Limiting Effects of Temperature on the Performance of a Si-PV Array in Trinidad and Tobago

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Problem / Question

To what degree is the efficiency of a PV cell affected by the cell temperature in Trinidad and Tobago?

Hypothesis

- The cell temperatures of PV Modules will be higher than NOCT
- At some Temperature value there will be a decrease in Power output hence efficiency, this value will be above NOCT

Project Overview

Project done by Trinidad & Tobago's Electricity Commission to investigate Grid tie capabilities. Site consists of 10 220 W units installed at 11 º South An anemometer was also installed connected to the web box so that wind data can also be recorded.

Randomly selected days from a four month data set courtesy T&TEC solar panel grid integrated system at their Mount Hope building. Time showed a 24hour segment where readings were taken at 5minute intervals but actual panel data was only recorded (at what was assumed to be 6am because of the strange make up of the data it is subjected to some interpretation) between 6am and 6:30pm. The values for current and voltage recorded from the T&TEC panel were based on the values entering the Inverter, not necessarily taken at the MPP, and definitely not at open circuit voltage or short circuit current. The actual size of the array and the reference values of; efficiency, Isc, and Voc was not known. The type of panel and actual size of the panel was not known. The purpose of proceeding with the calculations was to develop a proper method for use when pertinent data is obtained.

Variables / Research

Controlled variables

- The Array used was located at the Trinidad and Tobago Electricity Commission Building Mt. Hope Trinidad

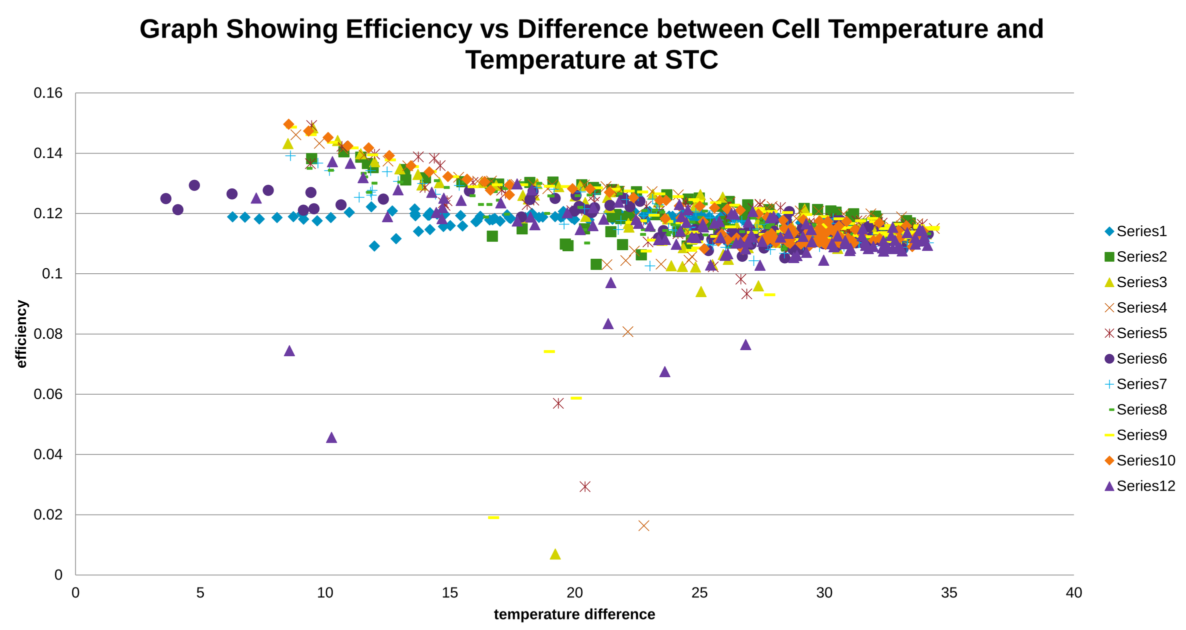
Independent variable

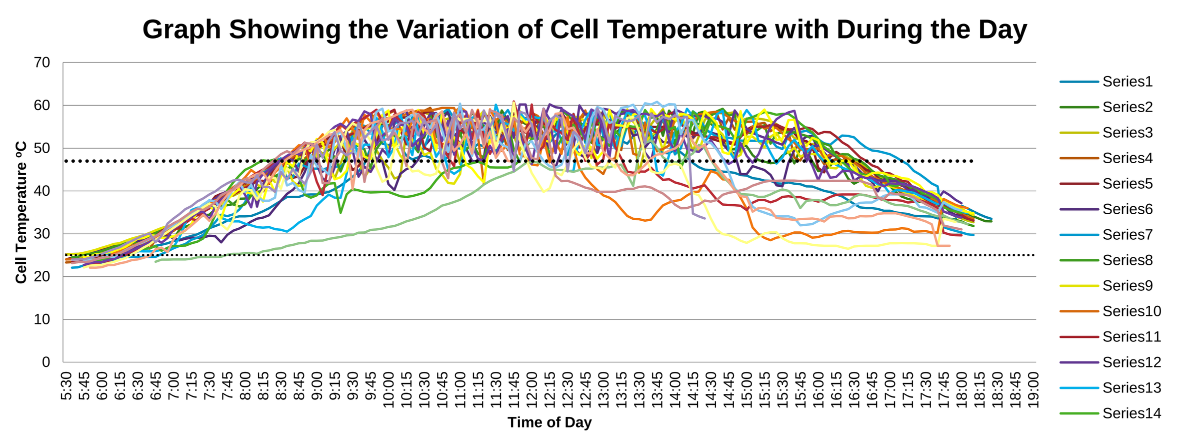
- The Irradiance values observed were grouped in 100 W/m² ranges when measured. It was assumed that the ±99 W/m² irradiance difference between the values would not significantly affect findings.
- Cloudy day was indicated by fluctuating irradiances
- Clear day by a rise and fall pattern of little fluctuation.

Dependent variable

- The Power increased with the Irradiance values
- The variation of Temperature was recorded

General Observations



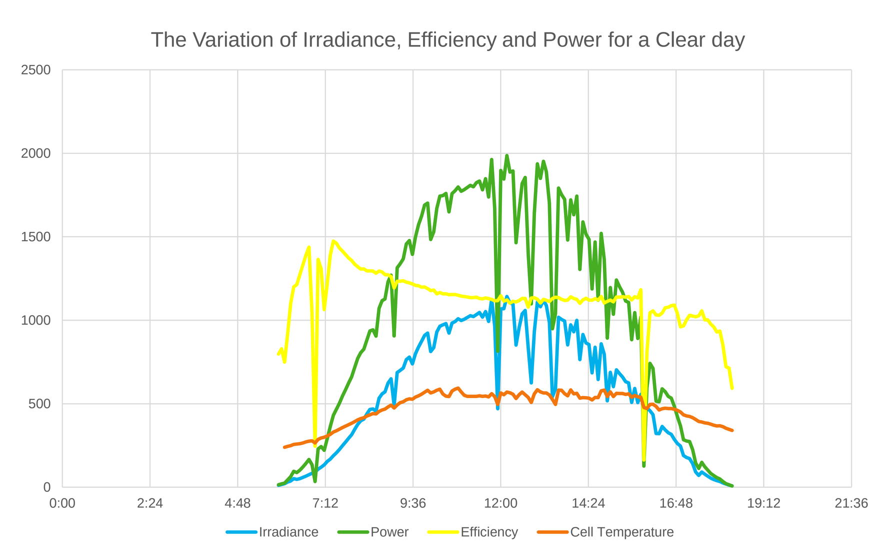


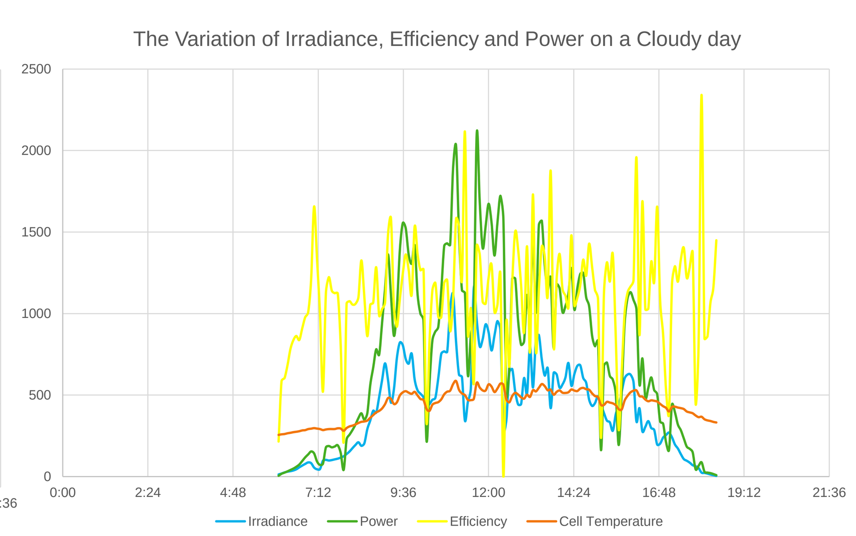
These graphs show the efficiencies and temperatures of several randomly chosen days over a 4 month period in 2012.

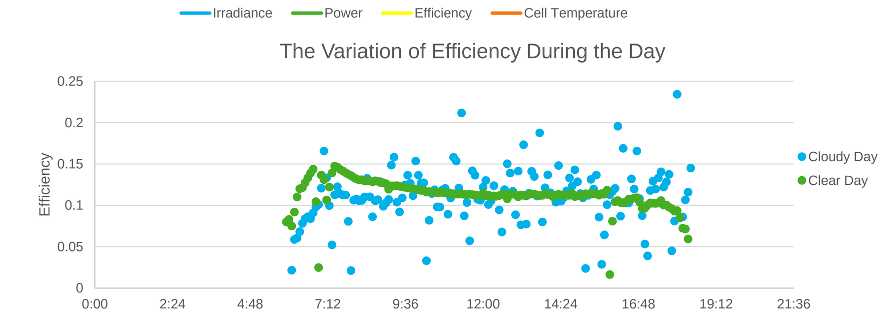
The top shows the variation of efficiency for each day (given in a different color)

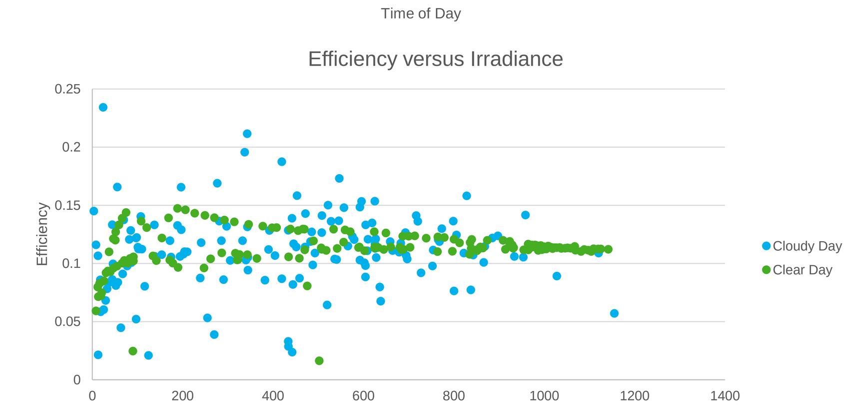
The bottom shows the variation of Cell Temperature taken from the back surface of a module. There are two indicator lines the lower showing STC temperature 25 ºC, the higher line at 47 ºC the typical NOCT temperature.

Cloudy vs Clear Days





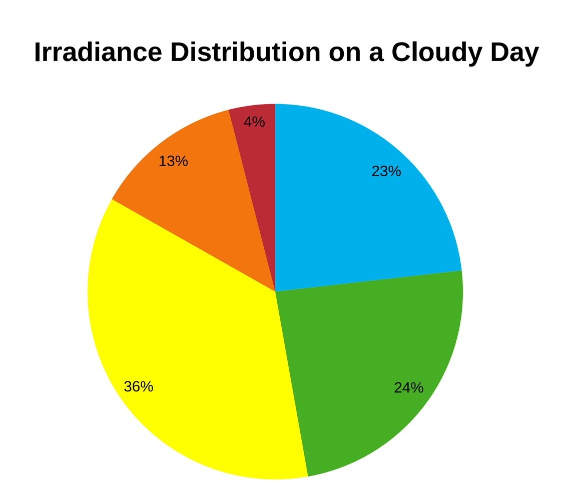


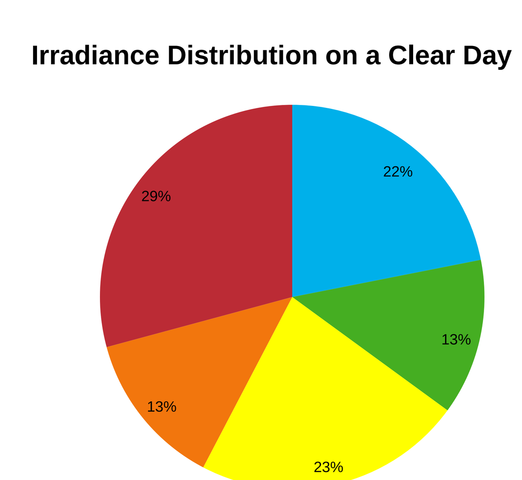


Trinidad and Tobago's Climate has two seasonal variations, due to the movement of the ITCZ. As a result there are two typical days observed clear and cloudy days. These graphs show randomly chosen clear and cloudy day and compare the variation of Irradiance, Cell Temperature and Efficiency on both days.

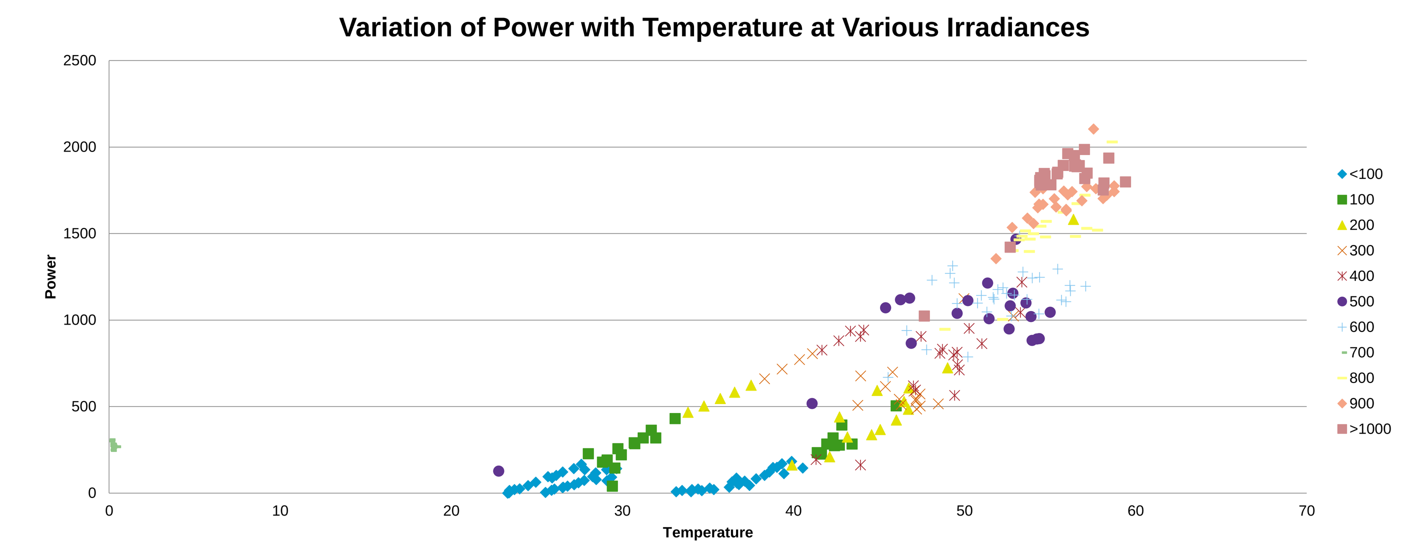
The last graph shows the variation of efficiency with Irradiance.

The pie charts below show the distribution of 5 Irradiance ranges within those two days.
Blue- less than 100 W/m²
Green- 100-300 W/m²
Yellow- 300-600 W/m²
Orange- 600-900 W/m²
Red- Over 1000 W/m²





Results



The graph above shows the variation of power with temperature for various irradiance levels. It shows linear increase of power with Irradiance and consequently cell temperature. However for Irradiances above 500 W/m² as the temperature increases the power decreases slightly.

Analysis & Conclusion

The greatest design advantage of the photovoltaic (PV) solar cell, is that the greater the intensity of the solar radiation incident on its surface, the greater the amount of current that can be generated. However, the solar radiation can only be absorbed within a particular range of wavelengths dependent on the material from which the PV cell is made. The remaining spectral wavelengths is absorbed as heat, which means the greater the intensity of the solar radiation, the greater the temperature of the cell which lowers the conversion efficiency of the cell which limits the current flowing through the cell. PV cells are manufactured to specific performance parameters set at Standard Test Conditions (STC irradiance of 1000 W/m² 25 ˚C cell temperature and air mass of 1.5), which do not naturally occur in the real world environment (especially not at near equator latitudes). Electrical characteristics of photovoltaic cells have temperature coefficients which are evaluated indoors for manufacturers, but outdoor field tests are a useful technique of testing coefficients. These can further be used in outdoor performance modeling to show the long term performance of the PV cell. For a poly-crystalline solar cell the temperature coefficient is approximately 0.45%/K. Makrides et al. 2010 showed maximum module temperatures of 54 ºC. In this study the temperature coefficients reached as high as 0.5%/K for poly-crystalline PV modules. For crystalline silicon cells (the main type of PV cells currently manufactured and the type of PV used in this study) approximately 50% of the incoming solar radiation is absorbed as heat (Chow 2010), setting a maximum possible efficiency of 40%. These factors can cause the cell temperature to be higher than ambient, through absorptance of the solar radiation especially since day-night variation in ambient temperature is fairly significant in Trinidad approximately 10ºC.

The array parameters of cell temperature, module current and voltage, as well as the inverters' output current and voltage were recorded and showed cell temperatures up to 59 ºC on clear sky days. The standard convention was that, (Sklopaki,2009)NOCT- nominal operating cell temperatures were estimated using a standard 45ºC $\pm$2ºC, which would estimate the actual cell temperatures under real world conditions, but they were found to overestimate temperatures for open rack mounted PV's (in temperate countries).

There was a clear 'heat up' and 'cool down' period that showed an inverse relationship with conversion efficiency.

During clear days, the voltage achieved a maximum value with irradiance between 300-600 W/m² and cell temperatures below 45 ºC, which was only for approximately 20% of the day (6am to 6pm). Between 200-400 W/m² the decrease in voltage with increased cell temperature is not as pronounced as with higher or lower irradiance values. For approximately 25% of the day the irradiance was over 900 W/m² with cell temperatures above 53ºC. This could be the reason the performance of a PV module is lower in Trinidad as average Irradiance is 500 W/m².

However it was found that during cloudy days the irradiance was under 300 W/m² for 20-44% of the day, but maximum voltage was achieved during moments of clear skies where the irradiance was over 600 W/m² and cell temperatures were below 50 ºC, which occurred for less than 11% of the day.

Efficiency values started the day slightly higher on a clear day but the cloudy day saw efficiency spikes where the clear day had a steady decrease. Other studies have shown that at low irradiance there is generally a decrease in efficiency in the PV panel (Biicher, 1997; Paretta et al., 1998; Schumann, 2009; Suzuki et al. 2002; Zinsser et al., 2009). The time of the day that showed the highest efficiency on clear days was less than 200 W/m2. On the cloudy day efficiency values showed some unexplained abnormalities, spiking way above theoretical values. The temperature effect can be seen in these graphs as the same irradiance values give a lower efficiency with higher cell temperatures.

The Irradiance distribution charts just show the percentage exposure the array received and can show the operating efficiency expected on similar days.

This shows that two patterns are generally expected with Trinidad's Climate and whereas the average Irradiance falls within expected range of 500 W/m2 the slight increase in temperature within a particular Irradiance value does affect the power and the efficiency of the PV array.

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