LIGHTNING: EARTHING ELECTRODES HARMONIC RESPONSE

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1.- Abstract. The grounding behavior (resistive, capacitive, inductive) to a lightning discharge is related to the electrodes geometrical dimensions [l], shapes, and the soil characteristics (resistivity ρ, permitivity ε, permeability μ). The border between the capacitive and inductive behaviors corresponds to a frequency value (critical frequency f_c), analyzed with the T line model. A practical relation (f_c, ρ/l) is obtained from variable frequency tests made over different electrodes.

2.- Introduction. To analyze the response of a ground electrode when a lightning discharge is scattered, we use the T line model (fig 1):

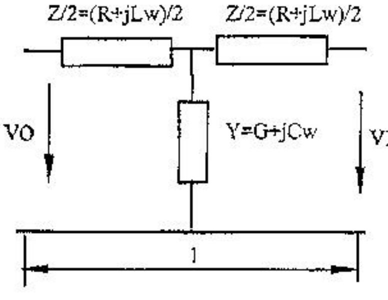

Fig.1. T line model

The expression for the input impedance is:

$$Z=\frac{jL\omega}{2}+\frac{1}{Y}=\frac{jL\omega}{2}+\frac{R_E}{1+jR_EC\omega}=\frac{jL\omega}{2}+\frac{R_E(1-jR_EC\omega)}{1+R_E^2C^2\omega^2}=$$

$$\frac{R_E}{1+R_E^2C^2\omega^2}+j\omega\frac{\left(\frac{L}{2}-R_E^2C+\frac{R_E^2C^2L\omega^2}{2}\right)}{1+R_E^2C^2\omega^2}$$

in which one the complex part value is function of the sing of ($L/2-R_E^2C$), if:

- ($L/2-R_E^2C$)>0 there is an inductive behavior for all frequencies.
- -($L/2-R_E^2C$)<0 there is capacitive behavior for the region between $\omega=0$, $\omega=\omega_c$
- -($L/2-R_E^2C$)=0 resistive behavior for all frequencies.

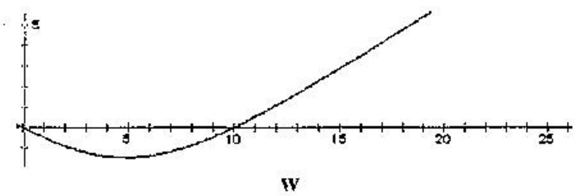

Fig.2 Zi Capacitive-Inductive behavior

For the last case the ω_c and f_c values are:

$$\omega_r=\sqrt{\frac{2R_E^2C-L}{R_E^2C^2L}} \qquad f_r=\frac{1}{2\pi}\sqrt{\frac{2R_E^2C-L}{R_E^2C^2L}}$$

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3.- Critical Frequency. Theoretically, from the f_c expression, one can choose values for R_E, L and C in a way that the grounding system works in capacitive zone for lightning discharge (1-2 Mhz.) [4] Taking in account the values of R_E, L and C are functions of soil characteristics (ρ, μ, ε) and electrodes shape and dimension, we can write $f_c = f_c(\rho, \mu, \varepsilon, l)$. To evaluate this expression, not in a theoretically way, we have done field tests. According the fall voltage method (fig.3) we injected an ac current wave in 1 using a frequency multifunction waveform synthesizer *Rohde and Schwarz* with output impedance of 50 Ω and a coaxial wire RG58U. We measured the voltage V (figure 4 to 6) in different electrodes and soils with a Fluke99 Scopemeter.

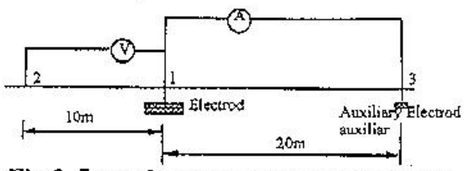

Fig.3. Impedance measurement circuit

We linked the f_c values to ρ/l ones, (l electrode length). In the lasts tests (fig.7) we have recorded the voltage and current simultaneously. The current (A) has been measured by a coupled current probe A6312-DC and a current probe amplifier AM508B.

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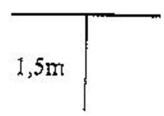
- *Electrode 1*: ρ=50 Ω.m, l=1,5m



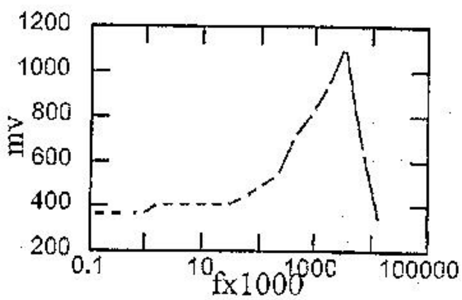
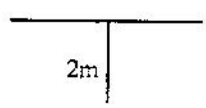


Fig.4. Frequency response electrode 1

f_c=50kHz, ρ/l=33,33

- *Electrode 2*: ρ=50 Ωm, l=2m



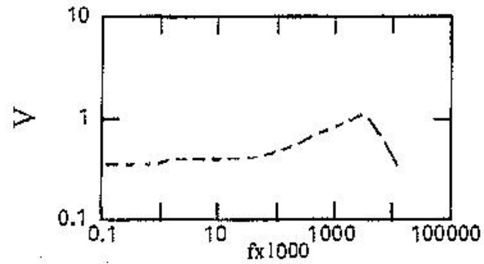
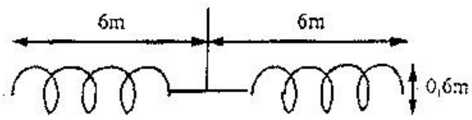


Fig.5. Frequency response electrode 2

f_c=50kHz, ρ/l=25

- *Electrode 3*: ρ=200 Ωm, l=6m



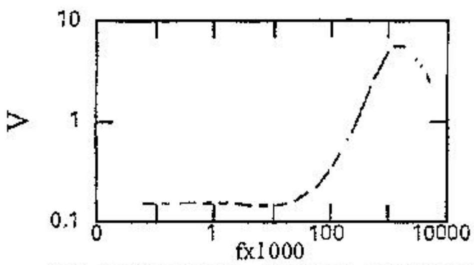
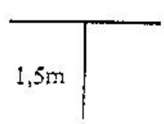


Fig.6. Frequency response electrode 3

f_c=20kHz, ρ/l= 33,33

- *Electrode 4*: ρ=800 Ωm, l=1,5m



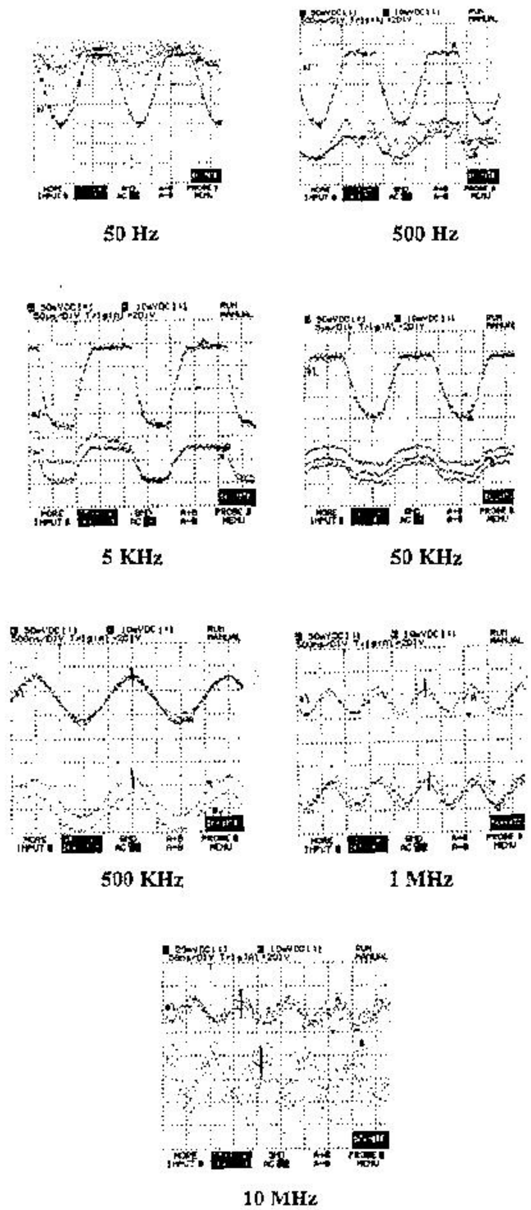


Fig.7. Frequency response electrode 4

One can observe that at 10 MHz the current lag voltage.

f_c=5 MHz, ρ/l= 533,33

Recording (f_c-ρ/l) we obtain fig.8

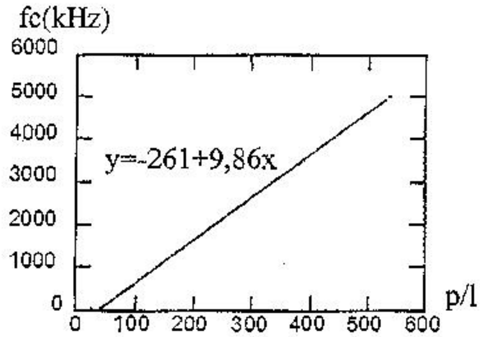


Fig.8. Relationship f_c-ρ/l

for 1-2 MHz the ratio ρ/l must between 120-220, and higher for higher frequencies scattered, existing a critical length (l_c) for every one f_c. If l is longer that l_c the electrode behavior is inductive.

Example: f_c 1MHz, ρ/l =120

ρ ($\Omega \cdot m$) 300 500 1000

l_c(m) 2,5 4,17 8,333

figures according with obtained in [3]

4.- Conclusions.

- The border between the capacitive and inductive behavior for a grounding system is related to the critical frequency.
- The critical frequency f_c is a function of soil characteristics and electrode dimensions (ρ, ε, μ, l).
- There is a relation between f_c and ρ/l. Are necessary more tests (different electrodes shapes and lengths, soils) to consolidate the relation.
- For each f_c there is an electrode critical length (l_c); for $l > l_c$ the electrode behavior is inductive.

5.- Bibliography

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