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Direct Lightning Strike Protection – Importance And Methods

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Abstract: Substations are vital components of the electrical power system and are particularly vulnerable to direct lightning strikes, which can result in severe equipment damage, insulation breakdown, and widespread power outages. The objective is to evaluate the effectiveness of various protection methods—namely the Fixed Angle Method, Rolling Sphere Method, Razevig Method, and Early Streamer Emission (ESE) Method for 33 kV / 220 kV Renewable substations. These methods are critically examined through analytical calculations and substation layout designs to determine their zone of protection and shielding efficiency. This Paper highlights how the geometry, height of structures, and positioning of lightning masts or shield wires influence the level of protection offered. Systematically analyzing and comparing different methods, this work proposes optimized lightning protection schemes that can reduce equipment failure rates, improve personnel safety, and minimize substation downtime. The findings contribute to more robust and resilient substation design, especially in regions with high lightning density.

***Index Terms* - direct lightning strike protection, substation, 33kv / 220kv, razevig method, rolling sphere method, ESE method, F.A. method**

I. INTRODUCTION

Substations are essential components of the electrical power system, responsible for voltage transformation, protection, and control of electrical energy between the generation and distribution stages. As the backbone of reliable power delivery, substations must operate with high levels of safety and continuity. However, due to their outdoor installation and metallic infrastructure, they are highly susceptible to natural phenomena-particularly direct lightning strikes.

Direct lightning strikes to substations can cause severe consequences such as insulation flashover, equipment failure, fire, and service interruptions. These incidents lead to costly repairs, extended downtime, and a reduction in system reliability. The risk is even more significant in high-voltage substations, where the physical layout and height of equipment increase the probability of lightning exposure.

To address these challenges, this study focuses exclusively on the protection of substations against direct lightning strikes through the application and comparison of standard protection methods. The techniques analysed include the Fixed Angle Method**,** Rolling Sphere Method**,** Razevig Method**,** and Early Streamer Emission (ESE) Method**.** These methods are used to determine the protective zones around substation equipment and ensure that critical components like bus bars, transformers, isolators, and circuit breakers remain shielded from direct strikes.

The protection schemes are designed and evaluated using geometrical and empirical approaches in accordance with international standards such as IEEE 998-2012 and NF C 17-102**.** Through proper placement of lightning masts, shield wires, and optimized protection angles, the objective is to reduce the likelihood of lightning damage and improve the overall resilience and safety of substation infrastructure.

This study aims to provide a practical and comparative understanding of direct lightning protection methods tailored to substation environments, ultimately supporting the development of safer and more reliable electrical networks.

II. Importance Of Lightning Protection In Substation

Substations serve as critical hubs within the electrical power system, facilitating the control, transformation, and distribution of electricity across various voltage levels. Their continuous and reliable operation is essential for ensuring the stability of the power supply. However, due to their outdoor exposure and tall metallic structures, substations are particularly vulnerable to direct lightning strikes, especially in regions with high lightning density.

Lightning strikes can release a tremendous amount of energy—typically in the range of tens to hundreds of kilo amperes—within microseconds. When such energy directly hits substation components like transformers, circuit breakers, bus bars, or control panels, it can lead to:

- Severe insulation breakdown
- Destruction of sensitive equipment
- Outages and blackouts
- Fire hazards
- Personnel safety risks
- High maintenance and repair costs

Even a single unprotected strike can damage critical assets and disrupt operations, leading to revenue losses and decreased system reliability.

Implementing a well-designed lightning protection system (LPS) in substations ensures:

1. Equipment Safety: By diverting lightning current safely to ground, LPS prevents flashovers and breakdowns in high-voltage equipment.
2. Operational Reliability: Protected substations are less prone to unplanned outages, improving power system reliability.
3. Personnel Protection: Proper grounding and shielding eliminate dangerous step and touch voltages, safeguarding the lives of maintenance workers and operators.
4. Reduced Downtime and Maintenance Costs: Effective protection minimizes damage and the frequency of emergency repairs.
5. Regulatory Compliance: Adherence to standards such as IEEE 998-2012.

III. Various Methods Of Direct Lightning Strike Protection

1. Fixed Angle Method

The fixed-angle is a type of empirical method. This design method uses vertical angles to determine the number, position, and height of shielding wires or masts. As its name shows fixed angle, means angle between two masts are fixed. This method is useful and economical for low voltage substation. Designers using the fixed-angle method can reduce the shielding angles as the height of the structures increases in order to maintain a low failure rate. Using the electro geometric model (EGM), calculated shielding failures as a function of the height of the conductor above ground and the protective angle for transmission lines. The protective angle is decreased as the protective wire height is increased. For Fixed angle method:-

$$X = (h - d) \tan \alpha$$

Where,

X= area of protection
h=height of the mast
α =protective angle

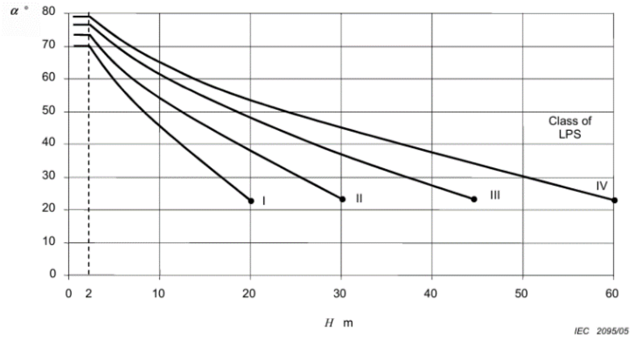

Fig. 1. Height Of Tower vs Protective Angle

2. Rolling Sphere Method

It is a type of electro geometric model. The technique involves rolling an imaginary sphere of prescribed radius over the surface of a substation. The sphere rolls up and over LM, shield wires, fences. And grounded metal objects intended for lightning shielding. An equipment is protected from a direct stroke if it remains below the curved surface of the sphere by benefit of the sphere being elevated wires or other devices. Equipment that touches the sphere or penetrates its surface is not protected.

TABLE I. PROTECTIVE SPHERE RADIUS

Class of LPS	Rolling sphere radius *r* m
I	20
II	30
III	45
IV	60

3. Razevig Method

Razevig method is one of the important method for protection of direct lightning. Prof.D.V.Razevig finds this method. It is used for determination of protective zone of lightning conductor. Moreover, it is developed by single lightning mast and combination of the mast.

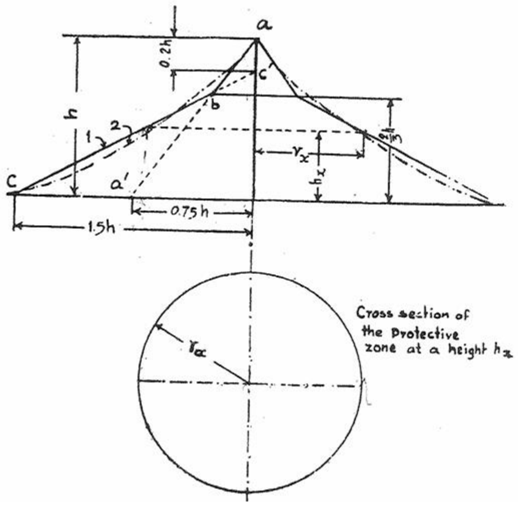

Fig. 2. Modeling of Razevig Method

Where.

h=Height of the lightning conductor

r_x=Radius of the protective zone at a height h_x

h_x=Height of the object to protected

The radius of protection at a level $h_x < \frac{2}{3}$ h is equal to

$$r_x = 1.5\,h\,(1 - \frac{h_x}{0.8h})$$

The radius of protection at a level $h_x > \frac{2}{3}$ h is equal to

$$r_x = 0.75\,h\,(1 - \frac{h_x}{h})$$

4. Early Streamer Emission Method

Early streamer is not a method but it is a one type of equipment, which is place over the simple lightning rod, which is called as early streamer emission air terminal.

The protection radius (Rp) of early streamer is calculated using the following formula as defined by the French national standard NF C 17-102.

$$R_p = \sqrt{h(2D - h) + \Delta T\,(2D + \Delta T)}$$

Where,
Rp = Radius of protection
h = Height of object
D = Diameter of the circle
Δ = Protection level

D depends on the selected level of protection, protection levels are specified by the standard NF C 17-102.

D = 20 m for protection level 1 (High protection)
D = 45 m for protection level 2 (Medium protection)
D = 60 m for protection level 1 (Low protection)

IV. RESULT

1. Fixed Angle Method

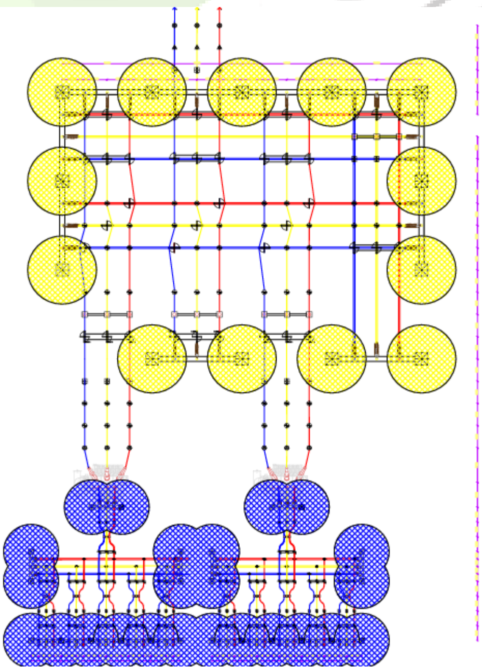

Fig. 3. Protection region of substation using F.A.Method

This substation layout uses the Fixed Angle Method for lightning protection, where the yellow regions represent the 220 kV side and the blue regions represent the 33 kV side. The goal is to protect the main bus, but in this design, only portions of the main bus fall within the protected zones. The fixed angle method draws protection zones from the top of lightning masts at a specified angle, but due to limited mast height and placement, many areas remain outside these zones. As seen in the layout, large unprotected spaces exist between the yellow and blue regions, which leaves critical parts of the main bus exposed. This indicates that the current mast arrangement and angles are insufficient for full coverage. The protection is only partial and may not meet the standard safety criteria for lightning protection. To ensure complete shielding of the main bus, additional masts or adjusted angles would be necessary. This highlights a design limitation in the present fixed angle application

2. Rolling Sphere Method

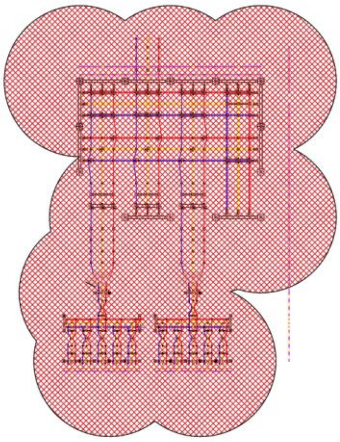

Fig. 4. Protected region of substation using Rolling Sphere Method

This layout uses the Rolling Sphere Method as per IEC 62305 Class II, with a 30 m radius sphere. The red shaded area shows the protected zone formed by lightning masts. The entire substation, including both 220 kV and 33 kV sides, is fully covered. All main equipment, especially the main bus, lies within the protected region. There are no unprotected areas, indicating effective mast placement. This method ensures complete and reliable lightning protection. It provides better accuracy for complex structures compared to other methods. The design meets standard safety requirements for direct lightning strike protection.

3 Razevig Method

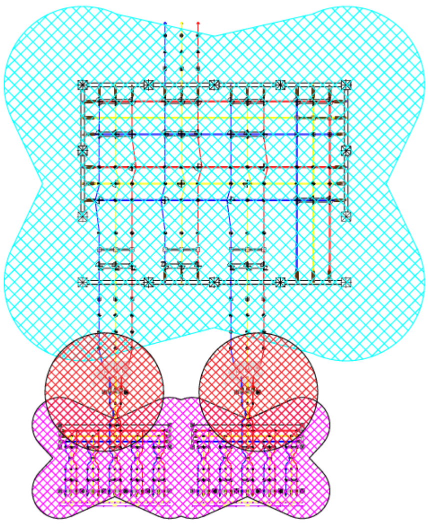

Fig. 5. Protected region of substation using razevig Method

This layout uses the Razevig Method for lightning protection. The sky-blue region represents the protected area for the 220 kV side, while the pink region covers the 33 kV side. Initially, the transformers were outside the protected zone, creating a risk of direct lightning strikes. To address this, two additional lightning masts have been added, shown by the red shaded areas, to specifically protect the transformers. The main equipment to be protected in this case is the power transformer, which is now covered.

4. Early Streamer Emission Method

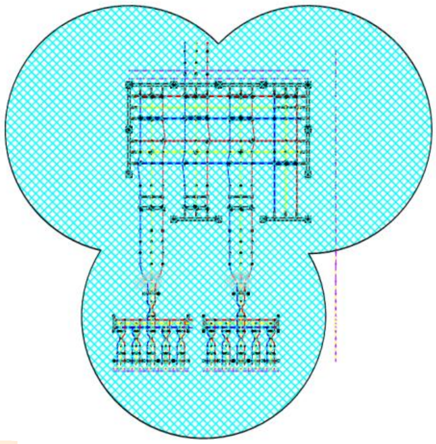

Fig. 6. Protected region of substation using ESE Method

This layout uses the Early Streamer Emission (ESE) Method for lightning protection. The light blue shaded region shows that the entire substation, including both 220 kV and 33 kV sides, is fully protected. ESE terminals emit an early upward leader, creating a larger protection radius compared to conventional methods. While effective in covering wide areas with fewer masts, this method follows the French standard NFC 17-102, not the Indian or IEC standards. Therefore, it is not commonly used in India for official or government-approved substation designs. Despite its wide coverage, its acceptance remains limited due to standardization concerns.

V. CONCLUSION

Method	Advantages	Disadvantages
Fixed Angle	Simple, easy, low cost	Inaccurate for large/tall systems, not IEC-compliant
Rolling Sphere	IEC standard, identifies all vulnerable points	High cost, complex for large substations
Razevig	Accurate for complex layouts, flexible design	Not standardized, complex, less accepted
ESE	Wide coverage, fewer rods, cost-effective	Not IEC-approved, dependent on conditions, controversial claims

In the 33/220 kV substation, all four lightning protection methods—Fixed Angle Method (FAM), Razevig Method, Rolling Sphere Method (RSM), and Early Streamer Emission (ESE) Method—were applied and compared. Among them, the Rolling Sphere Method proved to be the most effective and reliable. It considers the actual path of lightning using the electro geometric model, offering better protection coverage for equipment of varying heights. This method ensures that no critical part of the substation is left exposed, making it ideal for complex layouts. Unlike FAM and Razevig, which rely on fixed geometric assumptions, RSM adapts to real-world strike behavior. It also outperforms ESE by providing verified and standardized coverage. Therefore, for high-voltage substations like 33/220 kV, the Rolling Sphere Method is the most preferred and technically sound approach

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