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Study on Prediction of Lightning Impulses on Transmission Line Tower Due to Harsh Field and Variable Working Condition, Environmental Condition and Tower Footing Resistances

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Abstract

The current state of transmission system design and development is greatly hampered by over voltages caused by lightning. To mitigate over voltage problems, researchers must be nearly obsessive. Since lightning strikes transmission and distribution network components like lines and substations, personnel are also seriously put in danger. Lightning prediction holds great significance, in addition to Lightning Detection Networks (LDNs) that offer ample information regarding lightning activity. Through the use of a fuzzy forecasting system, we are able to determine the chance of lightning in the low, medium, and high range. The method used to forecast lightning threats is provided by this system.

Keywords: *Fuzzy Forecasting System, Lightning, Lightning Detection Network (LDN), Over Voltages*

1.0 Introduction

Everyone on earth has seen lightning, which is a natural occurrence. Lightning possesses a significant amount of power and has the ability to harm both people and property. It is a primary factor in power system disruptions and equipment damage. Given the severe damage that lightning can do, lightning occurrence prediction is essential. A few thousand people die from lightning strikes each year, and tens of thousands are injured. Over 30% of all electric power outages are caused by lightning, and lightning is the primary cause of many forest fires[1]. A transmission line tower experiences a traveling voltage when lightning strikes it. This voltage travels up and down the tower and is reflected at the top and base of the tower, increasing the voltage at the cross-arms and stressing the insulators. In the event that this transient voltage surpasses the insulator's tolerate level, a back flash will occur. There are several ways to enhance the lightning performance of lines, including adding lightning arresters, lowering grounding impedance, enhancing critical flashover of insulators, and installing shield wire for lines without it. The goal is to decrease the frequency of flashovers on the lines. In a transmission system, one of the elements affecting the back flashover voltage across the insulator is the tower footing resistance[1-5]. Lightning in thunderstorms can occur in four different ways: Between two clouds (cloud-cloud discharge), wholly within a cloud (intra-cloud discharge), and rarely between a cloud and the surrounding air (cloud-air discharges). Lightning can also occur between a cloud and the earth (cloud-ground discharges). The air pressure is significantly higher in the

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zone of Cloud-Ground discharges (CG) than it is in the regions of Intra-Cloud discharges (IC) or Cloud-Cloud discharges (CC). The Cloud-to-Cloud (CC) or Intra-Cloud (IC) discharges are never as powerful as the CG discharges[6].

2.0 Characteristics of Lightning

Lightning happens when an electric charge builds up to a point in the atmosphere where the electric fields causing the charge force the air to electrically break down. Although clouds over erupting volcanoes, sandstorms, snowstorms, and even clear air can all include lightning (Gifford, Baskin)[6]. Thunderclouds are the primary

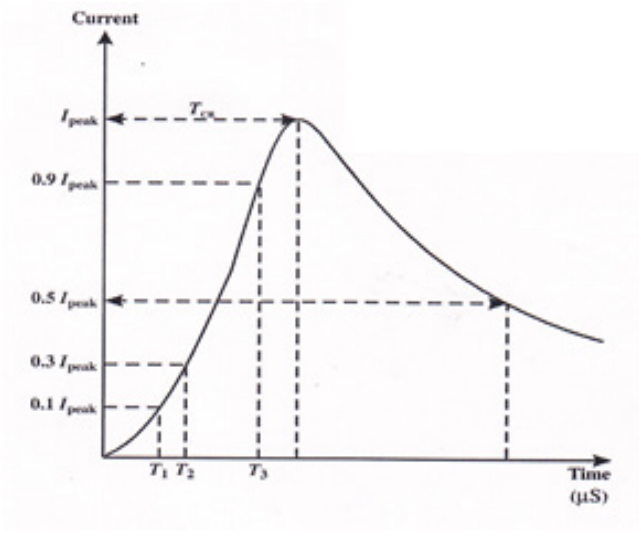


Figure 1. Typical waveform of lightning.

location for lightning strikes. A typical lightning waveform is depicted in Figure 1[7].

Where, T_{CR} –Time for attaining peak current (crest value)

T_1- Time for attaining 10% peak current

T_2 –Time for attaining 30% peak current

T_3 – Time for attaining 90% peak current

T_H –Time to drop to 50% of peak current

Every lightning strike is made up of multiple separate components, each of which is a stroke-a current wave. The initial current wave had a larger peak current but a comparatively lower dI/dT rate. There were then three more waves, on average, with substantially higher dI/dT rates but lower peak currents. A typical lightning discharge is depicted in Figure 2[7].

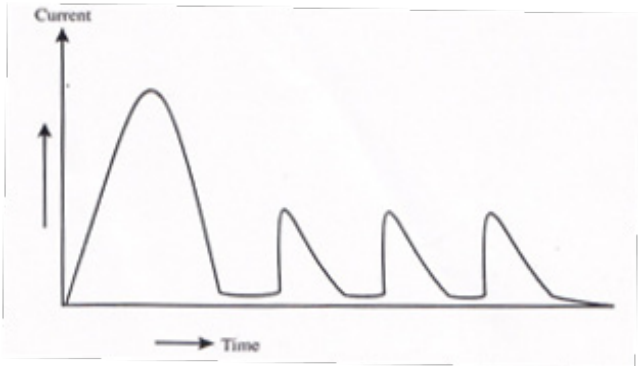


Figure 2. A typical lightning discharge with multiple wave components (strokes).

The amount of energy released and the air pressure at the lightning strike location have a significant influence on the amount of NOx (Nitrogen Oxide) that is produced[6].

3.0 Proposed System

A study conducted in the Matlab environment analyzes lightning and its consequences in their entirety. It will cover the tasks listed below.

3.1 Lightning Analysis

Matlab is used to plot the lightning signal, which has a high frequency and high voltage or current. A data set's signal values over time are extracted, and its fluctuations are then shown.

3.2 Tower Footing Resistance's Effect

The significance of tower footing resistance is examined. Tower footing resistances are assessed for various values, and its impacts are investigated.

3.3 Lightning Prediction

This is where lightning predictions based on values can be made.

We can utilize fuzzy notions based on probability or any other classification approach, like clustering, for this.

The effect might be categorized as low, mid, or high.

4.0 Fuzzy System for Forecasting

Fuzzy logic is implemented through the use of a "Fuzzy Interference System" (FIS). A function between input and output numbers can be approximated by the expert system known as the FIS[8].

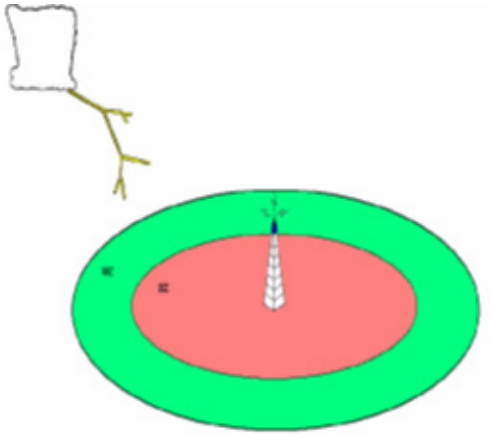


Figure 3. Fuzzy system model.

In this instance, the actual anticipated time of alert is changed using the FIS. The process of making it is as follows.

- The border of active thunderstorm cells is identified using the incoming data (the observed lightning density).
- The distance (D act) between this border and the Danger Zone (DZ) has now been calculated.
- The speed of the active cell (cells) can be ascertained by performing this computation on a regular basis (during each sampling period).
- A critical distance is obtained by multiplying this speed by the interval at which the preventive measure is activated.
- When D act approaches D critical, the alert needs to sound.
- D FIS is the result of modifying D critical with FIS.
- The moment D FIS and D act collide, an alarm must sound.

5.0 Environmental Factors Affecting on Lighting

Lightning is influenced by geographical and atmospheric variables[9] It is typically connected to regions that experience convective rainfall[10]. It needs both high ground surface temperatures and elevated air moisture content[11]. For instance, Florida has a very high frequency of lightning strikes, whereas northern regions like Canada, with similarly high atmospheric moisture levels, have very lower lightning rates[12]. The following list includes the several factors that are correlated with lightning phenomena. They are listed below[13].

5.1 Rainfall

Cloud-ground lightning strikes are more likely to occur when atmospheric rainfall increases[14]. A example correlation between rainfall and CG lightning strike is depicted in Figure 4. It is evident from the following figure that the grid blocks with 12 or more strikes had an average rainfall of 8.7 cm (3.4 in). This represents a significant increase of more than 12 times over the grid blocks with 0-2 CG strikes, and nearly twice as much as the next lower group (9-11 strikes). In other words, the amount of convectional rainfall over the research area determines the amount of CG strikes[15].

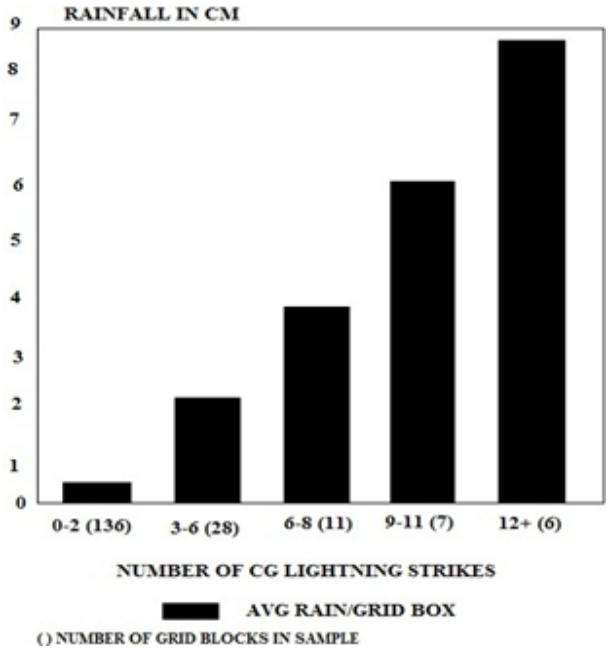


Figure 4. Average rainfall verses CG lightning strikes per grid box.

5.2 Temperature

The lightning phenomena necessitate a heated surface. Temperature creates the ideal environment for lightning

to occur[16]. A storm is created when warm or hot air rises and collides with cooler or colder air in the upper atmosphere; under these circumstances, electricity is produced[17]. This electricity is what causes the electrical discharges that we see as lightning to go from cloud to cloud or from cloud to ground[18]. The lightning discharge is so strong that it creates a dazzle of light, and the thunder we hear is caused by the atmosphere becoming extremely heated[19].

5.3 Water Vapor

One of the main components of the earth's climate is tropospheric water vapor. As a greenhouse gas, it affects the atmosphere directly as well as indirectly through interactions with clouds, aerosols, and tropospheric chemistry. The creation of lightning in the atmosphere is mostly dependent on water vapor. Typically, the true sources of static charge in the Earth's atmosphere are clouds[20]. The quantity of water vapor in the surrounding system, however, is closely correlated with clouds capacity to store enormous amounts of electrical energy[21]. The permittivity of the air is directly regulated by the concentration of water vapor. Low humidity levels facilitate rapid and simple static discharge[22]. Static discharges are less common under higher humidity conditions. Lightning generates megawatt outputs by a combination of permittivity and capacitance. The atmospheric water vapor, for example, functions as a material (or insulator) that reduces the clouds capacity to release its electrical energy once it has begun its journey towards becoming a lightning generator[23]. The barrier that was formed by the atmospheric water vapor would eventually dissolve due to the stored electrical potential energy if the cloud keeps producing and storing more static electricity over a given period of time. Lightning will be the result of the release of this energy into a locally oppositely charged area[24].

6.0 Relationship Between Tower Footing Resistance and Lightning Impulses

Tower base footing earth resistance influences both the ground potential rise at towers during ground faults and the lightning outage rates on transmission and distribution lines[25]. High currents flow into the ground through the tower footings after a tower is struck by lightning, causing thermal effects and soil ionization[26]. The construction of the tower footings, the current magnitude, and soil resistivity all affect how much the ground resistance of the tower base drops as a result[27]. In order to avoid line back flashover and keep the ground potential rise within safety tolerance bounds, it is preferable for the power system to operate with this resistance set low[28]. Sometimes the ground around the tower is controlled by grading loops or extra electrodes buried nearby.

6.1 Tower Footing Resistance and its Significance

A crucial factor in determining lightning flashover rates is the tower footing resistance[29]. More negative reflections are created from the tower base towards the tower top the lower the tower footing resistance, and this helps to reduce the peak voltage at the top of the tower. It is described as the resistance to current dissipation provided by tower footing[30]. The tower footing resistance has a significant impact on howeffective a ground wire is. All towers tower footing resistance must be assessed during dry weather soon after they are built and before earth wire is strung[31]. One way to compute the tower footing resistance is as follows.

$$R_T = \frac{R_g}{\sqrt{1+\frac{I}{I_g}}} \qquad (1)$$

Where RT- Tower footing resistance (ohm).

R_g - Tower footing resistance at low current and low frequency(ohm).

I - Surge current into ground (KA)

I_g -Limiting current initiating soil ionization (KA)

$$I_g = \frac{1}{2\pi}\left(\frac{E_o \rho_o}{R_g^2}\right) \qquad (2)$$

Where ρ_0 - Soil resistivity (ohm-meter)

E_0 –Soil ionization gradient (about 300 KV/m)

Tower footing impedance needs to be minimized in order to lower outage rates and the risk that lightning strikes pose to human life. If the resistance of the tower footing exceeds the standard value of 10Ω or less, then further actions might be taken to reduce the resistance[32].

To obtain a reduced tower footing resistance, such procedures could involve the use of a vertical or horizontal electrode or even the use of a particular resistance-reducing substance[1].

6.2 Effect of Average Tower Footing Resistance on the Lightning Outage Rate

A research conducted on a 500 kV transmission line by whitehead[1] to examine the impact of average tower footing resistance on the lightning outage rate revealed that the outage rate was roughly proportional to the average tower footing resistance, as shown in Figure 5. The lightning outage rate with a tower footing resistance

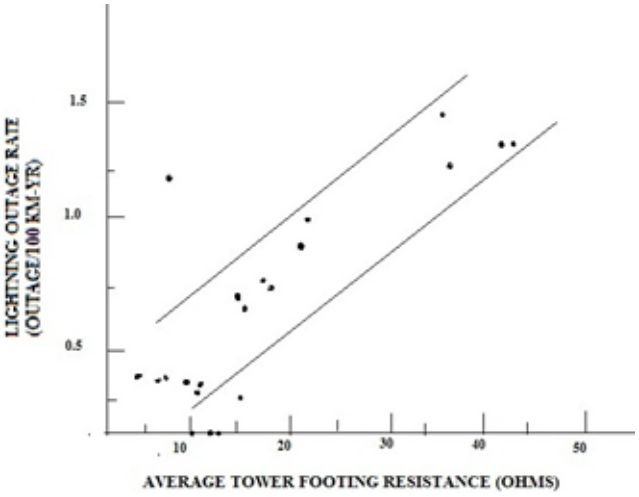


Figure 5. Lightning outage rate vs tower footing resistance for 500 kv line.

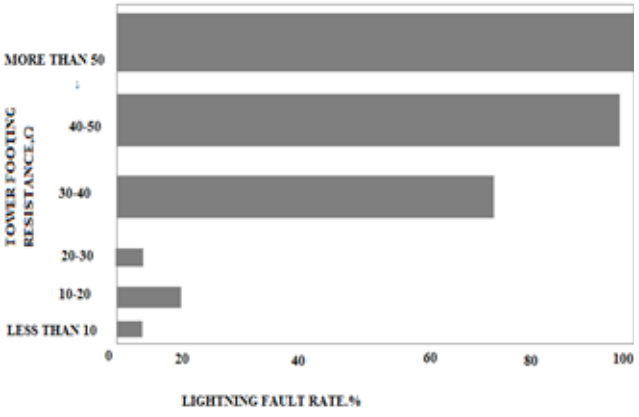


Figure 6. Tower footing resistance vs lightning fault rate.

of 30 Ω on average was one out of every 100 kilometers annually.

Tomohiro *et al.*,[2,5] also investigated the impact of tower footing resistance on the lightning fault rate. Figure 6[12] illustrates this relationship, demonstrating that the lightning fault rate rose as tower footing resistance increased.

6.3 Reduction of Tower Footing Resistance

The following methods can be used to reduce the tower footing resistance:

a. Instead of using a single long-length conductor, use short-length radial conductors bonded at the injection point. This creates the appearance of multiple conductors running in parallel.

b. Connecting vertical electrodes to the ends of radial conductors. When the resistivity of the soil is low to medium, these methods work well.

c. When reversing the direction of horizontal conductors, use wide bending radii. Inductance tends to rise at sharp bends.

d. Using earth-enhancement compounds to increase the resistivity of the soil near the conductors, which will lower the resistance of the tower footing.

6.4 Factors Depending on Tower Footing Resistance

Tower footing resistance depends on

1. Type of electrode configuration
2. Soil resistivity

Soil resistivity has the following ranges.

Table 1. Soil resistivity

Sea water	10 Ωm
Moist Soil	100 Ωm
Loose Soil	1000 Ωm
Clay Rock	>100 Ωm

The different types of earth electrodes are shown in Figure 7[12].

The resistance between the opposing faces of a cube of soil with one-meter-long sides is known as soil resistivity, and it is measured in Ohm-meters. The primary determinant of the charging electrodes resistance and

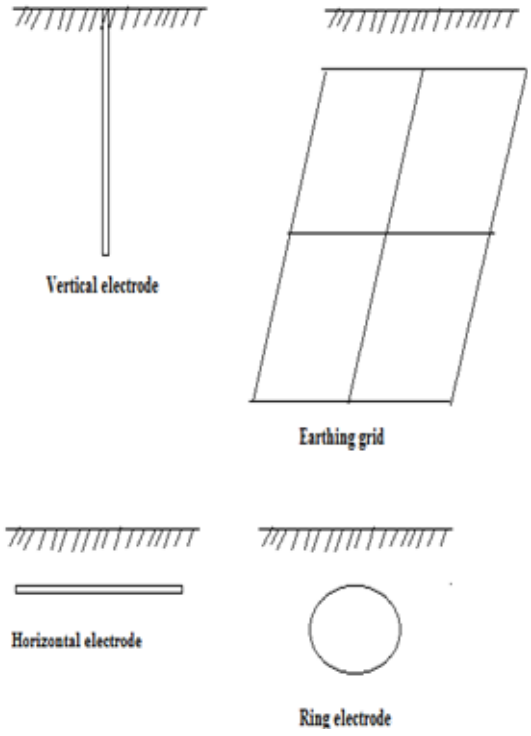


Figure 6. Tower footing resistance vs lightning fault rate.

the depth to which it must be driven in order to achieve low ground resistance is soil resistivity. Soil resistivity is a globally distributed property that fluctuates with the season. The electrolyte in soil is mostly made up of dissolved salt, minerals, and moisture. This electrolyte composition determines the resistivity of the soil

7.0 Conclusion

The proposed concept warns against predicting lightning strikes. With the help of this suggested concept, we can forecast when lightning will strike, allowing us to take preventative measures that will safeguard the entire power system. It also lessens the chance that lightning will endanger human life and safeguard electrical system equipment.

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