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# Hybrid Solar PV & Wind Generation System for EE 452 Lab

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# 1 Introduction

## 1.1 PROJECT STATEMENT

Develop and expand the current solar and wind generation to be more user friendly and educational for future EE 452 lab students.

## 1.2 PURPOSE

Recent technological advances have made solar and wind generation more economical and thus more common throughout the world. This increased demand of renewable energy produces a great demand for educated Electrical Engineers. Iowa state currently offers EE 452 Mechanical Drives and machines. This course discusses electromagnetic conversion, which is a key concept in renewable power systems.

Currently the class uses the Biorenewables Lab, and there is an educational station for student to collect data from solar panels. This station is currently disorganized and limits what the students can test and measure. Our project would rebuild the station and software at the station to give the students a better and safer learning environment. We will generate more lab manuals so students will have more time with the equipment. We would like to also like to expand that system either via more panels, more batteries or a sun tracking system. This way the closed system will be more powerful and last longer. Giving every student an equal chance to collect good and meaningful data.

## 1.3 GOALS

1. Create a more compact, updated, and user friendly workstation for students to conduct lab.
2. Create a solar tracking system that will move the panels to point squarely to the sun, thus getting maximum irradiance at all times of the day.
3. Generate ways to optimize small stand-alone systems to benefit those in remote areas.
4. Create lab material for future EE 452 labs.
5. Study and model theoretical daily power use and generation of a solar system

## 2 Deliverables

**Workstation:** For the workstation, we first need to come up with a concept design. This can come in the form of a drawing or a 3D design. Next, we will physically move the equipment in the designed arrangement.

**Lab Manuals:** Lab instructions to cover a few weeks of lab. These instructions need to cover; purpose, theory, data, analysis and conclusion.

**Additional Panels:** Provide cost analysis and scope for adding more panels to the current system. A project plan for installation will be needed as well as site location. The final result will be new fully integrated solar panels.

**Solar Tracking System:** Cost analysis comparing various tracking devices on the market as well as if we built one ourselves. We would also need survey the area to prospect new areas to place the panels.

## 3 Design

First and foremost, we can not begin implementing any of our main tasks until we have a complete working model of an isolated wind and solar power system. To do this, we will have separate designs for solar and wind and combine the two. This modeling is important not only for our understanding to the system, but we can use these models in our labs to help other students understand as well. These models will be used to create the lab manuals to make them more intuitive. Once we create the manuals we can test our work on Students and get their feedback. This will allow us the opportunity to refine our manuals and test again.

After the model is completed we can start cost analysis on adding more panels as well as a solar tracking system. When looking into add more panels we will need to conduct research to make sure that they will be compatible with our current system and possible future systems. We may also need to find another location to place the panels. This ties into the solar tracking goal because the current location the solar panels is not ideal for solar tracking.

The last goal to discuss is the new lab workstation. This begins by defining what we want to accomplish at this station. Once we understand this, we will start to evaluate what equipment is needed and how that equipment can fit in a given space.

So far we have a complete model minus battery usage. Battery implementation should be complete in 1-2 weeks from the revision date of this document. The next phase will more than likely split our efforts into designing the new workstation and creating lab material.

### 3.1 SYSTEM SPECIFICATIONS

Detail any specifications given and/or assumed about the project.

- Lab manuals should be concise, organized and able to be completed in a 3 hour time frame.
- Lab topics should include, but are not limited to, building an MPPT, Power measurement, PV cells, Buck/Boost Converters, Irradiance and temperature dependences.
- The Workstation should be neat, organized, intuitive, safe and dependable.
- All simulations should be organized and intuitive.

#### 3.1.1 Non-functional

Understanding of modeling a solar cell along with I-V, P-V curves plotted from the model. Proficient knowledge of maximum power point tracking its relationship to P-V, I-V curves and different algorithms used to attain max power from a solar panel. The physics of a charging/discharging battery and the advantage of using a rectifier, inverter and chopper in a standalone power generation system. Further it is required that ideas are generated about how this project can be used for other applications. Ideas can be proposed throughout the semester regardless of how outlandish or reasonable they seem at the time. The details will be worked out if the advisor is pleased with an idea proposal.

#### 3.1.2 Functional

Modeling solar panel and DC/DC converter in Simulink with visually representation of their respective characteristics. Also modeling MPPT algorithm in conjunction with the converter and solar panel. Integration of a battery bank and load into a solar PV/wind generation system while maintain power quality from the power supply. Combining new PV panels with existing panels and use of MPPT and other control techniques through real time controller. Calculating wind speed with use of a wind sensor also emulate wind turbine generation energy in the lab. Combination of pv panels and turbine connected to the load and battery bank.

#### 3.1.3 Standards

A variety of standards can be applied to this project. Since Wind and Solar power are relatively new sources of power standards are still being developed there are however IEEE standards that should be applied to the project. There are IEEE standards for the sizing, installation, and maintenance of lead acid batteries. There is also a IEEE standard that involves measuring different parameters for wind turbines. Standards are always important to follow regardless of the application so that it is easier for others to understand. Even if the project never has a use outside of the 452 lab educating college students it is important to design it as if it will which is why applying all applicable standards is especially important. It is also important that we follow the city of Ames Standards when importing solar energy into the grid. Even though there is no plan for this power to be connected to the grid following the method put forth by the city of Ames should be observed for the possible application at a later date. Ethical issues that may apply will

the safety of the students that will be interacting with the equipment in the lab. It is absolutely necessary that the measuring equipment is safe as some of the voltages and the current have potential to be fairly high. it is our responsibility to make sure all the equipment is safe and if it is not the user must be aware of it.

### 3.2 PROPOSED DESIGN/METHOD

Our team and advisor had agreed for us to solely focus on the solar generation aspect of the hybrid standalone system. We've designed Simulink models for a pv cell, boost inverter, Maximum power point tracking and a conjunction model of the PV array used in the lab with a DC/DC converter. We have decided to implement a battery source somewhere in the conjunction model so we'll be able to provide additional output power when the solar panel isn't providing enough power for a load. We've also decided to design a lab which involves students measure analytically and calculate limitations of a given boost converter with varying loads and analyzing implications of a battery over the course of 12 hours for different load values. Also we will bring a fresh new workstation to the EE 452 Renewables Lab by adding a new Kyocera panel to the existing panel. With the additional panels we would like to also implement a solar tracking mechanism looking into the maintenance required, safety issue, cost and lifetime of the prior panels to determine the feasibility of the mechanism.

### 3.3 DESIGN ANALYSIS

Attempt to develop an MPPT MATLAB algorithm code but it didn't work from errors in the code. However we've generated I-V / P-V from the pv array in conjunction with the boost converter by manual changing the duty cycle and using the prior group MPPT block diagram with the boost converter. We observed as the duty cycle gets closer to 1 the power deliver by the load gets smaller. Another observation for when irradiance is 1000 W/m<sup>2</sup> the load line for maximum power is 2.5 ohms 600 W/m<sup>2</sup> load line maximum power is 4 ohms and 200 W/m<sup>2</sup> load line for maximum power is 10 ohms. Knowing that a physical load line will vary over time we will modify our model by adding a battery to help supply power need to get close to the maximum power. We also made a diode model of a pv-cell then measured the current through each component (shown in Fig 2). Figure 2 plots gives us an visual representation of the the output current equation we're able to analytically and graphically analyze our silicon diode cell. We will continue working with our current model without a battery to see the trade offs of no battery and get an understanding of the limitations before we decide where to put, how much charge needed and the size of a battery.

## 4 Testing/Development

### 4.1 INTERFACE/HARDWARE SPECIFICATIONS

Students should have a workstation that they can change and measure elements of the system safely. They need to be able to measure currents, voltages and waveforms. Students should also be able to control the load on the system.

### 4.2 SOFTWARE

Software we used were Simulink and MATLAB. Simulink is a program within MATLAB, which is an environment for modeling, simulating and analyzing multidomain dynamic systems. Simulink allows us to model and analyze circuit characteristics like voltage/current across a component and behavior of AC components in non-ideal circumstances. Also if we need to implement another component we can get an idea of how it will affect or change characteristic of other circuit elements. Lab Students will have some simulink models provided by us. Some of these models will be complete, others partially completed for the students to finish. Simulink will play a vital role in quickly determining issue we will consider when setting up a physical circuit.

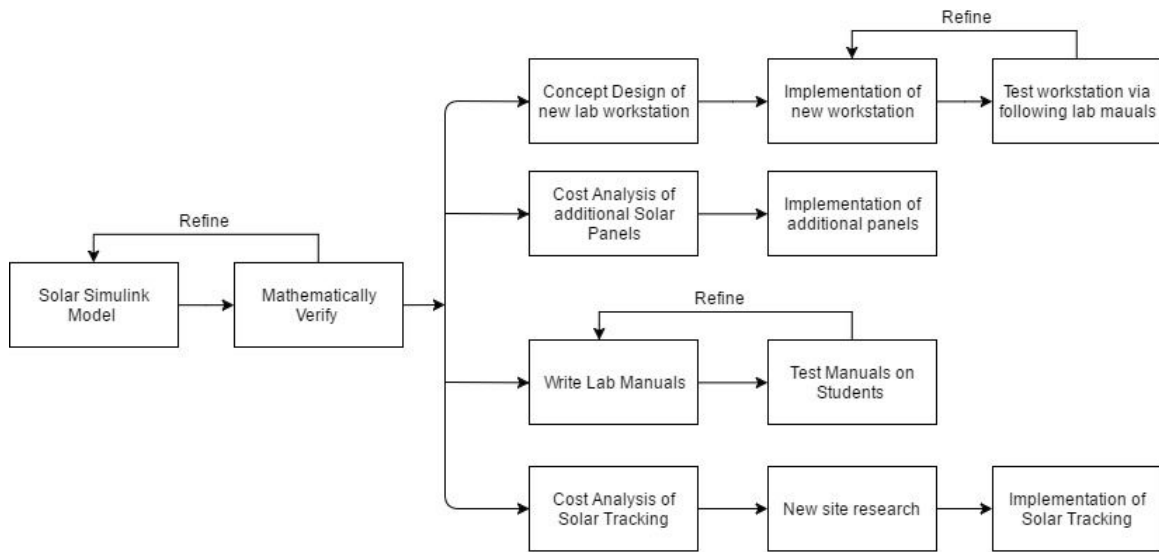
### 4.2 PROCESS

For testing of the model, we mathematically proved that our model was accurate. We used equations for the PV, Booster, conservation of energy, the diode equation and more. The last portion we of simulation we need to complete is adding a battery to the model. Once this is tested and mathematically verified we can begin the next stages.

When we get a concept idea of how the workstation should be set up, we will present the design to Prof. Ajarapu. We will then refine the design in accordance to his thoughts. When everyone agrees on the initial design we can implement the workstation. Once the station is complete, we can test the functionality of the space by doing the lab manuals (either ours or the other groups) and see if the station meets specifications.

Lab Manuals are the most important aspect of our project. To see if the manuals meet our specifications, we will have to complete the lab manuals ourselves as well as have other Electrical Engineering students attempt the lab. Lab reports will be used as a measure of how well the test subjects learned the material. Changes can be made based off of this data.

Cost analysis of solar tracking and additional panels do not require additional testing. If the cost analysis proves that having these systems would be beneficial to implement, then we can move forward with these subjects. More than likely do to time and budget constraints, this would be passed on to another senior design group the following semester.



## 5 Results

To prove that our design is providing maximum power to the load, first need to know what the maximum power is. In order to achieve max power, the impedance of the PV cell needs to match the impedance of the load. We used the simulink model of the PV cell for our specific model of solar panel. Table 1 shows our results of maximum power at various irradiance levels. This is consistent to what is found on the solar panel datasheet.

We know that impedance matching is the key to getting maximum power. The booster circuit in our design should change the effective resistance ( $R_{eff}$ ) seen by the PV cell.  $R_{eff}$  can be adjusted by changing the duty cycle of the MPPT. To test if the model is working correctly we can compare our power results to that of maximum power. We can also compare the  $R_{eff}$  to the load resistance that should give us maximum power. Results from this test can be seen in Table 2.

Based off of the results of table two, our simulation results were close enough to our calculated results to call the model successful. The accuracy of the model is highly dependant on the change in duty cycle provided by the MPPT. By decreasing the step size we can get more accurate results. The trade off is that it takes much longer to reach the max power point. Currently, we have the step size of 0.005 per iteration.



## 6 Conclusions

Summarize the work you have done so far. Briefly re-iterate your goals. Then, re-iterate the best plan of action (or solution) to achieving your goals and indicate why this surpasses all other possible solutions tested.

The generated project plan is to continue developing a simple understanding of the concept, model, design, proposal, implementation, and testing. This design method will be applied to the three goals which will be attempted. These are redesigning lab equipment, implementing additional solar panels, and implementing a sun tracking system. These three ideas should occupy the entirety of the two semesters along with the documentation and paperwork that will be involved in the process. Hindrances along the way will be communication as well as budget and understanding. We have laid out the methods and time line the group must follow in order to develop and expand the current solar and wind generation to be more user friendly and educational for future EE 452 lab students.

## 7 References

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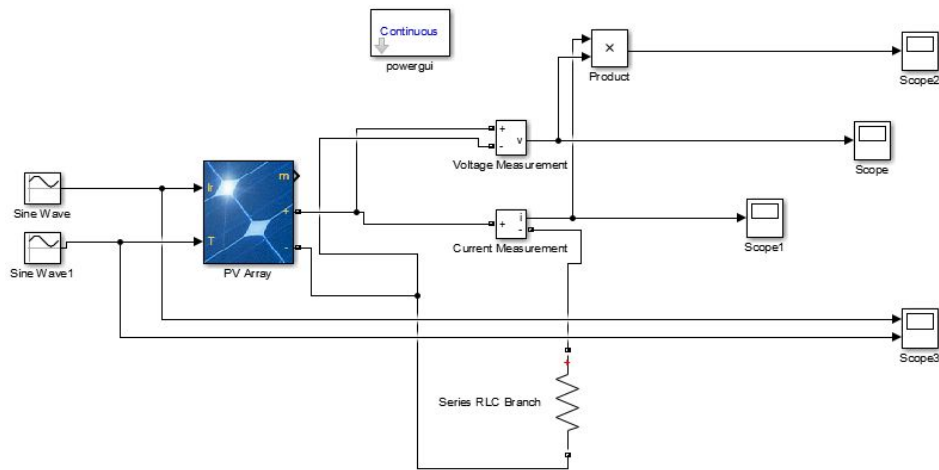
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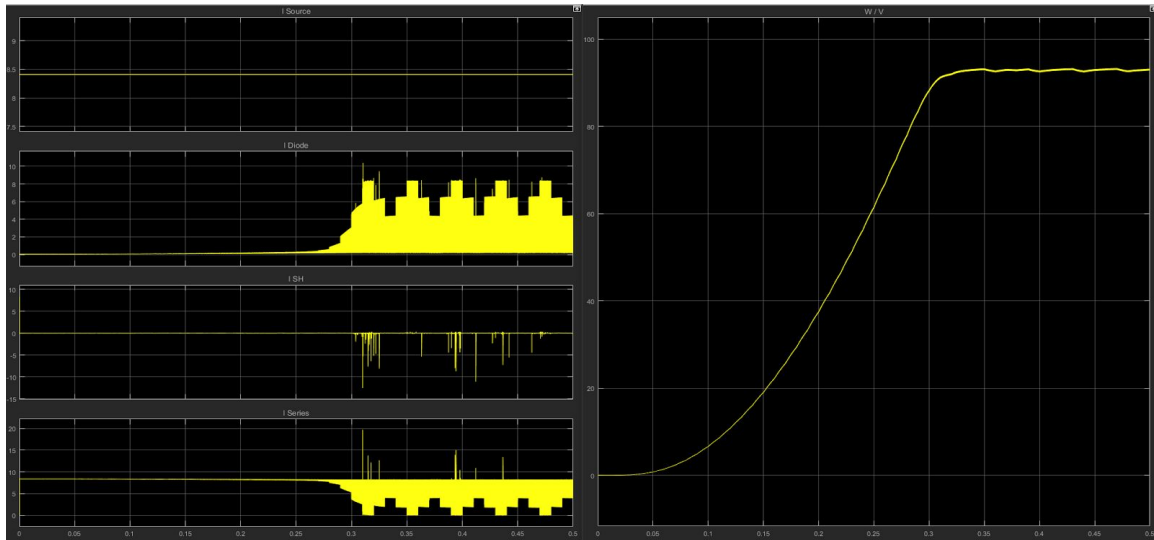
## 8 Appendices

If you have any large graphs, tables, or similar that does not directly pertain to the problem but helps support it, include that here. This would also be a good area to include hardware/software manuals used. May include CAD files, circuit schematics, layout etc. PCB testing issues etc. Software bugs etc.

Solar cell model Fig 1:



Solar cell Currents (Diode Model) Fig 2



Solar cell (Diode Model) Fig 3

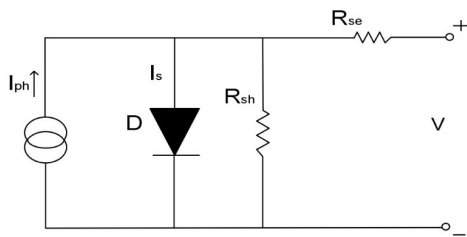


Table 1

IRR 1000(m <sup>2</sup> /W)					IRR 600(m <sup>2</sup> /W)					IRR 200(m <sup>2</sup> /W)				
Temp (C)	R (ohms)	Voltage (V)	Current (A)	Power (W)	Temp (C)	R (ohms)	Voltage (V)	Current (A)	Power (W)	Temp (C)	R (ohms)	Voltage (V)	Current (A)	Power (W)
25	0.1	0.8	8.4	7.0	25	0.1	0.5	5.0	2.5	25	0.1	0.2	1.7	0.3
25	1	8.2	8.2	67.4	25	1	5.0	5.0	24.7	25	1	1.7	1.7	2.8
25	1.5	12.2	8.1	99.2	25	1.5	7.4	4.9	36.7	25	1.5	2.5	1.7	4.2
25	2	16.00	8.00	128.0	25	2	9.8	4.9	48.3	25	2	3.3	1.7	5.6
25	2.5	18.27	7.31	133.5	25	2.5	12.2	4.9	59.7	25	2.5	4.2	1.7	6.9
25	3	19.2	6.4	122.9	25	3	14.6	4.9	70.8	25	3	5.0	1.7	8.3
25	3.5	19.7	5.6	111.0	25	3.5	16.7	4.8	79.9	25	3.5	5.8	1.7	9.6
25	4	20.1	5.0	100.6	25	4	18.1	4.5	82.3	25	4	6.6	1.7	10.9
25	5	20.5	4.1	84.1	25	5	19.3	3.9	74.8	25	5	8.2	1.6	13.6
25	10	21.3	2.1	45.5	25	10	20.7	2.1	42.8	25	10	16.1	1.6	25.8
25	20	21.7	1.1	23.6	25	20	21.2	1.1	22.5	25	20	19.7	1.0	19.3
25	50	22.0	0.4	9.6	25	50.0	21.5	0.4	9.2	25	50.0	20.4	0.4	8.3
25	80	22.0	0.3	6.1	25	80	21.6	0.3	5.8	25	80	20.5	0.3	5.3
25	100	22.0	0.2	4.8	25	100	21.6	0.2	4.7	25	100	20.6	0.2	4.2

Table 2

	A	B	C	D	E	F	G	H	I
1	<b>Parameters</b>								
2	Load	50	ohms						
3	Inductor	6*10^-6	Henry's						
4	Capacitor	324*10^-6	Farads						
5	Frequency	16000	Hz						
6	Irradiance	600	W/m^2						
7	Temperature	25	C						
8	Duration of Simulation	0.7	S						
9									
10									
11	<b>Measurements</b>								
12	Duty Cycle	V (Volts)	I (Amps)	Measured V/I(Ohms)	Calculated(Ohms)	%error	V*I		
13	0.5	20.9	1.7	12.29411765	12.5	1.6%	35.53	Watts	
14	0.55	20.71	2.082	9.947166186	10.125	1.8%	43.11822	Watts	
15	0.6	20.3	2.597	7.81671159	8	2.3%	52.7191	Watts	
16	0.65	19.91	3.308	6.018742443	6.125	1.7%	65.86228	Watts	
17	0.7	18.84	4.254	4.42877292	4.5	1.6%	80.14536	Watts	
18	0.75	14.98	4.849	3.089296762	3.125	1.1%	72.63802	Watts	
19	0.8	9.79	4.917	1.991051454	2	0.4%	48.13743	Watts	
20	0.85	5.62	4.966	1.13169553	1.125	0.6%	27.90892	Watts	
21	0.9	2.55	5.001	0.50989802	0.5	2.0%	12.75255	Watts	
22	0.95	0.667	5.023	0.13278917	0.125	6.2%	3.350341	Watts	
23	1	0.005031	5.031	0.001	0	N/A	0.025310961	Watts	
24					Req = (1-D)^2*Rload				
25									
26	<b>Max Power Point</b>								
27		3.8766234	Ohms						
28		82.42	Watts						
29	Calculated Duty Cycle	0.7215535							
30	Measurements								
31	Volts	17.75							
32	Amps	4.647							
33	V/I	3.8196686	Ohms						
34	Power	82.48425	Watts						
35									