APPLICATION GUIDE

GRADIENT CONTROL MAT DECOUPLING

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PROBLEM

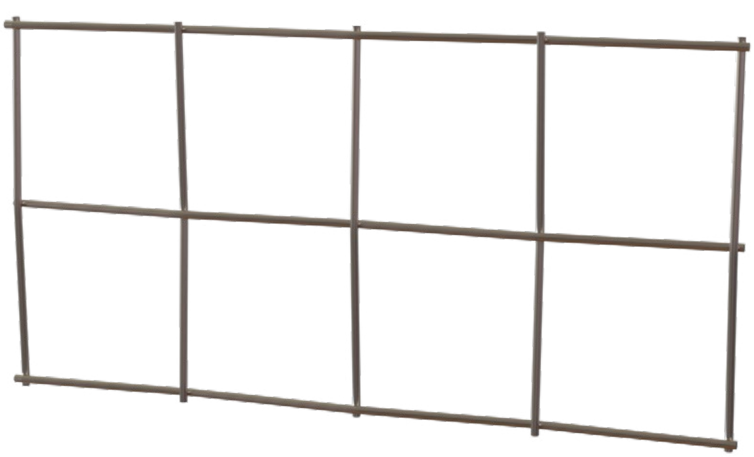
Gradient control mats, commonly referred to as grounding mats, are installed around above ground pipeline structures to protect workers from potentially hazardous voltages that can be present on cathodically protected pipelines. Hazardous pipeline voltages can result from the following:

- A lightning strike directly to or adjacent to a pipeline can transfer an unsafe potential to the pipeline.
- When a pipeline is in an AC electric power line corridor, current flow in the power line can magnetically induce an AC voltage on the pipeline due to inductive coupling. More notably, a phase-to-ground fault in the power line or a lightning strike to the power line can cause a significant rise in the earth potential around the base of the power line support tower and transfer this voltage to the pipeline through conductive coupling.
- An AC fault in improperly grounded electric equipment that is an integral part of a pipeline can raise the pipe potential to unsafe levels.

These voltage sources can be divided into two categories; namely, voltages that occur at the power frequency (i.e., 50 or 60 Hz) and voltages due to lightning or power system transients. Reducing power frequency voltages to safe levels is accomplished whereas limiting voltage due to lightning is considerably more difficult, but achievable at no additional cost with a properly designed and installed gradient control mat to address personnel safety when it comes to step and touch potential.

SOLUTION

Dairyland offers the engineered Gradient Control Mat (GCM) to address both lightning and AC fault current conditions. Step and touch potentials are limited with the Dairyland grid-type mat and recommended installation practices that include depth of mat, a two-layer soil with low resistivity on the bottom portion and a high resistivity crushed stone on the upper portion, in conjunction with an exterior grounding loop. Dairyland also recommends decoupling gradient control mats to improve cathodic protection (CP) on the structure with a Solid-State Decoupler (SSD).



Dairyland Gradient Control Mat

Safety Regulations

The industry is required to take steps to mitigate touch and step voltages via gradient control mats. "Gradient control mats shall be engineered to provide acceptable touch-and-step voltages during both load and fault conditions, accounting for the local soil conditions" as per NACE Standard SP0177-2014. This standard focuses on AC fault conditions for utilities and does not address step and touch voltages when lightning strikes. Currently in the United States and Canada, there are no standards that require a company to mitigate lightning conditions. Nevertheless, it is important for companies to design carefully and choose the right materials in order to protect workers from the safety hazards that can be created by lightning as well as induced AC and power company AC fault events.

The effectiveness of any gradient control mat is determined by the step and touch potential that it allows for the two categories of voltage sources described. IEEE 80 is the standard most commonly used to define allowable step and touch potentials due to power frequencies. Very often, gradient control mats are only designed to meet the IEEE 80 criteria and the effects of lightning are ignored, yet any pipeline subject to induced voltage is also subject to the effects of lightning and switching transients. Any gradient control mat that is designed and installed to limit lightning induced voltages to safe levels will inherently limit power frequency voltages to safe levels provided the connections to the mat and the mat itself can carry the fault current that may be shunted to ground through the mat.

BURIAL DEPTH AND SOIL RESISTIVITY LAYERS

Dairyland recommends installing the mat at a 150 mm (6 inch) depth as optimal with a low resistivity soil on the lower soil layer and a high resistivity crushed stone on the upper layer to reduce touch and step potentials.

Here is some data that illustrates the improvement and supports these recommendations.

Touch Voltages

In the figures below, the touch voltages for a person standing on the mat and touching the pipe energized at 1,000 V are shown looking at mat designs buried at depths of 150 mm (6") and 600 mm (24") while varying them in different soil resistivities for the upper and lower soil layer. It also demonstrates the advantage of the Dairyland GCM grid style design over a Spiral Loop or Zigzag design with the results of each configuration tested.

As evidenced, the Dairyland GCM provides the best protection over other mat designs regardless of the modeled soil configurations at a 150 mm (6") depth, represented by the solid blue dots in Figure 1.

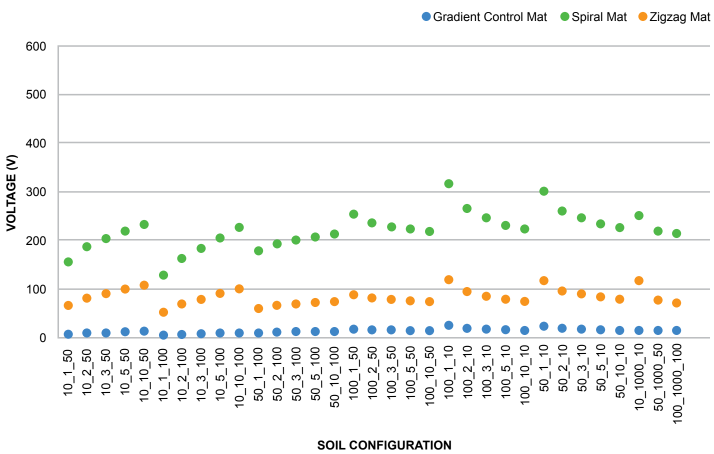


Figure 1 - Touch Voltage for Mat Placed at 150MM Depth

Note: The calculations were done for homogenous soils and two-layer soils, under three different soil resistivities (i.e., 10 Ω-m, 50 Ω-m, and 100 Ω-m) and five depths of the upper layer (i.e., 1 m, 2 m, 3 m, 5 m, and 10 m). The various configurations are displayed on the x-axis of the respective charts using the format [resistivity of 1st layer] [layer depth] [resistivity of 2nd layer].

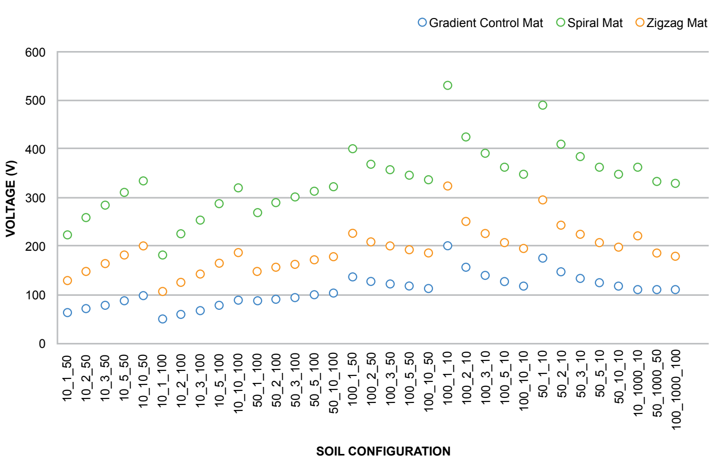


Figure 2 – Touch Voltage for Mat Placed at 600MM Depth

The GCM also surpasses other mat designs within each respective soil configuration at a 600 mm (24") depth as represented by the hollow blue dots in Figure 2. It is important to note that as the burial depth of the mat increases, correspondingly, the touch voltage increases, regardless of mat design as can be seen by comparing the results in Figure 1 with Figure 2. Furthermore, all designs perform better with the low-resistivity layer underneath the mat and the high resistivity layer above the mat. The depth of the high resistivity upper layer is dependent on the resistivity of the lower layer. If the lower layer of soil has a lower resistivity, then the shallower the upper layer depth the better the results. As the lower layer soil resistivity increases, the upper layer depth may need to increase correspondingly in most soil configurations. However, that is not always the case for each type of mat design as there are some soil configurations that appear to create a spike in voltage potential levels.

Step Voltages – Both feet on the mat

For step voltage concerns, the Dairyland GCM surpassed all other designs with the lowest voltage levels among each respective soil condition at a 150 mm (6") mat depth varying between 30v -115v. Next in line came the Zigzag design with voltages varying between 60v-145v. Lastly, was the Spiral loop design with much higher voltage levels varying between 135v-285v.

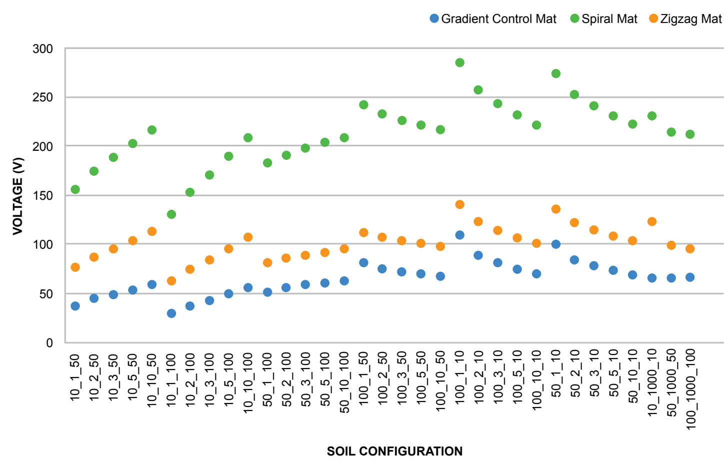


Figure 3 – Step Voltages for Both Feet on Mat Placed at 150MM Depth

Figure 4 displays that at a 600 mm (24") mat burial depth, the Dairyland GCM still performed better for Step Voltages than the other two mat designs with the Dairyland GCM at 55v-210v, the Zigzag mat at 75v-200v, and the Spiral mat at 115v – 245v.

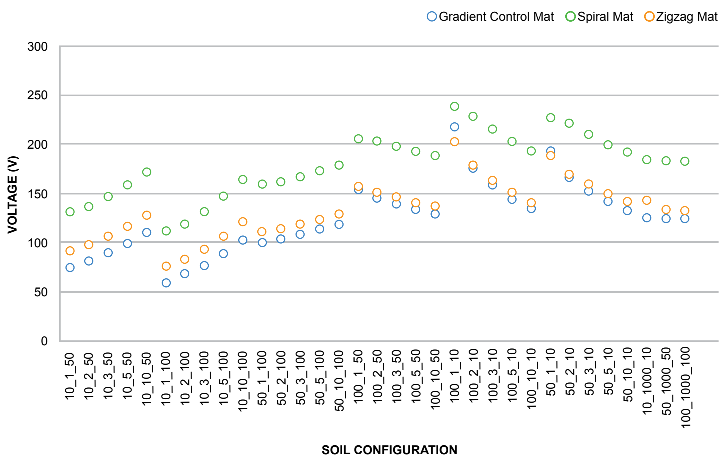


Figure 4 – Step Voltages for Both Feet on Mat Placed at 600MM Depth

When comparing Figure 3 and Figure 4, it is evidenced that the Dairyland GCM performs optimally at a six-inch burial depth when comparing step potentials between a 150 mm (6") mat depth versus a 600 mm (24") mat depth. Furthermore, using a low resistivity lower layer and a high resistivity upper layer with crushed stone produces the lowest voltage differentials when measuring step potential.

GROUNDING LOOP

Dairyland recommends installing a grounding loop approximately 3' from the outer edge of the Dairyland GCM matted area. The conductor should be redundantly connected (two conductors at each connection point) in at least two separate locations on the GCM (preferably opposite of one another). For larger matted areas, connect the grounding loop multiple times with a maximum spacing of 75' between connections around the perimeter of the matted area.

Below is the data that supports this recommendation by comparing the different mat designs, mat placement depth, and soil resistivity configurations with and without a grounding loop installed.

Step Voltages – One foot on mat & one foot off mat without a grounding loop

The Dairyland GCM uses a 3" x 3" grid design to provide a denser coverage area in order to minimize the rise in soil potential at the surface over the matted area for both step and touch potentials while both feet are on the mat. Conversely, it does create a larger differential when having one foot on the mat and one foot off the mat. Therefore, some further design considerations need to be implemented to provide maximum personnel safety while exiting the matted area by adding a grounding loop to the overall GCM design.

Figure 5 and Figure 6 show the results of the GCM, Spiral, and Zigzag design at a 150 mm (6") and 600 mm (24") burial depth with one foot on the mat and one foot off the mat without a grounding loop added to the Dairyland GCM.

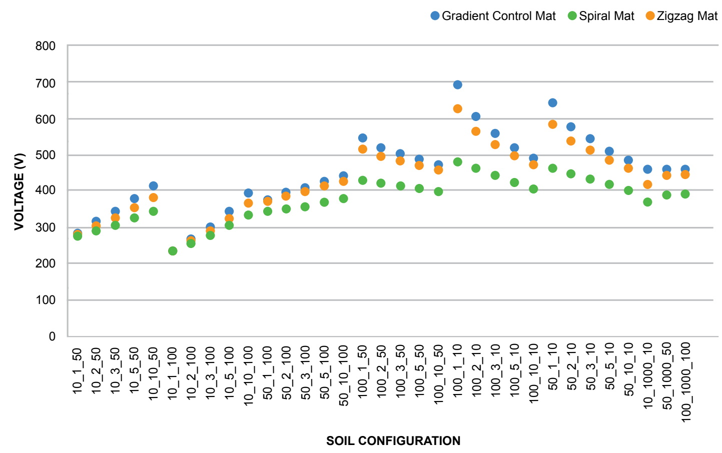


Figure 5 – Step Voltages for One Foot On and One Foot Off Mat Placed at 150MM Depth

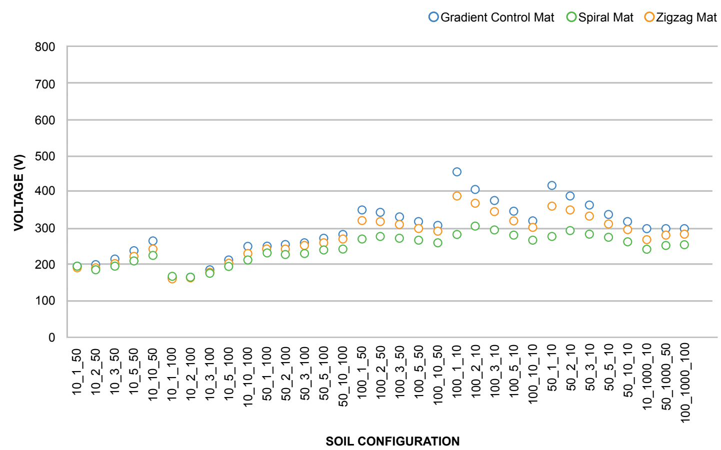


Figure 6 – Step Voltages for One Foot On and One Foot Off Mat Placed at 600MM Depth

Factoring in that the Zigzag and Spiral loop designs typically have a higher step voltage potential when on the mat, this causes those two designs to have a smaller differential when having one foot on and one foot off the mat. In this instance the Dairyland GCM varies in voltage levels from 174v -700v, the Zigzag mat has voltage levels between 175v – 625 v, and the Spiral mat has the least voltage differential with a 175v – 490v variance.

As a result of the above data, some additional design considerations were taken to lower the voltage differential to compensate for the one foot on the mat and one foot off zone area. By simply installing an additional grounding loop approximately three foot from the outside edge of the Dairyland GCM, the voltage differential can be significantly reduced. This will split the step voltage with one foot on the mat and the other on a grounding loop and then a second step voltage to consider would be with one foot on the loop and the second foot approximately 3 foot from the loop.

Step Voltages – One foot on mat & one foot off mat with a grounding loop

It is important to note that with the grounding loop installed, the premise is that the first zone will be with one foot on the mat and one foot above the buried grounding loop and the next zone will have one foot on the buried grounding loop and the other foot on the soil (typically high resistive soil).

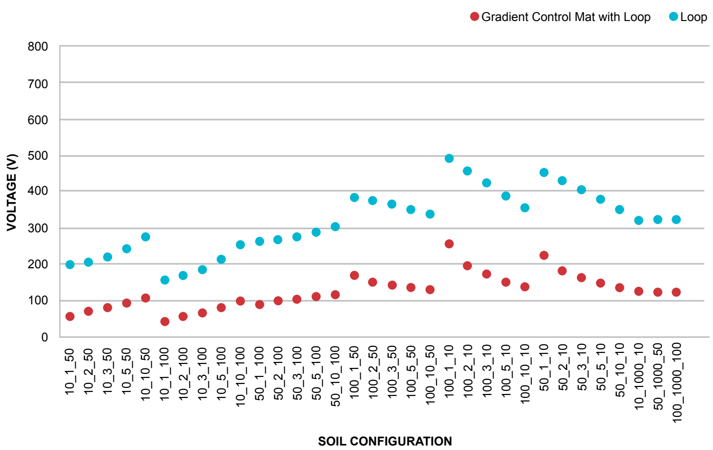


Figure 7 – Dairyland Gradient Control Mat Step Voltages for Grounding Loop on Mat Placed at 150MM Depth

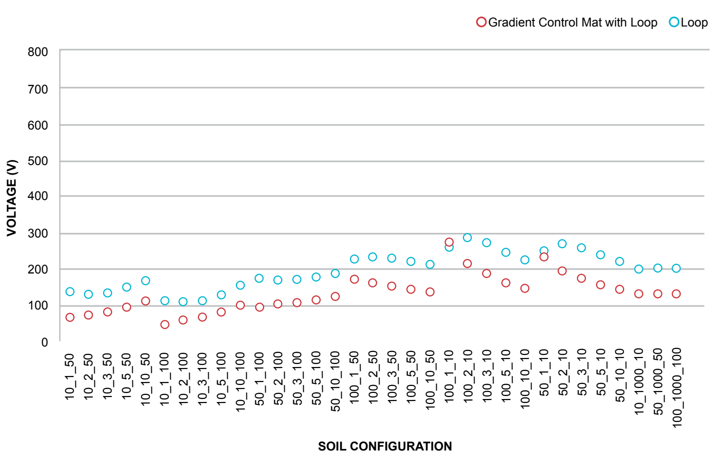


Figure 8 – Dairyland Gradient Control Mat Step Voltages for Grounding Loop on Mat Placed at 600MM Depth

After installing the grounding loop around the GCM, there is a resulting reduction in voltage differential with one foot on the mat and one foot off the mat. As can be seen, this significantly improves the results of the step voltage for the Dairyland GCM and brings the step potential variance down to 50v – 290v with one foot on the mat and the other on the grounding loop zone and 160v – 490v with one foot on the grounding loop and the other on soil zone at a 150 mm (6”) burial depth. This is an improvement of the GCM results with no grounding loop at a 150 mm (6”) burial depth which had voltages of 240v – 690v. At a 600 mm (24”) burial depth, with one foot on the mat and the other on the grounding loop zone the GCM variance was 50v – 290v (represented by red circles) and with one foot on the grounding loop and the other on soil zone the variance was 100 – 300v (represented by blue circles). This is an improvement of the GCM results with no grounding loop at a 600 mm (24”) burial depth which had voltages of 170v – 460v. With this additional design consideration added, the Dairyland GCM provides a lower step voltage potential than either the Zigzag mat or the Spiral loop mat.

Lightning

The Dairyland GCM is the only mat design that is engineered to limit potentially hazardous voltages due to lightning. Step potentials are inherently controlled by the design of the mat (grid wire size, grid spacing, etc.), but the touch potential that a worker may be subject to is determined by both mat design and the installation. Therefore, installation guidelines must be followed to provide maximum protection from lightning-caused voltages.

Data supporting this can be found in the study below that was performed to determine the peak body current that personnel could experience when standing on different gradient control mat designs. All modeling was conducted using CDEGS, software developed by Safe Engineering Services and Technologies ltd. Again, an 8 ft. x 8 ft. mat was selected to make comparison easy between the zigzag mat and spiral mat design of similar dimensions, the mats were placed at a depth of 6 inches in a uniform soil with a resistivity of 50 Ω-m. This analysis examined the body currents for a person standing on the mat while touching the pipe. That pipe was energized by an indirect strike of lightning 50 feet away having a current of 30 kA, a rise time of 1 μs, a half-value time of 50 μs, and total duration of 300 μs.

Figure 9 models the threshold limits of a lightning strike causing ventricular fibrillation, which is much higher than the threshold limits of an AC fault causing ventricular fibrillation. A typical lightning strike will last approximately 10 μs, in comparison to an AC fault, which may last on the order of 0.2 s or 20,000 times longer. The longer the event, the less amperage necessary to put a person into ventricular fibrillation.

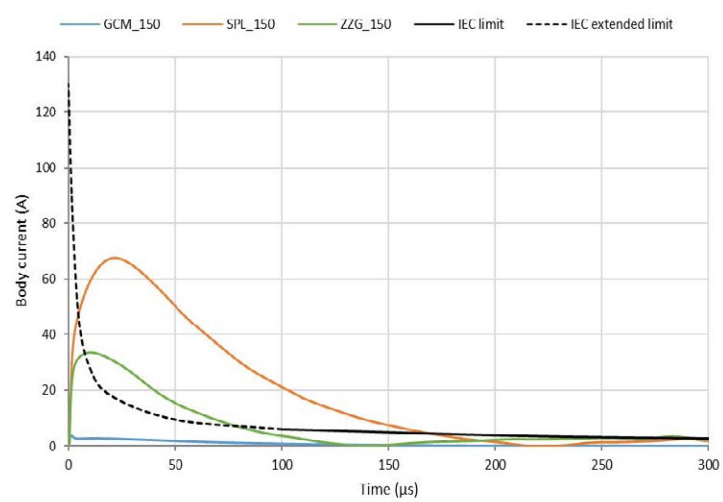


Figure 9 –Threshold Limits of Lighthing Strike Causing Ventricular Fibrilation

As evidenced, “the Dairyland GCM provides the best overall performance under the assessed configuration and remains below the IEC limit for the entire duration of the strike. The peak body current for the Dairyland GCM, spiral mat, and zigzag are 4A, 67A, and 33A, respectively”. It is important to note that this is looking at an indirect strike as opposed to a direct strike to the appurtenance within a station. If lightning were to strike the appurtenance directly, it would result in arcing to any personnel in the area regardless of the type of mat that was used.

Decoupling

While the mat may be directly connected to the pipeline, it is recommended that the mat be connected to the pipeline, or decoupled, through a Solid-State Decoupler (SSD). Decoupling offers a number of distinct advantages; namely, the galvanic potential of the mat material becomes irrelevant, pipeline CP readings can be taken in the vicinity of the mat, any interaction with the pipeline CP system is eliminated, and the life of the anodes used to protect the mat is significantly increased. If the matted area is significant, Dairyland recommends using multiple decouplers to connect the matted area to the pipeline with a spacing no greater than 75’ apart.

Conductor Length Issues

As described in other Dairyland application documents, conductor (or lead) length plays a significant role in determining the touch potential between any two connected points, in this case between a pipe and gradient control mat. Lead lengths must be kept very short in order to achieve acceptable touch potentials - on the order of inches. This is due to the inductance added with increasing lead length, which can be controlled by shortening the length, and by adding an additional conductor in parallel. As an additional conductor may be needed in parallel for ampacity reasons anyway, this has a side benefit of lowering the inductance. Note that only touch potentials are affected by lead length, and step potentials remain unaffected, as this relates to properties of the mat alone. Contact Dairyland if additional information is needed.

SUMMARY

Dairyland’s 3” x 3” grid design of the GCM provides a denser layout than a Zigzag or Spiral mat design resulting in significantly lower voltage differentials for step and touch potentials for all configurations while on the mat.

By burying the Dairyland GCM at a 150 mm (6”) as opposed to a 600 mm (24”) depth will produce the lowest voltage differentials in conjunction with a high resistivity soil upper layer of crushed stone and a low resistivity soil lower layer for both step and touch potentials.

Pairing the GCM with a grounding loop buried three foot from the edge of the matted area provides superior personnel safety when considering step potentials while exiting the matted area.

Use a Dairyland SSD between the pipeline and GCM to isolate the CP to structure and remove the concern of a galvanic differential between the pipeline and GCM.

Use two conductors to connect the pipeline to the GCM and maintain as short a lead as possible to reduce the amount of inductance that could to generated.

The Dairyland GCM is the only mat designed to protect workers against a lightning strike by significantly reducing the inductance effect with its grid design.