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A Comparative Analysis of Lightning Rod and Early Streamer Emission Equipment for Direct Stroke Lightning Protection on 765/400 kV AIS

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Abstract — The substation equipments can be protected by shield wires and lightning rods from direct strokes occurring due to lightning phenomenon. This paper introduces a protection scheme for substation against lightning strokes by Early Streamer Emission Equipment and ordinary lightning rod using Rolling Sphere Method. Early Streamer Emission Equipment is relatively good and the chances of damage due to lightning are less. The system gives more powerful assurance against lightning strokes. Moreover, it has a simple methodology and the most proficient equipment to plan a powerful lightning protection. This paper describes a contextual analysis of 765/400 kV substation.

Keywords- Direct stroke lightning protection, Rolling Sphere Method, Early Streamer Emission Equipment, Lightning Rod.

I. INTRODUCTION

Lightning strokes can create basic damage and can lead to failure of the equipment. The characteristics of lightning stroke varies from range to region. The lightning occurs due to an emission of electricity from cloud to cloud, from cloud to ground or from ground to cloud. When the lightning occurs to ground, it picks a way with low resistance. According to the IEEE standard [1] the stroke happens in basic two stages, (a) Ionization of the air encompassing the center and the advancement of stepped leaders, which proliferate charge from the cloud into the air. (b) Return stroke, as indicated by the IEEE standard [1], "the return stroke is an extremely bright streamer that propagates upward from the earth to the cloud following the same path as the main channel of the downward stepped leader".

Open air substations and switchyards are protected against direct strokes lightning by using shield wires, masts and lightning rod. The strategies to decide the protected territory of shield wires and lightning rod are mostly like this, parts:

(a) The classical empirical method.
(b) The electro-geometric model.

In electro-geometric model, Rolling Sphere Method is widely used for calculation of direct stroke lightning [2]. The capability of ordinary lightning rod depends upon production of corona effect near its tip due to electric field produced in the lightning storm. The downward leader due to cloud lightning and upward leader due to corona heating produce highly conductive arc that will meet at a common point, that will produce new leader at the gap and produce high discharge current to flow from conducting path to ground.

In this paper, protection scheme for a 765/400 kV substation against direct strokes lightning is introduced by using lightning rod. In order to check the practicality and effectiveness of the proposed plan, Early Streamer Emission Equipment and ordinary lightning rod by Rolling sphere method have been compared in respect of radius of protection, in which only 765 kV bay is considered for calculation. Result shows only consideration of 765 kV bay. Remaining portion of 765/400 kV substation will be calculated as per same method.

II. DSLP DESIGN FOR 765/400 KV SUBSTATION

Direct stroke lightning protection (DSLP) for the 765/400 kV substation is done by putting simple lightning rod on each column structure in all bays of switchyard. The structure height is 46m and the length of lightning rod is 3m for 765 kV bay. The structure height is 29m and the length of lightning rod is 3m for 400 kV bay.

In this paper, direct stroke lightning protection is firstly designed by using lightning rod and secondly by using early streamer emission equipment. These two equipments are compared as per radius of protection covered by them using rolling sphere method. The height of early streamer emission equipment with lightning rod is 3m.

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III. DSLP DESIGN FOR LIGHTNING ROD USING ROLLING SPHERE METHOD

A. Principle of rolling sphere method

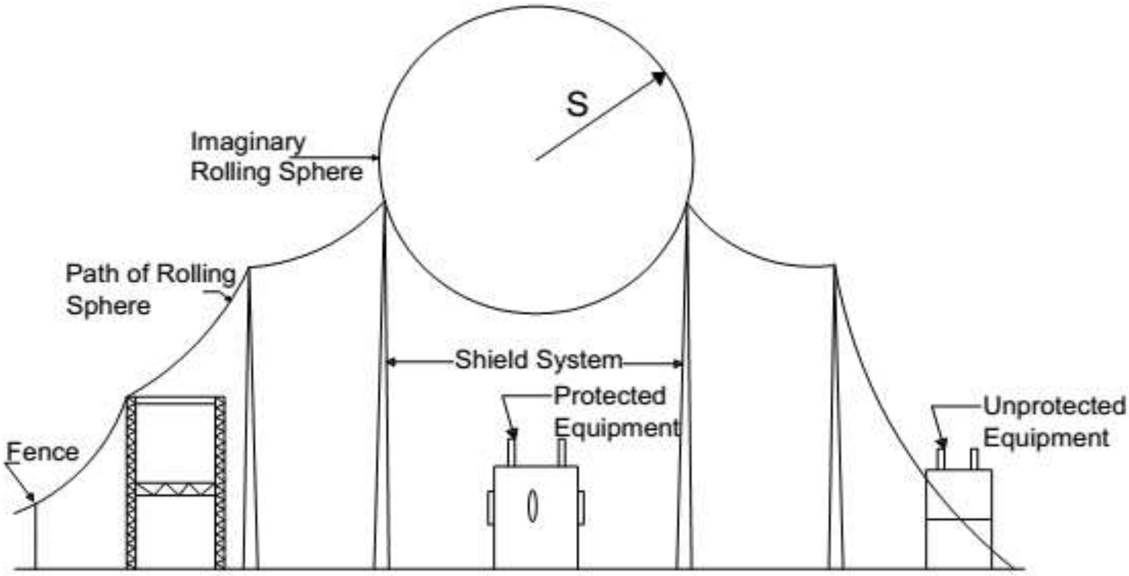

Figure 1. Principle of Rolling Sphere Method [1]

As shown in Figure. (1) The principle of Rolling Sphere Method can be mentioned as "An imaginary sphere of radius S is being rolled over the surface of a substation. The sphere rolls up and over (and is supported by) shield wires, lightning masts, substation fences. This method is based on the Electro-geometric Model and other grounded equipments that can be covered by shielding. A portion of equipment is said to be protected from a direct stroke if it remains below the curved surface of the sphere by virtue of the sphere being elevated by other device or shield wires. Moreover, the equipment that touches the rolling imaginary sphere or penetrates its surface is not protected in this scheme" [3]. This fundamental principle is represented in Figure. (1).

B. Design of substation protected area using lightning rod

The design of DSLP for Air Insulated Substation by lightning rod considering Rolling Sphere Method is given below. The substation has ACSR Quad Bull conductor for 765 kV and ACSR Quad Bersimis conductor for 400 kV. The limiting corona gradient (E_0) is 1500 kV/m for both the conductors. Only Section-1 (as shown in Fig.3) is calculated below:

Table 1. Conductor Input Data

Description	Value	Value
Type	AAC BULL	ACSR Bersimis
Diameter (d)	0.03825 m	0.03504 m
Radius (r)	0.019125 m	0.01752 m
No. of Conductor	4 (Nos)	4 (Nos)
Sub - Conductor Spacing (l)	0.450 m	0.450 m
Rated lightning Impulse Voltage (V_C)	2100 kV	1425 kV

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Table 2. DSLP Calculation Data for Section-1

Description	Value
Height of Installation Above Ground Level (h)	19 m
Height of Shield Wire (H)	46 m

1. Calculation of DSLP for section-1

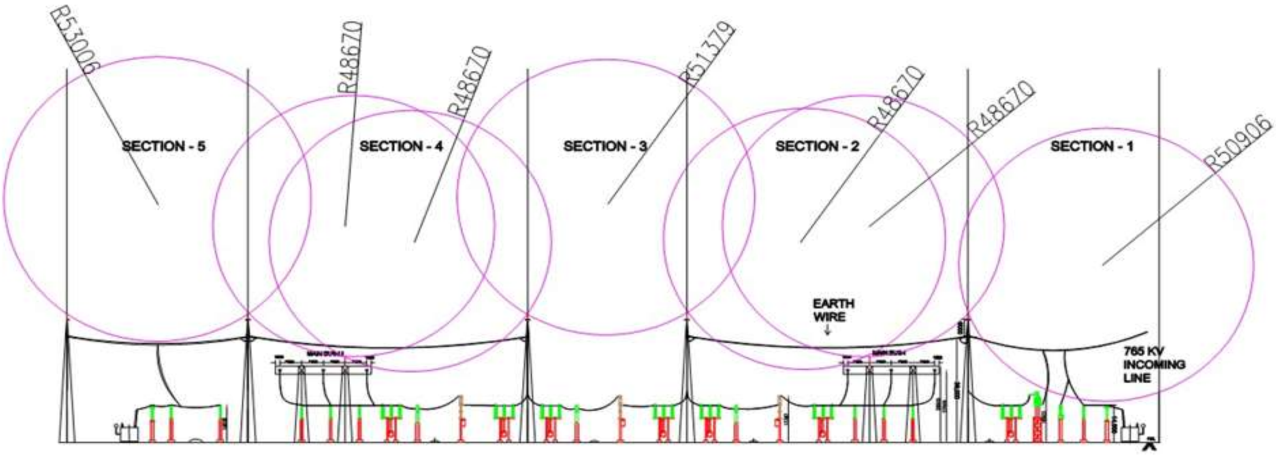

Figure 2. Section Elevation of Protected Area of Only 765kV Substation Bay by Using Lightning Rod (R53006 = 53.006 m Similar For All)

As Per Figure 2.Equivalent Radius is given by,

$$\mathbf{R_C \times \ln\left\{\frac{2\times h}{R_C}\right\} - \frac{V_C}{E_O} = 0} \qquad \text{……………. (1)}$$

$$\mathbf{R_C = 0.286424\ \Omega}$$

In case of a Quad bundle conductor, the equivalent radius is given by,

$$\mathbf{R_0 = \sqrt{r \times l}} \qquad \textbf{(Refer Table 1)} \qquad \text{……………. (2)}$$

For single conductor, the radius of the bundle under corona is [1],

$$\mathbf{R_{C'} = R_0 + R_C} \qquad \text{……………… (3)}$$

The surge impedance of conductors under corona is given as,

$$\mathbf{Z_S = 60 \times \left\{\ln\frac{2\times h}{R_{C'}} \times \ln\frac{2\times h}{r}\right\}^{0.5}} \qquad \text{……………… (4)}$$

For substation, when the value of the lightning current specifically striking conductor is bigger than a specific worth I_S, the lightning over voltages at the equipment will increase their BIL and destroy the equipment. The allowable stroke current (Is):-

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$$\mathbf{I_S} = \frac{2.2 \times \mathbf{V_C}}{\mathbf{Z_S}} \qquad \text{..................} \ \textbf{(5)}$$

Where,

V_C = Rated lightning impulse withstand voltage.
Z_S =Surge impedance of current carrying conductor.

The allowable strike distance is obtained by [1],

$$\mathbf{R} = \mathbf{8} \times \mathbf{K} \times \mathbf{I_S}^{\mathbf{0.65}} \qquad \text{(K = 1.2 for Lightning Rod)} \qquad \text{...............} \ \textbf{(6)}$$

$\mathbf{R = 50.905 \ \ m}$ **(Refer Figure 3.)**

2. Object to be protected

D = Elevation difference between Shield wire and Object to be protected.

D= H –A **(Refer Figure 3)** **…………….. (7)**

E = Elevation difference between Origin of the Rolling Sphere and Shield wire.

E= S – D **(Refer Figure 3)** **..…………… (8)**

.

L = Horizontal distance between Origin of the Rolling Sphere and Shield wire.

$$\mathbf{L} = (\boldsymbol{S}^2 - \mathbf{E}^2)^{\mathbf{0.5}} \qquad \textbf{(Refer Figure 3)} \qquad \text{...............} \ \textbf{(9)}$$

$\mathbf{L = 44.94} \ \ \boldsymbol{m}$

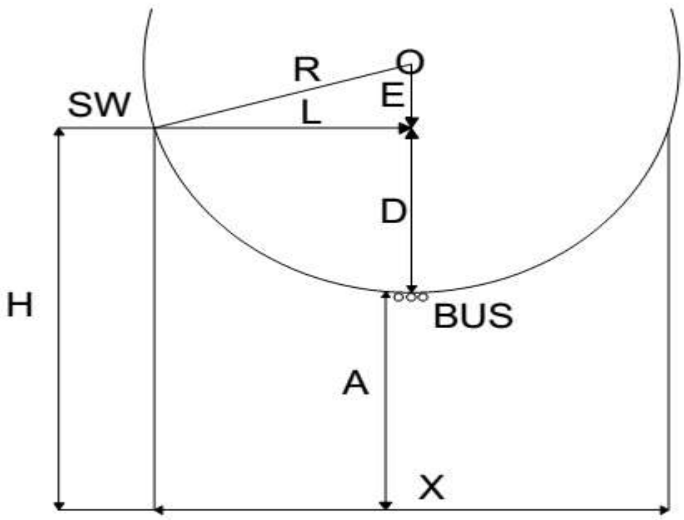

Figure 3. Protected Area of Shield Wires at Equal Height

Where,

O = Origin of the Rolling Sphere.
SW = location of the shield wire.

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Figure (2) and Figure (5) show protected area by lightning rod. As shown above, design for DSLP of other section can be calculated. Radius and Horizontal distance between origin of the Rolling Sphere and Shield wire (L) are given in Table (III).

IV. DSLP DESIGN FOR EARLY STREAMER EMISSION EQUIPMENT

A. Principle of early streamer emission equipment

The principle is given as "Lightning rod is prepared with a gadget that triggers the early initiation of the upward associating streamer leader discharge, compared to a routine lightning rod under same condition" [4]. This equipment has been developed in recent years with high efficiency.

B. Design of substation protected area using early streamer emission equipment

The accomplishment of this gadget relies upon the corona initiation timing in connection with the downward leader and the velocity with which the leaders can append contrasted. In the midst of the lightning stroke when it's in negative polarity, the engendering of a negative downward leader efficiently prompts the improvement of a positive upward leader. The advancement of upward leader is molded by the electric field increment impelled by the downward leader close to a sharpness (e.g. lightning protection gadget). On account of an early streamer emission air terminal (ESEAT), upward leader is started by the active direct stroke lightning protection gadget paying little heed to the position of the downward leader or positive corona. The time of breakdown is along these lines is diminished.

The motivation behind a direct stroke lightning protection (DSLP) is to keep lesser damage from an immediate lightning strike to the protected equipment. A traditional DSLP is intended to avoid damage by giving various particular air terminals rod with low impedance ways to lead the substantial lightning current to the ground without any damage. ESEAT equipment are guaranteed to have a much more bigger zone of protection than routine lightning air terminal rod, bringing about a lightning protection system with altogether less down conductors and air terminal rod than a conventional one. After Studies, we came to know that considering the upward leader we can raise the radius S of the protection sphere (as discussed in rolling sphere method) in the electro-geometric model [4].

Few types of early streamer emission air terminal working on an alternate rules are given in [4]:

- By utilizing wind energy, air ionization at the tip is delivered by piezoelectric component.
- By providing electrical impulse, air ionization is conveyed by generator. The generator supplies energy to capacitor for charging electric field of downward leader.
- Electromagnetic impulse in a coil is produced by high voltage.

C. Design of protection radius

The protection radius of Early Streamer Emission air terminal gadget is related with its height (h) relative to the surface to be protected, to its efficiency and to the selected protection level [5].

$$\mathbf{R_p(h) = \sqrt{2rh - h^2 + \Delta(2r + \Delta)}} \qquad \textbf{For } (\mathbf{h \geq 5\ m}) \qquad \text{…………… } \mathbf{(10)}$$

And,

$$\mathbf{R_p = h \times R_P(5)/5} \qquad \textbf{For } (\mathbf{2\ m \leq h \leq 5\ m}) \qquad \text{…………… } \mathbf{(11)}$$

Where.

$R_P(h)$ = Protection radius at a given height (h) in m.

h = Height of the ESEAT tip over the horizontal plane through the point of the object to be protected in m.

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r = 20m for protection level-1,30m for protection level-2,45m for protection level-3,60m for protection level-4.
(r = 60 m because in this case gantry height is 46 m)

Δ = Field experience has proved that Δ is equal to the efficiency obtained during the ESEAT evaluation tests. ($\Delta = \Delta T \times 10^6$) = 60 m (Decided as per requirement)

Δ T=Indicate efficiency of ESEAT equipment it is depend on requirement of substation protection.

This calculation apply to the above system (Figure. (4)) for section-1.

So, radius of the protective zone at height **(R_p) = 119.49 m.**
(L= 44.94 m must be same in both design)

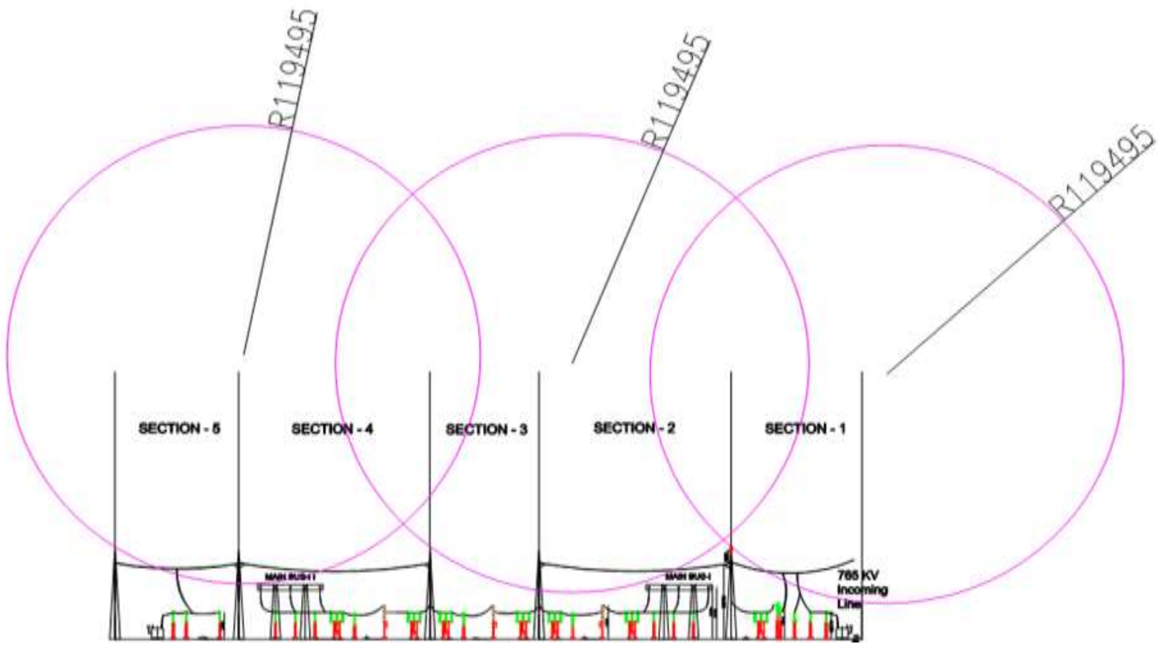

Figure 4. Section Elevation of Protected Area of Substation by Using Early Streamer Emission Equipment (R119495 = 119.495 m Similar For All)

Figure. (4) And Figure. (6) Shows the section elevation and plan of protected area by using ESEAT equipment.

V. RESULTS

After calculation of protected area by using rolling sphere method results are shown in table (III). LR shows the protected radius for lightning rod and ESEAT shows protected radius for early streamer emission air terminal equipment.

Table 3. Results after Calculation

DSLP Protection		**LR**	**ESEAT**
	L(m)	**R(m)**	**R_p(m)**
Section-1	44.94	50.9	119.49
Section-2	38.63	48.66	119.49
Section-3	46.11	51.37	

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Section-4	38.63	48.66	119.49
Section-5	48.66	53.00	

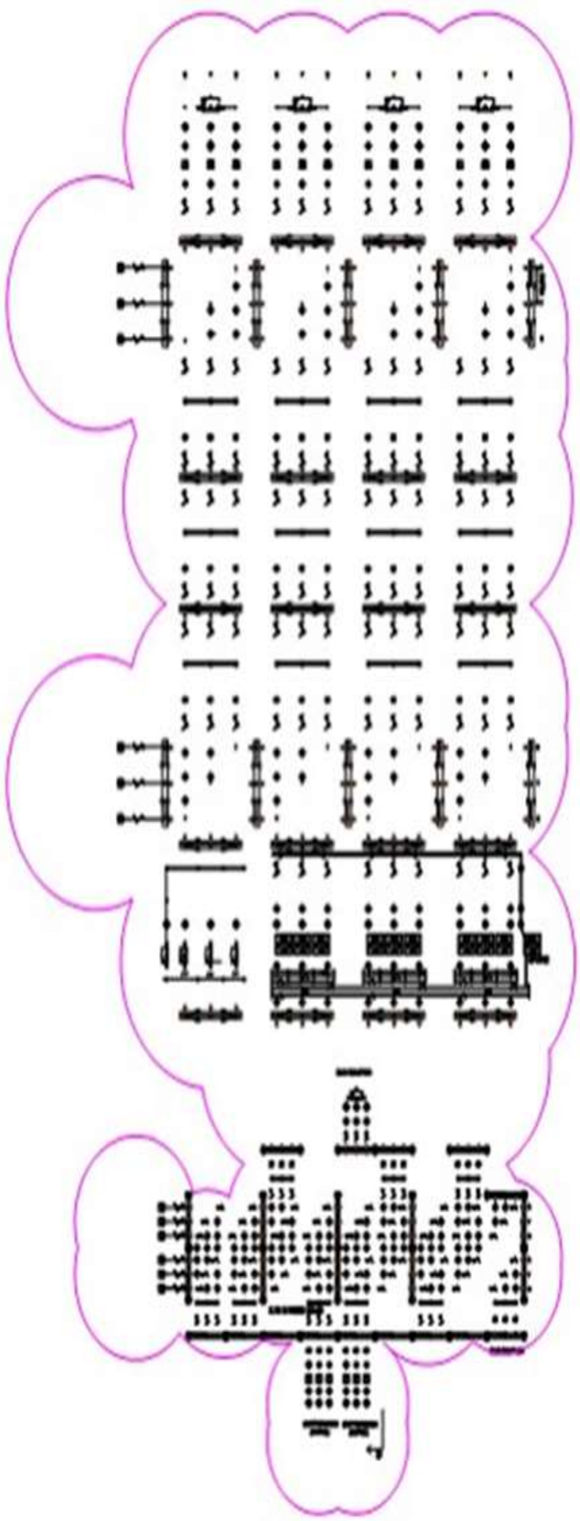

Figure 5. Plan Elevation of Protected Area for All Substation by Lightning Rod.

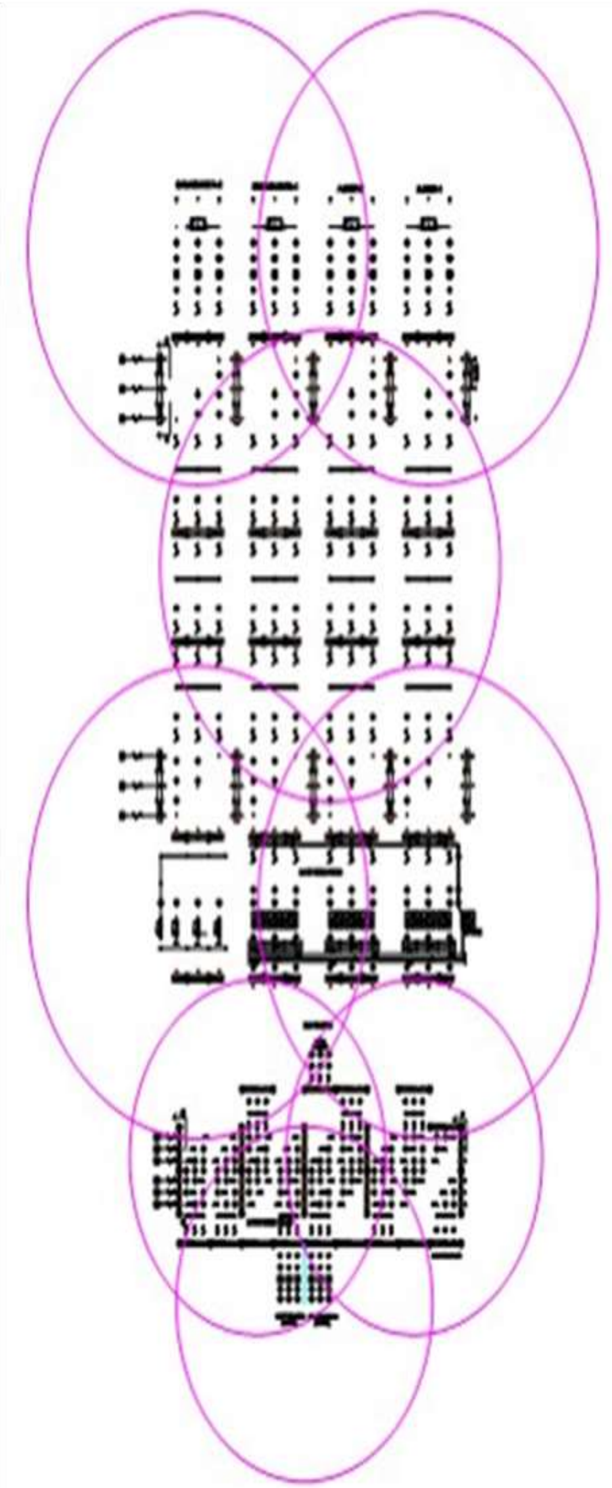

Figure 6. Plan Elevation of Protected Area For All Substation by ESEAT

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Equipment.

VI. CONCLUSION

In this paper the direct stroke lightning protection scheme for the 765/400 kV AIS substation has been discussed. From the results available we can conclude as follows:

- We can conclude from Table (III) that the protected radius for Early Streamer Emission Air Terminal equipment is greater compared to lightning rod by using rolling sphere method.
- The streamer from an Early Streamer Emission air terminal can be launched at an earlier time than streamer from simple air terminal. So that efficiency for this method is higher than simple rod.
- The total number of simple Lightning rods used in substation (47 Nos) is more compared to Early Streamer Emission Air Terminal Equipment (8 Nos).
- The Early Streamer Emission air terminal equipment has higher cost compared to simple air terminal rod.

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