Solar Instrumentation Lab

By: Rene Canedo & Rong Gui Chen

Project Advisor: Dale Dolan

Senior Project

ELECTRICAL ENGINEERING DEPARTMENT

California Polytechnic State University

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Abstract

This project is a mobile platform that will allow experiments on different solar panels to be done easily while keeping the cost of the lab to a minimum. California Polytechnic State University's motto is 'learn by doing' and this lab structure will allow students to get practical experience with photovoltaic cells and the instruments that are required to take measurements. The solar instrumentation lab is a potential hardware lab for the electrical engineering department's Sustainable Electric Energy Conversion class EE 420 and Solar-Photovoltaic Systems Design EE 520. This group took the current solar structure as a base for the lab's functions and also the input from professors who would be running these solar labs as to what they would like to see in future labs and incorporated their suggestions into the solar structure capabilities. The result will be a user friendly mobile solar lab on which students can perform experiments that is affordable for the electrical engineering department.

I. Introduction

The solar instrumentation lab is a structure mounted on a cart that gives the person a user-friendly platform in which to do several solar panel experiments. The electrical engineering department at Cal Poly San Luis Obispo currently has a structure that allows some measurements to be taken easily with one pair of 50W panels. The panels output in this set up can be put in series or parallel and their individual and combined output voltages and currents can be read by a volt and ammeter provided on the platform. Voltage readings can also be taken at points after the charge controller, at the battery, and before and after the inverter. The current lab has two very big limitations which are the angle of the solar panel only having two settings, fully extended and perpendicular to the ground, and the expense of the lab itself which restricts the amount of platforms that can be provided. The new solar lab overcomes these limitations and provides even more features including the use of different sized panels and the ability to lock the panel at the desired angle in case of accidental movement of the panel [3]. The lab will also have containers that can hold the instruments such as an infrared thermometer, multimeter, irradiance meter, and a digital compass. The new solar instrumentation lab is inexpensive and easy to build so several of these carts can be constructed to accommodate a large laboratory class.

II. Background

The world is quickly changing and the once thought of infinite resource of fossil fuel is running out. A new power source is needed to keep up with a planet's ever increasing need for power. Everything runs on electricity from cars to books to the simple toothbrush. The electricity needs to be produced from another source other than oil and coal, and that is solar energy which is a renewable source. Unlike coal and oil that pollute the planet and are limited, the sun will shine every day and provide solar energy

The call for renewable energy and cleaner air has been put into a goal by the Obama administration for 80% of the nation's energy to come from clean resources such as solar energy by the year 2035 [4]. In order to achieve the advances necessary to meet this goal education needs new lectures and tools to teach upcoming engineers the workings of solar technology so they can have a strong impact in the energy field. Cal Poly San Luis Obispo is currently developing such courses such as Sustainable Electric Energy Conversion and needs a hardware lab to add practical knowledge to the class. The goal of these courses and tools is to produce more knowledgeable engineers who will drive the Earth to a cleaner and better future.

III. Requirements and Project Specifications

Solar Instrumentation Lab Features:

1. Angle Control from 0 degrees (facing flat upward) to 90 degrees
2. Locking system for panel angle.
3. Variable sized platform for different panel sizes (50w 25.2" x 25.7", 125w 58.9" x 26.5" and 200w 58.3" x 39.1").
4. Allows different configuration of panels (series or parallel).
5. Angle measurement.
6. Voltage and Current measurements.
7. Control of radiation intensity using filters.
8. Easily transportable.
9. Easily constructed.
10. Storage for equipment.
11. Much less expensive than current solar demonstration lab.

IV. Design and Construction Process

The design process was broken down into five steps: research, concept design, 3D design, component selection, and construction. Research provides a direction for the entire project by finding which experiments would be useful in teaching how photovoltaic cells react to the environment and what equipment is available to build such a lab. The next step was concept design where several different sketches of the general layout of the lab were evaluated for look and functionality. The approved designs were drafted into 3-D using Google sketch to check for any more design flaws unforeseen through 2D sketches alone and were later used for blueprints for construction. Along the design phase a concept design or 3D model may not be completely dismissed but require modification on the original design. Once the 3-D model was chosen components from different brands were compared using the information from the research step and the chosen parts were ordered through the school. Finally the entire structure was built using the 3-D model as a blueprint.

A. Research

The first step was to see how off grid solar installations were set up and what do the professionals use to take useful measurements. The basic setup for a household solar installation is panels to the charge controller which leads to the battery; the battery's charge goes to a sine wave inverter which leads to the plugs in the household (shown in Figure 1).

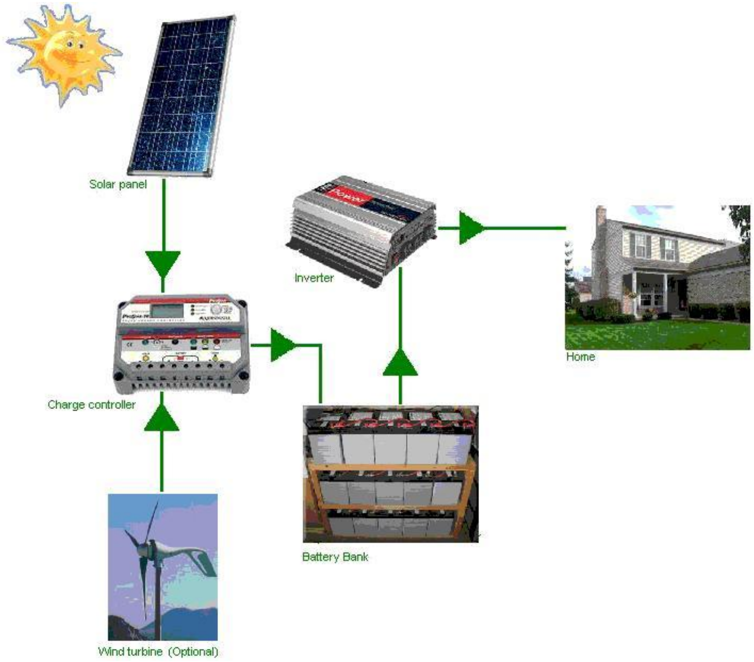

Figure 1 Basic setup for household solar system

The group interviewed the owner of AM Sun Solar, a local solar installation business in Atascadero, to discuss their installation methods and for advice on what devices to use. They provided industry experience and recommendations such as using unistrut for the frame for its flexibility and large selection of parts that are designed to work with its channel. They also explained different mounting techniques for solar panels that they personally use onsite and gave a demonstration of their exhibition tools.

The appropriate circuit diagram is needed to make sure to have access to all important data in the solar lab. The electrical connection set up for the solar lab lets the user take current and voltage readings at each individual panel and the output of the two panels. The user can also take voltage readings before and after the charge controller, the battery, and the sine wave inverter to see how

voltages change throughout the solar installation. The circuit diagram in Figure 2 shows how testing points for the solar installation are provided.

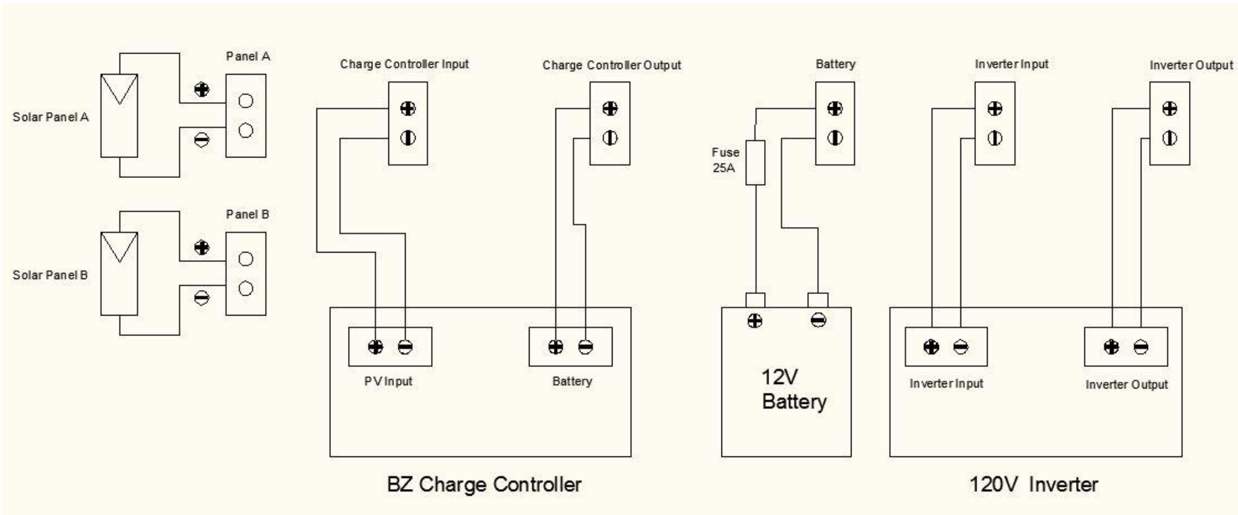

Figure 2 Circuit diagram

B. Concept Design

The precursor to this project is a solar photovoltaic trainer that the electrical engineering department currently owns. The group took the good features from the lab while trying to overcome its limitations such as no angle control and its high cost. Each concept was evaluated for appearance and functionality and the accepted ones would be turned into 3D figures for further evaluation.

1. Concept Design # 1

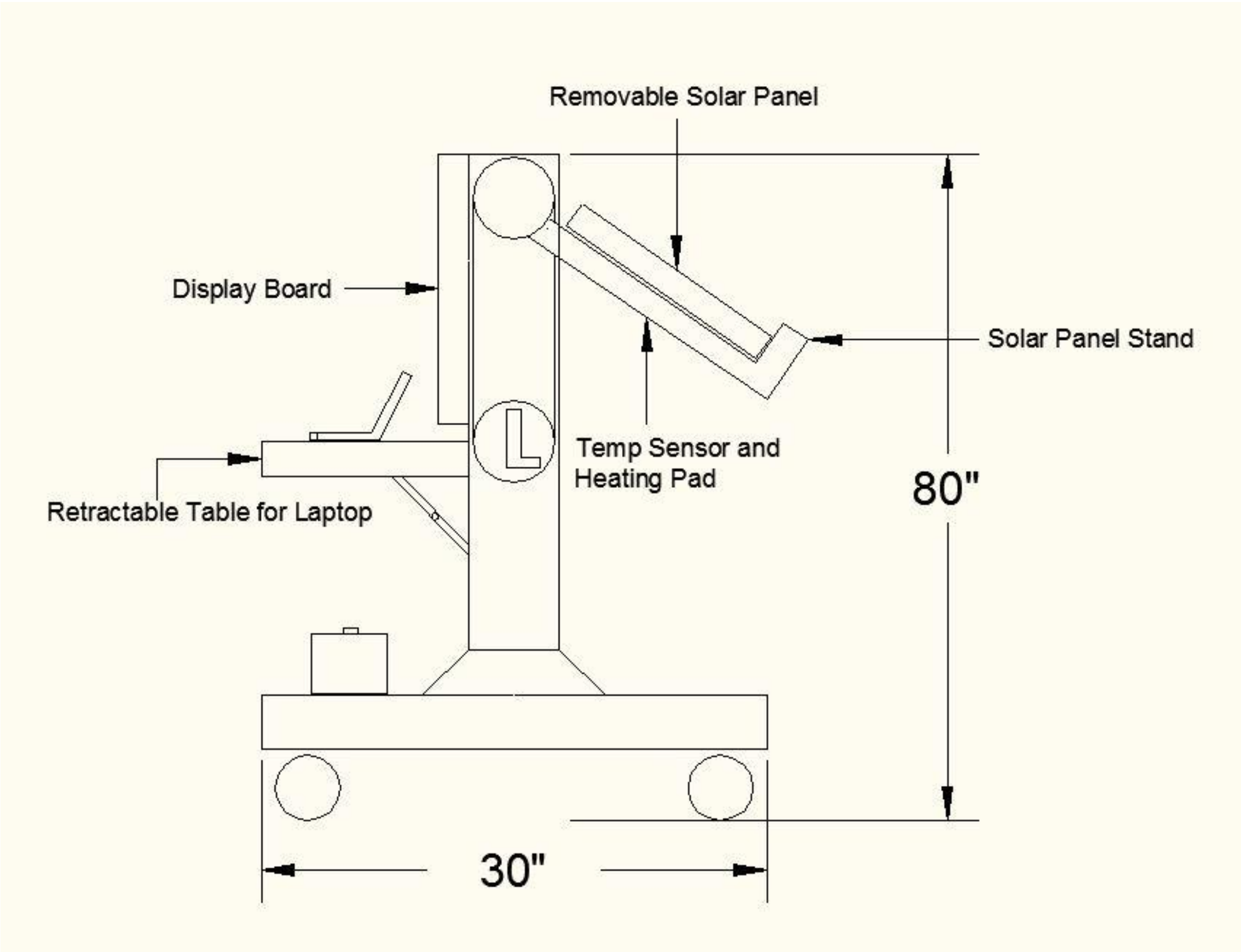

Figure 3 Concept Design 1

This concept drawing has a crank and chain system so as user turns the crank, the motion is transferred to the gear on top to spin the shaft which is connected to the base of the solar panels. The user will be able to lock the crank thus, locking the position of the panel. Heating pads are attached to the bottom of the panel to control the temperature of the panels to measure the loss of efficiency due to temperature. The base is the same as the solar trainer with a U-frame base on the bottom to support the structure.

The group and faculty advisor rejected this concept due to its system of chains and pulleys which over complicates the system and there are better alternatives to the suggested system.

2. Concept Drawing # 2

The concept drawing was modified to use a cart to hold the different instruments and the shaft control system was simplified to avoid the use of cumbersome cranks and chains to control the panels. The current concept design uses a 30”x 60” cart with 2”x 6” boards on each side of the cart and a rotating shaft going through them. The shaft is connected to a pegboard through pipe clamps and sheet metal screws to ensure the base stays attached to the shaft. At the point where the board meets the pipe a larger diameter but smaller length pipe surrounds it and is secured with floor flanges against the 2x6 and a coupling attached at the end. This allows a large diameter screw to be placed through the coupling and outer pipe to put pressure against the inner pipe thus holding it in place. The angle control is done manually and is locked with the screw against the inner pipe.

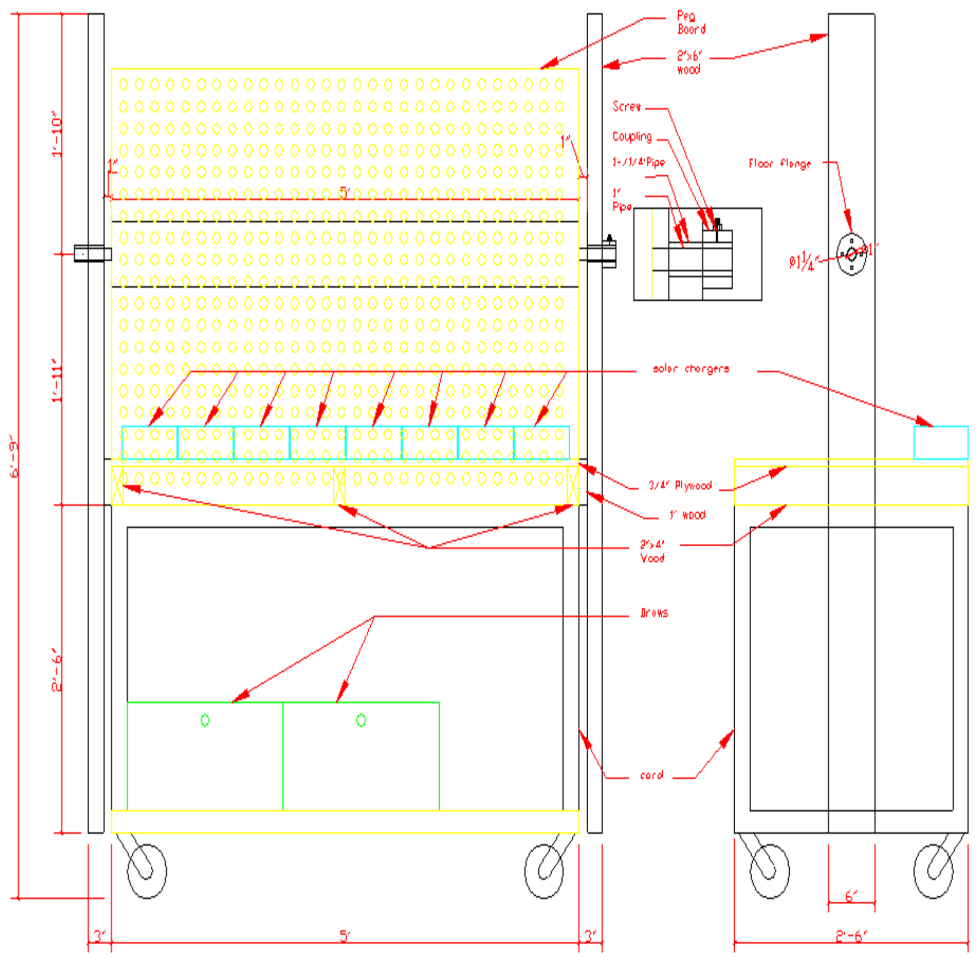

Figure 4 Peg Board Concept Design

All of the instruments needed are in the cart and the user can take measurements and set up the configuration conveniently on the top of the table. To switch out the panel the user must remove the screws of the current panels and reinstall the new panel by lining up the holes of the

pegboard with the solar panel. The electrical connections can be switched out by lifting the top of cart and making appropriate connections. This design went to the 3D design phase for its simplicity and flexibility with adjustments later down the design process.

C. 3D Design Stage

The 3-D model gives a clearer picture of the potential final design and its flaws. All of the models must take into consideration the measurements of the door which is 34”x83” and the longest width and length of the panels which is 30”x64”.

1. 3D Model of Concept Design #2 – Peg board design

The peg board acts as a base for the solar panel and the numerous holes will be the points where the panel is secured. The coupling and floor flange prevents the shaft from scrapping and wearing away the wood. The outer diameter pipe with a threaded hole for a bolt will act as the break; by screwing the bolt down it will apply pressure against the conduit, holding in position.

This exact model was not improved because there is a strong possibility once one side of the panel is secured, the other holes will not line up with the panel and the panel will not be sufficiently secured. Also in order to get a peg board of the desired size, two peg boards would have to be placed side by side, which would negatively affect its appearance

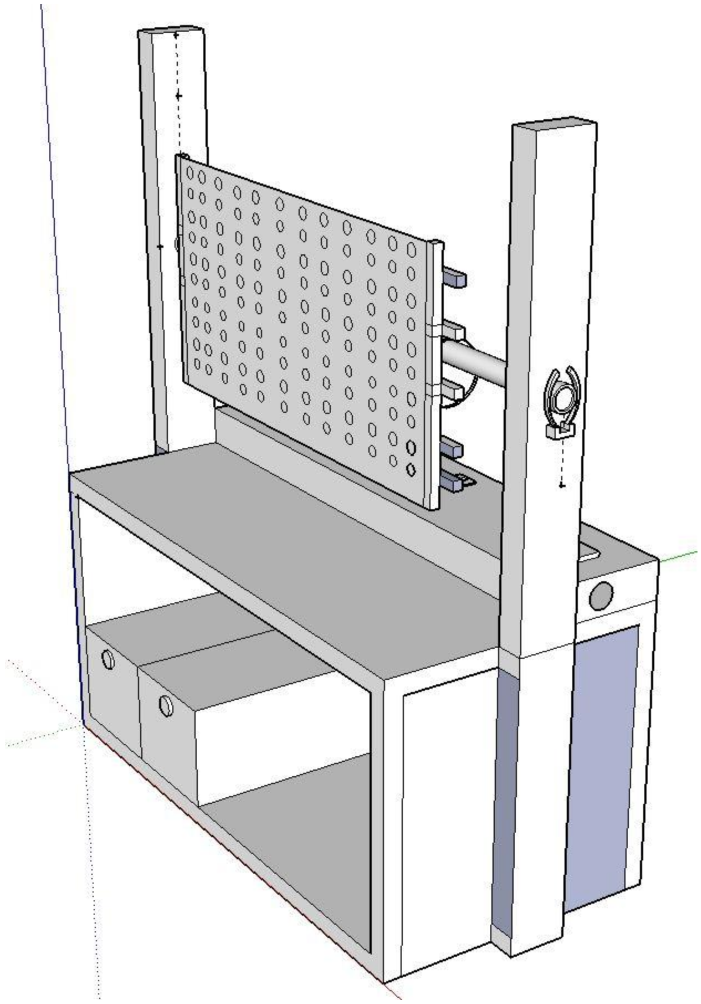

Figure 5 Peg Board 3D model

a. 1st Modification of Design Concept #2- Unistrut frame

Instead of completely throwing out the Peg board design the model was modified with a new frame system and braking system. The frame is made up of unistrut, a metal rectangle tube with holes throughout the base used in industrial and electrical industries for light structural support. The nuts are specially designed to the unistrut so it fits in the channel and can travel through the pipe to any location. The vertical channel is stationary and acts as the rail for the horizontal channels, once the channel is lined up with the panel the bolts are secured with the nuts already

in the horizontal channel. Once the horizontal unistrut is locked in place, the panel is secured against the frame by finding where the holes of the panel and the unistrut line up and using a cone nut on the inside of the panel base and a bolt going through the other side. This system uses the holes of the unistrut which are much larger than the holes of the panel to ensure that there is an available point to secure the panels and uses the channel as a rail to easily change the size of the frame to accommodate any size panel.

The brake was also modified to use a pipe clamp to assert the pressure instead of a screw because the screw has a small contact area with the pipe which would not offer enough braking power. The pipe clamp is curved so it has more contact area which will hold the panel in place. The 3D model can be seen below in Figure 6. This design was used for the construction stage of the project but some of the aesthetic qualities such as the placement of the plates and the location of the charge controller are changed.

The storage system was changed because of a storage containers benefits over the sliding drawers. The containers were about $50 cheaper and held more material than the drawers did. The sliding drawers do look nicer but not advantageous enough to justify the price.

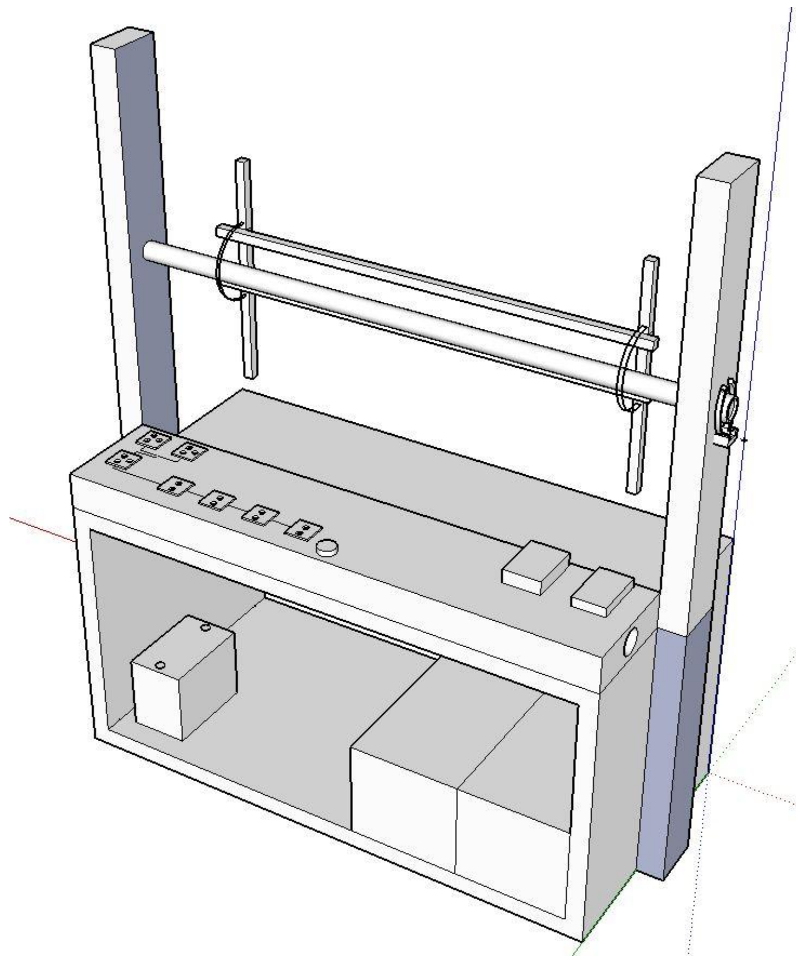

Figure 6 3D Unistrut Frame Model

D. Component Selection

There are hundreds of different types of equipment available in the market place from just as many suppliers so components must be selected systematically to find the best one to reach the objective. The main components are the charge controllers, battery, inverter, and the cart, which the entire structure is going to be on. The following component selections are what would be ideally be used for this project but isn't necessarily on the project due to external conditions such as the use of the component for another project or already being in possession of another brand.

1. Charge Controller Selection

The characteristics for the charge controller are flexibility, functionality, and price. Table 1 shows the side by side comparison of seven different charge controllers. The BZ MPPT500 was chosen for this project because it is able to take voltages up to 100V. The MPPT500 is a Max Power Point tracking charge controller which bucks down the voltage to 12V and provides the extra power to higher current. The MPPT500 also has different charge point up to 48V which allows for different experiments with multiple batteries, giving the solar lab more flexibility. The range of the price averages $200; the next charge controller was about $100 more with much less tolerance for voltage. The MPPT500 was chosen over the MPPT500HV because the HV version is most efficient at array inputs of above 48V, which is going to be less common in these labs. The charge controller used for this project was the BZ MP 25, which is a PWM controller. This charge controller may be used in other projects or classes in the future. It would be interesting to see the bucking down of voltage and rise in current but that concept is for another class.

Table 1 Charge Controller Comparison

Charge controller	Variable Battery Types	Warranty	Solar Current Display	Charge Current Display	Battery Voltage Display	Trickle Charger	Input Voltages	Charge Points	Max Voc	Max Battery Current	Max Power	Price	Shipping	Notes
SunSaver MPPT	x	x					24,36	12,24	75	15.0	200W	200-240	12.00	
BZ MPPT250	x	x		x	x	x	12,24	12	50	25.0	250W	105-150	13.20	
BZ MPPT250HV	x	x		x	x	x	up to 100	12	100	25.0	250W	120-175	13.20	
BZ MPPT500	x	x	x	x	x		up to 100	12,24,48	100	45.0	500W	175-220	15.00	highest efficiency at lower PV input
BZ MPPT500HV	x	x	x	x	x		up to 100	12,24,48	100	45.0	500W	195-250	15.00	highest efficiency at 48V PV input
Blue Sky Solar Boost	x	x	x	x	x		up to 30	12	30	25.0	250W	220-350		
Xantrex XW MPPT60-150	x	x					up to 150	22251	150	60.0	3000W	520-600	50.00	

2. Battery Selection

The battery holds the charge generated by the solar panels and supplies the inverter with power; it is required to have enough capacity that it will not discharge too far so as to damage the battery. The battery characteristics beneficial to achieving the objective are enough capacity to run the inverter, maintenance, and price. According to Professor Ahlgren, he would like to run a couple of multimeters off of the inverter which consumes 10W each. The following calculations are used to find the minimum capacity.

$$P_{required} = P_{min} * safety\ factor = 20W * 1.2 = 24W$$

Equation 1: Minimum Power Capacity

$$24W * 10hours = 240Wh$$

$$240Wh * leeway = 240Wh * 1.1 = 264Wh$$

$$\frac{264Wh}{12V} = 22Ah$$

The battery should not be discharged past 50 percent to prevent damage.

$$22 * 2 = 44Ah$$

The battery should at least be able to hold more than 44Ah.

The Sun Xtrender Pvx-690T was chosen because it passed the minimum capacity with some to spare in case more power is required to run the inverter. The battery is an AGM which is about $60 more, but at worst case the AGM lasts twice as long as the Gelled batteries. The AGM batteries also require very little maintenance which is useful over the summer where there might

not be anyone to refill the battery (which is needed for flooded batteries). The battery comparison is shown below in Table 2.

Table 2 Battery Comparison

Battery Name	Battery Types			Amp/hr	Voltage	Price($)	Weight (Lbs)	Maintenace Free	Spill proof
	Gelled	Flooded	AGM						
MK battery S22nf	x			50.9Ah	12v	167.12	37.00	yes	yes
MK Battery 8G40-DEKA	x			40Ah	12v	141.00	32.00	yes	yes
Sun Xtrender Pvx-690T			x	69Ah	12v	205.85	51.00	yes	yes
West Marine group 27		x		90Ah	12v	150.00	39.00	no	no
Trojan 27 Tmx		x		115Ah	12v	144.35	55.00	no	no

3. Irradiance Meter Selection

Table 3 Irradiance Meter Comparison

Product				Watt/M^2	LCD Reading	Price ($)
	<5% Accurate	Data Saving	Different Wave Length			
Daystar DS-05A Digital Meter	Yes	No	No	0-1200	Yes	155.0
Digital Solar Power Meter	Yes	Yes	No	0-2000	Yes	165.0
Radiometer UVA Sensor	Yes	No	Yes	0-20 mW/cm2, 0-2000 uW/cm2, 0-200uW/cm2	No	596.0

The irradiance meter helps measure the efficiency of the solar panel by comparing the power generated to the power available to the panel. The higher end irradiance meters such as the

Radiometer UVA sensor can measure the irradiance coming from different wavelengths and so its price is much higher. The extra function is not worth the extra $450 and does not add enough value to reach the project's overall objective. The Digital Solar Meter can sense a wider range of irradiance and saves the data which can be referred to on the irradiance meter's display for the price increase of $10.

The measurements were taken with the DayStar DS-05A Digital Meter because the local solar installation company was generous enough to loan us theirs.

4. Cart Selection

Table 4 Cart Comparison

Carts	Rubber Wheels	Unassembled	Sliding Drawers	L" x W"	Capacity (LB.)	Price ($)
CJ579223 Utility Cart	Yes	Yes	No	60 x 30	1200	327.10
CJ502603P Utility Cart	No	No	No	36 x 24	1200	403.43
Waterloo - 3-Drawer Metal Utility Carts 3 Drawer Metal	Yes	Yes	Yes	34" x 20.75"	750	353.00
Stainless Steel Equipment Utility Cart	Yes	Yes	Yes	36" x 20"	500.00	1260.00

The cart is one of the most important components for the structure of the laboratory. The cart must be able to go through the door of the room that it is being stored in and long enough to hold

the longest solar panel between its posts. The posts can be extended a bit but the length of the cart is the deciding factor on the longest panel that it can hold. The solar lab also needs to be able to travel outside so it must be durable enough to traverse cement and grassy areas.

The Waterloo and the Stainless steel equipment utility cart both have drawers which would eliminate the need to install other ones. Unfortunately, they are too short to be of use; carts that have drawers are usually used to transport tools, not to carry large items so the carts with drawers are usually shorter.

The CJ579223 utility cart was chosen over the CJ502603P because of its size difference and it arrives unassembled which saves around $60 for fifteen minutes of extra work.

5. Inverter Selection

Table 5 Inverter Comparison

Inverters	Output Watt (Watt)	Pure Since Wave	THD<5%	Frequency	Peak Efficiency (%)	Peak Power Rating (Watt)	Input Voltage (V)	Price ($)
MorningStar SureSine Inverter	300W	Yes	Yes	50 or 60Hz	92	600W	10-15.5	191.27
Samlex ssw-350-12A	350W	Yes	No	60Hz	89	700W	10.5-15	129.00
Xantrex XS400	400W	Yes	Yes	60Hz	88	800W	10.3-15.3	449.00
TruppLite PV375	375W	No	No	60Hz	N/A	600W	12.00	72.00

The inverter takes in the voltage from the DC battery and converts it to AC voltage. There two types of inverters in this comparison are true sine wave inverters and twelve step sine inverters; the true sine wave outputs a voltage sine wave with less total harmonic distortion than the twelve step inverter. In order to run sensitive equipment such as the multimeters the THD must be less than 5%.

Only the Xantrex and the Morningstar have a THD less than 5%. The price difference of the inverters is $250 more for the Xantrex, it has a higher output power but that high output power is not required for the labs uses. The MorningStar SureSine Inverter was selected for the solar laboratory for its THD and lower price. The inverter used in the project is the Samlex 750W inverter because it will be used for another purpose besides this project.

E. Construction

An advantage of this solar lab design versus the previous model is being able to build them without having the ability to weld and the majority of the material is available at your local Home Depot. The following sections describe how to build the solar lab.

1. Wooden Post Construction

Table 6 Wooden Post Materials

Wooden Post		
Quantity	Item	Item Letter
2	56" 2x6 Wood plank	A
4	23" 2x6 Wood plank	B
12	5/8"x 5" bolt	C
12	5/8" washer	

12	5/8" nut	
2	1" 1/4 Floor Flange and screws	D
2	Pipe Coupling	E
1	Gray Paint	

a. Drill a 1 ¼" hole in both pieces of A as shown in Figure 7 making sure they are even.

b. Drill with 5/8" bit through one piece of A and two of B where the bolts are shown in Figure 7.

c. Drill with the 5/8" bit through the cart's shelves as in Figure 8.

d. Sand and paint the post. Several coats of paint are recommended.

e. Secure C bolts to the cart with the appropriate nuts and washers.

f. Attach floor flange D around the 1 ¼" hole.

g. Screw in coupling E in the floor flange.

h. Repeat the previous steps for the other post.

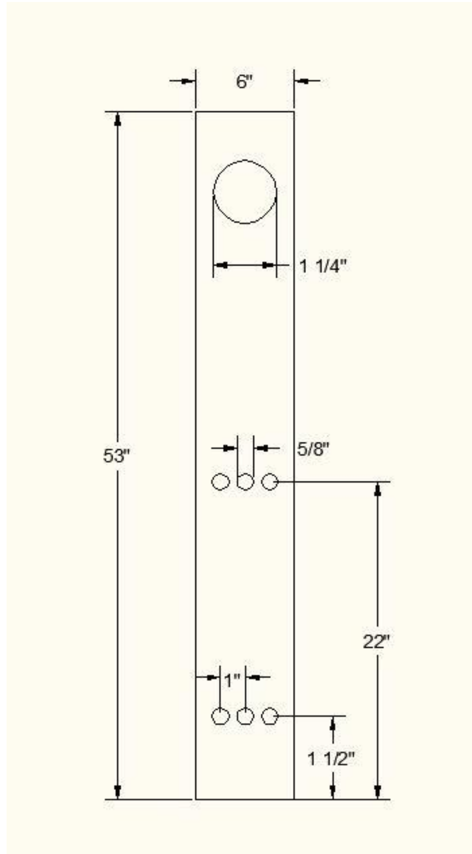

Figure 7 Wooden Post Design

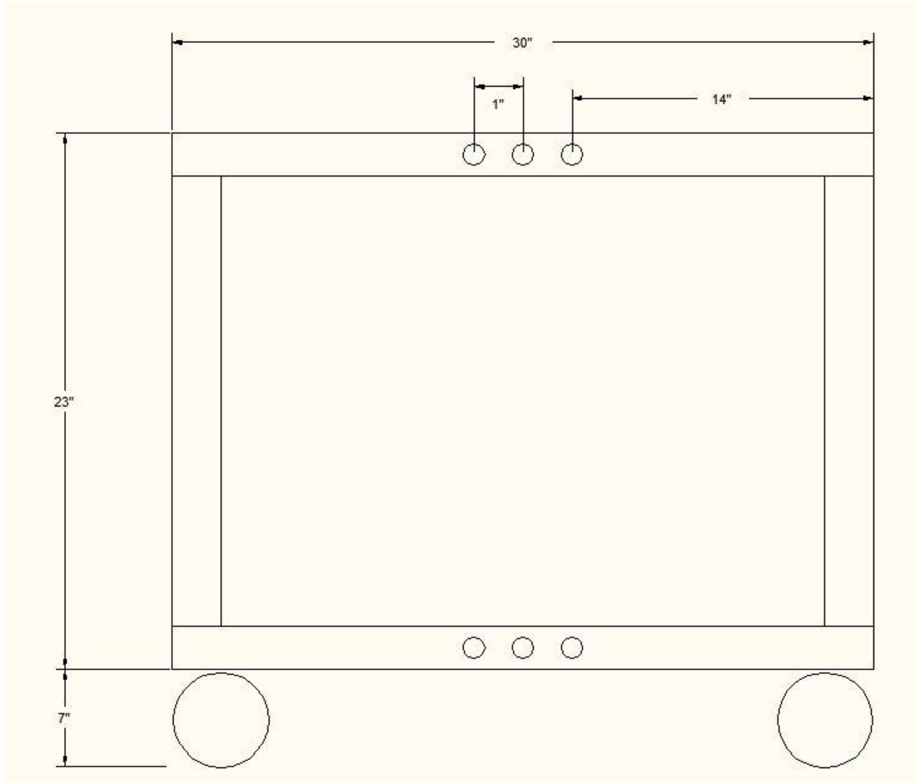

Figure 8 Hole layout for Wood Post

2. Wooden Box Construction

Table 7 Wooden Box Materials

Wooden Box		
Quantity	**Item**	**Item Letter**
1	60" 2x6 Wood plank	F
2	13" 2x6 Wood plank	G
1	Box of ¼”x2” wood screws	H
1	12” x 60” plywood (bottom)	I
1	11 ½” x 60” plywood (top)	J
1	Hinge	
1	White Paint	

a. Cut wood F and G according to Figure 9.

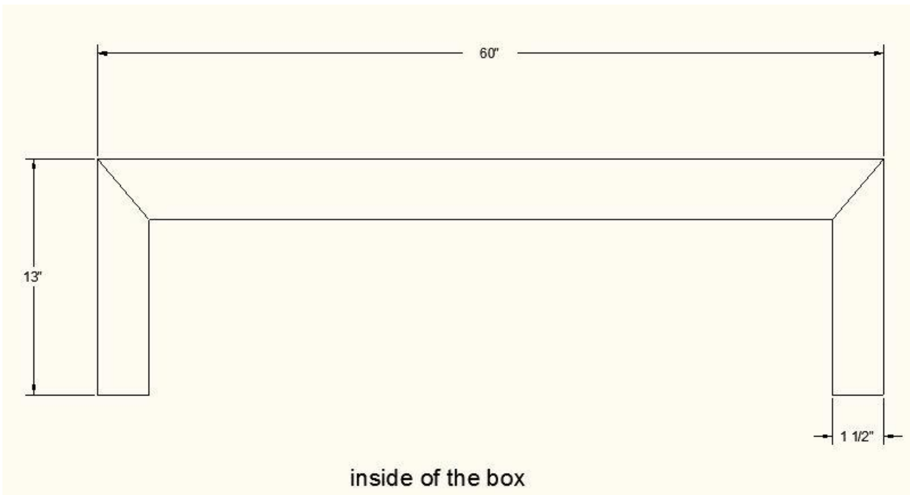

Figure 9 Box Plank Design

b. Apply several coats of white paint on the planks and plywood

c. Place plywood I against the cart and planks F and G on top of them.

d. Drill pilot holes underneath the top of the cart through the bottom of the box and into planks I and J where the screws will go.

e. Drill H screws to secure the box to the cart.

CAREFUL!! The next step is the most precise and if done wrong the entire top part must be redone.

f. Measure out the square hole large enough for the circuit board to go through plywood J but small enough for the top panel of the charge controller to lie on top of it. This gives about a .5 cm leeway.

g. Use the hole cutter to place a hole tangent to the border of the desired cut to take up as much of the inner border as possible. This will reduce the time guiding the saw manually.
h. Drill into plywood J using the hole cutter at the locations shown in Figure 10 for the banana plugs.

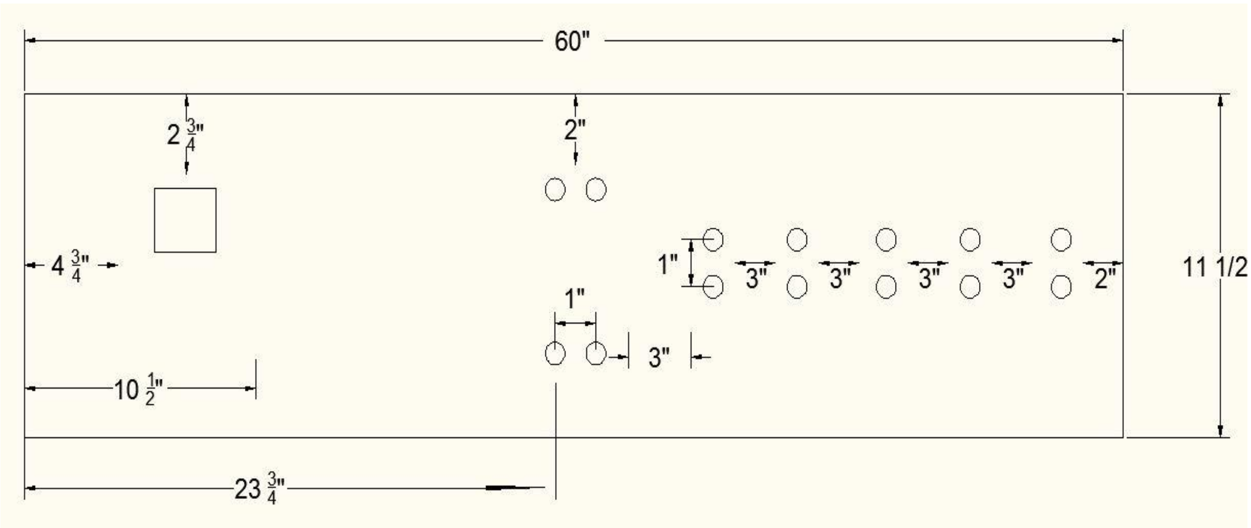

Figure 10 Box Lid Layout.

i. Drill through the left plank with a 5/8” hole bit
j. Drill the holes where the bolts will secure the plates using a ¼” bit.
k. Use the #6 machine screws and nuts to secure the plates against plywood J.
l. Install the hinge with the screws included in the kit.
m. Install the charge controller and place labels as shown in Figure 11.

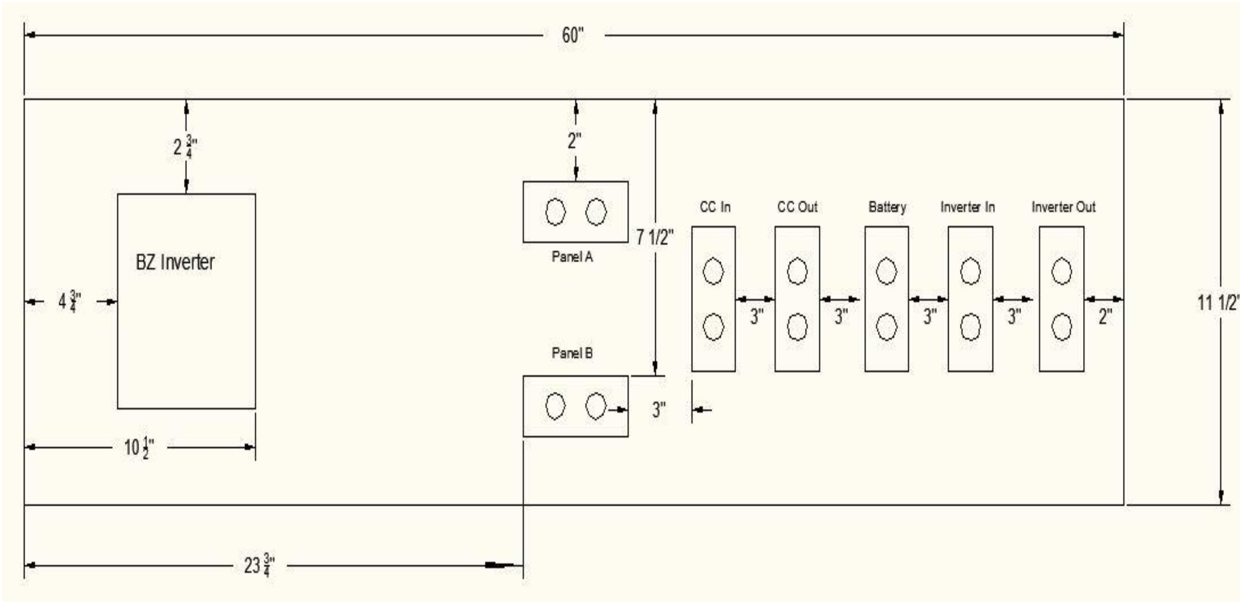

Figure 11 Box Lid Component Layout

n. Install Inverter as seen in Figure 12.

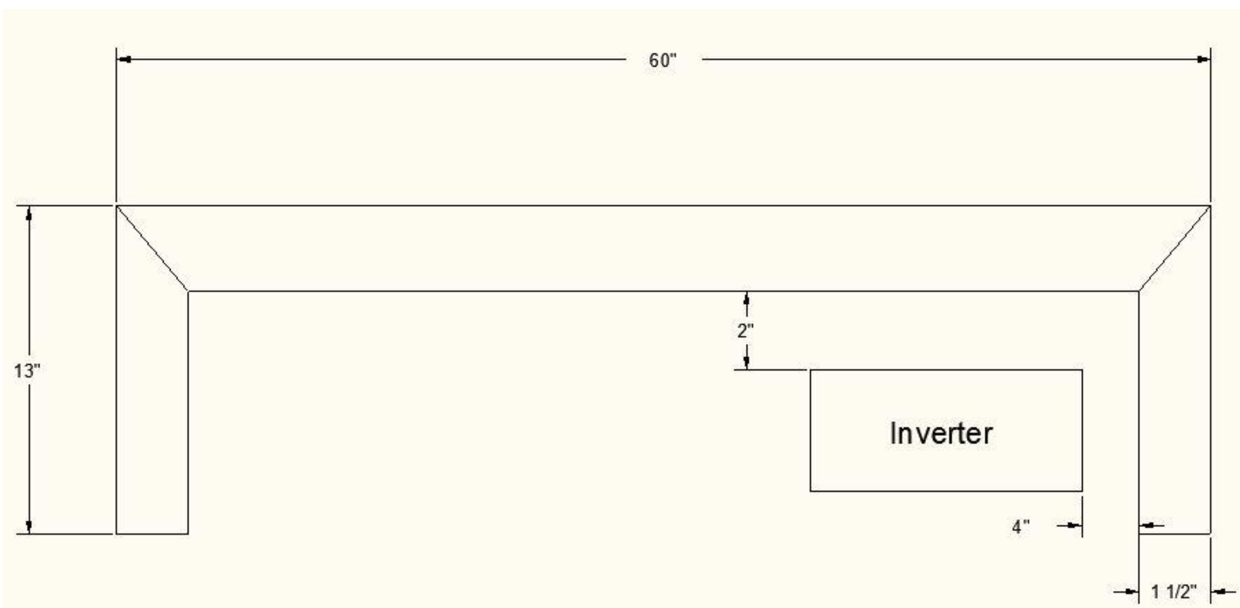

Figure 12 Lower Box Component Layout

3. Screen Clamps

Table 8 Clamp System Materials

	Clamp System	
Quantily	Item	Letter
2	2 Hole 90 degree bracket	K
2	90 degree bracket	L
2	1/2" x 1" Bolt	M
4	1/2" Nut	N
4	1/2" Washer	
2	1/2"x 1 1/2" Bolt	O
1	Super Glue	

a. Connect the 90 degree angle brackets K and L together as shown in Figure 13.

b. Glue nut N on top of the hole of angle bracket L to provide thread for the bolt.

c. Repeat the previous steps to make another one.

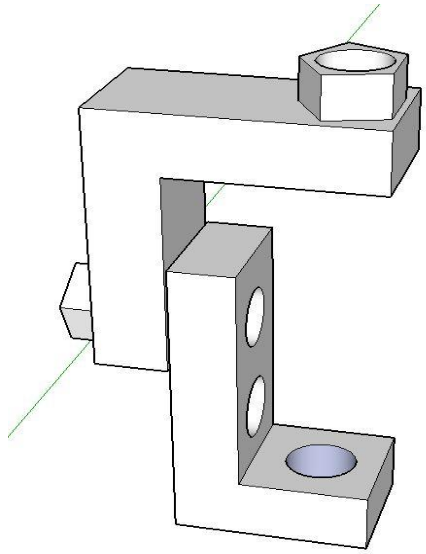

Figure 13 Clamp Design

4. Unistrut Frame

Table 9 Unistrut Frame Materials

Unistrut Frame		
Quantity	**Item**	**Item Letter**
2	12" Unistrut	P
2	44"" Unistrut	Q
1	64" Unistrut horizontal	R
2	50" Unistrut	S
2	1” pipe clamps	
1	66”conduit	
1	Box ¼” x ½” sheet metal screws	T
1	1/2"x3/4" bolt	U
1	1/4" fender washer	V
1	1/2" spring nut	W
1	1/4" cone nut	X
1	1/4" x 2" bolt	Y

a. Place the conduit in between the posts.
b. Attach the pipe clamps to the conduit and unistrut P.
c. Attach unistrut Q on the other side of unistrut P with bolt U, washer V, and spring nut W. The channel should be pointing away from the conduit and the spring nut spring should be removed.
d. Attach unistrut R for the horizontal piece with bolt U and spring nut W as shown in Figure 14, make sure not to tighten it until it is placed at the desired length, this will allow the vertical unistrut to act as a track for the horizontal unistrut.
e. Place another spring nut near the center of the top and bottom horizontal unistrut and attach the clamp.
f. Secure the panel by placing the cone nut S and the bolt T on the inside of the lip of the panel where there is an opening for both the unistrut and the panel, two on each side is more than enough to support any sized panel.

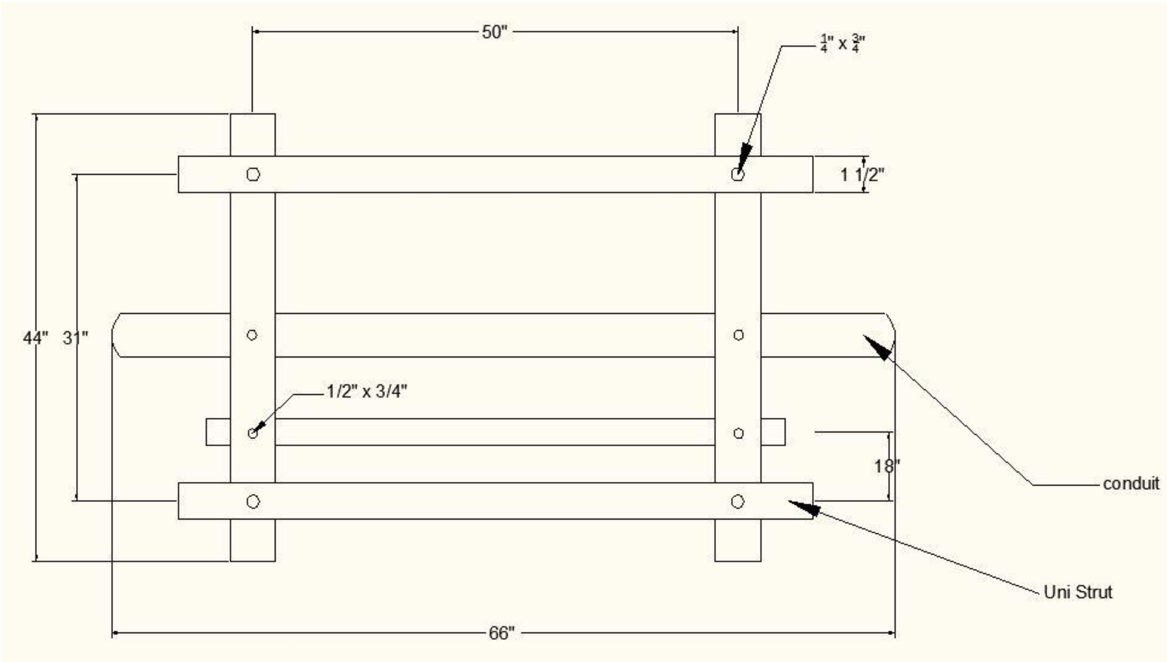

Figure 14 Unistrut frame

5. Electrical

Table 10 Electrical Materials

	Electrical Parts List	
Quantity	Item	Letter
15 feet	10 Gage Wire	
5 feet	12 Gage Wire	
7 feet	16 Gage Wire	
2	Battery clips	
1	Box of Spades	
1	10 Gage 30 Amp Fuse	
1	16 Gage 15 Amp Fuse	
1	Electrical Case	
1	1/4" x 1 " metal bolt	

a. Splice a 15 A inline fuse to the positive wire of the solar panel.

b. Splice a 16 gauge wire stranded to the positive and negative wires of the solar panel long. Enough to run through the hole on the left side of the box and reach the corresponding plates.

c. Splice the end with a spade and connect to the back of the corresponding banana plug.

d. Run 12 gauge stranded wire through the bottom of the charge controller.

e. Place wires into the positive and negative slots of the input and output by raising the screw with and flat head screwdriver and keeping it in place by lowering it.

f. Connect the wires from the charge controller to the appropriate plates.

g. Wire the battery to the plate and place an inline 30A fuse about 9” away from the battery on the positive wire.

h. Wire the inverter input to its corresponding plate.

i. Remove the three pronged plug side from the outlet side of your surge protector.

j. Open the wire revealing three wires, black, white, and green. The black wire is hot, the white is neutral and the green is ground.

k. Run the cable through the metal incasing and connect the green wire to the casing and the black to the positive banana plug and the neutral to the neutral plug.

l. Screw the casing against plywood J using ¼” x ½” screws.

m. Clean up the wiring using wire clips and zip ties, make sure to not tie the panel wire together with other ones because it will make changing panels more difficult.

6. Braking System

Table 11 Breaking System Materials

	Breaking System	
Quantity	Item	Letter
1	1 " pipe Clamp	Z
1	1/4" x 2 1/2" bolt	AA
1	1/4 Nut	AB
2	Lock washer	AC
1	6" 2"x4" wood	AD
1	6" Unistrut	AE

n. Drill Unistrut AE on block AD

o. Place block AD underneath the conduit on the inside of the right post.

p. Attach a small thin piece of rubber on the inside of pipe clamp Z using industrial strength glue. Wait a couple of hours to dry.

q. Install the pipe clamp around the conduit.

r. Bolt the tabs on the bottom together with bolt AA

V. Improvements for Solar Lab

The main improvement for the solar lab is the angle control system. An alternative to the brake system and the shaft control is the worm gear, which a gear that connects to the shaft through a key which fits into the gear. The gear is turned by a screw, or worm, that turns across the gear moving the gear which moves the shaft. The worm gear is naturally locking as the shaft cannot move the gear. Figure 15 shows a model of a worm gear.

Figure 15 Worm Gear

Another place for improvement is the quality of craftsmanship in the woodwork. The hinge can be more aesthetically pleasing by installing it in a notch in the back of the box. The plates can also be more precisely lined up using a laser straight instead of the chalk line that was used.

As for ease of measurements the tilt meter and the compass can be installed into the solar lab's structure so data can be taken from one specific spot and to free up the user's hands. Also the screen clamps can be set up on a stationary platform that covers the largest dimensions so the screen would be able to cover the entire panel.

VI. Potential Experiment

ELECTRICAL ENGINEERING DEPARTMENT

California Polytechnic State University

San Luis Obispo

EE 420 **Experiment #1**

Solar Panel Tilt Factor

Introduction

Solar panels are affected by many factors when exposed to the elements from the time of the year to the weather conditions for each day. The angle of the solar panel is one of the most important factors for efficiency that people have control of; with proper angle tilt efficiency will rise which means more electricity for less panels. The equation for calculating the efficiency of the panel is

$$Efficiency = \frac{P_{generated}}{Irradiance * Area} \text{ x } 100$$

Equation 2 Efficiency Equation

$P_{generated}$ can be found by measuring the array current and voltage and Irradiance can be found using the irradiance meter, and area is in the unit that the irradiance is in, usually meters. This gives you the efficiency of the solar panel.

Another important ratio is the solar panel tilt ratio which compares the max amount of power generated out of all angles against the power generated at a certain angle.

$$Tilt\ Efficiency = \frac{P_{angle}}{P_{max}}$$

Equation 3 Tilt Efficiency

In the northern hemisphere the most efficient year long orientation is true south which is different than south on a compass due to magnetic declination [2]. Go to http://www.ngdc.noaa.gov/geomagmodels/Declination.jsp to find the magnetic declination and adjust appropriately. If the declination is 5 degrees west then point your compass until it is five degrees west from south and then you are pointing to true south.

Procedure

1. Set up the circuit shown in Figure 16.

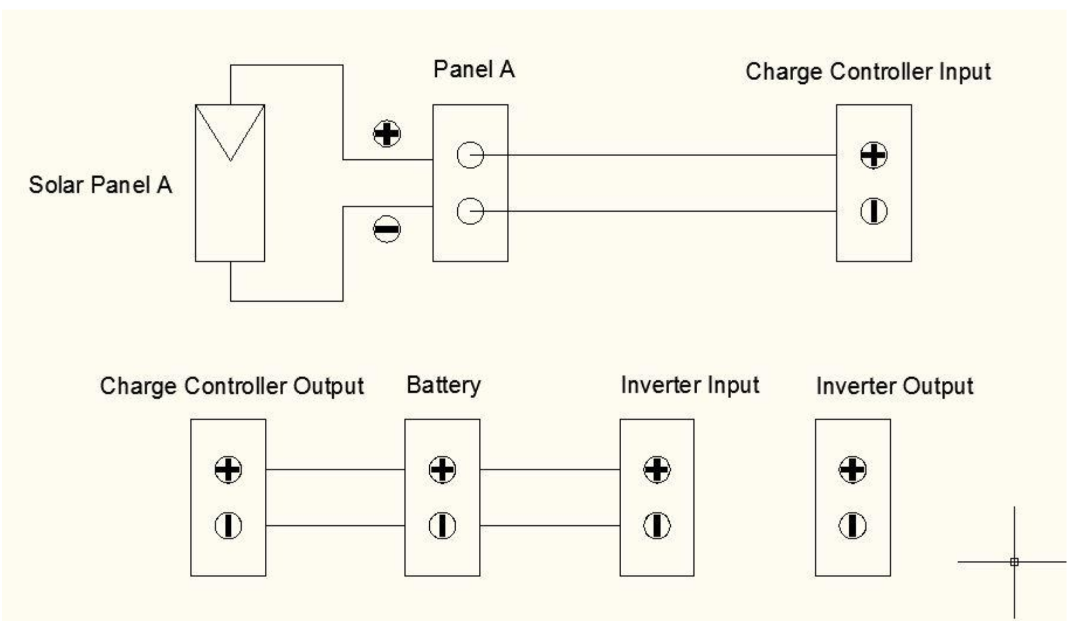

Figure 16 Solar Circuit

2. Orient the panels to true south which is not determined by the compass alone.
3. Using your protractor start from 90˚ which is perpendicular to the ground and record voltage and array current.
4. Record the time and date the measurement are being taken.
5. Move in steps of 5 degrees to 0 which is parallel to the ground.
6. Find the range where the panel produces maximum power.
7. Measure every two degrees around peak power angle up to ten degrees both sides.
8. Calculate the efficiency at every angle recorded.
9. Calculate the Tilt Efficiency at every angle recorded.
10. Plot Power vs. Angle.
11. Plot Efficiency and Tilt Efficiency vs. Angle.

Discussion Questions

1. What angle produces the most power?
2. Why is the time and date of the experiment important?

VII. Conclusion

Renewable energy is a necessity and will become more vital in the years to come. In order to keep with the demand, students must have practical experience with renewable sources such as photovoltaic cells. The solar lab offers this practical experience in a user friendly structure. Other solar labs such as the one purchased by the Electrical Engineering project are extremely expensive but necessary for the sake of their students. The solar lab designed in this senior project, with some modifications, can save the department thousands of dollars by building their own solar laboratories.

This project allows a platform for several types of solar panels to be tested and to simulate conditions that affect the efficiency of the solar panel such as shading and angle of the panel. The box on top of the cart allows students to interchange components for experimentation while giving teachers the flexibility to use the equipment that they choose to use. The banana plugs give students easy access to measurement points throughout the circuits and the configuration can be changed to simulate different systems.

The solar laboratory has room for improvement in function with the worm gear box that gives precise angle control and a natural braking to the shaft. The professionalism can also be improved with straighter lines and notched hinges.

The solar laboratory project turned out well but had potential for so much more. The project required some knowledge of electrical engineering in knowing what measurements are useful, what made it the most interesting is that this was mostly a mechanical project. This project laid a strong base for future solar laboratory projects.

VIII. Reference

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[2] Landau, Charles R. "Optimum Orientation of Solar Panels. " *MACS Lab, Inc.* Web. 28 May 2011. <http://www. macslab. com/optsolar. html>.

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Appendix A. Project Timeline

Table 12 Projected vs. Actual Timeline

	Estimated Time	Actual Time
Proposal	3 Weeks	5 Weeks
Research	3 Weeks	3 Weeks
Requirements	2 Weeks	3 Weeks
Design	2 Weeks	4 Weeks
Build	3 Weeks	3 Weeks
Test/ Trouble shooting	3 Weeks	1 Weeks
Project Report	4 Weeks	4 Weeks
Total	20 Weeks	23 Weeks

Appendix B. Materials and Cost

Table 13 Materials and Cost

Bill of Materials					
Section	**Quantity**	**Item**	**Make and model**	**Price per (shipping included)**	**Current value**
Solar Components					
	1	Solar Panel	Bp 140W Solar Panel (Sx-3140)	700.00	$ 700.00
	1	Charge Controller	BZ M25 12/24 Charge Controller	127.00	$ 127.00
	1	Inverter	SAMLEX America 750W inverter	118.00	$ 118.00
	1	Battery	Sun Xtrender Pvx-690T	206.00	$ 206.00
	1	Electrical housing		5.00	$ 5.00
	1	Irradiance meter	Digital Solar Power Meter	165.00	$ 165.00
	30	Wire	30' stranded wire	0.33	$ 9.90
Building Material					$ -
	2	Wood plank	2x6x16	8.00	$ 16.00
	1	Plywood	49x97 1/2"	30.00	$ 30.00
	1	Conduit	Aluminum 70"	13.00	$ 13.00
	3	Unistrut Pipe Clamp	1"	1.50	$ 4.50
	3	Unistrut	10' 12 gauge	16.00	$ 48.00
	1	1/4"Cone Nut	5 pack	2.74	$ 2.74
	2	1/2" Spring Nuts	1/2" 5 pack	4.25	$ 8.50
	12	1/2"x5" Bolts		0.79	$ 9.48
	12	1/2" Washer		0.24	$ 2.88
	12	1/2" Nut		0.33	$ 3.96
	5	1/4" x 3/4" bolt		0.24	$ 1.20
	4	1/4" x 2" bolt		0.59	$ 2.36
	1	Spade terminals	12# gauge pack of	4.00	$ 4.00
	3	#6 bolts 1 1/4"	pack of 6	1.00	$ 3.00
	5	1/4" Fender washers		0.12	$ 0.60
Other					$ -
	1	Utility Cart	CJ579223 60"x30" Unassembled	327.00	$ 327.00
				Total	$ 1,798.22

The total price of building the solar laboratory is $1798.22

Appendix C. ANALYSIS OF SENIOR PROJECT DESIGN

Project Title: Solar Instrumentation Lab

Student's Name: Rene Canedo & Rong Chen	Student's Signature: R.C & R.C

Advisor's Name: Dale Dolan	Advisor's Initials: D.D	Date: June 9,2011

Summary of Functional Requirements

Describe the overall capabilities or functions of your project or design. Describe what your project does. (Do not describe how you designed it).

The solar instrumentation lab is a structure that allows the student to easily conduct solar experiments with different solar panels in different configurations. The solar lab has different access points to take measurements at any point in the solar circuit. The project is easy to transport and durable enough to withstand the weather outside. It also holds containers to store the equipment such as a compass, tilt meter, and irradiance meter.

- **Primary Constraints**

Describe significant challenges or difficulties associated with your project or implementation. For example, what were limiting factors, or other issues that impacted your approach? What made your project difficult? What parameters or specifications limited your options orb directed your approach?

The biggest challenge in completing this project was that the Solar Instrumentation Lab was more a mechanical project than a solar project. The project involved during research in braking systems and worm gears that the group hasn't even heard of before the start of the research process.

• ***Economic***

• *Original estimated cost of component parts (as of the start of your project).*

The original estimated cost of the project was under $1200.

• *Actual final cost of component parts (at the end of your project)*

The final cost of the project was below $2000.

• *Attach a final bill of materials for all components.*

Bill of Materials					
Section	**Quantity**	**Item**	**Make and model**	**Price per (shipping included)**	**Current value**
Solar Components					
	1	Solar Panel	Bp 140W Solar Panel (Sx-3140)	700.00	$ 700.00
	1	Charge Controller	BZ M25 12/24 Charge Controller	127.00	$ 127.00
	1	Inverter	SAMLEX America 750W inverter	118.00	$ 118.00
	1	Battery	Sun Xtrender Pvx-690T	206.00	$ 206.00
	1	Electrical housing		5.00	$ 5.00
	1	Irradiance meter	Digital Solar Power Meter	165.00	$ 165.00
	30	Wire	30' stranded wire	0.33	$ 9.90
Building Material					$ -
	2	Wood plank	2x6x16	8.00	$ 16.00
	1	Plywood	49x97 1/2"	30.00	$ 30.00
	1	Conduit	Aluminum 70"	13.00	$ 13.00
	3	Unistrut Pipe Clamp	1"	1.50	$ 4.50
	3	Unistrut	10' 12 gauge	16.00	$ 48.00
	1	1/4"Cone Nut	5 pack	2.74	$ 2.74
	2	1/2" Spring Nuts	1/2" 5 pack	4.25	$ 8.50
	12	1/2"x5" Bolts		0.79	$ 9.48
	12	1/2" Washer		0.24	$ 2.88
	12	1/2" Nut		0.33	$ 3.96
	5	1/4" x 3/4" bolt		0.24	$ 1.20
	4	1/4" x 2" bolt		0.59	$ 2.36
	1	Spade terminals	12# gauge pack of	4.00	$ 4.00
	3	#6 bolts 1 1/4"	pack of 6	1.00	$ 3.00
	5	1/4" Fender washers		0.12	$ 0.60
Other					$ -
	1	Utility Cart	CJ579223 60"x30" Unassembled	327.00	$ 327.00
				Total	$ 1,798.22

• *Additional equipment costs (any equipment needed for development?)*

All the equipment that was used was available without purchase.

• *Original estimated development time (as of the start of your project)*

The original estimated time of development was 80 hours.

• *Actual development time (at the end of your project)*

The Actual Development time was 110 hours.

• ***If manufactured on a commercial basis:***

• *Estimated number of devices to be sold per year*

The estimated number of devices sold per year is 10 a year.

• *Estimated manufacturing cost for each device*

The estimated manufacturing cost of each device is under $2000.

• *Estimated purchase price for each device*

The Electrical Engineering department has purchased a similar solar lab for about $13000.

The Solar Instrumentation Lab with some modifications can be sold at around $10000 each.

• *Estimated profit per year*

The estimated profit per year at a profit of $8000 per year with 10 sold is $80000.

• *Estimated cost for user to operate device, per unit time (specify time interval)*

There is no cost of operation for the user.

• ***Environmental***

• *Describe any environmental impact associated with manufacturing or use.*

The amount of material used for this project is very little so the resource drain has minimal negative impact. The solar lab gives students hands on experience that will help them

become better engineers in the field of renewable energy so there is a potential positive impact on the environment.

• ***Manufacturability***

• *Describe any issues or challenges associated with manufacturing.*

The solar lab was built by students who have an average amount of experience in building. There is no welding or any other type of metal work involved so there are no issues in manufacturing.

• ***Sustainability***

• *Describe any issues or challenges associated with maintaining the completed device, or system*.

There are no issues with maintaining the project. The panel will need to be cleaned before use or the data may be skewed due to less energy generated.

• *Describe how the project impacts the sustainable use of resources.*

The project does not have any significant impact on resources.

• *Describe any upgrades that would improve the design of the project.*

The Solar Instrumentation Lab's shaft control system could be improved with the use of a worm gear. The worm gear is naturally braking and has precision control of the shaft. Also the tilt meter and compass could be attached to the structure, which would give readings from a consistent area and free up one of the user's hands.

• *Describe any issues or challenges associated with upgrading the design.*

The only issue with upgrading the design is the price of the worm gear, which the group found to be expensive.

• ***Ethical***

• *Describe ethical implications relating to the design, manufacture, use, or misuse of the project.*

The project is only a teaching tool so it has very little potential to be misused.

• ***Health and Safety***

• *Describe any health and safety concerns associated with design, manufacture or use of the project.*

The health and safety concerns of this project is the weight of the structure; if not careful someone may be run over with the solar lab become injured.

• ***Social and Political***

• *Describe any social and political concerns associated with design, manufacture* or use.

There are no social and political concerns associated with this project.

• ***Development***

• *Describe any new tools or techniques, used for either development or analysis that you learned independently during the course of your project.*

The group learned new software and hardware techniques in the designing of this project.

The group learned to use AutoCAD and Google Sketch Up to produce 3-D models of the solar lab. The group also learned new building techniques such as cutting the corners to build a more professional looking workstation and using the versatile framing material, Unistrut, to construct the frame that adjusts in size to accommodate different solar panels.