Quantifying Power Losses from Inverter Voltage Floor Limitations

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INTRODUCTION

An inverter voltage floor refers to the minimum DC input voltage required for an inverter to remain operational, a critical parameter in utility-scale photovoltaic (PV) design. Power losses due to inverter input voltage limitations are an often-overlooked factor that can significantly affect overall system performance. This important topic was first discussed by Clay Helms, Nick de Vries and Jeremy Schaefer (Silicon Ranch) at NREL's 2023 Photovoltaic Reliability Workshop (PVRW) regarding module degradation and system level reliability [1].

Significant power losses may occur in PV systems when inverters cannot track the PV array's DC maximum power point (Vmp) because it falls below the inverter minimum input voltage ("voltage floor").

We are conducting an experiment to explore how three factors—inverter voltage floor limitations, module voltage loss due to high temperatures, and reactive power demand —interact to impact the overall efficiency of PV system operation at a utility-scale site. By measuring and quantifying power losses due to these factors, the experiment aims to provide a more accurate understanding of system performance and offer insights into possible methods for mitigating these losses in both current and future PV plants.

METHODOLOGY

The experiment is conducted at a 100 MW utility-scale photovoltaic (PV) power plant in California, starting in the spring of 2025. The primary goal of the experiment is to detect and quantify power losses due to inverter voltage floor limitations, module voltage loss at high temperatures, and high reactive power demand.

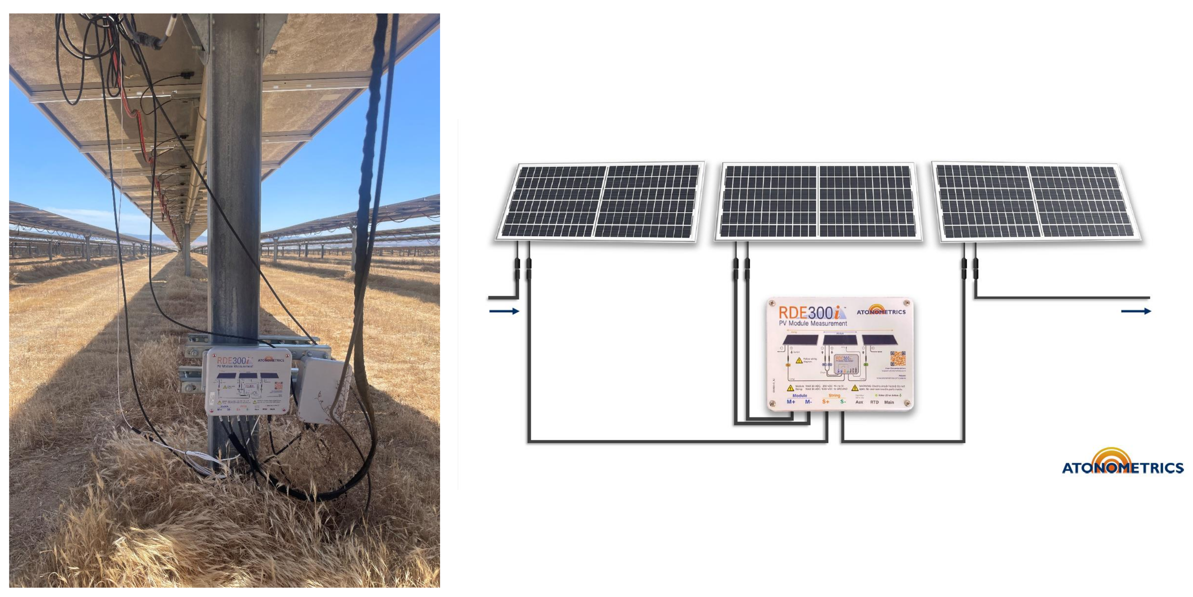

Figure 1. Left: RDE300i PV module in-situ I-V tracer installed at one of Leeward Renewable Energy's operational assets in California.
Right: Schematic of RDE300i connected in-situ and wired into a PV string

In-situ IV sensors RDE300i (Manufactured by Atonometrics) are deployed to monitor PV modules and DC operating points directly. These sensors have the capability to periodically perform IV sweeps on PV modules by isolating them from the system [3][4], which is crucial for obtaining real-time, accurate data on the module's maximum power point (Pmp). By comparing the actual DC array Pmp determined from module IV sweeps with its operating power, we can directly quantify power losses where the inverter is operating above the module's maximum power point, indicating power limitations due to the inverter voltage floor.

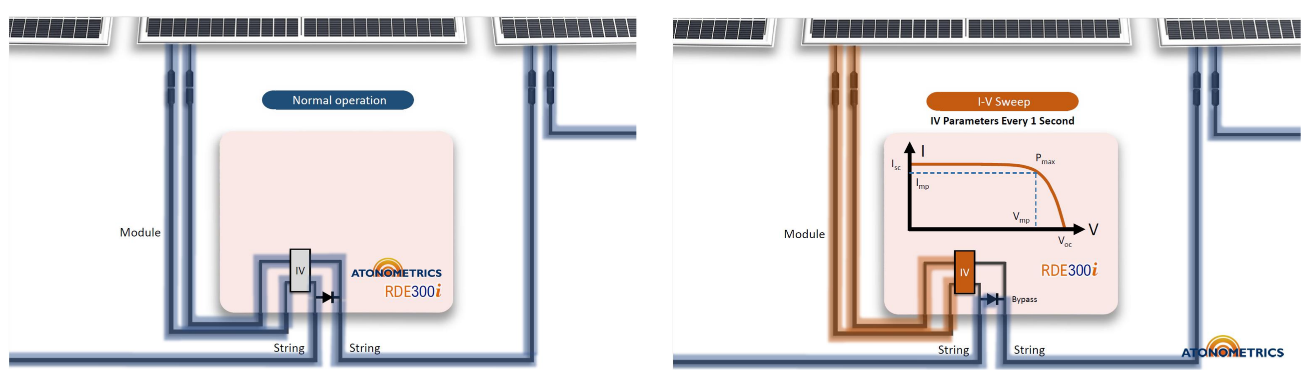

Figure 2. Left: RDE300i acts as a passive measurement device during normal operation (connected to string), measure module voltage and current to obtain the actual operating voltage and current when grid forces inverters off Vmp
Right: During a sweep, RDE300i briefly isolates the individual PV module from the string to perform a full I-V curve measurement, measure the isolated module voltage and current (Vmp/Imp, where the modules want to operate)

RESULTS

To ensure analysis accuracy, data cleaning/filtering was performed to exclude all timestamps not associated with inverter voltage floor events. The remaining data set consists solely of relevant voltage floor time series.

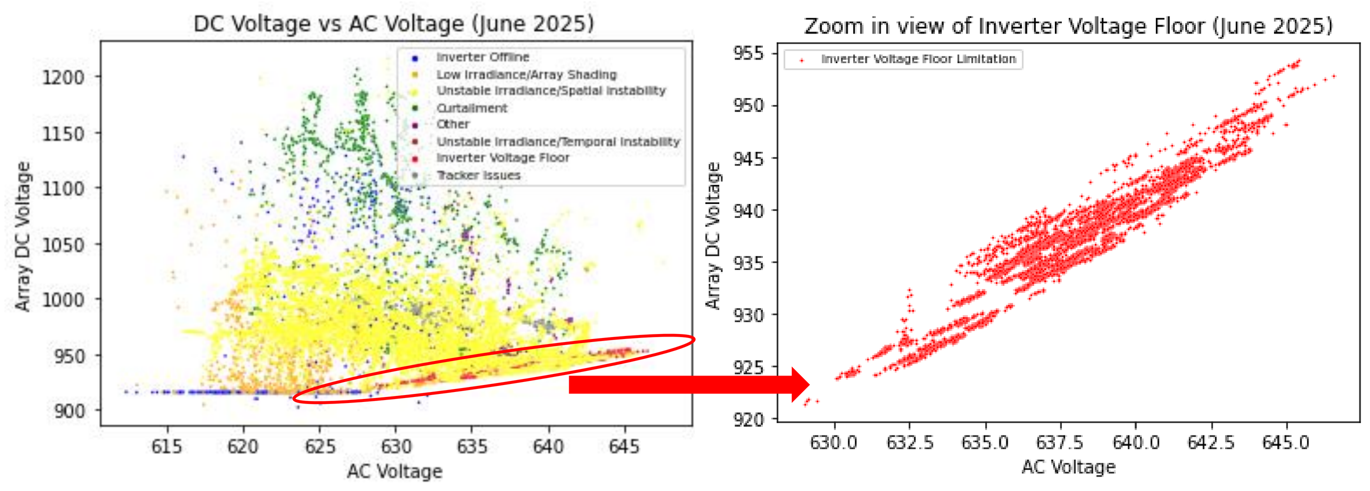

Figure 3. Left: Array DC Voltage vs AC Voltage by different filtering technique to identify inverter voltage floor events
Right: Zoom in view of Inverter Voltage Flooring Events

During periods of high reactive power demand by the utility grid, inverter DC voltage floor may rise, which can exacerbate voltage-floor losses. Furthermore, the compounding effects of high-temperature conditions and module degradation can cause further voltage loss, also potentially pushing the system into conditions where the DC voltage falls below the inverter's voltage threshold [2]. These losses are cumulative and may result in substantial energy deficits over the life of the system, especially in systems that are not properly designed to mitigate these effects.

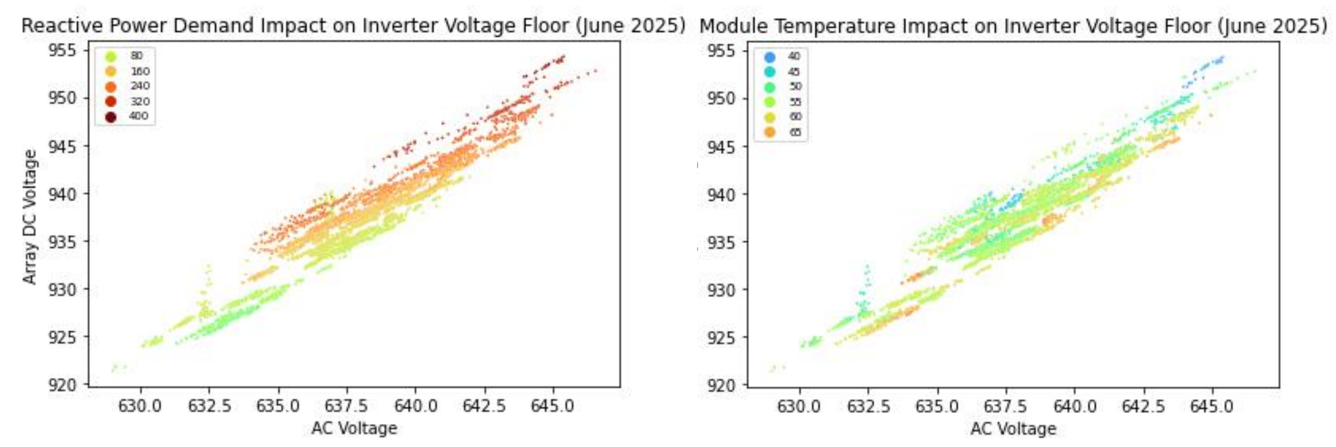

Figure 4. Left: Inverter Voltage Floor rises as reactive power demand increases
Right: Higher module temperature pushes the system DC voltage below inverter voltage threshold

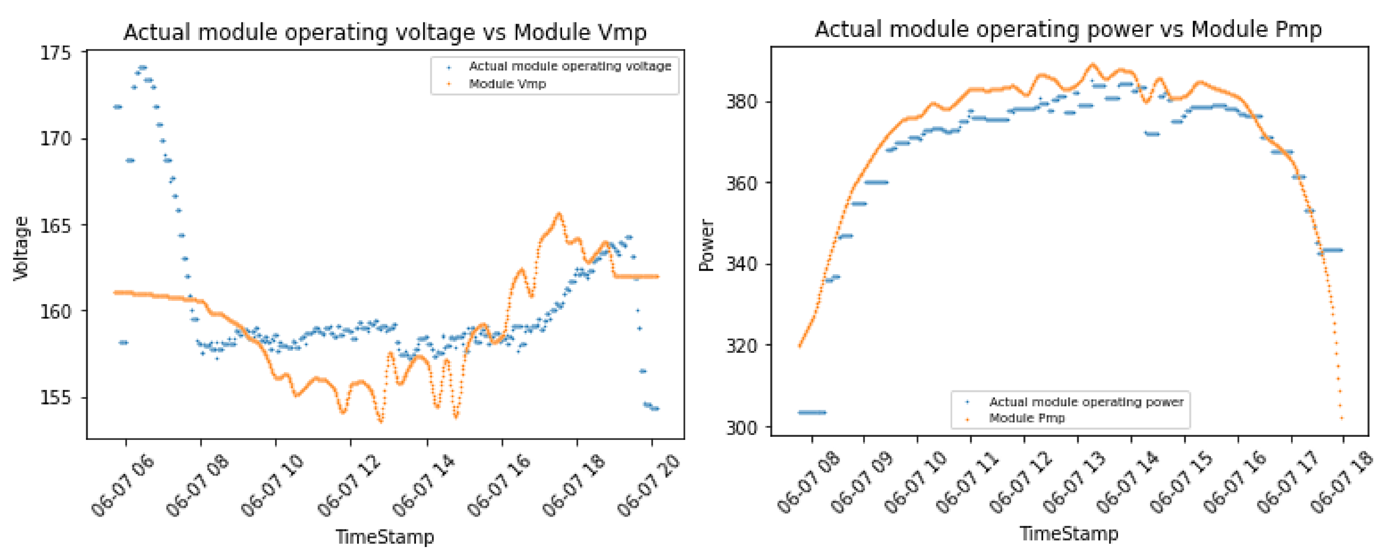

Figure 5. Left: Vmp, where the module wants to operate (Orange) vs Measured module voltage, where grid forces inverters off Vmp (Blue)
Right: Pmp from I-V curve tracer (Orange) vs Measured module power (Blue)

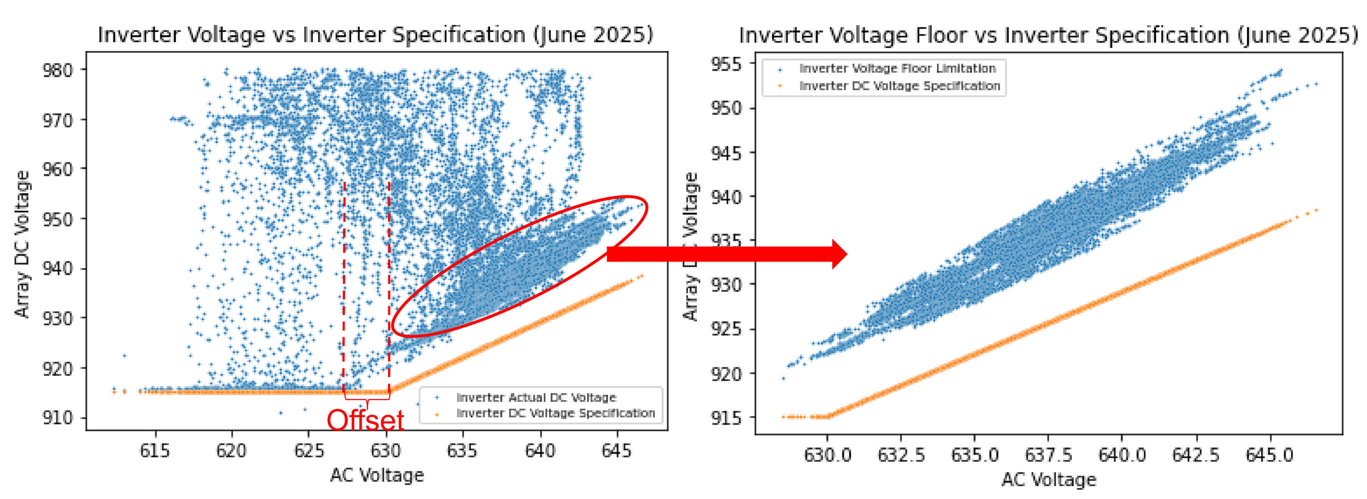

Figure 6. Left: Inverter Voltage Flooring Events vs Inverter Specification
Right: AC Voltage hysteresis (Inverters not able to control to Specification minimum Vdc at nominal Vac due to an "Offset" in inverter setting)

CONCLUSION

For summer 2025, an average of 1-2% energy losses due to Inverter Voltage Flooring have been observed. On average, implementing Voltage Adjustment (Reduce "Offset" in Inverter Setting) could potentially reduce energy losses by approximately 80%.

The table below shows a monthly breakdown of energy losses related to inverter voltage flooring and the impact of voltage adjustments over a four-month period in 2025.

	Measured Inverter Voltage Floor Loss	Projected Voltage Floor Loss after Mitigation	Opportunity for Recoverable Losses
June 2025	1.29%	0.26%	1.03%
July 2025	1.34%	0.34%	1.00%
August 2025	1.42%	0.23%	1.19%
September 2025	1.45%	0.56%	0.89%

Table 1. Monthly Energy Losses due to Inverter Voltage Flooring Events and Recoverable Potential

FUTURE WORK

1. Two Inverter Voltage Floor Mitigation Opportunities have been identified and will be implemented over the summer of 2026 to test the recoverability of the measured losses:

a. Tap Adjustment - The dynamic tap on the Main Power Transformer will be adjusted to reduce the positive reactive power needed from the Inverters, allowing them to operate closer to their nominal AC voltage.

b. Modification to Inverter Settings - Working with Inverter Manufacturer to remove the observed Offset, with the goal to remove the AC Voltage Hysteresis effect observed in Figure 6.

2. Recommendation for Simulation Engine Updates regarding Inverter Voltage Floor Limitation. Currently, industry standard simulation engines (PVsyst, PlantPredict etc.) and Inverter OND file do not explicitly model a "Rising Voltage Floor" constraint. This limitation can lead to overestimation of performance in high-temperature scenarios. We recommend that future software updates allow for explicit "Minimum MPPT Voltage parameters, forcing a clipping behavior in the simulation when the array voltage falls below this threshold.

REFERENCES

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