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Are Solar Panels a Viable Power Source for a Green Energy Vehicle?

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Senior Thesis

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Are Solar Panels a Viable Power Source For a Green Energy Vehicle?

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ABSTRACT

A solar cell powered go-kart has been build and tested. The result showed using solar energy alone cannot meet the requirement of running a regular passenger car. This is due to the limited surface area of the passenger car. This thesis also discussed the operating principle of solar panel, the physics of P type and N type semiconductors, and the formation of the PN junction as well as the solar current. Modifications of an existing go-kart have been described in detail in this thesis. The suggestions of making green vehicles have been discussed as well.

Chapter 1

The Solar Powered Car

1.1 Introduction

The U.S. department of energy, as well as some of our nations leading economists have predicted that within the next 30 years 80 percent of our energy will come from renewable sources. This is due to the continual rise in the greenhouse gases and pollutants that cause climate change. One major source of pollution that is depleting our ozone layer stems from our automotive vehicles. As the trend of green energy technology continues to become more prominent it will continue to revolutionize the transportation industry. Green energy is an important topic that bridges all disciplines because in order for humankind to survive renewable energy needs to become the face of the energy industry. With green energy technology transportation will become lighter, and cheaper in the long run. This is why the focus of this research is based on the concept of engineering a solar-electric vehicle. The theoretical calculations show that in order for the car to successfully operate there needs to be roughly 315 Watts of solar power.

Solar energy now has a wide array of applications due to it becoming more cost efficient. It is used for electricity, heating, and water heating. However, solar powered vehicles still have some practical issues. Solar vehicles need to be lightweight, and highly efficient. As of now, any mode of transportation that is 100 percent solar powered needs to have an enormous surface area, or the vehicle needs to be very small. There is currently a single passenger plane that is powered by solar panels, but its wingspan has a calculated surface area of 269.5 $meters^2$ and has 17,248 solar cells. The plane is slightly over 5000 pounds and can only support a pilot, and one passenger. This research shows that it is impossible to have a car that is solar powered.

Conventionally we have seen battery packs in cars consisting of thousands of silicon doped cells connected together. Their purpose of maximizing the amount of energy that can be discharged, over the longest period of time. A few companies such as Google, Volks Wagon, Range Rover, and now Tesla Motors has started to use this technology in their car batteries. The worlds leader in electric battery research, Tesla Motors, is now approaching the maximum energy density limit that a lithium-ion car battery can hold. Energy density needs to be increased as much as possible in order to make the battery more powerful without increasing its size. The 2017 Model S has a record distance of 300 mile range per battery charge, and can accelerate from 0 to 60 in 2.50 seconds. This makes it the industrys fastest, and fastest accelerating passenger car. Tesla is approaching the physical and molecular limitations of energy that modern car batteries can produce. By introducing a new power source such as a solar panel it will allow cars to become more green, lowering their carbon emissions. The new generation of silicon doped batteries are more consumer friendly than anything other batteries on the market. The three factors that make these batteries stand out are their rapid charge time, high power density, and the immense of current that can run through them. To prove that a solar energy is an option that helps reduce carbon emissions, there needs to be tests run based off of the theoretical calculations. The theoretical calculations show that solar power alone will not provide enough power to run a mid-size car.

Chapter 2

Theory

2.0.1 History

The solar panel is a key player in this research. The solar panel used is a mono-crystalline solar panel. Mono-crystalline solar sells were first invented in 1954, and the first commercial grade solar panel was engineered in 1959. In order to understand the how the solar panel works, the science behind it needs to be explained.

2.0.2 P-types and N-types

Solar panels convert solar radiation into electrical energy through the reactions that occur in the depletion region. Generally speaking, intrinsic semiconductors have little free ”holes” and free electrons when at room temperature By doping different elements into a semiconductor we can change an ordinary semiconductor into a p-type or an n-type semiconductor. The p-type has ”holes” in it that represent the positive charge. N-types have free electrons that represent its negative charge. Because doping changes the band gap in semiconductors, it makes the electrons jump to the conductive band more easily. This also makes the n-types find the ”holes” easier in the p-types. In conclusion, doping semiconductors make the electrons and holes higher mobility in their respective n-type and p-type materials.

2.0.3 P-N junction and the Depletion region

When a p-type and n-type semiconductor are put together a P-N junction is formed. The P-N junction is also known as the depletion region. The depletion region is formed through the process of diffusion. The n-type has a high density of electrons and the p-type has a high density of "holes". When the n-type and p-type touch each other the electrons will diffuse from the n-type to the p-type and the holes will diffuse from the p-type to the n-type. This is where the depletion region forms. As a result, this will build up an internal electric field which prevents diffusion from further happening. The diffusion process has now reached an equillibrium status where no diffusion is occurring. When light hits the soar panel the energy will create holes in the p-type and electrons in the n-type. This makes the depletion region thinner.
When light hits the depletion region the equillibrium status is broken. When equillibrium is broken, diffusion is forced to occur. Because the depletion region is thinner, diffusion is now forced to continue. When the generated electrons and holes neutralize each other, the depletion region becomes thinner. This allows for diffusion to continue to occur. This provides solar panel current. See figure 1.

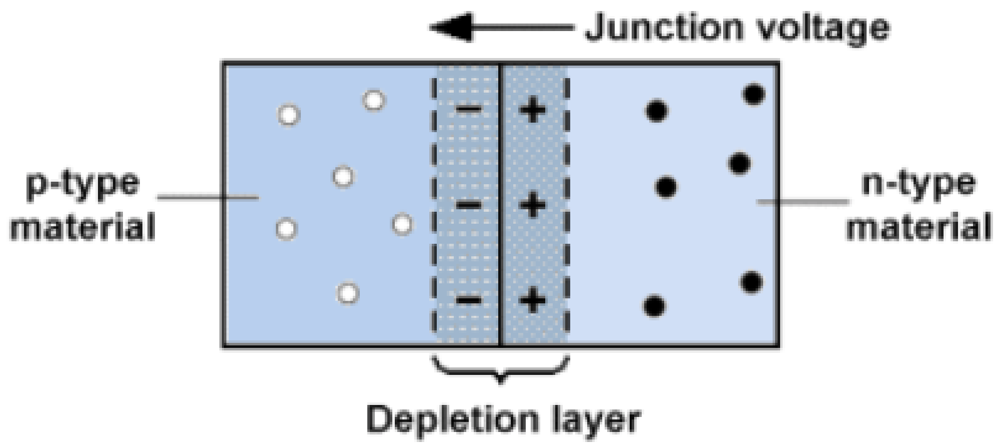

Figure 2.1: figure 1 depicts how the P-types and N-types interact at the P-N junction (AeroChapter)$_{(1)}$

2.0.4 Simple Calculations

To understand how much power is needed to run an ordinary car, real data needs to be analyzed. An average sized car has roughly 160 to 300 horse power. The car engine power can be found from online databases. The RPM range of a given engine is the range at which that engine will normally operate without causing damage by over-use. Typical engine RPM ranges will vary by the size of the engine, the number of cylinders, engine construction methods and what type of transmission is backing up the engine to deliver torque to the drive wheels. A 4-cylinder engine will operate normally between 700 RPM and about 3,500 RPM.

Knowing the RPM and the weight of the car along with the friction coefficient between the tire and the road, the resistance torque can then be calculated. The resistance torque is useful for determining the power output needed in order to operate the car.

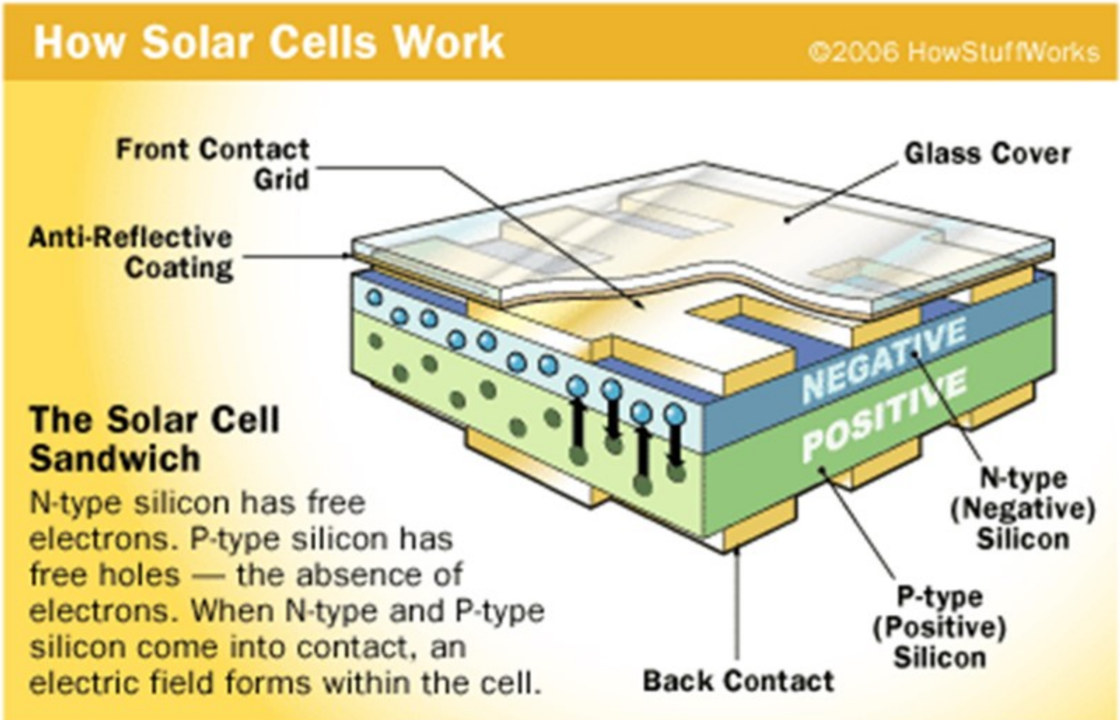

Figure 2.2: figure 2 is an infographic on solar cells (HowStuffWorks)(2)

The following equations are useful when determining how effective a power source is. Power is defined as the amount of work done over a period of time. Horse power is another unit for power. But horse power specifically looks at the performance of the power source in contrast to the output power of the entire car.

$$Power[J/s] = \frac{W}{\triangle t}$$

.

$$\tau = \vec{r} \times \vec{F} sin\theta.$$

$$Horse\ Power = \frac{\tau \times RPM}{5252}.$$

$$1Watt = 1J/s$$

$$1hp = 746Watts$$

so with 365 Watts, $0.49hp = \frac{365W}{746W}$

Solar panels are useful for helping to determine the horse power (hp) of a car because they both use power units. The 315 Watt solar panel leaves us with less than 1hp generating from 2^2 meters of solar panel. For a mid-size vehicle, roughly twice the surface area, 0.98 hp is produced. This is still not nearly enough to run a car.

Horse power is an important factor in car performance because it is defined as the rate at which work is done on the given system. With the 2^2 meter area of solar panel which roughly half of what the average car would use approximately 632 Watts or 0.632KW are produced. This is not enough of a power output to independently power a car. By doubling the surface area to 4 square meters, approximately 1.7hp will be generated. This is still not nearly enough horse power for the surface area sacrificed to use the extra panel.

Chapter 3

Experimental Methods

Solar energy is praised as an inexhaustible fuel source that is pollution and noise free. The technology is also versatile due to its wide array of applications. For example, solar cells generate energy for distant places like satellites in Earths orbit and even structures in mountain ranges as easily as they can power city buildings. But solar energy doesn't work at night without a storage device such as a battery, and cloudy weather can make the technology unreliable during the day. In order to answer this question we first need to address what defines performance, and how do we test it? The most important aspect of performance is the kilowatt-hours, this is the amount of power that can be generated from the battery multiplied by the time the battery is operable for. In car batteries there are allowable voltages, currents, and torque amounts that can run through the battery. These tests determine the energy density of the battery as well as the power, and range of miles the car can run. In order to determine if solar energy is an adequate power source, the panel will need to be able to efficiently power the vehicle.

The tests performed are designed with the purpose of establishing the efficiency of the solar power source. In order to get numerical values, digital multi-meters will be connected to the battery, solar panel and controllers in the car. Then from there, the tests will include putting the car onto prop blocks which will show the max rotational velocity of the wheels.

Calculations from there will find the maximum cruising range. The cruising range needs to be at least 250 miles minimum in order for the solar panel to be a viable power source. The cruising range is greatly increased by the solar panel depending on the available sunlight. However if there is no other power source other than the panel, the speed will have to vastly be reduced.

$$cruising\ range = energy\ dissipation\ rate \times velocity_{max}(\approx 20mph)$$

3.1 How does a Solar car work?

To determine whether or not the solar panel alone can be used to power a passenger car the current of the go-kart was examined. The examination involved 5 major components. These components consist of a panel that is 315 Watts minimum, an inverter, a bridge rectifier, then a motor and solar controller. These components are used in order to regulate the voltage, current, and power output of the car. The panel generates a DC current through the solar controller. From there the inverter converts the DC current into an AC current. This is because changing the voltage from a DC current is very difficult. The new AC current can change its voltage easily to meet the operational needs of the car. The amplifier is used to raise or lower the voltage. The bridge rectifier then changes AC current back to DC current. This is so the motor controller can operate sensory functions.

Figure 3.1: The final product of the car(3)

This is the final product of the car. Modifications had to be made to the frame and axles in order to handle the torque that the system would undergo. The triangle bracing was used as a safety aspect to handle the tilt the car would undergo. The thicker rubber wheels and extra triangle stability greatly increased the amount of tilt the car could undergo.

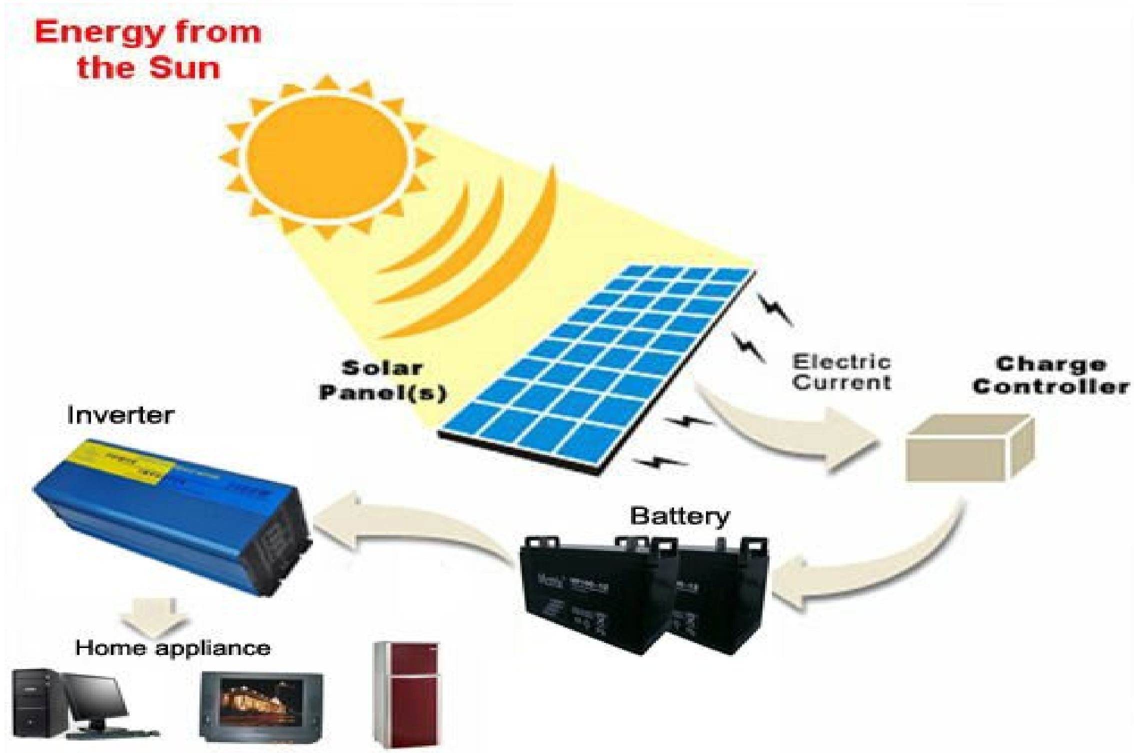

Figure 3.2: How solar energy is converted to a desirable DC voltage and current$_{(4)}$

This graphic shows how the system intakes solar radiation, then runs it through the controllers and batteries to produce power for operating various appliances. When the car was being engineered a bridge rectifier was added after the inverter to change the current back to DC in order to operate the motor sensory controller. AC currents aren't as effective or safe when generating power in a solar-electric vehicle.

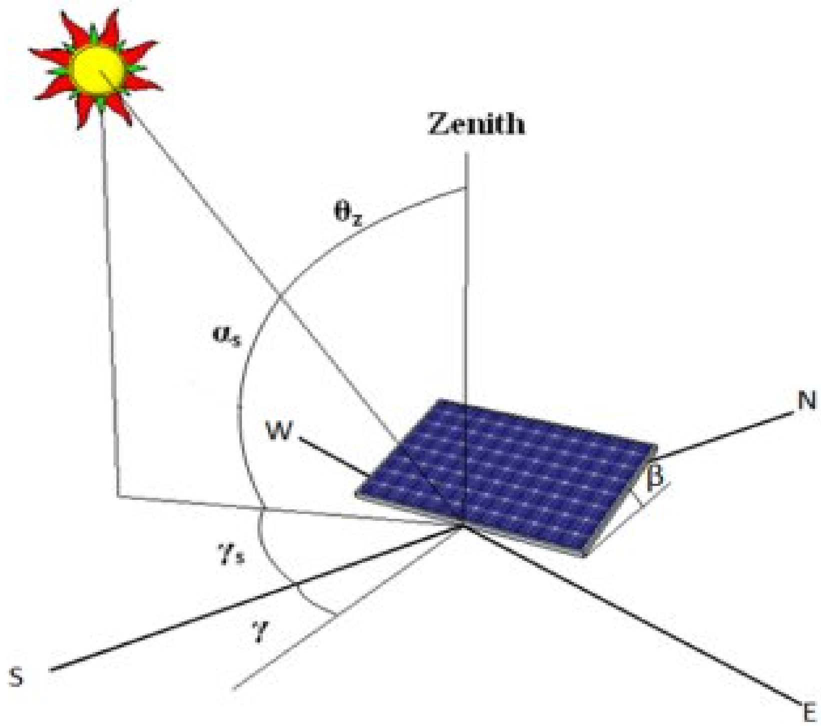

Figure 3.3: This figure shows the trigonometry needed in order to calculate proper tilt$_{(5)}$

3.1.1 Choosing a car frame material

There are several different material choices when making a frame. The angles and bracings were made out of aluminum. Aluminum is a good choice for them because aluminum is durable, and is easy to weld. For the same amount of strength that is needed for the car, aluminum is much lighter than steel. The aluminum alloy has a wide array of applications due to its tensile strength and weight. There are parts in the car that are connected to the pre-existing go-kart. They are the "add-ons" and the "X-Bracings". These parts were added on in order to increase the surface area of the car. The pre-existing go-kart had a steel body, so only steel could be welded to it.

3.1.2 Solar Panel Orientation

The orientation of the solar panel has a huge effect on efficiency. When the angle of the solar panel is change, there is not as much sunlightabsorbed. This results in less energy received. While having the solar panel orthogonal to the sun is the best solution, that is not always possible. By connecting a multi-meter to the solar panels output voltage, there was a similar voltage in the panel as long as it remained within $17°$ of being $90°$. Once the angle tilt is greater than that $17°$ allotment, the energy received rapidly drops. The above diagram is a set up for what variables to consider when calculating where the tilt should be on the panel.

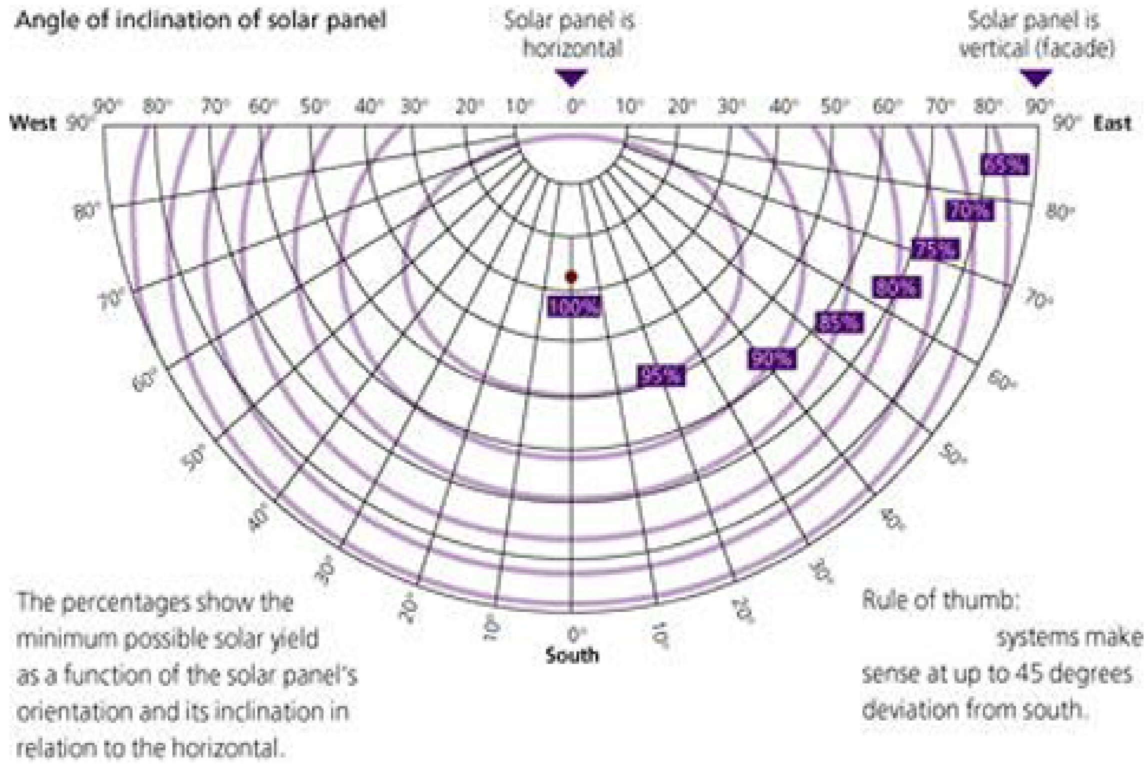

Figure 3.4: Solar panel efficiency based off the location of the sun$_{(6)}$

The above plot is the minimum amount of solar radiation that the panel will take in depending on the orientation of the panel. This data shows that the more orthogonal the panel is, the more solar energy it absorbs.

3.1.3 Batteries

solar energy cannot power a car all the time. For night time or rainy days there needs to be an alternative energy storage source. The most practical energy storage source would be a battery.

While engineering the car, there were several options for what kind of battery to use. The final two choices were a lead acid battery or a lithium ion battery. Lithium ion batteries are roughly $\frac{1}{3}$ of the weight of a lead acid battery. The most important factor for a battery is the energy density. As of now, lithium ion batteries have the highest energy density available on the market.

Efficiency is also something to consider. Lithium-ion batteries are nearly 100 percent efficient in both charge and discharge, allowing for the same amp hours both in and out. This increases both the current flow as well as the energy density of the battery. Lead acid batteries inefficiency leads to a loss of 15 amps while charging and discharging. These voltage drops reduce the batteries overall life time. Lead acid batteries are discharged at 80 percent, as opposed to the 100 percent discharge of lithium-ion batteries.

Green energy wise, lead acid batteries cycle themselves around 400-500 times as opposed to the 5000 times that lithium ion's can cycle. The lead acid cycle rate is so much lower because the 80 percent discharge level in lead acid batteries. Lithium-ion batteries are also much safer to the environment and have cleaner emissions.

Lithium ion batteries are unique in their own right because they can maintain their voltage throughout their entire discharge cycle. This allows for a greater efficiency and durability within the batteries electrical components. Lead acid batteries drop consistently throughout their discharging cycle making them not as efficient.

Due to the budget, the lead acid batteries were chosen. The lead acid battery has a short charge time of 8-16 hours which is perfect for overnight charging. Within the car, the dual batteries can take a high voltage of 2.40V per cell. This gives optimal performance on a minimal charge time. But long term, the stress of 2.40V per cell will cause grid corrosion to damage the battery.

3.1.4 Controlling Voltage and Current

There are two controllers set up within the system. They will be referenced as the solar controller, and the motor controller. Both of which have 6 diodes connected to their back end circuiting in order for their AC currents to act as DC currents. The solar controller is used as a regulator for the current flow from the solar panel. This is designed so that the solar panel doesnt output its maximum allowable current at all times. If the solar controller was connected without diodes it would run the risk of having the current run back through to the start of the circuit and damage both the controller and the panel. The diodes increase both the efficiency, and the safety of the vehicle in cases where variable power and torque is needed for the car. The motor controller has diodes, or what will be referenced as a bridge rectifier at the front end of the electrical wiring because the transformer will change our AC current into a DC current. The transformer that changes our original current serves the purpose of producing an alternating current from the primary coil winding and then harnessing the alternating flux produced in the magnetic core of a transformer. This changing flux induces an emf (voltage) in the secondary coil winding. This process changes our DC voltage and current and converts it into an AC source, in order to modify the voltage and current running through the system depending on the variable load put on the engine. This is a more economic and efficient process than using a voltage divider because the load resistance is smaller than the secondary resistance. This causes a diminishing output voltage and would require a larger current and total power from the energy sources (the solar controller and lithium ion batteries). If a voltage-divider was used within the system the motor controller system will require another induced load to divide the voltage and will cause a much greater waste of electrical current compared to a transformer solution. The voltage-divider solution also cant multiply" the voltage input to higher value. Therefore, the transformer is more beneficial to utilize in cases of motor functions within solar operated vehicles. In the case of DC current, the voltage will be constant, causing the current obtained to also be constant. The non-changing magnetic flux induced by this current does not induce any emf in the secondary coiling, causing the change in voltage to be much more difficult to obtain. Reducing the speeds at which the car can travel, compromising the cars performance when connected to a solar panel. Regulating the voltage and current are essential for making a solar powered vehicle. The controllers and bridge rectifier are the pieces of equipment that need to be tested in order to determine power generated and horse power contributed to the car. The process of determining horsepower of a solar hybrid vehicle variables such as the torque on the axles, the engine speed in revolutions per minute, and the power produced are the main variables needed. Hooking up multiple digital multi-meters to the solar and motor controller while operating the vehicle on various terrains is what will generate voltage, and current values needed to calcite power. The various terrains that will be tested will be a 15 degree incline, a 15 degree decline, and then flat ground on simulated asphalt.

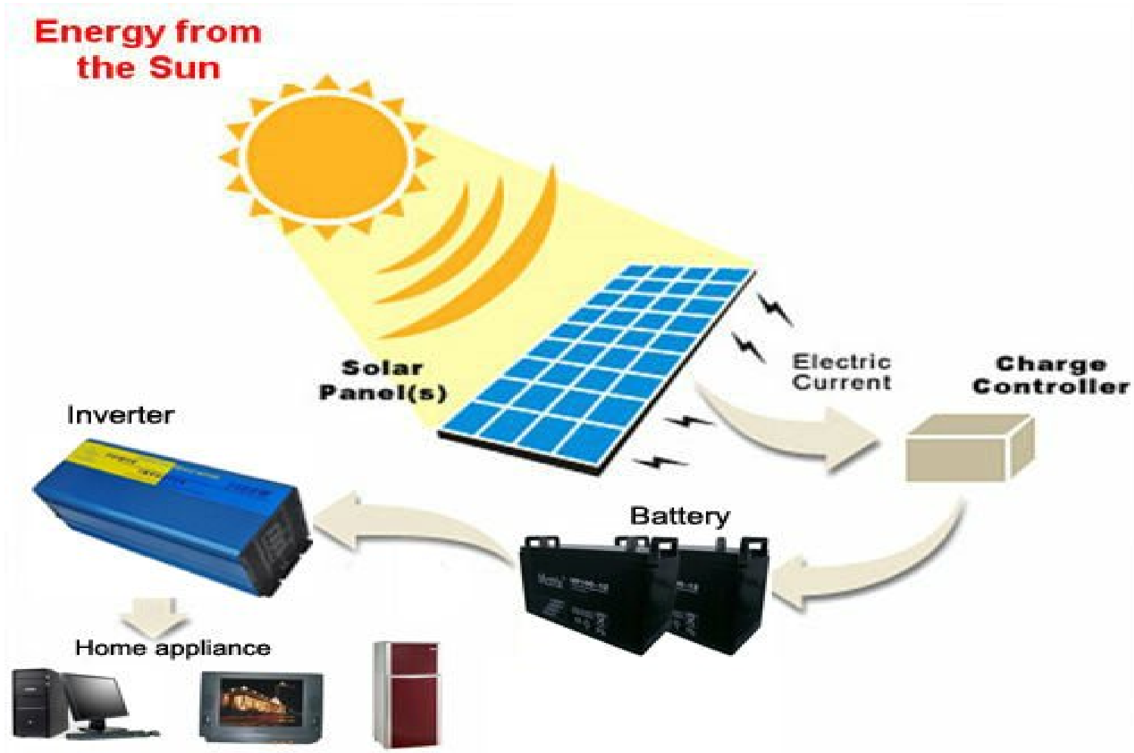

Figure 3.5: The above figure is how solar energy is converted to usable electricity(7)

This graphic shows how the system intakes solar radiation, then runs it through the controllers and batteries to produce power for operating various appliances. When the car was being engineered a bridge rectifier was added after the inverter to change the current back to DC in order to operate the motor sensory controller. AC currents aren't as effective or safe when generating power in a solar-electric vehicle.

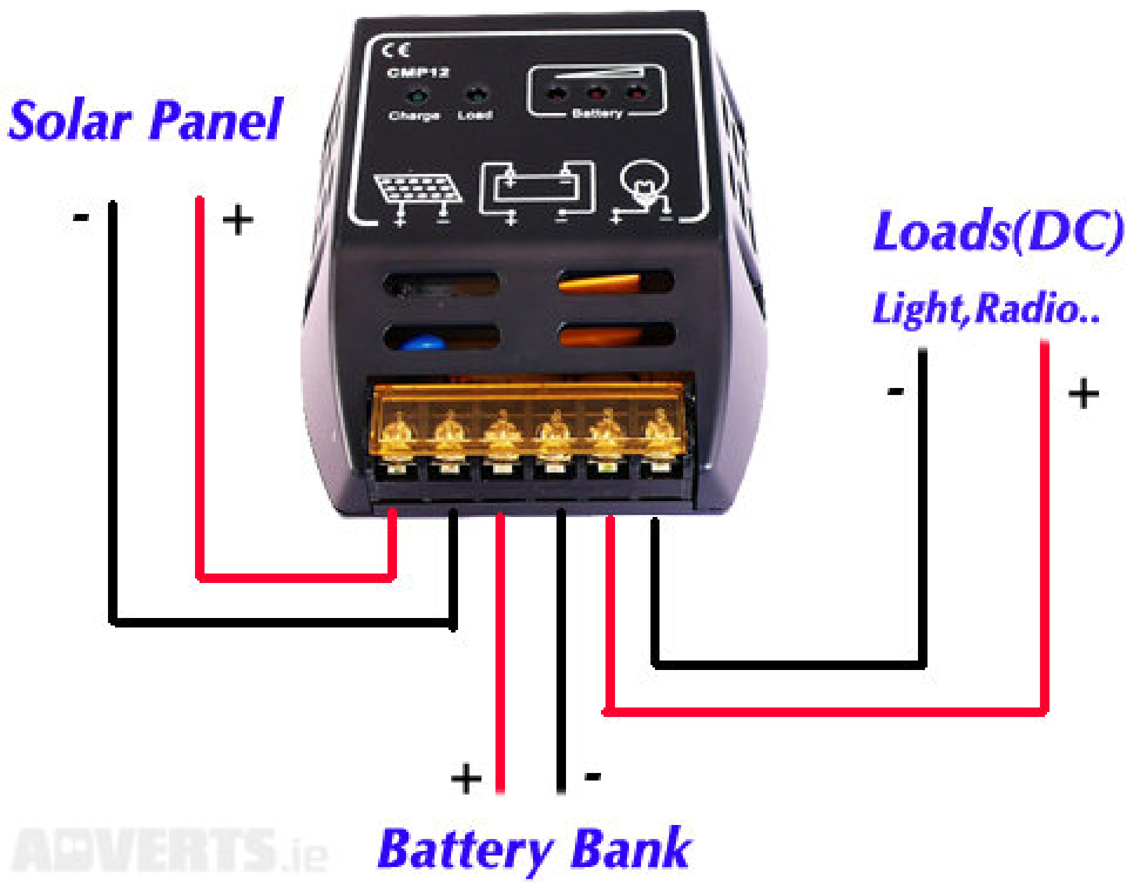

Figure 3.6: The controller as it intakes solar current (DC) and converts it to electrical current (AC)(8)

This graphic is a picture of the controller used for the solar panel set up. The 6 input and outputs are controlled by diodes to ensure that current flows one way. The motor controller functions the same way, except the input is the current from the transformer, and then the output loads are the sensory functions of the car. These controllers are two of the most valuable pieces of technology when engineering a green vehicle operated by renewable energy sources.

Chapter 4

Data and Analysis

4.0.1 Pre-data notes

The physical apparatus has already been built and from here there are just a few tests left. The voltage, current, and stresses put on the car were already numerically calculated. From here the data points will serve the purpose of verifying the expected results. These data points and theoretical calculations are then used to determine the expected energy produced by the solar panel.

4.0.2 Data Analysis

Graphic one shows the applied current that runs through the motor and solar controllers while the car undergoes acceleration from 0 to 17 mph. These trials are a critical piece to assessing whether or not it is possible for an electric car to have a solar powered fuel source. In order for this to occur the current needs to stabilize at or less than 19 Amps. When the current exceeds the maximum amount of amps, the bridge rectifier and controllers run the risk of malfunctioning. If the malfunction occurs due to the excessive stress, then all of the electrical wiring as well as power sources could become useless. The diodes used are to prevent the back through current. The battery would need a jump, but is a far less likely result due to the stability

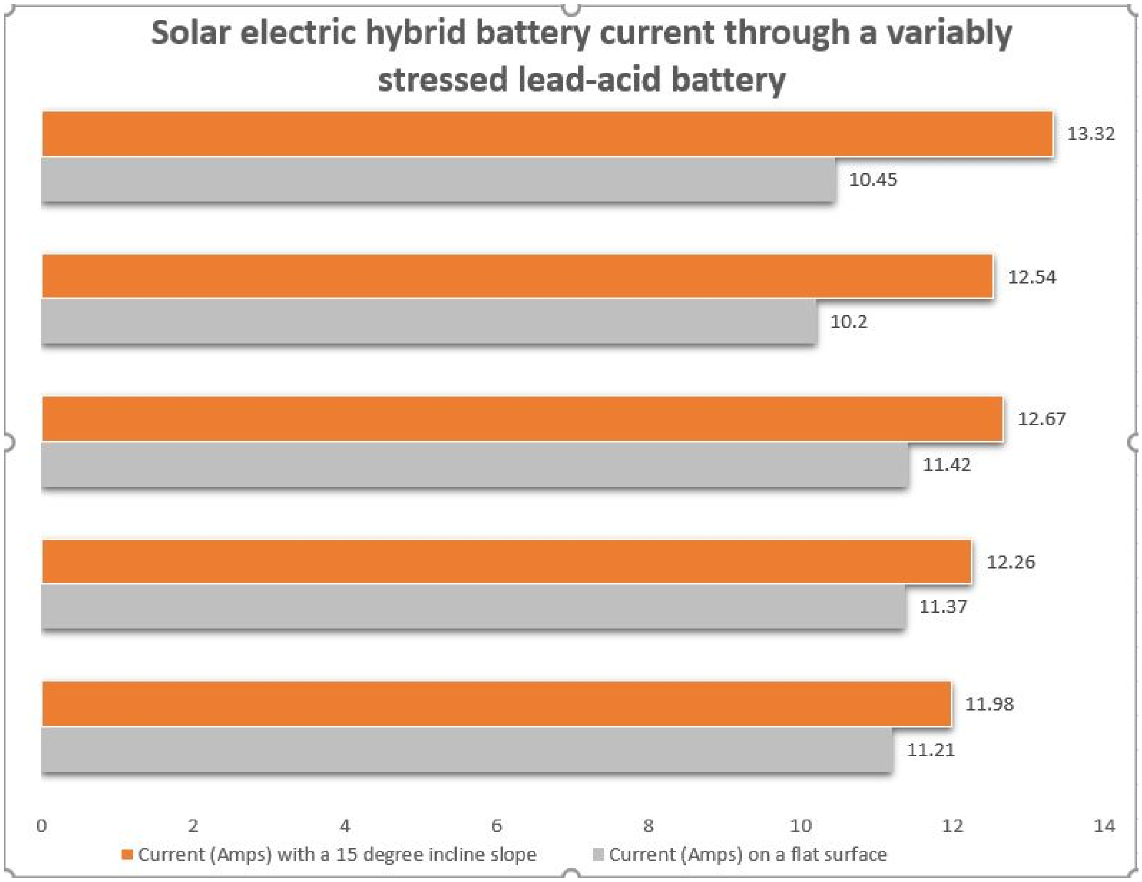

Figure 4.1: The controller as it intakes solar current (DC) and converts it to electrical current $(AC)_{(9)}$

of the lead acid battery. Through the current results, it is apparent that the solar panel is capable of sustaining it's current under the appropriate parameters. With only 7-10 Amps being the current needed to operate the solar panel, there is more than enough current to work the car. The maximum current that can be used is 19 Amps because the power supply is 315 Watts. 315 Watts has been determined as the maximum power produced. Theoretically 2^2 meters at 100% efficiency receives approximately 2000 Watts of power. Since the monocrystalline panel is 19% efficient, roughly 315 Watts are produced. It is important to note that the 19% is when the panel is operating at its maximum efficiency.

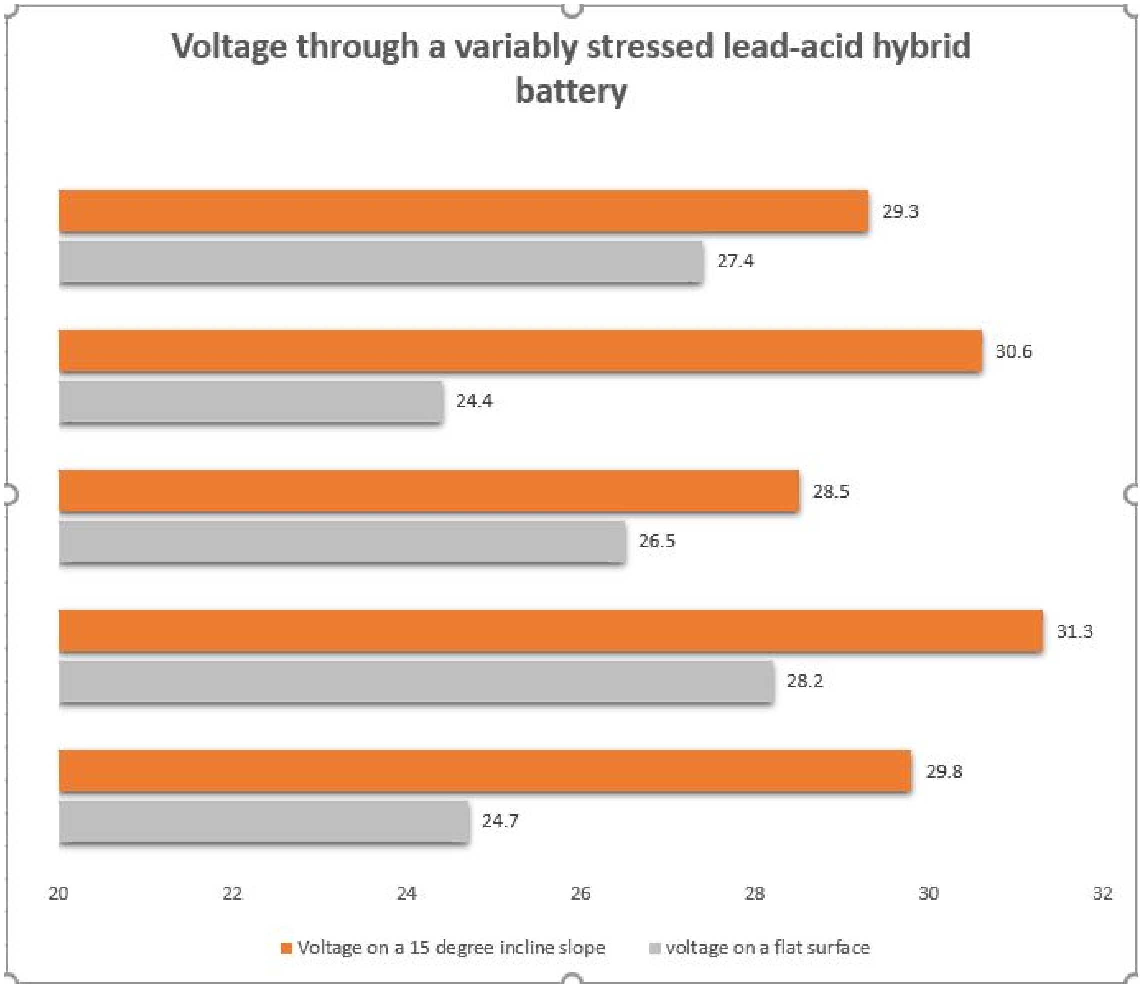

Figure 4.2: The controller as it intakes solar current (DC) and converts it to electrical current (AC)$_{(10)}$

While the applied voltage through the system is important to note, it is not a critical factor when determining the viability of the power source. The voltage just needs to be 32 Volts or less, and can easily be controlled by the controller. Theoretical voltage calculations are important in determining the type of controller that should be used. If the voltage were to exceed 32 volts the controller runs the risk of breaking its connected diodes. However, this is very unlikely due to the controllers internal automatic protection circuit.

Chapter 5

Conclusion

Effectively integrating a solar grid into the body of an electric vehicle is not practical. However, just because it is possible does not mean it is an effective power source. The panel does not produce enough horse power to operate effectively as an independent power source for a small or mid size vehicle. With only producing 1.7hp, that comes no where near the 160hp an average mid-size car produces. By introducing a lithium-ion battery it would improve the performance of the car by a considerable amount, but it still would not be enough to independently power the car. A lithium ion battery would improve the energy storage of the solar panel. Solar panels should only be used as an additional power source.

Solar panels should not be used as the lone power source for the car.

Using solar panels to operate vehicles such as golf carts, city-bound smart cars, and other small vehicles is also a viable solution to engineering a green energy vehicle. Integrating solar panels into a mid-size vehicle is not practical for engineering a completely green energy car. This is why solar panels shouldn't be introduced into the market of electric vehicles.

Chapter 6

Acknowledgements

I would like to begin with thanking my parents and my sister for their unwavering support and love. They have motivated me to be the best competitor that I can be, and I am so grateful for them. Next I would like to thank Dr. Xie for being the best mentor and professor I could ever ask for. I have never had a professor that looks out for me as much as you do, and I am incredibly grateful for all of your guidance throughout the years. Lastly, I would like to thank Dr. Murray for being the ”mother hen” that has helped to keep me focused on my goals. Through your guidance I have learned how to put things into perspective, and how to approach learning.

Chapter 7

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