Evaluating PV Field Grounding Performance with Simulations for Lightning Transient Energy

Time Domain Analysis of Lightning Current Distribution

- Lightning discharge near to or within a PV field creates a Ground Potential Rise (GPR) and transient current dissipating through the PV arrays, grounding conductors and the inverter ground electrode.
- Without effective means of distribution and dispersion, potentially harmful energy values (A^2s) of lightning current are diverted through the power trenches and inverter electrodes to other low impedance parts of the PV field.
- When large parts of the PV fields are not interconnected at specific points, the distributed energy through the inverter ground electrode could result in operational issues and equipment damage.

Modeling of the Solar Power Plant

Modeling of the PV field structure layout, DC / AC trench grounding conductor installations, messenger/CAB bonding conductor and inverter grounding electrodes.

Simulation scenarios:

1. Scenario 1: The initial scenario to consider the PV field grounding system design. (Initial Condition)
2. Scenario 2: Recommended grounding and bonding solution implemented. (Improved Condition)

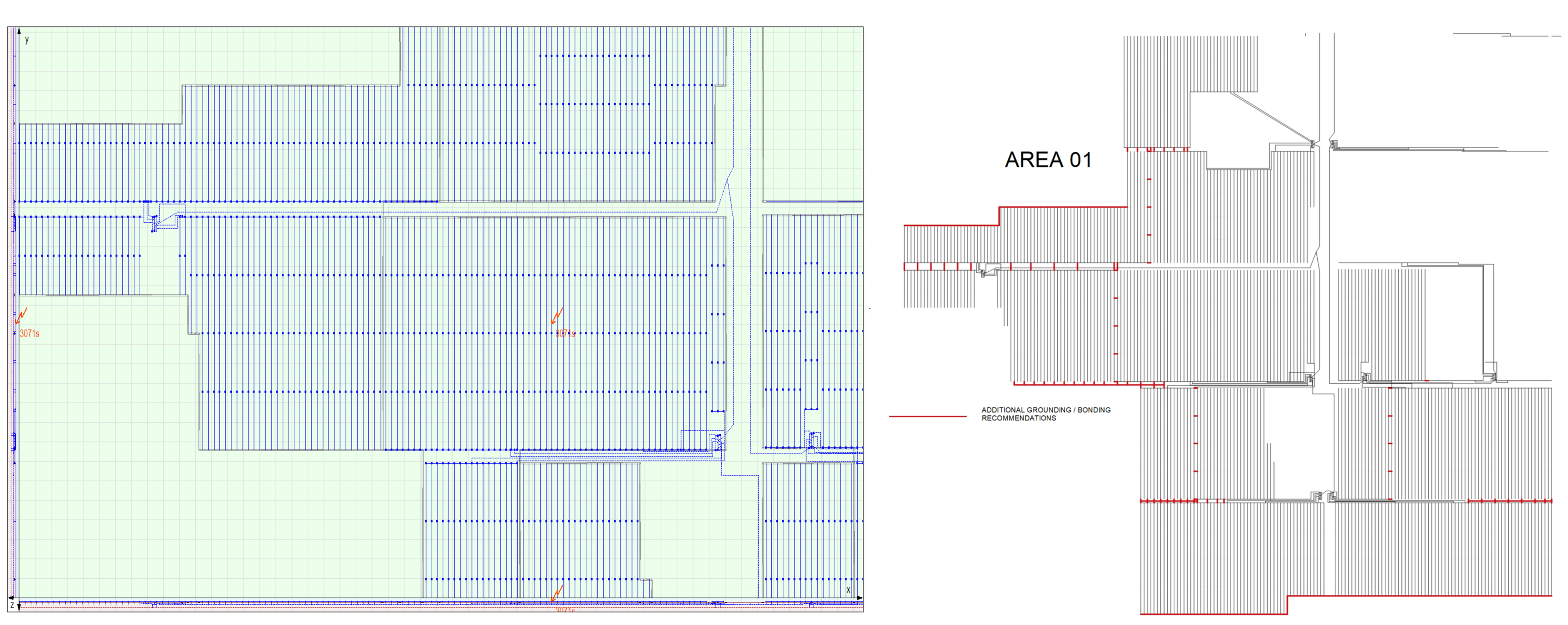


FIGURE 1: ILLUSTRATION OF MODELED PV AREA SCENARIOS

The modeled elements and their conductor representation is summarized:

Area	Model Element Description	Material
General PV Field	PV Structure and Support Piles	Galvanised Steel
	Messenger Wire (Above ground CAB System)	AWG #3 Copper Clad Steel Wire
Inverter Skids	Ring Ground Electrodes Around skid (underground) + vertical earth rods	Ring: AWG #4/0 Bare Stranded Copper Rods: 10′ x Dia. 3/4″ Copper Clad
Underground Ground Conductor DC trenches	Bonding of messenger wires to inverter ring.	AWG #2 Bare Stranded Copper
Underground Ground Conductor AC trenches	MV trenches grounding wire	AWG #4/0 Bare Stranded Copper

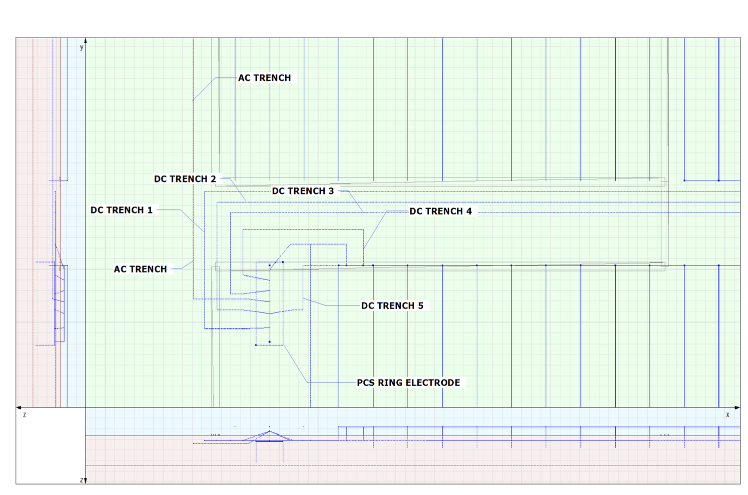


FIGURE 2: LOCATION IDENTIFIERS FOR CRITICAL MEASUREMENT POINTS IN THE ANALYSIS

Soil Resistivity Modeling

Soil resistivity models influence the dissipation of current and energy. Accurate field soil resistivity measurements is required to increase accuracy of the analysis.

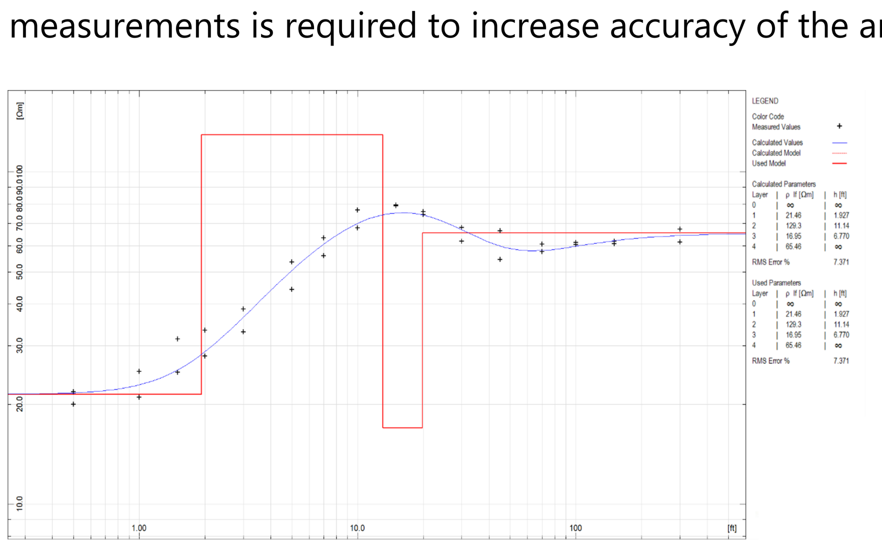
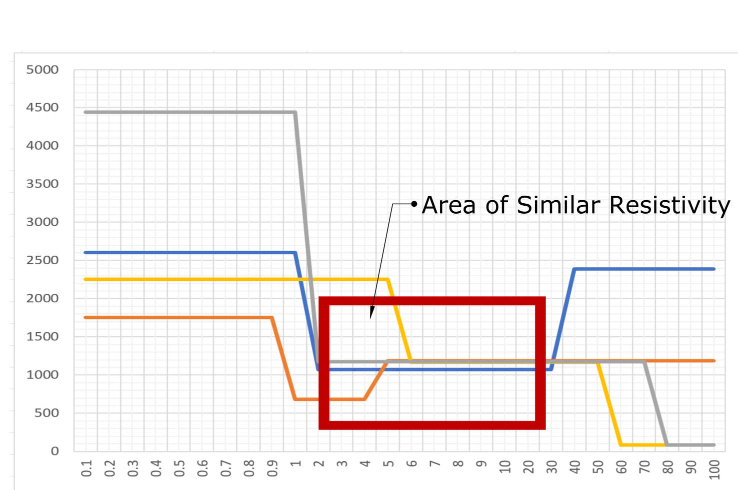


FIGURE 3: SOIL RESISTIVITY MODEL

- 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.

Soil Resistivity Layer Parameters:

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 Injection Time Domain Analysis

To model lightning current as an impulse, the analysis should be conducted in the frequency domain and converted back to the time domain. The lightning transient impulse will consist of multiple frequencies.

The characteristics of the First Negative Stroke for LPL III is extracted from IEC 62305-1:

TABLE 1: LIGHTNING IMPULSE PARAMATERS OF FIRST NEGATIVE STROKE FOR SIMULATION PURPOSES (IEC 62305-1)

Parameters	First Negative Stroke
	LPL III
I (kA)	50
T1 (µs)	1.82
T2(µs)	285
k	0.986

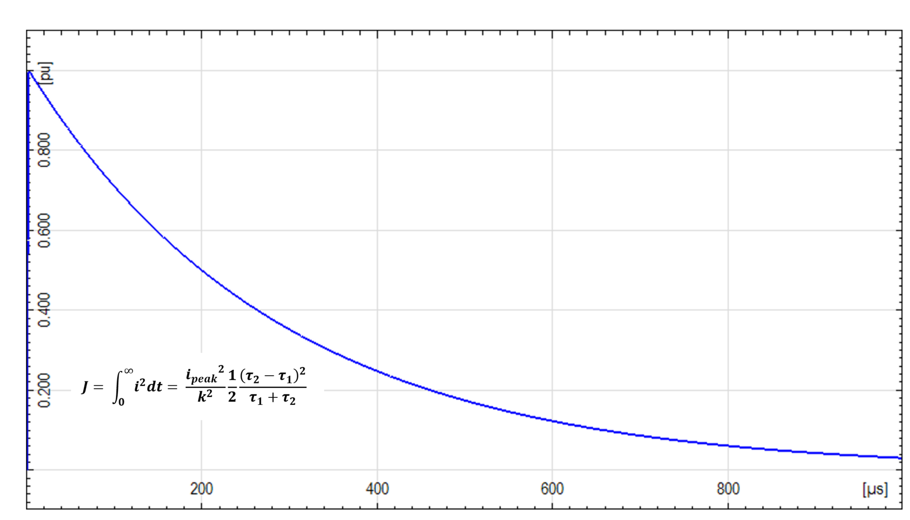


FIGURE 4: FIRST NEGATIVE STROKE WAVESHAPE USED FOR TIME DOMAIN ANALYSIS

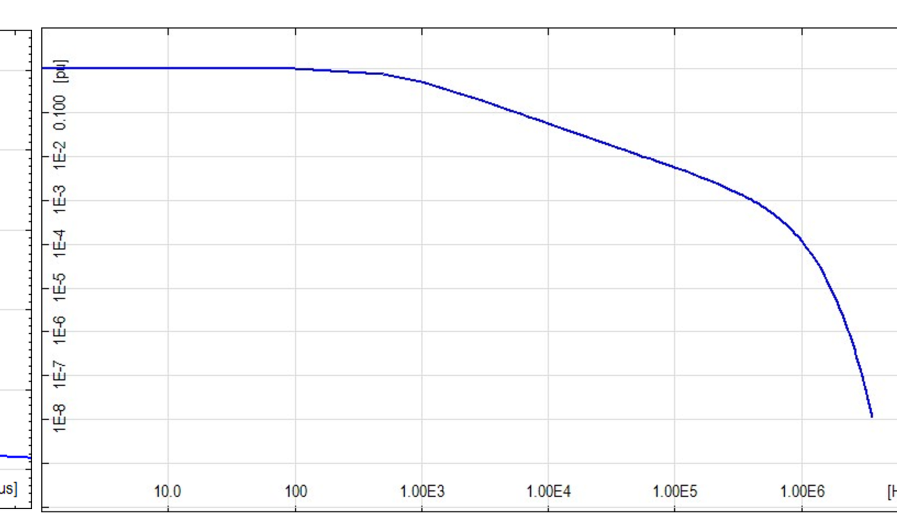


FIGURE 5: NORMALIZED FREQUENCY SPECTRUM

For each simulation scenario the lightning current impulse waveform is calculated at critical locations in the PV field to compare the **peak magnitude** and **specific energy** contributed by the lightning injection. Bonding recommendations that create additional conductive paths within the area are simulated for comparison to the initial condition.

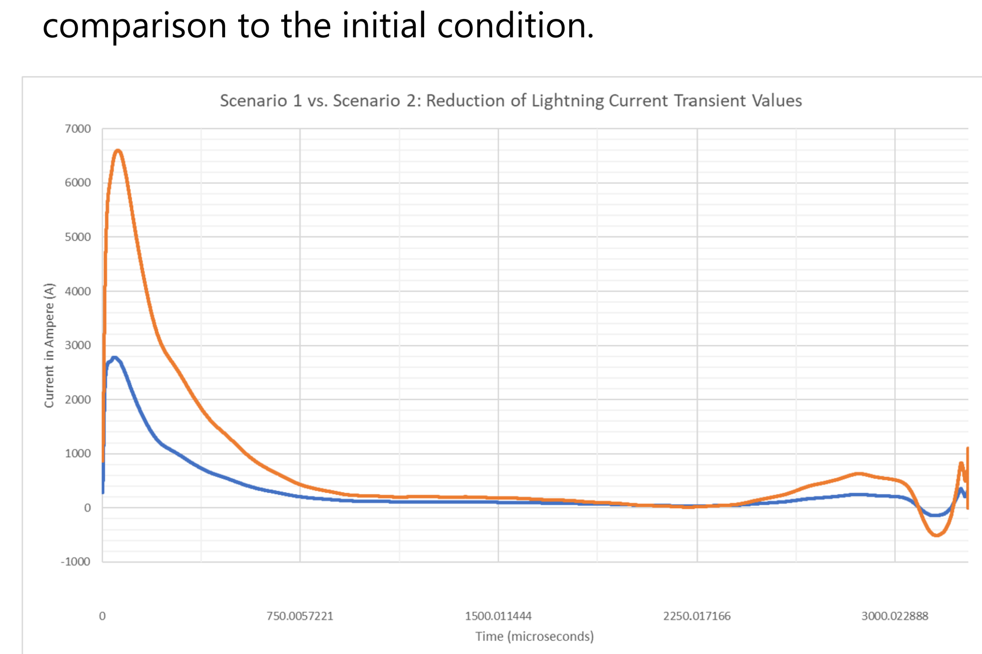


FIGURE 6: COMPARISON OF CALCULATION RESULTS FOR PCS-0016 – DC TRENCH 3

TABLE 2: SUMMARY – PEAK CURRENT CALCULATIONS FOR AREA 1: SCENARIO 1 AND 2

Critical locations considered within the Area of the Solar PV Field	Scenario 1 – Peak Current (kA)	Scenario 2 – Peak Current (kA)
Current Impulse into PCS – 0016 (DC 1)	7.1	5.5
Current Impulse into PCS – 0016 (DC 2)	6.1	2.8
Current Impulse into PCS – 0016 (DC 3)	6.6	2.75
Current Impulse out PCS – 0016 (DC 4)	3.9	2.1
Current Impulse out PCS – 0016 (DC 5)	5	2.5
Current Impulse out PCS – 0016 (AC)	8.5	5.9
Current Impulse at PCS – 0016 (Ground)	12	7.2

TABLE 3: SUMMARY – SPECIFIC ENERGY CALCULATIONS FOR AREA 1: SCENARIO 1 AND 2

Critical locations considered within the Area of the Solar PV Field	Scenario 1 – Energy (A^2s)	Scenario 2 – Energy (A^2s)
Current Impulse into PCS – 0016 (DC 1)	8 900	4 730
Current Impulse into PCS – 0016 (DC 2)	6 850	1 310
Current Impulse into PCS – 0016 (DC 3)	7 360	1 250
Current Impulse out PCS – 0016 (DC 4)	974	357
Current Impulse out PCS – 0016 (DC 5)	4 740	1 150
Current Impulse out PCS – 0016 (AC)	9 170	6 760
Current Impulse at PCS – 0016 (Ground)	27 700	8 980

Sinusoidal waveforms can be used for calculating and illustrating the GPR during a lightning strike condition.

This frequency domain analysis will illustrate the localized GPR with a high rate of rise and peak value to be expected by lightning striking the PV field (sinusoidal waveform with frequency of 250 kHz).

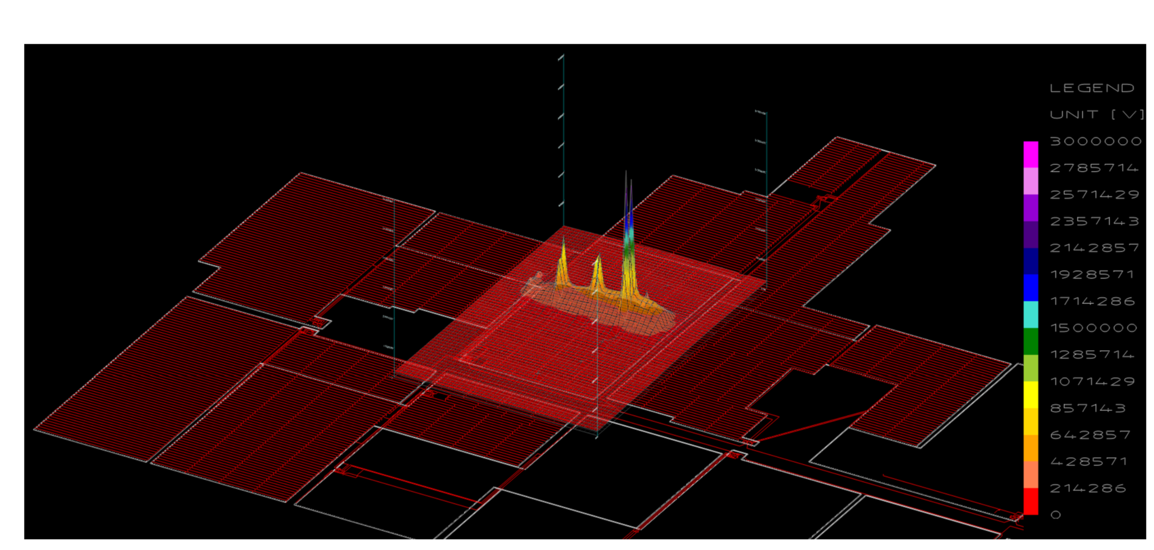


FIGURE 7: GPR 3D VIEW DURING LIGHTNING INJECTION (SINGLE FREQUENCY 250 KHZ)

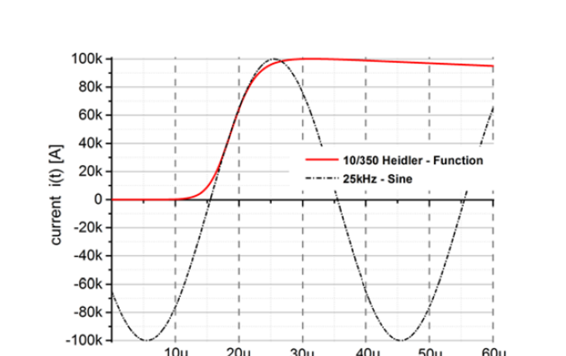


Image above taken from:

J. Meppelink, R. Andolfato and D. Cuccarollo, "Calculation of Lightning Effects in the Frequency Domain," in International Colloquium on Lightning and Power systems, Bologna, 2016.

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