METHODOLOGY FOR MEASURING AND ENHANCING TOWER FOOTING IMPEDANCE FOR LIGHTNING PROTECTION IN A TRANSMISSION LINE

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**** IEEE 81-1983 - IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System

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Abstract:

Tower footing resistance are only measured till date to effectively ground the power frequencies. It is important to do the above, but it is also important to measure and maintain low tower footing inductance and impedance to ground higher frequencies like Lightning surges etc. This paper specially relates to the importance and methods of measuring tower footing inductance and impedance.

Lightning strikes tend to terminate on the earth wire and/or tower. Depending on factors such as the conductor, tower, soil impedance and magnitude of the strike, it will result in flashover across an insulator and the resultant fault surge will tends to 'damage' and reduce the life span propagate along the line until it is extinguished or the breaker operates. This movement of the surge currents of associated equipment such as circuit breakers and transformers and impacts network performance adversely. The paper investigates the concept of tower footing impedances and the factors that influence the Earthing impedances. Tower footing impedance needs to be kept uniform and as low as possible to prevent back flashovers across the insulator under lightning conditions. A special focus is given on the importance of Inductance Measurement as Tower Footing Earth parameter. An increase in inductance increases the impedance of tower footing earth and decreases the chance of grounding high frequency surges like Lightning. A good Tower footing impedance only improves the grounding of 50Hz i.e. Power Frequency surges. But to ground High Frequency Lightning surges it is equally important to keep the Tower Footing Impedance and Inductance low.

1. INTRODUCTION

Tower footing impedance is the impedance offered by the metal parts of the tower combined with the ground impedance to the dissipation of current. The significance of a low value of tower footing impedance results in less voltage stresses across the line insulation. A lightning strike to the tower results in high currents flowing into the ground through the tower footing. Electrode configuration sometime improves the ground resistance but majority time detoriates the inductance and thereby the impedance resulting in not easily permitting the grounding of High Frequency surges & lightning. Hence the tower footing impedance value should be as low as possible to prevent line back flashover and maintain the ground potential rise within safety tolerance. The lower the tower footing impedance, the more negative reflections are produced from the tower base towards the tower top. This assists in lowering the peak voltage at the tower top.

Transmission line towers play a crucial role in electrical power transmission as they support/carry the power conductors as well as significantly provide a safe clearance to ground & thus life. In India, a common negligence due to lack of knowledge or generations of usual practice can be observed in tower grounding methodologies. Proper Earthing is of utmost importance from the view of Earthing transient surges due to lightning, if not could compromise the safety & stability of power system and working personnel. Tower earthing impedance could also affect nearby railway or telecommunication systems in account of their proximity to power lines.

FACTORS AFFECTING TOWER FOOTING IMPEDANCE

There are two key factors the affect the tower footing impedances: These are:

(A.)Electrode Configuration

(B.)Soil Resistivity

Good soil resistivity gives room to soil ionization and thermal effects improving ground resistance and enabling quick flow of large currents of power frequency to ground.

An earth electrode is a metal plate, pipe or conductor electrically connected to earth. They are usually made of copper or aluminum or mild steel or galvanized steel. Some of the factors that influence the Earthing are:

(I.) Impedance of the electrode or group of electrode

(II.) Composition of the soil in the immediate Neighborhood.

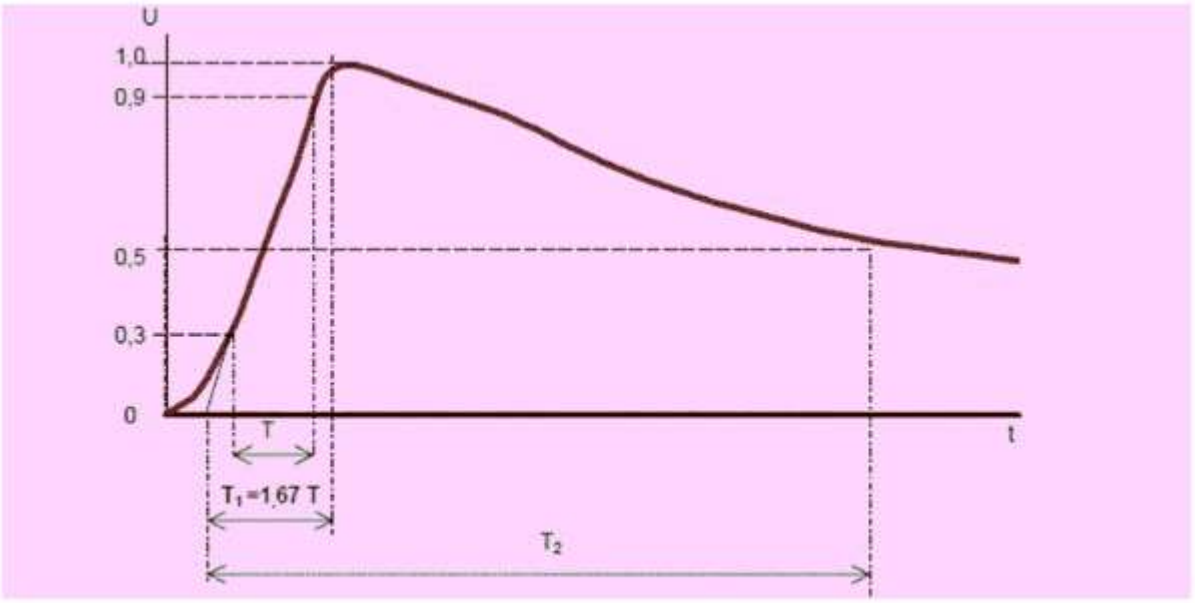
(III.) Temperature of the soil

(IV.) Moisture content of the soil

(V.) Depth of the electrode

2.1 IMPORTANCE OF IMPEDANCE OVER RESISTANCE IN TOWER FOOTING EARTH PARAMETERS

The *degree of lightning protection* depends on the impedance and not the power frequency resistance of the tower footing. For low frequencies, the earth impedance is a purely resistive and rises with constant and equal to its dc impedance. *At high frequency, the* Earthing *behavior is inductive* and the impedance value rises with the square root of frequency.



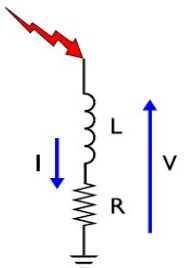
Waveform of a lightning impulse

Hence the top tower earth wire provides a low impedance path only for power/low frequency. In order to ascertain proper tower earthing during lightning/high frequency, it is necessary to find the tower footing inductance (L) & impedance (Z) becomes indispensable.

2.2 MEASUREMENT OF TOWER FOOTING IMPEDANCE

Specialized instruments need to be used to measure tower footing inductance/impedance. These meters should inject a high frequency lightning-like pulse into the base of the tower and measures the voltage response as a function of the injected current to give one an impedance value. This is similar to as the fall of potential method, except that we use higher frequency.

For Example:



Consider a Tower having a DC resistance of 5Ω and inductance of 50μH subject to a typical lightning with peak current and rise time of 50 kA/10μS for 1st pulse and 25 kA / 0.5μS for repeat pulse (as is the case with 75% of lightning condition)

The Voltage rise is sum of Resistive and Inductive term giving a peak voltage rise of

$$V = L\frac{dI}{dt} + IR$$

$$V_R = I \times R = 50kA \times 5\Omega = 250kV \quad + \quad V_L = L\frac{dI}{dt} = 50\mu H \times \frac{50kA}{10\mu s} = 250kV \quad = \mathbf{500\ kV}$$

For the repeat pulse, the results are even more dramatic with a total voltage rise of being over 2500 kV of which is due to inductive term alone. Thus, it is very important to measure impedance of the tower rather than measuring resistance alone. This high KV is a sure cause of back flashover of insulator and Line tripping.

Due to effect of parallel towers there are many parallel paths available for the injected signal and net value of total effective resistance is measured which is very less than actual value. True value of the isolated earth resistance is difficult to measure. It can be measured only if it is literally isolated.

Conventional Earth Testers use a low frequency generator that measures the power system impedance of a tower and adjacent parallel towers. Due to the high frequency nature of lightning, the affected tower is treated as isolated and ignores the further benefit of a reduction of Earthing values. This information is valuable in carrying out optimum economic design of Earthing systems. Because Impedance is an AC property it cannot be easily measured like resistance. Connecting an Ohm meter across the input or output of an amplifier only indicates the DC resistance.

2.3 REASONS FOR HIGH TOWER FOOTING VALUES:

1. Using large bending radii when changing the direction of horizontal conductors.
   Sharp Bends tend to increase the inductance.
2. Longer rods effects directly proportional to resultant Earth impedance value.
3. Soil Resistivity, Soil condition, Moisture
4. Presence of Granulated Soil, Rocky Components etc.
5. Climate Condition.
6. Effect of Altitude.

2.4 EFFECT OF HIGH TOWER FOOTING IMPEDANCE ON EPR [EARTH POTENTIAL RISE]

If a transmission line tower is struck by lightning and the potential of the tower is raised above the voltage impulse strength of the insulator string, a flashover will occur from the tower to a phase conductor which may lead to serious outages of the system. This type of flashover is called back flashover. The electrical impedance of the tower footing is a significant parameter affecting back flashover voltage across the insulator(s) in transmission systems. The individual performance of each tower is important in determining the lightning performance of the transmission line. The overall performance of an entire transmission line is influenced by the individual performance of the towers rather than by the average performance of all the towers together.

2.4.1 Options to improve high tower footing impedance

The tower footing impedance can be minimized by adopting the following techniques:

(I.) Using large bending radii when changing the direction of horizontal conductors. Sharp bends tend to increase the inductance.

(II.) The use of earth enhancing compounds to improve the soil resistivity in the proximity of the conductor, which will reduce the tower footing impedance parallel effect of adjacent towers. To simulate the high frequency response of the single affected tower, a high frequency pulse generator** is required to calculate the towers impedance.

(III.) Introducing parallel paths in the tower footing with respect to earth in order to decrease the equivalent impedance of the particular tower leg.

2.4.2 Remedies for Reducing Resistance/Inductance of Tower Footing Impedance

A. For Resistance:

a. Parallel Earthing

b. Counter poise Earthing instead of pipe Earthing for high soil resistivity

c. Increase the area of counter poise Earthing and Dissolved Salts

d. Increase earth conductance by using chemical compounds

e. Lowering earth rod resistance by suitable materials.

f. Soil Resistivity, Soil condition, Moisture

g. Length / Depth of the ground electrode – double the length, reduce ground resistance by up to 40%

h. Diameter of the ground electrode – double the diameter, lower ground resistance by only 10%

i. An inorganic electrolyte such as sodium chloride, or the like, is injected into the soil surrounding the earth electrode to reduce the earth resistance.

j. Dead Sea water method can reduce 77% of soil resistance.

k. Using a potential control ring in the case of tower lines and redesigning the tower footing to reduce the tower footing resistance in order to meet the limits specified.

B. For Inductance:

l. Lower Inductance value of electrode material by adopting number of short parallel earth electrode instead of single long earth electrode.

m. Multiple paths of Earthing conductors are better for High frequency response.

n. Keeping grounding conductors as straight and as short as possible.

o. To reduce the inductance of the buried bare conductor in order to utilize longer length to contribute in reducing the electrode earth impedance.

p. Installation of additional Transmission line LA's on adjacent towers reduces the probability of flashover due to high impedance of tower footing by taking risk factor in case of double circuit lines.

**It should be noted that a low frequency generator will not give one the same high frequency response and as a result will under read the impedance value since the shield-wire and adjacent towers dampen the frequency response of the injected current pulse.

Note: High footing resistance in the case of few towers may be acceptable in view of the statistical nature of the risk involved. Engineering judgement in assessing how exposed the towers are to lightning has to be exercised in such cases. In the case of a tower on the top of a hill or in the case of an exceptionally tall tower (for Example River crossing tower) every practicable step has to be taken to keep the footing resistance low.

4. CONCLUSIONS

In high voltage, energy transmission is done in overhead lines that are exposed to various factors that may lead to the occurrence of defects which can cause an interruption in the electricity supply.

Various methods are available to calculate, measure and correct tower footing impedance.

Following aspects need to be addressed before choosing a suitable Tester for testing are as follows:

a) Virtual Isolation of Top Earth wire i.e. No need to remove the O/H Earth Wire with HF Method* only as Impulse and other LF methods found having interference effects of adjacent towers.

b) Measures Impedance (Z), Resistance (R) and Inductance (L) in single press of button as per the connection diagram given below.

c) Complete suppression of induction and leakage power frequencies & its harmonics

d) Compact, portable & battery operated system immune to the influence of adjacent tower Earthing, station Earthing etc.

By measuring Inductance, resistance and impedance and having found that these values are within limit, it is assured that even when ever lightning strikes will get grounded. Thus, protecting transmission line components, and continuously giving necessary ground path for the leakage power frequency.

Of the factors that may cause defects, the largest contributor is the lightning stroke. Being a natural phenomenon, it is impossible to prevent its occurrence, but it is possible to estimate the performance of transmission lines to lightning, and plan its construction in order to minimize the effects of the lightning discharge. This research highlights the importance of tower footing impedance on tower voltage rise during a lightning impulse. A lower impedance will lower the tower voltage rise thus reducing the risk of back flashovers. A section of line was modelled in an electromagnetic transient simulation program and its base case lightning performance calculated. The results showed the preferred method to improve line lightning performance was to reduce tower footing impedance. The improvements in tower footing impedance from shorter parallel electrodes outperform other electrode configurations. This is important as shorter electrodes require less material and installation costs compared to traditional longer electrodes. The measured tower footing impedance after installation of electrodes showed the simulated improvement correlated with the actual measured improvement.

* HF Method – Recommendations from IEEE 81-1983 - IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System.

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