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PARAMETRIC ANALYSIS ON GROUND LEVEL SAFETY NEAR STEEL POLES UNDER FAULT CONDITIONS

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ABSTRACT

When a fault occurs on a distribution or transmission steel pole, the faulted pole or the adjacent poles can be subjected to very high ground potential rise. The earth surface voltage gradient near the tower is increased and could represent a hazard for a worker or a person who is touching the pole or just happens to be nearby. Appropriate pole grounding design may represent a relatively simple, durable, and economic solution. This paper carries out a detailed parametric analysis that shows how the grounding system can effectively reduce the touch and step voltages on the pole ground level. Generally speaking, installing a buried grounding loop around the pole decreases the touch voltages but increases the step voltages. Increasing the grounding system radius can improve the touch voltage tremendously without increasing significantly the step voltage. Significant variations in soil resistivity with depth have important impact on the performance of the grounding system. Burying the grounding system in a relative low soil resistivity layer can maximize the effectiveness of the grounding system for both touch and step voltages. Not surprisingly, the presence of bare metallic pipes in a residential or urban areas improves the touch and step voltages considerably.

KEY WORDS

Ground potential rise, Touch voltage, Step voltage, Electric lines, Customer neutral, Ground loop

1. Introduction

Steel poles on distribution or transmission lines represent a desirable ecological, aesthetical and economical choice for today's power industry. However, because steel is a good conductor, concerns regarding safety have arisen. Appropriate grounding and bonding practices must be developed to accommodate the steel pole design [1, 2] during fault conditions, pole grounding potential can increase to very high levels at the faulted and adjacent towers. Therefore, safety concerns exist for people who may contact the pole at ground level and at pole top, and for dangerous potentials that may be transferred to customer service neutrals etc.

Oversimplified analysis may lead to either significant unnecessary expenses because of overdesign or unsatisfactory safety measures because of inadequate design. The concern to be addressed is electrical safety at the base of faulted steel poles. The addition of a layer of insulating material on the possible hand contact locations on the steel pole or the laying of a layer of insulating material at foot contact points within reach of the pole are possible and effective solutions. However, these solutions are uncertain because of durability, maintenance and cost. On the other hand, the installation of a buried grounding loop around the base of the pole is relatively simple, durable, less likely to be vandalized and economical.

This paper presents a detailed study performed to investigate the design of a buried grounding loop around the base of the pole. A series of computer simulations were carried out to determine the effectiveness of various ground loop arrangements in various soil models in minimizing touch and step voltages near a faulted pole. Such detailed study hasn't been published in the literature. The results presented in the paper are useful for tubular steel poles.

2. Scenarios Studied

A typical steel pole base, a single 2.5 m long x 30 cm diameter (8 feet long with a 1 foot diameter) cylindrical conductor is buried in the soil. A large number of computer simulations were carried out to demonstrate the effectiveness of the ground loop arrangements and soil models in minimizing touch and step voltages near the pole. The following parameters were considered:

2.1 Loop configuration

- A simple loop, 1 m (3.3 ft) from the pole, connected to the pole by means of 4 bare conductors (see Figure 2a, for example). Two burial depths of all conductors, 0.2 m (8 inches) and 0.5 m (20 inches) were considered.
- Two loops, three or six loops, the outer loop being 1 m (3.3 ft) or 1.5 m away from the pole and connected to the pole by means of 8 bare conductors (see Figure 4a, for example). Two burial depths of all conductors, 0.2 m (8 inches) and 0.5 m (20 inches) were considered.
- The influence of water services and mains on the performance of the six loops configuration was also examined. See Figure 6a and Figure 7 for more details.

2.2 Soil structure

- For all grounding loop configurations, a uniform soil was considered. Computed loop ground resistances or ground potential rise are based on a 10 ohm-m soil, but can be scaled proportionately to the soil resistivity to determine the ground resistance or ground potential rise for any other soil resistivity.
- In order to illustrate the effects of soil layering, the 6-loop grounding configuration was modeled for six scenarios (various thicknesses) of two-layer soils (Table 1) in addition to the uniform soil:

Table 1
Modeled Two-Layer Soils

Soil Model	Layer	Resistivity (ohm-m)	Ratio (Top / Bottom)	Thickness (m)
1	Top Bottom	1 20	0.05	0.5(1,2,4) infinite
2	Top Bottom	1 10	0.1	0.5(1,2,4) infinite
3	Top Bottom	1 0.2	0.2	0.5(1,2,4) Infinite
4	Top Bottom	1 0.2	5	0.5(1,2,4) Infinite
5	Top Bottom	1 0.1	10	0.5(1,2,4) Infinite
6	Top Bottom	1 0.05	20	0.5(1,2,4) Infinite

All results were computed as a percentage of the pole GPR (ground potential rise). In this form, the results are not influenced by the magnitude of the injected tower fault current and the soil resistivity, only by the thicknesses and relative resistivities of the different soil layers.

Touch voltages were computed throughout an area extending up to a distance of 1 m (3.3 ft) from the surface of the pole. Step voltages were computed throughout an area of about 4.88 m x 4.88 m (16 ft x 16 ft), centered at the pole.

In addition, touch voltages occurring throughout a 500 m x 500 m neighborhood along a water main were considered, for a 100 ohm-m uniform soil resistivity. See Figure 7 for a plan view plot of the water mains that were modeled. The water mains have a 24” diameter and are buried at a depth of 1. Touch voltages are computed at 3 m intervals.

3. Computation Results

The touch and step voltages for the tubular pole only were computed first. Figures 1a and 1b show touch and step voltage variations as shaded grey levels on a plan view plots of the soil. The highest values are black and the lowest light grey. The legend indicates the maximum voltage corresponding to each grey shade level and also indicates the maximum and minimum value present in the plotted data. As can be seen, the maximum touch and step voltages in percentage of the pole GPR are 93.7% and 5.77%, respectively.

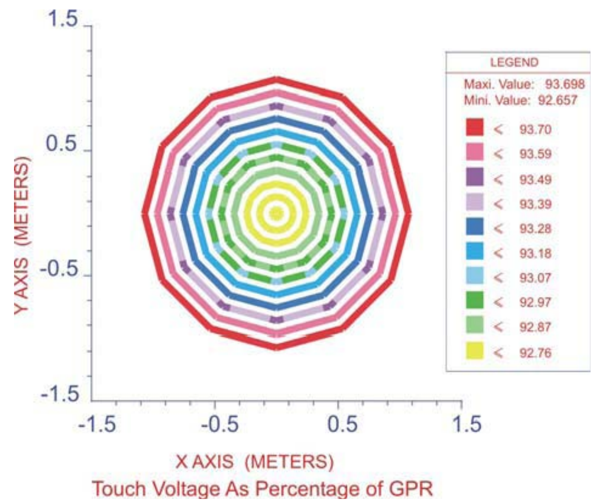

Figure 1a Touch Voltages as a Percentage of GPR - Bare Pole Base (0.6 m Length Beginning at Depth of 1.5m) in Uniform Soil

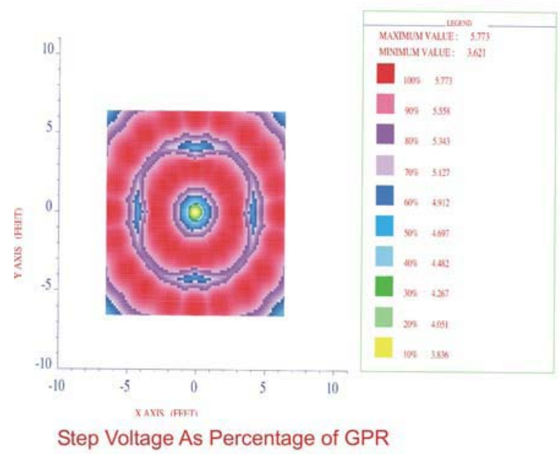

Figure 1b Step Voltages as a Percentage of GPR - Bare Pole Base (0.6 m Length Beginning at Depth of 1.5m) in Uniform Soil

3.1 Effects of a Single Loop

In order to reduce the touch voltages, we added a conductor loop around the base of the pole. Figures 2a & 2b show the touch and step voltages for a single loop with a 1 m radius, buried at a depth of 0.2 m in a uniform soil. As can be seen, the touch voltages improve a lot. The touch voltage deceases from 93.7% to 19.2% of the pole GPR. However, the step voltages increase considerably, from 5.8% to 48.9% of the pole GPR, due to the presence of the loop.

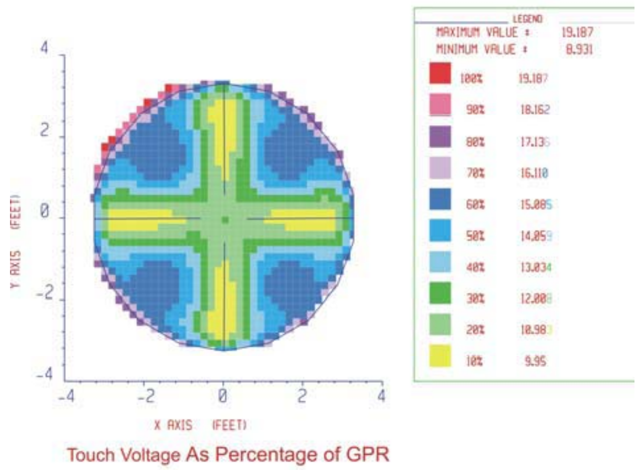

Figure 2a Touch Voltages as a Percentage of GPR - Single Loop (1 m Radius, 4 Cross Conductors), 0.2 m Burial Depth, Uniform Soil

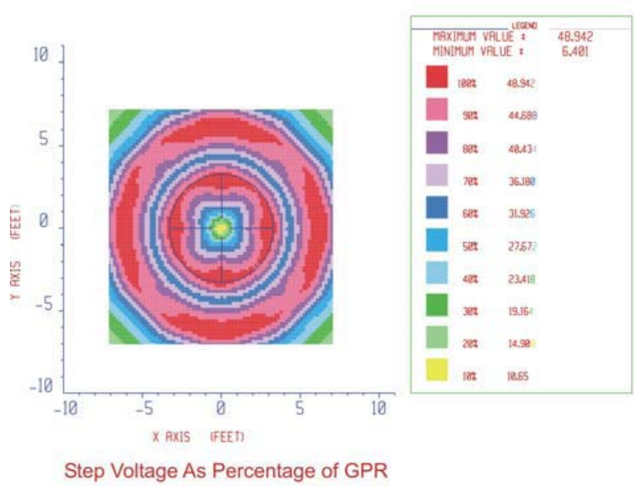

Figure 2b Step Voltages in as a Percentage of GPR - Single Loop (1 m Radius, 4 Cross Conductors), 0.2 m Burial Depth, Uniform Soil

Table 2
Effects of Loop Depth

Loop Depth (m)	Touch Voltage as a Percentage of GPR	Step Voltage in as a Percentage of GPR
0.2	19.2	48.9
0.5	28.9	32.1

3.2 Effects of Loop Depth

Table 2 lists the touch voltages for different loop depths that were used based on a two loop system.

It shows that ground loops buried at shallow depths result in lower touch voltages and higher step voltages than those buried at greater depths. Step voltages are considerably higher than touch voltages for the loops buried at shallow depths. For a 0.5 m depth, step voltages remain higher than touch voltages but are significantly lower than for a 0.2 m depth.

3.3 Effects of Loop Radius

Two more loops are added to the single loop system. They are located at a distance of 0.5 m, 1 m, and 1.5 m from the pole, respectively. The loops were buried at a depth of 0.2 and 0.5 m for comparison purposes. This 3-loop system decreases touch voltages remarkably, almost by a factor of 3, compared with the 2-loop system, while increasing step voltages slightly (see Table 3). For a 0.2 m depth, the touch and step voltages are 5% and 44%, respectively. For a 0.5 m depth, they are 9% and 31%, respectively.

The touch voltages are improved considerably while step voltages are increased marginally when the buried depth is decreased from 0.5 m to 0.2 m.

Table 3
Effects of Loop Radius

Loop Radius (m)	Loop Depth (m)	Maximum Touch Voltage (%GPR)	Maximum Step Voltage (%GPR)
1	0.2	19.2	48.9
	0.5	28.6	32.1
1.5	0.2	4.9	43.5
	0.5	9.3	31.1

Table 4
Effects of Number of Loops

Number of Loops	Loop Depth (m)	Maximum Touch Voltage (%GPR)	Maximum Step Voltage (%GPR)
1	0.2	19.2	48.9
	0.5	28.9	32.1
2	0.2	17.7	48.3
	0.5	26.7	31.1
6	0.2	17.4	50.0
	0.5	26.1	35.8

3.4 Effects of Number of Loops

More loops are added within a radius of 1 m from the base of the pole. As can be seen in Table 4, increasing the density of loops within the zone of concern has a small effect on the overall performance of the system. In other words, the single-loop, two-loop and six-loop grounding systems exhibit similar behavior. For the 1 m radius zone in a uniform soil, the maximum touch voltage varies from 17.4% to 19.2 % of the pole GPR when placed at a depth of 0.2 m. At a depth of 0.5 m, the maximum touch voltage varies from 26.1% to 28.9% of the pole GPR. On the other hand, maximum step voltages are on the order of 48% to 50% for loops at 0.2 m depth and 31% to 36% for loops at 0.5 m depth.

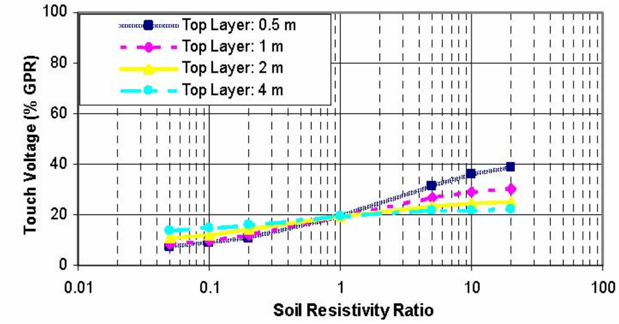

Figure 3a Touch Voltage vs. Soil Structure – 6-Loop (1 m Radius), 0.2 m Burial Depth: Effects of Soil Structure

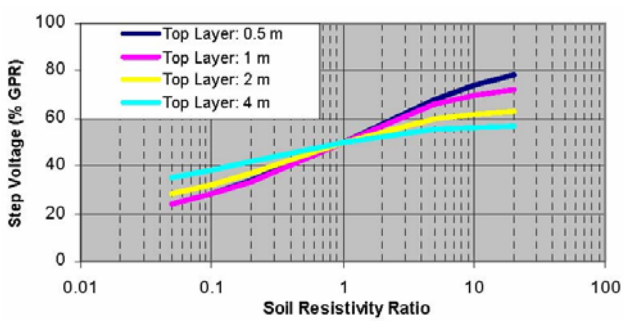

Figure 3b. Step Voltage vs. Soil Structure – 6-Loop (1 m Radius), 0.2 m Burial Depth: Effects of Soil Structure

3.5 Effects of Soil Structure

As one may expect, variations in soil resistivity and in the layer thickness can have an important impact on the performance of the grounding loops. Figures 3a & 3b show the results for the 6-loop system in different soil structures, with the loop in the top soil layer. The following conclusions can be made.

- The touch voltages vary from 7.2% of the pole GPR to 38.7% depending on which two-layer soil model is selected.
- With a fixed top layer thickness, the higher the soil resistivity ratio (top to bottom), the higher the touch voltage as a percentage of pole GPR.
- With a fixed resistivity contrast ratio, when the top layer soil resistivity is higher than the bottom layer, one, the thicker the top layer, the higher the touch voltage as a percentage of pole GPR. When the bottom layer soil resistivity is higher than the top layer one, the thicker the top layer, the lower the touch voltage as a percentage of pole GPR.
- The step voltages vary from 71.4% of the pole GPR to 39.3%. The Step voltage exhibits a similar behaviour as the touch voltage.

Table 5 and Figures 4 and 5 summarize the results when the loop depth is changed. The touch voltage, not surprisingly, gets worse when the loop is in a high soil resistivity layer, whether it is in top or bottom layer. Let's look at the case when the loop is at 0.8 m depth. When a low soil resistivity layer is on top of a high resistivity one, the maximum step voltage drops a lot (decreasing from 18.1% to 4.6%) while the maximum touch voltage can get a lot worse (increasing from 31.8% to 61.0%). This is because the low soil resistivity layer smooth the voltage gradient along the earth surface and therefore step voltage decreases. On the other hand, the GPR of the loop stays high due to its presence in the high soil resistivity layer while earth surface potential becomes low because the low top soil resistivity layer is better connected to the remote earth potential near the pole area. As a result, the touch voltage becomes higher.

3.6 Effects of Metallic Pipes in the Vicinity

Finally, the effects of metallic bare pipes in the vicinity of a pole are examined. For comparison purposes, Figure 6a corresponds to the case where the water pipe is not present at all, Figure 6b corresponds to the case where the water pipe is not connected to the pole neutral system and Figure 6c represents the case where the water pipe is connected to the pole neutral system. The maximum touch voltages decrease from 19.1% of the pole GPR (no water pipe case) to 17.88% when the pipe is not connected to the pole and to 4.9% only when the pipe is connected to the pole. This means that in urban environments, where poles and water pipes are connected to a common neutral, the touch and step voltages associated with a pole can be reduced tremendously compared to the value obtained by a pole alone. Note that the above discussion applies for a uniform soil.

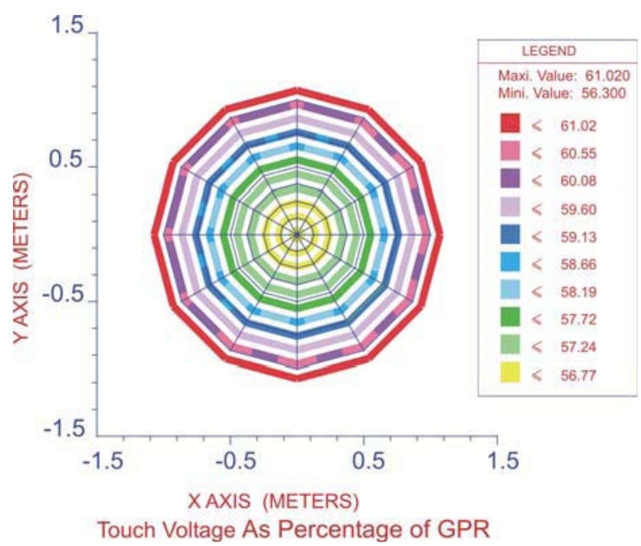

Figure 4a Touch Voltages as a Percentage of GPR – 6-Loop (1 m Radius), 0.8 m Buried Depth, 1 ohm-m over 20 ohm-m 2-Layer with Top Layer 0.5 m Thickness, Loop in Bottom Soil Layer.

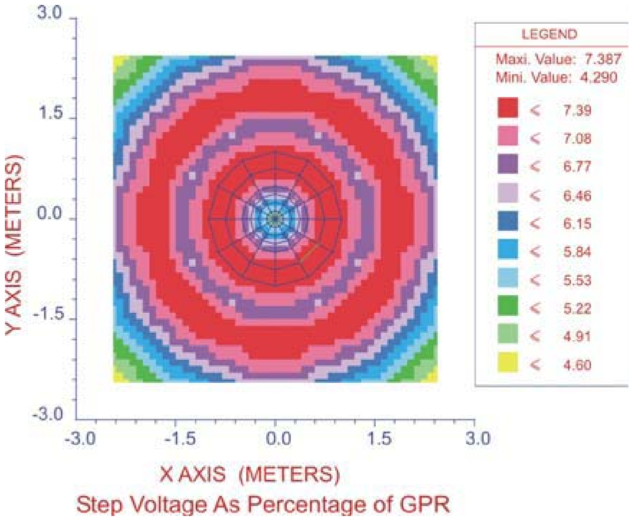

Figure 4b Step Voltages as a Percentage of GPR – 6-Loop (1 m Radius), 0.8 m Buried Depth, 1 ohm-m over 20 ohm-m 2-Layer Soil with Top Layer 0.5 m Thickness, Loop in Bottom Soil Layer

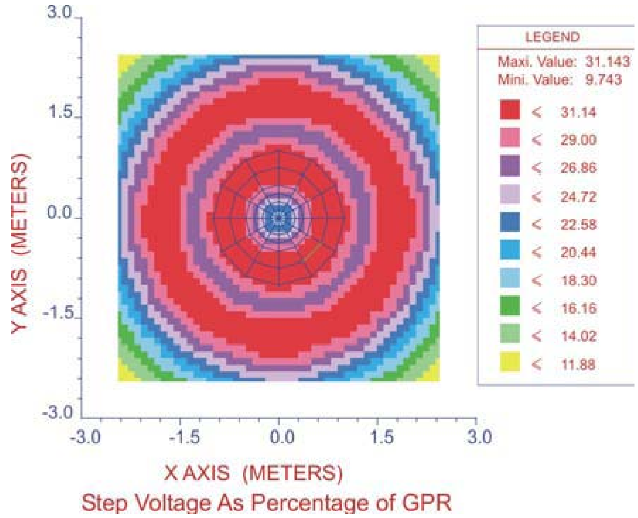

Figure 5b Step Voltages as a Percentage of GPR – 6-Loop (1 m Radius), 0.8 m Buried Depth, 1 ohm-m over 0.05 ohm-m 2-Layer Soil with Top Layer 0.5 m Thickness, Loop in Bottom Soil Layer

Table 5
Effects of Loop Depths and Soil Resistivity Contrast Ratio

Loop Depth (m)	Soil Resistivity Ratio	Maximum Touch Voltage (%GPR)	Maximum Step Voltage (%GPR)
0.2	0.05	7.2	23.8
	20	38.7	78.1
0.8	0.05	61.0	7.4
	20	31.9	31.1

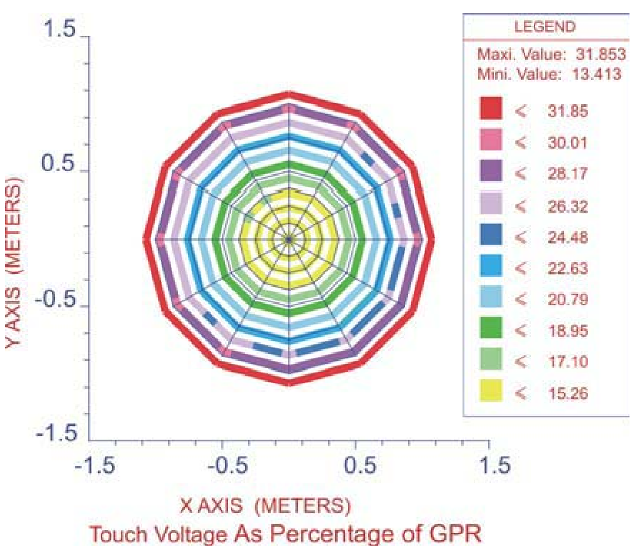

Figure 5a Touch Voltages as a Percentage of GPR – 6-Loop (1 m Radius), 0.8 m Buried Depth, 1 ohm-m over 0.05 ohm-m 2-Layer Soil with Top Layer 0.5 m Thickness, Loop in Bottom Soil Layer

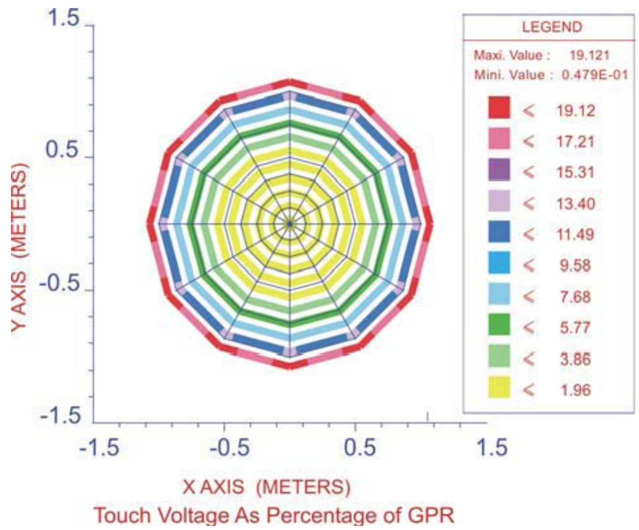

Figure 6a Touch Voltages as a Percentage of GPR – 6-Loop (1 mRadius), Uniform Soil, without the Water Pipe

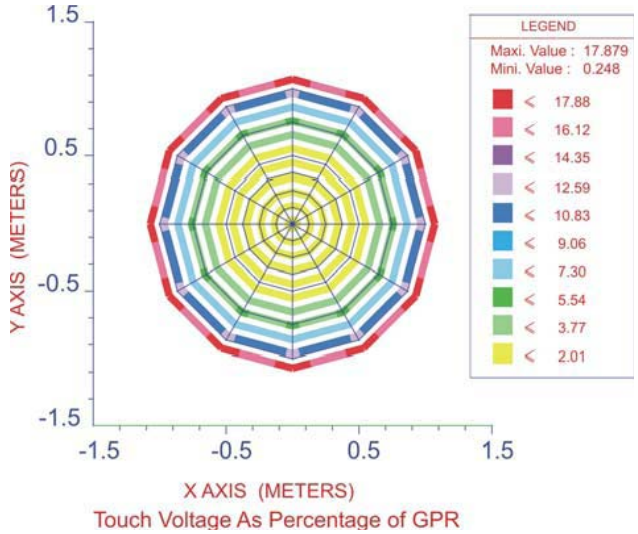

Figure 6b Touch Voltages as a Percentage of GPR – 6-Loop (1 m Radius), Uniform Soil, With Water Pipe, Water Pipe Not Connected to the Pole

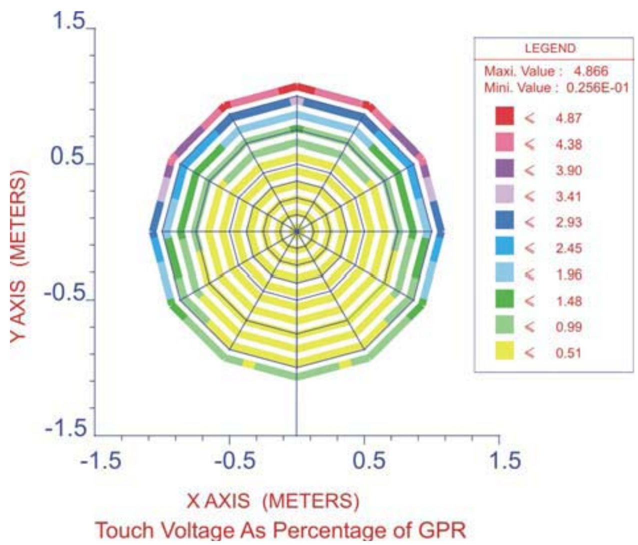

Figure 6c Touch Voltages as a Percentage of GPR – 6-Loop (1 m Radius), Uniform Soil, With Water Pipe, Water Pipe Connected to the Pole

Figure 7 shows that touch voltages throughout a neighbourhood zone heavily interconnected with a 24" water pipe main are as low as 10% of the pole GPR, except at locations very close to the pole where they may reach about 28.7%. Note that the water mains are assumed to be metallic and connected to the pole neutral system. Also, a 100 ohm-m uniform soil is assumed.

Different results are possible for other soil structures. Furthermore, the fault location is also expected to make a difference. Touch voltages near a fault occurring close to the edge of an urban zone are typically higher than those occurring at the center of the urban zone

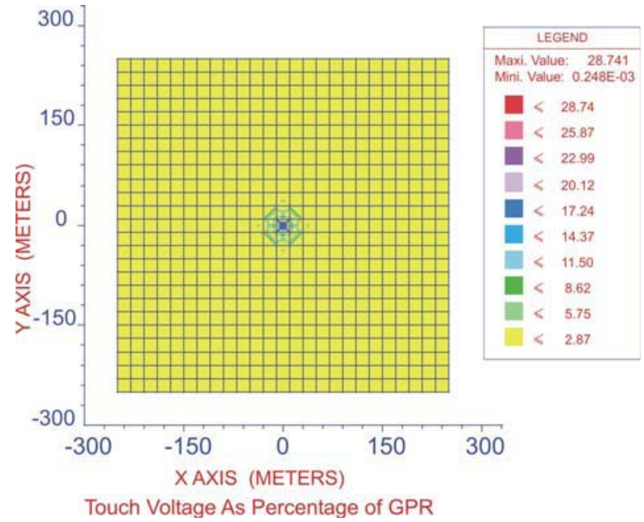

Figure 7 Touch Voltages as a Percentage of GPR – High Density Metallic Pipe Zone, Uniform Soil

4. Conclusion

During fault conditions, power line pole ground potential can rise to high levels at the faulted and adjacent towers. Installing appropriate conductor loops around the pole base can reduce touch voltages considerably, provided that the ground loop is buried in a relatively low soil resistivity layer. Step voltages can increase significantly, compared to the value with the pole alone.

Extending the radius of the ground loop system can improve touch voltages without increasing significantly step voltages. However, for a given outer loop radius touch and step voltages change only slightly by adding more loops. Furthermore, significant soil variations with depth have important impact on the effectiveness of the ground loop.

In urban areas with a network of metallic pipes that are connected to the neutral customer service, the touch and step voltages are significantly reduced.

Acknowledgements

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References

[1] F. P. Dawalibi, J. Ma, and R. D. Southey, "Behaviour of Grounding Systems in Multilayer Soils: a Parametric Analysis," *IEEE Transactions on Power Delivery, Vol. 9*, No. 1, January 1994, pp.334-342.

[2] F. P. Dawalibi and D. Mukhedkar, "Parametric Analysis of Grounding Grids," *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-98, No. 5, September/October 1979, pp. 1659-1668.