

A SIDE-BY-SIDE COMPARISON OF MICRO AND CENTRAL INVERTERS IN SHADED AND UNSHADED CONDITIONS

David M. Lee
Department of Technology and
Environmental Design
Appalachian State University
Katherine Harper Hall
Boone, NC 28608
Email: mleedm@lowes.com

Brian W. Raichle
Department of Technology and
Environmental Design
Appalachian State University
Katherine Harper Hall
Boone, NC 28608
Email: raichlebw@appstate.edu

ABSTRACT

Photovoltaic system adoption has exploded in recent years due to several contributing factors, including the availability of reliable, efficient, affordable grid interactive inverters. Traditionally, inverters smaller than around 1 kW haven't been available, keeping the entry price for PV relatively high. Very recently, however, single panel inverters, or microinverters, have entered the market, providing a much lower entry price. In addition, microinverters may provide greater energy per panel compared to central inverters due to reduced loss from partial array shading. However, third-party verification of microinverter manufacturer's claims is currently lacking.

This effort will directly compare the power produced by two nominally identical arrays each of four PV panels: one array feeding a small central inverter and one array feeding four microinverters. The panels are Sharp NE-170-U1, the central inverter was a SunnyBoy SB700, and the microinverters were Enphase D380s. Power output was recorded every minute. Partial shading was artificially introduced equivalently to each array. These measurements were taken during fall 2011 in Boone, NC.

Preliminary results suggest that the microinverter system produced on average 20% additional power compared to the central inverter system in no shade conditions. In partial shade conditions the microinverter system produced on average 26% more power.

1. INTRODUCTION

More than 50,000 photovoltaic systems were installed in the US during 2010 with a grid-tied capacity of nearly 900

MW_{DC}, representing nearly a 50% growth from the previous year (1). Single-panel, or microinverters, a very recent addition to the market, saw a 500% increase during that same time period (2). While still representing less than 1% of the total PV market, microinverters are expected to capture a 6% of market share by 2015 (2).

Conventional inverter technology uses a centralized topology in which several PV panels feed a single inverter unit. Residential central inverters range in power from around 1 kW to around 10 kW. Central inverters operate at a relatively high DC voltage (typically around 1.5× the AC voltage output) and require careful PV string sizing. Further, central inverters are prone to significant shading losses since each PV panel in the string is wired in series. The entire central-inverter based system must be purchased and installed at inception. However, central inverters may benefit from economies of scale, since the ratio of inverters to panels is low.

Microinverter technology has been on the US market since 2008. This technology uses a distributed inverter topology, with an inverter associated with each individual PV panel. This topology provides the greatest flexibility, with no need for string sizing and "grow as you go" capability. Conventional wisdom suggests that a microinverter-based system will be less prone to partial shading. However, microinverters are typically sited at the PV panel – a harsh environment – and may experience a cost penalty due to increased maintenance and diseconomies of scale.

2. REVIEW OF PREVIOUS STUDIES

No published third-party comparisons of micro- to central-inverters could be found in the literature. However, several

studies conducted by a leading microinverter manufacturer were identified that attempt to compared inverter performance.

A white paper from Enphase Energy (3) describes three tests of their M190 microinverter. The first test directly compared a 2,000 W system using M170 microinverters to an equivalent undisclosed central inverter. Under some partial array shading, over a 12-week period the microinverter system produced 14% more energy than the central inverter system. The panels were cleaned weekly. The second test compared two equivalent 4,600 W systems, one utilizing M170 microinverters and the other an undisclosed central inverter. After 12 weeks without regular cleaning, the microinverter system produced 7% more energy. The third test, conducted over a single day with two equivalent 5,000 W systems, was specifically designed to determine inverter sensitivity to partial shading from leaf-sized debris. The microinverter-based system outperformed the central inverter systems by 3.5%.

An indirect comparison between micro- and central – inverters is provided by another Enphase study (4). This report cites a published comparison (5) of small (mostly less than 4 kW) central inverter-based PV systems in Texas to predictions of the well-known NREL software PVWatts. This study finds that central inverter systems underperform PVWatts predictions by on average 8%, with 36% of systems exceeding predicted output. Briggs performed a similar analysis – comparing 143 small (average size around 5 kW) microinverter-based systems to PVWatts predictions and found that microinverter systems outperformed PVWatts predictions by on average 8%, with 76% of systems exceeding predicted output. By extension, microinverters would outperform central inverters by 16%.

A summary of previous microinverter studies is shown in Table 1. All studies found that microinverters outperform central inverters, but a considerable variation in magnitude exists.

TABLE 1: SUMMARY OF PREVIOUS MICRO AND CENTRAL INVERTER COMPARISONS.

	Duration	Size	Sample	Result
Enphase (3)	12 weeks	2 kW	1	+14%
Enphase (3)	12 weeks	4.6 kW	1	+7%
Enphase (3)	1 day	5 kW	1	+3.5%
Briggs (4)	Varied	Varied	143	+16%

3. METHODOLOGY

3.1 The Photovoltaic system

Power output from two nominally identical four panel arrays were compared; one set of panels was connected to a grid connected SunnyBox 700U central inverter, and the other set connected to two grid connected Enphase D380 microinverters (each D380 is a pair of 190 W single-panel inverters). Sharp NE-170-U1 PV panels were used in both arrays. A summary of system configuration is shown in Table 2.

TABLE 2: SYSTEM CONFIGURATIONS.

	Central	Micro
Inverter	SMA SunnyBoy 700U	2 @ Enphase D380
Panels	4 @ Sharp NE-170	4 @ Sharp NE-170
Inv. Setting	200 V _{DC}	-
Voltage	120 Vac	208 Vac single phase

The panels were mounted in portrait orientation in a checkerboard pattern on the same pole mount facing south with a tilt of 36°. The eight panel's power output had a measured standard deviation of $\pm 2\%$. The system was installed at the Appalachian State University Solar Research Lab in Boone, NC (36° latitude) and data was collected during fall 2011.

For around half of the time, shade was introduced to both arrays by placing 1" $\times$ 2" wooden strips across one panel in each array, as shown in Figure 1. The resulting shade represented 3.2% of the total array area.



Fig. 1: A photo of the two arrays showing the shading.

3.2 Instrumentation

AC electrical current was measured with two Magnelab SCT-0400-005 transducers using an oversampling technique at 2,000 Hz. This technique will tend to underreport current during intervals of rapid current fluctuations; however, both systems will experience similar fluctuations. Voltage was taken to be the nominal grid voltage. Since both systems were grid connected at the same service panel, a power comparison will be insensitive to voltage fluctuations.

Total solar irradiance in the plane of aperture (POA) was measured on a 30 sec basis using a Hukseflux LP-02 pyranometer located around 300 m away from the arrays.

Data was collected using a Campbell Scientific CR-800 data logger. One minute averages were calculated and analyzed.

3.3 Data Validation

Data were collected during August, 2011 through October, 2011. A total of 72 days of data were collected, 30 in unshaded conditions and 42 in shaded conditions. Entire days with excessively erratic irradiance were discarded. Data between 3 PM and 9 AM were disregarded. Also, minutes in which the irradiance and power measurements were not consistent in magnitude, for example if irradiance increased but power did not, were discarded. Two representative days with periods of discarded data are shown in Figure 2. Finally, individual minutes with irradiance and power measurements which varied significantly from the previous minute are discarded.

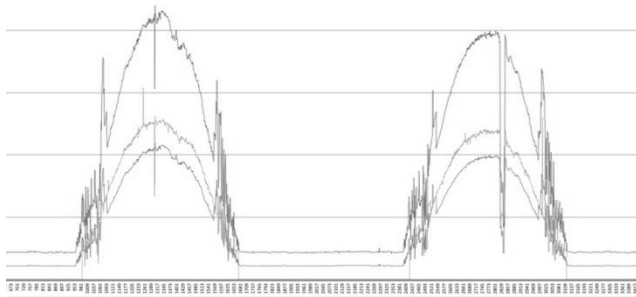


Fig. 2: Two sample days of irradiance and power measurements.

After validation, a total of 6,221 minutes of unshaded data were remaining, and 11,314 minutes of shaded data remained.

3.4 Analysis

Instantaneous power outputs of the central- and micro-inverter systems were binned in total irradiance and compared on a minute-by-minute basis for both shaded and unshaded configurations.

4. RESULTS

A summary of the power comparison binned in irradiance is shown in Figure 3. The histogram at the bottom of the chart shows the amount of data collected in each irradiance bin. The most data, and resulting smallest statistical uncertainty, occur for the highest and lowest total irradiance values.

The upper pair of curves are power outputs from the microinverters, and the lower pair of curves are outputs from the central inverters. The lighter two curves are power outputs from the unshaded configuration, and the darker two curves represent the shaded configuration. For all irradiance values the unshaded configuration outperformed the shaded configuration, as expected. For irradiance values above around 700 W/m² the microinverters clearly outperformed the central inverter; a comparison below around 700 W/m² is statistically inconclusive. More data is needed in the moderate irradiance range.

Tabulated power differences for the unshaded configuration for irradiance between 950 and 1,050 W/m² are shown in Table 3.

TABLE 3: UNSHADED POWER DIFFERENCES.

POA (W/m ²)	Micro Power (Watts)	Central Power (Watts)	Power Diff. (Watts)	% Power Diff.
950	598	495	103	21%
960	607	504	104	21%
970	617	510	107	21%
980	618	510	108	21%
990	625	516	109	21%
1000	630	519	111	21%
1010	638	525	113	21%
1020	644	531	114	21%
1030	651	536	115	21%
1040	652	536	116	22%
1050	657	536	121	23%
Avg	633	521	111	21%

The microinverters consistently outperform the central inverter by over 20% across all irradiance values above 950 W/m². While not shown in this table, over the range of 660 - 1,200 W/m² the average power difference between the micro and central inverters is over 20%.

Tabulated power differences for the shaded configuration for irradiance between 950 and 1,050 W/m² are shown in Table 4.

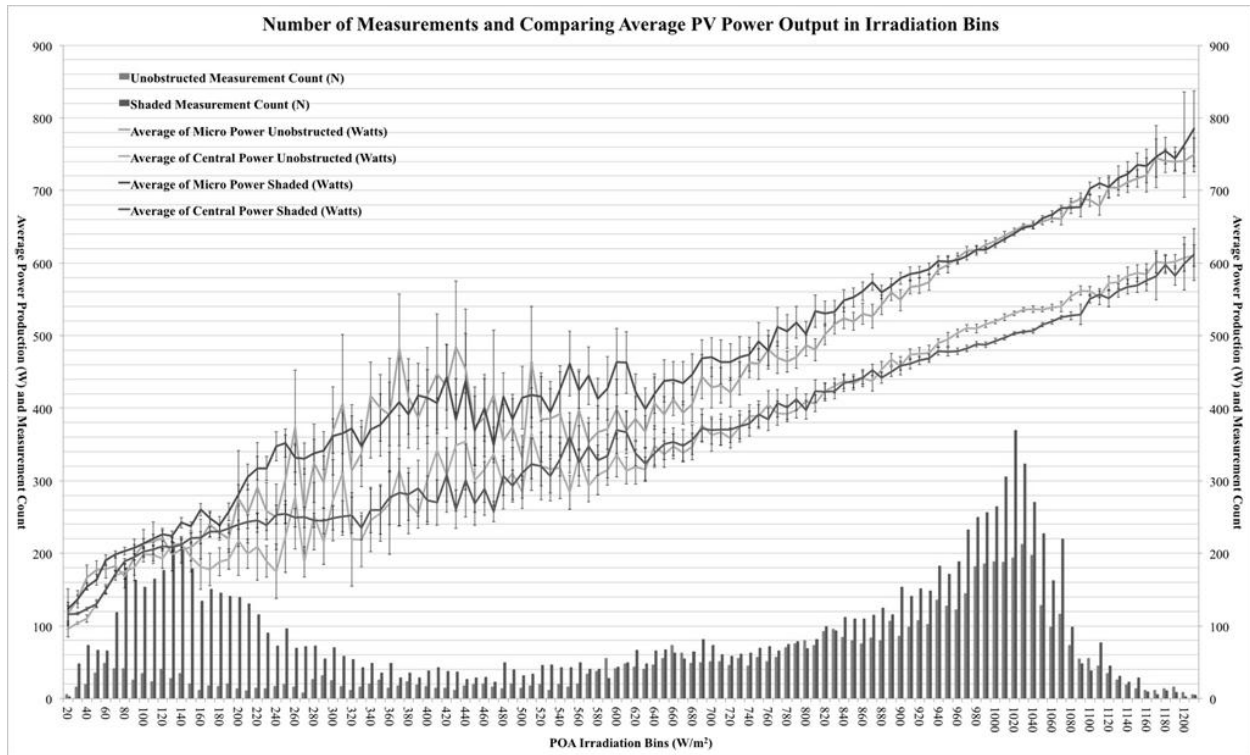


Fig. 3: Summary of measured power difference between the micro and central inverters.

TABLE 4: SHADED POWER DIFFERENCES.

POA (W/m ²)	Micro Power (Watts)	Central Power (Watts)	Power Diff. (Watts)	% Power Diff.
950	602	478	124	26%
960	604	479	125	26%
970	609	482	127	26%
980	618	488	130	27%
990	618	487	131	27%
1000	626	493	133	27%
1010	633	497	136	27%
1020	641	503	138	27%
1030	649	505	143	28%
1040	651	506	145	28%
1050	661	515	146	28%
Avg	631	495	135	27%

In the shaded configuration the microinverters consistently outperformed the central inverter by 27% for irradiance values above 950 W/m². While not shown in this table, over the range of 660 - 1,200 W/m² the average power difference

between the micro and central inverters is over 26%. It is worth noting that the microinverter power output is virtually unaffected by shading.

5. SUMMARY AND CONCLUSIONS

This study found that one particular microinverter (the enPhase D380) outperformed one particular central inverter (SunnyBoy 700U) during the fall 2011 at a site in Boone, NC. In unshaded conditions the microinverter provided on average 20% more power output than the central inverter. Under partial shading conditions (shading of 3.2% of the total array area) the microinverter outperformed the central inverter by 20%. Additionally, microinverter output was virtually unaffected by small amounts of array shading.

While this one study represents a single snapshot of performance comparison, the results are consistent with previous studies. What seems clear is that microinverters outperform central inverters, the magnitude of this enhancement

This data set contains measurements of direct and diffuse beam radiation. A comparison of system power output as a function of direct beam fraction is planned.

6. REFERENCES

- (1) Sherwood, L. (2011). *U.S. Solar Market Trends*. International Renewable Energy Council
- (2) IMS Research. (2011, September 13). Microinverters & power optimizers grow 500% in 2010, but still a long way to mainstream. Retrieved November 8, 2011, from *IMS Research Press Releases*: http://imsresearch.com/press-release/Microinverters_Power_Optimizers_Grow_500_in_2010_But_Still_a_Long_Way_to_Mainstream
- (3) Enphase Energy. (2009). *Enphase energy value proposition: A comparison of microinverter and traditional inverter technologies*. Petaluma
- (4) Briggs, D. & Baldassari, M. (2011). *Performance of Enphase microinverter system v. PVWatts estimates*. Petaluma: Enphase Energy
- (5) IEEE. (2010, February 17). *Performance analysis of photovoltaic installations in a Solar America City abstract*. Retrieved October 3, 2011, from IEEE Xplore: http://ieeexplorer.ieee.org/xpl/freeabs_all.jsp?arnumber=5411283