Shade Impact: How Solar Systems Handle Sub-optimal Conditions

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SUMMARY

PV Evolution Labs (PVEL), in partnership with the National Renewable Energy Laboratory (NREL), recently performed a series of field tests to measure the impact of shade on solar array output. In 78 different side-by-side shade configurations, Enphase Microinverters demonstrated higher output than a string inverter, producing more than twice the power in certain cases. NREL used the field test measurements to generate an annual performance prediction for three residential solar arrays with light, medium and heavy shade. The results of the NREL model indicate that Enphase Microinverters increase energy harvest by 4%, 8% and 12.6% in light, medium and heavy shade, respectively.

Additional testing standards are still needed to evaluate inverter performance relative to other source of module mismatch, such as manufacturing tolerance, degradation and soiling. These new testing standards can increase the accuracy of solar simulation programs, such as PVWatts, SAM or PVsyst, in predicting the long-term performance of solar installations.

INTRODUCTION

Shade is a significant design factor affecting the performance of many, if not most, of today's photovoltaic systems. Measuring the extent of shade on a solar array can be challenging due to the fact that shadows move as the sun position moves throughout the day and year. This is further complicated by changes in the source of shade itself—for example, a tree can sway in the wind or lose its leaves during the winter, changing the type of shade it casts on a solar array.

Compounding the complexities in shade analysis is the fact that even a small area of shade can have a significant impact on the total output of the PV system [1]. In particular, solar power electronics, such as inverters, microinverters or power optimizers, have a range of responses to shade, depending on their ability to adapt to complex power curves (Fig. 1). [For example, it's possible—and some would argue common—for an inverter to select the wrong operating point for the array and, in effect, exacerbate the impact of the shade (Fig. 2).]

Up to this point, scientific tests of shade impact have been performed using a variety of products and procedures, resulting in an equal variety of claims about the effects of shade and the best products and processes to deal with it. Therefore, there is a need for standardized procedures for evaluating the effect of shade and for standardized modeling methods to predict lifetime impact.

NREL recently developed a repeatable test procedure for simulating shaded operation of a PV system, and evaluating the long-term performance impact of shade. Enphase and PVEL collaborated with NREL to perform the tests for the first time.

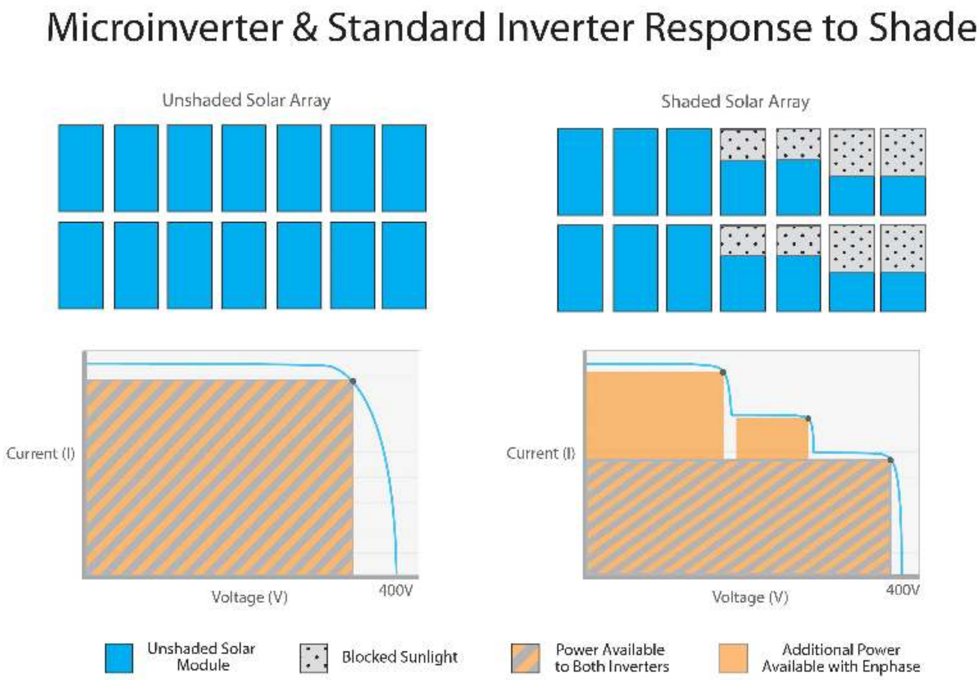

Figure 1: (Top) Unshaded and shaded solar array are depicted, with their power curves (Bottom). The boxes represent the available power for two types of power electronics.

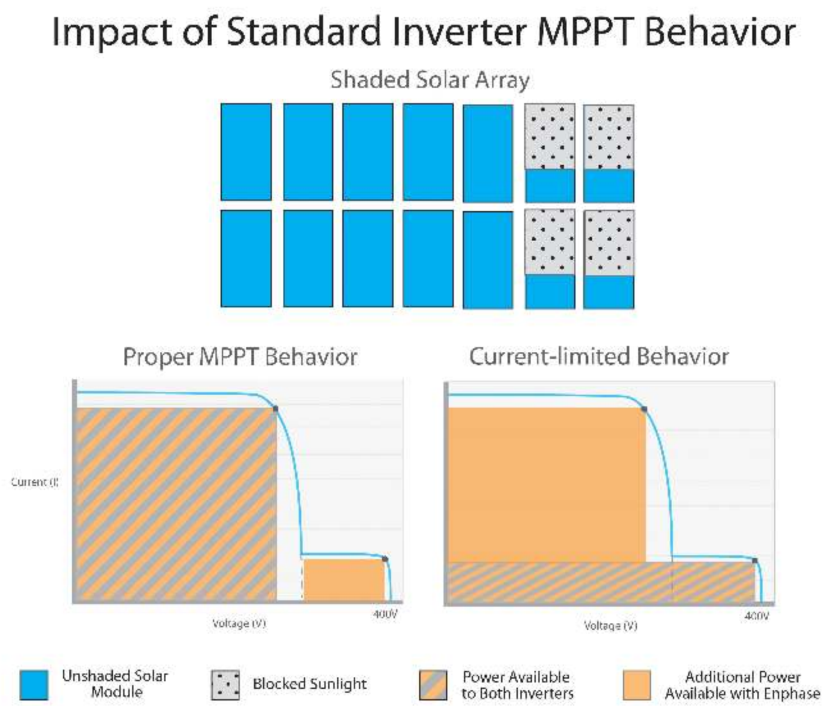

Figure 2: (Top) A simple shade pattern on a solar array is depicted, with two potential inverter behaviors (Bottom).

METHODOLOGY

Shading Testbed

Performance testing on two identical 8kW PV arrays—one outfitted with a string inverter and one outfitted with Enphase Microinverters—was performed under 78 different shade configurations. The arrays consisted of 60-cell solar modules arranged in three strings of 12 modules per string. This design is representative of most residential solar installations.

Figure 3: Semi-transparent mesh applied to solar modules to simulate shade.

Figure 4: Setup of in-field shade simulations.

Shade conditions were simulated using a semi-transparent mesh applied directly to the front of the modules (Fig. 3 & 4). The mesh used had a transparency of 36%. The mesh was applied simultaneously to each array, in 78 unique configurations. Each shade configuration was held constant for a minimum of 20 minutes, and care was taken to ensure that all power electronics devices were operating properly during the tests. Performance measurement was performed with revenue-grade meters.

Annual Modeling

To model the annual impact of shade, the test measurements were incorporated into a model which weighted them based on (1) probability of occurrence throughout the year, and (2) the expected irradiance level at the time of occurrence.

Three different weightings were used to represent solar arrays with different levels of annual shading (light, medium and heavy), based on detailed site surveys of actual solar installations. For the full details of the analysis methodology, refer to "Photovoltaic Shading Testbed for Module-level Power Electronics" (Deline, 2012).

RESULTS

Shading Testbed

The results of the shading tests showed that Enphase Microinverters outperformed the string inverter in all 78 different scenarios, with Enphase producing twice as much power in certain shade conditions (Fig. 5).

Additionally, the procedure discovered that the string inverter is susceptible to "getting stuck" on a local maximum power point, causing current-limited operation of the system—commonly referred to as "The Christmas Light Effect" (Fig. 2). Further testing was able to show that these improper inverter behaviors are reproducible through specific sequencing when applying the mesh.

Annual Modeling

The results of NREL's annual performance model indicate that Enphase-equipped systems recover approximately 50% of the energy normally lost to shade by a string inverter. Specifically, for the light shade condition, Enphase increased annual energy harvest by 4%, for medium shade by 8% and for heavy shade by 12.6% (Fig. 6).

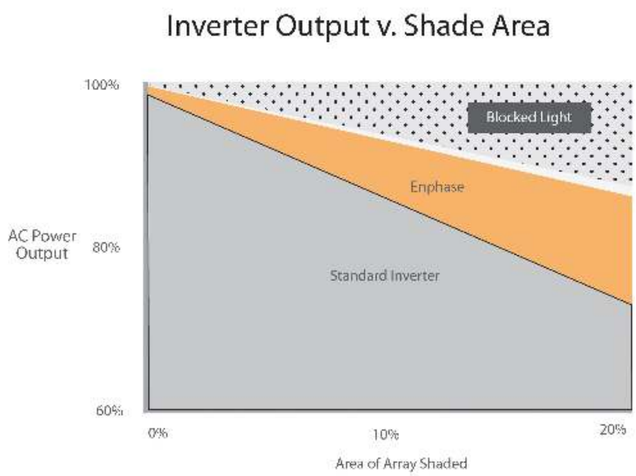

Figure 5: Linear fit of inverter power level versus percent of array shaded.

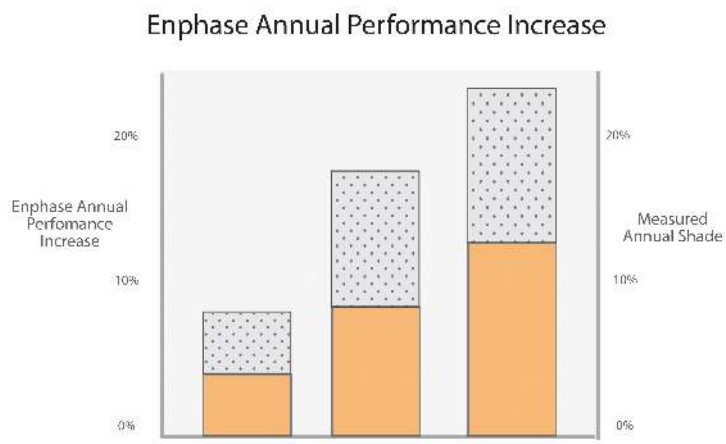

Figure 6: Annual energy harvest increase of Enphase-equipped solar arrays.

CONCLUSION

As the solar industry adopts standardized practices for measuring the extent of shade on a particular installation site, it's increasingly valuable to be able to predict the impact of this factor. This study demonstrates a testing methodology to accurately evaluate inverter performance under shaded conditions.

Additional testing standards are still needed to evaluate inverter performance relative to other sources of module mismatch, such as manufacturing tolerance, degradation and soiling. These new testing standards can increase the accuracy of solar simulation programs, such as PVWatts, SAM or PVsyst, in predicting the long-term performance of solar installations.

REFERENCES

1) C. Deline, "Partially Shaded Operation of a Grid-Tied PV System," NREL, 2009.
2) C. Deline, "Photovoltaic Shading Testbed for Module-level Power Electronics," NREL, 2012.