Lightning Protection

Study/Report

Cyclone Generation Substation

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Executive Summary

The lightning study was developed to protect the Cyclone Generation Substation from the impacts of lightning. Lightning strikes damage equipment, can cause severe transients in the bulk power system, and are a general hazard to substation personal. To aid in our analysis we consider the empirical curves method described in the IEEE Standard 998-2012, "IEEE Guide for Direct Lightning Stroke Shielding of Substations".

The finding of the report in short are as follows to reduce the exposure of the substation to lightning strikes to be 0.01%:

- Utilize the lightning masts affixed on both sides of the H-frames termination structures at the Cyclone Generation, Des Moines, and Cedar Falls exits
- Add an additional six (6) lightning masts at positions indicated on drawing number IA-000-24-02 to provide additional protection.

Taking these recommendations into account the total protected areas of the substation are represented in the following figure:

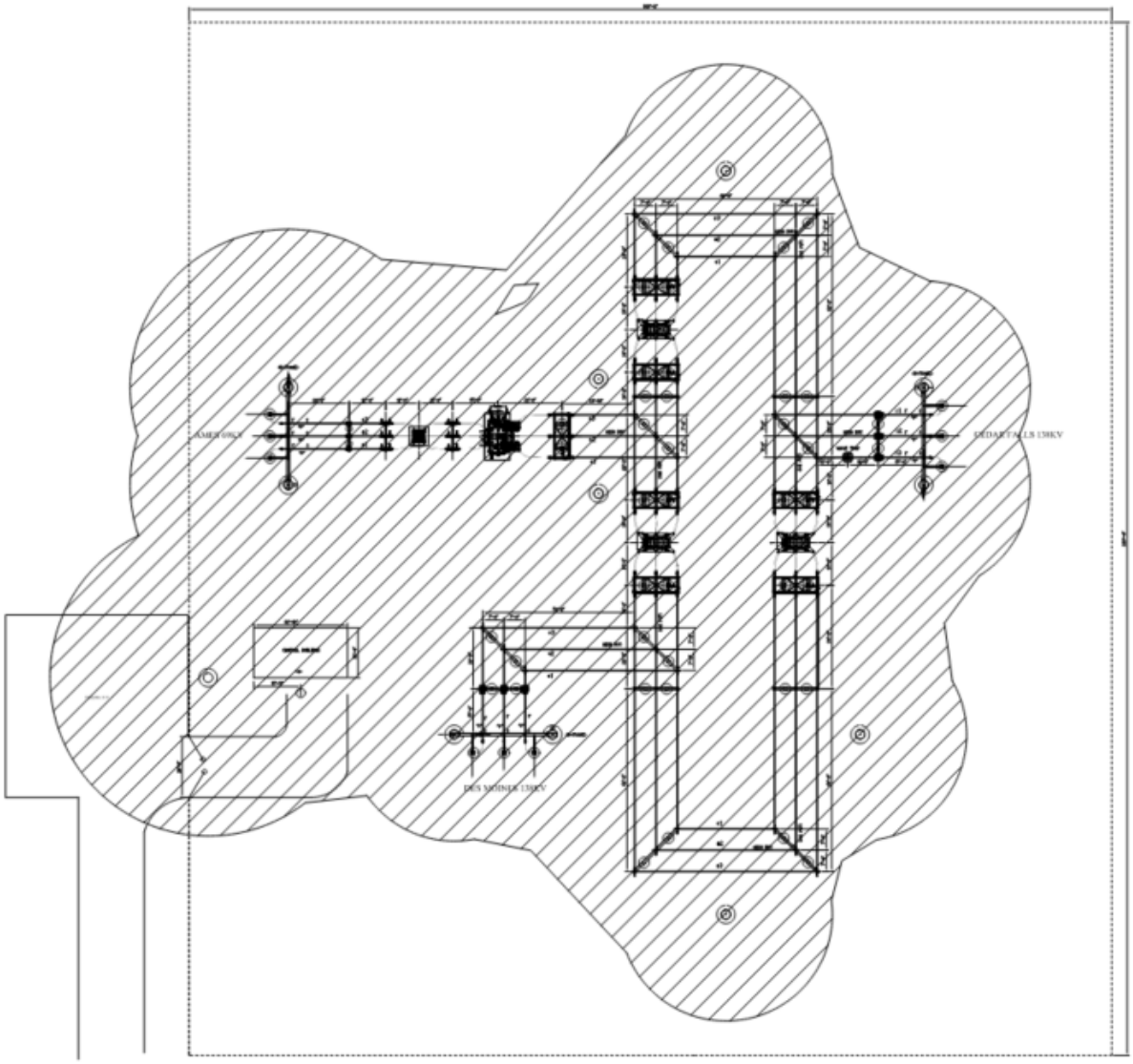

Figure 1 - Overall protection of substation using the lightning protection methods described in the executive summary

Introduction

The purpose of this lightning study, along with the accompanying drawings, is to portray the suggested lightning protection to be installed upon construction of the Cyclone Generation Substation. This is as requested in the project scope and requirements provided at the beginning of the work period.

This lightning protection study was done based on the protection of equipment in the substation using different combinations for the electrodes and shield wires to provide the best protection to the equipment within the substation from lightning strokes. All protection calculations have been derived from the IEEE Standard 998-2012, "IEEE Guide for Direct Lightning Stroke Shielding of Substations". The empirical curves method is used in this study.

Two main groups of protection devices were identified for the purposes of this study: lightning masts affixed to termination towers and auxiliary lightning masts. The lightning protection is done in two phases. The first phase considers the protection offered from the lightning masts on the termination towers of the Des Moines, Cedar Falls, and Cyclone Generation line exits. The second phase focuses on the placement of additional masts to cover the shortcomings of the termination tower lighting masts.

Figures and Charts:

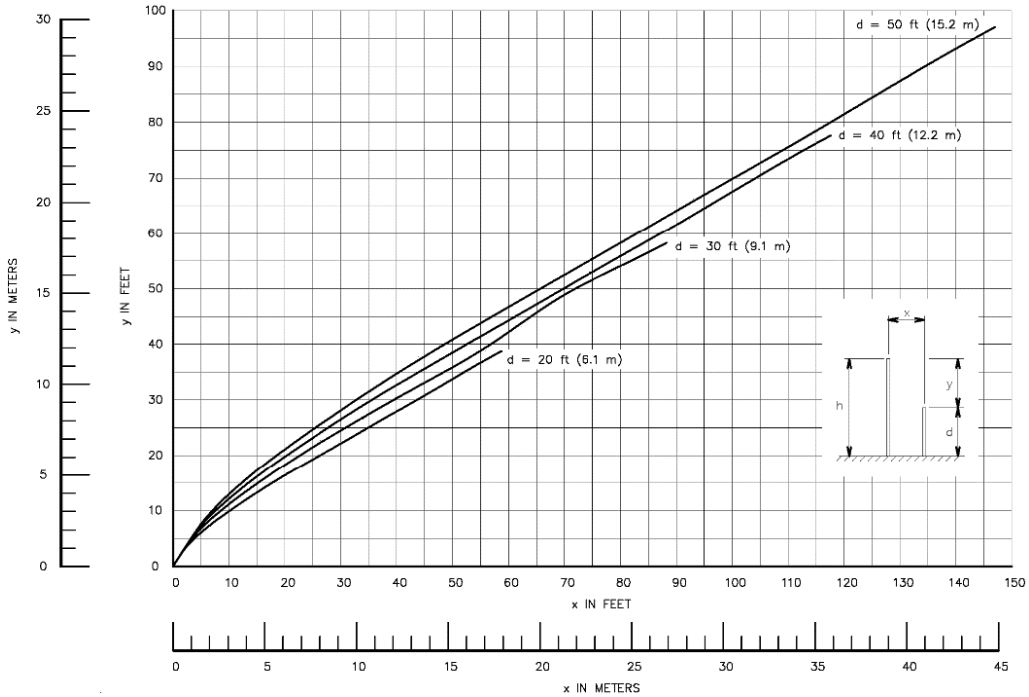

Figure 2- Single lightning mast protecting single object - 0.1% exposure. Height of lightning mast above protected object, y, as a function of horizontal separation, x, and the height of protected object, d.

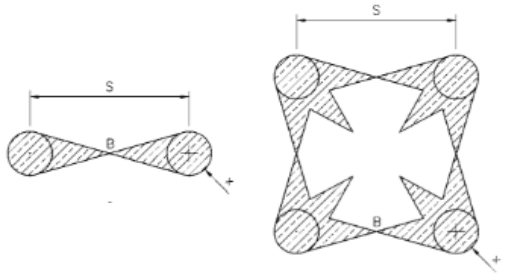

Figure 3 - Protection provided by two (left) and four (right) lightning masts without overlap of protection

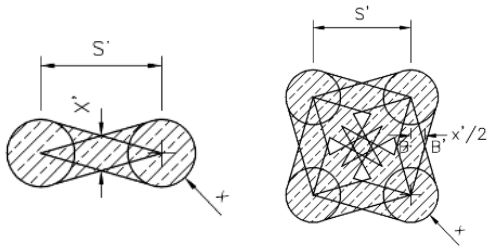

Figure 4 - Protection provided by two (left) and four (right) lightning masts with overlapping zones of protection

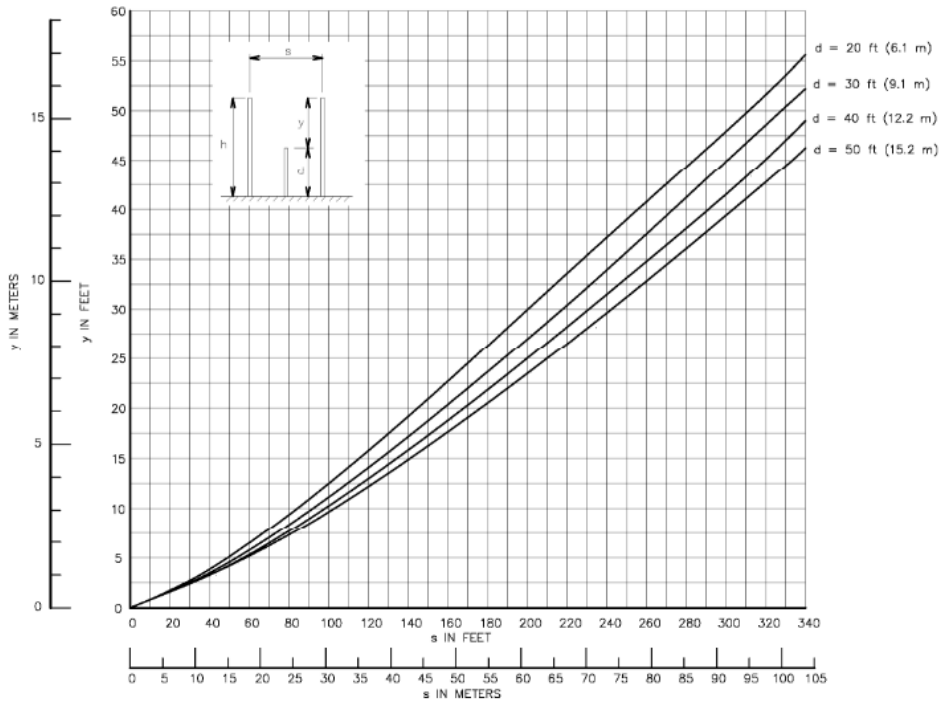

Figure 2 - Two lightning masts protecting single object, no overlap - 0.1% exposure. Height of mast above protected object, y, as a function of horizontal separation, s, and height of protected object, d

Definitions and Equations:

- d: Referred to as the height of the equipment in feet. This is the tallest piece of equipment needing protection around the electrode.
  - $d \in \{20, 30, 40, 50\}$
- h: Referred to as the height of the shielding mast above ground in feet.
- r: Referred to as the radius of conductor in feet. This is the radius or effective radius (in feet) of the energized bus needing protection.
- x: Referred to as the protected radius in feet. This is the radius of the protection provided by the lightning mast
  - Calculated using Figure 1
- y: Referred to as the vertical separation between mast and object in feet.
  - $y = h - d$
- s: Referred to as the horizontal separation between two lightning masts in feet without overlap
  - Calculated using Figure 2
- s': Referred to as the horizontal separation between two lightning masts in feet with overlap
- $I(s)$: Referred to as the stroke current. This is the maximum allowable current the station bus and insulation can withstand before experiencing flashover in kA.
  - $I(s) = \frac{2.2xBIL}{Z(s)} \frac{2.2xBIL}{Z_S}$ for BIL > 350kV
  - $I(s) = 2\text{kA}$ for BIL $\leq 350\text{kV}$
  - $Z(s) = 60\text{Ln}(2d/r)$
- T: Referred to as the average isokeraunic level, or the number of thunderstorm-days in a year. A thunderstorm-day is a day where thunder was heard at least once.
- A: Referred to as the area (in square feet) of the unprotected region.
- GFD: Ground flash density
- N_s: Number of flashes to the substation area
  - $N_S = \frac{(GFD*A)}{1000^2}$
- SP: Shielding performance of the substation
  - $SP = N_S * 0.001$
- F: Referred to as the failure rate of insulation within unprotected area describes the number of years between failures.
  - Failure Rate

$$F = \frac{1}{P(f)xN}$$

Calculations for Protection

- **Protection from DWG # IA-000-24-01 (See Appendix Figure A-1)**
    - Termination Tower Protection
        1. Mast 1A – New lightning mast located above the North leg of the new Cyclone Generation H-frame termination tower
           Mast 1B - New lighting mast located above the South leg of the new Cyclone Generation H-frame termination tower
           Protecting 3" bus whose radius is 0.1458'.
            - Parameters:
                - $h(m) = 55.7',\ d = 20',\ y = \ 35.7'$
            - Protection results:
                - $x = 52$' (From figure 2)
        2. Mast 2A – New lighting mast located above the North leg of the new Cedar Falls H-frame termination tower
           Mast 2B – New lightning mast located above the South leg of the new Cedar Falls H-frame termination tower
           Protecting 3" bus whose radius is 0.1458'.
            - Parameters:
                - $h(m) = 55.7,\ d = 30',\ y = \ 25.7'$
            - Protection results:
                - $x = 35$' (From figure 2)
        3. Mast 3A – New lightning mast located above the West leg of the new Des Moines H-frame termination tower
           Mast 3B – New lightning mast located above the east leg of the new Des Moines H-frame termination tower
           Protecting 3" bus whose radius is 0.1458'.
            - Parameters:
                - $h(m) = 55.7,\ d = 30',\ y = \ 25.7'$
            - Protection results:
                - $x = 35$' (From figure 2)
        4. Overlapping zones of protections for lightning mast groups 1, 2, and 3 (mast 1A, 1B, 2A, 2B, 3A, and 3B)
           Protecting 3" bus whose radius is 0.1458'.
           We use a common horizontal separation, s, for the entire station to ensure maximal protection
            - Parameters:
                - $h(m) = 55.7,\ d = 30',\ y = 25.7'$
            - Protection results:
                - $s = 185'$ (From figure 5)

- **Protection from DWG # IA-000-24-02 (See Appendix Figure A-2)**
    - Auxiliary Lightning Mast Protection
        1. Mast 4A – New lightning mast located North of East-to-West 138 kV bus run off MOAB
           Mast 4B – New lightning mast located South of East-to-West 138 kV bus run off MOAB
           Protecting 3" bus whose radius is 0.1458'.
            - Parameters:
                - $h(m) = 55.7,\ d = 30',\ y = \ 25.7'$
            - Protection results:
                - $x = 35$' (From figure 2)
        2. Mast 5A – New lightning mast located North of East-to-West 138 kV Northernmost bus run
           Mast 5B – New lightning mast located South of East-to-West 138 kV Southernmost bus run
           Protecting 3" bus whose radius is 0.1458'.
            - Parameters:
                - $h(m) = 55.7,\ d = 30',\ y = \ 25.7'$
            - Protection results:
                - $x = 35$' (From figure 2)
        3. Mast 6A – New lightning mast located on the Southeast side of the 138 kV ring bus structure
           Protecting 3" bus whose radius is 0.1458'.
            - Parameters:
                - $h(m) = 55.7,\ d = 30',\ y = \ 25.7'$
            - Protection results:
                - $x = 35$' (From figure 2)
        4. Mast 7A – New lightning mast located on the Southwest side of the control building
           Protecting control building structure.
            - Parameters:
                - $h(m) = 55.7,\ d = 20',\ y = \ 35.7'$
            - Protection results:
                - $x = 52$' (From figure 2)
        5. Overlapping zones of protections for lightning mast groups 4, 5, 6, and 7 (mast 4A, 4B, 5A, 5B, 6A, and 7A)
           We use a common horizontal separation, s, for the entire station to ensure maximal protection
            - Parameters:
                - $h(m) = 55.7,\ d = 30',\ y = 25.7'$
            - Protection results:
                - $s = 185'$ (From figure 5)

6. Overlapping zones of protections for lightning mast groups 4, 5, 6, and 7 (mast 4A, 4B, 5A, 5B, 6A, and 7A) with lightning mast groups 1, 2, and 3 (mast 1A, 1B, 2A, 2B, 3A, and 3C).
   We use a common horizontal separation, s, for the entire station to ensure maximal protection
   - Parameters:
     - $h(m) = 55.7,\ d = 30',\ y = 25.7'$
   - Protection results:
     - $s = 185'$ (From figure 5)

Recommendations

According to the IEEE 998-2012 standard definition of the empirical curves method, the exposure to lightning strikes of the substation equipment is limited to 0.01%. To achieve this the following recommendations are made for the Cyclone Generation Substation team by the Iowa State Senior Design Team:

1. Usage of the lightning masts atop the H-frame termination structures at the Cyclone Generation, Des Moines, and Cedar Falls line exits
2. Add a lightning mast on both sides of the East-West 138 kV bus run nearest the MOAB before entry to the ring bus
3. Add a lightning mast on both the Northern and Southern most East-West 138 kV bus runs in the ring bus
4. Add a lightning mast near the gate into the substation
5. Add a temporary lightning mast East of the Eastern North-South 138 kV bus run in the ring bus. Future protection will be provided via termination towers during line expansion at the substation.

The above recommendations limit the exposure of the equipment to 0.01% in the protected zones.

APPENDIX

Reference Figures For Configurations

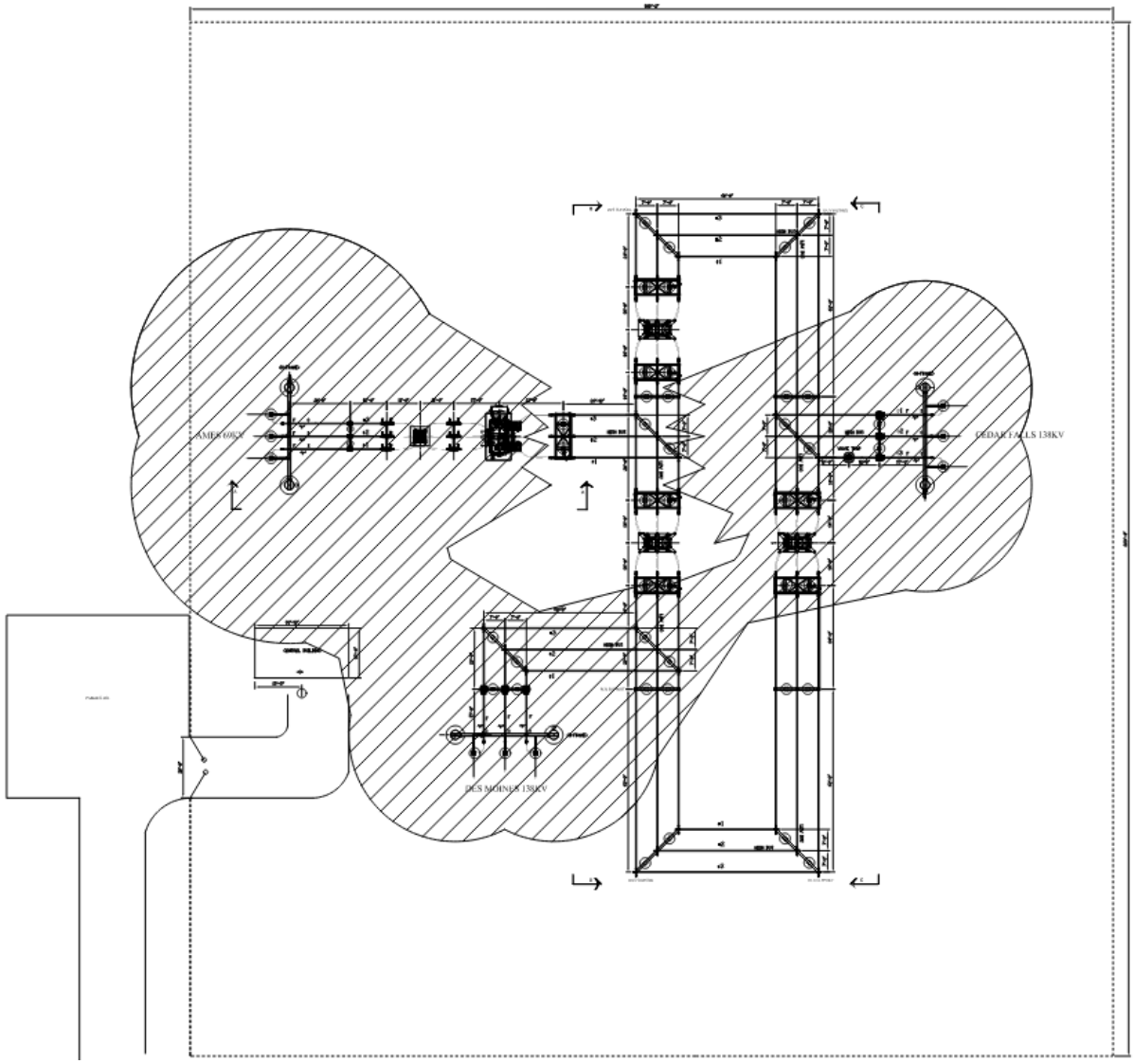

Figure A-1 – Plan view shoading the zones of protection provided via the lightning masts affixed atop the termination tower structures.

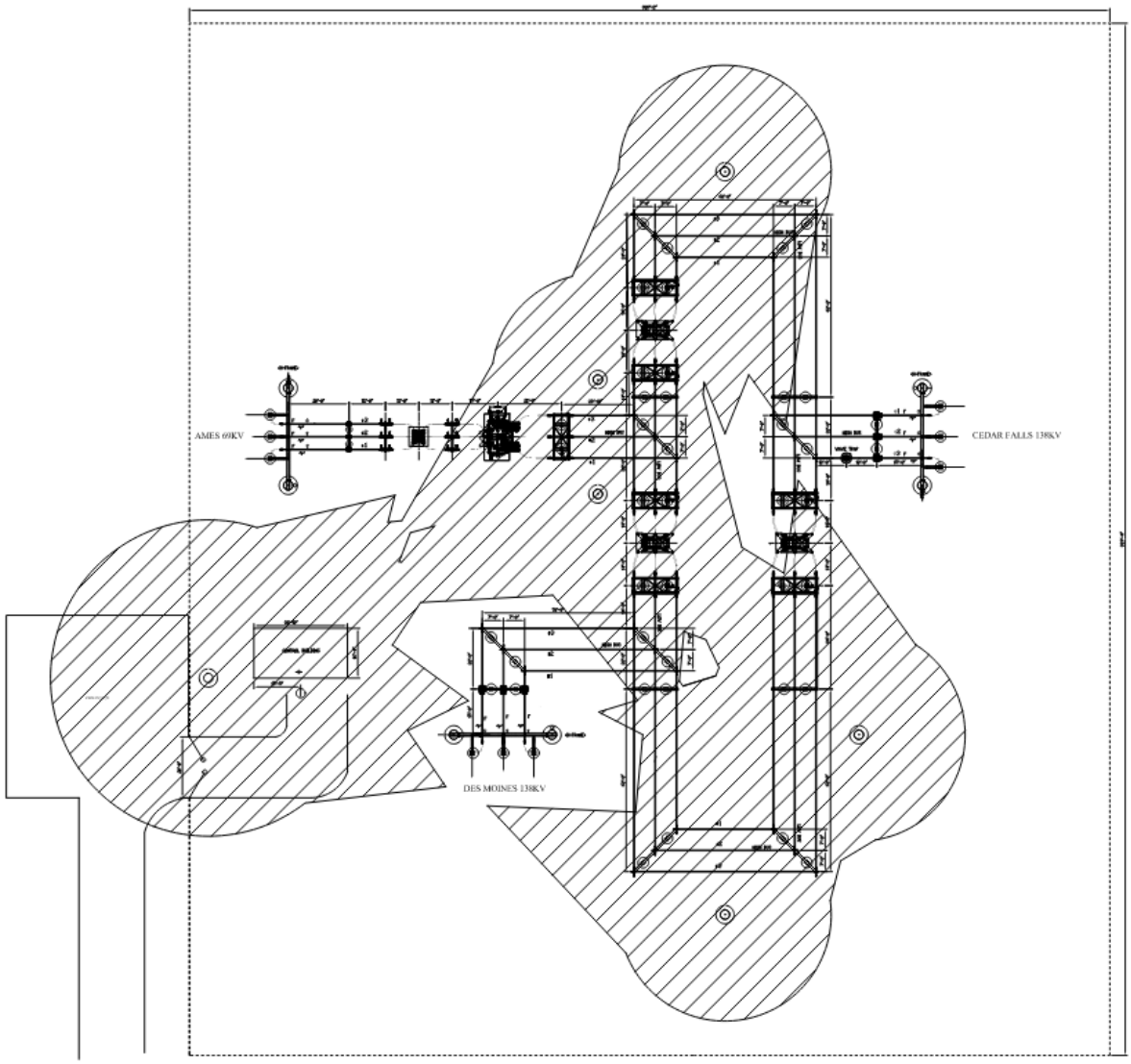

Figure A 2 – Plan view shoading the zones of protection provided via the auxiliary lightning masts.

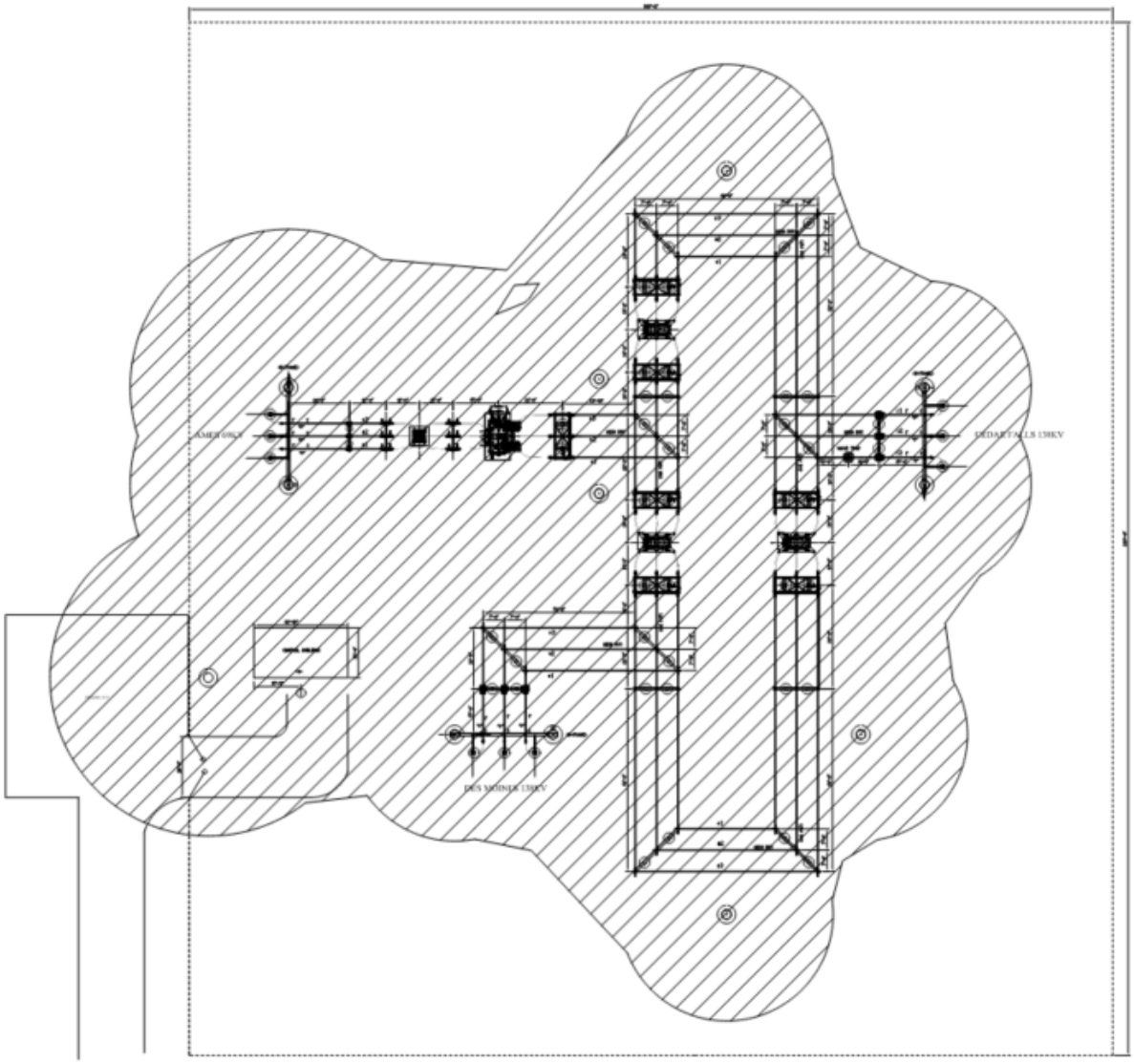

Figure A 3 – Plan view depicting overall zones of protection at the substation