# Stand-Alone PV System Lab

**<u>Experiment 1:</u>** Basics of PV - Simulation

The objective of this first experiment is to simulate the basic characteristics of photovoltaic (PV) cells. We will test the effects of temperature, irradiance, and load resistance on the solar panels, and the resultant change in the I-V characteristics. All tests for this experiment will use the provided Simulink model called “Resistive Load Only.” **You must open Simulink prior to opening the file in order for the file to work properly.**

1. Changing temperature
    a. Set the resistor to 10Ω, and irradiance to 1000 W/$m^2$
    b. Run the simulation several times with varying input temperature (into the PV Array).
        i. Hint: use a range between 0 - 200 °C
    c. Record the Voltage, Current, and Power output, and take note of any trends.

**DELIVERABLE 1:** Document your observations about the effects of both changing temperature.

- What patterns did you notice?
- What do you notice as Temperature increases/decreases?
- Does this make sense, why or why not?
- What temperature provides max power?

2. Changing irradiance
    a. Set the resistor to 10Ω, and temperature to 25 °C
    b. Run the simulation several times with varying input irradiance (into the PV Array).
        i. Hint: use a range between 0 - 1000 W/$m^2$
    c. Record the Voltage, Current, and Power output, and take note of any trends.

**DELIVERABLE 2:** Document your observations about the effects of both changing irradiance.

- What patterns did you notice?

- What do you notice as irradiance increases/decreases?
- Does this make sense, why or why not?
- What irradiance provides max power?

3. Changing resistance
    a. Set the irradiance to 1000 W/$m^2$ and temperature to 25 °C
    b. Run the simulation several times with varying resistance
        i. Start with these values: 1, 2, 3, 4, 5, 7.5, 10, 15, 20, 50, 100, 200
    c. Record the Voltage, Current, and Power output
    d. Plot both Voltage vs. Current and Voltage vs. Power (Voltage on x-axis)
        i. Use plots to estimate the resistance value that draws the maximum power
    e. Based on your value from the last part, run the simulation a couple more times and try to get close to the maximum power point.

**DELIVERABLE 3:** Include both plots created in your report.

- What happened when you changed the load resistance?
- What resistance value did you find that drew the most power from the solar panels?

4. Effect of irradiance and temperature on the maximum power point
    a. Find the MPP for each of the values given in the tables below.
    b. For each step you do not need to plot as many points as part 3 – 5 to 7 for each should suffice.

| Irradiance ($W/m^2$) | Temperature (°C) | Resistance for MPP (Ω) |
|---|---|---|
| 200 | 25 | |
| 400 | 25 | |
| 600 | 25 | |
| 800 | 25 | |
| 1000 | 25 | |

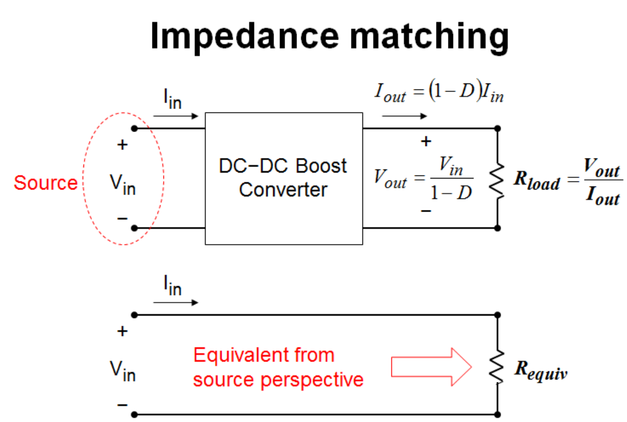
| Irradiance ($W/m^2$) | Temperature (°C) | Resistance for MPP (Ω) |
|---|---|---|
| 1000 | 0 | |
| 1000 | 10 | |
| 1000 | 20 | |
| 1000 | 30 | |
| 1000 | 40 | |

**DELIVERABLE 4:** Include both tables from part 4. You do not need to include each individual graph created to find the MPP for each of the values. Describe any trends you noticed as you filled out the tables.

**Experiment 2:** Solar Panel with MPPT – Simulation

As seen in the first experiment, solar panels are nonlinear devices. The curve obtained in Experiment 1 from varying the load resistance is called the I-V characteristics. As we have already seen, these characteristics vary with changes in temperature and irradiance, each with its corresponding maximum power point. When using solar panels in real life, however, the temperature, irradiance, and load can all be changing – sometimes all at the same time! This makes always drawing the maximum power from a solar panel very difficult, because as the variables around it all change, so does its maximum power point. To remedy this issue, an impedance matching circuit is used to remain at the maximum power point. The device that does this, is called Maximum Power Point Tracking (MPPT). It utilizes a DC conversion circuit, along with a logic circuit to alter the duty ratio continuously. In our case, we will use a Boost Converter. All tests for this experiment will use the provided Simulink model called "MPPT_MANUAL" and the "Duty Cycle" page in the "Simulink SpredSheet".

1. Duty Cycle (D)
    a. You should see a similar model to Experiment 1, except there is an additional circuit in the middle
    b. To begin, make sure that the Irradiance is set to 1000 W/m$^2$ and temperature to 25 °C
    c. Find the MPP to the **nearest tenth.** Hint: This is very similar to your work in part 3 of Experiment 1.
        i. This is your equivalent resistance




$$R_{equiv} = \frac{V_{in}}{I_{in}} = \frac{(1-D)V_{out}}{\frac{I_{out}}{1-D}} = (1-D)^2 \frac{V_{out}}{I_{out}} = (1-D)^2 R_{load}$$

    d. Set the load to 50Ω, and using the formulas provided above, solve for the duty cycle required to reach the maximum power point.
    e. Run the simulation several times, with a varying duty cycle, and record the Voltage, Current, and Power output. You should also calculate the effective resistance using Ohm's Law.

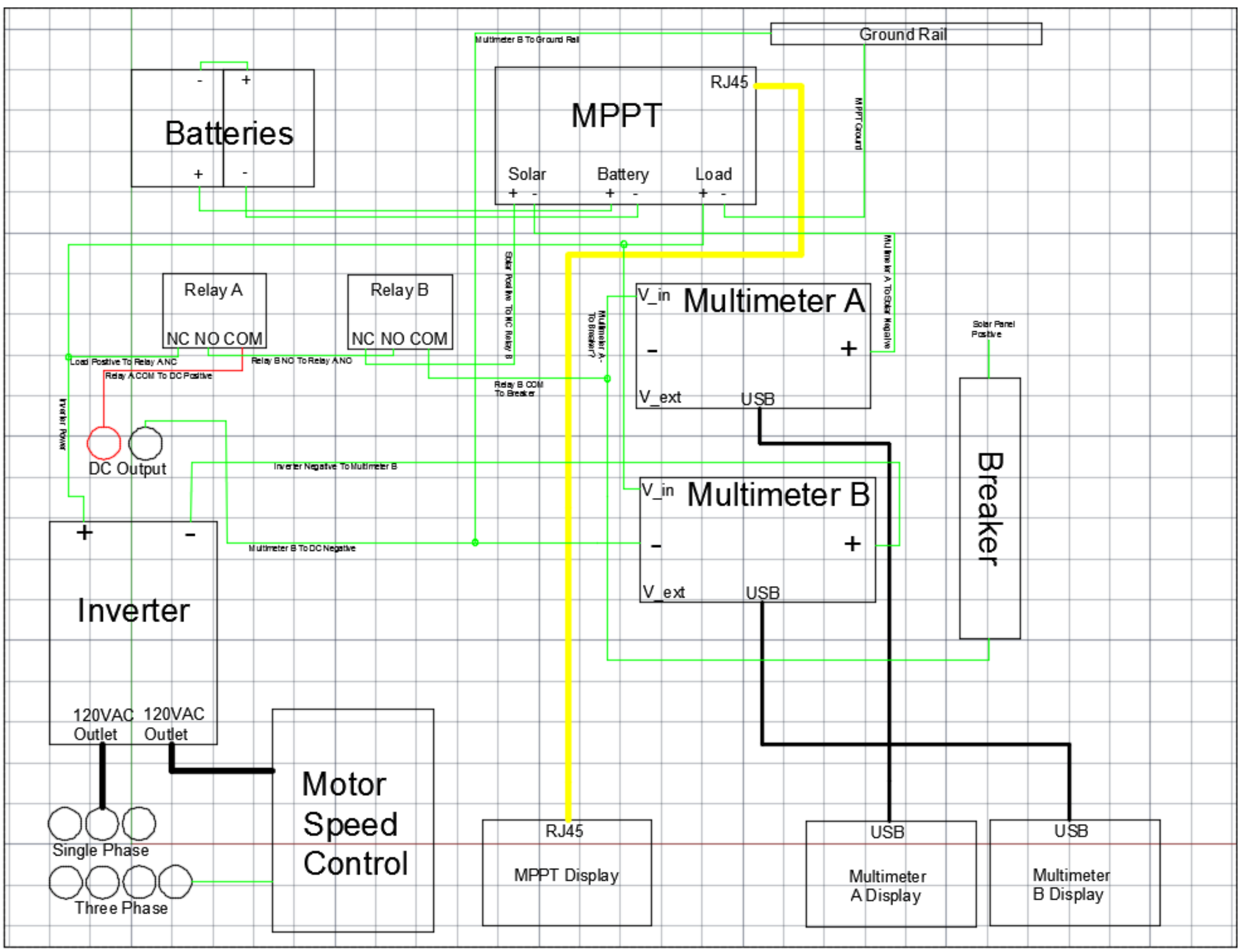
i. Be sure to use your value from part d as one of the duty cycles!
ii. Note: the input to the switch is 1-D, not D

**DELIVERABLE 5:** With the irradiance and temperature unchanged, what is the duty cycle needed to reach maximum power? Hint: you want to keep the equivalent resistance constant

**DELIVERABLE 6:** Document your observations about the effects of changing the duty cycle of the converter. What patterns did you notice?

## HARDWARE BACKGROUND

The general layout of the equipment is as follows: the PV array takes inputs of irradiance and temperature, which feed into the MPPT, which adjusts voltage and current inputs to find the maximum power output of the panels. From there, power is outputted from the MPPT to an inverter and DC output. The inverter converts the DC power into single phase. The single phase has its own output and also enters a VFD that converts the single phase to three phase. When the load requires more power than what solar can currently provide, supplemental power will be taken from the batteries. The relays are used to allow the solar to bypass the MPPT and go directly to the DC Output terminals at the flick of a switch. The Arduino powers the graphical display showing IRR and Temp. Lastly the switch turns the measurement devices on or off.




*Main Circuit:* All the circuitry shown above, is contained in a metal enclosure that has three outputs – DC, single phase AC, and three phase AC. We will use each of these in the following three experiments.


*Solar Panels:* Two Kyocera KD135GX-LPU panels with maximum power rating of 135W per panel.

*Batteries:* Two 12V batteries in series for 24V output.

*Inverter:* Peak efficiency of the inverter is 85%. Converts DC voltage to 120VAC to power load.

*MPPT (maximum power point tracker):* A DC to DC converter that optimizes the match between the solar panels and battery of the PV array. Its functionality is to convert higher DC output voltage from solar panels to lower voltage output needed to charge batteries. The maximum power point tracking comes from the MPPT reading the output of the solar panels in order to compare it to the battery voltage. From these readings, it figures out what the optimum power the panels can output to charge the battery.

*Load:* A resistor box with 8 different resistors (1, 2, 5, 16, 25, 100, 150, and 200 ohm)

Note:

This experiment is extremely weather dependent. The available irradiance will determine how many measurements you will be able to take. If you attempt to increase the load, or isolate PV and battery to power the load, it may pull the inverter under its required power. You will know that this is happening because the inverter will beep before it cuts power to the load. If this happens, power all of the equipment down and decrease the load.Turn the inverter off and back on again. If this issue persists with only one light bulb powered by both PV and battery, you will not be able to complete this portion of the lab.

Safety:

Refer to the circuit diagram provided for the graphical connections and locations of each switch for the equipment. *For the safety of everyone using the hardware, it is very important that the equipment is hooked up correctly. Verify with the TA that everything is correctly connected before moving on to the next steps. Do not manipulate the circuit while it is powered on.*

**<u>Experiment 3:</u>** Solar to Resistive Load – Hardware

In the first 2 experiments, you were working only with simulated models of the solar panels and MPPT. In this experiment you will begin working with these devices in the real world. The objective of this experiment is to see how the hardware compares to the ideal simulated models. In the first part you will test the characteristics of our solar panels by connecting them directly to the load.

1. PV directly to load
    a. The system should be set up correctly for you to use, the only switch you need to touch is the breaker on the far left side
        i. **NOTE: DO NOT touch any of the other switches on the hardware**
    b. Flip the breaker and measure the DC output voltage using a voltmeter, this is the open circuit voltage
        i. This voltage will very throughout the day as it is dependent on temperature and irradiance as we learned in the previous experiments
    c. Look up the current temperature using a commonly used weather app and convert into Celsius
    d. To find current irradiance outside observe the voltage being read on the voltmeter connected within the hardware and use the following equation to calculate Irradiance in W/m2
        i. V*(5/1024)*(245)*(1000) = Irradiance W/m2
    e. Open the "Resistive_Load_Only" file in Simulink and input the current temperature and irradiance
        i. **NOTE: Remember you have to open Simulink first in Matlab before opening the file**
    f. Double click on the solar panel symbol and change the "Series-Connected modules per string" to 2 instead of 1, this is because we have 2 solar panels outside in the courtyard
    g. Find the correct resistance value for the MPP under these conditions in simulink (Very similar to Experiement 1 part 3 "Changing Resistance")
        i. This value is the MPP for the current condition outside

h. Using the resistance box load and the DC output, connect the PV to several different values of resistance, half above and half below the maximum power point
    i. Note: include the simulated maximum power point as one of your values!
        1. This resistance value may not be the same for the hardware
    ii. Record voltage, current, and power for each different load value

**DELIVERABLE 7:** Create 2 plots like you did in experiment 1, Voltage vs. Current and Voltage vs. Power. Was the simulated MPP the same as you found with the hardware? What do you think accounts for any discrepancies?