Air-termination is a common point of lightning strike for downward flashes or upward flashes which is elevated at the top of the Antenna structure. According to the standard IEC 62305-3, the necessary separation distance between the air-termination system and down-conductors and conductive installations is determined by the following equation: $S = K_i \frac{k_c}{k_m} l$ where, K_i is the induction coefficient that contains steepness of the subsequent stroke, mutual inductance between down conductor and loops as well as the dielectric strength of air for sub-microsecond impulse voltages. K_i depends on the selected class of the LPS. K_c depends on the lightning current flowing in the down conductors. K_m is the dielectric strength of materials other than air present at the location of the proximity. For air K_m=1 applies. K_m depends on the electrical insulation material. l is the shortest length, along the air-termination or the down conductor, from the point where the separation distance is to be considered, to the nearest equipotential bonding point[7,8].

2) Down conductor

Down conductor is any metallic part in the form of wire or tape that is particularly installed to pass lightning current from top of the tower to the ground level[3]. Stations having lattice towers or masts typically have metal top masts for supporting the antennas acting as a down conductors connecting air-termination system to the earth-termination system, because the cross-sectional area of the support structure is usually adequate, provided that there are sufficient contact areas between the various sections of the lattice tower or mast[9].

3) Earth-termination system

Earth-termination system is the process of providing a low-impedance path to earth for the current resulting from lightning flashes to the station, in order to minimize the potential rise of the internal systems. It works as the linkage between the discharge path and geological earth in dissipating the excess voltage and current. Most of the transmitting stations are located on terrain with poor soil conductivity, so measurement of the soil resistivity is the first step for designing the earth-termination system and calculations concerning conventional earth impedance of the earth-termination system for correctly dimensioning the earth electrodes.

Surge protection

Surge protective devices (SPDs) are used to limit the maximum overvoltage value on protected circuits[10]. The electrical characteristics (maximum continuous voltage, lightning impulse current, nominal discharge current, voltage protection level, short circuit withstand capability) and the Type (I, II, III) of the SPDs have to be appropriately selected, considering the nominal characteristics of the system to be protected and the expected lightning currents[11].

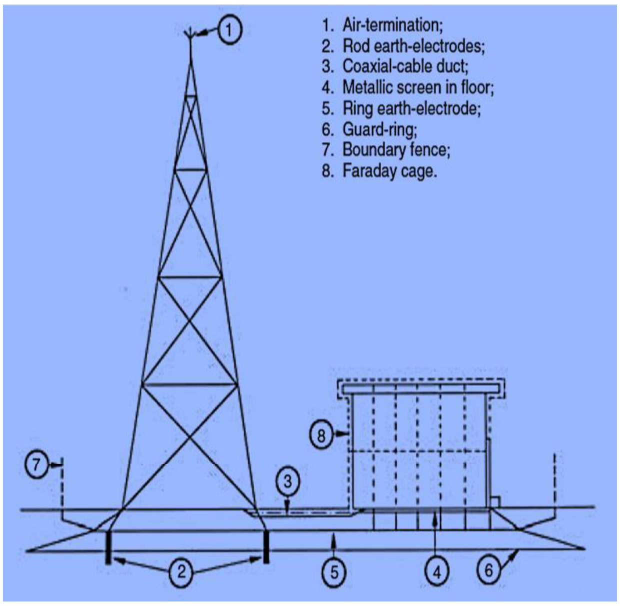

Figure 1: Components of lightning protection system on a tower as per IEC 62305. [Adapted from 9]

Co-ordinated SPD protection system protects electrical and electronic systems of the station against surges for both power and signal circuits. The coordinated SPD protection is a set of properly selected SPDs, coordinated energy and is installed in the system. For a proper selection and installation of SPDs, it is essential to know the stress, which an SPD will experience under surge conditions, such stress, as underlined by the standard is a function of many complex and interrelated factors. These include: the location of the SPDs within structure; the method of coupling of the lightning strike to the facility (resistive and inductive); the routing of internal circuits within the structure to the earthing system and to the connected services, mainly the current peak value and wave shape, which the SPD will have to conduct under surge conditions. Furthermore, the different behavior of the SPD containing spark gaps (switching type SPD) SPD containing metal oxide varistors (limiting type SPD) should be considered[12].

Shielding

High amplitude of lightning current cause strong magnetic fields that occur in the vicinity of the conductors as a consequence of their very steep wave fronts, the magnetic field that occur in their vicinity also changes very rapidly, causing induction effects in the circuits inside the building. So, this effect is minimized by shielding the equipment and cable.

For the protection of an external cabling and equipment connected inside the station must be connected to the single earthing system. Circuits can be screened effectively by connecting to the earth-termination system the screens and the meatal sheaths of all the cables, the chassis of the electrical and radio apparatus and the frames of the machines and the isolating transformer. All the earth conductors must have the least possible impedance, and therefore short and straight routes, frequent bonding, and so on. The RF cables do not pose any particular problems, because they are always screened. The power supply circuits also should be carried in screened cables and should be arranged symmetrically in the ducts with respect to the shield-wires electrically connecting earth electrodes located at the two extremities of the duct itself[9].

Equipotentialisation and bonding

Lightning protection equipotentialisation bonding is that part of the internal lightning protection which reduces the potential difference cause by lightning current. Lightning protection equipotential bonding is realized by bonding the conductors of the external lightning protection system with the metal frame of the structure, with the metal installations, with the external conductive parts, and with the power and information technology equipment in the volume to protect. Bonding measures include: equipotential bonding lines, if the continuous electric conductivity is not achieved by the natural connections; and arresters, if direct connections with the equipotential bonding lines are not allowed. Lightning protection equipotential bonding must be carried out in accordance with IEC62305-4[6]. Equipotential bonding is the main ways to reduce the resistance of the external tower devices and the minimum impedance for the dissipation of the over voltages, over currents that arise from the lightning strike, internal transients, surges etc. Equipotential bonding can protect equipment from lightning attack by providing a potential reference point for all equipment. Equipotential bonding is classified into two categories: one is the steady equipotential generated by using the earthing wire to directly connect; the other is to connect through the SPD which is disconnected at other times, and when there is over voltage from thunder and lightning, the SPD is converted to lower the resistance to let lightning current discharge through earthing system. The equipotential bonding of power lines, signal lines and feeders if unable to be directly earthed must add SPD on the lines in a parallel manner to discharge lightning current when the lightning occurs. Equipotential bonding is necessary because the rise of ground potential when lightning happens or the potential difference between equipment due to surge voltage caused by lightning electromagnetic fields leads to the breakdown of equipment insulation and internal components, which finally damages equipent[13].

The main technique to equipotentialize the earth-termination system is to use screened cables for connection of equipment to each other; with the screen having an adequate cross-section of equipment to each other, with the screen having an adequate cross-section bonded to the earth-termination system. A useful rough way to estimate the over voltage U affecting cable takes into account of its geometrical and physical surroundings and uses the equation:

$$U = \frac{k_p.\rho.l}{S} I_F.$$

Where K_p is the installation coefficient, S the screen cross-section, ρ the resistivity of the cable, l the length of the cable and I_F the current flowing inside the cable[9].

All the above factors should be taken into account to achieve the complete protection of the tower and communication system. Furthermore, to maintain the quality of the service intact, regular assessment of maintenance must be done.

Implementation of protective measures

The lightning protection of transmitting stations requires a large number of precautions against the effects of lightning flashes, and those precautions must be effectively coordinated. In the case of lightning flashes to the station, the lightning energy must be dispersed harmlessly, whereas in the case of lightning flashes affecting the energy supply system, telecommunication connections, cable ways, and the like dangerous voltage surges must be limited to tolerable levels.

The problems that arise in the planning and implementation of lightning protection installations result mainly from the high peal amplitudes and steep wave fronts of the current surges and the resultant potential differences of up to several thousands of kilovolts, and high electromagnetic field strengths.

The essential precautions must be primarily directed towards the avoidance of potential differences dangerous for the personnel, building and equipment, as well as towards the limitation within predetermined limits of the voltages induced in electrical and electronic systems[9].

Protection measures against step voltages

The outside area within 3 m from the down-conductors of LPS (e.g. the legs of the metallic lattice tower supporting the antenna systems, or the installed down-conductors in the case of non-metallic towers or buildings) may be hazardous to life even if the LPS has been designed and constructed according to IEC 62305-3[9].

One or more of the following protection measures is suitable for this purpose.

- The resistivity of the surface layer of the soil, within 3 m of the down-conductor, should be increased to 5 k Ω m or more. This can be achieved by covering the soil with a layer of insulating material, e.g. Asphalt of 5 cm thickness (or a layer of gravel 15 cm thick)
- Equipotentialisation should be achieved by means of a meshed earthing system.
- Physical restrictions and/ or warning notices should be provided to minimize the probability of access to the dangerous area, within 3 m of the down conductor[9].

Protective measures against touch-voltages

- The resistivity of the surface layer of the soil, within 3 m of the down-conductor, should be increased to 5 kΩ m or more. This can be achieved by covering the soil with a layer of insulating material, e.g. asphalt of 5 cm thickness (or a layer of gravel 15 cm thick).
- Physical restrictions and/ or warning notices should be provided to minimize the probability of access to the dangerous area within 3m of the down-conductor[9].

Nepal with its complex terrain, is one of the lightning prone country across the globe with lightning strike density as high as 30 strikes per sq. km per year[17]. Owing to the elevation, the middle hills (that are mostly cladded with telecom towers) are subject to receive more lightning ground flashes than those in the flat lands. It is therefore, the telecom towers are exposed to the extremely high risk of lightning. Hence, the towers need to be effectively protected and a regular assessment of the towers and communication system, as such, are inevitable not only to ensure the safety of the towers but also to protect the humans and livestock from the indirect effect of lightning.

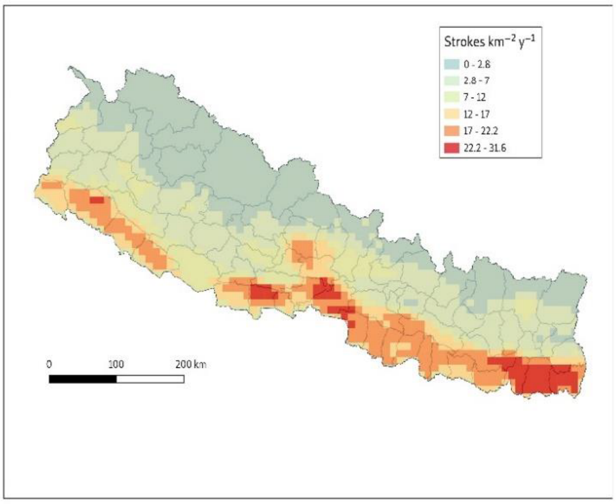

Figure 2: Lightning strike density over Nepal between the years 2015 to 2020 (Adapted from [17])

The lightning protection system has direct relation with communication quality and safety of communication tower so we have made field assessment in order to investigate whether the protective measures comply with international standards. In the present study, we investigated the status of the communication towers and system in the perspective of their vulnerability by lightning hazards. For the investigation, field assessment was carried out in various

BTS stations and Repeater towers sites belonging to Nepal Telecom in and around the Kathmandu Valley.

Methodology

In this study, the main task was to make field assessment of the communication towers belonging to Nepal Telecom Corporation (NTC). We inspected seven communication tower sites including Signal Repeater and Base Transceiver Stations (BTS) of the NTC tower. Our main task was to investigate the nature and installation of the Air-termination, down conductor and Earth-termination system. Mostly, filling out the questionnaire were adopted as principal methods of this research work. Qualitative measurements of Earth resistance were taken by the digital earth resistance meter. Confirmed lighting history for the period of five years was collected to study the intensity of lightning in each designated site. All the lightning protection system, and layout of the grounding system have been investigated based on information provided by the site-engineer and visual inspection. The installation of air-terminations and upper parts of down conductors have been observed from the ground level, from locations at few meters or from certain distance was observed with unaided eyes.

Working method of earth resistance meter

Earth resistance meter is based on the three-point (Fall-of-potential) method. Earthing plays a vital role in all electrical systems. It is used to conduct lightning current to earth and thus limiting voltages on transmission lines, objects and structures so it is important to measure the earth resistance of the site. For the measurement we had used two-pole digital earth resistance meter (VC 4105 A), under dry earth conditions. This device is based on the three-pole method. This method involves the use of two test electrode to be measured designated r_1. The resistance between each pair of electrodes is measured and designated r_{12}, r_{13} and r_{23}[14].
where,

$r_{12} = r_1 + r_2$ and so on.

Solving the simultaneous equations, it follows that:

$$r_1 = \frac{r_{12} + r_{23} + r_{13}}{2}$$

Hence, by measuring the series resistance of each pair of ground electrodes and substituting the resistance values in the above equation, the value of r_1 may be established. If the two test electrodes are of materially higher resistance than the electrode under test, the errors in the individual measurements of the electrodes it must be at some distance from each other else absurdities may arise in the calculations, such as zero or even negative resistance.

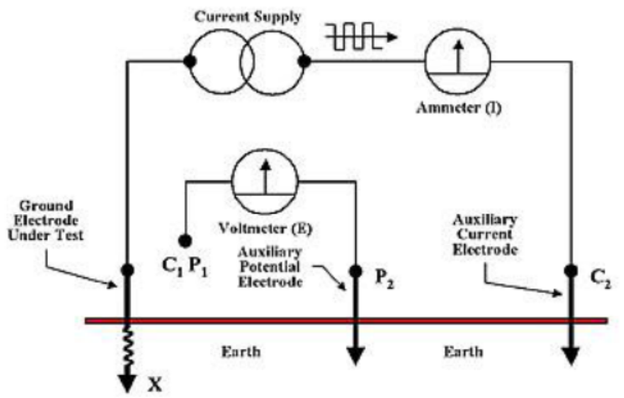

Figure 3: Schematic diagram for the measurement of the ground potential. Adapted from [15].

In measuring the resistance of single driven electrode, the distance between the three separate ground electrodes should be at least 5 m with a preferable spacing of 10 m or more. For larger area grounding systems, which are presumably of lower resistance, spacing in the order of the dimensions of the grounding systems are required as a minimum. This method has demerit for large substations, and some form of the fall-of-potential method is preferred, if high accuracy is required[14].

It solely works on the principle of ohm's law E=RI or R=E/I. The ground tester will measure directly by generating its own current and displaying the contact resistance of the ground electrode. The potential difference between rods X and Y is measured by a voltmeter and the current flow between rods X and Z is measured by an ammeter[14].

To measure the resistance of ground is to place auxiliary current electrode Z far enough from the ground electrode under test so that the auxiliary potential electrode Y will be outside of the effective resistance areas of both the ground electrode and the auxiliary current electrode. The best way to find out if the auxiliary potential rod Y is outside the effective resistance areas is to move in between X and Z and to take a reading at each location. If the auxiliary potential rod Y is an effective resistance area or in both if they overlap, as shown in figure 3, by displacing it the readings taken will vary noticeably in value. Under these conditions, no exact value for the resistance to ground may be determined. On the other hand, of the auxiliary potential rod Y is located outside of the effective resistance areas figure 4, as Y moves back and forth the reading variation is minimal. The readings taken should be relatively close to each other, and are the best values for the resistance to ground of the ground X. The readings should be plotted to ensure that they lie in a "plateau" region as shown in figure. The region is often referred to as the "62% area". Figure 5 shows the schematic diagram for working of ground potential[15].

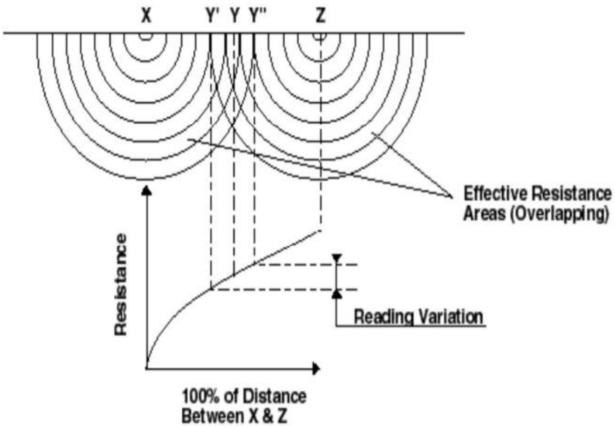

Figure 4: Schematic diagram for working of auxiliary rod. [Adapted from 15, 16]

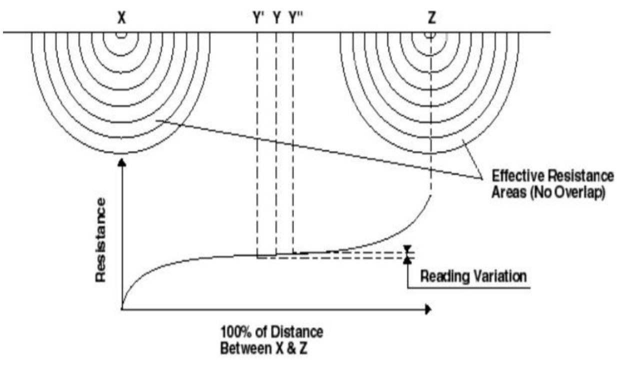

Figure 5: Schematic diagram for working of ground potential. [Adapted from 15, 16]

Results and discussion

We have made field assessments of seven tower sites in and around Kathmandu Valley to investigate the health status of the BTS and repeater towers in the perspective of lightning threats. Although, most of the tower inside Kathmandu valley were reportedly free from lightning wrath however that does not provide the sufficient evidence that they are free from possible lightning interception. Neither, a systematic records of service interruption was available for the investigation of possible cause. As can be seen from the Table 1, a thorough assessment could not be pursued in the towers located in Kathmandu valley.

Figure 6. A repeater tower site (one of the sites under assessment) located at Indrasthan, Chandragiri, Kathmandu.

Tower elevated around the valley were, however, observed to be under the threat of the lightning not only due to their height but also due to the status of protective measures against lightning.

In the Table 1, the measured values of resistance for earth electrode and each tower footing are given. As, seen from the table, the values of resistances at Nagarkot, and Maitrinagar are much above the prescribed values under IEC 62305. Neither have the efficient bonding nor equipotentialization were accomplished. The measured earth resistance value is given in Table 1.

Table 1: Earth resistance of different site stations.

S.N.	Stations	Location	Earth Resistance (Ω)	Resistance of Each Footing (Ω)	Remarks
1.	Repeater Tower	Nagarkot	a. 19.1 b. 18.7 c. 18.6 d. 19.2	a. 19.1 b. 18.7 c. 18.6 d. 19.2	
2.	BTS STATION	Maitrinagar	a. 8.05 b. 8.28	inaccessible	
3.	BTS and REPEATER TOWER	Chabahil	inaccessible	a. 2.13 b. 2.08 c. 13.97	For both ADSL and Mobile network
4.	BTS STATION	Jawlakhel	a. 1.28 b. 1.32	a. 1.15 b. 1.18 c. 1.21 d. 1.03	For both ADSL and Mobile network.
5.	REPEATER TOWER	Indrasthan	a. 0.17 b. 0.16	a. 0.03 b. 1.53 c. 0.14 d. 0.04	
6.	BTS STATION	Sanothimi	a. 4.15 b. 4.17	inaccessible	
7.	BTS STATION	Babarmahal	a. 4.45 b. 4.57	inaccessible	

It is to be noted here that the contact resistance of earth electrode plays a crucial role in protecting the tower equipment and humans and animals in the vicinity of the tower. This is due to the fact that the lightning current raises the potential of the point of strike depending upon the magnitude of the resistance and impedance given by:

$$V = i\,R + L\,di/dt$$

Where, V = the rise in potential

i = lightning current,

R= contact resistance of the earth electrode

L= inductance of the electrode and

di/dt= the time rate of change of lightning current.

The rise in potential reaches its maximum value when the lightning current rises to 80% of its maximum value.

As is seen from the table 1, the resistance values of the electrodes as measured in the Nagarkot site are fairly high. For the measured resistance at Nagarkot, R=19 Ω, if the inductance of the earth electrode is considered to be 2 μH/m, the value of potential at the surface of the earth in contact of the electrode can be calculated for the average lightning current of 30 kA as:

$$V = 0.8 \times 30 \times 10^3 \times 19 \times 10 + 2 \times 10^{-6} \times 10 \times 2.4 \times 10^3/10^{-6}$$

$$V = 4.5\ MV + 48\ kV$$

Therefore,

$$V=4.55\ MV$$

This results in huge potential rise at the ground that would lead to the surface arcing. This surface arcing might prove to be disastrous for the equipment close by the tower and the passerby. Meaning, such a potential can damage the electrical and electronic equipment in the transmitting and receiving unit of the communication system and can pose fatal accidents to the humans and animals that approach the tower site.

Furthermore, as the standard practice of equipotential bonding was not observed in almost all the BTS and repeater towers and communication system as such are under the threat of lightning hazards.

Conclusion

Every tower that were inspected in this work had no record of the lightning strikes on the BTS station inside the Kathmandu valley but lightning problems were found in the Repeater tower, where it was located in the mountainous region elevated at the altitude range from 1,886 to 2,102 meter. There were cases where measurements were not available due to deep down buried condition of the electrode and foot of the tower were concretized along with the house. But most of the tower were integrated and grounded properly to minimize the impedance. In Indrasthan the electrode resistance was measured by using the clamper but for the effective data three pole earth tester were used in rest of the site. SPDs were not found which the major issue except for Indrasthan was. Communication cable from antenna to system is brought in and coaxial are rounded. High resistance was also observed so, requirement of the addition of the resistance reducing step like long conductor is needed and should be integrated. Ring conductor with proper equipotentialisation should be done in most of the tower. International standards measure was not followed in some sites like Nagarkot, Maitrinagar, Chabahil but, in the rest of the site like Jawlakhel, Indrasthan, Sanothimi and Babarmahal the measures were strictly applied.

Clearly, there is an acute need of adoption of protective measures as per the international standards for the safety of communication towers, equipment and human and animals. The personnel working on the repeater site should be well informed about the consequences of lightning and take the necessary precautions during the time of lightning.

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References

1. Dwyer, J. R. and Uman, M. A. 2014. The physics of lightning. *Physics Reports*. **534(4)**: 147-241.
2. Rakov, V. A. 2013. The physics of lightning surveys. *Geophysics*. **34(6)**: 701-729.
3. Gomes, C. and Diego, A. G. 2011. Lightning protection scenarios of communication tower sites: human hazards and equipment damage. *Safety science*. **49 (10)**:1355-1364.
4. Rakov, V. A. and Uman, M. A. 2003. Lightning physics and effects. *Cambridge university press*.
5. Loboda, M. 2009. Lightning protection of structures. *Lightning: principles, instruments and applications*. Springer, Dordrecht. 573-592.
6. Hasse, P. 2000. Overvoltage protection of low voltage systems. *IET*. **33**.
7. Zischank, W. and Stimper, K. Separation distances for air termination systems in proximity to large conductive areas. *In International Conference on Lightning Protection (ICLP)*. 1-5.
8. Kern, A., Beierl, O. and Zischank, W. 2009. Calculation of the separation distance according to IEC 62305-3: 2006-10. *Remarks for the application and simplified methods*.
9. Piparo, G. B. L. 2009. Lightning protection of telecommunication tower from lightning, edited by V. Corray. *Power and Energy Series* **58**: IET.
10. Amicucci, G. L. and D'Elia, B. 2004. Reliability of surge protective devices stressed by lightning. *Journal of electrostatics*. **60 (2-4)**: 247-256.
11. IEC 62305-3. 2010. *Protection against lightning* physical damage to structures and life hazard.
12. Kisielewicz, T., Fiamingo, F., Flisowski, Z., Kuca, B., Piparo, G. L. and Mazzetti, C. 2012. Factors influencing the selection and Installation of surge protective devices for low voltage systems. *In International Conference on Lightning Protection (ICLP)*. 1-6.
13. Liu, J., Lin, Y., Chen, Q., Qi, Z. and Wang, Z. 2013. Research on equipotential earthing optimization bonding in radio base station. *In 3rd International Conference on Electric and Electronics*. Atlantis Press. 207-211.
14. Ground impedance and earth surface potentials of ground system. *An American National Standard IEEE Guide for Measuring Earth Resistivity*, *Resistivity*, *Earth*.
15. https://electrical-engineering-portal.com/mesuring-resistance- earth-electrode/ (viewed on 26 March 2021).
16. https://testguy.net/content/233-4-Important-Methods-of-ground-Resistance-%20Testing/ (Viewed on 26 March 2021).
17. Sharma, S., Neupane, B., KC, H. B., Koirala, M. P., Damase, N. P., Dhakal, S., Gomes, C., Cooper, M. A., Holle, R. L., Bhusal, R. J., Cramer, J. and Said, R. 2022. Lightning threats in Nepal: occurrence and human impacts. *Geomatics, Natural Hazards and Risk*. **13(1)**: 1-18. doi: 10.1080/19475705.2021.20099