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Tech Talk Presents

Using a Solar Concentrator with Photovoltaic Cells

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About Mantaro

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Using a Solar Concentrator with Photovoltaic Cells

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Abstract
A solar concentrator was built using photovoltaic cells and mirrors in a linear Fresnel reflecting pattern. Various data was taken to determine if there is an advantage to building a concentration system versus purchasing additional photovoltaic cells to harvest more energy. The results illustrate that there is a power output gain to be realized from concentrating solar energy and that thermal issues are a limiting factor that must be deal with.

Introduction
The cost of photovoltaic cells remains a significant hurdle in the deployment of home scale systems to generate electricity. Since the output of the photovoltaic cell increases with the intensity of the light it is exposed to, it should be possible to increase the power output of such a cell through light concentration. If this is true and the cost of the concentration mechanism is less expensive than the cost of purchasing additional photovoltaic cells, then such a system would have a cost advantage. The purpose of this document is to presenting the results of a series of tests that were made to determine the performance of a standard off the shelf photovoltaic (PV) cells in a concentrated light application.

To test the performance of PV cells under concentrated light conditions we built a single axis tracking solar concentrator fixture (shown in Figure 1). The concentrator was built on the principle of Fresnel reflector where mirrors were used to focus sunlight on a PV cell. The sun tracking system that was developed for this system insured that maximum light was focused on the PV cell by the concentrator. For these tests we purchased two commercially available “3 Watt” PV cells model number SPE 350-6 from SOLARWORLD® and mounted them onto the test fixture. This document describes the test procedures, results and findings of these tests.

Equipment Used
Solar Concentrator Assembly - The solar concentrator assembly consists of a Linear Fresnel reflector that tracks the sun in one axis. Two PV cells of size 4.5” by 8.5” were mounted at the focus of the Fresnel reflector such that light from the mirrors covers the full face of the cell. The cells were rated by the manufacturer for a nominal output voltage of 9V, a current output of 350 mA, and a total power output of 3 Watts.

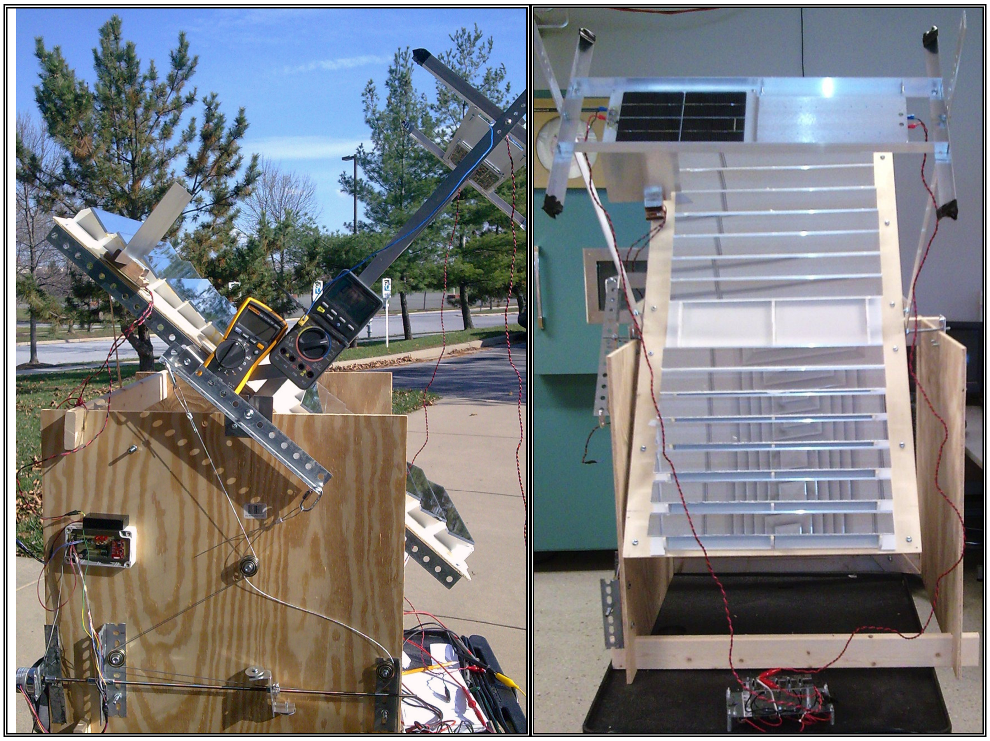
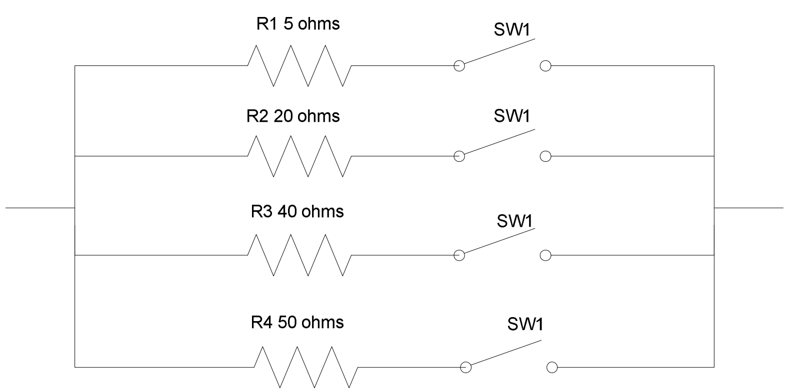


Figure 1 - Solar Concentrator Assembly

The left photo shows the Fresnel reflector assembly and the tracking fixture focused at the sun. The right photo shows the Fresnel reflector assembly with the photovoltaic cells mounted at the focus.

Resistor Bank – The maximum power output of a photovoltaic cell occurs when the load resistance is matched to the operating point of the photovoltaic cell. This operating point varies with light intensity. The resistor bank allows us to determine the maximum power point of the photovoltaic cell under various light conditions by varying the load and measuring the output power. A schematic of the resistor bank is shown here. Various combinations of switch positions on the resistor bank provide the following load resistance: 50, 40, 20, 10.5, 5, 4, 3.6 and 3.4.



Test Equipment - The measurements were made with two multimeters so that both current and voltage could be measured simultaneously. We also used a multimeter equipped with a thermocouple to measure the temperature of the PV cell.

Test Setup

- The solar concentrator assembly was taken outside on October 21, 2009 and November 3, 2009 during a sunny part of the day. It was aligned to the sun and the tracking system was turned on so that concentrator was collecting maximum light.
- To check the performance of the solar cells one of the solar cells was turned to face the Fresnel reflector and the other was placed so that it faces the sun. This allowed us to profile the cell against each other so that a comparative study could be done to check the advantage of using solar cell with concentration versus a solar cell under normal sun. Additionally, as both solar cells were at the focus of the Fresnel reflector they were heated to similar temperatures. This assured that performance difference due to temperature was minimized.
- The industry standard for measuring the output power of the solar cell is to measure the open circuit voltage and short circuit current and multiply the two values to arrive at photovoltaic cells rated power. However, this approach does not provide a measure of the useable output power of a photovoltaic cell. To measure the useable output power we used the switchable resistive load discussed above and measured the maximum power point under varying light conditions.

Power Test

First test was to compare the output of the photovoltaic cell facing the Fresnel reflector with an identical cell facing directly at the sun. Figure 2 shows the results of three tests performed under similar ambient conditions. For each set of readings, voltage and current measurements were taken for different resistance values as quickly as possible for cells facing the sun and mirrors. After each test, the cells were allowed to cool and the readings were taken again.

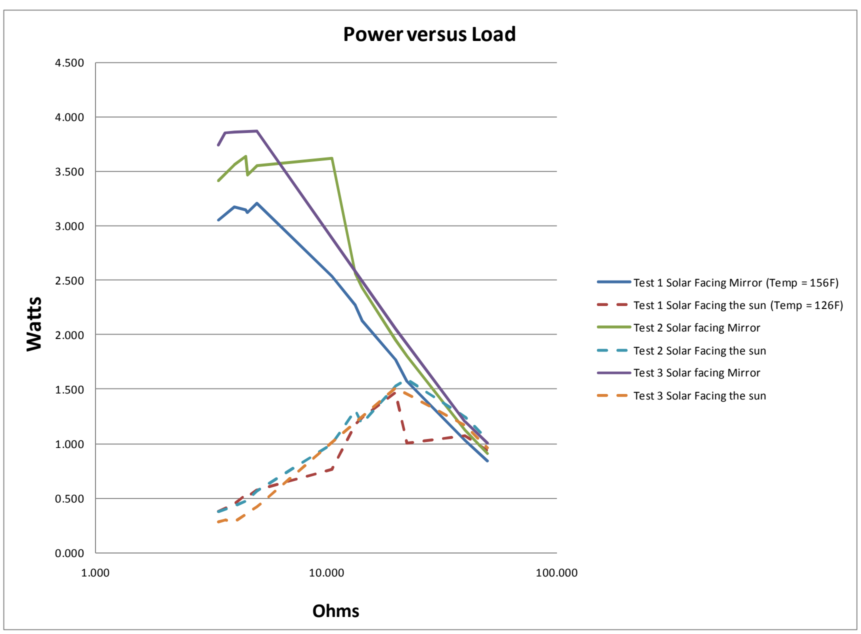


Figure 2 - Power vs. Load

The result of this test show that the power output from the photovoltaic cell facing the Fresnel has at least twice the power output compared to the cell facing the sun directly. However, the amount of light being concentrated on the PV cell is nearly 6 times that directed at the cell facing the sun directly. So we would expect to be measuring closer to 9 Watts if the power output was directly proportional to the additional light.

Temperature Test

This test measured the effects of temperature on the photovoltaic cells. For this test the Fresnel mirror assembly was covered such that photovoltaic cells were shielded from direct sun light and heat. The assembly was then aligned to face the sun and tracking was turned on. Once the tracking was complete the covers were removed from the mirrors and measurements were taken as the temperature increased at the photovoltaic cells. For this test all measurements were made with a single fixed resistance of 3.63 ohms as this value gave the peak performance under similar light conditions in the previous test shown in Figure 2.

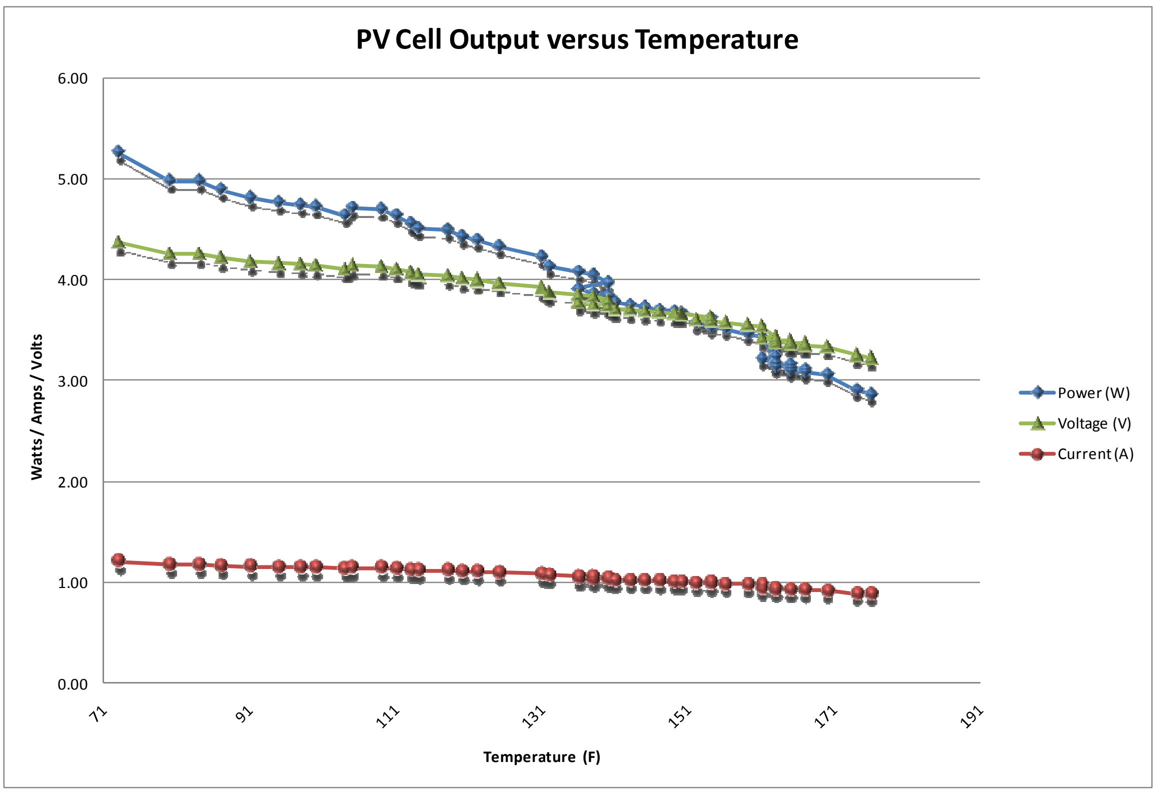


Figure 3 - PV Cell Output vs. Temperature

From the graph above it is clear that the output power reduces as the temperature increases. In this test we observed a 46% reduction in photovoltaic cell power output as the temperature increased a little over 100 degrees Fahrenheit.

Photovoltaic Cell Output with Concentration

The next test measured the output of the photovoltaic cell as the concentration of solar energy was increased using the Fresnel reflector. At the start of the test, all of the mirrors on the Fresnel reflector were covered with white paper. Then mirrors were uncovered in pairs, one from each side of the assembly, and the power output of the photovoltaic cell facing the mirror was measured for different resistance values.

Figure 4 - Solar Tracking Assembly with Mirrors Covered

The graph below shows the output power of the photovoltaic cell for mirrors 2 through 14 in 2 mirror steps. Note, the power output when all mirrors were covered was due to reflection from the white paper and ambient light.

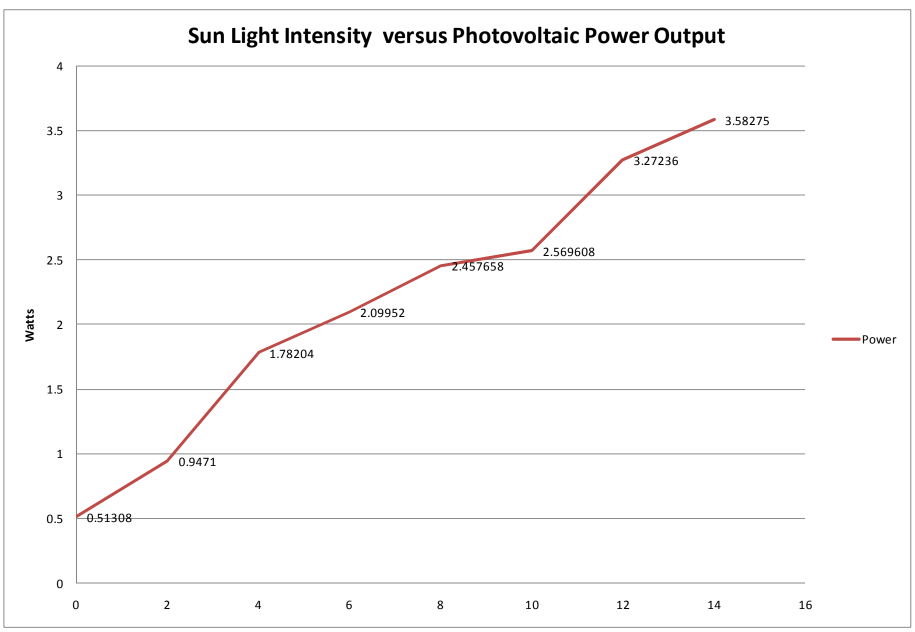


Figure 5 - Sun Light Intensity vs. Photovoltaic Power Output

Each of the points in the graph above was determined by varying the load resistance on the photovoltaic cell until the peak power point was located. The following graphs show the results data from each mirror pair. Figure 6 shows the V-I curve for mirror sets 2 through 14.

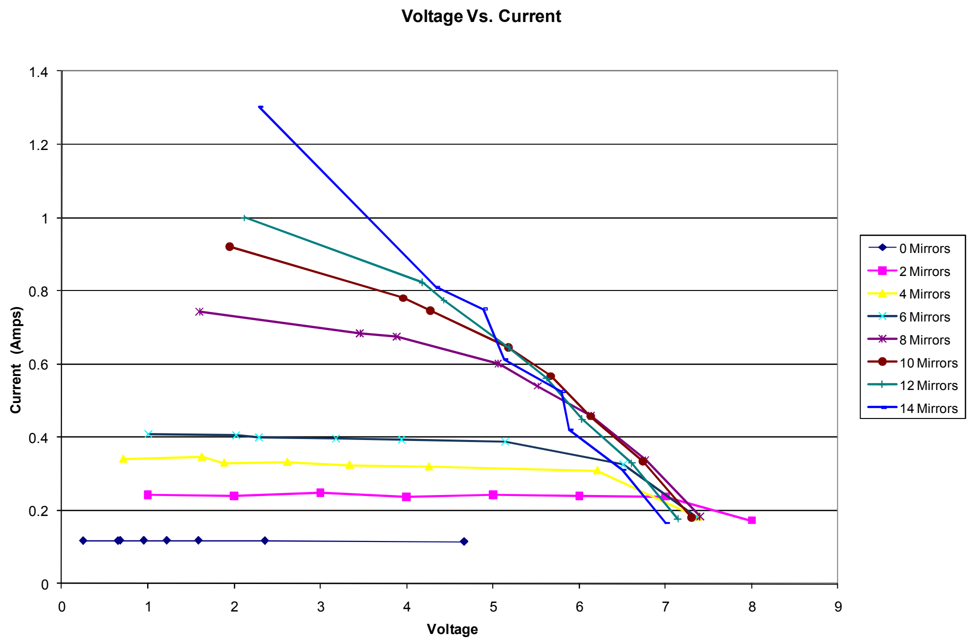


Figure 6 - V/I vs. Mirrors

Figure 7 shows the power output of the photovoltaic cell for each mirror pair. The peak power was determined by varying the resistive load and measuring current and voltage. The figure below shows that as the intensity of light falling on the solar cell changes, the peak power point changes. It is evident from the data that with increasing light intensity the resistance at which the power peaks decreases indicating that the internal resistance of solar cell decreases with increase in irradiance.

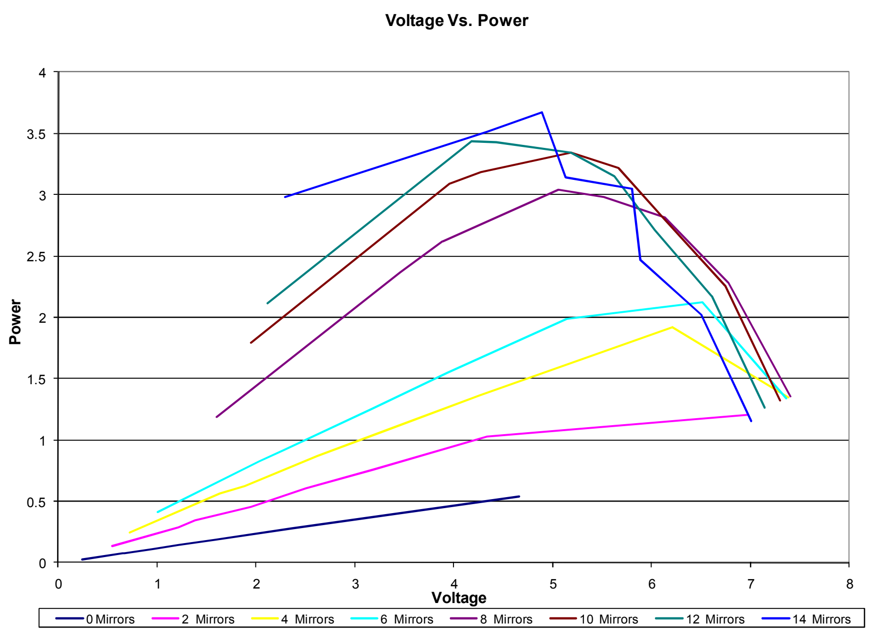


Figure 7 - Power/Voltage Vs Mirrors (Reading 2)

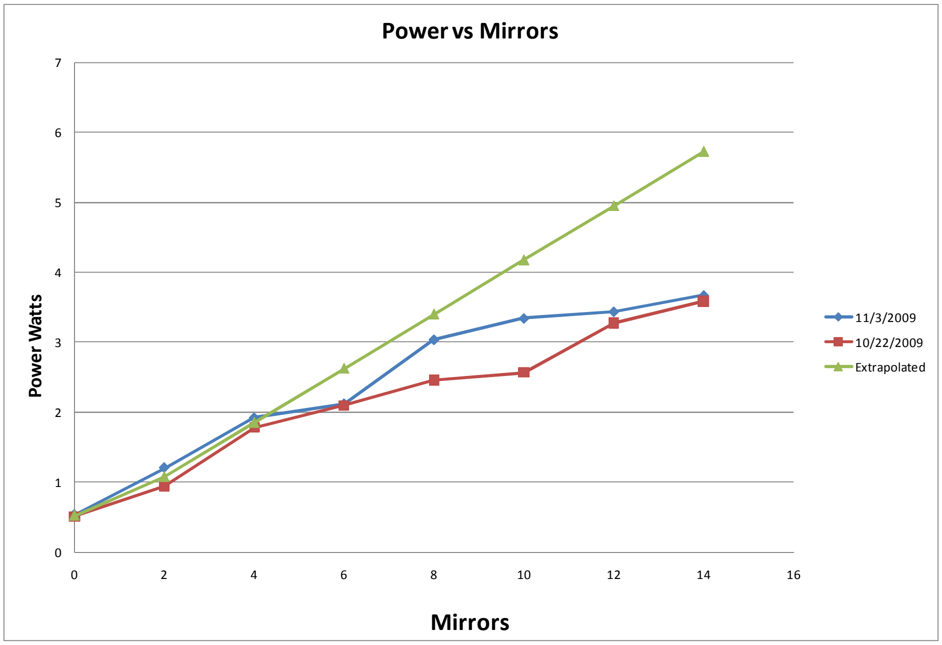


Figure 8 - Power versus Mirrors

Figure 8 shows that the actual output power diverges from what was expected when the data from the first two mirror pairs were linearly extrapolated and compared with data from a full mirror set.

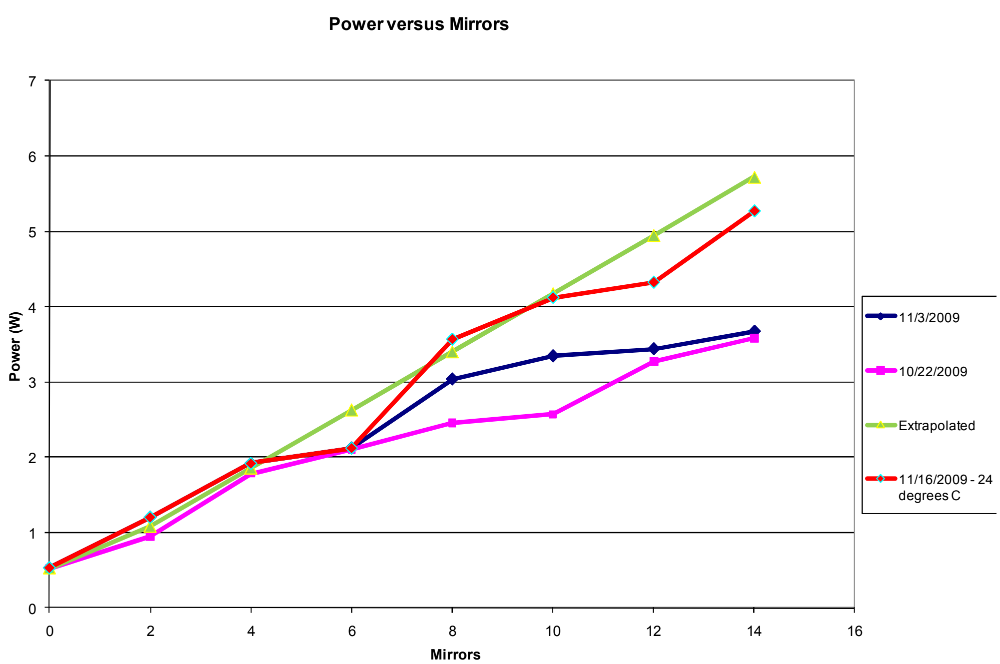


Figure 9 - Impact of Temperature

Figure 9 shows an additional data set that was taken on 16th November where care was taken to keep the PV cell at 75.2F (24C). This shows that the divergence from the expected power output is due to increase in the temperature of the PV cell caused by heating under high levels of concentration.

Sources of Error:

The potential sources of error in the measurements reported here include:

- Human error while taking the readings
- Variation in ambient temperature
- Variations in wind conditions
- Varying sky conditions

However, we believe the overall results are informative and accurate enough to draw some meaningful conclusions.

Conclusions:

- After the experiment, a general profile of how the photovoltaic cells work under actual load conditions was established. The useable power output of the system highly depends on matching the load to the output of the cell. It is also noted that the measured output is much lower than would be expected from the manufacturer's specification. For example the manufacturer's rating for the cells used here are 3 Watt whereas the actual output was measured at 1.5 Watts in non concentrated applications.
- We did confirm our expectation that the power output of solar cell receiving concentrated light from the Fresnel mirrors was higher than the cell facing sun. At peak output the concentrated cell was producing about 2 to 3 times the power of the cell facing the sun. However this was much lower output than would be expected if the output was directly proportional to the amount of light focused on the cell.
- One of the most important findings is that heat being generated by the concentrated light reduces the peak output of the cell. Minimizing the temperature rise of the PV cell would allow for nearly doubling the output power as the data in Figures 3 and 9 indicate.

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