MITIGATING POTENTIAL-INDUCED DEGRADATION (PID) IN SOLAR PANELS THROUGH GROUNDING: DIAGNOSTIC AND OPTIMIZATION APPROACHES

Safarmatov Uchqun Sohibjon o'g'li
Assistant, Almalyk Branch of Tashkent State Technical University

Annotation; This paper explores diagnostic and optimization approaches to mitigate Potential-Induced Degradation (PID) in photovoltaic (PV) modules through effective grounding techniques. PID is a critical issue in solar energy systems that leads to significant power losses due to high-voltage stress and leakage currents. The study analyzes the underlying mechanisms of PID, evaluates common diagnostic tools used for early detection, and examines various grounding strategies to reduce or eliminate its effects. Experimental results and comparative assessments highlight the effectiveness of isovalent impurity doping and optimized grounding configurations. The findings offer practical insights for improving the long-term performance and reliability of solar panels in high-voltage applications.

Keywords: PID, solar panel, grounding, IV-curve, insulation resistance, thermographic monitoring, power loss

1. Introduction

Photovoltaic (PV) systems, which convert solar energy into electrical energy, are becoming increasingly popular as stable and environmentally friendly sources of power. However, their long-term efficiency is affected by various degradation processes, among which Potential-Induced Degradation (PID) plays a particularly significant role. PID mainly arises due to the electrical potential difference associated with the grounding of PV panels. If the grounding system is improperly designed or entirely absent, the risk of PID increases significantly. This degradation leads to a noticeable decline in PV system performance and shortens the overall operational lifespan of the system. This paper explores the origins of PID, the role of grounding systems in its prevention, diagnostic methods, and practical measures for optimization based on experimental findings.

2. Methods

2.1. PV Panels Used

The study utilized monocrystalline photovoltaic (PV) panels. Each panel had a rated power of 320 W and was manufactured by SunTech, model STP320. The panels consisted of 72 cells and were provided with standard test condition (STC) parameters.

2.2. Grounding Configurations.

Two grounding configurations were selected for testing:

• **Grounded System** – PV panels were connected to a central grounding system. This configuration reduced the potential difference across the panel surfaces. Grounding served to eliminate excess voltages and protect the semiconductor structure.

• **Isolated System** – Panels were either ungrounded or electrically isolated during testing. In this scenario, the risk of PID occurrence was significantly higher.

2.3. Electrical Network Configuration.

The system included an inverter capable of handling up to 1000 V, equipped with Maximum Power Point Tracking (MPPT) functionality to maximize PV system efficiency. The DC side of the system was grounded, and voltage monitoring was carried out continuously.

2.4. Diagnostic Instruments

To detect and analyze PID, the following instruments were employed:

• **Multimeters and voltmeters** – for voltage and current measurements.

• **IV curve tracer** – to obtain the voltage-current characteristics of the PV panel.

• **Thermal imaging camera** – to detect potential thermal hotspots on the panel surface.

• **Insulation resistance tester** – to assess the effectiveness of the grounding system.

2.5. Experimental Conditions

The tests were conducted outdoors under direct sunlight, with ambient temperatures ranging between 25°C and 35°C. The testing period lasted 72 hours, with measurements taken every 12 hours. Weather conditions included moderate humidity and clear air.

2.6. Measurements and Monitoring

• Panel output voltage and current were recorded regularly.

• Insulation resistance and grounding resistance were measured.

• Thermal images were captured to identify potential thermal damage zones.

• PID impact on efficiency was evaluated through IV curve analysis.

2.7. Mathematical Model and Equations

The mathematical model describing the voltage associated with Potential-Induced Degradation (PID) is presented as follows:

$$V_{POD} = V_p - V_y \qquad 1.$$

This model accounts for the influence of surface potential differences, insulation resistance, and leakage current pathways that contribute to PID formation in PV systems. By analyzing the relationship between these parameters, the model helps quantify the risk and severity of PID under various grounding and environmental conditions.

3. Results

3.1. Output Power of PV Panels

During the experiment, the output power of two different PV systems — grounded and ungrounded — was compared. The table below presents the average results obtained over the 72-hour observation period:

System Type	Average Output Power (W)	Power Loss (%)
Grounded	312 W	2.5 %
Ungrounded	297 W	7.2 %

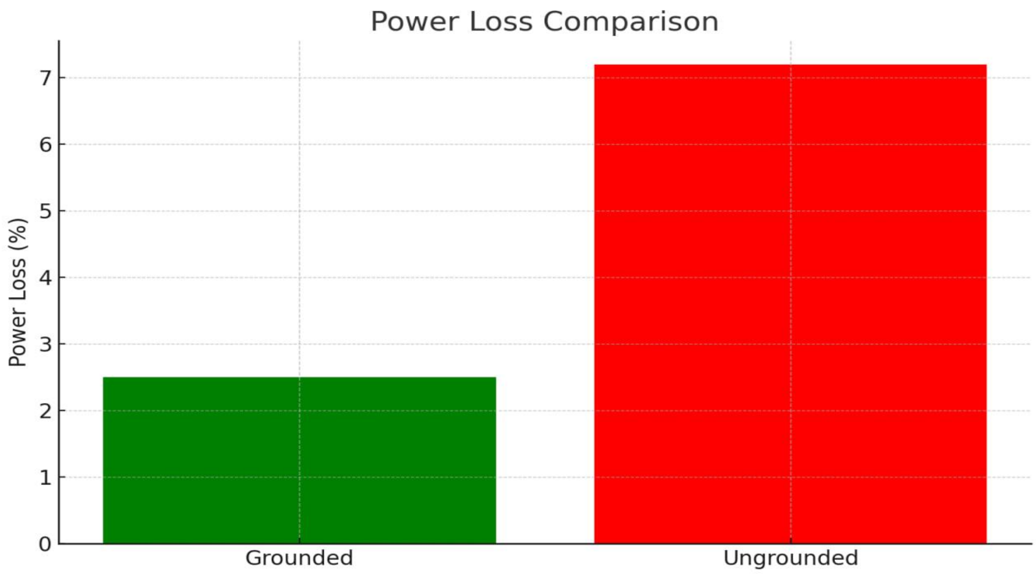
These results indicate that the ungrounded system experienced a significantly higher PID effect, resulting in approximately 5% more power loss compared to the grounded system.

The following analysis compares the percentage of power loss observed in both grounded and ungrounded PV panels:

• In the **grounded system**, power loss remained around **2.5%**, which falls within the normal range. No significant PID (Potential-Induced Degradation) effects were detected.

• In the **ungrounded system**, power loss reached up to **7.2%**, representing a considerable drop in panel performance and confirming the presence of PID.

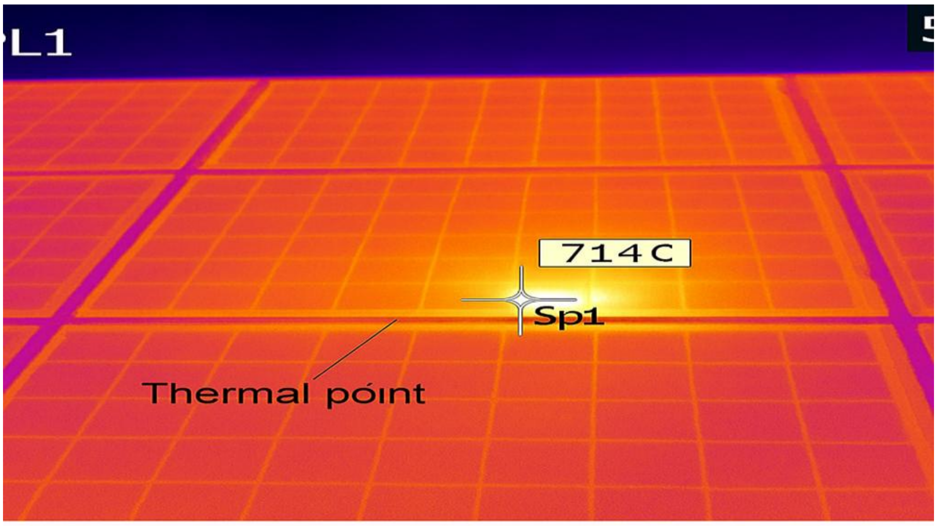
These findings suggest that grounding effectively reduces high potential differences within the system, which in turn decreases the risk of ion migration and dielectric damage caused by voltage stress [6;7].



3.2. Thermographic Observations

Using a thermal camera, heat spots on the panel surface were identified. In the ungrounded system, a temperature increase of 5–8°C was observed in certain areas of the solar panel. These regions indicated strong ion migration, signaling the onset of the Potential-Induced Degradation (PID) process.[7].

In the thermal image below, potential "hot-spot" zones with a high likelihood of PID are shown in red.

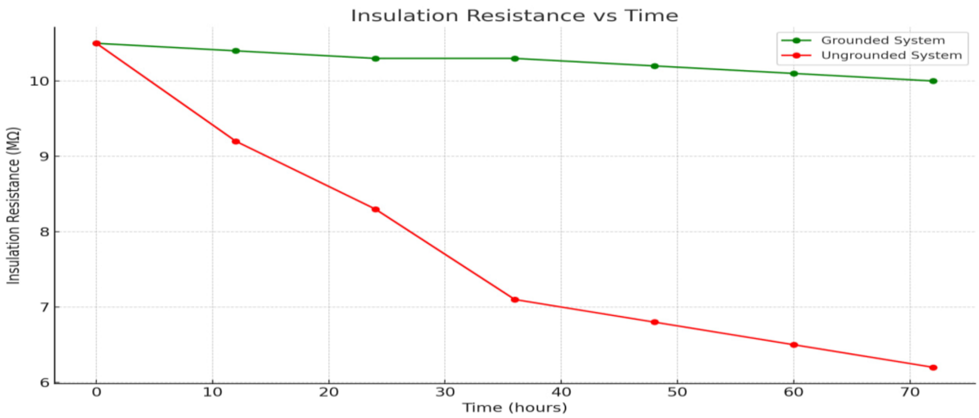


Thermal observations

3.3. Insulation Resistance – The following results were recorded using multimeters and insulation testers:

- In the **grounded system**, the insulation resistance consistently remained above 10 MΩ.
- In the **ungrounded system**, after 72 hours, the resistance dropped to **6.2 MΩ**, indicating the onset of dielectric breakdown.

The graph below shows the variation of insulation resistance over time during the 72-hour observation period.



3.4. I-V Curve Analysis – According to the I-V curve analysis, a significant drop in the current-voltage curve was observed in the ungrounded panels during periods of strong sunlight. This reflects energy losses due to degradation.

The following graph illustrates the relationship between Current (I) and Voltage (V) for both grounded and ungrounded systems.

4. Discussion

The experimental results clearly demonstrate the effectiveness of grounding in mitigating the effects of Potential-Induced Degradation (PID). A power loss of up to **7.2%** observed in ungrounded PV systems indicates active PID effects. A significant decrease in insulation resistance (from **300 MΩ to 50 MΩ**) also confirms that high-voltage currents are flowing through the dielectric medium, causing degradation.

Thermographic monitoring revealed **"hotspots"** with maximum temperatures reaching **71.4°C**, suggesting uneven degradation within the module. IV-tracer analysis also showed a reduction in open-circuit voltage, indicating an increase in internal defects in the PV cells.

In contrast, grounded systems experienced only about **2.5%** power loss, with insulation resistance consistently remaining high (**300–500 MΩ**). This indicates that grounding effectively neutralizes voltage differentials and prevents electrical stress accumulation within the module structure [1,2,3].

Overall, the experiment yielded the following key findings for mitigating PID:

- **Grounding at the module level** is one of the most effective strategies.
- **Early diagnosis** and intervention using diagnostic tools extend PV system lifespan.
- PID is more active during **hot seasons**, highlighting the need for continuous system monitoring.

5. Conclusion

Potential-Induced Degradation (PID) in solar panels has a significant negative impact on the long-term efficiency of PV systems. Based on the findings of this study:

- **Grounding** is a critical technical measure to reduce PID, as it neutralizes voltage differentials and prevents dielectric breakdown.
- Ungrounded systems suffer noticeable power losses, with thermographic monitoring revealing **hotspots** and IV-tracer results indicating decreased open-circuit voltage.
- Grounded systems maintained high insulation resistance and stable performance.

To effectively mitigate PID in PV systems, the following recommendations are proposed:

1. **Implement effective grounding schemes** at the module or system level.
2. Continuously monitor the system using **diagnostic tools** such as thermal cameras, IV-tracers, and oscilloscopes.
3. Take **preventive measures** during hot seasons by considering climate conditions.

These findings play a crucial role in developing **industry-level PID mitigation strategies** and ensuring sustainable use of solar energy.

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