

Solar PV Energy Generation System

Final Report

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Advisor:

Venktaramana Ajarapu

Team Members:

Dylan Hird

Jeremy Helgeson

Xiangpeng Yang

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System Design

System Requirements

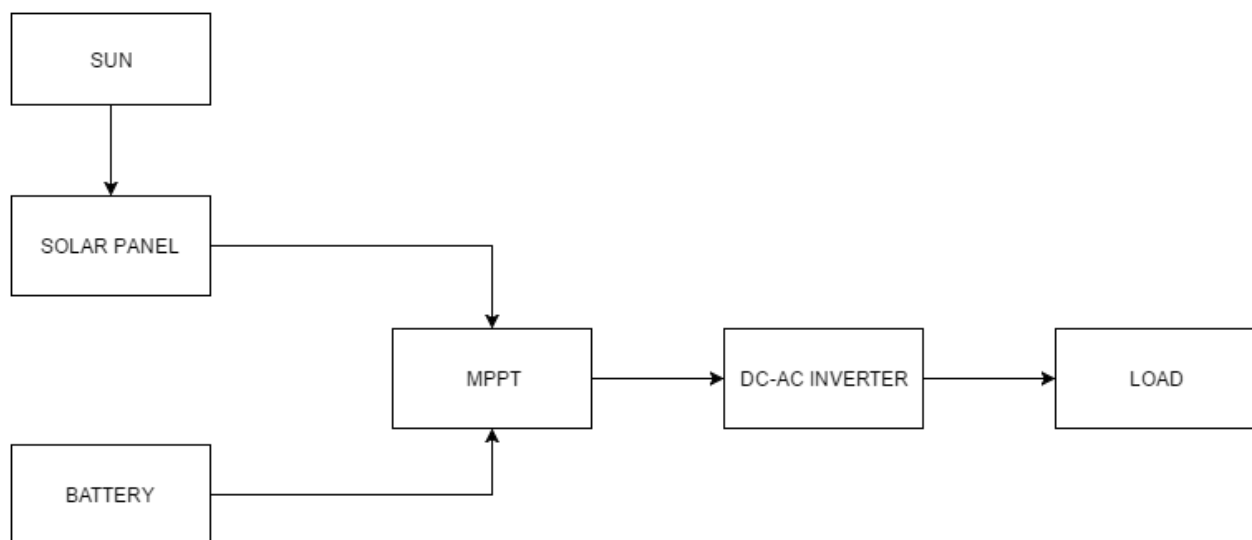
Our project is a Solar PV Energy Generation System. In order to create a system that can run properly we had to evaluate the criterion that was asked of us. Our system will be first created in a simulation using Simulink/Matlab and then implemented in the hardware aspect.

1. Design and modeling of solar PV panel and maximum power point tracking (MPPT) algorithm using electronic converters.
2. Design and modeling of voltage inverter and its switching mechanism to convert solar DC power to AC.
3. Loads, battery bank and their integration to the energy generation system.
4. Integration of solar PV generation system and maintaining power quality of power supply.

Also, because this project has been worked on by past groups, we also have to understand the system that had been already created. This means that we must take the past data and documents that we had been given and be able to run what has already been done.

Interpretation of System

This system can be best described using a block diagram that shows how each part of this system is combined together. Each block can be represented as an essential component and their order shows how the system generates output step by step.



Project Design

Overview

For our project, we have been tasked to create and implement a solar PV energy generation system. This system should be able to produce electricity without being connected to the grid. This will be useful for remote parts of the world or third world countries where electricity is not easily available. We also created a lab document for future electrical engineering classes to be able to gather understanding on PV systems.

Interface Specifications

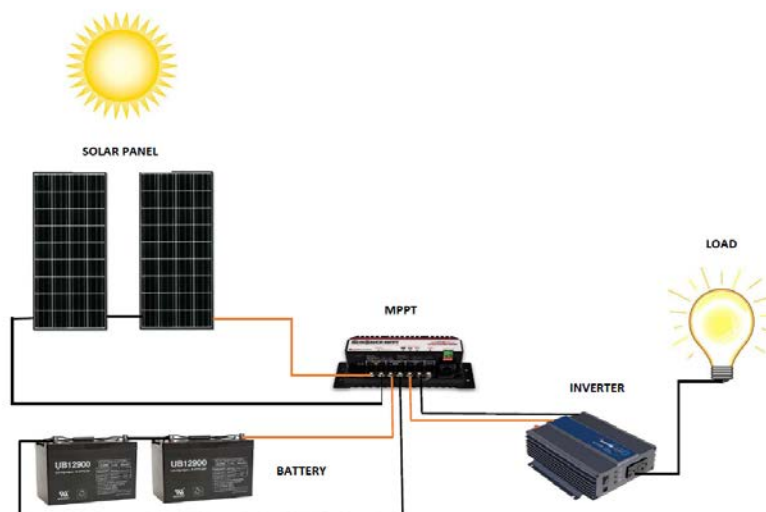
For our solar power system, we are currently using oscilloscope and sensors that are linked with lab computer to read the data from each component. By using two different methods to read and record all the data, it increases our measurement accuracy. And by using LabVIEW and sensors, we can get real-time data continuously day and night.

Hardware Specifications

Our system is using solar energy to generate electricity but under some conditions the solar panel may not be able to generate enough power to accommodate the load. In this case our system also consists of a set of batteries. The batteries are not only a resource that can supply power when solar panels are not producing enough power, but also the power supply for the inverter. Also, in order to make the system work at its maximum power rate, our group uses a MPPT (maximum power point tracking) among connections of solar panel, battery and inverter.

Implementation details

Our system is implemented as the following concept sketch and details of each component is introduced below.



Photovoltaic Array

For our array, we are using two Kyocera Model KD135GX-LPU solar panels in series (1.5m by .668m). The output for these arrays are dependent on the solar irradiance that is received by each solar cell. The nominal voltage of the two panels in series is 17V and 7.63A. It gives a nominal power of 270W at peak irradiance.

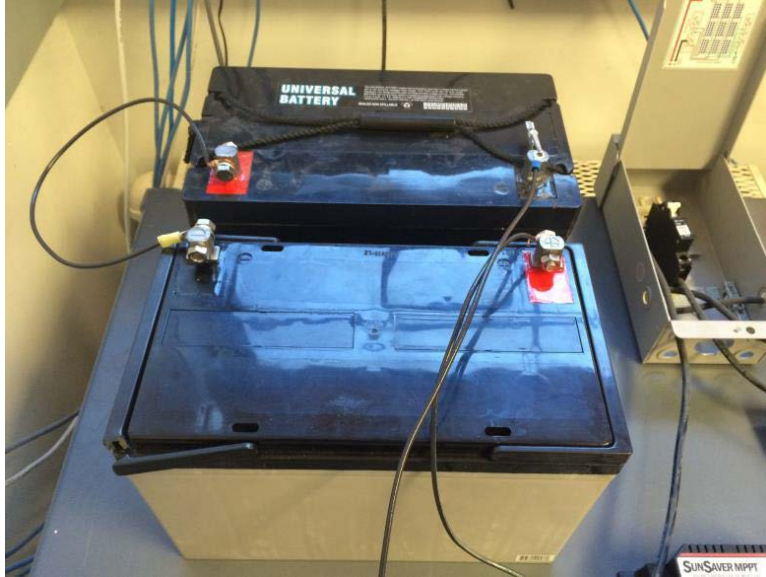
The Photovoltaic arrays work by transferring the energy from the solar irradiance into current. Since these arrays do not follow the linear VI curve, we work with them by attempting to draw the maximum amount of power from the system. Depending on the solar irradiation and temperature values present the solar array will produce a certain amount of current and voltage that will be able to power the varying load of the system.



Kyocera Model KD135GX-LPU solar panels

Battery

Also attached is a battery which will run the system when the PV system is not fully able to produce the power that is needed. Two 12V batteries are to be connected in series to achieve the desired 24V for the battery bank. The battery bank will be connected in parallel to the inverter and load in order to store charge at the desired level of voltage and feed the load when necessary. A switching mechanism will be used to determine which of the generation systems is charging the battery, and when to disconnect the battery when fully charged.



2 Batteries of 12V in series connection

Maximum Power Point Tracking (MPPT)

In order to draw the largest amount of power from the PV cells, we need to attach a device that finds out what the maximum is. There are many different ways of locating the ratio between voltage and current in order to maximize the power output but for our system we used a device especially for this task. The device we use is a Morningstar SS-MPPT-15L SunSaver 15A MPPT. This device uses a boost converter in order to step up the voltage from the solar cells. The boost converter is dependent on a duty cycle created, through power electronics and the voltage and current differences, which runs an internal IGBT.



Morningstar SS-MPPT-15L SunSaver 15A mppt

Inverter

Attached to the other end of the MPPT is Samlex PST-600-24 Pure Sine Wave inverter which converts the 24V DC voltage to a steady 120V 60Hz AC voltage (US values). This device uses pulse-width-modulation in order to regulate the output.



Samlex PST-600-24 Pure Sine Wave inverter

Load

In our system we want to be able to control a variety of loads in order to show the usefulness of our system. Right now the system is connected to a purely resistive load consisting of a few lightbulbs. In order to create a system that can run on other loads, we will have to examine the complex powers of other loads and make sure that we do not exceed any power ratings for our system.

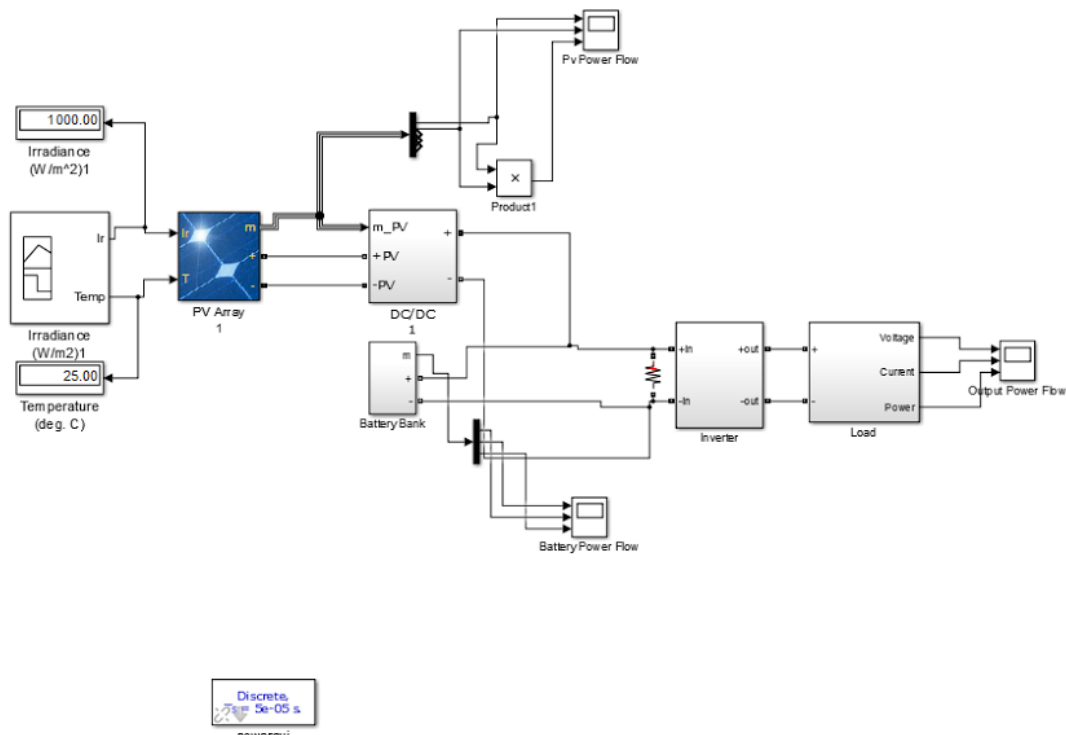


Load

Simulation/Modeling

Solar

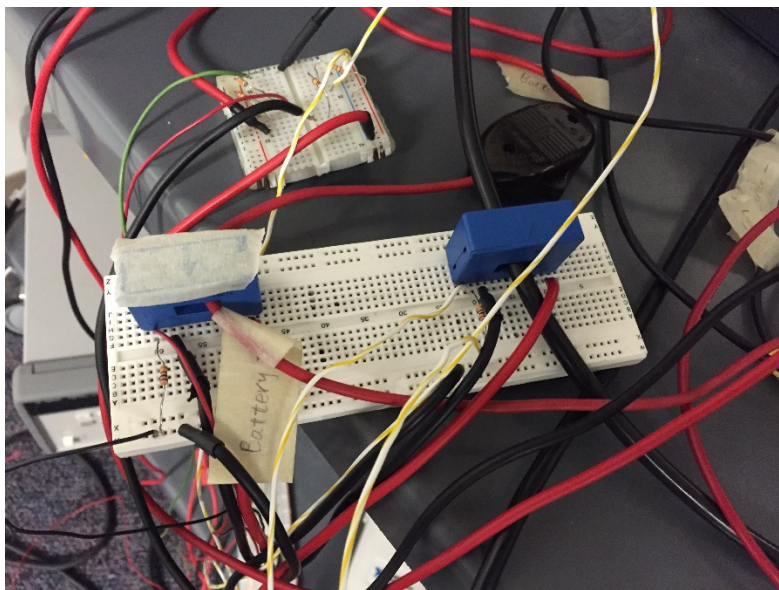
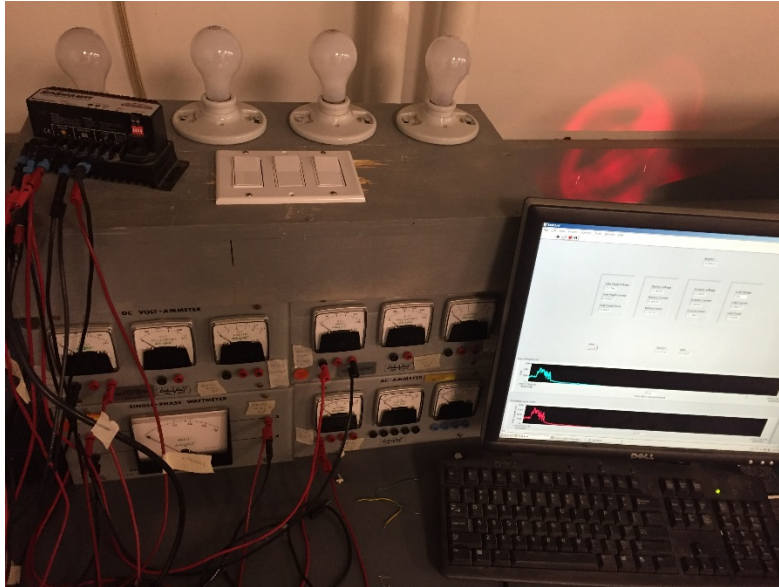
The PV system can easily be modeled in Simulink and simulated to observe how the system works. We were able to create a model of the system as seen below.



Our system takes given values of the solar panel characteristics and then simulates them through the PV panel. In a new simulation we hope to use a model with the same specifications as our own solar panels. This then goes through a MMPT controlled boost converter that feeds into an inverter. This is also connected to a battery to control the voltage that is fed into the inverter. This inverter then delivers an AC current onto our load.

Testing

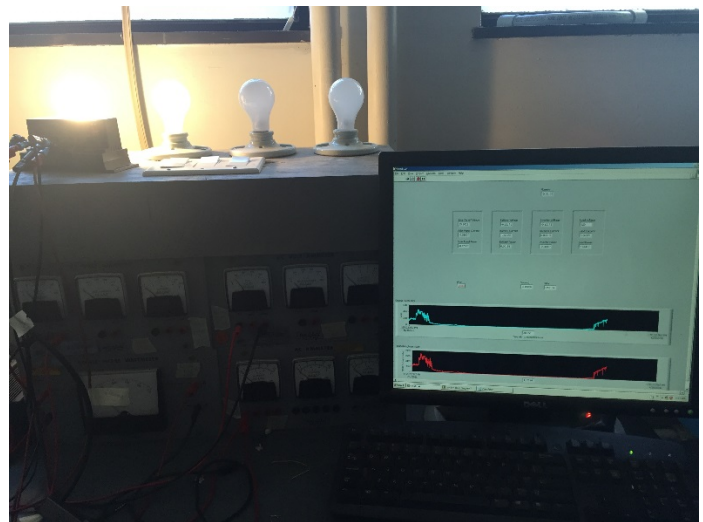
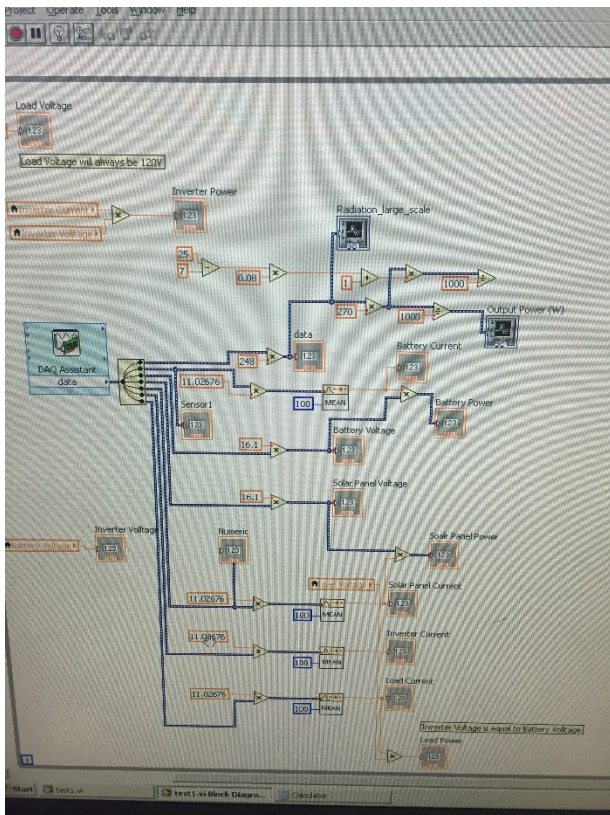
Our group is testing the system by connecting various meters and sensors to the system. From the picture, it shows all the meters that can be used to display voltage, current, and power for each component of the system. The sensors are linked with computer and can display real-time voltage, current, and power of all the components by using LabVIEW. (Refer to Appendix I for step by step testing details)



Pictures of meters and sensors

Testing result

Once we decided on a design for the system and implanted it we were able to begin the testing of the system. With our test procedure we were able to verify that the solar panel charges the battery when there is no load. We were also able to observe the system operating when there was no input from solar panels. Our other cases are when the solar panels supply enough load to run the system and to charge the battery and the case of when the solar panels do not supply enough power to run the load and the system draws power from the battery. These cases are harder to see in experimentation because they depend on the temperature and the solar irradiance, both of which are out of our control.



The LabVIEW front panel and meters we used for testing

Appendix I: Operation Manual

Setup

To set up the whole system, the first step is to connect solar panels and place them on a ground that has plenty of sun light during the daytime on a sunny day. In our case, we connect two solar panels in series to increase the voltage. Then, we use a wire to make a connection between our solar panels and a MPPT that we use to make our system reach its maximum power all the time. After that, we connect our inverter to the MPPT as well. In this way, all the current from solar panel can be converted into AC from DC to our load. To get a power for the inverter, two 12V batteries in series are connected to the MPPT and supply power to the inverter. The last step for the setup is to connect a load to the inverter.

Demo

In order to do the demo, our group has attached 4 sensors to each part of our system: Solar panel, battery, inverter and load. Then we connect our sensors to the NI senior based I/O that is linked with the lab computer. To read data from sensors, we use the LabVIEW on the lab computer. Once we turn on our system, LabVIEW will display and record all the data of voltage, current and power of each part of our system.

Test

To test our system, we make an assumption that our system will run at 4 different situations: Battery Discharging Case, Only Solar Case, Only Battery Case and No Load Case.

Battery Discharging Case:

In this case, the system will run under a normal condition that both solar panel and battery will work properly. All the current from solar panel and battery will go into MPPT and then be supplied to the inverter and consumed by load.

In this situation, our group is focusing on analyzing on voltage, current and power of each part of the system. The following table shows all the data we gather for studying our system for Battery Discharging Case:

	Solar Panel	Battery	Inverter	Load
Voltage	○	○	○	○
Current	○	○	○	○
Power	○	○	○	○

o: the data of the part is measured and needed for analyzing the system

x: the data of the part is not needed for analyzing the system

Only Solar Case:

In this case, the system will run under a condition the load is only getting power from the solar panels. All the current from solar panel will go into MPPT and then be supplied to load. The battery will not be working under this.

In this situation, our group is focusing on analyzing on voltage, current and power of solar panel and load. The following table shows all the data we gather for studying our system for Only Solar Case:

	Solar Panel	Battery	Inverter	Load
Voltage	o	x	x	o
Current	o	x	x	o
Power	o	x	x	o

o: the data of the part is measured and needed for analyzing the system

x: the data of the part is not needed for analyzing the system

Only Battery Case:

In this case, the system will run under a condition that only battery will work properly. All the current from battery will go into MPPT and then be supplied to the inverter and consumed by load. The solar panel will not be working under this situation.

In this situation, our group is focusing on analyzing on voltage, current and power of battery, inverter and load. The following table shows all the data we gather for studying our system for Only Battery Case:

	Solar Panel	Battery	Inverter	Load
Voltage	x	o	o	o
Current	x	o	o	o
Power	x	o	o	o

o: the data of the part is measured and needed for analyzing the system

x: the data of the part is not needed for analyzing the system

No Load Case:

In this case, the system will run under a condition that only solar panel and battery will work properly. Under this situation, the system will not be able to supply any power to the load; however, all the current of solar panel will go into battery and charge the battery. It can also be considered as a Battery Charging Case.

In this situation, our group is focusing on analyzing on voltage, current and power of solar panel and battery. The following table shows all the data we gather for studying our system for No Load Case:

	Solar Panel	Battery	Inverter	Load
Voltage	o	o	x	x
Current	o	o	x	x
Power	o	o	x	x

o: the data of the part is measured and needed for analyzing the system

x: the data of the part is not needed for analyzing the system

Appendix II: Alternative Versions of the Design

In this section, we outline different versions of our current project design. These alternatives were generally dismissed in favor of designs that more suited our design specifications or merely worked better with certain components of the system. Our client, Dr. Ajjarapu, never dramatically shifted design specifications to the point of forcing us to make major changes.

1. Solar Panels in parallel, 12V battery level

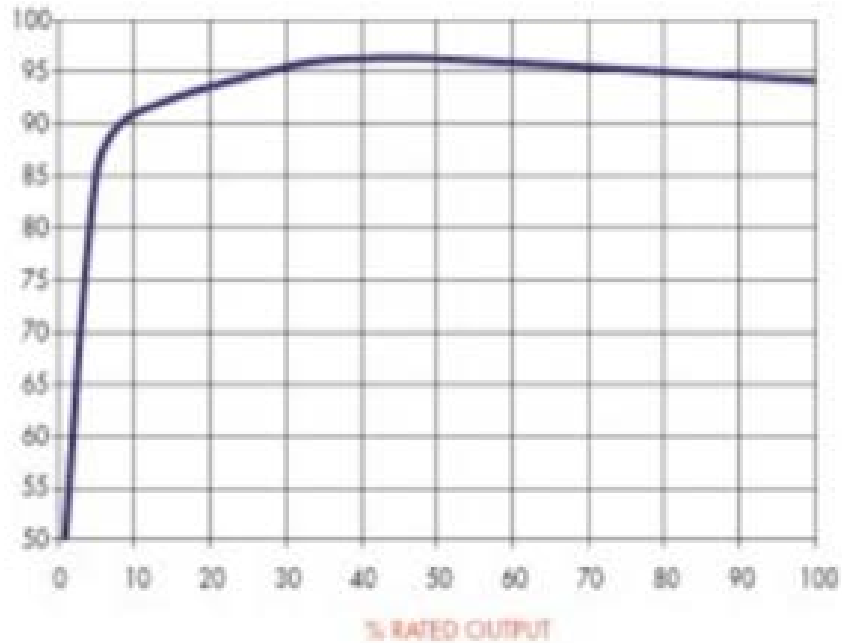
One alternative setup for solar panels was to have the panels in parallel, rather than in series. This creates a nominal voltage of 17.7V and current of 15.26A. This is the same total power that the panels in series would produce. This would mean that only a single 12V battery would be necessary to power the MPPT and complement supply to the load. Since our goal is to keep the battery around full charge, having fewer total ampere-hours is not a major issue.

However, we discovered that the MPPT will allow 15A to pass through it at any given time. This means at a 12V battery level, the maximum size load can never be greater than 200W. The 24V system will allow for the supply of our maximum load level of 400W. Additionally, two panels in series made for a less cluttered solar combiner. An additional benefit is that the entire photovoltaic array may be enabled and disabled with a single circuit breaker with a series configuration.

To turn off the system, first open the switch for the circuit breaker which will disconnect the solar from the system. Then open the switch that connects the batteries to the MPPT. The inverter will shut off and the system will not be powered.

2. 2500VA Inverter

In the original design of the system we were using an inverter that was rated for 2500VA. This inverter was significantly over our max load of the system and was dragging the efficiency of the whole system, with average efficiency around 65%. When we changed the inverter out for the one with a lower power rating we saw a significant increase in efficiency with a new average efficiency of around 85%.



Appendix III: Other consideration

An interesting consideration is when the solar produces enough power for the load and the battery is already fully charged. In this case there needs to be a way to dissipate the energy or cut off the connection to the power source to protect the battery and the load. The way we found to achieve this is to disconnect it manually.

We also we need to make sure that the power from the solar panel is being prioritized over the power from the battery if it is available. Luckily, the MPPT does this for us automatically so all the energy from the solar panels is either being used to power the load or to recharge the batteries.

Appendix IV: Lab Document

Introduction to Photovoltaic Systems

Summary:

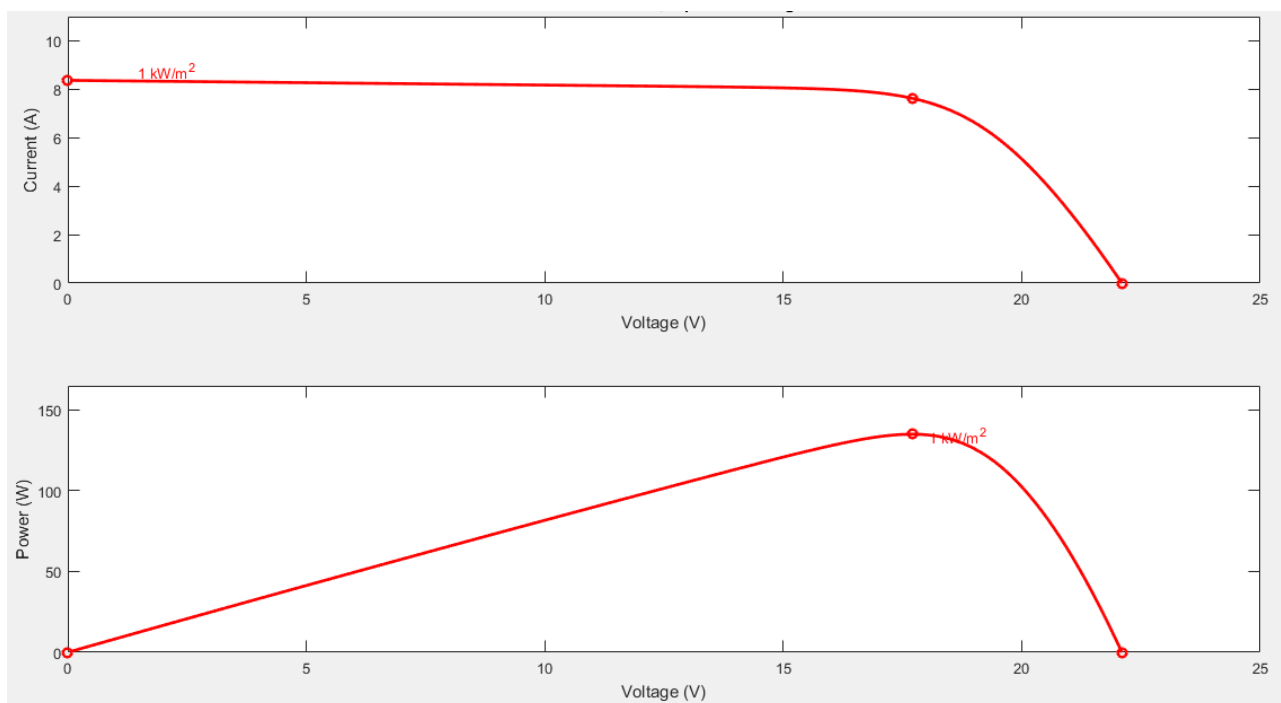
In this lab, PV behavior will be analysed. In addition the resulting I-V curves will be generated from simulation.

Learning Objectives:

- Understanding PV cells
- Reproduction of design

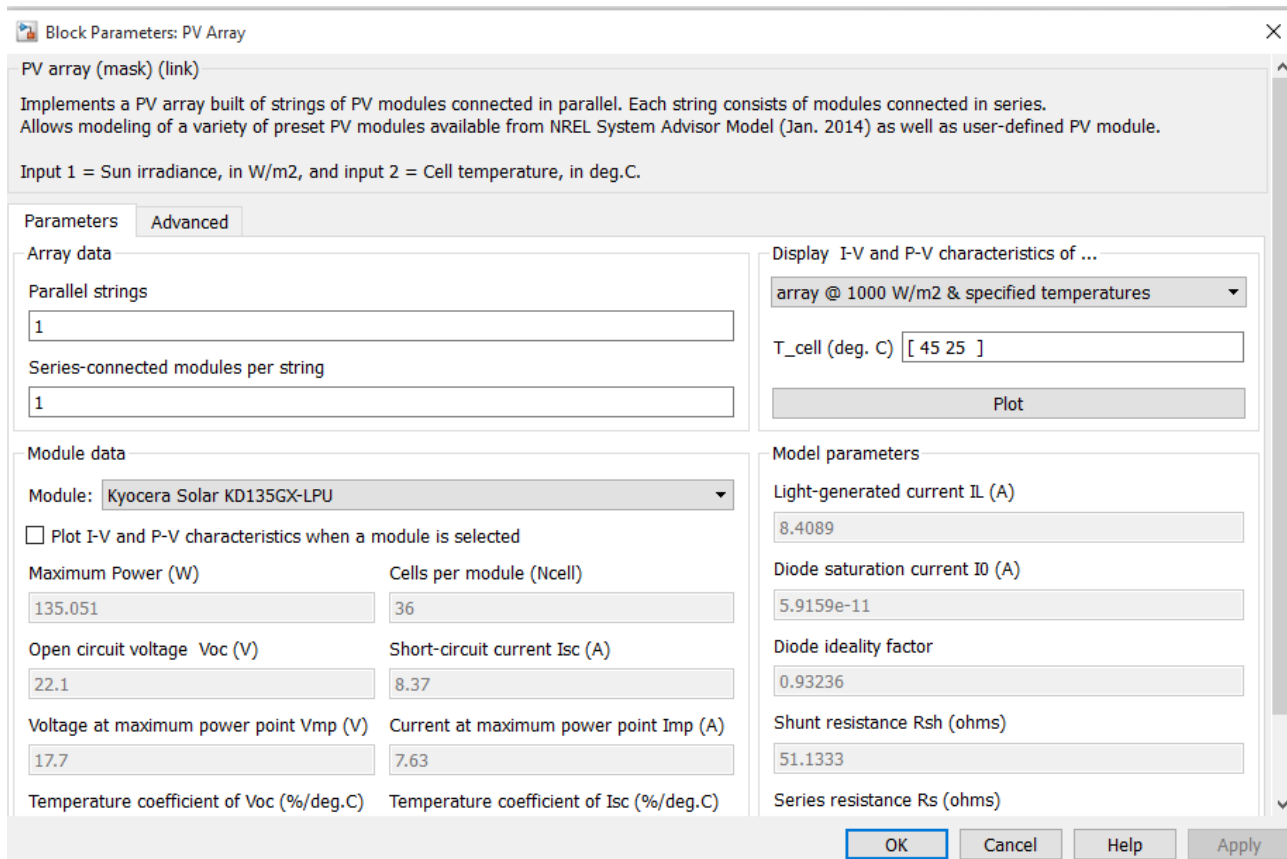
Prelab:

Observe the following I-V curve and P-V curve. These are the graphs of the Voltage, Current, and Power across a resistor. In what ways are these different from a curve using a normal voltage source? Report whether or not you believe the system is linear or non-linear?



Part 1: PV cell

For this lab we will be using a different library. In Simulink most of the components that we will be using are found Simscape>>SimPowerSystems>>Specialized Technology. In the solar area of this library find the block PV Cell. Open the block and get familiar with what's inside.

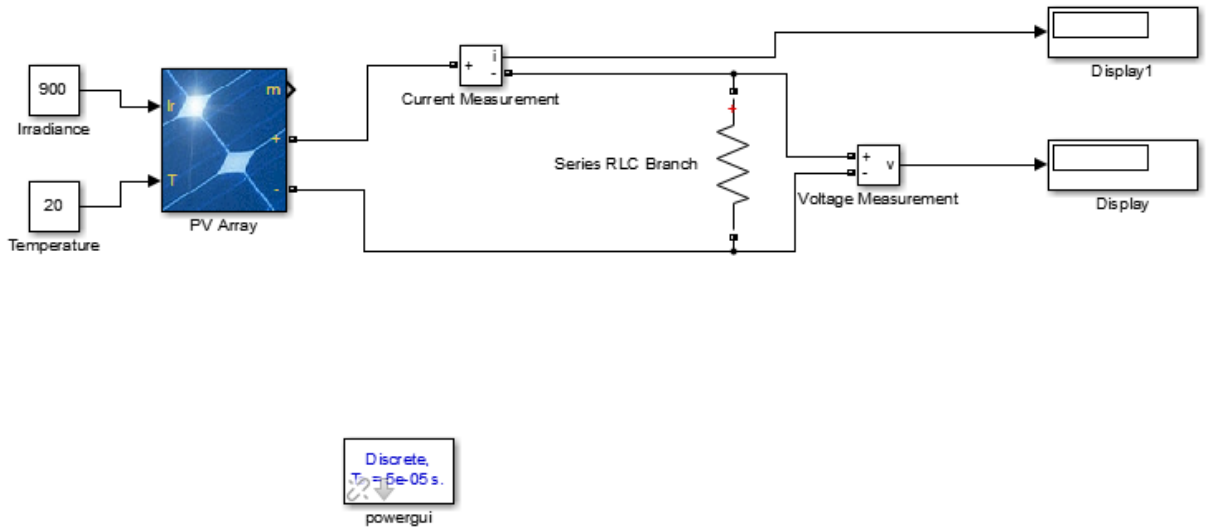


In order to match the results of everyone else, change the number of parallel strings and series connected models to 1. This is because we are only going to simulate one solar panel, but if we wanted to go back we can easily simulate larger systems. In addition please change the module to the Kyocera Solar KD135GX-LPU, which are the solar panels that we will use at a later time. Make sure to click apply and compare your characteristics.

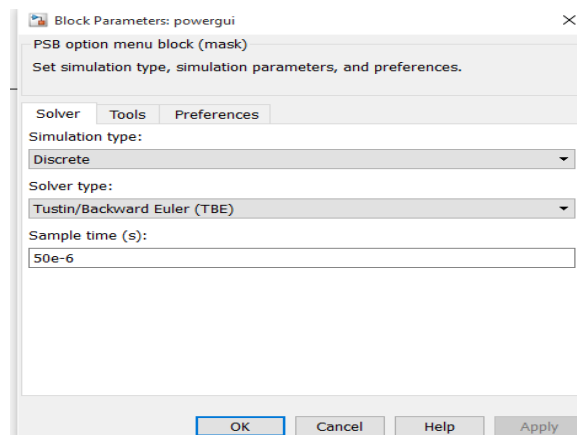
Once everything matches the picture above, plot the array characteristics using several different parameters, we will use this for reference.

Simulation:

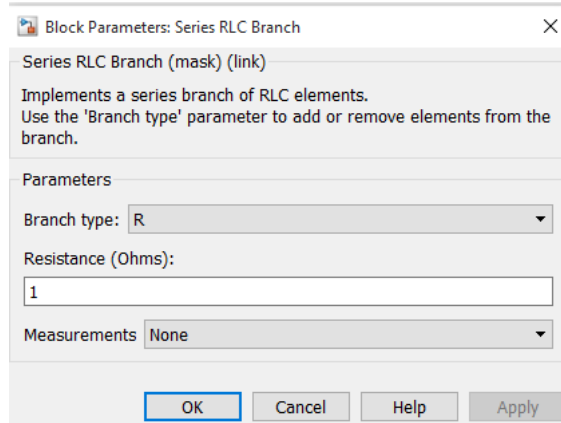
Use the components in the Specialized Technology library to recreate the system below



Assuming the PV array is still in the correct format, we will now apply the correct settings to the rest of the system. First make sure that the Irradiance value is 900 and the temperature is 20(Celsius). First we need to change the power gui to discrete, as shown below. This allows us to run fast simulations at different step sizes.



In addition we need to make sure the RLC branch is purely resistive. In the settings we can change the value of the resistor and the components in the branch. Note: make sure to use the branch and not the load for correct simulation.



Once everything is correct proceed to take measurements with different values of resistors. This is because the PV system acts like a current source and we need to induce different characteristics across our resistor. Using the table below fill out and take measurements on each case.

Resistor (ohms)	100	20	10	6	5.5	5	4	3	2	1	.01
Voltage (volts)											
Current (amps)											

Plot the values that you simulated in Excel or MATLAB and compare this to the graph in the beginning of the lab. The values will not be the same but does this system react the way that we expect? If we reduce the difference in some of our resistor steps would we receive a better graph?

Next given that we have completed the last part, we can test our system to see how everything reacts to different values of Irradiance and time. Repeat the previous table as shown below for an Irradiance of 500 and temperature of 20. Then compare this new graph to the one that you made in the last part.

Resistor (ohms)	100	20	10	6	5.5	5	4	3	2	1	.01
Voltage (volts)											
Current (amps)											

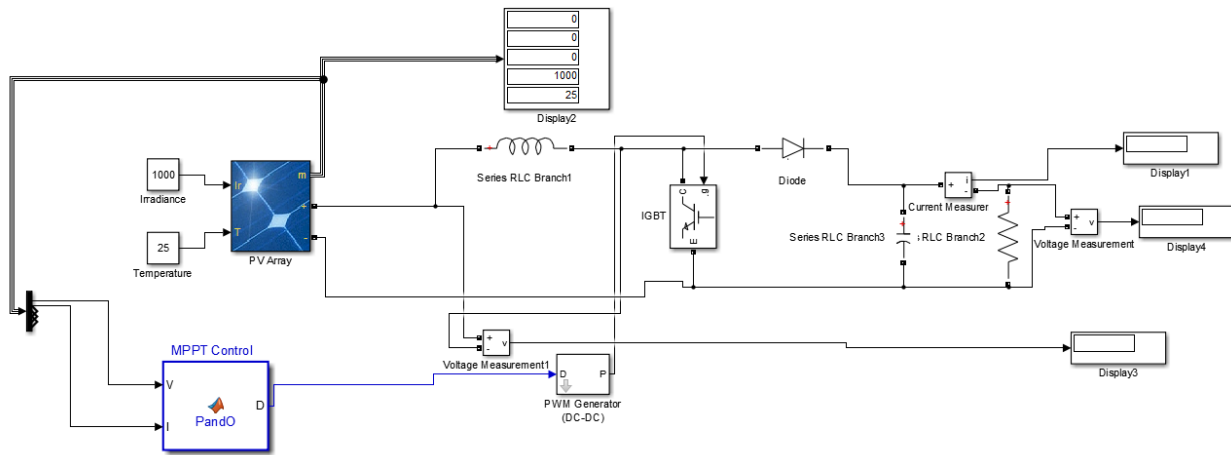
Then redo the graph again for a temperature value of 15 degree and an Irradiance of 900, report the graphs for comparison.

Resistor (ohms)	100	20	10	6	5.5	5	4	3	2	1	.01
Voltage (volts)											
Current (amps)											

System with MPPT (Design Problem)

As we have found in the graphs before, we can only get the maximum output from the solar panels at a specific resistive value. Because it would be impractical to go through at every irradiance and temperature value to come up with the perfect point, we will go ahead and create a system that can do this for us. As we have learned in the class there are many ways to simulate a load being exerted on a system, for this system we will use a boost converter much like the one that we have created before.

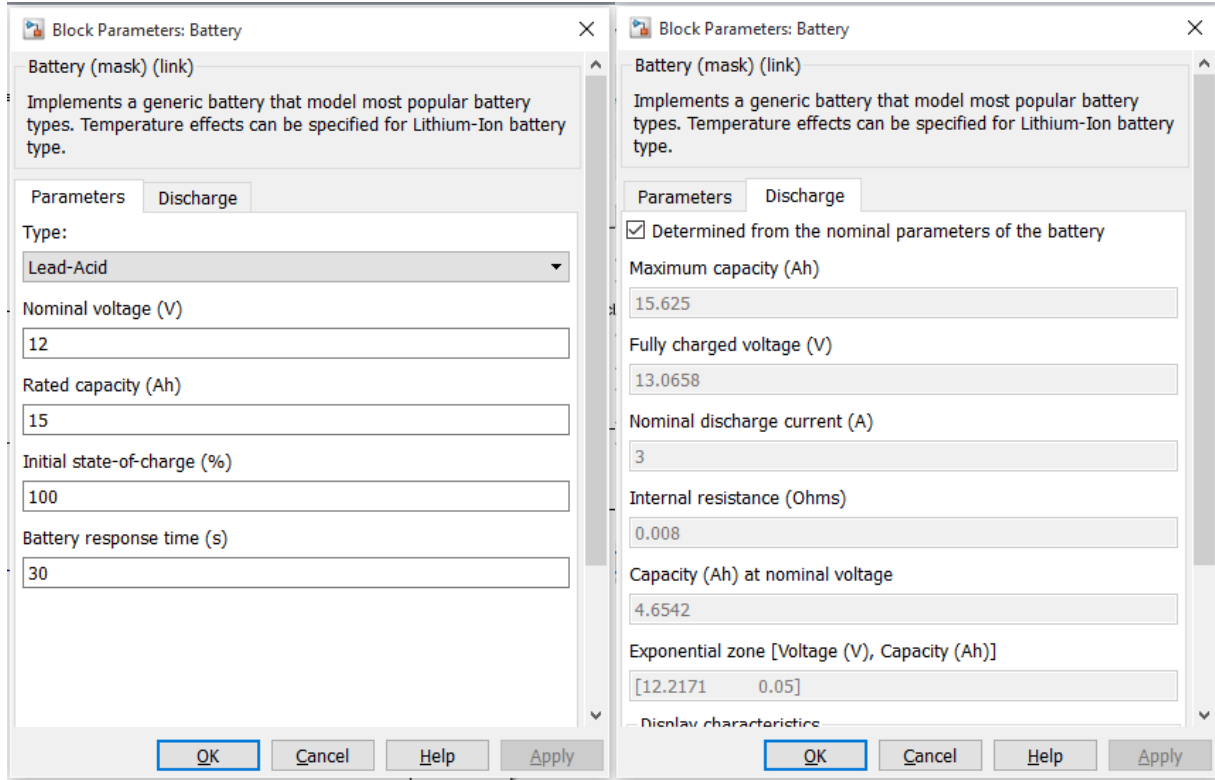
Recreate the Simulink block that is shown below.



We have provided the block for the MPPT Control, this will help us run the system at the maximum transfer rate of power. As you can see this MPPT block is attached to a PWM generator that runs a boost converter. In order to receive a .1V ripple in the output what size of capacitor should we use? For the output resistor use a 10ohm resistor and a .1H inductor. Determine the value of the PWM switching frequency also.

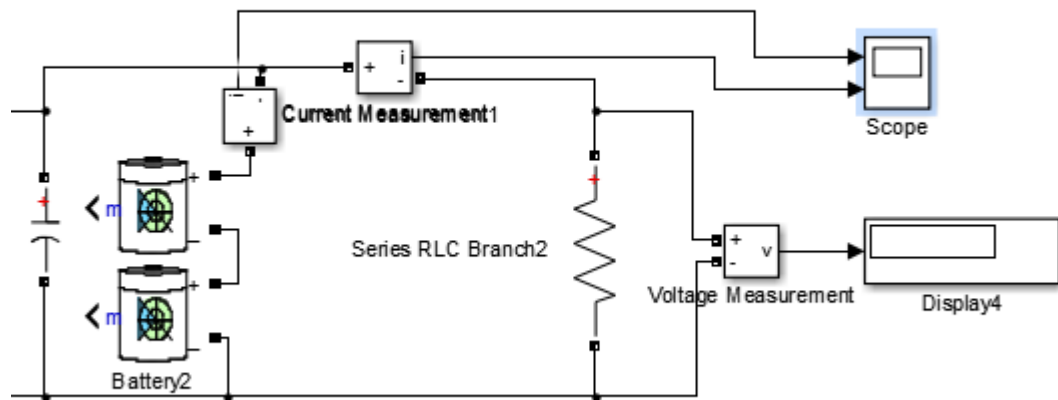
System with battery attached

Next we will attach a battery to the system, this is put in for system stability and to provide when our solar panels are not providing. In the Power Systems Library>Specialized Technology>Electronic Drives>Extra sources select the battery and insert it in the previous system.



Make sure that the settings match the ones in the previous pictures. By clicking the Determined from nominal parameters box we can have Matlab help us with simulating a normal battery. Once everything looks the same press apply and we will continue.

Because we are running the system with a boost converter we will need to keep the value of the output higher than that of the input. To do this we will insert two batteries in parallel to maintain a constant voltage of 24V. Although the value of the batteries can change a little, it should not go below the max value of the solar panels.



Insert the batteries with a current measurement to the right of the capacitor, as shown above. After the batteries are ready, we will now need to change the value of the resistor. Since we are maintaining a constant value of the output voltage we will now have a large change in current. We will monitor this current so that we can observe where in the system it is going. Change the value of the resistor to 2.4Ohms to observe a constant current of around 10A. Observe the behavior of the current across the battery, is the voltage going up or down? Repeat this with a resistor of the value 10Ohms, and observe the voltage. Report the previous graphs and voltage values.

Conclusion

Write a short paragraph about what you learned in this lab and interesting points. Also, if there were any major problems report them in this part.