Transmission Line Tower Earthing Analysis using SafeGrid™

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Background

The purpose of transmission line grounding is to (a) provide adequate lightning performance of the line; and (b) effectively dissipate fault current avoiding the build-up of unsafe step and touch potentials around the tower base.

The tower earthing system is provided by an electrically interconnected system of conductors and rods, connectors, foundation and the local soil.

Individual tower earthing must consider the performance of the line and the individual tower. Different tower earthing designs can occur from tower to tower due to the variation in parameters and conditions along the length of the line.

During a phase to earth fault current flows back to the source via the overhead earth wires and through the earthing systems of the individual towers. Potential gradients which are expressed in terms of step and touch occur in the soil surrounding the towers need to be evaluated with respect to safety limits imposed by regulations and standards.

The requirement to evaluate and limit step and touch potentials around transmission line towers can govern the earthing system design and layout.

Case Studies

The safety of two transmission tower designs has been assessed using analytical modelling software.

Case 1 - Single potential control ring:

Case 1 is an example from EPRI grounding system design guide.

Table 1 Case 1 – earthing parameters

Phase to earth fault current	400 *A*
Depth of burial of control ring	0.25 *m*
Top layer soil resistivity	100 *Ω.m*
Top layer soil depth	2 *m*
Bottom layer soil resistivity	500 *Ω.m*

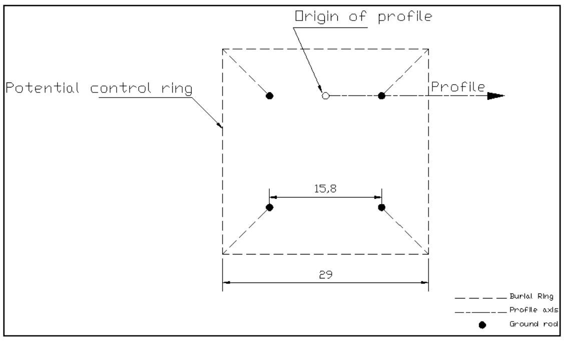

Figure 1 Transmission tower earthing with single potential control ring.

Case 2 - Double potential control rings:

Table 2 Case 2 – earthing parameters

Phase to earth fault current	162 *A*
Depth of burial of control rings	0.25 *m*
Top layer soil resistivity	393 *Ω.m*
Top layer soil depth	1.16 *m*
Bottom layer soil resistivity	897 *Ω.m*

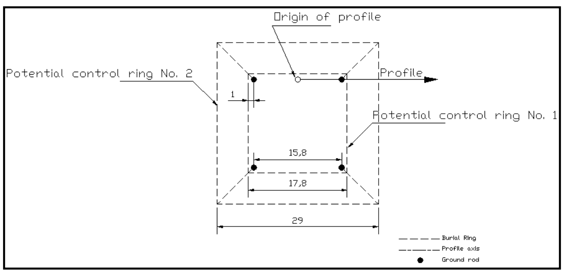

Figure 2 Transmission tower earthing with double potential control rings.

Methodology

Both case studies were modelled and analysed using SafeGrid™ earthing design software.

Grid models were built using the integrated grid editor. However, 3D grids of any arbitrary configuration can also be built in CAD and imported as a DXF file.

Common inputs for buried conductor internal resistance and inductance calculations are:

Table 3 Common inputs for conductor internal R+X

Conductor radius	0.01 *m*
Frequency of supply	50 *Hz*
Conductivity of buried conductor	57E6 *S/m*

Results

The calculation results of the two case studies are given below.

Step and touch potentials are calculated for up to 1 m and 5 m, respectively, from the perimeter set by the outside control ring.

Case 1 - Single potential control ring:

Table 4 Calculation results for Case 1

Tower footing resistance	5.23 *Ω*
Tower potential rise	2093 *V*

Surface potentials (Figure 3):

Max. surface potential rise	2033 *V*

Touch potentials (Figure 4):

Touch potential 1 m from tower (i.e. hand touching tower and feet 1 m away)	69.8 *V*

Step potentials (Figure 5):

Max. step potential	261 *V*
Step potential 5 m from tower earthing control ring	33.8 *V*

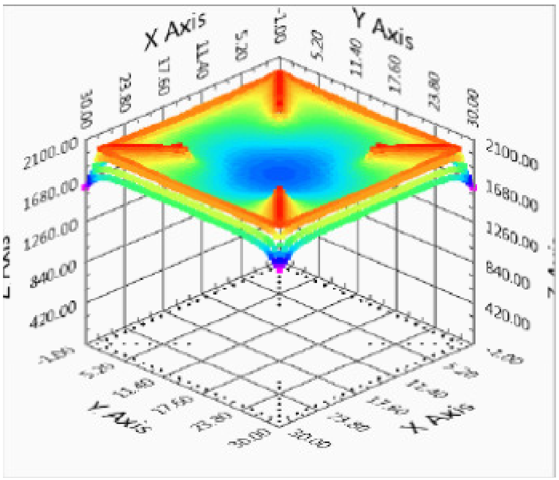

Figure 3 Surface potentials (V) in 3D view – Case 1

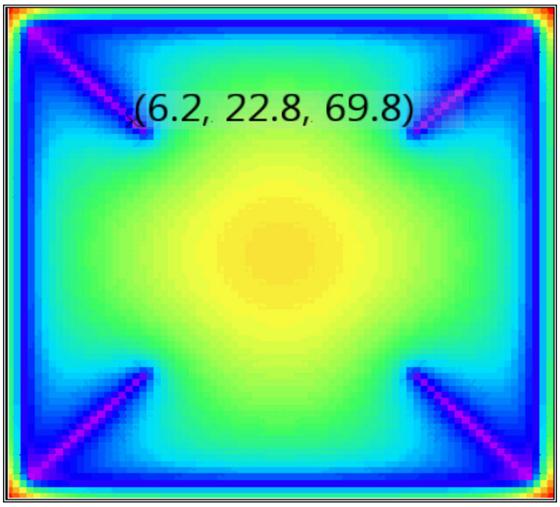

Figure 4 Touch potentials (V) in X-Y view – Case 1

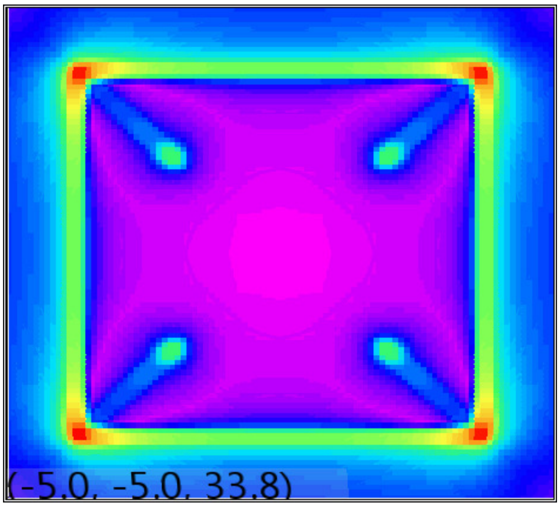

Figure 5 Step potentials (V) in X-Y view – Case 1

Case 2 - Double potential control rings:

Table 5 Calculation results for Case 2

Tower footing resistance	12.48 *Ω*
Tower potential rise	2022 *V*

Surface potentials (Figure 6):

Max. surface potential rise	1967 *V*

Touch potentials (Figure 7):

Touch potential 1 m from tower (i.e. hand touching tower and feet 1 m away)	86 *V*

Step potentials (Figure 8):

Max. step potential	335.3 *V*
Step potential 5 m from tower earthing control ring	32.5 *V*

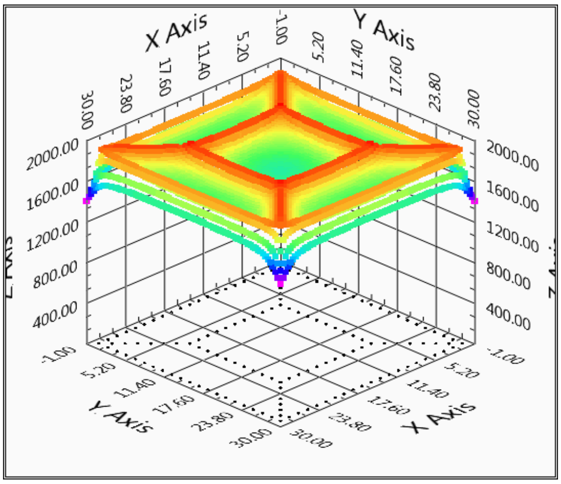

Figure 6 Surface potentials (V) in 3D view – Case 2

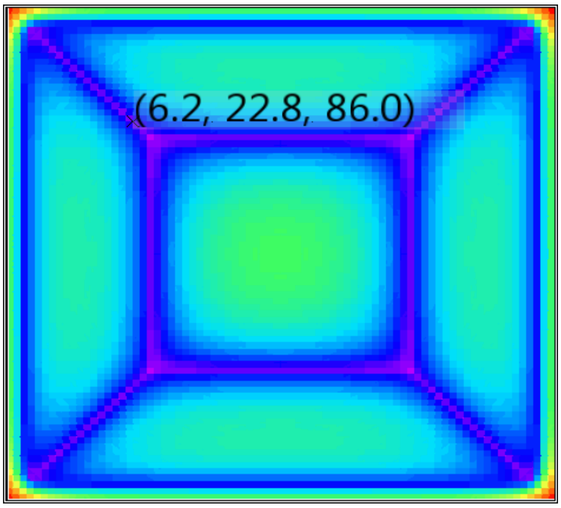

Figure 7 Touch potentials (V) in X-Y view – Case 2

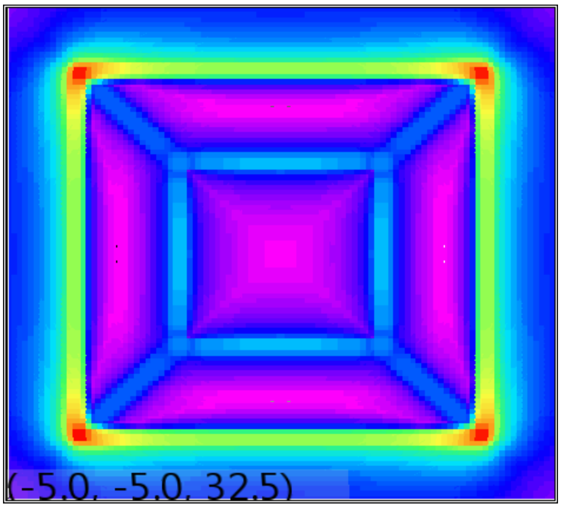

Figure 8 Step potentials (V) in X-Y view – Case 2

Tower footing resistance is much higher for Case 2 compared with Case 1 due to higher soil resistivity values.

Tower potential rise is similar for both cases (despite higher tower footing resistance for Case 2) due to lower fault current magnitude for Case 2.

Higher step and touch potentials occur for Case 2 than for Case 1.

The highest step and touch potentials occur at the edges of the outer control ring.

Safety criteria

The allowable safety criteria limits are calculated using SafeGrid™ in accordance with both IEEE Std-80 and IEC 60479.

Table 6 Common inputs for safety criteria calculations

Fault clearing time	0.22 *s*
Additional surface layer (i.e. blue metal rock)	None
Additional resistance (i.e. shoe, glove)	None
X/R Ratio	20

Table 7 Step and touch potential limits to IEEE Std-80

Inputs:

Fibrillation current calculation	50 *kg* - IEEE
Foot resistance calculation	IEEE Std-80: 2000

Safe limits:

Touch voltage limit	250.5 *V*
Step voltage limit	348.5 *V*
Permissible body current	0.2473 *A*
Body resistance	1000 *Ω*

Table 8 Step and touch potential limits to IEC 60479

Inputs:

Fibrillation current calculation	C1 - IEC
Foot resistance calculation	IEEE Std-80: 2000

Safe limits:

Touch voltage limit	295.4 *V*
Step voltage limit	442.6 *V*
Permissible body current	0.3713 *A*
Body resistance	753.4 *Ω*

Note that safety criteria limits calculated for IEC are less stringent than for IEEE when fault clearing time is less than 0.4 seconds.

Assessment of safety

Touch voltages

Generally for this situation the touch voltages which need to be assessed are for those areas which are within 1 m (reach) from the steel tower legs.

Figure 9 shows an X-Y plot of unsafe touch potentials. These are defined as touch potentials which exceed the safe limits given in Table 8 Step and touch potential limits to IEC 60479. Note the location of the four tower structure legs are highlighted by a 1 metre radius circle. Only touch potentials which exceed the safe limits and fall with this circle are unsafe. Therefore no unsafe touch voltages exist.

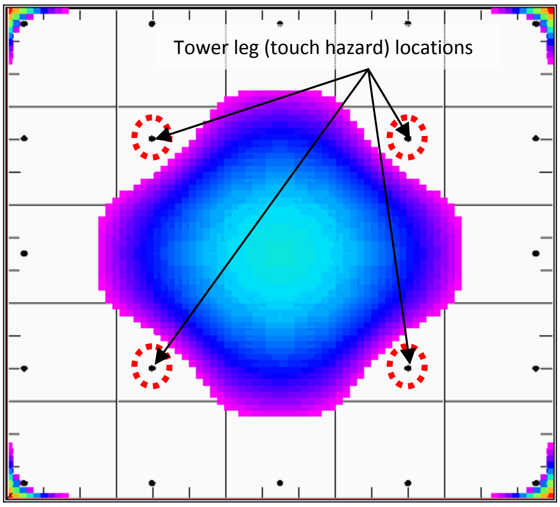

Figure 9 Touch voltages which exceed IEC safe limits – Case 1

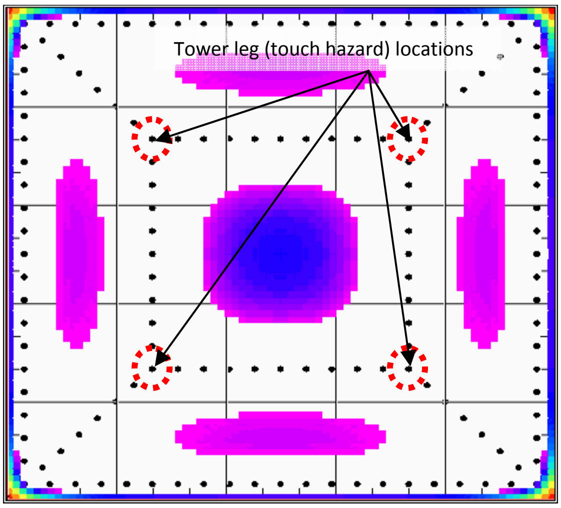

Figure 10 Touch voltages which exceed IEC safe limits – Case 2

Step voltages

Since touch voltages are safe then it is expected that step voltages will also be safe.

Since the calculated maximum step potential is 261.2 V (Figure 11) which is less than the IEEE and IEC safety limits (348.5 V and 442.6 V respectively) then no unsafe step potentials exist.

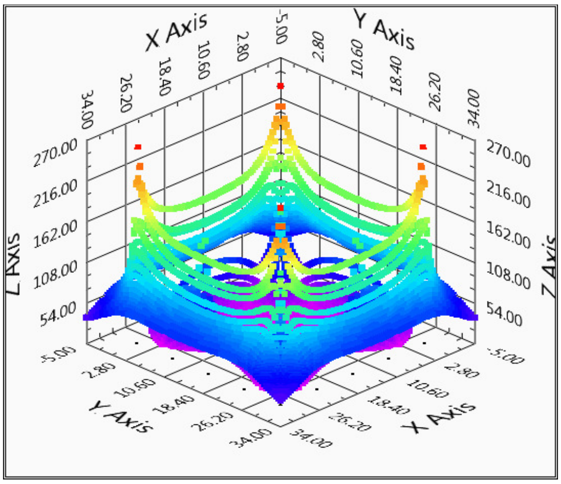

Figure 11 Step potentials (V) in 3D view – Case 1

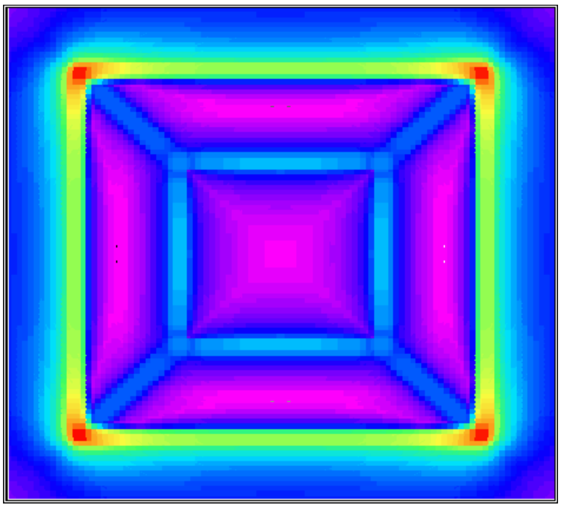

Figure 12 Step potentials (V) in X-Y view – Case 2. Max. step potential = 335.3 V which is less than limit of 348.5 V for IEEE.

Effects of adding vertical rods

Four vertical rods of 5 metres in length were included in the model for Case 2. The locations for the rods were at the location of the tower legs.

The expected reduction in tower footing resistance was not significant. The tower footing resistance for Case 2 was reduced from 12.48 Ohms to 11.66 Ohms. The tower potential rise was reduced from 2022 V down to 1888 V.

In both cases due to the soil consisting of a low on high soil model the addition of vertical rods will not be effective at reducing the tower footing resistance. Generally rods are only effective (economical) when the bottom layer soil resistivity is lower than the upper layer.

Conclusions

The assessment of safety related to the earthing of transmission towers is necessary however it is inherently complicated. Access to intuitive software which can accurately model the designs for various scenarios is necessary.

References:

[1] SafeGrid™ – Earthing Design and Analysis software. Visit www.elek.com.au for more information.

[2] EPRI grounding system design guide.

[3] IEC 60479 Effects of current on human beings and animals.

[4] IEEE Std-80 Guide for safety in AC substation grounding.