REFERENCES AND REASONING ABOUT THE ANGULAR COVERAGE AND PROTECTION OF THE HIGH-EFFICIENCY FARAGAUSS LIGHTNING ROD LINE COMPARED TO THE STANDARD LINE

BACKGROUND:

The theoretical basis that allows differentiating the effective coverage advantage of the high-efficiency Faragauss lightning rod line is explained below.

REASONING:

1 1.- The high-efficiency Faragauss lightning rod line is supported by the polarization factor of the Faragauss electrode called magnetoactive, as this type of electrode provides a predominant polarization factor with an average value of 85 meters in radius for all its models. This allows us to obtain, through its value opposite to the ground (lightning rod tip), a factor called power vector, which, together with other variables, we present below through a schematic drawing.

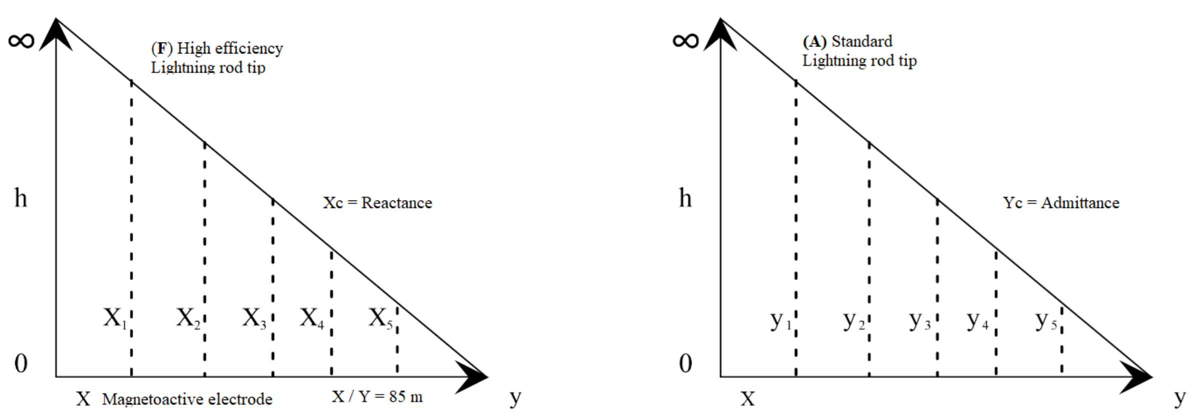

Figure 1: Reasoning on the operation difference between a high-efficiency lightning rod system (F) and a standard system (A).

Conclusion:

The goal is to improve the protective coverage of the lightning rod system by shortening the angular factor to thereby decrease the value of the adjacent side (h) while increasing the actual value of the hypotenuse (L).

$$H_A = \frac{1}{\mu} \nabla \times A \quad \text{(10-15a)}$$

$$E_A := \frac{1}{j\omega\epsilon} \nabla \times H_A = \frac{1}{j\omega\mu\epsilon} \nabla \times \nabla \times A \quad \text{(10-15b)}$$

$$\nabla \times \nabla \times A - \omega^2 \mu\epsilon A = \mu J - j\omega\mu\epsilon \nabla \psi_e \quad \text{(10-15c)}$$

In a source-free region, (10-15c) reduces to

$$\nabla \times \nabla \times A - \omega^2 \mu\epsilon A = -j\omega\mu\epsilon \nabla \psi_e \quad \text{(10-15d)}$$

2.- Why should I use a high-efficiency Faragauss lightning rod system?

The potential vector chapter between a system (F) and one (A) is governed by capacitive reactance (Xc) for the high-efficiency one, and by admittance (y) for the standard one, understanding that both have a free zone which is the distance "n" between the magnetoactive electrode immersed in earthing and the tip of the lightning rod at a distance (h) with respect to x.

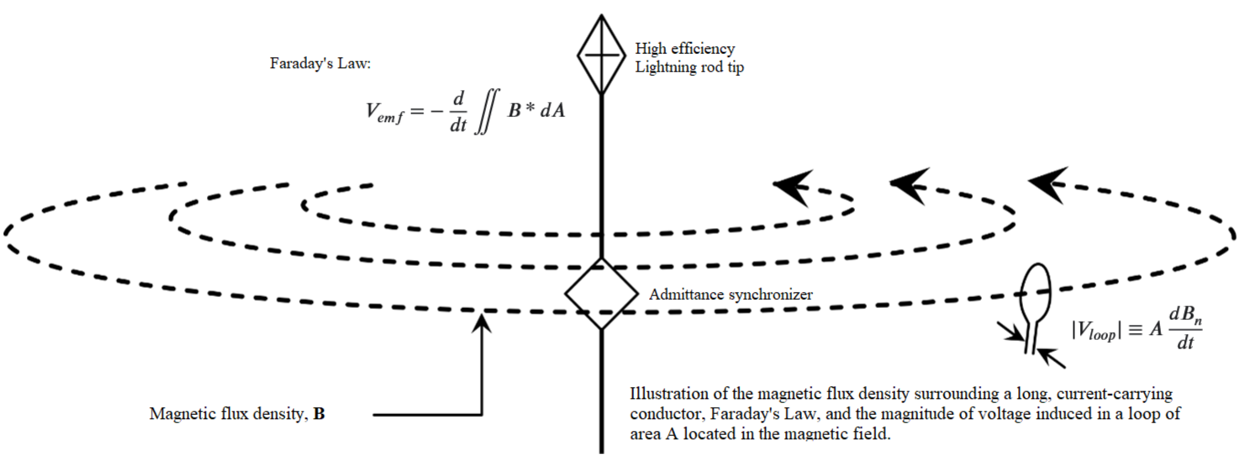

Figure 2: Formulas applied by the high-efficiency lightning rod system according to Faraday's law in a free zone determined by an earthing scalar.

Synthesis: The high-efficiency lightning rod system increases its efficiency through Faraday's law, described in figure 2, by modifying the angle of protection of the lightning rod, the magnetic flux density applied by the coupler to the lightning rod tip specifically created as a high-efficiency lightning rod tip considering its horizontal rods that allow the creation and application of Ohm's law by the voltage induced in the specific areas named coupler and earthing.

3.- The two modes of operation of the aforementioned lightning rods are, in the high-efficiency one, in reactance mode (x), and the standard lightning rod system in admittance mode (y); both models are governed by a set of variables that derive from events characterized through a discipline of measurements made by various specialized laboratories around the world, starting from the 1975 Berger's parameters table.

Lightning current parameters

			Percentage of cases exceeding tabulated value		
Number of events	Parameters	Unit	95%	50%	5%
	Peak current (minimum 2kA)				
101	Negative first strokes	kA	14	30	80
135	Negative subsequent strokes	kA	4.6	12	30
20	Positive first strokes (No positive subsequent strokes recorded)	kA	4.6	35	250
	Charge				
93	Negative fist strokes	C	1.1	5.2	24
122	Negative subsequent strokes	C	0.2	1.4	11
94	Negative flashes	C	1.3	7.5	40
26	Positive flashes	C	20	80	350
	Impulse charge				
90	Negative first strokes	C	1.1	4.5	20
117	Negative subsequent strokes	C	0.22	0.95	4.0
25	Positive first strokes	C	2.0	16	150
	Front duration (2kA to peak)				
89	Negative first strokes	µs	1.8	5.5	18
118	Negative subsequent strokes	µs	0.22	1.1	4.5
19	Positive first stroke	µs	3.5	22	200
	Maximum di/dt[b]				
92	Negative first strokes	kA μs^{-1}	5.5	12	32
122	Negative subsequent strokes	kA μs^{-1}	12	40	120
21	Positive first stroke	kA μs^{-1}	0.20	2.4	32
	Stroke duration (2kA to half-value)				
90	Negative first strokes	µs	30	75	200
115	Negative subsequent strokes	µs	6.5	32	140
16	Positive first stroke	µs	25	230	2000
	Action integral ($\int i^2 dt$)				
91	Negative first strokes	A^2s	6.0×10^3	5.5×10^4	5.5×10^5
88	Negative subsequent strokes	A^2s	5.5×10^2	6.0×10^3	5.2×10^4
26	Positive first stroke	A^2s	2.5×10^4	6.5×10^3	1.5×10^7
	Time interval				

133	Between negative strokes	ms	7	33	150
	Flash duration				
94	Negative (Including single-stroke flashes)	ms	0.15	13	1100
39	Negative (Excluding single-stroke flashes)	ms	31	180	900
24	Positives (Single-stroke flashes only)	ms	14	85	500

[a] Impulse charge is the charge contained in the rapidly changing part of the return stroke waveforms. It is somewhat subjective.
[b] Maximum current derivative is likely to be underestimated because measurements were made by photographing oscilloscope traces of finite width. Typical values for first and subsequent strokes to small, well-grounded objects are thought to be near 100 kA μs^{-1}.
Adapted from Berger et al. (1975)

Figure 3: Table of lightning parameters characterized in current mode (I).

4.- Potential vectors in high-efficiency mode and in standard mode.

$$E = E_F + E_A = -\frac{1}{\epsilon}\nabla \times F + \frac{1}{j\omega\epsilon}\nabla \times H_A = -\frac{1}{\epsilon}\nabla \times F + \frac{1}{j\omega\mu\epsilon}\nabla \times \nabla \times A \quad (10\text{-}16a)$$

$$H = H_F + H_A = -\frac{1}{j\omega\mu}\nabla \times E_F + \frac{1}{\mu}\nabla \times A = \frac{1}{j\omega\mu\epsilon}\nabla \times \nabla \times F + \frac{1}{\mu}\nabla \times A \quad (10\text{-}16b)$$

Where F and A are, respectively, solutions to

$$\nabla \times \nabla \times F - \omega^2\mu\epsilon F = \epsilon M - j\omega\mu\epsilon\nabla\psi_m \quad (10\text{-}16c)$$

$$\nabla \times \nabla \times A - \omega^2\mu\epsilon A = \mu J - j\omega\mu\epsilon\nabla\psi_\epsilon \quad (10\text{-}16d)$$

Which for a source-free region (M = J = 0) reduce to

$$\nabla \times \nabla \times F - \omega^2\mu\epsilon F = -i\omega\mu\epsilon\nabla\psi_m \quad (10\text{-}16e)$$

$$\nabla \times \nabla \times A - \omega^2\mu\epsilon A = -j\omega\mu\epsilon\nabla\psi_\epsilon \quad (10\text{-}16f)$$

Figure 4: The previous formulas show us the behavior of both lightning rod models in both the electric field and the magnetic field. Therefore, the operation of the high-efficiency model is characterized in reference to the standard model.

The aforementioned formulas allow us to highlight the work of the free zone in the presence of a high-efficiency lightning rod tip, resulting in increased efficiency in coverage and in the complex summation of the reactance itself.

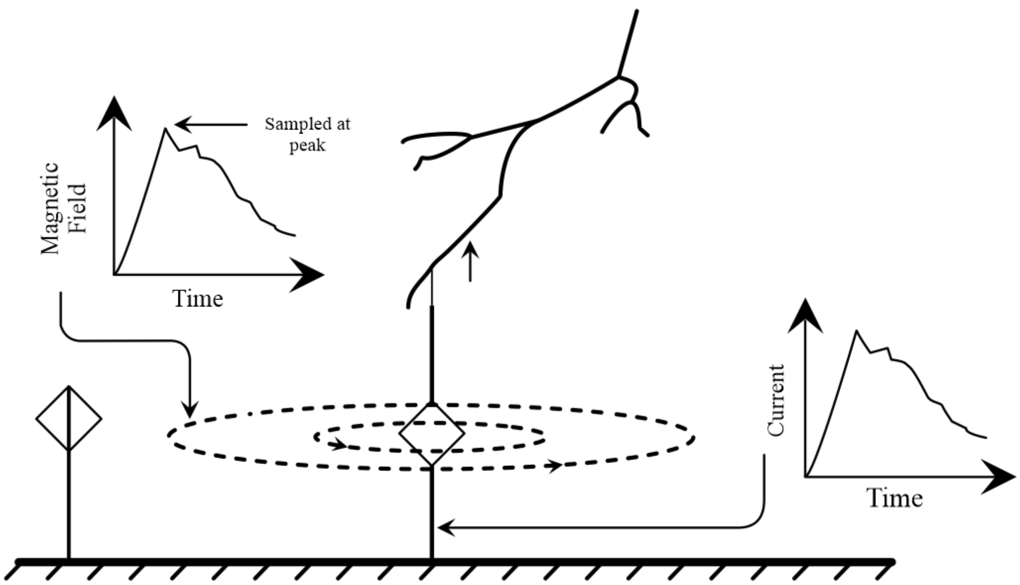

Figure 5: This figure schematically demonstrates the magnetic field values in protection mode and the current value in destruction mode, both based on the time domain, thus demonstrating the great advantage of using a high-efficiency lightning rod system.

5.- Demonstration of the high-efficiency lightning rod system compared to the standard system using the Helmholtz scalar equation.

$$F = \hat{a}_r F_r(r, \hat{\theta}, \phi) \quad (10\text{-}17a)$$

$$A = 0 \quad (10\text{-}17b)$$

Since F_r is not a solution to the scalar Hemlholtz equation

$$\nabla^2 F = \nabla^2(\hat{a}_r F_r) \neq \hat{a}_r \nabla^2 F_r \quad (10\text{-}18)$$

We will resort, for a source-free region, to (10-16e).

Expanding (10-16e) using (10-17a) leads to

$$\nabla \times F = \nabla \times (\hat{a}_r F_r) = \hat{a}_\theta \frac{1}{r \sin\theta} \frac{\partial F_r}{\partial \phi} - \hat{a}_\phi \frac{1}{r} \frac{\partial F_r}{\partial \theta} \quad (10\text{-}19a)$$

$$\nabla \times \nabla \times F = \hat{a}_r \{ \frac{1}{r \sin\theta} [\frac{\partial}{\partial \theta} (-\frac{\sin\theta}{r} \frac{\partial F_r}{\partial \theta}) - \frac{\partial}{\partial \phi} (\frac{1}{r \sin\theta} \frac{\partial F_r}{\partial \phi})]\}$$

$$+ \hat{a}_\theta [\frac{1}{r} (\frac{\partial^2 F_r}{\partial r \partial \theta})] + \hat{a}_\phi (\frac{1}{r \sin\theta} \frac{\partial^2 F_r}{\partial r \partial \phi}) \quad (10\text{-}19b)$$

$$\nabla \psi_m = \hat{a}_r \frac{\partial \psi_m}{\partial r} + \hat{a}_\theta \frac{1}{r} \frac{\partial \psi_m}{\partial \theta} + \hat{a}_\phi \frac{1}{r \sin\theta} \frac{\partial \psi_m}{\partial \phi} \quad (10\text{-}19c)$$

Thus for the r, θ , and ϕ components, (10-16e) reduces to

$$\frac{1}{r \sin\theta} [-\frac{\partial}{\partial \theta} (\frac{\sin\theta}{r} \frac{\partial F_r}{\partial \theta}) - \frac{\partial}{\partial \phi} (\frac{1}{r \sin\theta} \frac{\partial F_r}{\partial \phi})] - \beta^2 F_r = -j\, \omega\mu\epsilon \frac{\partial \psi_m}{\partial r} \quad (10\text{-}20a)$$

$$\frac{1}{r} \frac{\partial^2 F_r}{\partial r \partial \theta} = -j \frac{\omega\mu\epsilon}{r} \frac{\partial \psi_m}{\partial \theta} \Rightarrow \frac{\partial^2 F_r}{\partial r \partial \theta} = \frac{\partial}{\partial \theta} (\frac{\partial F_r}{\partial r}) = \frac{\partial}{\partial \theta} (-j\, \omega\mu\epsilon\, \psi_m) \quad (10\text{-}20b)$$

$$\frac{1}{r \sin\theta} \frac{\partial^2 F_r}{\partial r \partial \phi} = -j \frac{\omega\mu\epsilon}{r \sin\theta} \frac{\partial \psi_m}{\partial \phi} \Rightarrow \frac{\partial^2 F_r}{\partial r \partial \phi} = \frac{\partial}{\partial \phi} (\frac{\partial F_r}{\partial r}) = \frac{\partial}{\partial \phi} (-j\omega\mu\epsilon\, \psi_m) \quad (10\text{-}20c)$$

Where $\beta^2 = \omega^2 \mu\epsilon.$ The last two equations, (10-20b) and (10-20c), are satisfied simultaneously if

$$\frac{\partial F_r}{\partial r} = -j\omega\mu\epsilon\psi_m \Rightarrow \psi_m = -\frac{1}{j\omega\mu\epsilon} \frac{\partial F_r}{\partial r} \quad (10\text{-}21)$$

With the preceding relation for the scalar potential ψ_m , we need to find an uncoupled differential equation for F_r To do this, we substitute (10-21) into (10-20a), wich leads to

$$-\frac{1}{r^2 sin\,\theta}\frac{\partial}{\partial\theta}(sin\,\theta\frac{\partial F_r}{\partial\theta}) - \frac{1}{r^2 sin^2\theta}\frac{\partial^2 F_r}{\partial\phi^2} - \beta^2 F_r = \frac{\partial^2 F_r}{\partial r^2} \quad (10\text{-}22)$$

Or

$$\frac{\partial^2 F_r}{\partial r^2} + \frac{1}{r^2 sin\,\theta}\frac{\partial}{\partial\theta}(sin\,\theta\frac{\partial F_r}{\partial\theta}) + \frac{1}{r^2 sin^2\theta}\frac{\partial^2 F_r}{\partial\phi^2} + \beta^2 F_r = 0 \quad (10\text{-}22a)$$

Which can also be written in succinct form as

$$\boxed{(\nabla^2 + \beta^2)\frac{F_r}{r} = 0}$$

Figure 6: The high-efficiency solution of lightning rod systems under this mode is given in its calculation method for both the transverse electric field and the transverse magnetic field. Therefore, by applying the Helmholtz equation in a high-efficiency lightning rod system, the scalar of the vectors is given by the ends of the free zone, thus having the presence of two vectors, one called lightning rod tip and another called magnetoactive electrode. The Faragauss coupler works as a transverse electromagnetic device according to the random values present in an atmospheric discharge.

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