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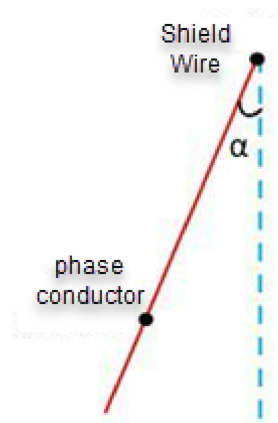
Lightning Protection checks of overhead lines in PLS-CADD

Shield wires are vital parts of transmission lines. A shield wire is typically an uninsulated, non-energized wire installed to protect the energized conductors, structures and equipment from lightning strikes. Shield wires are attached or grounded at each structure so that any voltage surges from lightning, safely and quickly travels to the ground. This prevents lightning induced outages and minimizes damage to the overhead lines and equipment.

The PLS software can check the required clearances between shield wires and conductors as well as check that shield wires provide the required coverage from lightning for the conductors. The PLS-CADD user manual describes the options available for the lightning protection tools within Section 11.2.12. **PLS-CADD** creates a Lightning Protection TIN surface to check shield wire coverage of conductors, and it can do this using one of two methods. 1) Fixed Angle Method. 2) The Rolling Sphere Method. This technical note describes the **PLS-CADD** features that can help a PLS user check that shield wires have appropriate protection to meet their system's requirements.

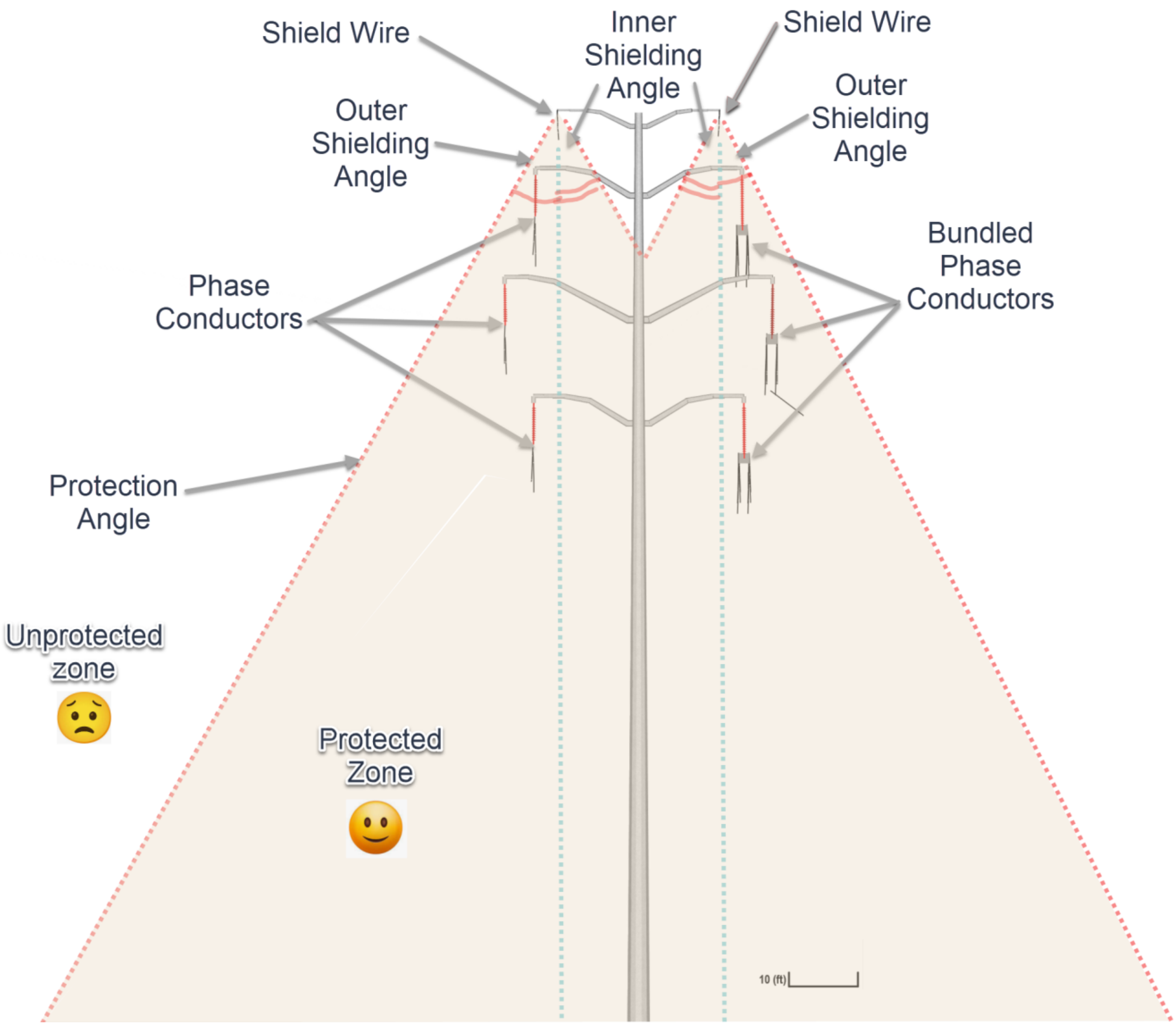
Fixed Angle Method

The Fixed Angle Method is the simplest way to check shielding coverage. The shielding angle is defined as an angle between the shield wire and the phase conductor(s). The angle, α, shown in the diagram below is defined between the vertical line through the shield wire (dashed blue line below) and the line joining the shield wire through a phase conductor (solid red line below) is taken as a shielding angle.

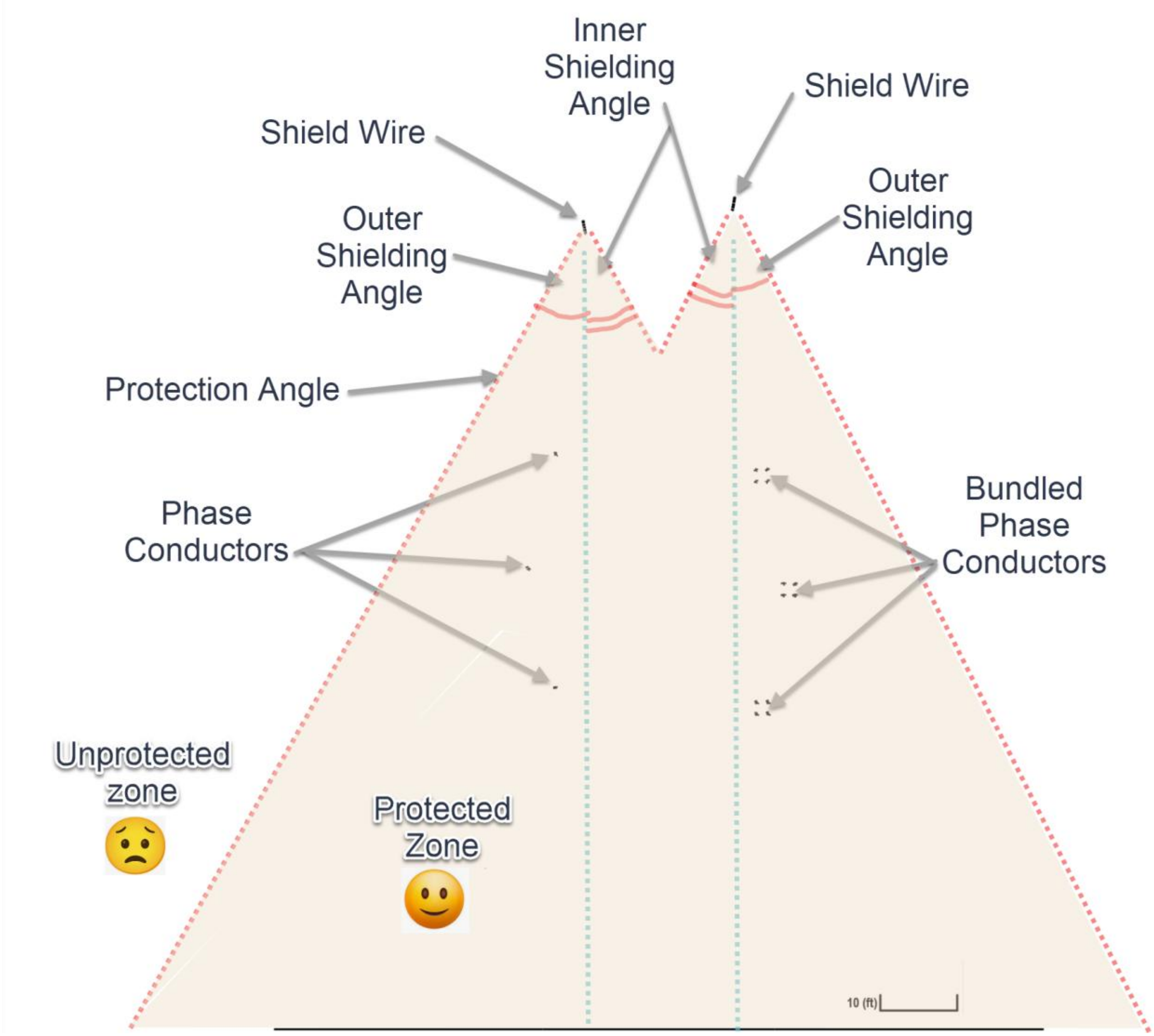


For effective shielding, the protective angle should be kept as small as possible. A shielding angle between 20° and 30° is typical, with lower angles usually used for taller structures. Two shield wires can be used on high voltage lines where there is a wider spacing between the conductors. As shown below, the two shield wires can provide much better coverage than a single wire, because it can provide a smaller shielding angle for all conductors with a lower structure height.

PLS-CADD allows for specifying both an inner and outer shielding angle inputs. The inner shielding angle extends from the shield wire at the specified shielding angle towards the centerline of the structure, if there is another parallel shield wire in proximity, and terminates at the structure. The outer shielding angle extends from the shield wire, at the specified shielding angle, towards the outside of the structure and terminates at the ground as depicted in the image below.

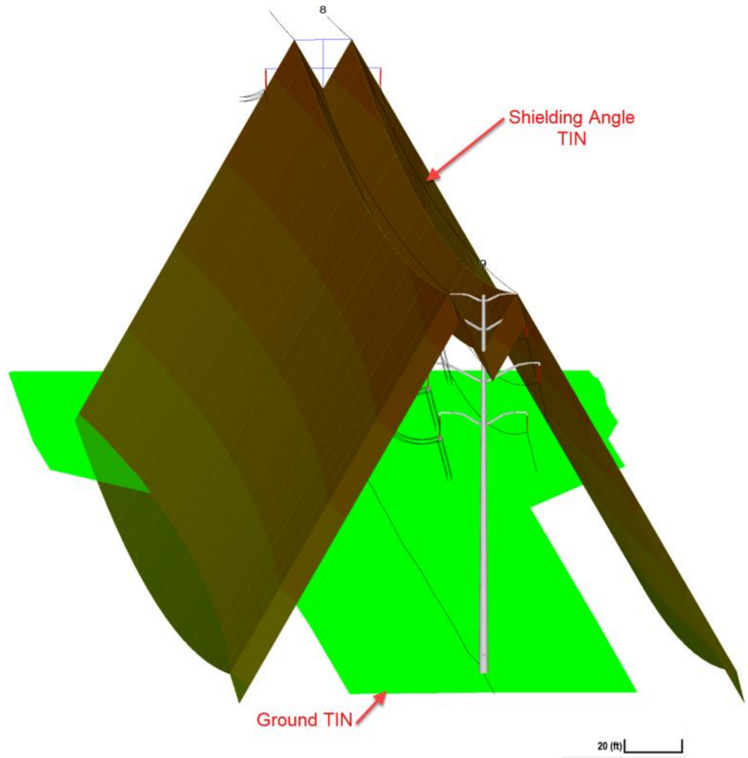


Traditionally, the shielding angle check is performed at structure positions only. However, **PLS-CADD** can also check shielding angles along the span at a specified interval. Using the built in sag-tension calculations in **PLS-CADD**, the locations of the shield wires and conductors along the span under any weather case or cable condition are known. The example below shows the shield angle displayed along the span (away from the structure location). In this example line there is a traditional shield wire and an OPGW, which have different sags along the span. **PLS-CADD** can account for the different sags and still perform shielding checks for these conditions.

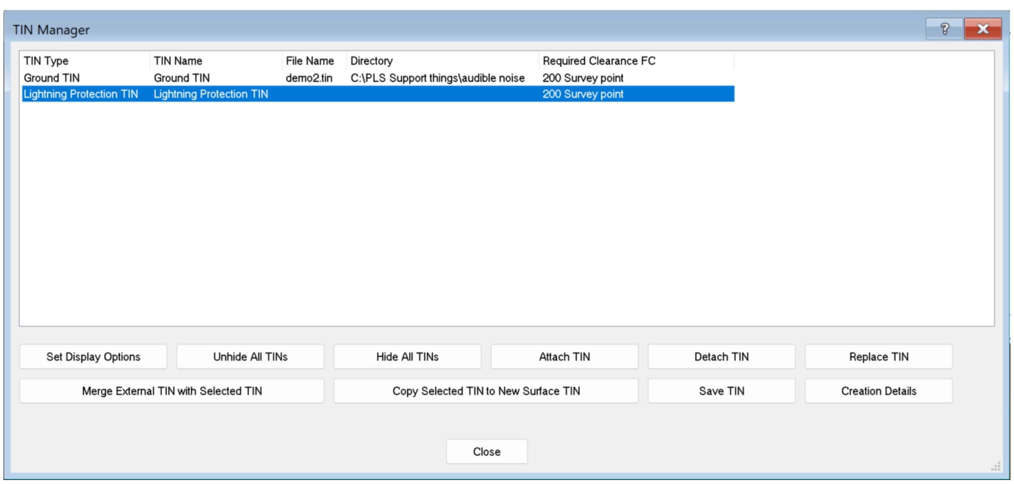


A Lightning Protection TIN surface is created between these cross-section intervals. Conductors that extend outside of this TIN surface do not have protection from lightning strikes for the outer and inner angles entered.

The tool also outputs a report that provides the length of exposed conductor in the spans that were analyzed.



The Lightning Protection TIN is saved in the TIN Manager in **PLS-CADD** once it is created. To access the TIN Manager, use the menu command **Terrain/TIN/TIN Manager**. Here you can update the TIN display settings or show/hide this TIN.



Rolling Sphere Method

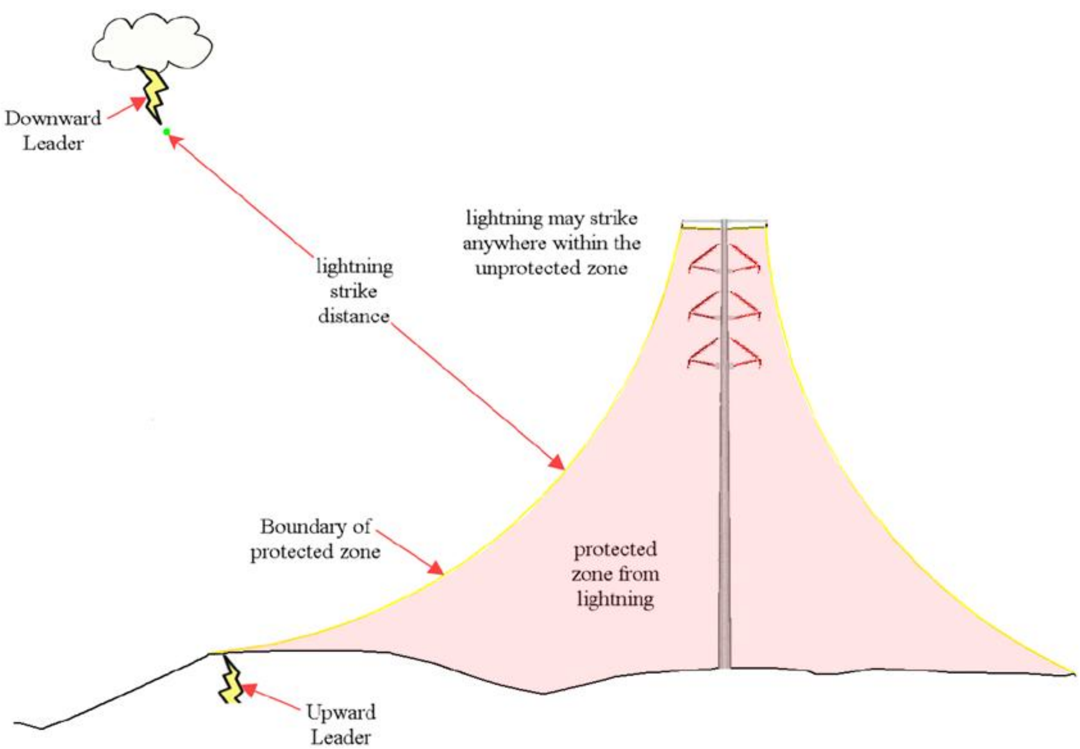
The rolling sphere lightning protection method is a derivative of the electrogeometric method (EGM) and is credited to Ralph H. Lee's studies in the USA (1977) for building protection. Then it was J.T. Orrell, who expanded on this concept for use in substation design.

The rolling sphere theory is based on two assumptions:

1. The point of strike of lightning is determined when the downward leader approaches the earth or a structure with a striking distance.
2. Lightning will strike the nearest grounded object from the orientation point. Its worst position is the center of a sphere which attaches the shield wire and ground.

This method uses a fictitious sphere with a defined radius to help determine if adequate lightning protection is provided. The starting point is the existence of a spherical volume with a radius equal to the striking distance, positioned around the stepped leader's tip. When lightning strikes the earth, a downward leader grows from clouds towards the earth. An upward leader will be discharged at points of greatest electric field intensity and can move in any direction towards an approaching downward leader. This is why lightning can strike the side of tall structures rather than the top.

The sphere should touch only the protection system elements when it is rolled around the protected portion of structure, i.e. the shield wire(s) and intersect with the ground. Where the sphere touches the structures or conductors then lightning strikes are a hazard. An overhead line or equipment is said to be protected from a direct stroke if it remains in the zone between the sphere and ground. The figure below describes the rolling sphere method and shows the protected and unprotected zones.



Determining the proper strike distance to use for an overhead line is important for design of the lightning protection system using this method. The radius of the sphere is determined by the lightning protection level, intensity of lightning strikes in the area and surge impedance. Please refer to your standard for appropriate values to use. The smaller the strike distance (or sphere radius) is used, the greater the level of protection that is offered. However, a small strike distance may not intersect with the ground surface TIN and if that is the case the conductors are exposed or unprotected.

There is a video about the rolling sphere method available in our lightning protection calculator in **PLS-CADD** at https://www.youtube.com/watch?v=Cksfqt8LBJ4&t=4s.

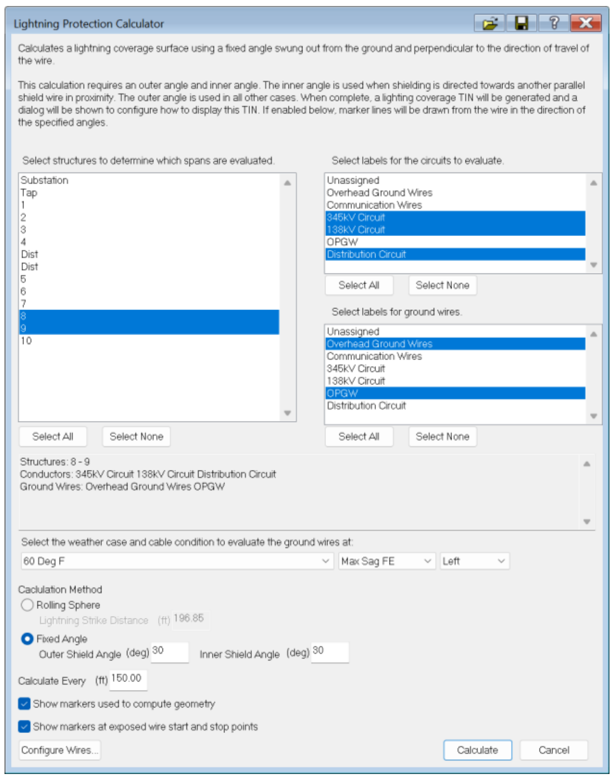
A lightning protection TIN is created as an output (as mentioned for the fixed angle check and accessed in the TIN manager) as well as the report listing out exposed sections of conductor if there are any.

An example and a comparison of methods

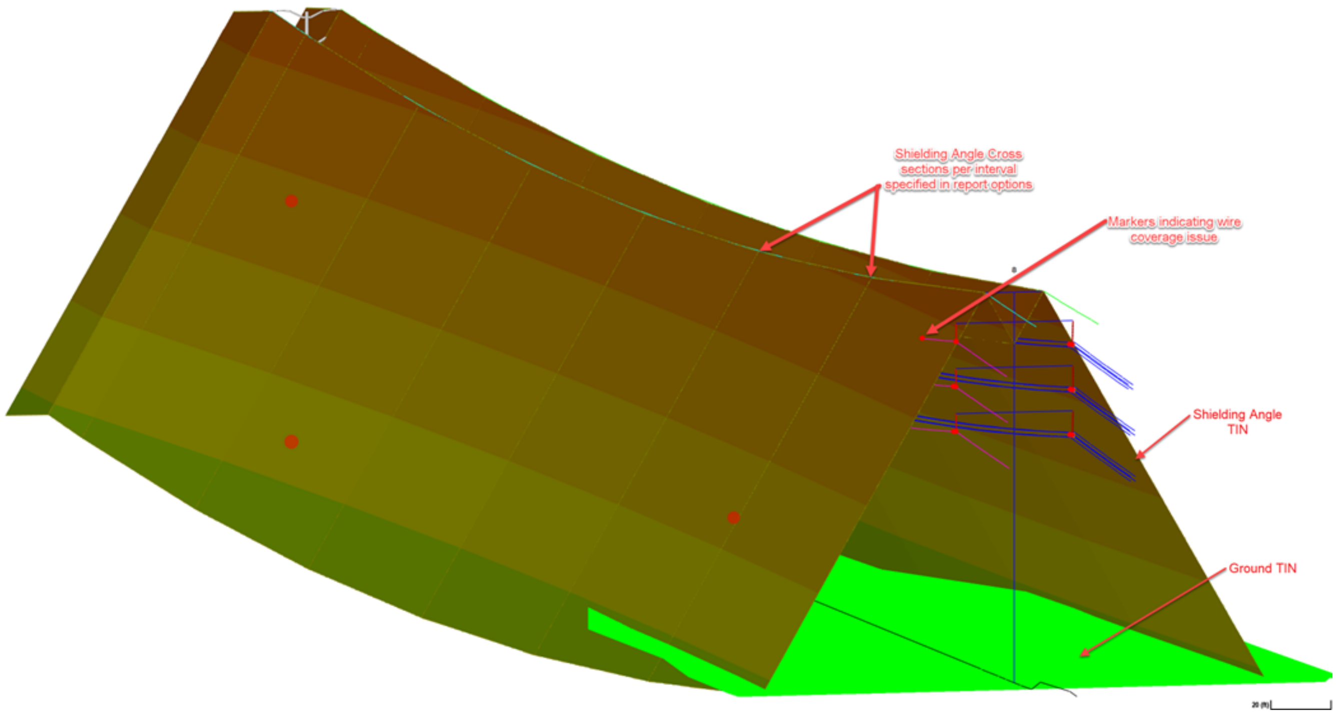
Let's run through a shielding check on a **PLS-CADD** project. *This PLS-CADD model has been attached to this technical note and can be accessed once this pdf is downloaded and opened from Adobe on your machine.* Use the menu command **Sections/Electric/Lightning Protection Calculator…** to run this feature on this example model and it will feature a single span in this project to help show the differences between the two available methods.

Fixed Angle:

The following Lightning Protection Calculator options were used:



The Lightning Protection TIN was then created and rendered. The image below shows the resulting surface, as well as red markers that indicate where there is a lack of protection with the 30 degrees shielding angle from the shield wire at a cable condition of 60 deg F, Max Sag FE.



A report is also generated to show the results of the analysis. All exposed conductors are listed in this report so any entry should be treated as No Good, **NG**. A total of **82 feet** of conductor is exposed to lightning on this span as stated in this report, but phase 5:1 is really the only one exposed and outside the lightning protection TIN surface.

```
Weather Case: 60 Deg F
Cable Condition: Max Sag FE
Wind from the Left
Outer angle: 30.00 (deg)
Inner angle: 30.00 (deg)
Evaluating ground wires every  150.000 (ft)
```

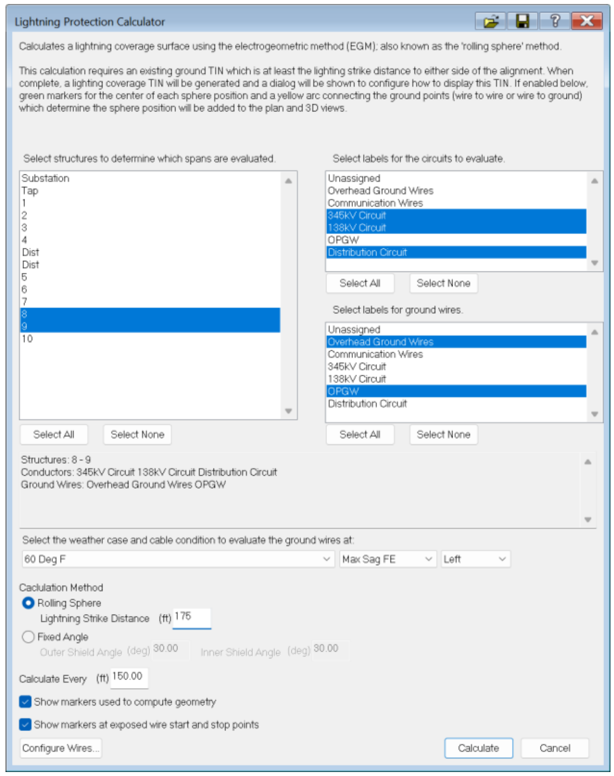
Lightning Coverage Exposed Conductors:

Back Structure	Set #	Phase #	Circuit Label	Phase Label	Section Note	Distance to Start (ft)	Length Exposed (ft)	Start of Exposed Wire X (ft)	Start of Exposed Wire Y (ft)	Start of Exposed Wire Z (ft)	Start of Exposed Wire Station (ft)	End of Exposed Wire X (ft)	End of Exposed Wire Y (ft)	End of Exposed Wire Z (ft)	End of Exposed Wire Station (ft)
8	5	1	138kV Circuit			0	49	4696.10	-2368.18	1405.82	7084.09	4741.98	-2368.42	1402.36	7129.97
8	5	2	138kV Circuit			0	7	4696.10	-2368.03	1390.82	7084.09	4699.37	-2368.03	1390.56	7087.36
8	5	3	138kV Circuit			0	7	4696.10	-2368.17	1375.82	7084.09	4699.37	-2368.19	1375.55	7087.36
8	6	1	345kV Circuit			0	7	4696.06	-2407.77	1403.82	7084.05	4699.34	-2407.75	1403.54	7087.33
8	6	2	345kV Circuit			0	7	4696.06	-2407.96	1388.82	7084.05	4699.34	-2407.96	1388.54	7087.33
8	6	3	345kV Circuit			0	7	4696.06	-2407.79	1373.82	7084.05	4699.34	-2407.77	1373.53	7087.33

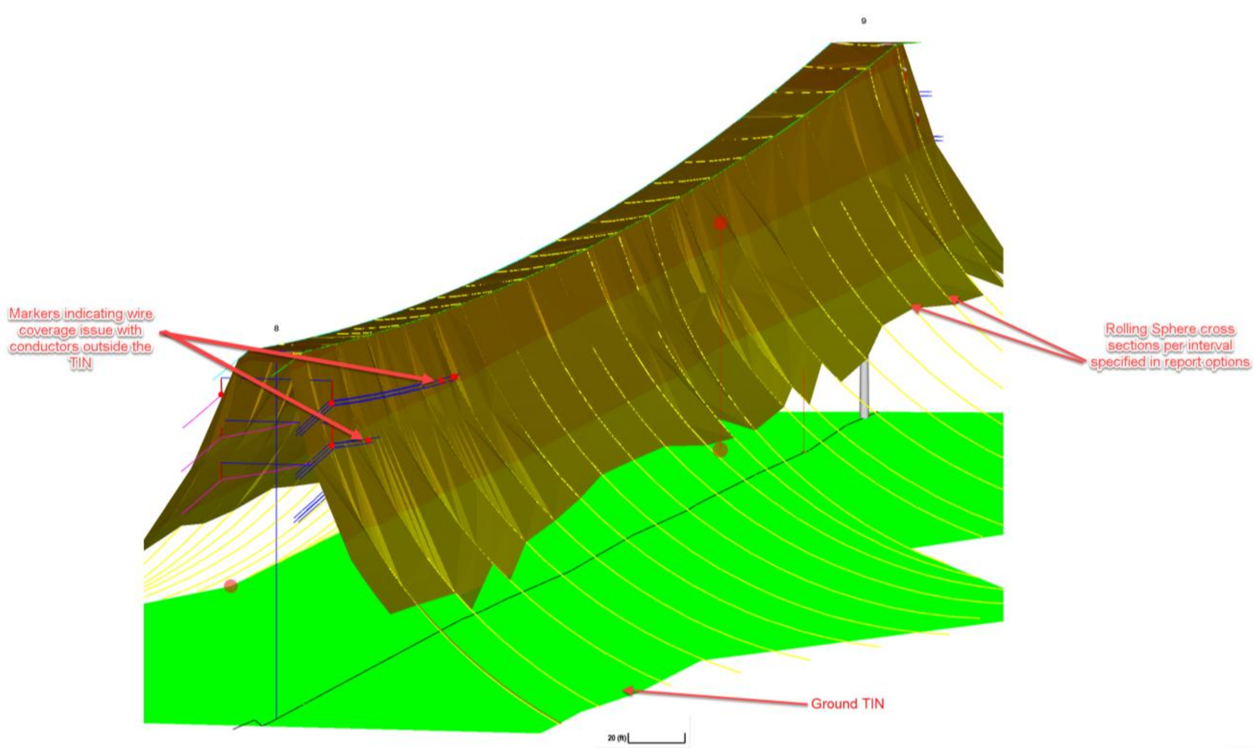
Approximate total length of exposed conductor: 82 (ft)

Rolling Sphere:

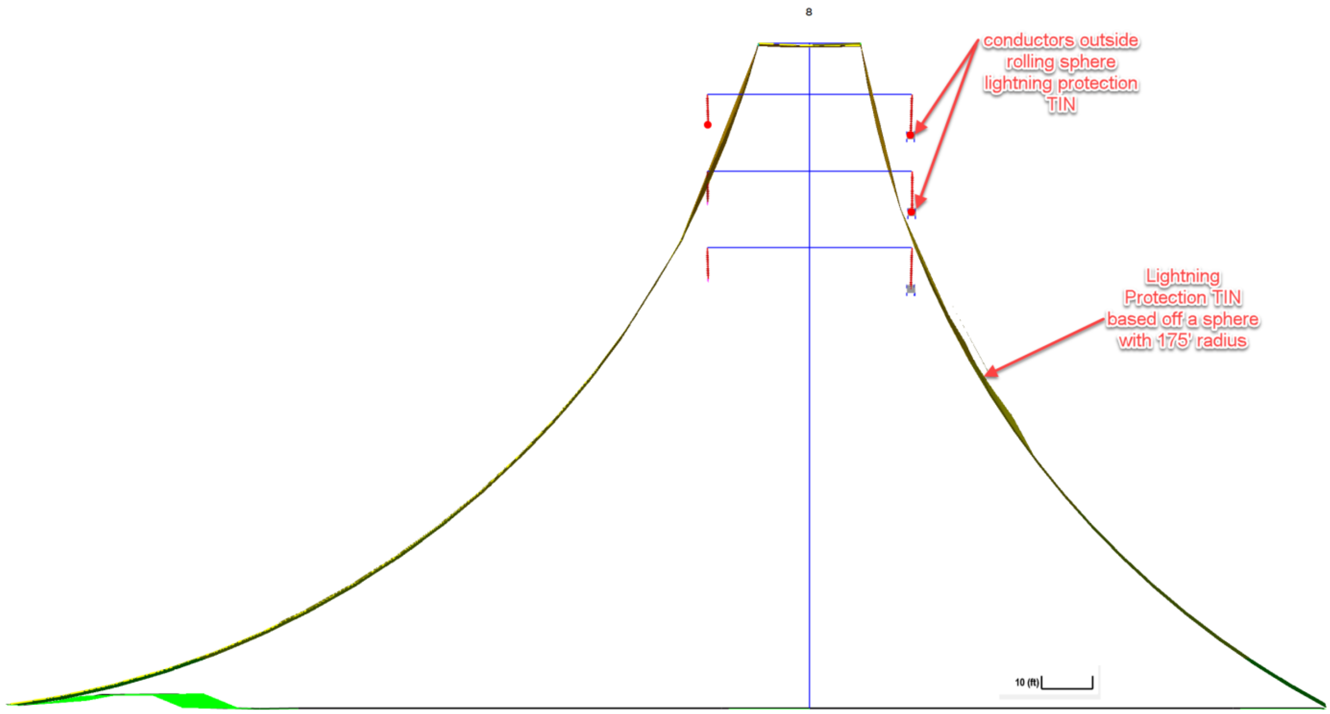
The following Lightning Protection Calculator options were used:



The Lightning Protection TIN was then created and rendered. The image below shows the resulting surface, as well as red markers that indicate where there is a lack of protection with the 175’ lightning strike distance from the shield wire at a cable condition of 60 deg F, Max Sag FE.



The cross-section view below shows the radius of the sphere. **PLS-CADD** does have an option to drop markers at the center point of the sphere and intersections with the ground to help visualize how the sphere was rolled along the protection system. It is evident from this image that the terrain impacts the results, with the more exposure on the right of this image where the terrain is at a lower elevation. This effect would be more pronounced in areas with side-slopes.



In this case the output report indicates a total of 906 feet of conductor is exposed to lightning on this span with the settings used.

```
Weather Case: 60 Deg F
Cable Condition: Max Sag FE
Wind from the Left
Lightning Stroke Distance (radius of sphere):  175.000 (ft)
Evaluating ground wires every  150.000 (ft)


Gaps in Lightning Coverage:
The following spans have gaps in coverage provided by the specified ground wire starting near the specified distance along the span.

     Back Set Phase Section Distance
 Structure   #     #    Note   to Gap
                                 (ft)
-------------------------------------
         8   1     1              899

Lightning Coverage Exposed Conductors:

     Back Set Phase       Circuit Phase Section |  Distance |    Length | -----------------Start of Exposed Wire----------------- | -----------------End of Exposed Wire------------------ |
 Structure   #     #        Label Label    Note |  to Start |   Exposed |          X          Y          Z    Station |          X          Y          Z    Station |
                                                |      (ft) |      (ft) |       (ft)       (ft)       (ft)       (ft) |       (ft)       (ft)       (ft)       (ft) |
------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
         8   5     1 138kV Circuit                        0         617      4696.10   -2368.18    1405.82    7084.09      5308.92   -2371.30    1389.77    7696.91
         8   5     1 138kV Circuit                      748          10      5443.28   -2371.99    1394.96    7831.27      5449.83   -2372.02    1395.29    7837.82
         8   5     1 138kV Circuit                      922          26      5616.96   -2372.87    1406.31    8004.95      5639.76   -2372.99    1408.19    8027.75
         8   5     2 138kV Circuit                        0           7      4696.10   -2368.03    1390.82    7084.09      4699.37   -2368.03    1390.56    7087.36
         8   5     2 138kV Circuit                      935          13      5630.09   -2368.68    1391.64    8018.08      5639.76   -2368.68    1392.44    8027.75
         8   5     3 138kV Circuit                        0           7      4696.10   -2368.17    1375.82    7084.09      4699.37   -2368.19    1375.55    7087.36
         8   6     1 345kV Circuit                        0         180      4696.06   -2407.77    1403.82    7084.05      4872.99   -2406.88    1391.50    7260.98
         8   6     2 345kV Circuit                        0          39      4696.06   -2407.96    1388.82    7084.05      4732.10   -2407.93    1385.80    7120.09
         8   6     3 345kV Circuit                        0           7      4696.06   -2407.79    1373.82    7084.05      4699.34   -2407.77    1373.53    7087.33


Approximate total length of exposed conductor:     906 (ft)
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PLS-CADD provides tools to check shielding of overhead lines with the shielding angle method and rolling sphere method. Which method to use is up to the judgement of the engineer tasked with design of the line. There are considerations for both methods.

The Shielding angle method uses an angle check from shield wire(s) to see if any portion of the line is exposed to lightning. The simplicity of the method and history for successful designs makes it a popular choice. The exact shielding angle to use needs to be determined by the operating company that will assume the risk.

Considerations for this should be structure height(s) and operating voltage. This method does ignore structure resistance and ground terrain.

The rolling sphere method checks that the strike distance of certain level of lightning will not contact the line. This method is used widely in substation and building design but is also a method that adapts well to overhead lines. Another big advantage of this method is it does consider terrain along the line. There is also consideration of the structure resistance and operating voltage as part of the strike distance determination.