Operational scheme for detailed PV simulation results

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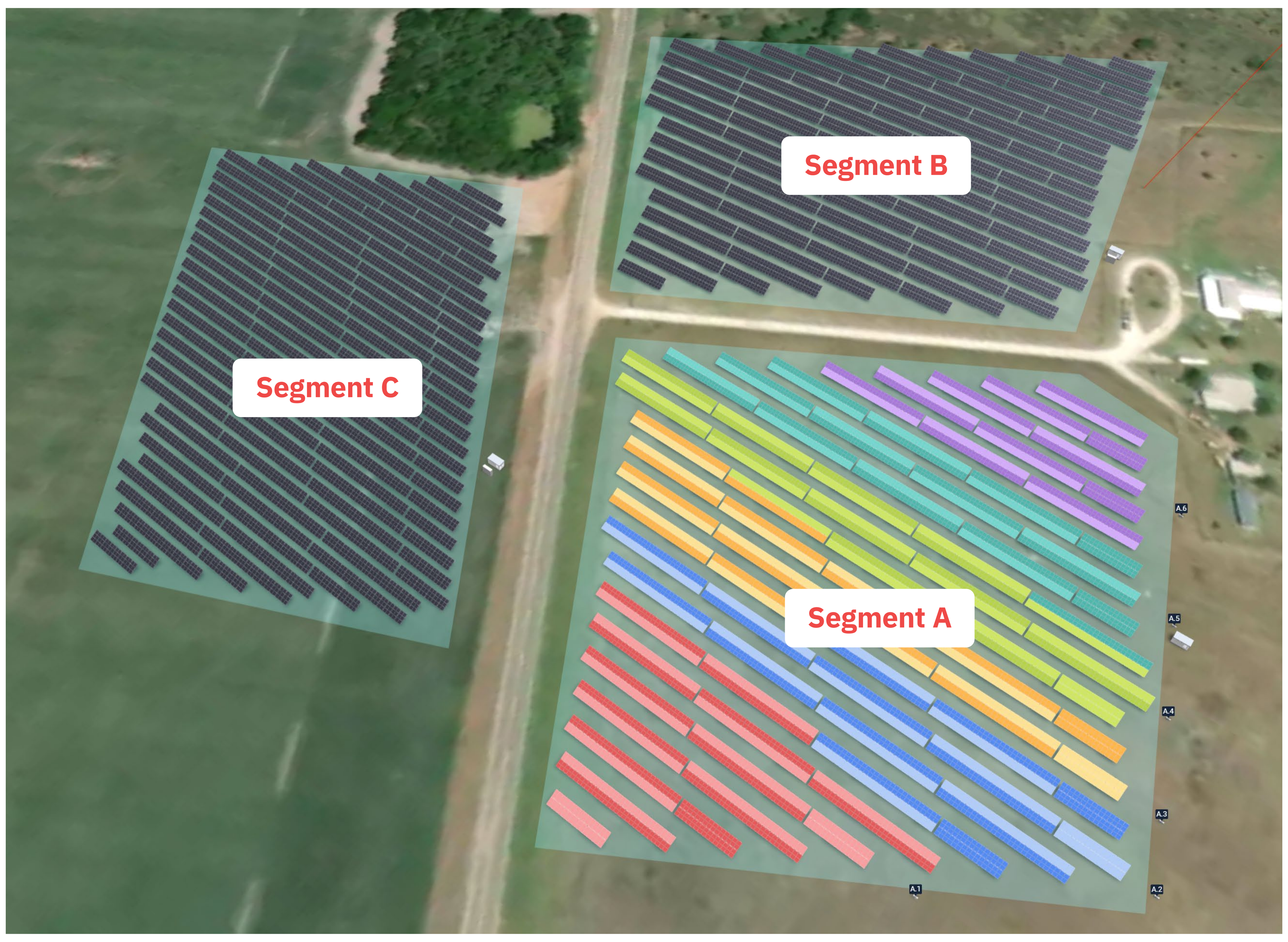
Introduction

Typically, the photovoltaic (PV) industry analyzes simulation results at a system level, focusing mainly on long-term average solar radiation and PV power output (PVOUT). A detailed performance analysis of PV design enables a deeper understanding of the complex relationships between a proposed technical solution (considering the technical parameters of individual components) and site conditions (described by high-resolution terrain and local climate data). This presentation describes a detailed PV energy simulation methodology that uses sub-hourly time-series data and a digital twin concept.

Methodology

Solargis Evaluate PV Simulator provides detailed outputs on the level of transformers, inverters, and MPP trackers, including:

- Monthly statistics for each inverter to identify sources of clipping and power-limiting losses
- Time-series data for each electrical component, including operational points and clipping events
- I-V curves on MPP trackers to further analyze which operational limits (current, voltage and power) were reached by specific inverter and the causal factors



Case study

A case study PV system was developed comprising three segments (A, B, and C), each uniquely configured to investigate distinct inverter operational limiting conditions. The PV system is located in Texas, USA (31.463, -96.823). The analysis was performed using the Solargis Evaluate PV Simulator with 15-minute resolution time-series data for the full year of 2021.

Common System Parameters:

- **Modules:** 400 Wp Monocrystalline, Monofacial, Half-cut cell
- **Total DC Capacity (per segment):** 1.7 MWp
- **DC/AC Ratio:** 1.2
- **Mounting:** Fixed-tilt
- **Azimuth:** 181°
- **Tilt:** 28° (Optimized)

Segment A

Ground cover ratio (GCR) : 50%
Module orientation: Portrait
String size: 30

Inverters: 5x Generic 250 kW
Min MPPT voltage: 860 V
Max MPPT voltage: 1300 V
Maximum DC input voltage: 1450 V

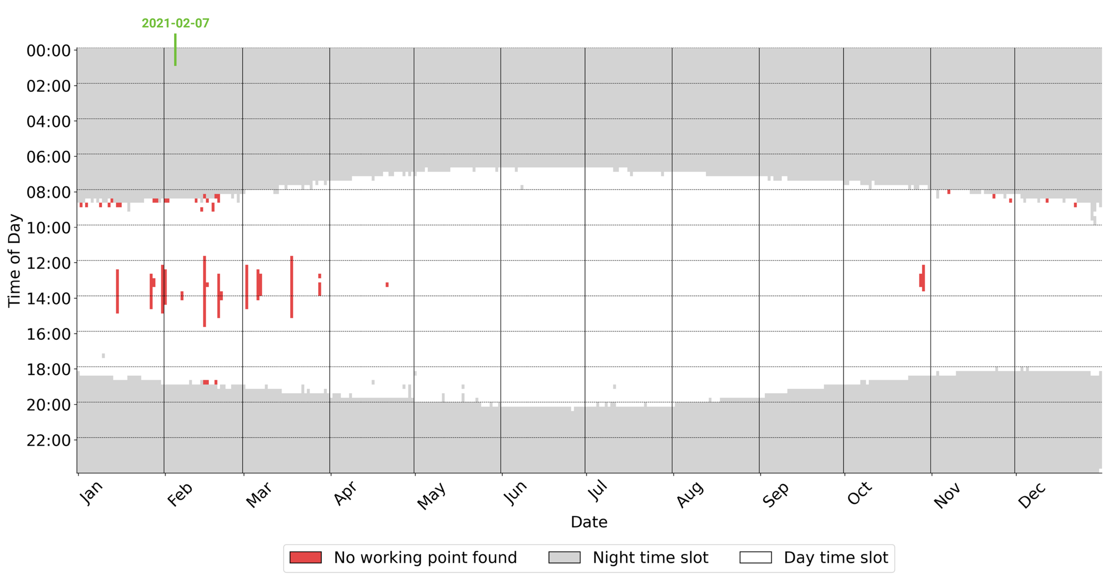


Figure A1: No working point available on Inverter IV curve which meets all I,V,P limits

The highlighted (red) 15-minute intervals in the Figure A1 heatmap and Figure A2 time-series plot denote periods where the inverter **failed to identify a valid operating point** on the I-V curve that satisfied all specified current, voltage, and power limits.

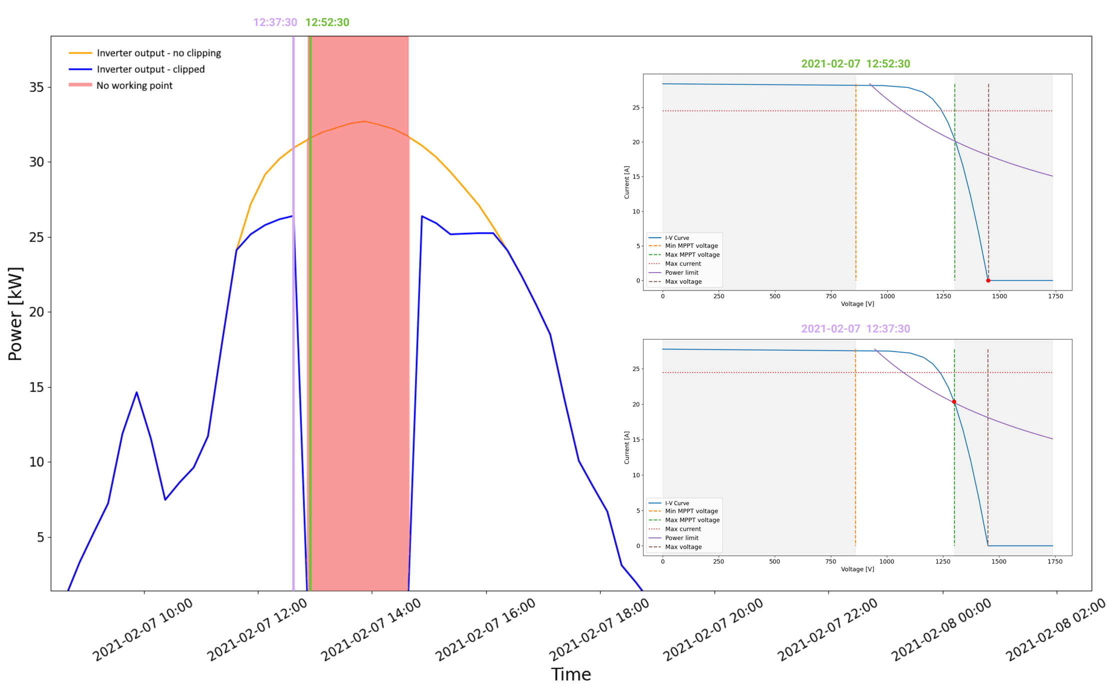


Figure A2: Time series and IV curve for "no working point available" scenario

This operational fault is typically seasonal, triggered when low ambient temperatures and high solar irradiance coincide in a system with long module strings. These factors can push the array's I-V curve completely outside the inverter's I-V-P operational envelope, preventing the MPPT from establishing a valid working point. Appropriate string design and inverter configuration are therefore essential to prevent such production-halting events.

Segment B

Ground cover ratio (GCR) : 50%
Module orientation: Portrait
String size: 30

Inverter: 1 x Generic 1500 kW
Min MPPT voltage: 822 V
Max MPPT voltage: 1300 V
Maximum DC input voltage: 1500 V

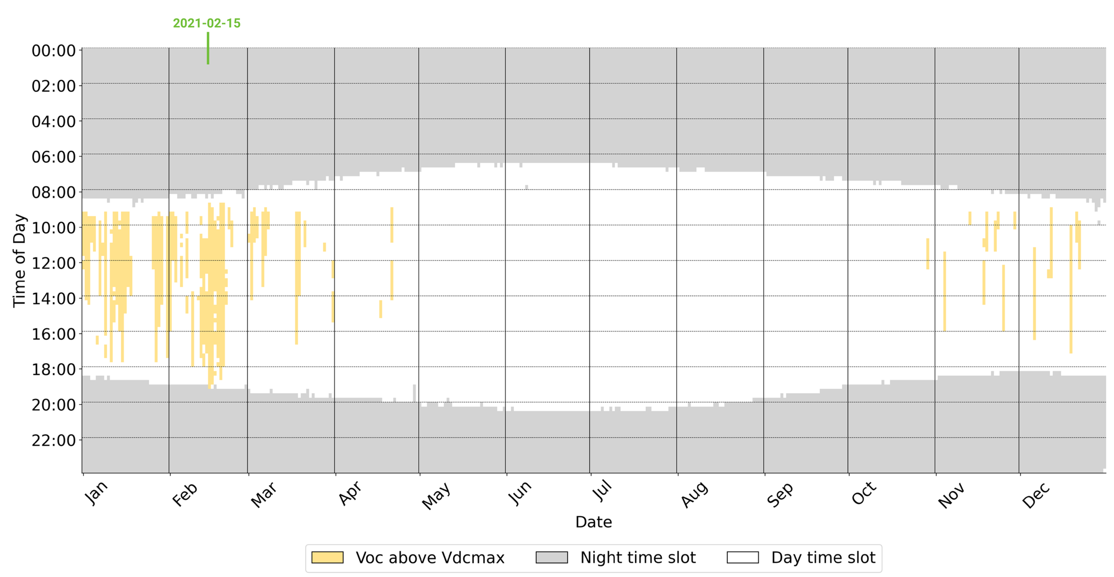


Figure B1: Open circuit voltage on one of the inverter inputs is higher than Vdcmax

The highlighted (orange) 15-minute intervals in Figures B1 and B2 denote periods where the array's **open-circuit voltage (Voc) exceeds the inverter's maximum DC input voltage** limit of 1500 V.

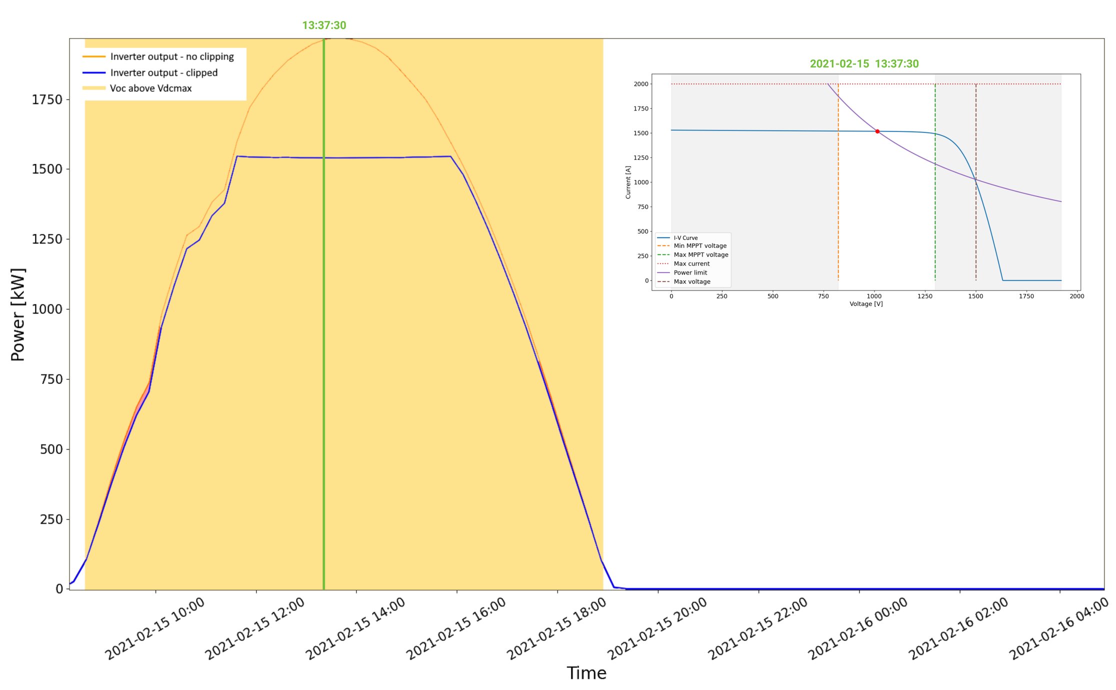


Figure B2: Time series and I-V curve for "open curcuit voltage above Vdcmax" scenario

Crucial condition for this scenario is larger string size (30 modules per string) in combination with low ambient temperature (-12.2 °C for the shown I-V curve). The I-V curve is shifted into higher voltages, causing the open circuit voltage to exceed the maximum DC input voltage (1500 V). The open circuit voltage will appear on the input once the inverter goes to stand-by mode and draws no current from the string. This may cause the malfunction or damage of the inverter input. Cautios string sizing is recommended in environments with substantial sub-zero ambient temperatures.

Segment C

Ground cover ratio (GCR) : 65%
Module orientation: Landscape
String size: 24

Inverter: 1 x Generic 1500 kW
Min MPPT voltage: 822 V
Max MPPT voltage: 1300 V
Maximum DC input voltage: 1500 V

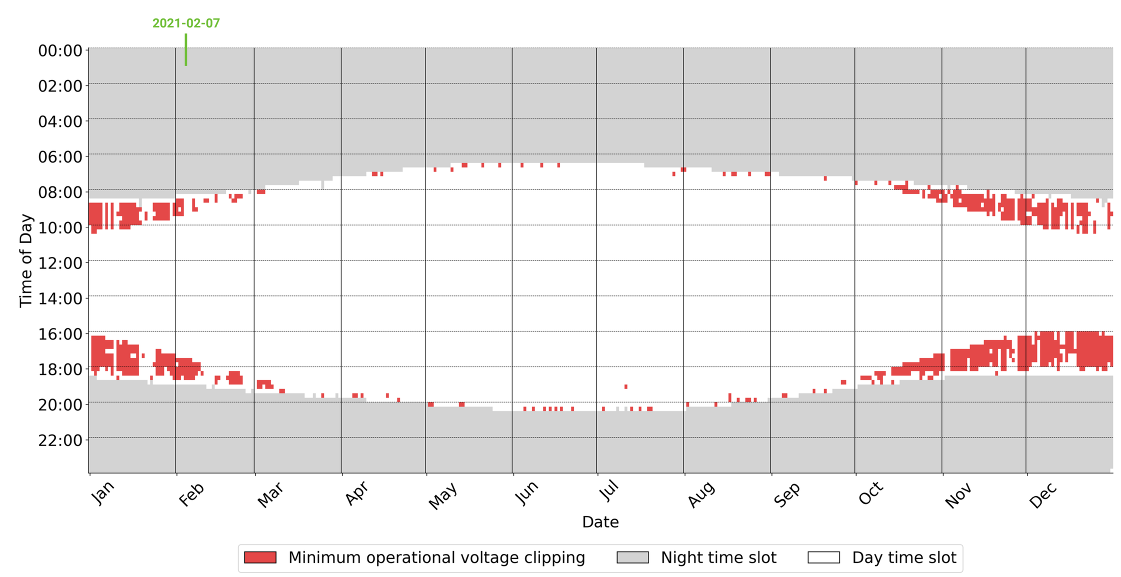


Figure C1: Inverter clipping caused by minimum operational voltage limit

The highlighted sections indicate periods where significant inter-row shading caused the PV string's voltage to fall below the inverter's MPPT minimum voltage threshold. Consequently, the inverter is bound to select a working point within the MPPT operation envelope, causing **clipping**.

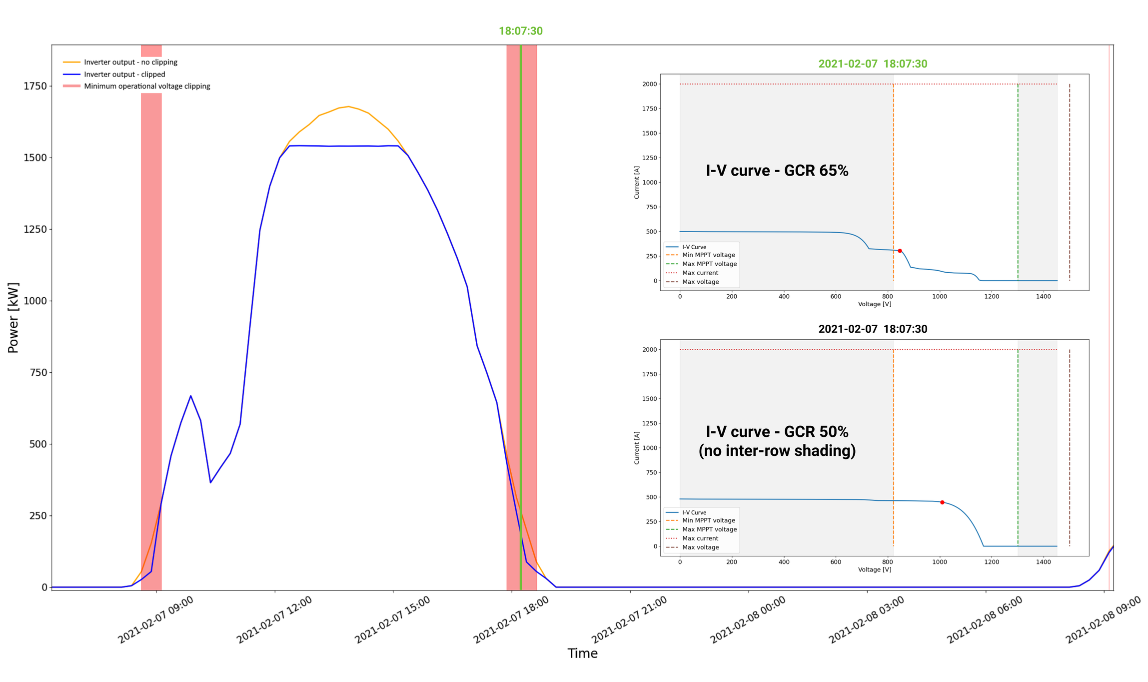


Figure C2: Time series and I-V curve for "clipping by minimum operational voltage" scenario

The impact of inter-row shading on the I-V curve is evident in Fig. C2. This phenomenon is analogous to shading from nearby obstructions, such as fences or vegetation, and represents a critical factor in the design phase of any PV system. For installations where such shading conditions are unavoidable, the selection of an inverter with a lower minimum operating voltage is an effective strategy to mitigate power losses from voltage clipping.

Conclusion

This analysis successfully demonstrated how sub-hourly simulations can identify critical operational scenarios, such as voltage limit breaches and shading-induced power losses, that are missed by conventional energy yield assessments. The results highlight the necessity of considering dynamic climate conditions and site-specific configuration when designing PV systems. Neglecting these factors can lead to significant energy losses or even pose a risk to equipment.

References

[1] Sevim Zeynep Celik, Marta Pelfort Ojer, Branislav Schnierer, Jozef Rusnak, Giridaran Srinivasan: Time-Series vs Typical Meteorological Year Data: Verification of PV String Sizing and Design, Solargis Americas Inc., Toronto, ON, M5H 1J9, Canada