Electrical/Solar Report

Solar Cup 2018

Palos Verdes Peninsula High School

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Electrical System
Introduction

The team would like to show appreciation to the Metropolitan Water District, since due to their benevolent sponsorship of the Solar Cup Competition, student are now able to have valuable hands-on experience in activities within the engineering field. The Palos Verdes Peninsula Solar Boat team has been able to achieve what it has due to our gracious advisors, teamwork, and accurate reports to guide us, and would have never made it this far without them. The skills honed with the team can be utilized in numerous other opportunities, not only in the engineering field, throughout our lives.

Design Theory

The batteries themselves will be the most important utility in the electrical component of our boat. The solar panels, being arranged in the same fashion as the previous solar cup competition, will charge the batteries during the races. Although the solar panels are also a key part of creating the synergy that allows the boat to be able to be driven, the batteries will be providing most of the power required for the boat to operate. We test our batteries weekly to make sure they are efficient and competition-ready, and we aim to use the best current output, based on the data we collect, in order to allow the boat to focus on endurance or efficiency. Our data seems to show an exponential decay with current as time progresses, so the data collection allows us to be as precise as possible. Our team has reached a consensus when it comes to the endurance and sprint events: we will utilize about 25 amperes of current for the endurance event and, at maximum, 400 amperes for the sprint event. 25 amperes is a feasible output for the endurance event, as it will last the necessary length of the competition based on our data. Having

400 amperes as the limit during the sprint event is an important note to acknowledge since going over that limit may cause damage to anything within the circuit of the boat, such as the motor itself. The only major adjustment we made this year is the removal of the shunt. In order to make our boat compatible with the updated rules, we had to eliminate cruise control, switching the power to manual throttle and eliminating the need for a shunt.

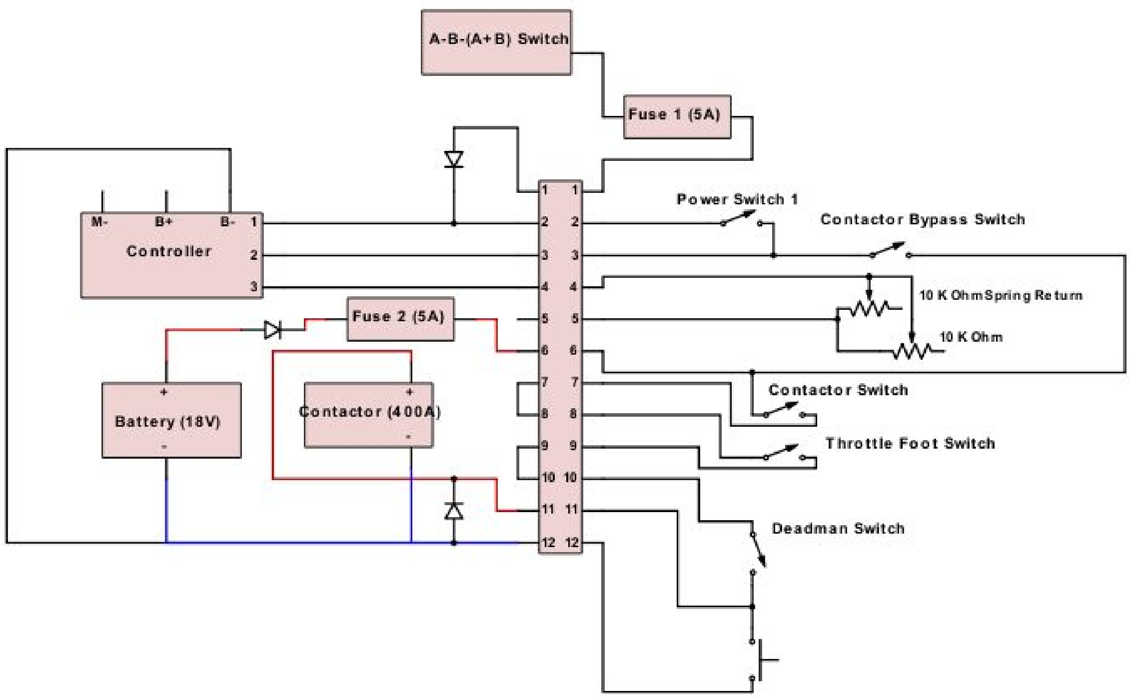


Figure 1: Control Circuit

High Current Fuse

A fuse, a safety device implemented in the electrical system, is designed to prevent damages from excessive amounts of current. In order to do so, the fuse opens the circuit by melting internal wires once the current begins to exceed 350 amps for a significant period of time. With keeping this information in mind, we plan to run the motors at 400 amps for the sprint event which would open the circuit and disable the entire electrical system. Additionally, running the motor above the amperage limit of the fuse will ultimately increase our speed. Of course, the fuse may break if we are careless with our amperage control, a factor we must take into consideration; we have decided to bring spares to the competition as they are inexpensive and relatively convenient to replace.

Figure 2: 350A Fuse

Kill Switch

The kill switch acts as a fail-safe if the skipper were to incapacitated from operating the boat due to unforeseen circumstances. Also known as a Skipper Safety Device (SSD), the switch shuts off the propulsion system if the key were to detach from skipper's life jacket. With the SSD switch dislodged from the jacket, the motor control unit cannot be activated from the power supply, thus causing the propulsion system to be disabled. If the skipper were to fall out of the vehicle, the detached SSD switch will discontinue the electrical power in the boat's drive train and stop the boat.

Batteries

In this year’s competition, we are continuing usage of the Odyssey Extreme PC 1100 model batteries that we have used in years past. This model has proven to be reliable in competition, especially during the endurance race, which requires a steady battery. This model also fits within the weight and max voltage restrictions. In place of metal boxes, which can lead to short circuiting batteries, we have opted to use wooden boxes to keep the batteries out of the way of the motor and drive train.

We have opted this year to purchase 8 new batteries to replace the ones we used in past competitions. There have also been more battery tests to find which batteries would be better for use in the endurance race. We ran the batteries at 25 Amps, roughly the same current they would be put under during the race and stopped the test when the voltage of the batteries tested went below 10 Volts.

Figure 3: Odyssey Extreme PC 1100 Battery

Battery Calculations

Table 1: Sample Battery Test

	2016D	2016F	2016I
Initial Voltage	**12.07**	12.13	12.13
5	**12.06**	12.12	12.13

10	**12.01**	12.08	12.08
15	**11.94**	12.02	12.02
20	**11.87**	11.95	11.95
25	**11.79**	11.88	11.87
30	**11.70**	11.78	11.79
35	**11.61**	11.70	11.70
40	**11.50**	11.58	11.58
45	**11.38**	11.48	11.47
50	**11.22**	11.37	11.34
55	**10.80**	11.19	11.14
60		10.95	10.84
65		10.29	

As evident by the table, the 2016D and 2016I batteries are not suitable for racing. However, 2016F lasted for 65 minutes, the longest out of all three.

Bilge Pump

The function of the bilge pump is to rid of the excessive water that may enter the boat caused by cracks or holes in the sealant from the hull. Due to its reliability, we have decided to continue to use the bilge pump we have been using for the past two years, a 500 gallon/hour 12VDC/2.5A bilge pump. This model is powered by its own 12V battery and discharges at 2A/h. The bilge pump can either be manually activated by the skipper using a switch or automatically through a float switch located near the pump. Also, the bulkhead of the boat was designed with intentional openings, which exists to equally distribute the excess water entering the boat. As a result, water will not built up in a single area of the boat, allowing us to disregard small leakages as they would ultimately be negligible to the speed and efficiency of the boat. We have placed the bilge pump at the lowest part of the boat after strategic consideration.

Figure 4: Bilge Pump

Contactor Solenoid

The contactor is a used to switch the electrical power circuit and is remotely controlled with a lower power switch. It contains a starter solenoid that switches on the high power circuit when activated by a lower power electrical circuit. There are three components to it: the contacts, the electromagnets, and the enclosure.

Figure 5: Contactor Solenoid

A/B Switch (Main Switch)

The main switch isolates or combines battery banks that are isolated to all loads. In the past, we have used the Blue Sea Heavy Battery Switch. Since it can efficiently control the Alltrax AXE 2434 Speed Controller with up to continuous 350A, intermittent 600A, and 32V DC., we decided to use it again this year.

Motor

In this year's Solar Cup, we will be using the same motors that we have used for previous competitions. There are two options that we have, the Motenergy ME0909 that was used in 2012 and the B95R which was used in our competition in 2015. The ME0909 has a maximum RPM of 480 and weighs 28 pound, while the B95R has a maximum RPM of 5000 and weighs 24.25 pounds. The B95R motor is lighter and can run faster compared to the ME909 motor, so we will use the B95R since it is our best performing battery. This battery is manufactured by Saietta Engineering and is also known as agni batteries. These motors utilize brushes to rub against the spinning motor, hence the name brushed motor. We chose this specific brush motor since it is one of the better brush motors there are. Although motors without a have a better performance and last longer, we have opted for the brush motor because it is the less expensive option and does not require a special motor controller, which would add to the costs. For endurance events, we run the motor at 25 apms, even though it can run a maximum of 24 volts at a maximum of 140 amps.

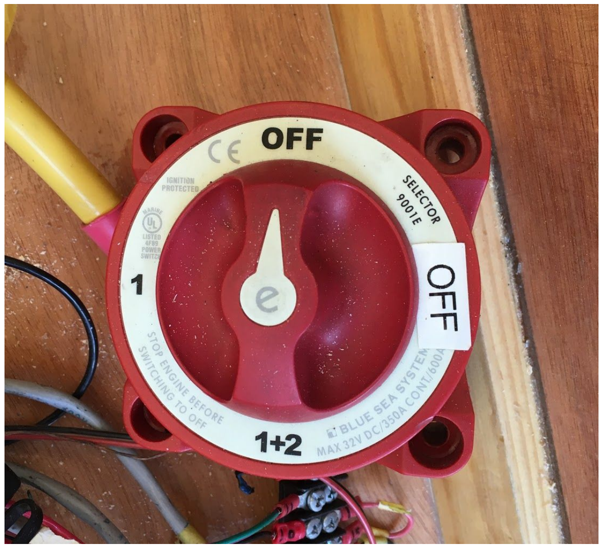


Figure 6: Main switch

Solar Panels

We decided to use Sacred Solar high efficiency bendable pv module solar panels, just as we have in our last two competitions. By using these solar panels, we can take advantage of the their optimal weight and dimensions. In past years, we produced our own solar panels by soldering cells to heat resistant styrofoam. We found these self-produced solar panels are not as efficient as those from Sacred Solar, and prove to be much heavier and less adaptable to the shape of the boat. We will continue to use the same Sacred Solar panels as last year due to their lightweight, versatility, and ability to conform to structure of the boat.

Figure 7: Front View of Sacred Solar panel

Motor Controller

We decided to use the Alltrax SPM48400 like last year, a motor controller that can hold a maximum of 400 amps for two minutes, making it great for the sprint event. The motor controller's high reliability and manageability, as it is easy to mount and wire, further makes it great to use at this year's Solar Cup. In comparison to the model we used in the past, the Alltrax AXE-4844, which has a sixty minute rating of 300 amps and a two minute rating of 400 amps, the Alltrax SPM48400 has more voltage drop and slower RPM. We are confident that the Alltrax SPM48400 will increase the efficiency and speed of our boat in this year's competition, as the SPM48400 has a sixty minute rating of 300 amps and a two minute rating of 400 amps, making it great for both the endurance and sprint race.

This year, we are hoping to increase the sensitivity of the throttle in order to compensate for the lack of a cruise control and utilize a clamp meter during competition rather than a digital readout.

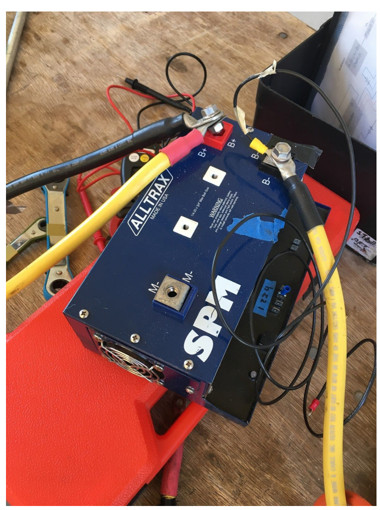


Figure 8: Motor Controller

Model (1)	Peak (Amps)	2-Min (Amps)	5-Min (Amps)	60min+ (Amps)
SPM48200	200/225 (2)	200	150	125
SPM48200	200/225 (2)	200	150	125
SPM48300	300/350 (2)	300 (1.5min)	230	210
SPM48400	400/460 (2)	400	320	300
SPM48500	500/575 (2)	500	420	380

Table 2: SPM48400 Amperage Table

Throttle

We decided to use a rheostat throttle to control the speed of the boat during performance. The throttle is essentially a rheostat that is connected to the speed control electronics. It includes a micro-switch that disrupts the connection to the contactor solenoid when the throttle is disengaged. The micro-switch works when the throttle is let go of as a result of a spring that brings the throttle to zero for safety.

Due to the fact that a cruise control isn't allowed in the competition anymore, the throttle limit circuit has been removed. The only item controlling the speed of the boat now is the rheostat throttle.

Wire Size

AWG indicates the cross-sectional area of each wire, and is the factor that distinguishes the variety of wire sizes. AWG can range from as thick as 0000 gauge to as thin as 40 gauge. Having a 40 gauge wire signifies the wire has been drawn through 40 sizing dies to reach the desired diameter.

Our team decided to use 1-gauge wires again this year, since they are light enough to be easily configured to the desired form, yet large enough to avoid overheating. Compared to the thicker wires we have used in past competitions, our current 1-gauge wires accommodate to the placement of the battery and limited space within the boat. They are able to bend to the most optimal shape to fit in the electrical configurement. Yet, using a wire thinner than 1-gauge, while more flexible, increases the risk of overheating. The large amount of current running through their high resistance would lead to a significant loss of power and cause the wire to melt. In order to increase the amount of power carried in the wire and minimize energy loss, we decided 1-gauge wires are the most optimal for the purpose of our boat. Furthermore, the 1-gauge wire is reasonably priced compared to other wire sizes, and contains a low voltage drop.

The only aspect we are changing with our wires this year are the lengths. We decided to shorten our wires in order to decrease weight and the amount of power lost, since more energy is needed to transfer between long distances. We are able to shorten the wire length this year since we are not utilizing a backboard, as we did in past years. Rather than retaining a disorganized circuit configuration wrapping through the backboard, we can efficiently reduce wire lengths by placing the electrical components tangentially to the sides of the hull.

Wire Size	Ohms/1000 ft	Weight/Foot (lb.)	Length (ft)	Max Amp	Cost/Foot ($)	Voltage Drop	Total Weight (lb.)	Total Cost ($)
4	0.2485	0.178	20	350	1.64	1.7395	3.56	32.8
2	0.1563	0.277	20	350	2.65	1.0941	5.54	53

1	0.1239	0.35	20	350	3.44	0.8673	7	68.8
0	0.0983	0.437	20	350	4.44	0.6881	8.74	88.8
00	0.0779	0.549	20	350	5.3	0.5453	10.98	106

Table 3: Data in relation to wire size

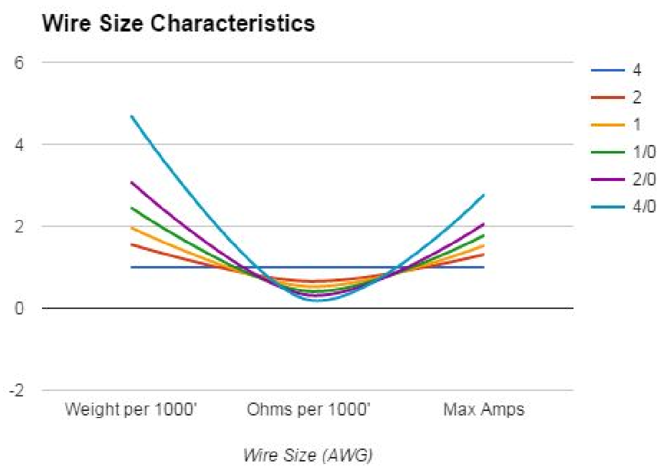


Table 4: Wire Size Characteristics

Figure 9: 1 gauge wire connected to fuse

Figure 10: 1 gauge wire

Final Analysis

Our boat this year is primarily comprised of the same electrical components, some with updated models. This applies for our six Sacred Solar bendable pv module panels, a B95R agni motor, an Alltrax SPM48400 motor controller, two 12V Odyssey Extreme PC 1100 batteries, a Cole-Hersee 3-Position switch, a 400 Amp contactor, and Johnson 500 GPH bilge pump. We have removed the shunt and will use a new kill switch.

Renewable energy has become more important throughout the years. The renewable energy industry is at risk due to plans to use more coal and oil, which makes it all the more important to have a competition like the Solar Cup.

Solar Array

Introduction

We live in a world in which the amount of energy necessary to sustain our existence has been steadily increasing at an unstoppable rate. As a result, it has become of paramount importance that a sustainable and environmentally friendly resource be found. Among the possible candidates, solar energy is perhaps the most efficient and reliable option. Many people have already made the switch because of its economic advantages and its lack of harmful byproducts. Ergo, it is key that we fully understand the capabilities of solar energy by using it to power our solar boat.

Solar panels are a sustainable form of energy since they rely on energy from the sun's rays. The cells on our solar panels contain photovoltaic cells. These cells contain semiconducting material to form electric fields. Based on the concept of the photoelectric effect, when the sun's rays hits the cell, electrons are knocked loose from the semiconductor to produce an electric current. This electricity is used to power our boat.

Design Theory

In order to charge the batteries on our boat during the race, we attached several solar panels to the boat. The photovoltaic systems used in these solar panels are comprised of electrically connected cells that form a module. A single solar panel is multiple modules connected together. Each solar cell absorbs photons from the sun through semiconductors and ionize the electrons. This allows them to travel freely through an electrical circuit. The current that is produced charges the batteries. We will connect the solar panels in parallel and to 2

Maximum Power Point Trackers (MPPT) devices that will adjust the current into one that is suitable for the batteries in competition.

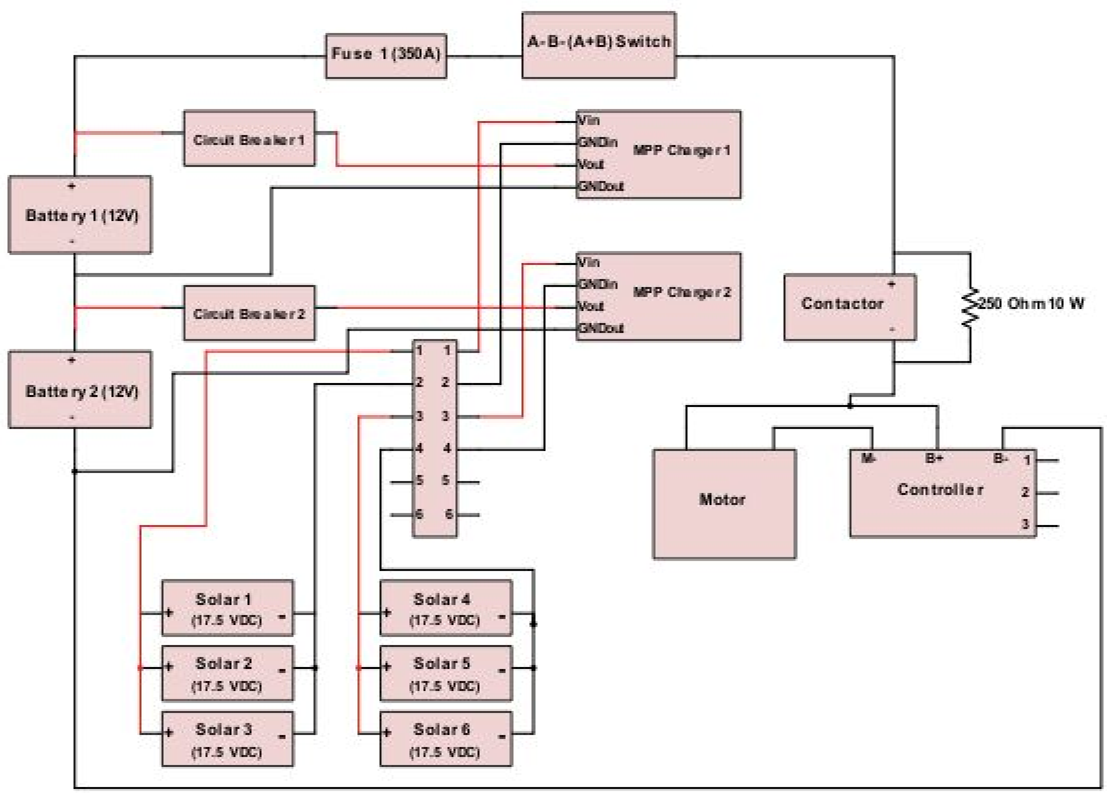


Figure 11: Power Circuit

Electrical Layout

Since the rules limit the source voltage to 24 VDC nominal, this year we decided to use two twelve volt Odyssey batteries connected in series. Our six solar panels are divided into two groups of three, each of which forms a circuit of three solar panels connected in parallel and is also connected to a battery. Two MPPT chargers connected in series convert the 17.5 volts produced by the solar panels so that it charges the batteries and ultimately travels to the motor controller to control the motor. Just like previous years, we decided to purchase Sacred Solar

Panels for their efficiency and lightweight structure. In order to ensure that the wattage did not exceed the maximum of 320 watts specified, we masked the cells with tape.

We will use 1 gauge wires because they are more flexible, less expensive, and they can carry a substantial amount of energy. We will not use the smaller wire sizes (40 gauge wires) because they may overheat and damage the circuit.

This year we are removing the shunt-ammeter system as we realized that utilizing a clamp meter is not only just as effective but also removes the necessity of the shunt-ammeter system.

Physical Layout

Just like previous years, we decided to use Sacred Solar panels again this year. Shown in figure 12 below, we will be positioning three solar panels on the gunwale of the stern and three on the bow, secured with zip ties in accordance to rules (7.14.3). This arrangement of solar panels ensures maximum exposure to sun in order to produce optimal levels of photovoltaic production, remaining parallel to the surface of the water at all times. By using Sacred Solar panels, we can take advantage of the boards light and adaptable characteristics to conform to our desired position, despite limited space. The only adjustment we made to the layout this year is the placement of the MPP closer toward the bow in order to shift the center of mass forward.

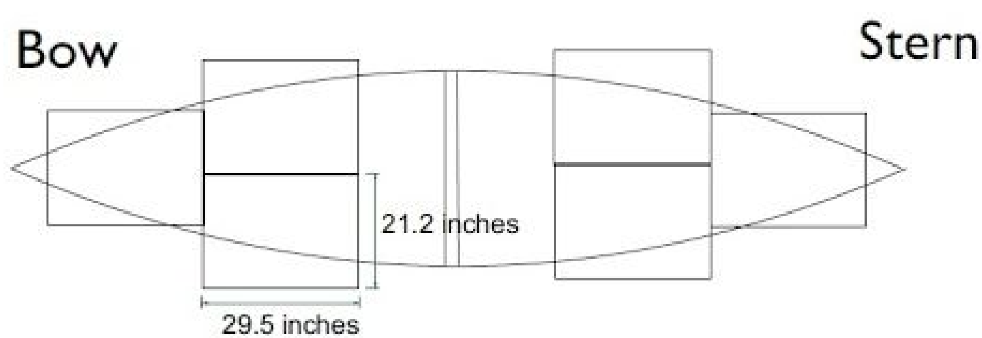


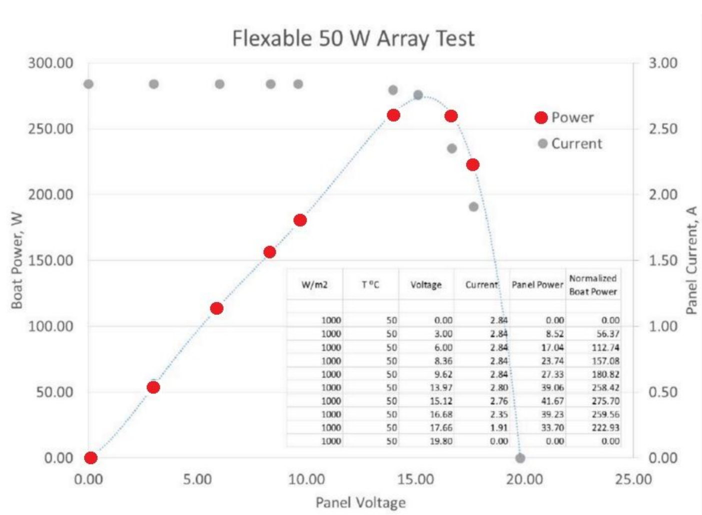
Figure 12: Placement of solar panels on boat's hull
The rectangular regions represent solar panels attached to boards underneath.

Research And Selection

As in previous years, this year we will once again be using Sacred Solar panels rather than building our own and risking flawed construction. Despite them weighing the same as homemade panels, they are more reliable and yielded successful results at previous competitions.

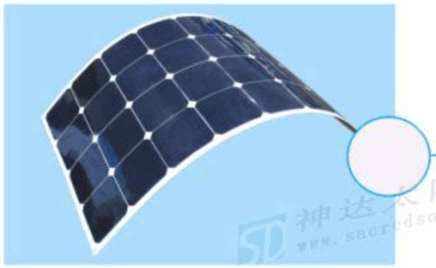
It was not without much consideration that we decided to reuse Sacred Solar panels due to their lightweight structure, great performance in the past, and abundant benefits. Since the panels are coated with thin PVDF film and is very flexible, it is 20/25% more efficient than conventional PV modules of the same size.

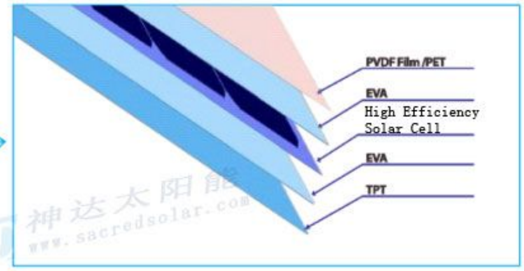
Among the many solar panels that we researched, the Sacred Solar panels were by far the lightest. In the past, we built our own solar panels because they were approximately four times lighter than conventional rooftop solar panels. However, in 2014 we purchased Sacred Solar panels because they were both lightweight and reliable.



W/m2	T °C	Voltage	Current	Panel Power	Normalized Boat Power
1000	50	0.00	2.84	0.00	0.00
1000	50	3.00	2.84	8.52	56.37
1000	50	6.00	2.84	17.04	112.74
1000	50	8.36	2.84	23.74	157.08
1000	50	9.62	2.84	27.33	180.82
1000	50	13.97	2.80	39.06	258.42
1000	50	15.12	2.76	41.67	275.70
1000	50	16.68	2.35	39.23	259.56
1000	50	17.66	1.91	33.70	222.93
1000	50	19.80	0.00	0.00	0.00

Figure 13: Acceptance test results for 50 W array





External Dimensions

Length: 74.93 cm

Width: 53.848 cm

Weight: 1.889 kg

Thickness: 3 mm

Output Cables: 90 cm

Output connectors: MC4 compatible

Front Surface: PVDF thin film

Back Surface: TPT

Electrical Specifications

Nominal Power (Pmax in Watts)	60
Voltage at Pmax (Vmp in Volts)	17.5
Current at Pmax (Imp in Amps)	3.43
Open Circuit Voltage (Voc in Volts)	21.0
Short Circuit Current (Isc in Amps)	3.84
Power Tolerance not to exceed	+/- 5%

Solar Charge Controller (MPPT Selection)

To convert the power from the Solar panels to the battery, the MPPT is absolutely necessary. The MPPT converts the power from the solar panels to charge the batteries by operating at the solar panels' maximum point of power and changing the voltage to what is required to charge the battery. The MPPT we plan on using is Sunsaver MPPT SS-MPPT-15L. We use the same MPPT units as we have used in the past as they worked well and we do not have the budget to purchase new units. We will use two so that each battery is charged by a separate set of solar panels.

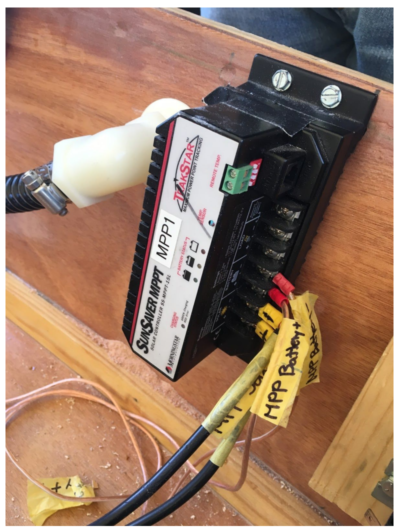


Figure 14: Solar Charge Controller

Final Analysis - Solar Analysis

In order to save costs as well as cut back on construction time, we have decided to purchase pre-made solar panels. Sacred Solar panels have proven to be an excellent choice for our boat because of their reliability as well as other factors that ensure a seamless application to the boat with the least effect on the other parts.

In order to fit enough solar panels on the boat, we will attach groups of three panels on the bow and the stern. The panels are attached by means of zip ties and lanyards to boards along the gunwale. Each forementioned group is attached to one battery with 1 gauge wires.

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