Substation Lightning Protection Design

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**   Shall be the Process Owner and is the person assigned authority and responsibility for managing the whole process, end-to-end, which may extend across more than one division and/or functions, in order to deliver agreed business results.*

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Revision Control		
Revision	**Date**	**Description**
0	3/10/2013	Original
1	24/10/2023	Review

STAKEHOLDERS *The following positions shall be consulted if an update or review is required:*	
Manager Engineering & Project Services	Asset Managers
Manager Systems & Network Planning	Manager Assets Services
Senior Manager Safety, Health and Wellbeing	*Generation*

TABLE OF CONTENTS

1 SCOPE

This design guideline sets out the lightning protection requirements for transmission substations, both greenfield and brownfield sites.

Lightning protection of substations is provided to minimise danger to personnel, damage to primary equipment and maintain reliable supply by shielding and providing a safe route for the lightning stroke to travel to earth.

2 NORMATIVE REFERENCES

2.1 Standards

2.1.1 Australian Standards

The following standards are available at http://www.saiglobal.com.

[1]. AS 1768:2021, Lightning Protection

2.1.2 International Standards

The following standards are available at http://www.saiglobal.com.

[2]. IEEE Std 998:2012, Guide for Direct Lightning Stroke Shielding of Substations

[3]. IEC 62305-2:2010, Protection against lightning – Part 2: Risk management

3 INTRODUCTION

The Substation Lightning Protection Design is a guideline to assist with understanding lighting protection design principles and provide a clear understanding of lightning stroke formation with transmission substations.

Transmission substations are typically shielded from lightning by a combination of lightning masts and overhead earth wires. Earthed structures such as floodlight masts or microwave towers can also contribute to the shielding of a transmission substation.

The design is based on the rolling sphere methodology devised in IEEE Std 998 [2]. This methodology uses a rolling sphere with a strike radius of 24 metres, that is, an assumed charged sphere with a 24 m radius shall come into contact with either lightning masts, overhead earth wires or an earthed object prior to getting low enough to come into contract with any substation conductors or equipment.

4 DESIGN METHOD

IEEE Std 998 [2] specifies two methods of lightning protection, the Empirical design methods and the Electro Geometric Model (EGM), however Horizon Power has opted the EGM method for its lightning protection design. The lightning protection designs main goal is to:

1) Intercept a lightning flash to structure, with an air termination systems such as masts and earth wires.

2) Conduct the lightning current safely towards earth, using a down conductor systems.

3) Disperse the lightning current into the earth using an earth-termination system.

4.1 Information Gathering

4.1.1 Substation Layout and Elevations

The substation layout drawings (electrical equipment and foundation) are required for initial placement of lightning masts (as proposed by design engineer). The elevation drawings are required to get the height of the equipment used.

4.1.2 Ground Flash Density of Area

Obtain the average annual lightning Ground Flash Density (GFD) for the substation location from the GFD Density Map. When substations are located in high lightning areas (i.e. high GFD) then increased protection is required – more lightning masts can be used is this situation.

4.1.3 Over Head Earth Wire Entries and Gantries

The location of Overhead Earth Wires (OHEW) coming into the substation along with the gantries supporting these lines, provide significant protection from lightning. These OHEW's and gantries must be included in the design.

4.2 Electro Geometric Model

Electro Geometric Modelling (EGM) is the chosen approach for the design of lightning protection within a transmission substation. The method involves modelling the substation that requires the placement of lightning masts and overhead earth wires using the rolling sphere method by which the following assumptions are made:

1) The strike is assumed to arrive in a vertical direction.

2) Different striking distances are taken into consideration; and

3) The model is not tied to a specific form of striking distance equations.

The application of the EGM, the process, the calculations along with working examples can be found in IEEE Std 998 [2]. Horizon Power's preference is the rolling sphere method.

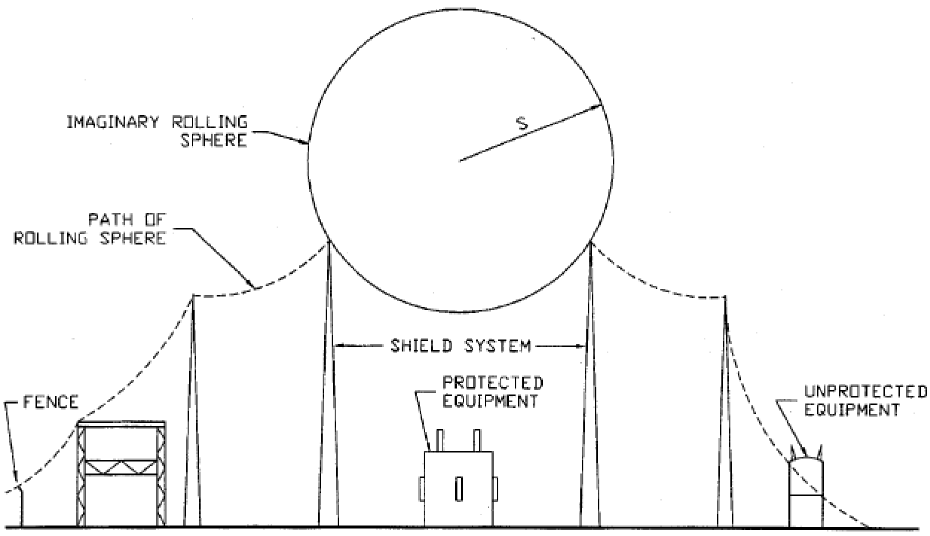
4.3 Rolling Sphere Method

The Rolling Sphere Method (RSM) is a geometric construction that ensures that the shortest distance between a lightning leader tip and any part of the structure is protection by an air terminal.

In application of the RSM, a fictional sphere of a radius, S, is rolled over the structure for all directions. Any part of the structure that the sphere touches is exposed to direct lightning strokes and shall be protected by air terminals. The air termination system is adequate for the lighting protection level if it can prevent the sphere from touching the structure.

AS 1768 Appendix D [1] provides step by step detail to calculate the striking distance and stroke current.

Figure 1 – Principle of RSM



4.4 Lightning Damage Probability

When the minimum strike current is used to determine the sphere size for the RSM, the substation and its equipment should be theoretically protected against a direct lightning strike. If larger sphere sizes are used for the design of the lightning protection systems, the following method is recommended to determine the risk and probability of failure due to lightning:

1) Determine the required strike distance (S).

2) Determine the alternative bigger strike distance (S_1) i.e. the size of the rolling sphere being considered.

3) Calculate the probability of a lightning strike current bigger than S but less than S_1.

4) Calculate the area not protected by the S_1.

5) Using the ground flash density for the substation area, determine the strokes per year expected on the substation area.

6) The product of items 3) and 5) will provide the calculated failures per year for the lightning protection design.

The value received from 6) will need to be evaluated for each design where standard values cannot be applied. However, it is anticipated that the standard rolling sphere can be applied in the majority of cases.

4.5 Tolerable Risk

The lightning risk assessment is conducted using the supplied spreadsheet with AS 1768 [1]. The assessment covers:

1) Potential difference causing death or injury from step and touch voltages.

2) Mechanical damage of the structure and contents.

3) Damage and failure of equipment within the structure.

4) Fire damage that may result from a lightning strike.

The spreadsheet provides a likelihood of damage and will determine what changes to the lighting design is required to bring that risk down.

All calculations are derived from *IEC 62305-2 Protection against lightning – Part 2: Risk management [3]*.

4.6 Design Modelling

The design of the lightning protection system can be modelled by 3D software.

4.7 Design Process

Incorporating the information discussed in section 4.1, a lightning protection system design shall be done with the following steps:

1) Engage with Stakeholders to determine/finalise the scope of work.

2) Determine if the lightning design system is for a Greenfield or Brownfield project.

3) Determine the soil resistivity by tests.

4) Lightning masts:

    a. Design masts suited for the specific wind.

    b. Determine the required height of masts.

    c. Consider the sail effect on masts and mast foundations.

5) Basis of design

    a. The designer shall undertake a lightning design using the rolling sphere method or alternative approved method. The rolling sphere size shall be 24 m.

b. The earthing layout drawings shall show placement and height of lightning spires, and any lightning shield wires, and all connections to earth.

c. Verify the integrity of the substation earthing system.

d. The lightning layout report shall show the calculations that demonstrate compliance with the 24 m rolling sphere.

e. All substation buildings and equipment shall be protected unless designed to intercept lightning strikes, in which case the interception and strike conditions shall be specified.

6) Keep record of all calculations in the earthing layout report. The rolling sphere approach is documented in *AS 1768 [1].*

7) Have the Lightning Design verified by an independent reviewer and arrange for sign off.

5 INSTALLATION REQUIREMENTS

5.1 Lightning Mast

The spacing of lightning masts inside the substation will be determined by:

1) A lightning design produced in accordance with the EDM and rolling sphere studies.

2) Practical placement not to interfere with operations and equipment access.

3) Required safety clearance from equipment (e.g. clearances from tilt-down mast swing).

Lightning masts can be used to mount floodlights for switchyard lighting. Where this is the case, tilt-down lightning masts shall be used. If no lights are required on a lightning mast, then a fixed mast should be used.

In order to minimise the surge impedance of lightning masts, multi-prong lightning interceptor spikes at the top of lightning masts shall be used. These should be installed on all fixed masts and tilt-down masts. In general, 600 mm long spikes should be used as standard, unless the mast has floodlights installed then 1500 mm long spikes should be used, to provide protection to the lights. Where masts are used for lighting purposes only and substation equipment is sufficiently protected from lightning strikes by overhead earth wires, then lightning spikes are not required.

All tilt-down masts shall have an earth braid installed across the mast hinge for earthing and lightning protection.

5.2 Overhead Earth Wire

Where overhead earth wires are used to provide lightning protection within a substation, a conductor with a minimum strand size of 3 mm diameter should be used to ensure ability of the conductor to withstand a lightning strike.

To minimise surge impedance, overheard earth wires should be bonded to the steelwork at the top of the gantry or pole they are connected to.

APPENDIX A REVISION INFORMATION

(Informative) Horizon Power has endeavoured to provide standards of the highest quality and would appreciate notification of errors or queries.

Each Standard makes use of its own comment sheet which is maintained throughout the life of the standard, which lists all comments made by stakeholders regarding the standard.

A comment sheet found in **DM# 1816108** can be used to record any errors or queries found in or pertaining to this standard. This comment sheet will be referred to each time the standard is updated.

Date	Rev No.	Notes
3/10/2013	0	Rev 0 published
24/10/2023	1	Review

APPENDIX B ELECTRO GEOMETRIC MODEL

In electro geometric modelling theory, the protective area of a lightning mast or earthing wire depends on the stroke current. This means that if a mast is installed to protect equipment against a stroke current of IS, the equipment might not be protected against stroke currents of less than IS, because of shorter strike distances. This appendix will aim to explain this concept through illustration.

B1 PROTECTION AGAINST STROKE CURRENT (I_S)

Stroke current I_s is calculated as the current producing a voltage that the insulation will just withstand. From the calculated I_s the striking distance S for this stroke current is calculated.

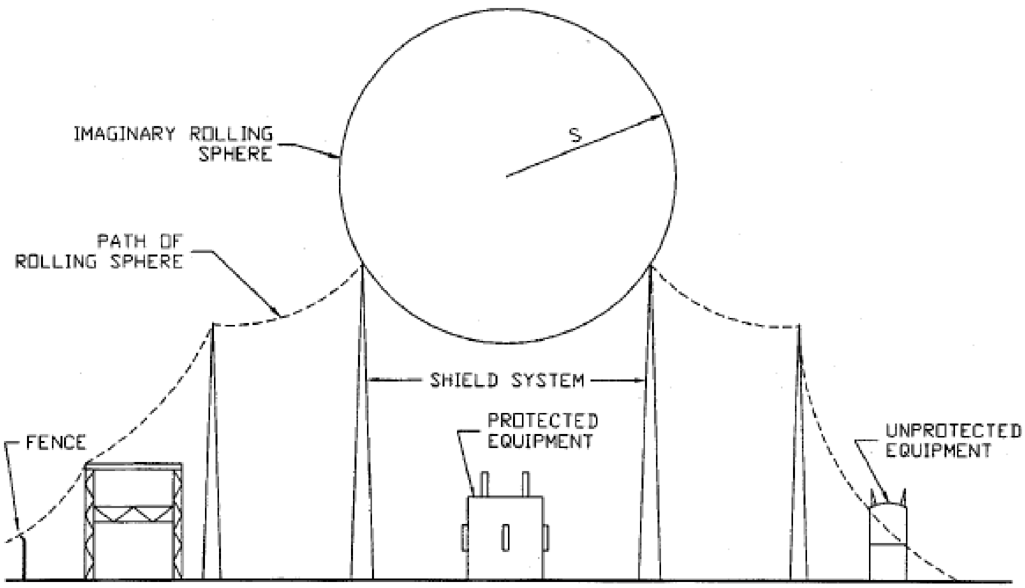
The distance S is used in the technique that has come to be known as the rolling sphere method. This method employs the simplifying assumption that the striking distances to the ground, a mast, or a wire are the same. With this assumption, the rolling sphere method has been updated in accordance with the revised EGM.

Use of the rolling sphere method involves rolling 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 by virtue of the sphere being elevated by shield wires or other devices. Equipment that touches the sphere or penetrates its surface is not protected.

The basic concept is illustrated in Figure B.1.

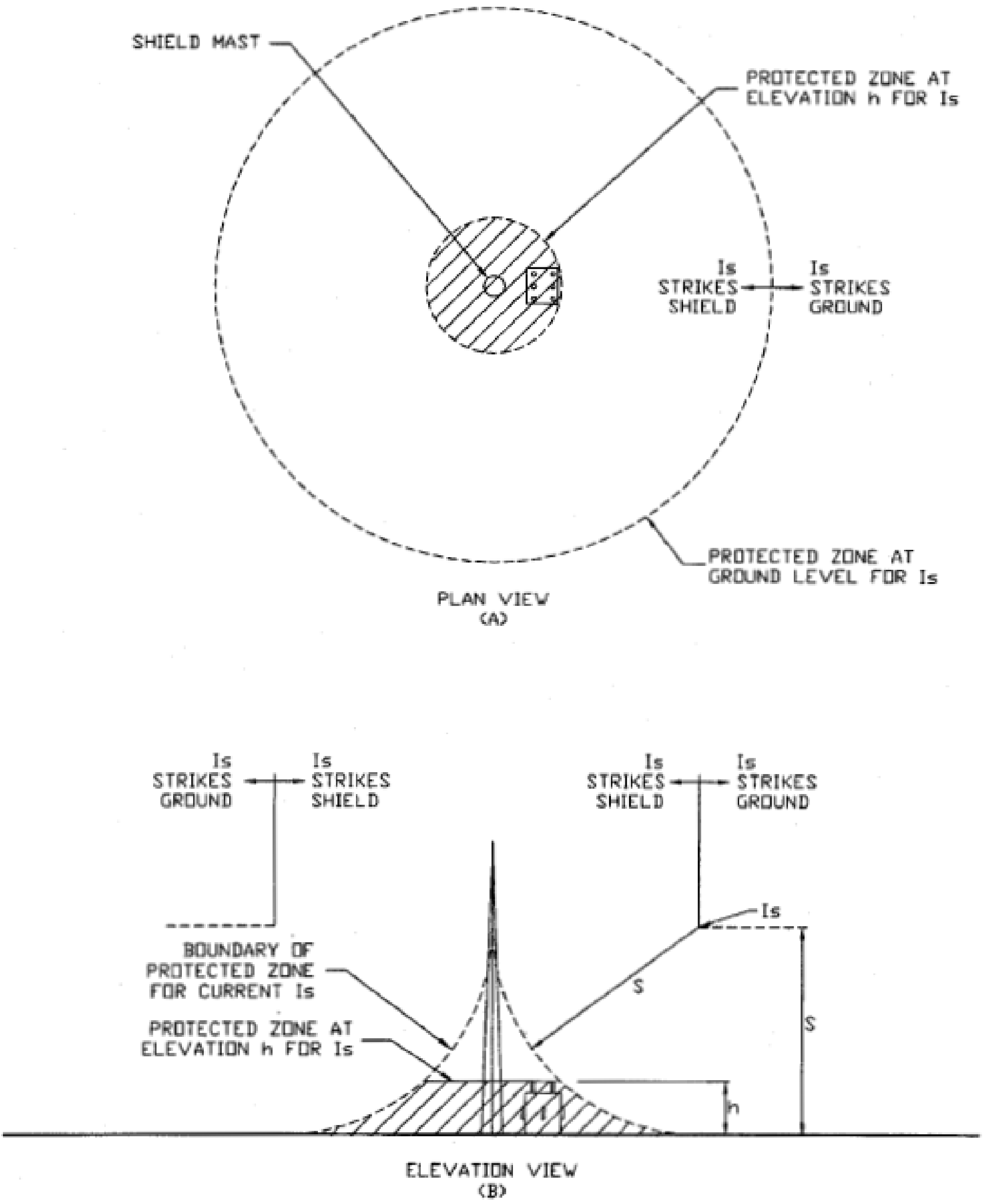
Figure B.1: Principle of the rolling sphere



Continuing the discussion of protection against stroke current I_s, consider first a single mast. The geometrical model of a single substation shield mast, the ground plane, the striking distance, and the zone of protection are shown in Figure B-2.

All points below this arc are protected against the stroke current I_s. This is the protected zone. is shown in Figure B.2. All points below this arc are protected against the stroke current I_s. This is the protected zone.

Figure B.2: Shield mast for protection for stroke current I



s

The arc is constructed as follows (refer to Figure B-2). A dashed line is drawn parallel to the ground at a distance S above the ground plane. An arc of radius S, with its centre located on the dashed line, is drawn so the radius of the arc just touches the mast.

Stepped leaders that result in stroke current I_s and those that descend outside of the point where the arc is tangent to the ground will strike the ground. Stepped leaders that result in stroke current I_s and that descend inside the point where the arc is tangent to the ground will strike the shield mast, provided all other objects are within the protected zone.

The height of the shield mast that will provide the maximum zone of protection for stroke currents equal to I_s is S. If the mast height is less than S, the zone of protection will be reduced. Increasing the mast height greater than S will provide additional protection in the case of a single mast. This is not necessarily true in the case of multiple masts and shield wires. The protection zone can be visualized as the surface of a sphere with radius S that is rolled toward the mast until touching the mast. As the sphere is rolled around the mast, a three-dimensional surface of protection is defined. It is this concept that has led to the name rolling sphere for simplified applications of the EGM.

B2 PROTECTION AGAINST STROKE CURRENTS GREATER THAN I_S

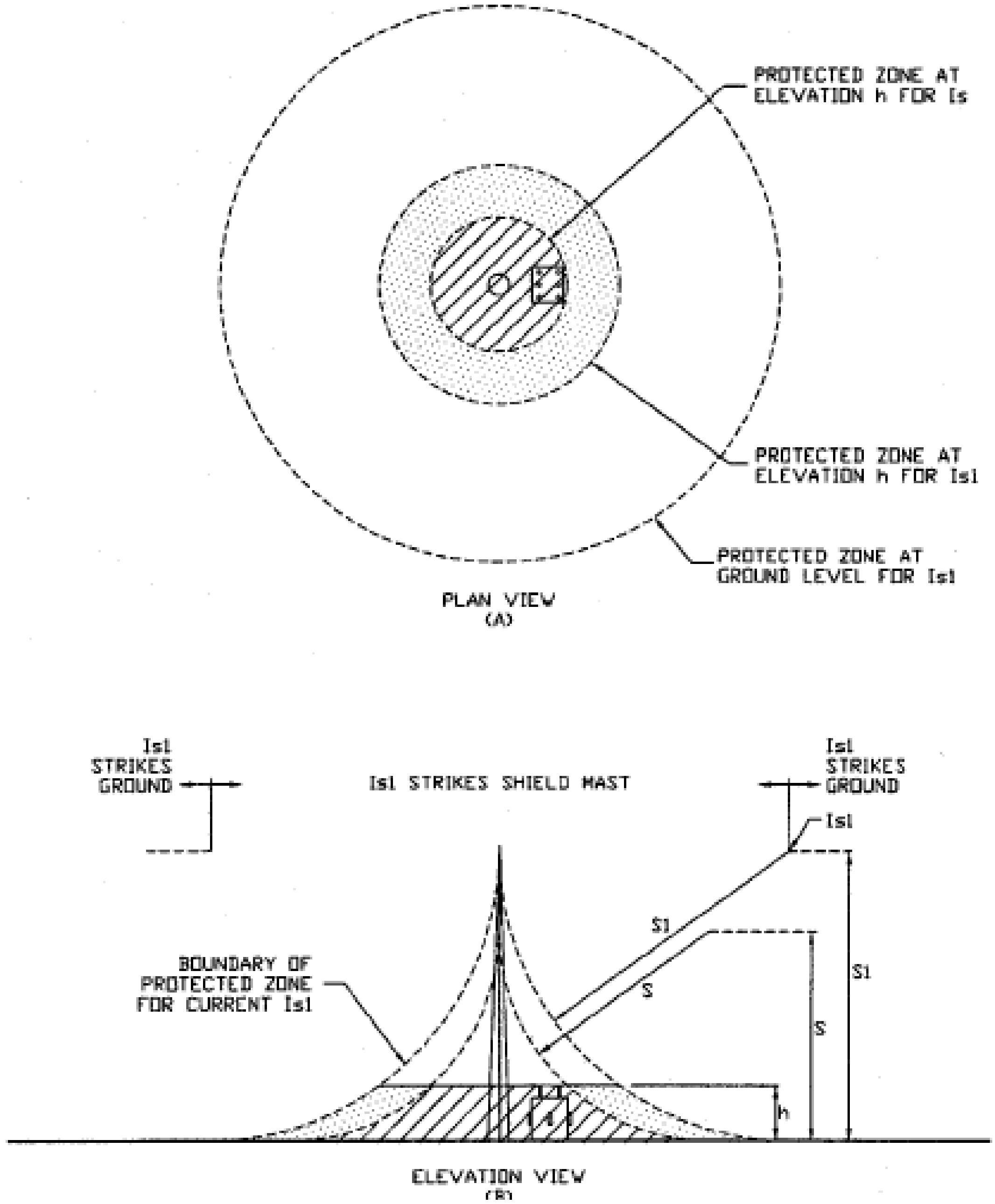
A lightning stroke current has an infinite number of possible magnitudes, so it can be useful to analyse if the system provides protection at other levels of stroke current magnitude.

Consider a stroke current I_{S1} with magnitude greater than I_s. Strike distance, determined from the calculations is S_1. The geometrical model for this condition is shown in Figure B.3. Arcs of protection for stroke current I_{s1} and for the previously discussed I_S are both shown. Figure B.3 shows that the zone of protection provided by the mast for stroke current I_{s1} is greater than the zone of protection provided by the mast for stroke current I_s.

Stepped leaders that result in stroke current I_{s1} and that descend outside of the point where the arc is tangent to the ground will strike the ground. Stepped leaders that result in stroke current I_{S1} and that descend inside the point where the arc is tangent to the ground will strike the shield mast, provided all other objects are within the S_1 protected zone.

Again, the protective zone can be visualized as the surface of a sphere touching the mast. In this case, the sphere has a radius S_1.

Figure B.3: Shield mast protection for stroke current I_{S1}



B3 PROTECTION AGAINST STROKE CURRENTS LESS THAN I_S

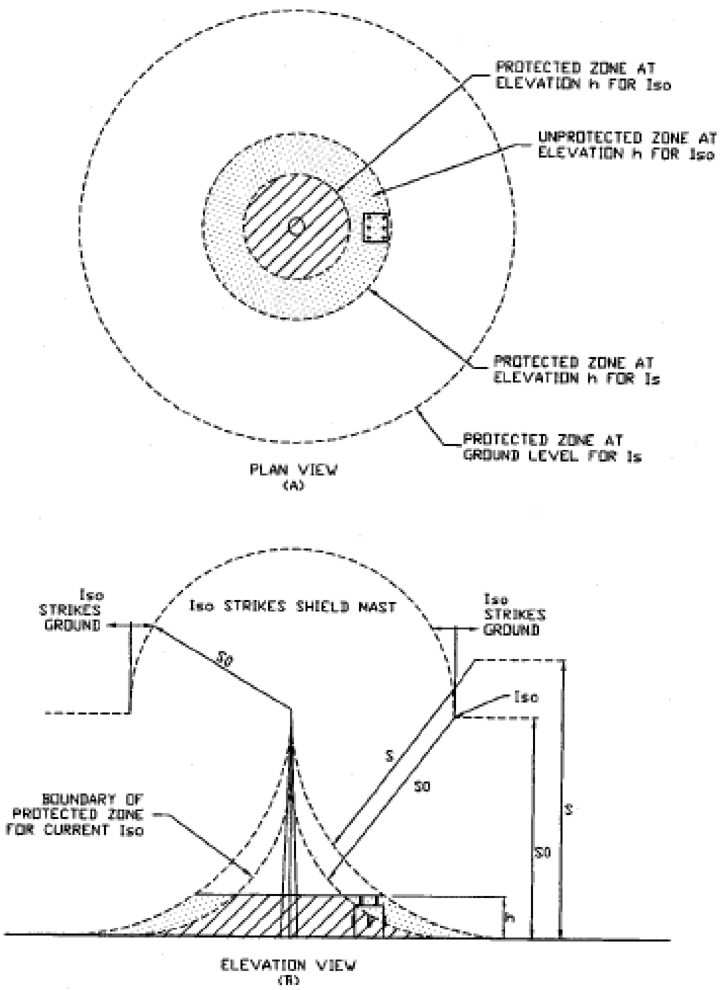
It has been shown that a shielding system that provides protection at the stroke current level I_S provides even better protection for larger stroke currents. The remaining scenario to examine is the protection afforded when stroke currents are less than I_S.Consider a stroke current I_{S0} with magnitude less than I_S. The striking distance, determined from calculations is S_0. The geometrical model for this condition is shown in Figure B.4. Arcs of protection for stroke current I_{S0} and I_S are both shown.

The Figure B.4 shows that the zone of protection provided by the mast for stroke current I_{S0} is less than the zone of protection provided by the mast for stroke current I_S. It is noted that a portion of the equipment protrudes above the dashed arc or zone of protection for stroke current I_{so}.

Stepped leaders that result in stroke current I_{S0} and that descend outside of the point where the arc is tangent to the ground will strike the ground. However, some stepped leaders that result in stroke current I_{S0} and that descend inside the point where the arc is tangent to the ground could strike the equipment. This is best shown by observing the plan view of protective zones shown in Figure B.4.

Stepped leaders for stroke current I_{so} that descend inside the inner protective zone will strike the mast and protect equipment that is *h* in height. Stepped leaders for stroke current I_{S0} that descend in the shaded unprotected zone will strike equipment of height h in the area. If, however, the value of I_S was selected based on the withstand insulation level of equipment used in the substation, stroke current I_{S0} should cause no damage to equipment.

Figure B.4: Shield mast protection for stroke current I_{S0}



APPENDIX C DESIGN PROCEDURE FLOW-CHART