Arizona State University
School of Electrical, Computer and Energy Engineering
EEE 465 591: Photovoltaic Energy Conversion
Mini Project #3: PV Modules

Overview of how this mini project fits into the goal of PV system design

The goal of the series of Mini Projects is to build a model to allow us to calculate and optimize a PV system. In the first project, you developed a program to calculate the solar insolation on a tilted surface. In project 2, you developed a program to calculate the efficiency of a solar cell.

In project 3, we will calculate the power output of a PV module. There are several features that make the output power of a module different that than of a solar cell. Two among the most significant are the temperature of the PV module and mismatched solar cells in the module.

In project 4, we will use all the programs to calculate the performance of a stand-alone PV system, and in the final project you will design either a stand-alone or grid-connected PV system.

Mini Project 3

The goal of Mini Project 3 is to calculate the power output of a PV module. We divide the assignment into two parts:

Part 1: Calculate the ideal power output of a module

Part 2: Calculate the power output of a module that is subjected to partial shading.

Part 1: Ideal power output of a module.

1. Calculate the power output of an ideal PV module under AM.15G conditions. *Hint: Compare your value with the "nameplate" power output listed for a commercial module you find on the web.*

   Use the voltage, current density and FF you calculated for Mini Project #2.

   a. The area of a typical solar cell is 15.6 x 15.6 cm. Calculate the current of one of the solar cells.
   b. Assuming that all the solar cells are exactly matched, calculate the power output of the module at AM1.5G conditions for 72 cells in series.

   Output: Print the power output of a 72-cell module under AM 1.5 conditions.

2. Calculate the energy from a PV module over the course of a year.

   **** Units alert *****

   For energy, we use units of kWh (simply the kilowatts multiplied by the number of hours that the solar cell or load is operating). This is not an SI unit, but it is how electricity companies charge and calculate.

   a. Find Jsc from the array for every hour of the year.

   Jsc is linearly related to light intensity. So, to find the Jsc at a light intensity other than AM1.5G, you simply scale by the ratio of the light intensity compared to that at AM.15G (which is 1000 W/m^2), or:

$$J_{SC} = J_{sc\ at\ AM1.5}\frac{Solar\ power\ density}{Power\ density\ at\ AM1.5G} = J_{sc\ at\ AM1.5}\frac{Solar\ power\ density}{1000\ W/m^2}$$

We have the light intensity for every hour from TMY data in Mini Project 1. The average light intensity during each time period is given by:

$$Solar\ Power\ density = TMY\ Hourly\ Energy\ Data\ \left(\frac{Wh}{m^2}\right)\left(\frac{1}{Time\ interval\ (h)}\right)$$

Since out time interval for TMY data is 1 hour, the equation for JSC becomes:

$$\boxed{I_{SC} = I_{sc\ at\ AM1.5}\frac{TMY\ hourly\ data}{1000}}$$

For example, if the energy generated in an hour interval is 600 Wh/m², then the J_{SC} from the cells is 0.6 times the value at AM1.5G.

For every hour of the year, calculate the current density from the PV module. We won't include the tilt of the module here (we do that in Mini Project 4 so don't erase these code components!!). Thus, in this project you just ignore the impact of the tilt of the module and use the energy density from the TMY data.

Output: Plot the current density output from the module and in the graph title give the total J_L in mA/cm² for the whole year.

b. Calculate V_{OC}, FF and efficiency exactly as in Mini project 2. The J_0 does not change with light intensity, so for each hour of the year, find Voc from J_0 and Jsc (same as project 2):

$$V_{OC} = \frac{kT}{q}\ln\left(\frac{J_{SC}}{J_0}\right)$$

From Voc, also find FF (same as Mini Project 2). Now, find the energy for each one-hour interval over a year and add them up to find the kWh/m² and kWh generated from your module.

Output: Plot the power density output from the module and in the graph title give the total energy density generated over the course of a year in kWh/m². Print the total energy received from the sun and the total energy generated from the module over the course of a year in kWh. Print the efficiency of the module by dividing the two values.

Part 2: Impact of Mismatch on a PV module.

1. To prepare for Part 2, find the IV curve of a grouping of 8 non-shaded solar cells and one shaded solar cell. All of the nine cells in total are identical except for the shading. Assume a breakdown voltage of 5V. Use the same J_0 as from Mini Project 2. As an input to the program, use the fraction of shading of the one solar cell.

   Output: Plot the IV curve for the combination of cells and overlay the IV curve of the unshaded and the IV curve of the shaded cell. In a separate plot, show the IV curve as well as the power curve, indicating the location of the maximum power point.

2. Find the IV curve of the same grouping above but add a by-pass diode. Use a turn-on voltage of 0.5V for the by-pass diode (or you may look up the V_F and J_0 of a by-pass diode from a spec sheet, it's called the forward voltage and reverse leakage current respectively. An example is given in the following link http://www.ti.com/lit/ds/symlink/sm74611.pdf).

Output: Plot the IV curve for the combination of cells and overlay the IV curve of the unshaded and the IV curve of the shaded cell. In a separate plot, show the IV curve as well as the power curve, indicating the location of the maximum power point. Print the total energy generated from the module over the course of a year in kWh.

3. Assume that the one cell in the group is shaded by 50% during the morning hours of 8-11 am every day of the year. Find the new the kWh/m² and kWh generated from your module in each hour interval and then over the course of a year.

   Output: Print the total energy generated from the module over the course of a year in kWh.

4. Compare the energy lost due the reduced light intensity to the energy lost due to shading of the series-connected cells in a module.

   Output: Print the total energy generated from the module with reduced light intensity and print the ratio between this value and the kWh obtained in Part 2.3.