DATA COLLECTION AND MODELING OF PHOTOVOLTAIC ARRAYS

TYLER OTTO
PHYSICS DEPARTMENT SAN DIEGO STATE UNIVERSITY

1. Purpose of research

Much research is taking place in the area of photovoltaics. The current rating system rates the panels at $1000W/m^2$ solar radiation, and a cell temperature of 25°C, two conditions rarely, if ever, met. The output of solar cells changes substantially as conditions change. There is research is taking place to try to quantify how these solar cells behave under different conditions. Many of these studies use single panels that are not actually being used to generate electricity. When solar panels are used to generate power, many panels are wired in series and in parallel in order to obtain the proper output voltage. To maximize power output, the power inverters also adjust the output such that the power is maximized. An array of panels operating at maximum power point may be affected by changing conditions differently than a single panel, or a single cell, and is more appropriate to how panels are being operated by users.

2. Goals of Research

I hope for this research to add to the book of knowledge of silicon based solar cells. Specifically I would like to be able to characterize the way different photovoltaic arrays perform under varying external conditions (weather). Specifically I would like to model the power output of *grid connected* silicon arrays. To this end, the array temperature and total solar radiation incident on the panels will be measured.

3. Rooftop Components

To obtain the required metrics, several different measurement devices are required

- 3 Multicrystal Arrays
- 1 Single Crystal Array
- 1 Amorphous Array
- Dedicated Weather Station
- Pyranometer (measure solar radiation)
- Individual Power Inverter for each array
- 2 Data Loggers

4. Power Models

The first model that was investigated was a model that assumed the power output from the panels was perfectly linear with respect to the solar radiation. Motivation for this can be seen in the figure below (Fig. 1).

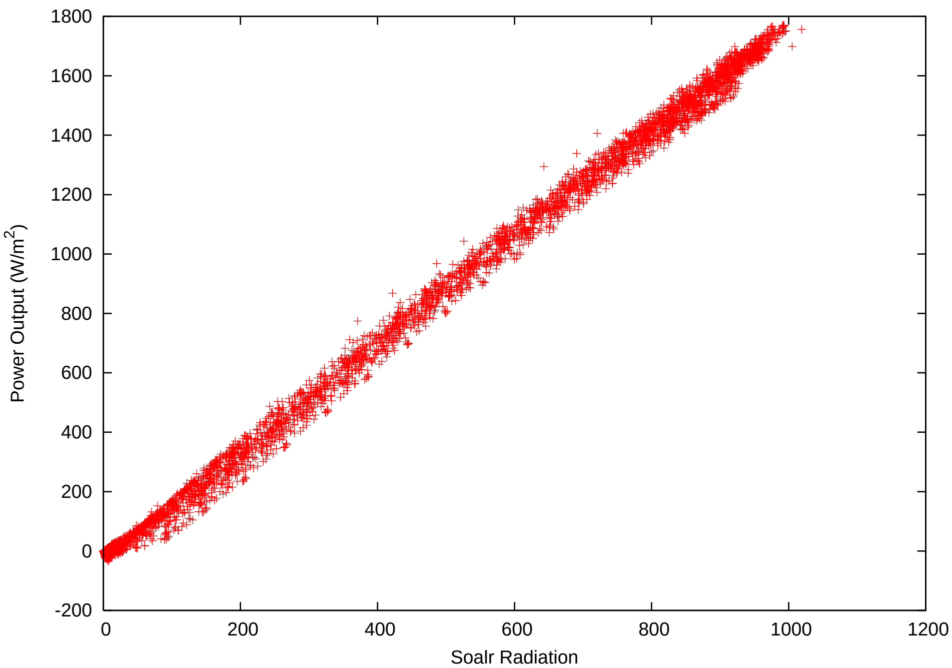

Figure 1. Power vs. Radiation

Using the assumption that the power output is linear, a correction term was then added that will adjust the power output as the temperature of the solar cells changed. Not all types of arrays will respond to this temperature change in the same way, so an unknown constant term was added. This unknown constant term was coined the temperature coefficient.

$$P_{model} = P_0 \frac{R}{R_0}(1 + \alpha(T - T_0)) \tag{1}$$

In this equation P_0 is the array's rated power, R_0 is the rated radiation $(1000W/m^2)$ and T_0 is the rated temperature 25°C, and α is the temperature coefficient.

5. results

In order to determine the temperature coefficients for the different arrays, data was collected to determine the DC power output from the arrays, the cell temperature, and solar radiation. The model was fit to the data by adjusting the temperature coefficient, and minimizing the square of the residual error between the model and the data. This was accomplished using the weighted fit function of gnuplot, using the uncertainty of the power output to weight the data points.

	Temp Coeff Value	Uncert.
$\alpha_{amorphous}$	-0.00208	$3e^{-5}$
$\alpha_{multicrystal125}$	-0.01039	$3e^{-5}$
$\alpha_{multicrystal120}$	-0.00917	$4e^{-5}$
$\alpha_{multicrystalBP}$	-0.00926	$9e^{-5}$
$\alpha_{singlecrystal}$	-0.01037	$8e^{-5}$

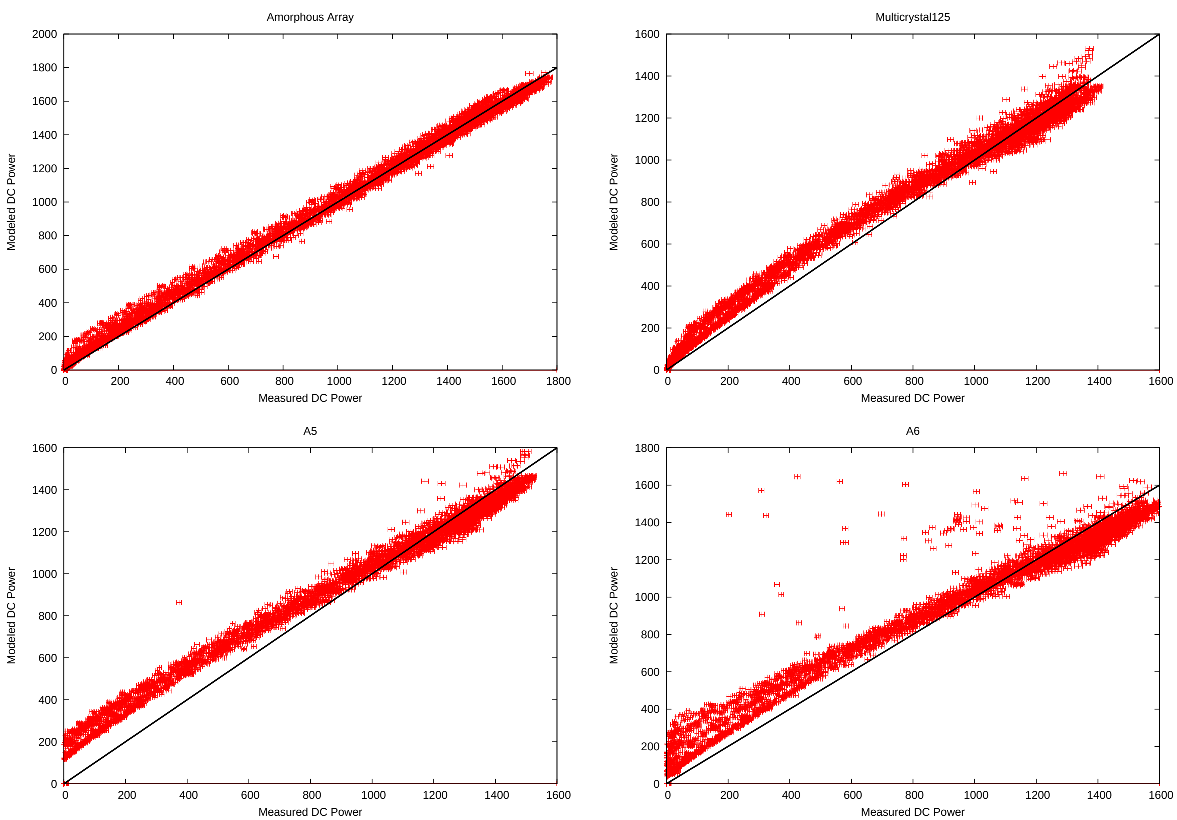

FIGURE 2. Fit Quality for Different Arrays

Looking at the the figures above, one immediately notices that the model works better at high solar radiation than it does at lower radiation. This error arises from the fact that the solar radiation *does not* affect the power output the same at all radiation values. it turns out that there is a non-linear response to radiation at lower solar radiation. It has been shown that the response goes approximately like R^4. Using this information, the model can be improved to include this non-linear response below approximately $200W/m^2$.

$$P_{model} = \begin{cases} P_0 \left[\frac{R}{R_0} \left[1 + \alpha'(T - T_0)\right] - k \left(1 - \left(1 - \frac{R}{200}\right)^4\right)\right] & \text{if } R \leq 200W/m^2 \\ P_0 \left(\frac{R}{R_0} \left[1 + \alpha'(T - T_0)\right] - k \frac{R_0 - R}{R_0 - 200}\right) & \text{if } R > 200W/m^2 \end{cases} \quad (2)$$

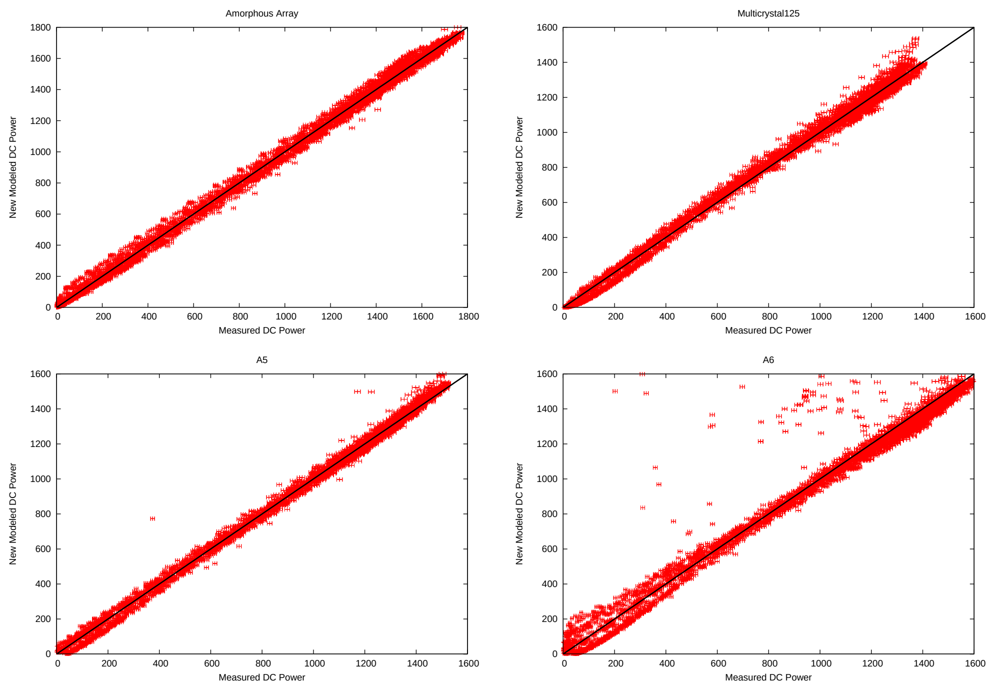

Figure 3. Improved Model

Where there is a new temperature coefficient and now there is a new coefficient that measures the non-linear response of power due to low radiation. The reason a new temperature coefficient is required has to do with how the model is being fit. Because I have used a least squares program, the program simply tries to get the best match between data and model. If there is a new model, with a new parameter to vary, less emphasis has to be placed on a single one. In the same fashion as before, the data can be fit to determine the temperature and radiation coefficient, see Fig. 3 and table 1 It can be immediately noticed that the overestimation at low solar radiation has disappeared. The new model better fits the data.

6. Discussion on Coefficients

A quick discussion on what the temperature and radiation coefficient mean. The temperature coefficient represents the *fractional* change in power output for a 1°C in cell

TABLE 1. Improved Model Coefficients

	α'		k	
Amorphous	-0.00162	$\pm 2e^{-5}$	0.0280	$\pm 3e^{-4}$
Multicrystal125	-0.00969	$\pm 1.5e^{-5}$	0.0537	$\pm 3e^{-4}$
Multicrystal120	-0.00820	$\pm 1.7e^{-5}$	0.0606	$\pm 3e^{-4}$
MulticrystalBP	-0.00748	$\pm 3e^{-5}$	0.0980	$\pm 4e^{-4}$
Single Crystal	-0.00912	$\pm 5e^{-5}$	0.0738	$\pm 7e^{-4}$

temperature. When the cell temperature is frequently in the 50°C range, there is a 25°C increase from the rated value. Looking at the values for α' we can see that this corresponds to as much as a 25% decrease in power output for the worse case. The shining star of the group is the amorphous array showing a decrease in power of around 4% due to temperature. The radiation coefficient is a little more difficult to visualize. Basically what k tells is that there is a decreased efficiency of the panel at low radiation, specifically k is the decreased efficiency at $200W/m^2$, k=$\Delta\eta\frac{200}{1000}$, where $\Delta\eta$ is the *relative* change in efficiency at $200W/m^2$. For example, the amorphous array has a k=0.0280, this implies that the efficiency is 14% lower than rated at $200W/m^2$.