



The Scaled Omni-Directional Solar Tracking Unit

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Abstract — The goal of this project was to design and implement an omnidirectional solar tracking system with the integrated capacity to charge multi-cell batteries with a balanced charging rate to allow for stable power delivery to a smart grid model. The intent of the tracking system is to maintain a perpendicular angle from the surface of the panel cells to the sun's emitting light rays in-order to maintain optimal power storage throughout the course of the day.

Improved design and development of an omni-directional solar tracking system can be considered for implementation at an industry scale for achieving optimal power generation and retainage. The solar tracking system features a power generation system, movement system, power management system, and a sensor system for achieving maximum sun exposure.

Index Terms— Actuators, Batteries, maximum power point trackers, Photovoltaic systems solar energy, solar panels, solar power generation.

I. Introduction

The goal of this project is to design and implement an omnidirectional solar tracking system with the integrated capacity to charge multi-cell batteries with a balanced charging rate to allow for stable power delivery to a smart grid city. The intent of the tracking system is to maintain a perpendicular angle from the surface of the panel cells to the sun's emitting light rays in-order to maintain optimal power storage throughout the course of the day.

Our team was tasked with optimizing the entirety of the solar tracking system by better enhancing the system's input capacity with added cells (expansion of the surface area), efficiency in elements of design for the power/voltage regulation, optimizing the microcontroller's system control and tracking capability with an efficient power distribution network to allow for a more stable power retainage and distribution rate. The new solar panel has solar cells sealed to a sheet of protective Plexiglas, where the forty-two solar cells are connected in the series formation to accumulate voltage and keep current a steady flow. The system is self-powered by a balanced battery network and input from the sun's solar rays.

Our team aims to provide a state-of-the-art design of a solar system at the capacity of expanding into large industrial use for power generation.

II. Design and Implementation

A. Controls system

Between the years, the control system maintained the same autonomous support. The movement was powered by the H-bridge and controlled using the Arduino. The Arduino receives input from 4 photoresistors. The control system for manual control changed. Last year the Arduino received input from a level shifted signal from the a Wi-Fi controller. Which connected to a modem to receive input from a laptop connected to the same modem. This year we opted to

build a physical controller to send input to the Arduino using buttons. The reasoning was our goal was to roll the system into a empty field with no previous infrastructure and run the system.

B. Power storage

This year the Smart grid used 30 AH at 12 volts DC or less than 10 A 110V AC under full load. The previous battery was not mentioned in previous years report. The only marking on the batteries was the brand. Using the brand and the terminal type we found that the battery at maximum was a 15 AH which can be used, but may last less than a hour. There were no technical manuals available for this battery.

This year we went to purchase a battery that would meet our design requirements. We need the two batteries and solar panel combined to provide 30AH for 3 hours. The first battery we considered was the Odyssey pc950. Using the technical manual, a single battery last 2 hours. It also features a \$40 school discount. See Figure 1 and Table 1.

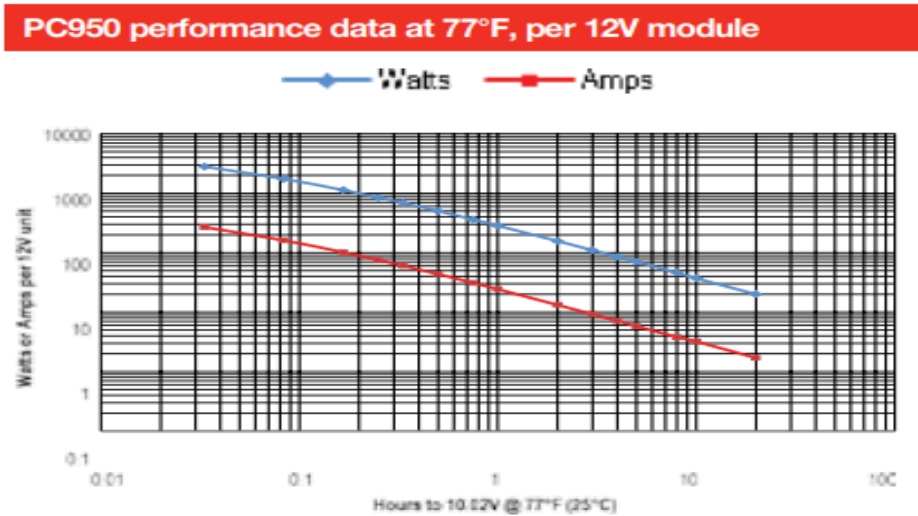


Fig. 1. Battery discharge diagram for the first battery chosen along with table below.

Time	Watts (W)	Amps (A)	Capacity (Ah)	Energy (Wh)	ENERGY AND POWER DENSITIES			
					W/litre	Wh/litre	W/kg	Wh/kg
2 min	2794	268.3	8.9	93.1	755.0	25.2	310.4	10.3
5 min	1745	161.3	13.4	145.4	471.6	39.3	193.9	16.2
10 min	1126	101.4	16.9	187.7	304.4	50.7	125.1	20.9
15 min	848	75.3	18.8	212.0	229.1	57.3	94.2	23.6
20 min	686	60.3	20.1	228.6	185.4	61.8	76.2	25.4
30 min	502	43.6	21.8	250.8	135.6	67.8	55.7	27.9
45 min	362	31.1	23.3	271.4	97.8	73.3	40.2	30.2
1 hr	284	24.3	24.3	284.4	76.9	76.9	31.6	31.6
2 hr	157	13.2	26.4	313.2	42.3	84.6	17.4	34.8
3 hr	110	9.2	27.6	329.4	29.7	89.0	12.2	36.6
4 hr	85	7.1	28.4	338.4	22.9	91.5	9.4	37.6
5 hr	70	5.8	29.0	348.0	18.8	94.1	7.7	38.7
8 hr	46	3.8	30.4	364.8	12.3	98.6	5.1	40.5
10 hr	37	3.2	32.0	372.0	10.1	100.5	4.1	41.3
20 hr	20	1.7	34.0	408.0	5.5	110.3	2.3	45.3

Table 1. Data observed for the first battery

The battery we used was the Odyssey 34R-790. It was a large battery than the PC950 and was cheaper by \$150 A single battery could meet out design requirements at full charge. This would help as the environment to demonstration would be indoors which is not ideal and our battery may not be fully charged. See Figure 2 and Table 2.

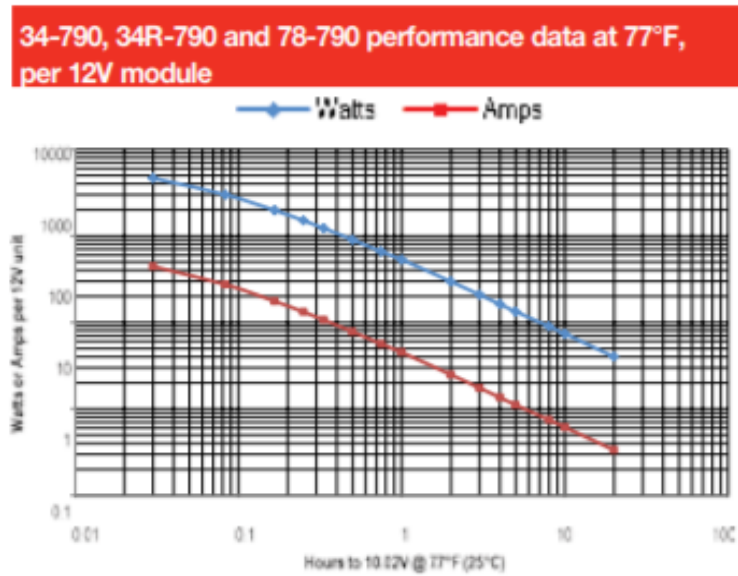


Fig. 2. Battery discharge diagram for the final battery chosen along with table below

Time	Watts (W)	Amps (A)	Capacity (Ah)	Energy (Wh)	ENERGY AND POWER DENSITIES			
					W/liter	Wh/liter	W/kg	Wh/Kg
2 min	4637	441.9	14.7	139.1	493.2	14.8	219.8	6.6
5 min	2991	273.6	22.8	249.3	318.2	26.5	141.8	11.8
10 min	1971	175.7	29.3	328.6	209.7	35.0	93.4	15.6
15 min	1501	131.9	33.0	375.2	159.6	39.9	71.1	17.8
20 min	1222	106.6	35.5	407.5	130.0	43.3	57.9	19.3
30 min	903	77.8	38.9	451.3	96.0	48.0	42.8	21.4
45 min	657	56.1	42.1	492.5	69.9	52.4	31.1	23.3
1 hr	531	45.1	45.1	531.1	56.5	56.5	25.2	25.2
2 hr	296	24.9	49.8	592.8	31.5	63.1	14.0	28.1
3 hr	209	17.4	52.3	625.7	22.2	66.6	9.9	29.7
4 hr	162	13.5	54.1	648.2	17.2	69.0	7.7	20.7
5 hr	133	11.1	55.5	665.5	14.2	70.8	6.3	31.5
8 hr	90	7.5	59.7	717.1	9.5	76.3	4.2	34.0
10 hr	74	6.1	61.3	735.8	7.8	78.3	3.5	34.9
20 hr	40	3.3	66.9	801.3	4.3	85.2	1.9	38.0

Table 2. Data observed for the final battery

C. Solar cells

This year we remade the solar panel and upped the number of solar cells placed in series from 36 to 42. This was to increase the voltage add a large buffer window in which the solar panel generates over 12 volts. To protect the cells we encased them in silicon and covered that with Plexiglas.

D. *Battery Switching Charging*

A simple NPN transistor relay switch circuit couldn't be able to switch between such big loads we have since they are just able to switch between low loads. After some research, we decided to use Darlington Transistors circuit. Where the sensitivity and the current gain of a relay can be greatly increased. The circuit would be controlled using a signal from Arduino connected to the base of the first transistor. When reading the voltage from a chosen drained battery, the relay would be energized and switch to start charging the particular battery. After a settled time already established it would change back to charge the other battery. The problem we had was thinking of a system to output and charge the batteries at the same time. Reading the voltage would be the simplest way, but once the solar panel started charging the battery, we would read the buck converted voltage from the solar panel. Once it begins outputting, you would measure voltage across the battery.

E. *Voltage regulation*

The previous design was self-made linear voltage regulator. It cause a problem with excess heating. This year we replaced it with a variable step-down converter. That could handle this year's increase in voltage.

III. Power Management System

A. *Inverter*

Converts 12V DC to 110V AC up to 500W. It can handle up to 30A DC before the two internal fuses blow. They are 790 automotive fuses. DC to AC conversion up to 30A is a senior project of its own so this was pre-manufactured. See Figure 3.



Fig. 3. Potek Inverter

B. *Wire gauge and bus gauge*

Most wires only use 12 AWG wire since they are only handling 5A from the solar panel. The output wires that lead from the batteries through the inverter are 10 AWG to handle 30A.

C. *Built in voltmeter*

The system has a 7-segment display that displays voltage for the output and solar generation. It

does not work during manual control. Using a voltage divider, we can drop and inputs between the range one of the analog pins of the Arduino can read 0-5V. Inside the software program, we multiply the output by the volts division before displaying. See Figure 4.

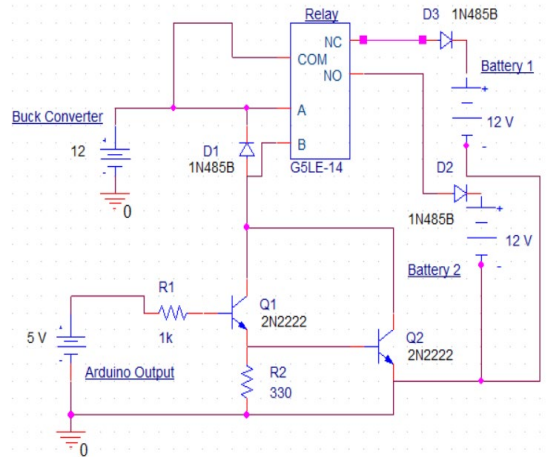


Fig. 4. Battery switching for draining circuit.

D. Battery Load/draining Switching

The battery switching system features two relays. These relays can handle the 30A that pass through. They could have been MOSFETS, but the relays required less attention and it could be easily be purchased without specific design. The relays do wear down over time. See Figure 5.

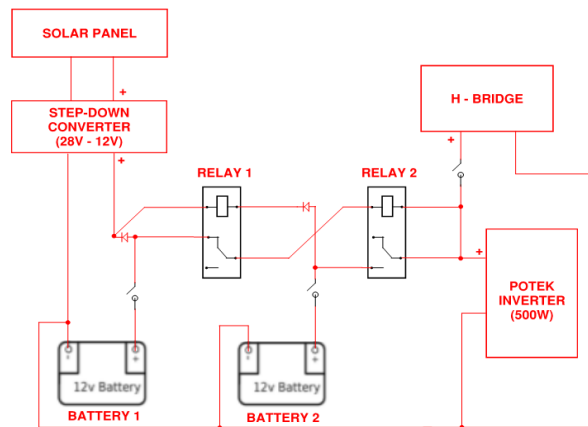


Fig. 5. Battery switching for draining circuit.

The reason we choose which battery drains is to allow the batteries to fully cycle. We want them to full drain and fully charge to maintain its life:

Relay 1 - always choose the opposite battery than the one that is charging.

Relay 2 - is a redundancy this relays handles the case of battery 1 one being fully drained and battery 2 is still charging. It will switch to battery 2 even if it is still charging in attempt to prevent power loss when power is still available.

E. *Battery charging switching*

Our system includes two batteries. We charge one from the solar panel and discharge the other to the smart grid. We used relays as our main switching device between the batteries. The advantage of relays is that it takes a relatively small amount of power to operate the relay coil. The small problem we encountered when trying to achieve this is the way we check the voltage in the battery. We cannot easily measure the battery percentage of the battery that is charging because we will only see the 12V coming from the buck converter. Therefore, we measure the battery that is not charging to see when it goes under the set limit of 3V. See Figure 6.

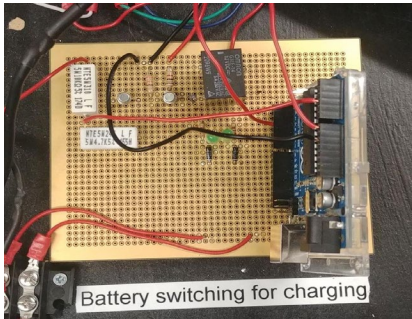


Fig. 6. Battery switching for charging circuit.

IV. Hardware

A. *Arduino*

Two Arduinos were placed in our system. An Arduino is an open source microcontroller. The Arduino can use 3.3V - 12 V to operate. Our Arduinos run of 12V. and each pin can take from 0V - 5V. They also require to be grounded to the common ground

1) Manual Movement and Voltmeter

The manual movement is 5 ft long to be sure the operator is out of the way of the solar panel. It send a high signal to the Arduino to tell it to operate certain ways.

2) Battery switching charging

A simple NPN transistor relay switch circuit couldn't be able to switch between such big loads we have. So after some research, we decided to use Darlington Transistors circuit. Where the sensitivity and the current gain of a relay can be greatly increased. The circuit would be controlled using a signal from Arduino connected to the base of the first transistor. When reading the voltage from a chosen drained battery, the relay would be energized and switch to start charging the particular battery. After a set time already established would change back to charge the other battery. See Figure 7.

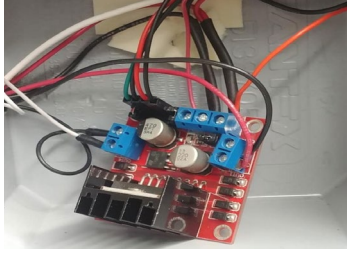


Fig. 7. Battery switching for charging circuit.

B. Switches

There are 4 switches on the system: main power, movement power, generated power, and manual movement.

1) *Main Power Switch*

Located on the side of the box as a big black switch with the label on and off printed on it. This switch separates the batteries from the rest of the circuit.

2) *Solar Generation Switch*

Features a 1 and a 0 this switch is located inside the box connected to a blue and green wire that runs down from the solar panel. Having both main power and solar generation off will leave the system without power.

3) *Movement Switch*

Runs from the inverter to the H-bridge and Arduino up top. It is located inside the box zip tied to the side wall. This switch is for the manual control and can turn off the entire system at any time.

4) *Manual Control Switch*

A silver flip switch located on the underside of the Arduino box up top. This switch sends a signal to the Arduino to tell the software to switch to manual control mode. This prevents autonomous movement, however push buttons on the controller will cause movement.

C. Actuators

The actuators can extend one feet, which provides enough movement as a proof of concept. They can hold their position even when not powered. See Figure 8.



Fig. 8. Silver and black actuators used

D. *Frame and solar face*

Building the solar face. First step is to solder the cells together in series in order to allow voltage to increase and current to remain constant. Aluminum corner angles were drilled into the Plexiglas. Solar cells were placed at equal distances and soldered in series. Cells were encased using encapsulated silicon based. Panel face was mounted back onto the unit. See Figure 9.

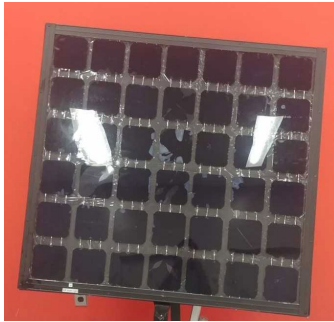


Fig. 9. Solar panel face using 28 cells connected in series

E. *Connections*

Most new connections made are made using crimp electrical connectors. This makes it easier for the next to team to add and remove components. The previous year had used solder and adhesive. This connection made modifications a bit harder and certain connections unsecure. See Figure 10.



Fig. 10. Crimp connectors used in the circuit

F. *Sensors*

We used four photoresistors connected to the actuators to track the sun so the solar face can have optimal light exposure. The Arduino was used to code the relationship between the photoresistors and the actuators. So the code focuses the actuators towards the resistor receiving the highest voltage. See Figure 11.

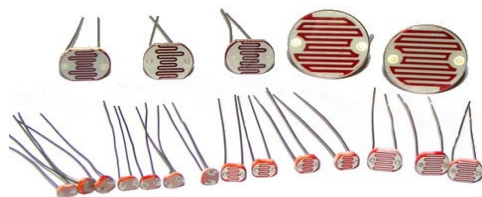


Fig. 11. Photoresistors

V. Integration and test results

A. Battery charging

Had a battery with low voltage plugged in since we know that battery would be low on charge and we can check that it charged by checking the voltage. Normally for a battery used you would need a coulomb meter to see how many electrons were available to be used

B. Voltmeter

Easily we compared the readout of a known working voltmeter to our own. It varied .4V maximum this is due to the Arduino analog pins sometimes affecting each other.

C. Battery switching

To test battery switching could take hours. To quickly test our system with ever change we would unplug a battery the this would simulate a full battery as no more current would flow through.

D. Output

Testing the output required plugging in to the smart grid and turning on. We also plugged in a drill since it had a similar power draw to what was calculated for the smart grid.

1) Solar panel

The solar cells are ~ (%) 21-24 efficient. Each cell generates .682V and 5A When arranged in series we get 28V and 5A. These solar cells were recommended from the previous year. As the year before it ran off monocrystalline cells that were prefabricated. This year we upped the number of solar cells.

2) Inverter

110 volts at <10A Whatever the smart grid draws maximum 500W

3) Battery

At maximum during smart grid powering no more than 30A as the inverter can only handle up to 30A

E. Movement system

Movement system was tested by blocking the sensor with any means and watching as the system reacted. Software also gives read outs of what movement

VI. Standards and Constraints

A. Standards

We made sure all connections were modular to be removable with the tools available in the senior project room

B. Constraints

The project itself can only be as big as the room we store it in. It must also fit through the door. Certain parts required scaling up to be practical. For example to power the smart grid using solar power alone we would need 6 times more solar cells.

There were many ideas we wished to implement like a fan to cool down the system in high temperatures. This may lead to us draining more power than we generate. Efficiency also changes based on what kind of power output we need to do.

VII. Development of the scaled model

Having developed an efficient working model of the solar tracking unit, the upscaled unit can be developed by a scaling factor of 8. The up-scaled unit will have a total surface sun exposure of 1,024 SQFT, where if-used-efficiently, can provide a maximum output of 1.2 Kilo-Watts per Hour for the duration of daytime exposure. See Figure 12.

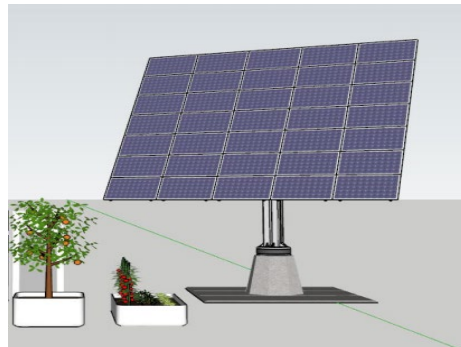


Fig. 12. Front View of the Model Assembly

A galvanized steel structure constructed with a concrete footing base assembly allows for an efficient use of space for the unit's assembly whilst providing the support to withstand average wind speeds of 110 MPH and harsh environmental conditions. See Figure 13.

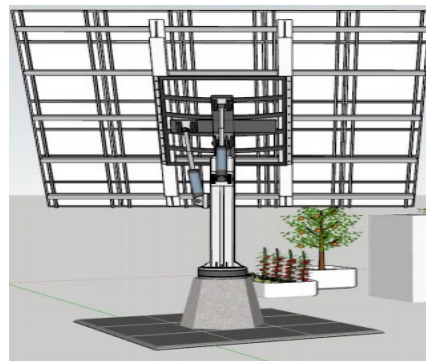


Fig. 13. Rear View of the Model Assembly

VIII. Student assessment and educational outcomes

At the completion of this project we would suggest the design and prototype of a printed circuit board, PCB, for integration of all system components. Also more research and diagnostics can be done in case of any potential power surges/distributions in overall power system output.

Enabling the pulse-width modulation pin on Arduino could be looked into for minimizing power losses. The H-bridge could have its speed modified in relation to the events of external and environmental influences.

For educational studies, we recommend providing details about the economic analysis for the project in order to obtain a much more profound understanding of how much the rate of return of the investment will be available to the owner. First step is to find the set-up cost, which is a one-time expense to include the initial cost of developing the solar panel unit(s); equipment used, shipping cost, and installation or any labor costs associated with the construction of the unit(s). There is also the consideration of annual operation and maintenance costs that need to be taken into consideration.

In order to calculate the operation cost, two factors need to be taken into consideration. The first one is that any type of cost will be influenced by an annual inflation rate, meaning that our operation cost for the following years after the first year will increase by a compounding interest rate. Another factor to have in mind is the products depreciation rate. Every product has a life cycle. The net worth of a product decreases by a rate called “depreciation rate;” this means that everyday that the product is being used, it is getting one day closer to the end of the life cycle of the product, and either some work needs to be done to keep the product such as replacing part of the product, or the product needs to be replaced as a whole.

The cash flow diagram below represents a breakdown of all cost considering present state, annual cost and future value. See Figure 14.

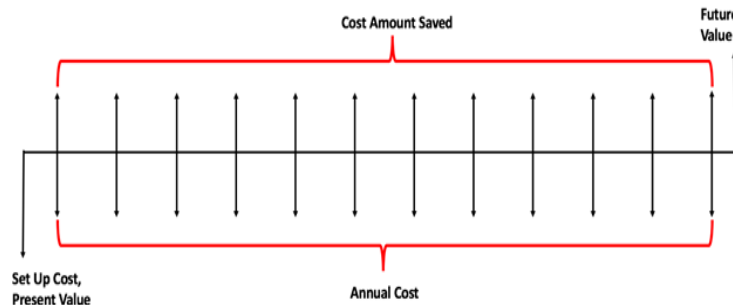


Fig. 14. Cash flow diagram

After calculating the yearly cost associated to the product, the rate of return needs to be calculated. Rate of return represents the time of the profit and the amount it will be. By finding out the rate of return, we can identify if the investment is a short term investment or long term; in-turn we can compare our profit margins to other alternatives and present investment opportunities to the owner.

IX. Project planning

Planning was done through communication with the previous team to discuss what were

improvements they had wish to complete. Then there were internal discussion on what we would like to see. We also discussed with the other team to see what kind of power requirements they would have. We also had in the back of our minds the idea to design the system to work for a land in Fontana to help gear a certain subject towards making that land into a solar farm. There were three main part of the project we split to work on: Power management, movement, and generation.

X. Educating students and broader impact

The project team was tasked with optimizing the entirety of the solar tracking system by better enhancing the system's input capacity with added cells (expansion of the surface area), efficiency in elements of design for the power/voltage regulation, optimizing the microcontroller's system control and tracking capability with an efficient power distribution network to allow for a more stable power retainage and distribution rate.

The new solar panel has solar cells sealed to a sheet of protective Plexiglas, where the forty-two solar cells are connected in the series formation to accumulate voltage and keep current a steady flow. The system is self-powered by a balanced battery network and input from the sun's solar rays. In summary, the project team was able to deliver the state-of-the-art design of a solar system with a future potential of expanding into large industrial use for power generation. As we all know the society is always in need of power. If we easily break down the ideas of a solar panel with this project, then the idea of solar being a future technology lessens and becomes a technology of today. In the class Vision of Science and Technology in Fiction, we talk about how we see possible future technology. How some never believe they will exist and how complicated it must be to do. That is until they see it with their own eyes. Now students here are doing this and that says something. It also attracts people interested in renewable energy. Any improvements or changes should be easily removable and plenty of space should be left for the next team. There are some high powered areas which should be covered. Since there are moving parts multiple shut off areas are implemented to stop all movement.

XI. Acknowledgment

This project was sponsored by Mr. Ganpat Patel. Advisor Dr. Sean Monemi. Special thanks to West Coast Batteries for discounted batteries. Acknowledgements to the previous project team members: Isai Rocha, Christina Ayad, Inge DipoSubagio, Derek Lim, Diego Lopez, Luis Ordaz, Tuan Vu, Ramiro Martinez, and Austin Rosen [2].

XII. References

[1] *Technical Manual*, 8 ed., Odyssey Bat., Corona, CA, 2014, pp. 6-17

[2] *Project Report*, Prototype Automated Solar Tracking with Power Generation System, June 2017