ENVIRONMENTAL AND MECHANICAL ENGINEERING LABORATORY
Solar Energy Systems – Week 3
Effect of Temperature on PV Panel Performance

General description
Solar energy systems are a viable option to produce zero-emissions, environmentally sustainable energy. There are two main kinds of generators that produce electricity and heat from solar energy: photovoltaic (PV) and solar thermal. PV panels are composed of many semiconductor wafers, convert solar energy directly to electricity without moving parts and are modular/scalable. In this laboratory experiment we will study several aspects of PV performance that inform the design and implementation of solar PV power plants to ensure that the maximum amount of energy is produced.

During your third laboratory section (Week 3) you will investigate the effect of PV cell temperature on the electrical conversion efficiency of the panel. The electrical performance of the panel is modeled using two parameters, the voltage-temperature coefficient [V/°C] and the current-temperature coefficient [mA/°C]. These coefficients model the reduction of the open circuit voltage and closed circuit current at the maximum power point in a linear function of temperature.

Objectives
1. Obtain baseline electrical performance data for a heated, steady state PV panel.
2. Measure the reduction in panel power output and efficiency as a function of the back panel temperature.
3. Investigate the effect of cooling on the current and voltage at the maximum power point, and measure the voltage and current-temperature coefficients for the panel.

Procedures (Read all procedures carefully before beginning the experiment)
1. The general procedure for operation and measurement with the MP-170 is the same as during Weeks 1 and 2. Refer to earlier lab handouts for instructions on how to use the MP-170 PV performance testing device.

2. Place the 10 W Unisolar PV panel on a flat surface in the sun and set up the MP-170 for measurement. Take one measurement of the I-V curve to ensure that everything is set up correctly.

3. Fill a plastic bag with enough ice to cover the entire surface are of the panel and seal the bag tightly. Cover the entire surface of the PV panel with the bag of ice and allow the panel to cool for approximately 10-15 minutes.

4. Remove the bag of ice from the panel and begin taking measurements with the MP-170. Take a measurement as frequently as possible until the panel reaches a steady state temperature. The goal of this procedure is to measure the I-V curve of the panel at several different panel temperatures. NOTE: There will be some delay between measurements to prevent overheating of the MP-170 device.

5. After the panel has reached a steady state temperature, repeat steps 3 and 4 once so that you have two complete sets of measurements. Wait 5-10 minutes between these two tests.

Error analysis

1. Calculate any systematic errors in the measurements you take.
2. Determine random errors from repeated samples.
3. Plot all data with appropriate error bars.

Questions

1. Generate two scatter plots of electrical conversion efficiency (η) and power output at the maximum power point (P_{MPP}) as a function of panel temperature, using all of your measurements from both tests. Fit a curve through the data using a linear least squares method. Color-code or otherwise label the dots on the scatter plot with GHI [W m^{-2}]. What does the trend in the GHI for each measurement indicate about the relationship between η and GHI?
2. Generate two scatter plots of voltage (V_{MPP}) and current (I_{MPP}) at the maximum power point as a function of panel temperature, using all of your measurements from both tests. Fit a curve through the data using a linear least squares method. Color-code or otherwise label the dots on the scatter plot with GHI [W m^{-2}] for each measurement.
   a. Compute the voltage-temperature coefficient and compare it with the rated value (-0.0027 V/°C).
   b. What trends do you observe between V_{MPP} and GHI, and I_{MPP} and GHI? Provide an explanation of these trends based on the typical shape of the I-V curve.
3. In order to accurately determine the current temperature coefficient you will need to remove the I_{MPP} to GHI dependence from your data. In order to do this you will assume that GHI difference between each test was small (<~50 W m^{-2}) so the I_{MPP} – GHI dependence can be linearized for your set of measurements.
   a. Separate the measurements from each test and compute the average GHI for each set of measurements. Compute the difference between these values ΔGHI.
   b. Generate a scatter plot of I_{MPP} as a function of panel temperature and plot the measurements from each test with different symbols. Using linear regression fit a line though each set of measurements $I_{MPP}(T)$. Using those two functions compute the average I_{MPP} for each set of measurements. Compute the difference between these values ΔI_{MPP}.
   c. Estimate the linearized I_{MPP} to GHI coefficient, defined as $\gamma = \Delta I_{MPP}/\Delta GHI$.
4. Compute the corrected I_{MPP} from $\{I_{MPP}^{n}\}_{corrected} = \{I_{MPP}^{n}\}_{measured} + \gamma(\overline{GHI} - GHI^{n})$, where $\overline{GHI}$ is the average GHI of all measurements from both tests and n is the measurement index.
   a. Compute the current-temperature coefficient from the corrected current data and compare it with the rated value (0.0001 A/°C).
5. Compute the corrected power from $\{P_{MPP}\}_{corrected} = \{I_{MPP}\}_{corrected}\{V_{MPP}\}_{measured}$ and the corrected electrical conversion efficiency from Equation 2 below.
6. Produce a second scatter plot of the corrected electrical conversion efficiency as a function of panel temperature, fit a line through the data and compare it with the graph from step 1. Describe qualitatively the difference between these two graphs and provide

an explanation for this difference in the context of steps 3 and 4?

Definitions

Electrical power (P) is related to current and voltage by

$$P = IV, \quad (1)$$

where I is the current and V is the voltage.

$$\eta = P_{mpp}/(GI_{POA}A), \quad (2)$$

where P_{mpp} is the power at the maximum power point on the I-V curve, GI_{POA} is the incident irradiance in the same plane as the surface of the PV panel and A is the panel surface area.
NOTE: η is automatically calculated during the measurement sequence of the MP-170, but you may want to check the value using Equation 2.