Determining the Effect of Temperature on Microinverter Inversion Efficiency

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***Abstract* — Sandia National Laboratories is working to develop a set of test procedures and characterization models which may be used to describe the performance of AC modules and serve as a basis of product comparison. However, in measuring the module/microinverter system output, it is difficult to determine the effects of correlated parameters on system performance. In particular, we have found that the module temperature and the inverter temperature are highly correlated when the system is operating, and thus it is difficult to separate their effects on system power output. In 2014, we have conducted temperature testing on microinverters and we will show that the effect of temperature on microinverter performance is sufficiently small to justify omitting it from the final characterization model for AC modules.**

***Index Terms* — inverters, photovoltaic systems, power electronics, solar energy**

I. INTRODUCTION

As photovoltaic (PV) modules with integrated inverters or microinverters enter the marketplace, consumers and system installers will need a reliable system performance metric upon which to compare these “AC modules”. Sandia National Laboratories is working to develop a set of test procedures and a characterization model which may be used to describe the performance of AC modules and serve as a basis of product comparison [1].

Initial stages of characterization involved measuring the performance of several module/microinverter systems with a series of tests designed to isolate input factors and determine the effect of a single input factor on system performance. Of course, a performance factor of particular interest is the module and microinverter temperature. However, the procedure used by Sandia to force a range of module temperatures also caused a range of correlated microinverter temperatures. Due to the correlation of microinverter temperature and PV module temperature, it is difficult to definitively establish the magnitude of each component’s temperature on the performance of the system.

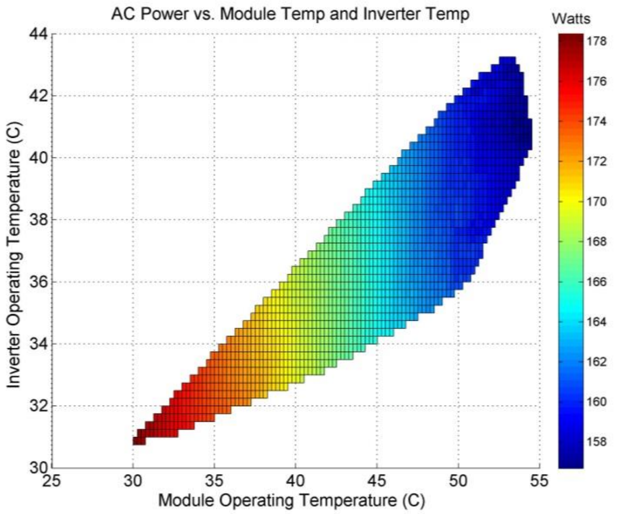

Fig. 1. Irradiance-corrected AC power as a function of module and microinverter temperature.

As shown in Fig. 1 the temperature of the microinverter generally increases with the temperature of the PV module. Fig. 1 also shows that the temperature of the PV module appears to be the dominant factor in determining the irradiance-corrected power output of the AC module system. If the effect of module temperature on system output is much larger than the effect of microinverter temperature on system output, it may be possible to omit or generalize the microinverter temperature in the AC module performance characterization model under development at Sandia.

In an effort to better understand the importance of the microinverter temperature on the performance of the entire AC module system, Sandia is conducting a series of tests to better quantify the effect of temperature on a microinverter’s inversion efficiency. This paper presents early results from such a test and allows us to draw conclusions about the need (or lack thereof) to explicitly include microinverter temperature within a performance model for AC modules.

II. SETUP AND PROCEDURES

Sandia recently conducted two thermal tests on a popular commercial microinverter to monitor the inversion efficiency of the microinverter under a range of temperatures. It is already known that the DC power and input voltage are important factors affecting the inversion efficiency of inverters [2]. It is therefore imperative to maintain a relatively constant input power and voltage while varying the temperature of the microinverter. Therefore, during the tests, the DC power and DC voltage were held approximately constant, with variations of approximately ±0.5%, while a temperature chamber varied the ambient air temperature around the microinverter. A detailed description of the power, voltage, and temperature levels for each test is provided in Table I. The DC input power of approximately 200 W is around 90% of the rated input power for the microinverter.

TABLE I
DESCRIPTION OF TESTS

	Test A	Test B
Nominal DC Voltage (V)	29.7	30.1
DC Voltage Variation (V)	± 0.15	± 0.15
Nominal DC Power (W)	199.5	201
DC Power Variation (W)	± 1	± 1
Initial Ambient Temperature (C)	18.9	19.5
Final Ambient Temperature (C)	49.7	37
Number of Temperature Steps	7	1

One thermocouple was adhered to the center of each of the two primary microinverter faces using Kapton® tape. Two ambient thermocouples were mounted in free air approximately 13 cm from the faces of the microinverter in order to monitor the conditions surrounding the microinverter.

Test A was conducted to obtain data at a range of temperatures. However, the temperature steps were of a fairly short duration of approximately 30-40 minutes each, and the microinverter temperature did not stabilize during any of the temperature steps. Test B was conducted with a single temperature step of longer duration which allowed the microinverter temperature to stabilize. Figs. 2 and 3 show the temperature changes over time during Test A and Test B, respectively.

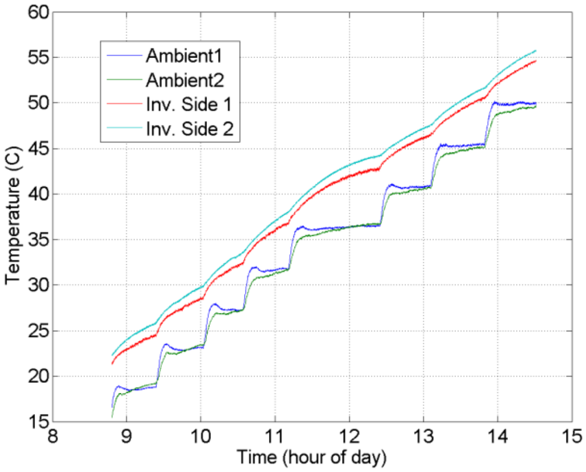

Fig. 2. Ambient and inverter surface temperatures from Test A

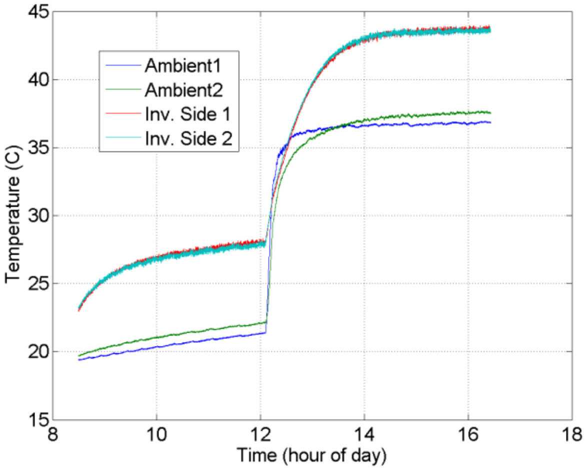

Fig. 3. Ambient and inverter surface temperatures from Test B

A custom data acquisition system measured the input voltage, input current, output power, temperatures, power factor, etc. at a 1 Hz frequency for later analysis.

III. RESULTS

The focus of the testing was to determine the effect of microinverter temperature on inversion efficiency. When the measured inversion efficiency is plotted as a function of microinverter surface temperature, it is possible to determine an approximate rate of efficiency change with temperature. Fig. 4 shows a scatter plot of inversion efficiency as a function of microinverter surface temperature during Test A and the data is fit with a least squares linear regression.

As noted before, Test A did not allow the microinverter to come to a stable operating temperature at each temperature step. Test B, while only using a single temperature step, allowed the microinverter to reach a stable operating temperature. If the efficiency data from the last 30 minutes of each step in Test B are plotted as a function of microinverter temperature as in Fig. 5, a higher temperature coefficient is obtained.

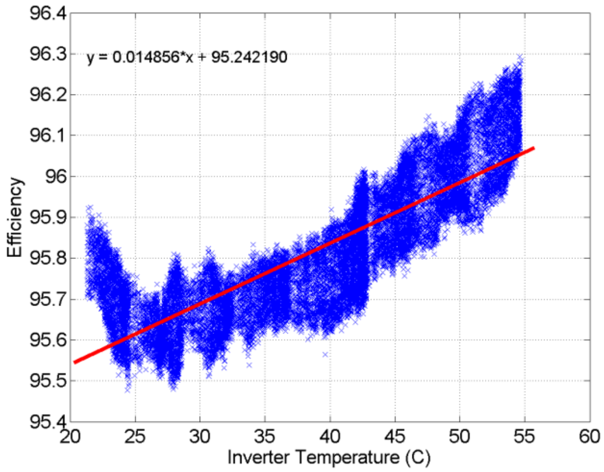

Fig. 4. Microinverter efficiency as a function of temperature during Test A

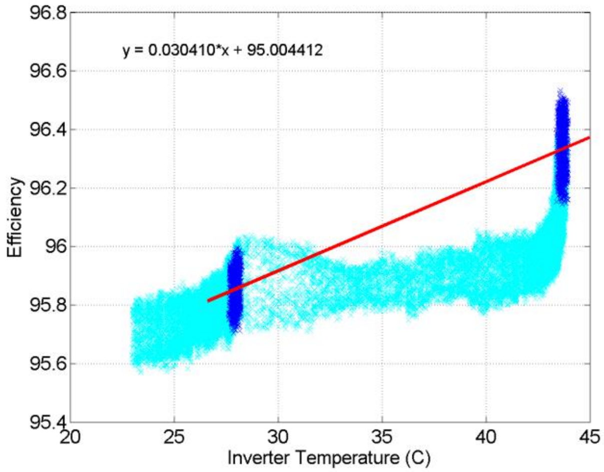

Fig. 5. Microinverter efficiency as a function of temperature during Test B. Stable temperature period highlighted and fit.

From the data gathered, we estimate an approximate absolute inversion efficiency change of about +0.01 %/°C to +0.03 %/°C for this microinverter.

The microinverter efficiency may change as a function of DC power and DC voltage. While we limited the variation of these quantities during the test, we must also investigate whether any variations may have caused efficiency changes. Figs. 6 and 7 present efficiency plotted as a function of the DC power and DC voltage input to the microinverter for Test A. From these figures, the efficiency does not appear to be strongly influenced by the small power or voltage fluctuations which occurred during testing.

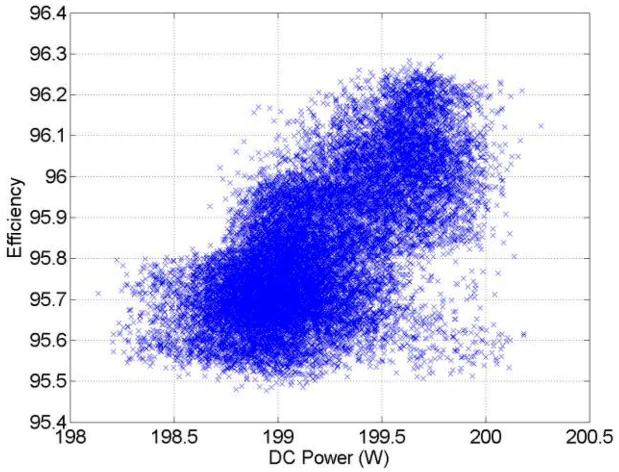

Fig. 6. Microinverter efficiency change with DC power, Test A

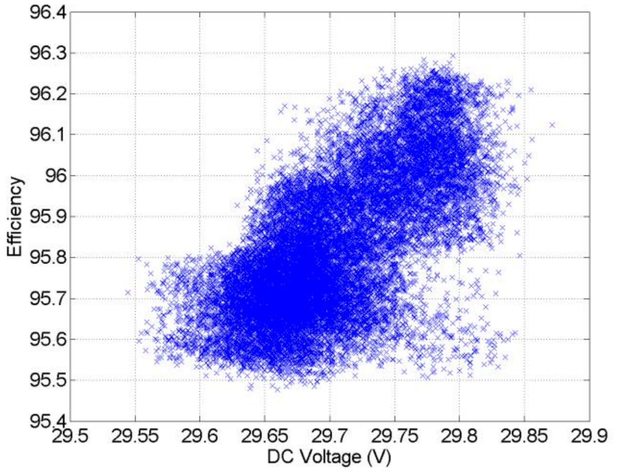

Fig. 7. Microinverter efficiency change with DC voltage, Test A

From these temperature coefficients it is possible to analytically show that the effect of microinverter temperature on the light conversion efficiency of an AC Module system is much smaller than the effect of module temperature.

The overall PV module/microinverter system efficiency for converting light to AC power (η_{sys}) is a function of the PV module's efficiency in converting light to DC (η_{pv}) and the microinverter's efficiency in converting DC to AC power (η_{inv}) as in (1).

$$\eta_{sys} = \eta_{pv} \times \eta_{inv} \qquad (1)$$

If we assume that the temperature of the microinverter does not change the efficiency of the PV module, then we know that the system efficiency change as a function of microinverter temperature (T_{inv}) can be described as in (2). While the most general equation for the effect of PV module temperature (T_{pv}) on system efficiency is shown in (3), we can simplify (3) to (4) if we assume that the temperature of the PV module does not change the DC to AC conversion efficiency of the microinverter. Of course, we understand that the PV module temperature will change the microinverter efficiency as the module changes voltage and power; however, we believe that the effect is sufficiently small as to be ignored in analysis which seeks to determine order of magnitude differences.

$$\frac{\partial \eta_{sys}}{\partial T_{inv}} = \eta_{pv} \times \frac{\partial \eta_{inv}}{\partial T_{inv}} \qquad (2)$$

$$\frac{\partial \eta_{sys}}{\partial T_{pv}} = \eta_{inv} \times \frac{\partial \eta_{pv}}{\partial T_{pv}} + \eta_{pv} \times \frac{\partial \eta_{inv}}{\partial T_{pv}} \qquad (3)$$

$$\frac{\partial \eta_{sys}}{\partial T_{pv}} \approx \eta_{inv} \times \frac{\partial \eta_{pv}}{\partial T_{pv}} \qquad (4)$$

If (2) and (4) are evaluated with typical values of $\eta_{pv} = 0.2$, $\eta_{inv} = 0.95$, $\frac{\partial \eta_{inv}}{\partial T_{inv}} = 0.0002$ (1/C), and $\frac{\partial \eta_{pv}}{\partial T_{pv}} = -0.004$ (1/C), then $\frac{\partial \eta_{sys}}{\partial T_{inv}}$ is on the order of 4E-5 (1/C), while $\frac{\partial \eta_{sys}}{\partial T_{pv}}$ is on the order of -4E-3 (1/C). Therefore, the effect of PV temperature on the module/microinverter system is approximately two orders of magnitude larger than the effect of microinverter temperature on the system.

These data also present an interesting look at the time lag between the microinverter surface temperature and the ambient temperature. Fig. 2 shows that after an ambient temperature change of 4-5 °C, the microinverter has not reached a constant operating temperature after 30-40 minutes. Fig. 3 shows that after an ambient temperature change of approximately 15 °C, the microinverter reaches a constant operating temperature after about 1.5 hours.

Furthermore, we can also determine a "worst case" temperature difference between the ambient air temperature and the microinverter surface temperature. During the portions of Test B where the microinverter surface temperatures had stabilized, the difference between the ambient temperature and the surface was approximately 16 °C. We believe that this is truly a "worst case" estimate of the temperature difference because the conditions inside the thermal chamber allow for only natural convection to occur. When AC modules are placed outside, there is the potential for forced convection due to wind. However, we note that this temperature difference will change with the amount of input power the microinverter is processing, so this temperature difference is limited to this inverter at the tested power level.

III. CONCLUSIONS AND FUTURE WORK

Sandia National Laboratories has recently tested a popular commercial microinverter under a range of temperature conditions to determine the change of inversion efficiency as a function of temperature. Our findings indicate that the inversion efficiency may change at approximately a rate of +0.01 %/°C to +0.03 %/°C. These efficiency temperature coefficients indicate that the effect of inverter temperature on the efficiency of the AC module system is approximately two orders of magnitude smaller than the effect of module temperature on the efficiency of the system. Since the effect of microinverter temperature on the system efficiency is much smaller than the effect of module temperature, we believe that it is possible to generate an accurate AC module performance model with either a very basic model to account for the temperature of the microinverter, or complete omission of the microinverter temperature from the model.

The results presented here are preliminary and only represent the results from testing product from a single microinverter manufacturer. Additional microinverters will be measured under similar conditions to determine if the effects are typical of the microinverter market as a whole or specific to individual manufacturers. We plan to measure products from at least a second manufacturer and possibly a third manufacturer.

Furthermore, inversion efficiency may not be the only factor which is influenced by the microinverter temperature. The power limiting or "clipping" power level may also be affected as the temperature of the microinverter changes. This effect will almost certainly be of interest as we develop a model for AC modules, since many AC modules are sized with DC/AC ratios in excess of 1 and power limiting could occur frequently.

ACKNOWLEDGEMENT

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REFERENCES

[1] D. Riley, J. Stein, and J. Kratochvil, "Testing and Characterization of PV Modules with Integrated Microinverters," in *39th IEEE Photovoltaic Specialist Conference, 2013*

[2] D. King, S. Gonzalez, G. Galbraith, and W. Boyson, "Performance Model for Grid-Connected Photovoltaic Inverters" SAND2007-5036