Performance of PV Topologies under Shaded Conditions

solaredge

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SUMMARY

The SolarEdge system outperforms SMA inverter and Enphase microinverter systems, in a standardized National Renewable Energy Laboratory (NREL) shading study conducted by PV Evolutions Lab (PVEL). This study simulates partial shading scenarios of typical residential rooftop photovoltaic (PV) systems, and evaluates the impact of different power conversion topologies on system performance.

The SolarEdge system harvests 1.9%, 5.0% and 8.4% more energy than SMA string inverter system with light, medium and heavy shading, respectively. The SolarEdge system produces more energy than Enphase microinverter system as well.

The test also determines a Shading Mitigation Factor (SMF) which represents the annual energy recovery of a power optimizer or microinverter system, compared to a traditional string inverter. The study found that the SolarEdge system recovered 28.3%, 21.9%, and 24.3% of energy lost by the string inverter system, with light, medium and heavy shading, respectively. These results indicate higher SMF results than even the Enphase microinverter system.

"The SolarEdge system yielded more energy than the string inverter system in all tests. On an annual average, the SolarEdge system recovered 24.8% of energy lost due to shading, while the microinverter system recovered only 23.2%"

says Matt Donovan, PV Evolution Labs.

PVEL ADVANCING SOLAR

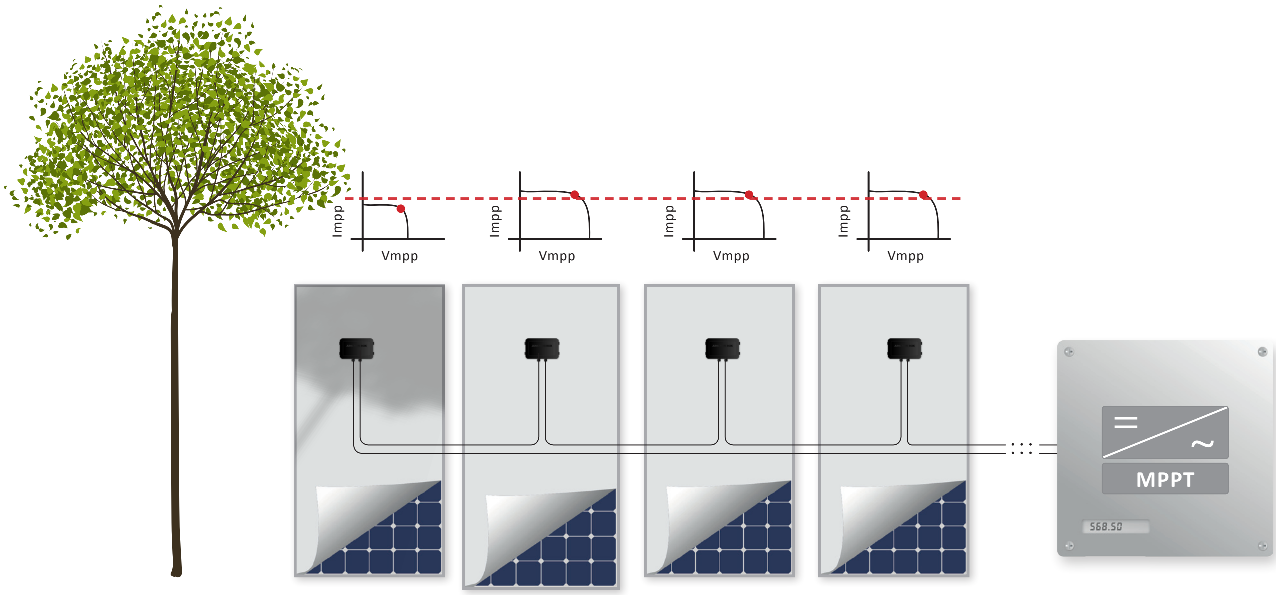
NREL NATIONAL RENEWABLE ENERGY LABORATORY

SHADING IMPACT ON ENERGY PRODUCTION

In PV systems, it is practically impossible to completely avoid shading, which can be caused by trees, chimneys, satellite dishes and more. In these systems partial shading losses are estimated to result in a 5%-25% annual energy loss.

Shading impact in string-level MPP topology

Shading of any part of PV array will reduce its output. Clearly, the output of any shaded cell or module will be lowered in correlation with the reduction in light falling on it. However in systems with traditional string inverters, unshaded cells or modules may also be affected by the shade. For example, if a single module in a series string is partially shaded, its current output will be reduced and this may dictate the operating point of all the modules in the string. Alternately, the shaded module may be bypassed, leading this module to stop producing power entirely (Fig. 1). If several modules are shaded, the string voltage may be reduced to a value lower than the inverter's minimum operating point, causing that string to produce no power.

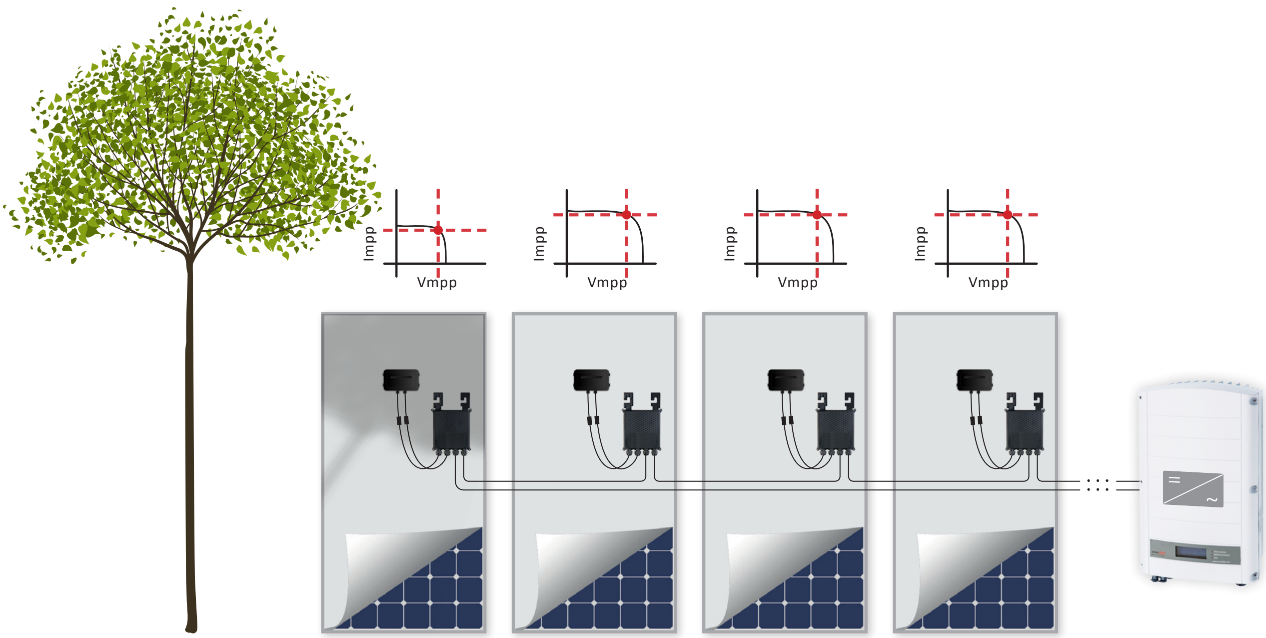


String- level MPP

Figure 1: The partial shaded module is bypassed

Shading impact in module-level MPP topology

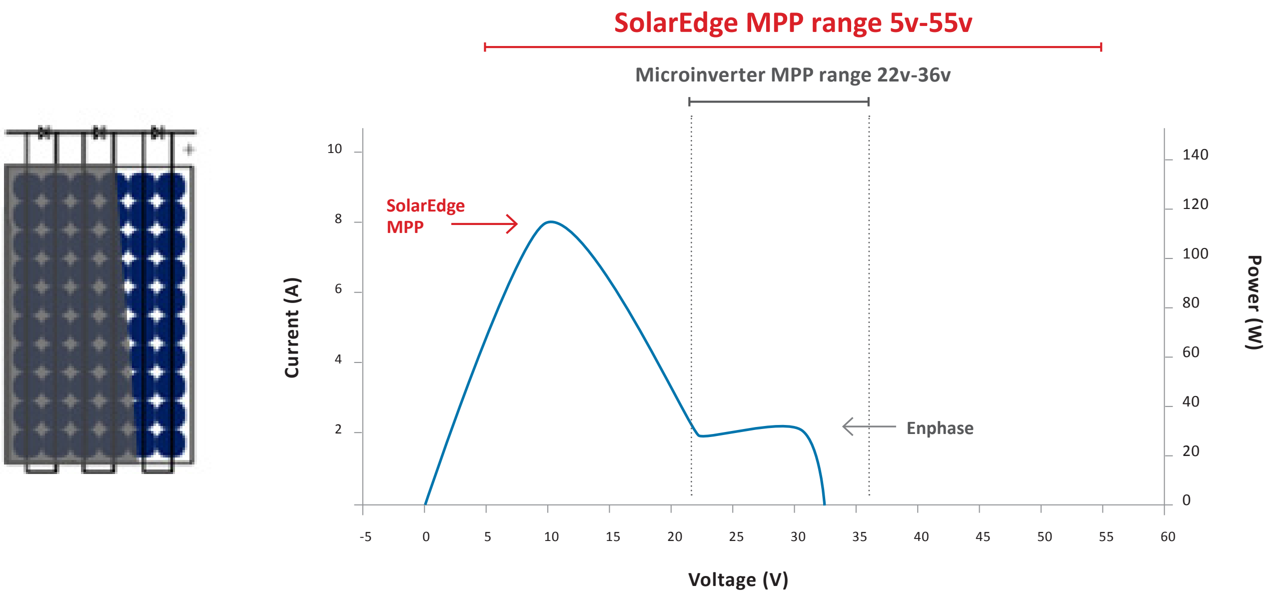
Module - level electronics, such as DC-DC converters and microinverters, mitigate the shading losses by isolating the shading impact to the shaded modules, allowing the unshaded modules to contribute their full power (Fig. 2).



Module-level MPP

Figure 2: The partially shaded module contributes it's power

To effectively harvest energy from a partially shaded module, low-voltage tracking capabilities are key.
However, microinverters need relatively high voltages, of about 20V, to be able to track a module's MPP. This means that if a module's voltage drops below this point, the microinverter will not track its MPP, rather it would maintain a voltage high enough for it to continue to operate, but at an un-optimized point. In contrast, the SolarEdge power optimizers start tracking MPP from a voltage as low as 5V, meaning they track a module's MPP even under severe partial shading (Fig. 3)



Partially Shaded Module I-V Curve

Figure 3: Microinverter module harvest is limited to the lower peak due to its narrow MPPT window

PVEL AND NREL SHADING STUDY PROCEDURE AND IMPLEMENTATION

The PVEL and NREL test procedure was developed in a manner that removes any bias from a comparison between systems. The tested systems are comprised of identical arrays, and the shading conditions are applied to the arrays simultaneously and not sequentially to minimize uncertainties associated with shifts in temperature and irradiance.
Measurements are taken during unshaded conditions as well, and used to normalize the measurements of each system.

In this study, each array consisted of two strings of 13 modules each. The modules were 240W 60-cell modules with 3 bypass diodes per module. Direct shading was applied using a semi-transparent mesh draped directly on top of the module. This mesh has a transparency of 36% and sufficiently uniform spectral transmittance. The test employs a range of shading conditions with as little as 1% of each array shaded to as much as 97%, for a total of 22 configurations.

In every configuration, each array has the exact same shading condition applied, a wait time of five minutes is given to ensure the systems stabilize, and then side-by-side energy harvesting measurements are taken for approximately ten minutes. Performance measurements are taken with revenue-grade meters.

Performance results are then extrapolated and applied to typical light, medium and heavy shading scenarios based on SunEye measurements from actual residences. These three shading scenarios correspond to systems with 7.6%, 19.0% and 25.5% shading, respectively.

In addition, the results are annualized by giving weight to each measurement according to its expected occurrence over the year. The final result is a Shade Mitigation Factor (SMF), which indicates the fraction of energy lost due to shading in a string inverter system that is recoverable using the SolarEdge system (or a microinverter system). An SMF was obtained for the three shading scenarios.

For full details of the procedure, refer to “Photovoltaic (PV) Shading Testbed for Module-level Power Electronics”, C. Deline, J. Meydbray, M. Donovan, J. Forrest, http://www.nrel.gov/docs/fy12osti/54876.pdf.
This document refers to a 3-string system; this study was adapted for a 2-string system.

RESULTS

Performance measurements show that the SolarEdge system harvests 1.9%, 5.0% and 8.4% (Table 1) more energy than the SMA string inverter system with light, medium and heavy shading, respectively. The SolarEdge system produces more energy than the microinverter system as well.

When determining the SMF - the annual energy recovery of a power optimizer or microinverter system, compared to a traditional string inverter - the study found that the SolarEdge system recovered 28.3%, 21.9%, and 24.3% of energy lost by the string inverter system, with light, medium and heavy shading, respectively (Fig. 4). These results indicate higher SMF results than even Enphase microinverter system.

NREL / PVEL SMF Results

Figure 4:

SolarEdge

Enphase

SMA

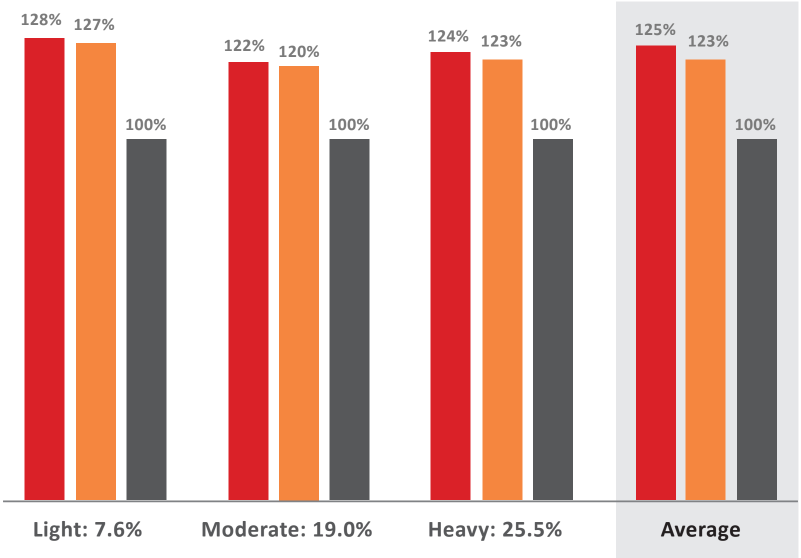


Table 1:

	Light	Moderate	Heavy
% of System shaded	7.6%	19.0%	25.50%
Available Energy [kWh/M²]	1813	1893	1784
SolarEdge Energy [kWh/M²]	1729	1616	1439
SMA string Inverter Energy [kWh/M²]	1697	1539	1328
Shade Mitigation Factor (SMF)	28.30%	21.90%	24.20%
Added Energy	**1.9%**	**5%**	**8.4%**