Rolling Spheres Method for Lightning Protection

EPOW 6860

Surge Phenomena

Fall 2007

Joe Crispino

Design Problems

- The unpredictable, probabilistic nature of lightning.
- Lack of data due to infrequencies of lightning strikes in switchyards.
- Complexity in analyzing system in detail ($$$).
- No known practical method of providing 100% shielding.

Design Procedure

- *Risk Assessment*
  - Evaluate the importance and value of the facility.
  - Consequences of a direct lightning strike.
- *Location*
  - Frequency and severity of thunderstorms in area.
  - Exposure due to surrounding area.
- Method of protection (surge arrestors, shielding).
- Evaluate the effectiveness and cost of design.

Design Methods

- *Empirical Design Methods (Classical)*

  Assume that the shielding device (wire or mast) can intercept all the lightning strokes arriving over the subject area if the shielding device maintains a certain geometrical relation (separation and differential height) to the protected object.

Design Methods

- *Electrogoemetric Design Methods (EGM)*
  - Attractive effect of the shielding device is a function of the amplitude of the current of the lightning stroke.
    - Less intense strokes get by.
    - More intense strokes get intercepted.
    - Only allow strokes that will not cause flashover or damage to protected object.

Design Methods

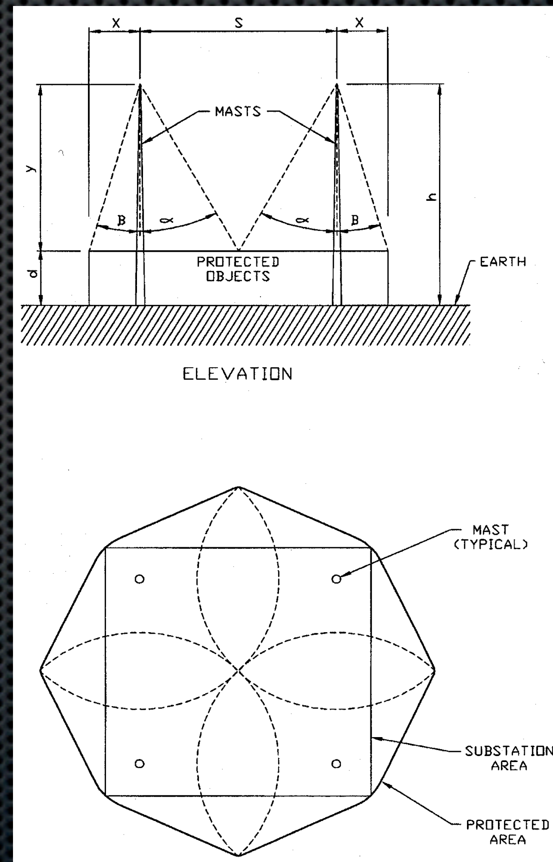
- *Empirical Design Methods (Classical)* - 69kV & below
  - **Fixed Angles Method (32.5%)**
  - Empirical Curve Method (12.6%)
- *Electrogeometric Methods (EGM)* - 345kV & above
  - **Rolling Sphere Method (16.3%)**
  - Mousa's Software Subshield (21.1%)

Fixed Angle Method

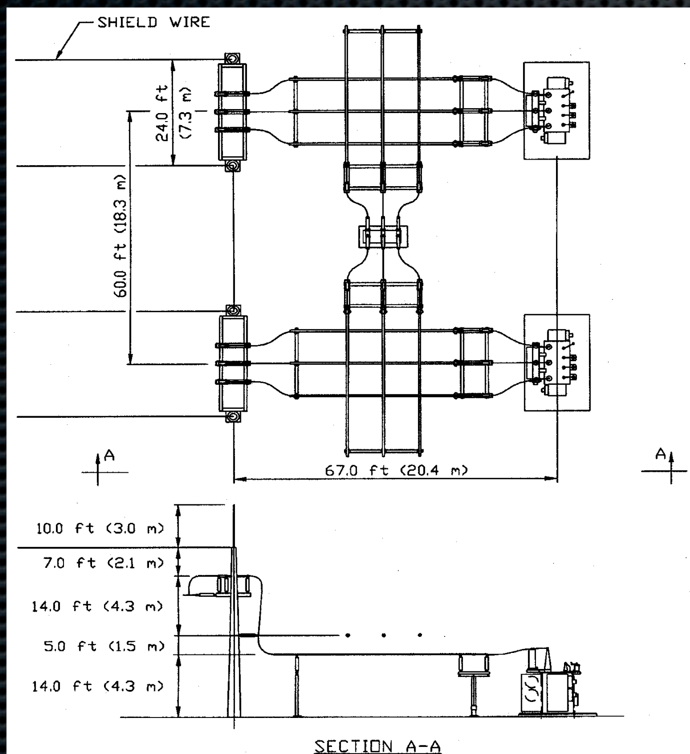
- “Rule of thumb” method.
- Uses vertical angles to determine:
  - Total number of protection devices.
  - Position
  - Height

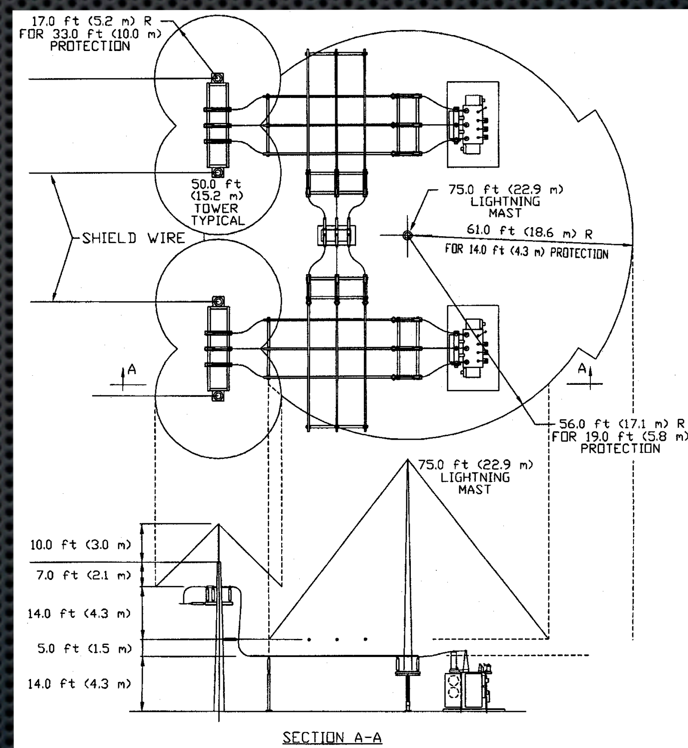
Fixed Angle Method

- Independent of voltage, BIL, surge impedance, stroke magnitude, GFD, insulation flashover, etc.
- α is commonly 45°.
- β is usually 30°-45°.



Fixed Angle Method





Electrogeometric Model

- 1950's - First 345kV transmission line.
    - Protection utilized empirical methods.
    - Outages due to lightning were much higher than expected.
    - Led to extensive amount of research.
        - E. R. Whitehead - EGM

Electrogeometric Model

- 1963 - Young, et al. - EGM
- 1973 - Whitehead & Gilman
  - Most significant research.
  - Only for transmission lines.
- 1976 - Mousa - Subshield program
  - Integrated substations into EGM.
- 1977 - Lee - Rolling Sphere

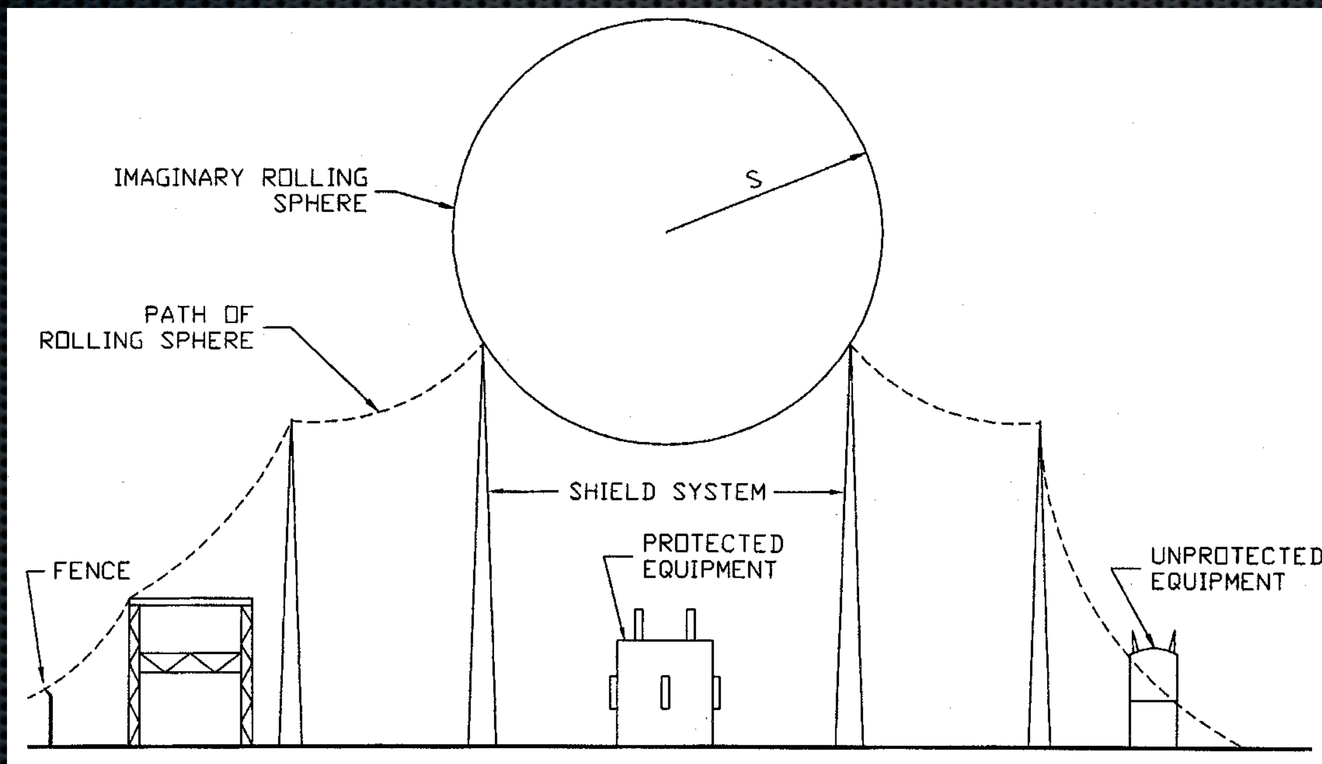
Rolling Sphere Method

- Developed by Ralph H. Lee in 1977 for shielding buildings and industrial plants.
- Extended by J.T. Orrell for use in substation design.
- Builds on basic principles and theories from Whitehead.

Rolling Sphere Method

- Use an imaginary sphere of radius *S* over the surface of a substation.
- The sphere rolls up and over (and is supported by) lightning masts, shield wires, substation fences, and other grounded metallic objects that can provide lightning shielding.
- A piece of equipment is said to be protected from a direct stroke if it remains below the curved surface of the sphere.

Rolling Sphere Method



Rolling Sphere Method

- Requires:
  - Surge impedance (Z_S).
  - Allowable stroke current (I_S).
  - Used to calculate striking distance, S. This determines the spheres radius.

Rolling Sphere Method

- Surge Impedance

$$R_C \ln\left(\frac{2h}{R_C}\right) - \frac{V_C}{E_0} = 0$$

$$Z_S = 60\sqrt{\ln\left(\frac{2h}{R_C}\right)\ln\left(\frac{2h}{r}\right)}$$

R_C = Corona radius

r = radius of the conductor

h = Average height of conductor

V_C = BIL

E_0 = Limiting corona gradiant, $1500\,{}^{\mathrm{kV}}\!/_{\mathrm{m}}$

Rolling Sphere Method

- Stroke Current

$$I_S = \frac{1.1(\mathrm{BIL})}{Z_S/2} = \frac{2.2(\mathrm{BIL})}{Z_S}$$

$$I_S = \frac{0.94(\mathrm{CFO})1.1}{Z_S/2} = \frac{2.068(\mathrm{CFO})}{Z_S}$$

Rolling Sphere Method

- Strike Distance - the probability of the stroke tip terminating on an object *S* far away is greater than the probability of it striking another object *S+n* away.

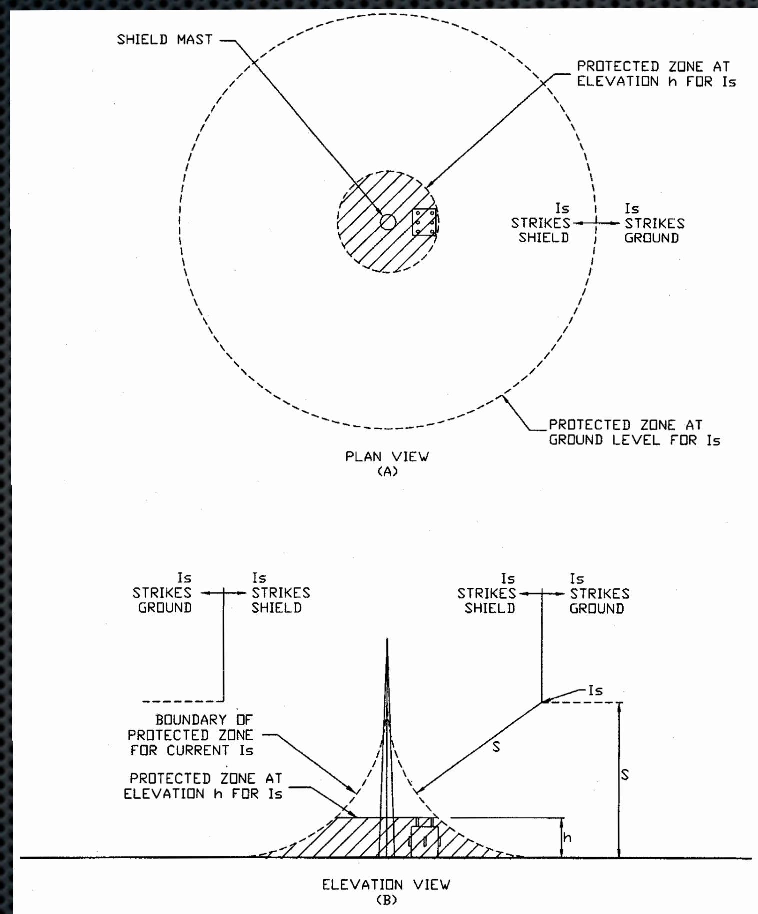
$$S_m = 8kI^{0.65}$$

$$S_f = 26.25kI^{0.65}$$

$$k = 1 \quad \text{Ground or Wires}$$

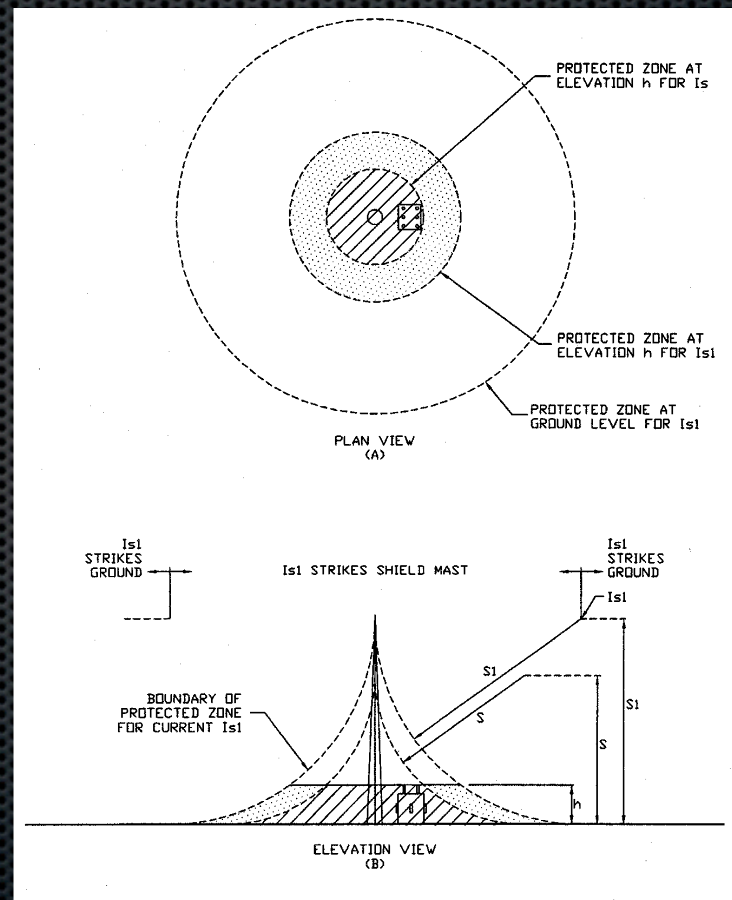
$$k = 1.2 \ \text{Lightning Masts}$$

Rolling Sphere Method



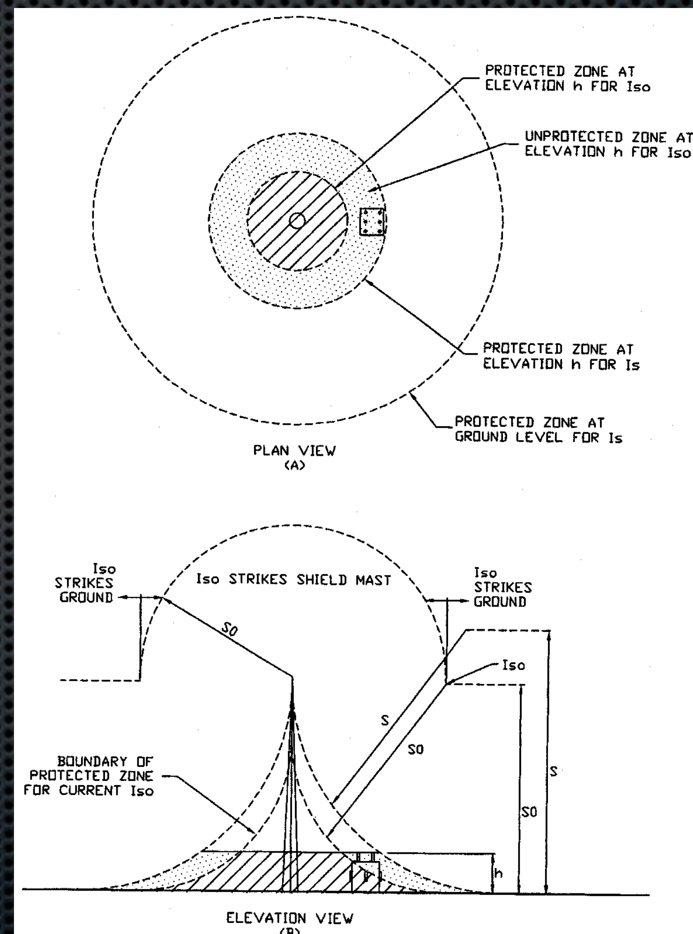
Rolling Sphere Method

- BUT WAIT!!!!!
  - What if the actual stoke current is greater than calculated?



Rolling Sphere Method

- What if the stroke current is less?
- As long as the stroke current was calculated using the BIL of the equipment, the equipment will be protected.



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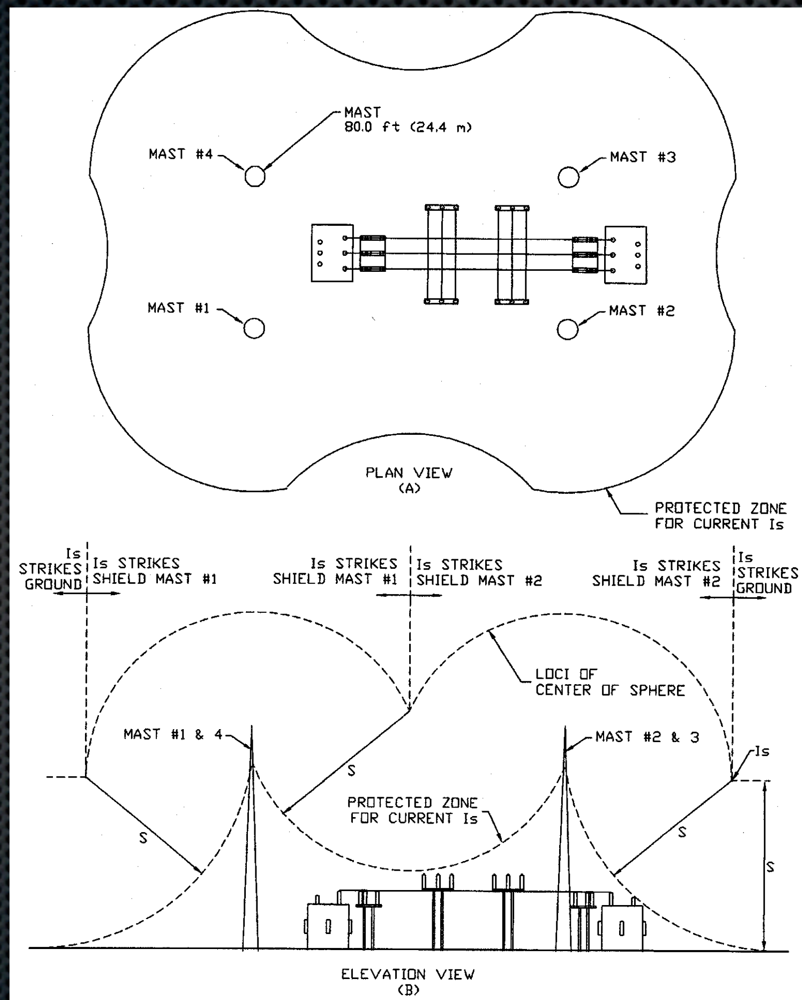

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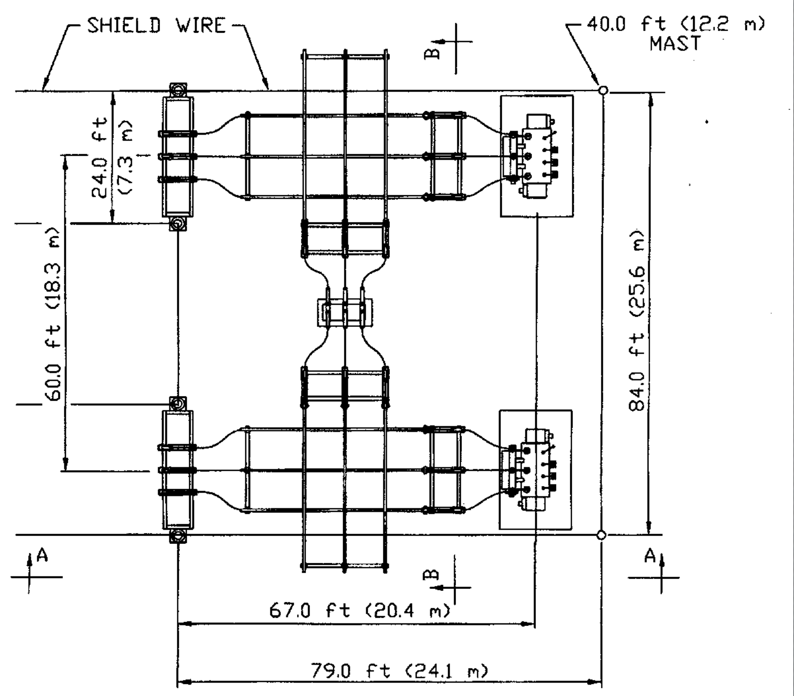

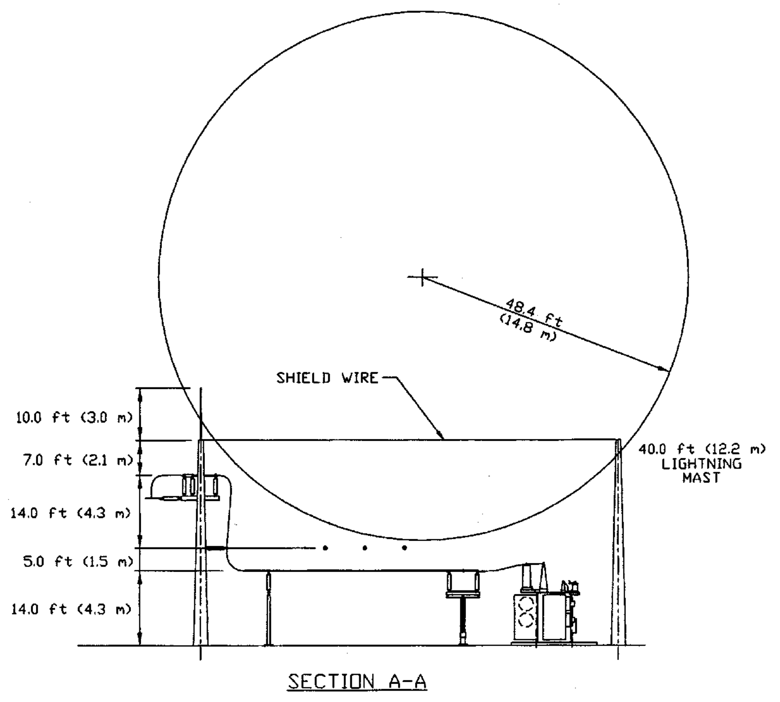

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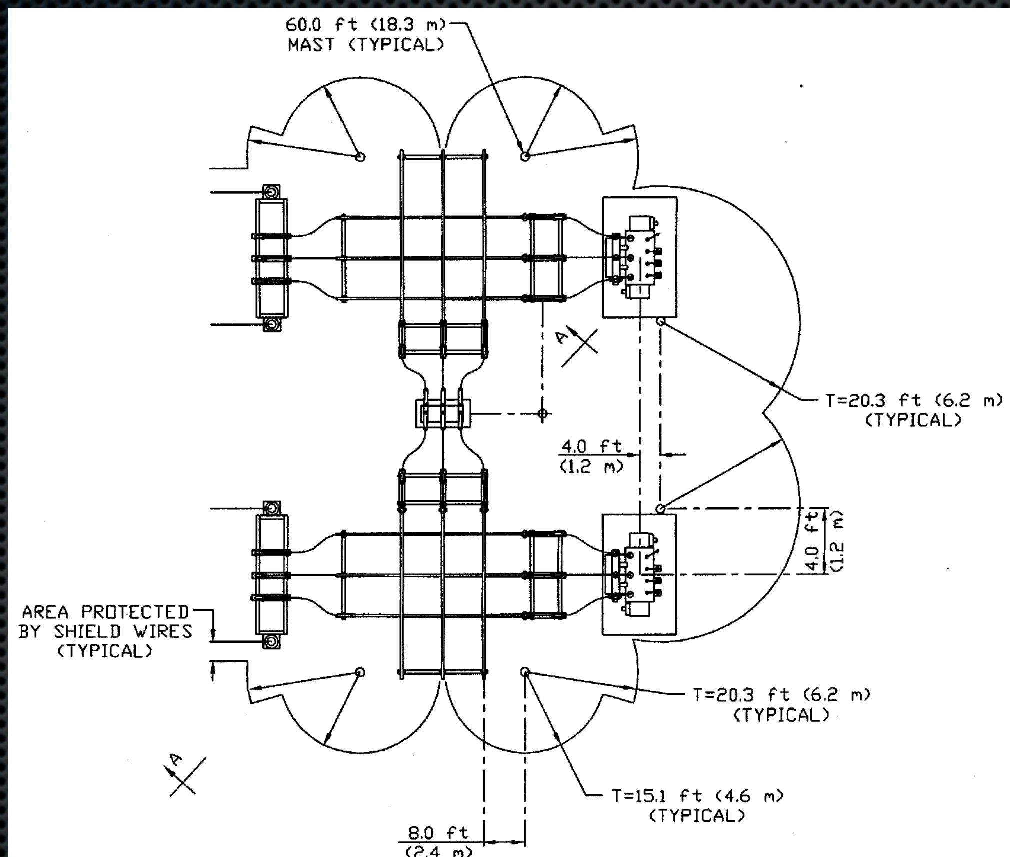

References

- IEEE Std. 998-1996. *IEEE Guide for Direct Lightning Stoke Shielding of Substations*.
- Greenwood, A. *Electrical Transients in Power Systems*.
- Abdel-Salam, M., et al. *High Voltage Engineering - Theory and Practice*.
- Zipse, D. *Lightning Protection Systems: Advantages and Disadvantages.* IEEE Transactions on Industry Applications, Vol. 30, No. 5, September/October 1994.