ENVIRONMENTAL AND MECHANICAL ENGINEERING LABORATORY
Solar Energy Systems – Week 1
PV Panel Performance and Tilt

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 first laboratory section (Week 1) you will learn to use the basic functions of the EKO MP-170 Photovoltaic Module & Array Tester, compare the performance of two different PV panels and investigate the effect of panel tilt on panel performance.

Objectives
1. Read and understand the instructions for the EKO MP-170 Photovoltaic Module & Array Tester. Learn how to download data from the MP-170 unit.
2. Compare the power output of two different PV panels for tilt angles $\alpha = 0°$ and $30°$.
3. Investigate the relationship between PV panel tilt angle and power output.

Procedures (Read all procedures carefully before beginning the experiment)
1. Open the MP-170 and remove the cables from the compartment underneath the sensing unit. Take inventory of the cables to make sure they are all there. If any cables are missing please inform a course instructor immediately.
   □ Power supply (black)
   □ Grounding cable (green with yellow stripe) and clip
   □ 2 PV leads (red and black with alligator clips)
   □ RS-485 cable for sensor unit (white telephone cable)
   □ USB-MiniUSB cable (grey)
   □ 2 thermocouple wires (brown)

2. Locate a sunny spot in the EBU2 quad within reach of a power supply (you will probably need an extension cord). **NOTE:** If it is overcast or partly cloudy you should still do the experiment.

3. Place both panels next to each other on a flat surface next to the MP-170. With *the MP-170 powered off* connect the black and red PV leads to the appropriate wires on one of the panels and connect the other ends to the ports on the MP-170. **WARNING: Do not reverse the polarity of the leads! Use the appropriate standard color coding. Only connect one PV panel at a time.**

4. Connect the thermocouple wires to the ports labeled "Temp 1" and "Temp 2" on the back

of the "Sensor Unit" using the correct polarity. Use conductive tape to attach the thermocouple connected to port "Temp 1" near the center of the back of the PV panel. The thermocouple on "Temp 2" is used to measure the air temperature. Put that thermocouple in the shade near the experiment and ensure that it does not touch any nearby objects. **NOTE:** Check that the switch on the back of the "Sensor Unit" below the RS-485 port is in the "INT" position.

5. Connect the "Sensor Unit" to the MP-170 using the RS-485 cable, and then place the sensor near the PV panel. Remove the level/shadow compass device from the "Sensor Unit" and rest it on surface of the PV panel. Check that the panel is oriented at 0° tilt angle using the level, and memorize the location of the shadows on the compass. Reattach the level/shadow compass device to the sensor unit and align the level and the shadow compass as they were on the PV panel. This procedure ensures that the PV panel and the pyranometer are on the same plane relative to the sun (this is often referred to as "plane of array"). Make sure to ground the MP-170.

6. At this point everything should be connected (except the USB-MiniUSB which is used later to download data) and we are ready to take measurements. Power on the "Sensor Unit" first and then power on the MP-170. **NOTE:** There is a battery inside the "Sensor Unit". Make sure to turn off the power on the "Sensor Unit" when you are finished using it so the battery does not discharge.

7. At the home screen press "CONFIG" > highlight "MEAS PAR" > press "Enter" > highlight "SELECT" > press "Enter". Highlight the measurement protocol from the "PARAMETER LIST" that corresponds to the brand of PV panel you are using (e.g. Unisolar, Sunwize, Kyocera, etc.) > press "Enter" (this step selects the correct measurement protocol and returns to the home screen)

8. At the home screen press "MEASURE". When the measurement is complete use the right and left arrow keys to scroll through the data display. All data are saved after each measurement. To view saved datasets, go to the home screen and press "DATA" > highlight "SEARCH" > press "Enter". A list of all saved datasets is displayed. **NOTE:** It is a good idea to check this list before you begin the experiment in case data is saved from a previous group and/or the data storage is full.

9. **Repeat steps 7-8 for both PV panels at 0° and 30° tilt angle. Make sure to change the measurement parameters before using a different PV panel.**

10. **Repeat step 8 for one PV panel at 10°, 20°, 40°, 50° and 60° so that you have a complete range of measurements between 0° and 60° at intervals of 10° <u>for only one of the panels</u>. Make sure the correct measurement parameters are selected (see step 7).**

11. You will need to download the data that you collected so that you can manipulate and plot it using MATLAB. In order to download the data you will need to access a computer that already has the "MP-170 Control Program" and USB-COM drivers

installed. Connect the MP-170 to the computer using the USB-MiniUSB cable and turn on the MP-170. Open the "MP-170 Control Program" (Start > All Programs > EKO). On the "Measure" tab click "General". Check that the proper COM port is selected and the "Data Folder" and "Converted Data Folder" fields show the correct path for saved data files. Click "OK".

12. On the "Measure" tab click "Load Data". This process loads all data as SQL files (the extension is MDF) and saves them on the computer in the path you selected in the "Data Folder" field. MDF files must be converted using the "MP-170 Control Program". Go to the "Save" tab and confirm that the directory in the field "File Name" is the same as the location of your MDF data files. The MDF files are automatically named with the date, time and measurement number YYYYMMDDHHMMSS###.MDF (e.g. 20110304100000001.MDF is measurement number 1 on March 4, 2011 at 10:00:00). Under the save tab ensure that the "Date" field shows the same date as the filename of the MDF file. Select all data records that you will need for your lab report and click "Convert". This will generate a comma separated value (CSV) file that is readable with MS Excel and MATLAB. Check to ensure that you can read the data and the values are reasonable. Each file should have approximately 440 lines and includes a list of measured properties of the PV panel followed by the data for the PV panel I-V curve. The I-V data are listed in x-y format, i.e. Voltage, Current.

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. On a single graph plot and label the I-V curves for the measurements in Procedure step 9. Are these curves consistent with the rated performance of the PV panel? If not suggest reasons for discrepancies between the measured values and the rated specifications.
2. Plot the short circuit current (I_{sc}) and the open circuit voltage (V_{oc}) as a function of the panel tilt angle (α) using the measurements from Procedure step 10.
3. Plot the voltage (V_{mpp}) and the power output (P_{mpp}) at the maximum power point as a function of the global irradiance in the plane of the panel (GI_{POA}). Plot a star on the value of absolute maximum power output, i.e. plot a star at $max\{P_{mpp}(GI_{POA})\}$. Use a least squares method to fit a line through the data, and provide an explanation for the observed trend.
4. Regarding Question 3: At which angle does the maximum panel power output occur, i.e. $max\{P_{mpp}(\alpha)\}$? What is the geographic / astronomical significance of this angle? Qualitatively describe the location of the maximum power point on the I-V curve.

Definitions
Electrical power (P) is related to current and voltage by
$$P = IV, \tag{1}$$
where I is the current and V is the voltage.

The short circuit current (I_{sc}) is defined as the current that would flow in the closed circuit (i.e. the load on the PV panel has zero resistance). The open circuit voltage (V_{oc}) is defined as the voltage drop across the circuit when no current flows in the circuit (i.e. the load on the PV panel has infinite resistance; see Figure 1).
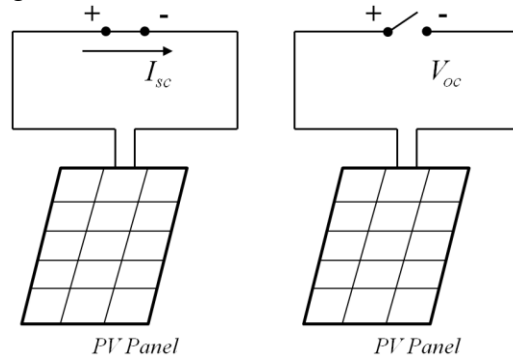

Figure 1 – A schematic circuit diagram illustrating the short circuit current (left) and the open circuit voltage (right).

The conversion efficiency of a PV panel (η) describes the percentage of solar radiation incident on the panel that is converted to electrical energy, and is usually listed for the maximum power point.

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

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.
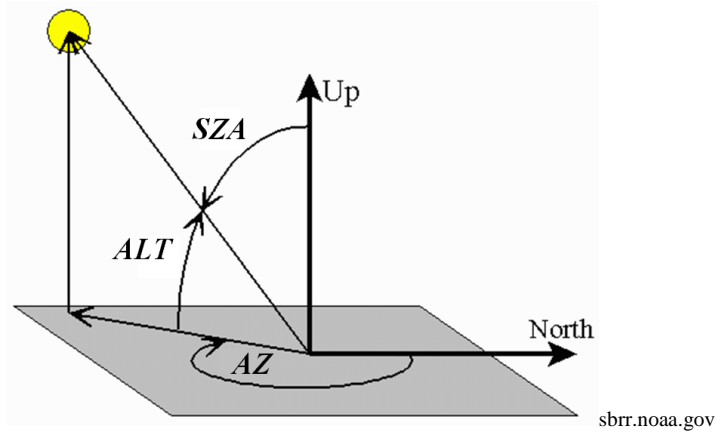

sbrr.noaa.gov

Figure 2 – Diagram illustrating some important angles relevant to solar geometry and PV system design. *AZ* is the azimuth angle (measured clockwise from North), *ALT* is the altitude angle (angle of the sun above the horizon) and *SZA* is the solar zenith angle.