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Software Designs for Grounding Remediation of Lightning Transient Problems for Solar Fields

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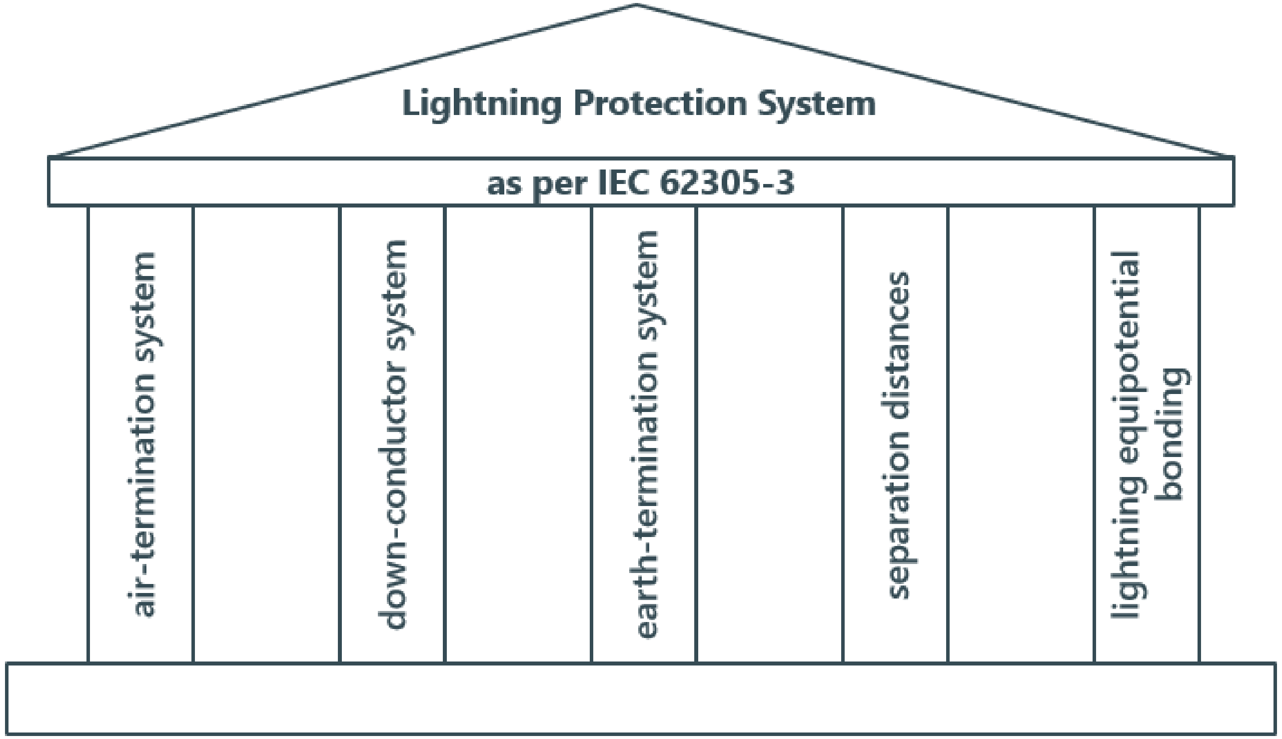
Session 2: *Grounding for GPR and Lightning Remediation*
March 17, 2022

Objective

- Challenges, approach, solutions for 75MW PV Plant
- Introduction of PV facility
- Problems they were facing
- How we developed the solution using software modeling
- What was our design
- How we installed/implemented it
- Positive results after the installation

Lightning Basics: Elements of a Lightning Protection System
Earth-Termination System & Lightning Equipotential Bonding

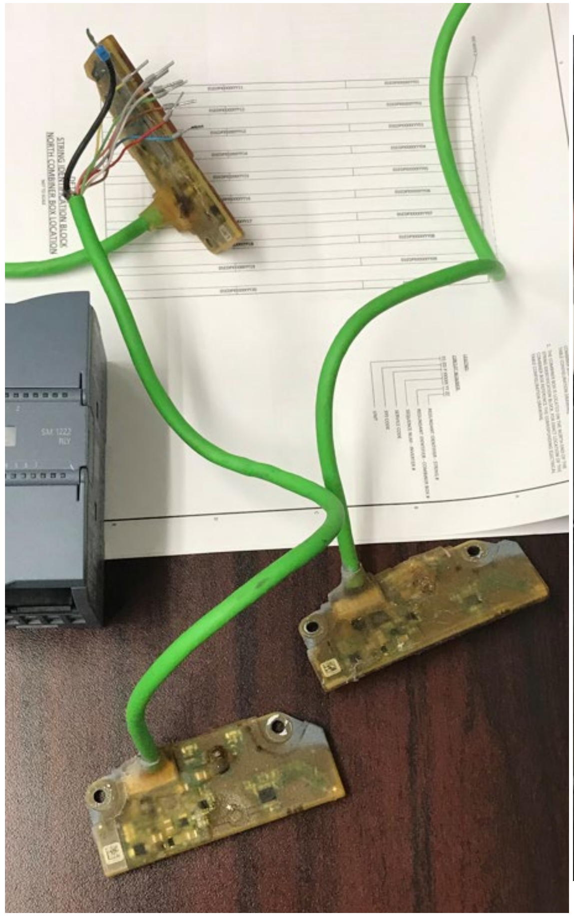


Lightning Fire Catastrophes

- Worst Case Scenario Direct Strike

Solar Field Equipment Damage

- It's not just direct strike damage to panels, or transient damage to inverters/combiners.
- Transients can burn out the encoders on the motors that drive the tracking systems.
- Damaged tracking systems greatly reduce the output for those power blocks.

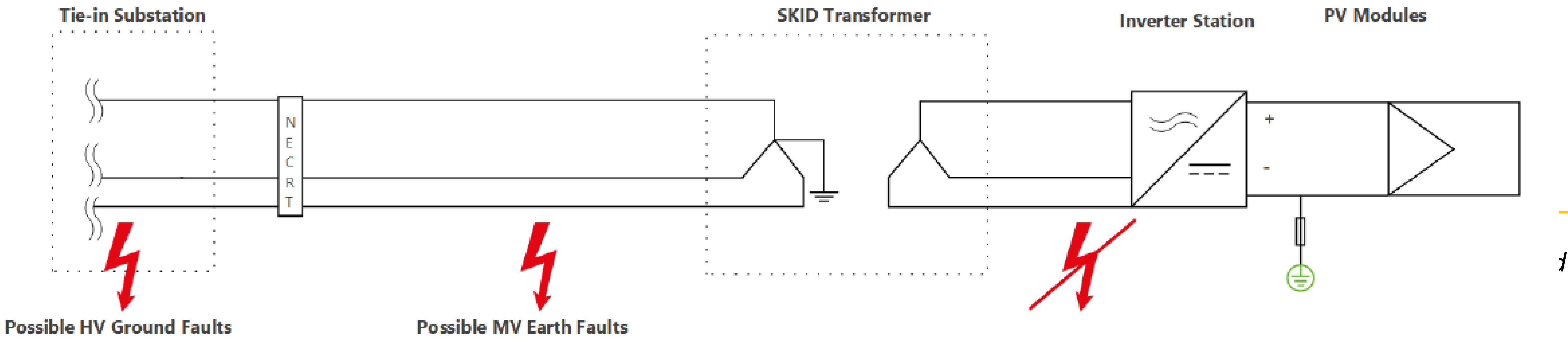


Problem Statement

- Many solar farms have been constructed that suffer from a fundamental flaw in the earthing system.
- Although the earthing is safe for DC power generation and 60Hz power transmission, these plants do not endure the transient environment.
- The symptoms appear as unrelated inverter tripping or similar faults that cause disruptions or reduction of generation capacity.
- But the actual problem is not in the inverter at all, it is a fundamental flaw in the earthing connections that directs all fault and transient energy straight into the inverter.
- Earthing Modeling Software is used to simulate the problem and design the solution to meet IEEE 80 requirements. Actual field installations have shown 80 to 90% reduction of events as per design goals.

Problem Statement

- Customer suffers frequent inverter GFCI fuse/breaker tripping.
- Normal ground leakage current is easily handled by the GFCI circuit, but when transient energy is superimposed into the circuit, the GFCI protection is overwhelmed.
- Direct and indirect lightning, and even blue sky static discharge events lead to damage and power plant outage.



Site Visit and Field Observations lead to Hypothesis

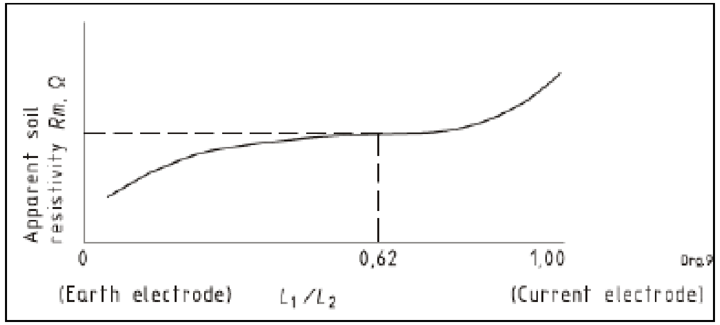
- **Hypothesis:**
- The existing solar field earthing is like a radial spider web with no cross connects.
- Any disturbance can only lead back to the central inverter.
- This seems to be what the customer observes when the GFCI circuits trip.

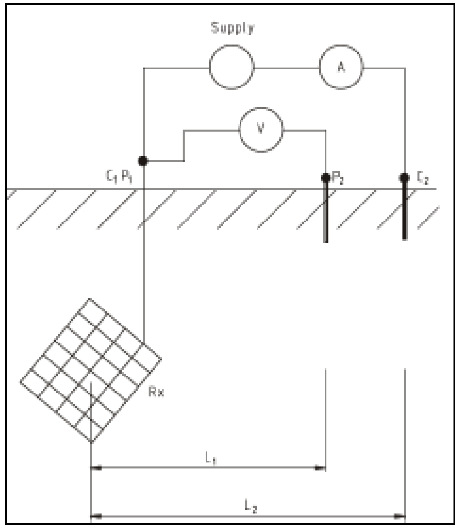
Validation

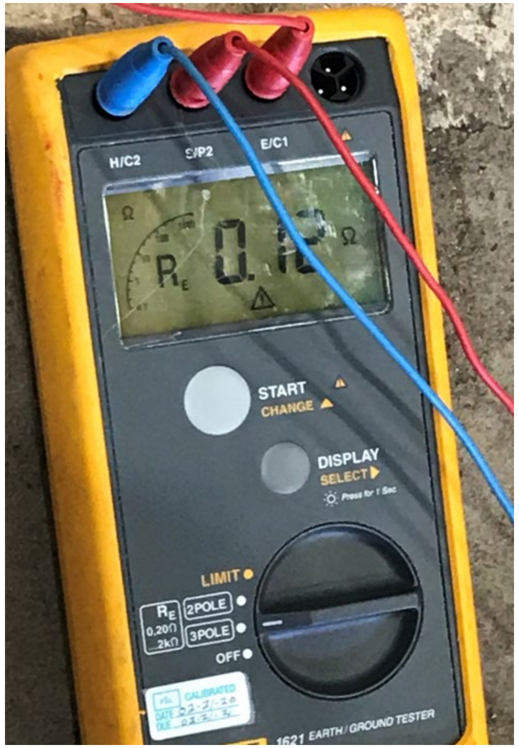
- Build an accurate model, simulate the existing layout and impose a transient.
- Calculate the additional currents that would then flow back into the GFCI circuit and compare results with the fuse element failure parameters.
- Add cross connects and rerun the simulations to see if the results fall below the fuse element failure threshold.

Soil Measurements on Site – Fall of Potential

- Conducting site measurements of soil resistivity provides real data to improve modeling and obtain useful results.
- Fall of potential methods are usually very accurate.



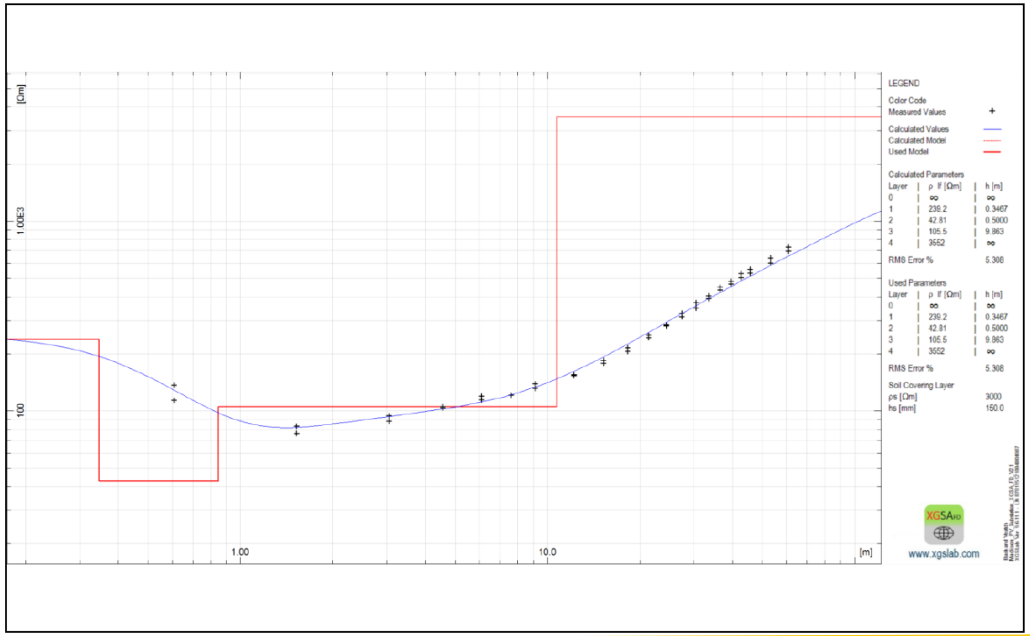




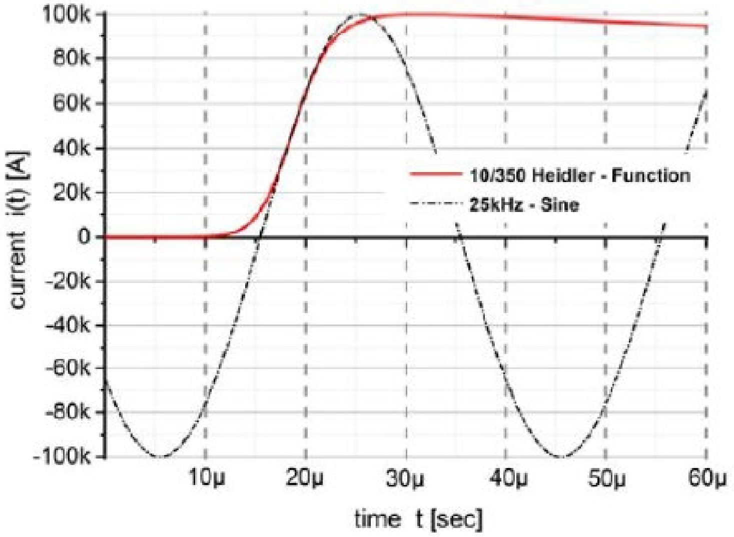
Soil Modeling and layers

- Soil conditions influence existing earthing and are a factor to determine how much additional bonding is required.
- Soil resistivity can vary across large plants and different depths, especially where the power blocks are disjointed due to complex terrain and site allocation.

Layer	Soil resistivity at low frequency ρ (Ω-m)	Soil relative permittivity at high frequency (εr)	Thickness (ft)
1	239.177	6	1.138
2	42.809	6	1.64
3	105.520	6	32.359
4	3552.300	6	infinite



Lightning Simulation – Wide band frequency sweeps to model transient behavior in addition to AC power fault behavior



The impulse consists of ~167 different frequencies (shown in Annexure A) which were selected based on the normalized frequency spectrum shown below.

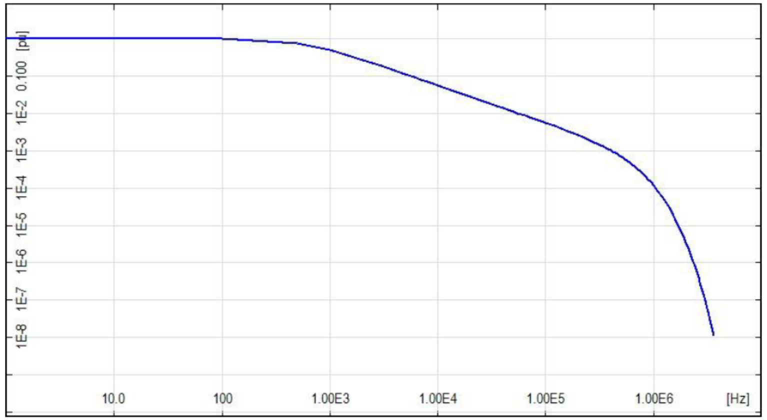


FIGURE 13: NORMALIZED FREQUENCY SPECTRUM

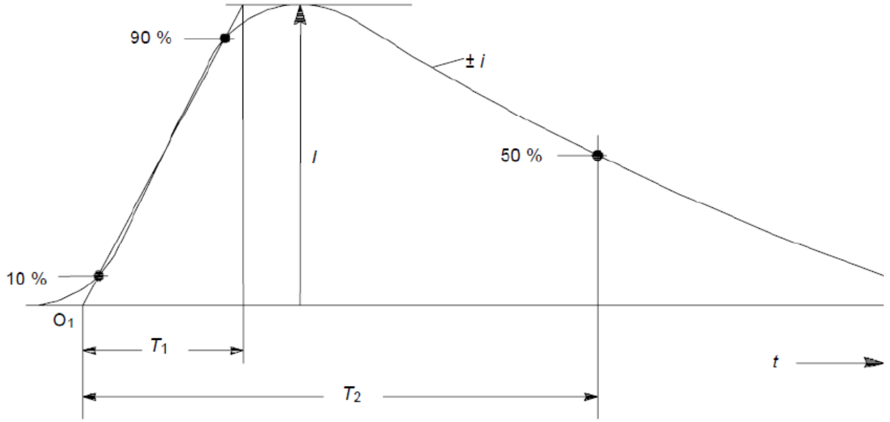
Lightning may be characterised by two different waveshapes (IEC 62305-1):

- 10/350μs – Direct Lightning Strike
- 8/20μs – Nearby Strike (Induced Surge).

What these values denote, are the following:

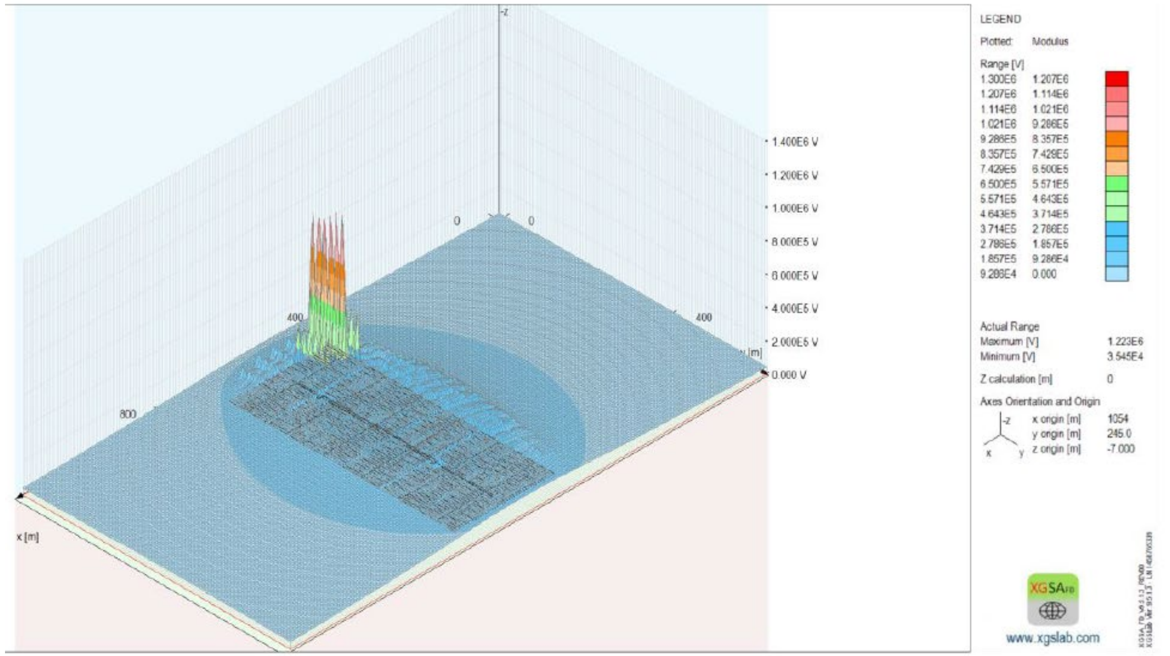
- Lightning current is an impulse which will reach its peak value in 8-10μs.
- Will decay to 50% of its value in 20-350μs.

Figure 2 illustrates the meaning of 10/350μs (T_1 = 10μs, T_2 = 350μs).



Simulations to Reproduce the Transient Problem

- Inject the transient and model the voltage rise response of the existing earthing system.
- Show the currents flow into the GFCI circuits and contribute to tripping problems.



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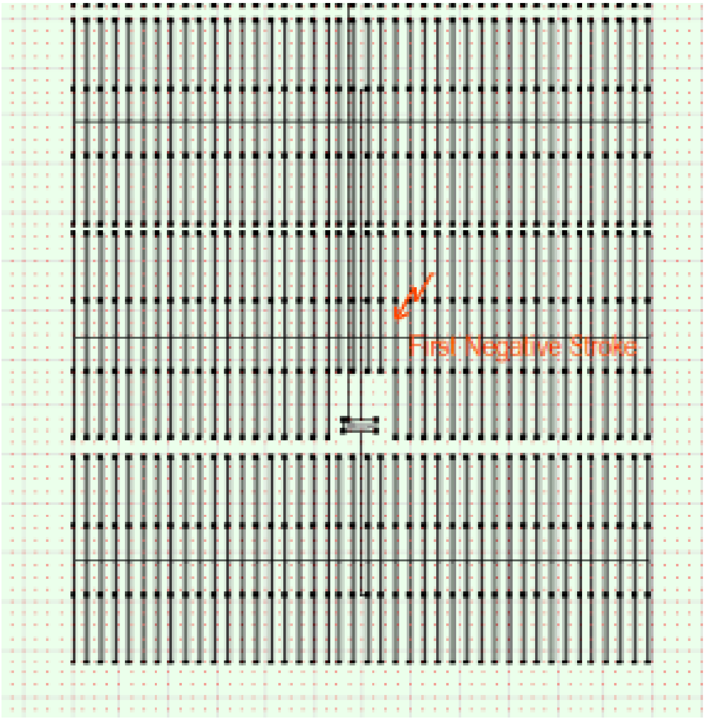
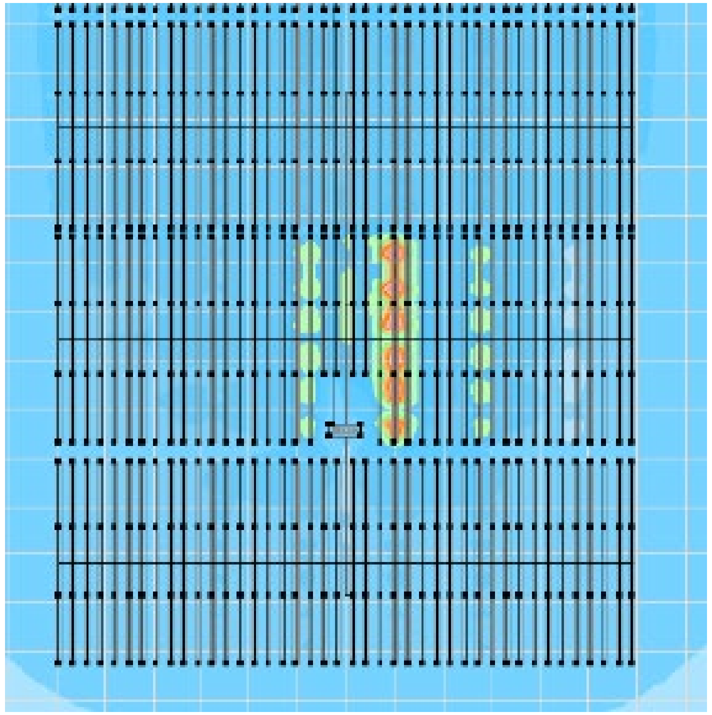
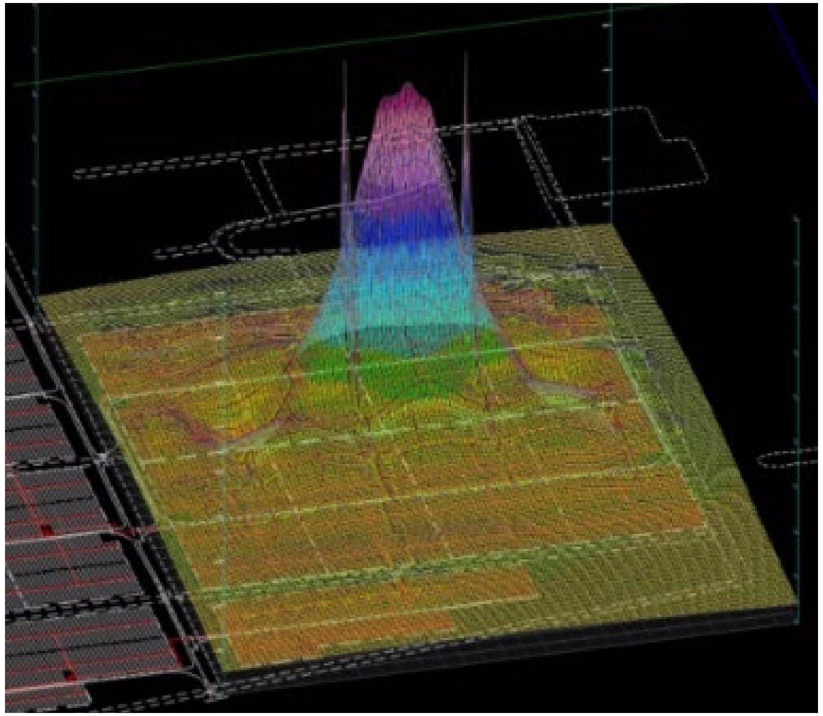






Simulation of strike near inverter

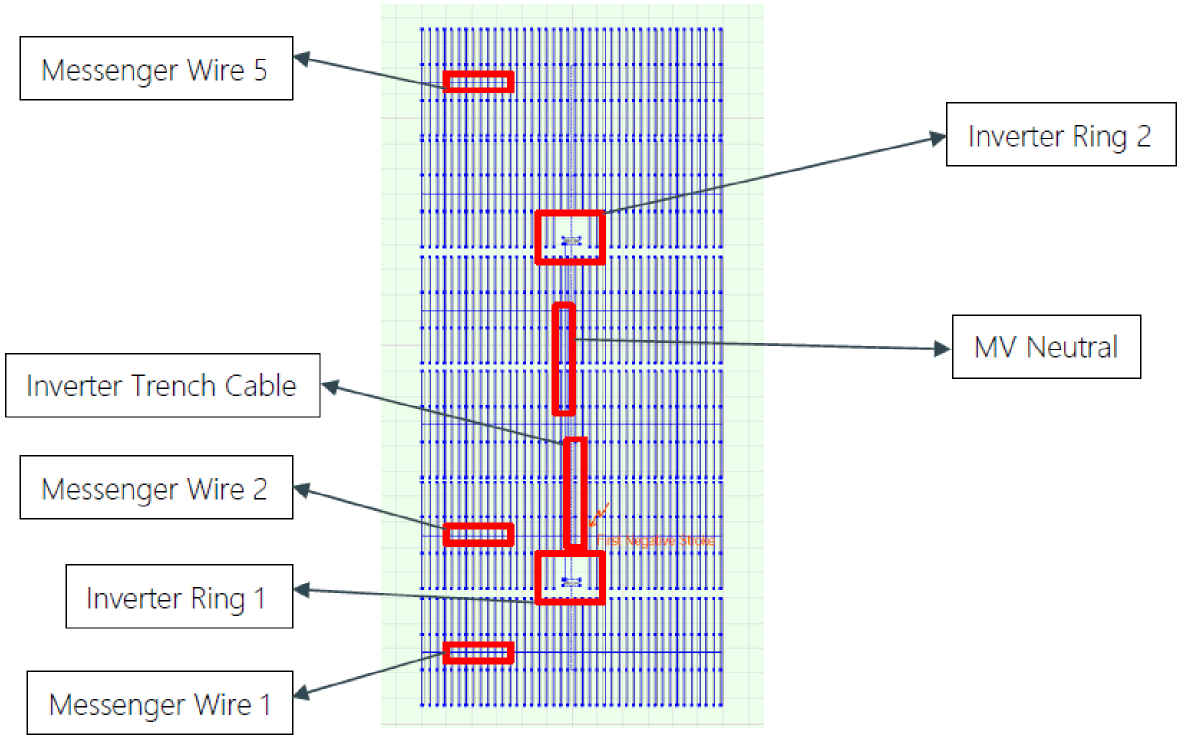


FIGURE 15: IDENTIYING EQUIPMENT NUMBERS

TABLE 7: SUMMARY - DIRECT STRIKE CURRENTS

Area on Plant	Peak Current (A)	Energy (A^2s)
Inverter Ring 1	7 606	6 274
Inverter Ring 2	7 313	625
Inverter Trench Cable	24 763	65 763
MV Neutral	16 276	4 333
Messenger Wire 1	2 290	552
Messenger Wire 5	843	32

Simulation of strike near inverter

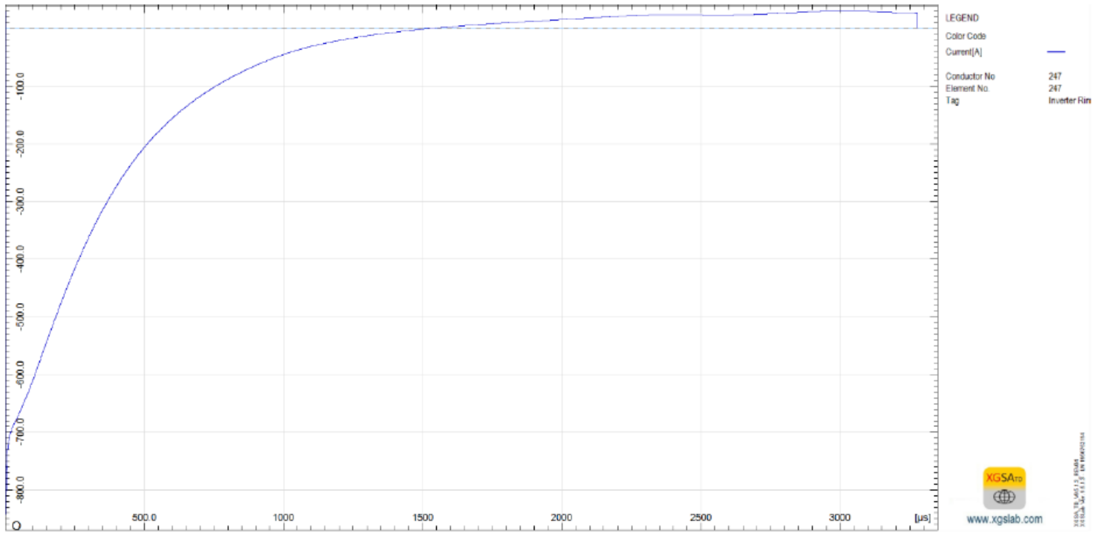


FIGURE 16: CURRENT MEASURED AT INVERTER RING 1 - DIRECT STRIKE

7.7 INTERPRETATION OF DATA FOR EACH SCENARIO

In analysing and interpreting the data from Sections 7.5 to 7.6 it is important to note the following:

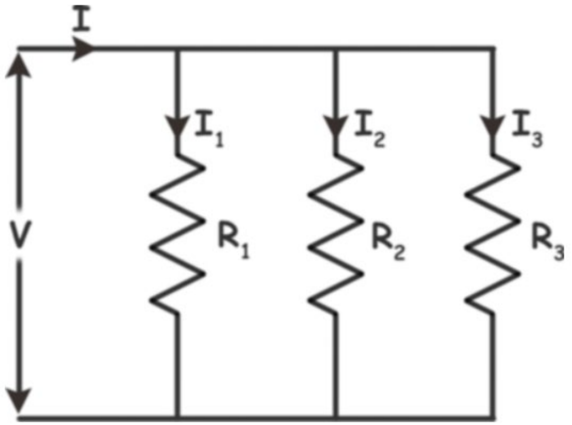
- The current injection of 50kA represents the worst case for First Negative Stroke LPL III and will be lower in practice for most cases.
- The Current measured at the Inverter grounding system passes through a 5A fuse to the DC system, meaning to assess for a fuse individually, the indicated A^2s value must be investigated for the specific fuse.

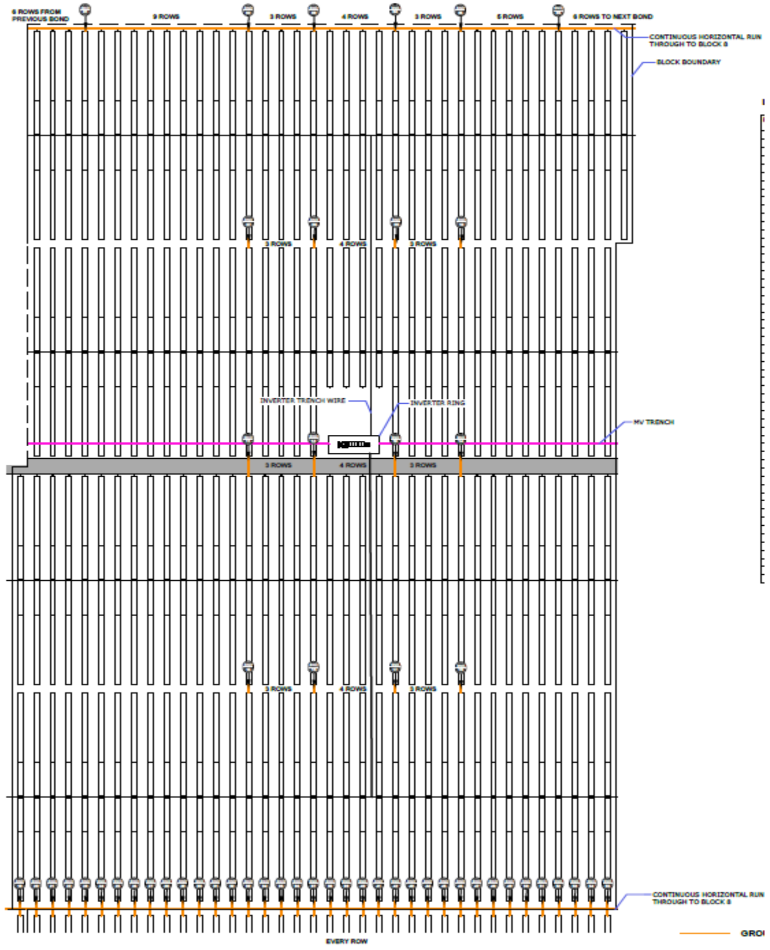
It can be seen from the results that the most likely possible damage is due to direct lightning strikes within the plant. In this specific case, the A^2s value of the fuse (29) is exceeded and causes the fuse to fail.

Strikes which occur further away provide very small energy values and do not exceed the fuse melting integral.

Design and Placement of Additional Bonding Paths Around the Inverter

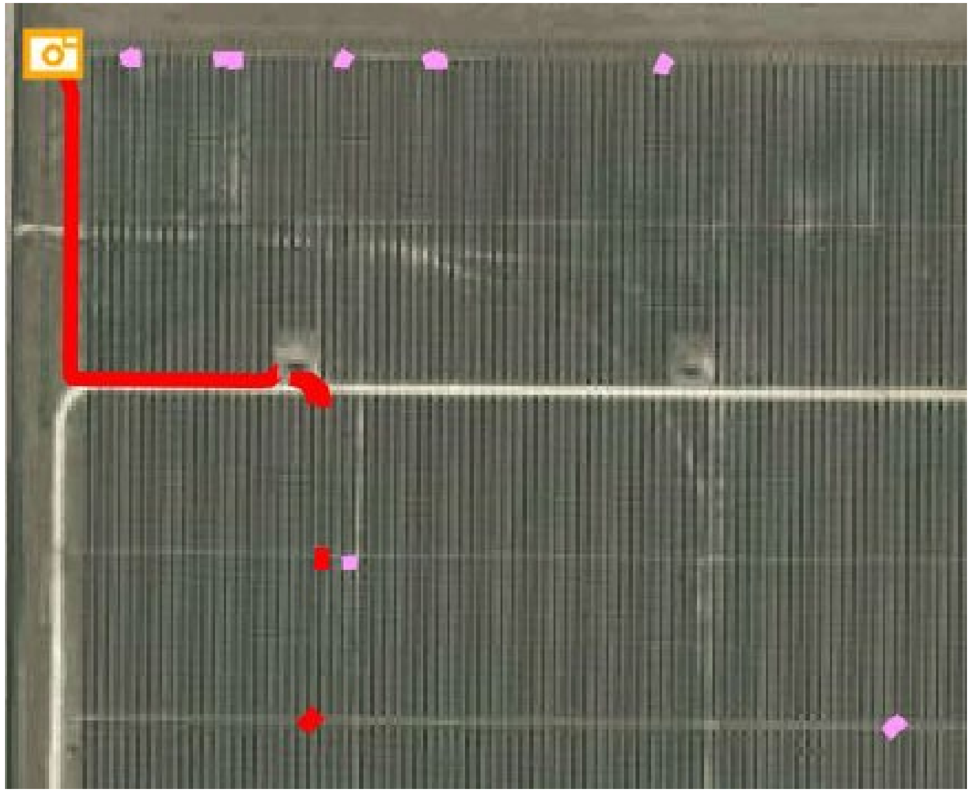
- Economical Solution to Optimize Effectiveness – Not a Shotgun Approach!
- In simplest terms, we create a current divider around the inverter to shunt some large % of current around the inverter and away from the GFCI fuse elements.
- $\mathbf{I = I_1 + I_2 + I_3}$





Ground Penetrating Radar Survey Results Overlay on Power Block

- The actual repair work involves digging and trenching between and around panels.
- Before any excavation, both GPR and radio frequency inspection is employed to be sure the intended paths are clear of any obstruction.
- The locations of buried power, camera and fiber cables are confirmed, and various unknown debris is revealed.
- You'd be surprised how often the as-built locations are not exactly "as-built"!



Ground Penetrating Radar Survey

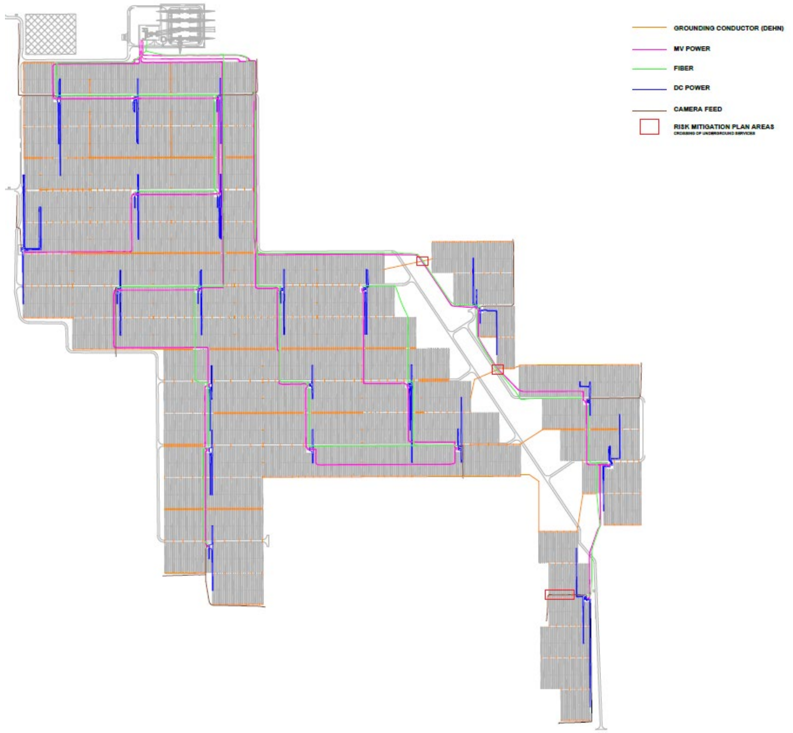
- Every foot of the intended trenching path is surveyed to assure that no electrical wiring system will be cut.

Field Installation

- And then the remediation work can begin!

Unique Challenges for Every Solar Plant

- Optimized Connection Solutions
- Buried Obstructions / MV Lines
- Distributed Power Blocks and Shapes
- Different Soil Models Across Site
- Logistics, Site Access and Facilities
- Weather Delays and Rainy Conditions



DEHN Protects. Thank you for your attention!