Voltage distribution in group-grounded 8 x 2 solar PV panel assembly during lightning strike

Abstract - **This paper is focused on the effect of group grounding of solar PV assemblies using both end-point and mid-point grounding on the potential rise across the solar PV panels during a lightning strike. This system consists of 16 assemblies forming an 8x2 array. Simulation has been carried out for various lightning attachment points in PSPICE using the lossy transmission line model. Voltage drop at various points in the assembly is determined for various soil resistivities. Based on the simulation results, group grounding of solar PV panels with middle grounding shows a lower voltage transient potential rise compared to end grounding.**

Keywords - Solar PV panels, Lightning protection systems, grounding

I. INTRODUCTION

Lightning strike can cause failures to the electronic equipment of the solar PV system like solar PV modules, inverters, transformers, and cables. This interruption or damage can contribute to losses and affect the solar PV performance. The extent of the electronics component damage depends on few characteristics like lightning peak current, lightning current waveshapes and the location of strucked points[1].

In a solar photovoltaic (PV) farm, solar PV panels are fixed on a grounded structure with bolts and nuts. The structure, the frame of the PV panels, and the bolts and nuts are made up of metal. Lightning protection systems which are installed on a solar PV farm are mostly based on a Franklin rod (connected to a down-conductor) as the preferred point of attachment. Consequently, it utilizes the concept of protective angle or rolling sphere method to determine the protective zone to the solar panel assemblies. Despite the installation of the lightning protection system (LPS), direct lightning strikes to the solar PV panel frame/structure might still happen. [2].

The general strategies in installing the PV system components and location design for optimized efficiency of power production should be compatible with strategies of lightning protection design [2]. Depending on the point of strike, the maximum impulse current and the soil resistance there is a possible risk that the voltage drops along the PV-module mounting system might damage the panel[3]. Ayub etal (Ayub, Siew et al. 2018) has compared the effect of individual grounding of solar PV assemblies based on either end grounding or middle grounding on distributed voltage drop across PV panels for different types of soil. Based on their findings, middle grounding does not offer any obvious advantage over end grounding for different soil resistivity [3]. The next question to consider is whether the same inference is valid when multiple assemblies are interconnected together before being grounded from a single point on the PV assemblies.

This paper investigates the effects of direct lightning strikes on overvoltage resulting on the system due to various grounding arrangements in a multiple solar PV assembly having 16 assemblies forming an 8x2 array. Group grounding of multiple solar PV panels in which effect of middle-grounding and end-grounding points to down conductors for various soil resistivities is compared for distributed voltage drops across the solar PV panels. This paper is organized into five sections. Research methodology is covered in section II. In section III modelling parameters are discussed. Results and discussions are included in section IV. Section V concludes the paper

II. METHODOLOGY

In this investigation, group grounding strategy using endpoint and middle grounding is applied to study the potential drop across solar PV panels in the assembly during lightning strike for different soil resistivities. RLC circuit model of solar PV panel is extracted from the panel specifications and simulated in SPICE transient simulation using a current source to represent the lightning leader. Voltage drops across various points were determined in the time domain and post-analyzed using Matlab.

III. MODELLING PARAMETERS

A. Solar PV Panel Array Model

The whole system consists of sixteen PV assemblies forming an 8x2 array. Each PV assembly consists of 10 PV panels of 350 W occupying an area of 5m x 4m with a total output of 3.5 kW. The dimensions of each solar frame are 1 m width and 2 m length and its cross-section is 2 cm width and 5 cm height. In Figure 2, each end of the assembly is connected to ground via a down conductor and this is termed as end-point ground. In Figure 3, the middle point of the assemblies are connected to ground via a down conductor and this is termed as middle-point ground. Ground connection of solar assemblies in Figure 2 and Figure 3 are shown in red lines.

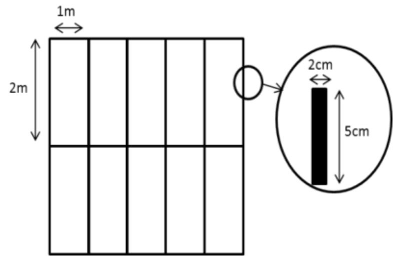

Figure 1: Illustration of an assembly considered and the blow-up image is the cross section of solar frame

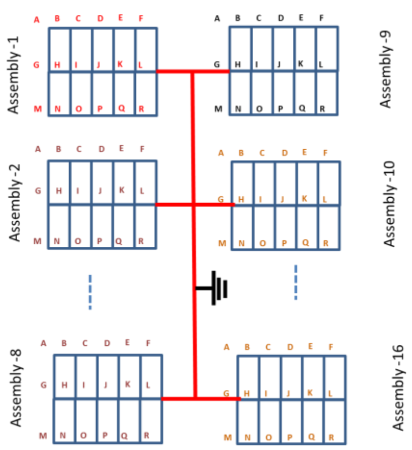

Figure 2: 8x2 Solar PV assembly array, end-point grounding

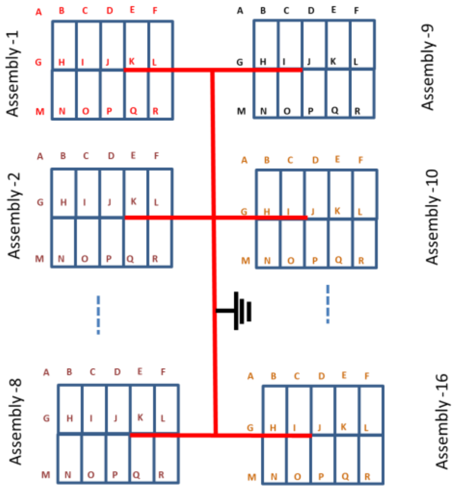

Figure 3: 8x2 Solar PV assembly array, mid-point grounding

B. *Lightning Impulse Current Prameters*

Commonly occurring cloud to ground discharges of a downward leader carrying negative charge resulted in more than one stroke. About 80% of flashes are negative and they comprise more than one stroke (usually three to five). Individual strokes are typically separated by 40 to 50 ms. Stokes subsequent to the firsts stroke are known as subsequent strokes and have shorter risetimes relative to the first stroke[4].

The lightning current considered in this investigation is defined by the double exponential expression as shown in equation 1

$$i = \frac{I}{k} \times \frac{(t/\tau_1)^{10}}{1+(t/\tau_1)^{10}} \times e^{(-t/\tau_2)} \quad (1)$$

where I is the peak current, k is the correction factor for the peak current, t is the time, $\tau 1$ is the front time constant, and $\tau 2$ is the tail time constant. The lightning current considered in this investigation is defined by the double exponential expression as in (1). Higher value of di/dt component present in the subsequent stroke increases the inductive voltage leading to high voltages. In this paper, subsequent lightning pulse parameters based on a worst case scenario are used to predict the likely potential distribution along the solar PV frames caused by lightning currents. Such subsequent stroke-currents can trigger dangerous sparking to human or other objects within the sparkover distance. The lightning protection level (LPL) 1 is used in this investigation where the subsequent stroke of 0.25 µs front time and 100 µs tail time current waveform is considered and its parameters are tabulated in Table 1 below. Figure 4 shows the lightning current impulse waveform generated from (1) using parameters tabulated in Table 1 below[5, 6].

Table 1 Parameters for Lightning Protection Level (LPL) 1 for subsequent stroke 0.25µs (front time) /100µs (tail time)

Parameters	Lightning Protection Level (LPL) 1
I (kA)	50
k	0.993
τ_1 (µs)	0.454
τ_2 (µs)	143

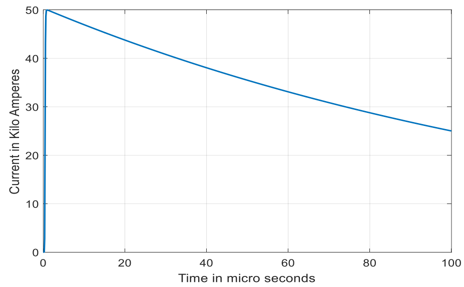

Figure 4. Lightning current impulse waveform of 0.25 µs/100 µs (Table 1)

IV. RESULTS AND DISCUSSION

In each of the grounding strategy, an impulse current is injected at panel A of the assembly 2 shown in Figure 2 and Figure 3. Potential drops were measured at panels A; I; and R across all of the 16 assemblies. Soil resistivity is a measure of resistance offered by the soil for the flow of current which is determined by solid constituents, water content, soil porosity, and fluid composition. It varies over a wide range and plays a critical role in grounding grid design[7]. Soil resistivity measurement shows exponential decrease from top layer(1500 Ω-m) of soil to bottom layer(10 Ω-m) [8, 9]. Typical wet organic soil can have soil resistivity of 10 Ω-m while bedrock soil can go up to 10,000 Ω-m[10]. Due to the wide range of variation in soil resistivity depending on various factors, in this paper, simulation is conducted for soil resistivities of 10 Ω-m and 100 Ω-m.

Voltage distribution (relative to ground) during a lightning strike in assemblies 2,1 and 16 for panels A,I and R for soil resistivity 10 Ω-m are shown in Figure 5 to Figure 7. For the mid-point grounding, peak voltage was observed in assembly 2, Panel-A (which was exposed to direct lightning strike) is 319 kV. However, voltage in panels I and R in the same assembly are lower - 260 kV. Voltages at I and R are much closer to each other. Voltage at various points in the rest of the 15 assemblies across various panels remains the same. For brevity, voltage distribution across panels A, I and R for assembly 1 and 16 are shown in Figure 5 and Figure 7 respectively.

For the end-point grounding, peak voltage was observed in assembly 2, Panel-A (which was exposed to direct lightning strike) is 2650 kV as shown in Figure 8 . Similar voltage distribution is found in panels I and R of assembly2. Voltages at various points in the rest of the assemblies due to a direct strike on assembly 2, panel A shows the same magnitude of 2650 kV. For brevity, voltage distribution across panels A,I and R for assembly 1 and 16 are shown in Figure 8 and Figure 10 respectively. Increased soil resistivity has no effect on the grounding topologies discussed.

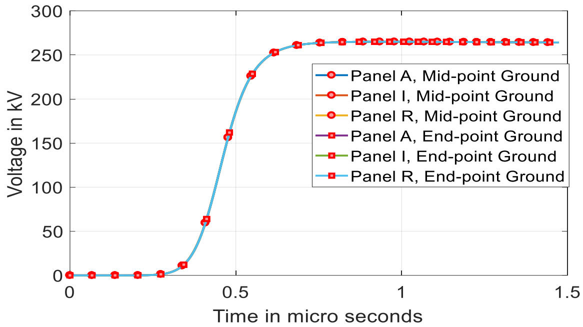

Figure 5 Voltage in Assembly 1, Rg=5.3 Ω

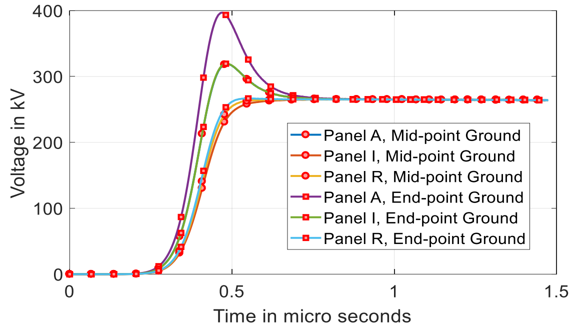

Figure 6 Voltage in Assembly 2, Rg=5.3 Ω

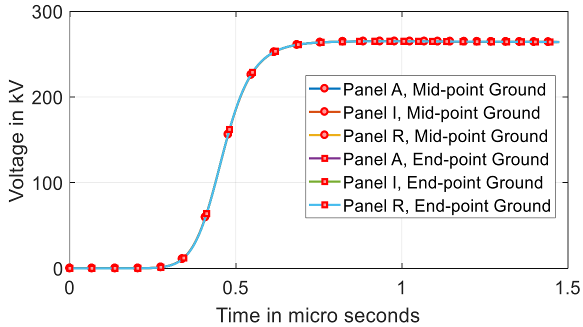

Figure 7 Voltage in Assembly 16, Rg=5.3 Ω

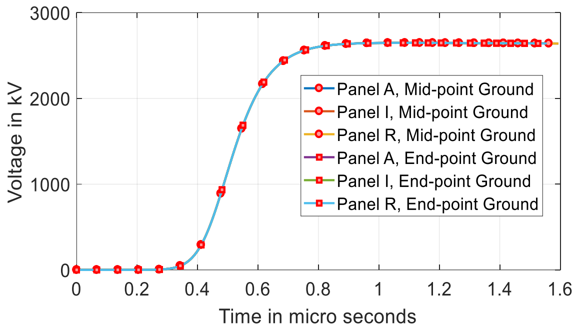

Figure 8 Voltage in Assembly 1, Rg=53 Ω

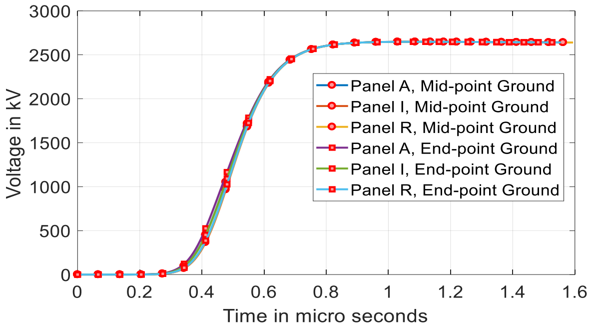

Figure 9 Voltage in Assembly 2, Rg=53 Ω

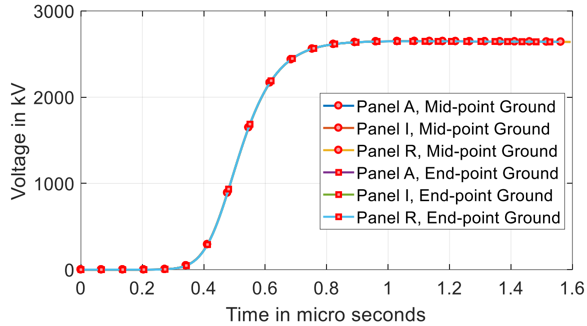

Figure 10 Voltage in Assembly 16, Rg=53 Ω

V. CONCLUSIONS AND FUTURE WORK

Group grounding of multiple solar PV panels having an 8x2 array in which the effect of middle-grounding or end-grounding for various soil resistivity is compared by looking at the distributed voltage drops across different points of the solar PV panels with respect to ground. It is found that potential drops gradually decrease from the point of strike to points approaching the ground point. Based on the simulation results, it is found that solar PV panels consisting of group assemblies having middle point grounding has a slightly better performance in terms of lower voltage potential rise compared to end point grounding. It is also evident that voltage drops in the panels that were not struck in both middle and end grounding are similar. During the energy dissipation process through the grounding system, if the electric field exceeds a certain threshold termed as critical electric field, rupture of the soil dielectric around the electrodes up to a certain radial distance may occur which affect the soil resistivity. Impact of soil ionization on the voltage drop due to lightning strokes needs to be considered and would be carried out in future work.

REFRENCES

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<u>Response to Reviewer comments</u>

Authors express thanks to reviewers comments. Reponses to reviewer's comments are included below in italics.

Reviewer -1

This paper discussed the importance of the grounding approach for PV panels. I have both technical and editorial comments:

1). Page 1, IIIA - numbers and units in the text should be separated by a space. The reference in the text to Figure 1 is in a different type face with italics. It should not be. Also there is a reference to Figures 2 and 2! This should be 2 and 3.

Authors agree with reviewer comments on typographical errors. All the typographical errors are now corrected. Changes made in the passage are highlighted in red.

2). Figures 2 and 3 have red coloring in many places without explanations in the text. Please add this information.

Authors agree with reviewer comments on figures 2 and 3. Explanation of those red-lines are now included in the manuscript. Please see Page -1 section III, A of the manuscript. Explanation are highlighted in red.

3). In Table 1 and Figure 4, a much faster rise time lightning direct strike waveform is used. Can you explain why you used this?

Higher value of di/dt component present in the subsequent stroke increases the inductive voltage. In this paper, subsequent lightning pulse parameters are used to simulate the potential distribution caused by lightning stroke which could trigger dangerous sparking resulted from high inductive voltages. Such subsequent stroke-currents can trigger dangerous sparking to human or other objects within the sparkover distance. The changes are amended in page 2, column 1, section B highlighted in red.

4). Page 2, IVA - why is one of the soil resistivities 10 ohm-meters. This results in a fairly high level of conductivity which is not usual. Can you explain why this was used?

Due to the wide range of variation in soil resistivity based on soil resistivity measurement across various geographical regions, in this paper, simulation is conducted for soil resistivities of 10 Ω-m and 100 Ω-m. Please see page 2 section iv first paragraph.

5). Page 3, Figures 9-14. In all of these graphs the legend indicates 6 sets of lines, but in most we can only see 2 lines. It is assumed that either there are many cases that are the same or some cases are not shown on some plots. Please describe in the text what is the situation here in some detail.

Authors agree with reviewers' comments. Apologies for the lack of clarity. Now figures 5 to 10 are plotted for both end-point and mid-point grounding for specific soil resistivity. Explanations for the plots are added. Please see page 2 section iv second paragraph. Changes are highlighted in red.

Reviewer -2

2: * Figures 2 and 3 appear to be the same diagram (mid-point grounding?). I suggest the author review these figures for clarity of the end point grounding case.

Authors agree with reviewer's comments that Figures 2 and 3 are not clear enough. Apologies for the lack of clarity. Explanations of Figures 2 and 3 are added in the manuscript. Please see Page -1 section III, A of the manuscript. Explanation are highlighted in red.

* Figures 5 - 14 provide results, but no direct comparison of end- and mid-point grounding affect on the voltage drop across simulated PV panels. I suggest the author plot both mid- and end-point results of each assembly onto 1 plot (so 10 plots to 5) to aid the reader in interpreting the results the author describe that mid point grounding provides a slightly better performance.

Authors agree with reviewer's comments. Now figures 5 to 10 are plotted for both end-point and mid-point grounding for specific soil resistivity. Comparative analysis of mid-point and end grounding are included in the manuscript. Please see page 2 section iv. Changes are highlighted in red.