FAMU-FSU College of Engineering
Department of Electrical and Computer Engineering

CONCEPTUAL DESIGN REVIEW

EEL4911C – ECE Senior Design Project I

Solar Car

Team # 2

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Project Executive Summary

The American Solar Challenge is a competition to design, build, and drive solar-powered cars in a cross-country time\distance rally event. The Solar Challenge hosted in 2012 will have teams competing in a 2400-mile course between multiple cities across the continent. It is hosted by Innovators Educational Foundation, an organization devoted to applied learning in the areas of science, engineering, and technology. FAMU-FSU College of Engineering has set up a team of senior undergraduate students from multiple disciplines to design and build a solar powered car to compete in this challenge. The team consists of three electrical engineers, three mechanical engineers, and three industrial engineers.

The energy from solar radiation is the most abundant and potentially the greatest source of renewable energy. Research is constantly conducted around the globe aimed at increasing solar cell efficiency and may one day enable us to harness the full energy of the sun. The technical design project that we have undertaken is attempting to introduce senior engineering students to solve the problem of designing, building, and racing a safe and functional car that is powered via sunlight.

The objectives of the technical design project are as follows:

1. Design a composite body
2. Design Solar array configuration
3. Design suspension system
4. Design Electrical system
5. Optimize Design
6. Test Mechanical system
7. Test Electrical system

The solar car project will be designed following lean six sigma's methodology DMEDI (Define, Measure, Explore, Develop, and Implement). DMEDI is a methodology used to systematically conduct projects that require a new designed process or product. The Define phase provides a clear problem statement that charters a project with a defined scope and Outcomes. The Measure phase is the step where the team converts the needs and specifications of the project into measurable and quantifiable targets. This allows for prioritizing and quantitative reasoning for making decisions or creating alternatives. In the Explore phase the team will then create a conceptual design of the solar car based on the data collected and analyzed in the measure phase. Then in the Develop phase the team optimizes the conceptual design to capture all the needs and specifications of the solar car. Finally, the solar efficient car will be fabricated into a full scale working design.

Table of Contents

1 Introduction

1.1 Acknowledgements

The 2010-2011 Solar Car design team would like to thank all of the people and organizations helping us to design and create a cutting edge solar powered vehicle. Particularly, the team would like to thank Dr. Bruce Harvey for giving the team direction on how to approach the task of designing and building this vehicle. The team would like to thank Dr. Chris Edrington, for the technical direction for the electrical integration, High Performance Material Institute (HPMI) and Jerry Horne, for the time and know how to create the composite body, and the FAMU-FSU College of Engineering, for the monetary donation to complete this project with the best materials available.

1.2 Problem Statement

In 2009, the FAMU-FSU College of Engineering revitalized the Solar Car design project. The solar car design project is intended to increase the knowledge of renewable energy generation, energy storage and increase the publics' awareness of advances in renewable energy technology. The students were assigned the task to reuse and update the solar car from the 1997 Solar Car design team. This project was to be Phase I of a two phase project. The team from 2009 utilized the existing frame but was unable to salvage any portion of the previous body. Their goal was to get a rolling chassis that could be used for the second phase of the project.

This year, Phase II of the project will start where the previous team of Phase I left off. The current 2010-2011 design team, comprised of electrical, mechanical and industrial engineers, are assigned with the task of designing and building a vehicle to be raced in the 2012 American Solar Challenge Race. The race regulations have changed since the 2010 race. Therefore, the new design team will take what was created from Phase I and design a new car to the 2012 race specifications.

In order to produce a vehicle to the 2012 race specifications, the team will have to work together to optimize efficiency, power and durability. To accomplish this, the team must utilize the knowledge learned from courses previously taken, keeping in mind a limited budget and a limited allotment of time. The team will incorporate some components of the previous solar car to expedite the process and to keep the cost down. The team will use the motor, motor controller and some electrical components used from Phase I. All other components will be designed and fabricated to meet the specifications of the race.

The new car will be designed using the idea of a monocoque body, which incorporates the chassis into the body. The monocoque body will be made using carbon fiber and composite materials to reduce weight and increase aerodynamic efficiency. The design will consist of three wheels, as opposed to four wheels, to reduce the overall friction loss of the vehicle. The design will undergo stress analysis to ensure safety and stability of the vehicle. Low friction disc brakes will be used on the forward two wheels for proper stopping force necessary to decelerate the vehicle in the allotted space. A rack and pinion steering system will be designed to best fit the vehicle for a turning radius specified by the race regulations.

For propulsion, the driving force for the vehicle will produced by an in-wheel brushless DC motor. The motor will be mounted on the rear trailing wheel assembly. To control the input power to the motor, a motor controller will be used by taking the power from the batteries. Sensor readings, such as temperature, voltage, will be continuously gathered to protect the batteries, motor and driver from over-heating or over-charging. Also, a protection circuitry, including breakers and fuses, will be implemented in order to safeguard components from power surges or cross wiring. These will ensure safety to the driver and vehicle, which is the number one priority of the team.

1.3 Operating Environment

During the race, the solar car may be subjected to harsh weather conditions due to the race being held on public roads and highways. Even though the route of the race has yet to be determined, it will be assumed to go anywhere in North America. The race is held in the month of July, so temperature ranges across North America can be as high as 134 °F or as low as freezing in portions of Canada. Solar radiation on a clear day increases drastically making it a factor when considering the temperature inside the vehicle.

The vehicle may have to endure areas of extreme humidity or extreme dryness. Rainfall or high winds are not uncommon during the month of July in places across North America. Keeping in mind the vehicle does require solar radiation to run; clouds and other water molecules in the air are a large factor in the production of energy from radiation. The vehicle will have to compensate for the lack of sunlight when the clouds are blocking the sunlight from striking the solar arrays.

Besides weather factors, the vehicle will have to withstand the conditions of the other traffic on the race route. Cars and trucks driving beside, in front or behind the solar car may cast shadows on the solar arrays making it impossible to produce energy from the sun. In addition to shadows, passing vehicles may generate turbulent wind conditions making it more difficult to operate the vehicle and may increase the drag on the solar car. The conditions of the roads are unknown. Therefore, the solar car may have to handle bumpy, pot hole ridden roads.

The team must consider the power required for uphill travel. There might be sections of the route that involve navigation through and around hills and mountains. Based on interstate highway standards, the maximum grade that will be encountered is six (6) percent. However, this standard does not apply to urban areas where grades can be as high as twelve (12) percent.

All factors must be taken into consideration when designing the vehicle for travel in North America.

1.4 Intended Use(s) and Intended User(s)

The solar car will be an eco-friendly way for a single driver to traverse distances with the normal speed and efficiency of a car. The car will be equipped with all the normal lights and signals of a regular vehicle and therefore should be able to safely travel on roadways throughout a city. The vehicle's top speed will prohibit it from travelling on any interstate highways or any other roads with high speed limits.

The solar car will be used primarily for daytime driving as this is the only way to collect the solar radiation necessary to charge the batteries. The vehicle will be capable of charging the batteries from certain wall sockets so it will not be entirely restricted to driving during the day, but as stated previously, will have no way to recover energy except stopping again to charge.

This project will continue on after this portion of the design is completed in the hopes that it will be able to compete in the American Solar Challenge. This challenge is a competition that occurs bi-yearly and will give the finished product a chance to compete against other schools with similar design restrictions. To enter this competition will be the primary goal of this car as it progresses through design projects.

1.5 Assumptions and Limitations

1.5.1 Assumptions

1. This portion of the design phase will continue to move the car towards competition in the American Solar Challenge
2. Many of the electrical systems from phase one portion of the design will be useable in the design work for this phase
3. The car will be allowed to be to carry a full charge before any competition, which may be achieved through wall charging
4. There will be changing race restrictions for future races and the car will have to be left in a state where systems can be changed cheaply and simply

1.5.2 Limitations

1. Budget will be restricted and it will be necessary to seek donations wherever possible
2. The solar array will be limited to a size of 6 m^2
3. The driver's eye line must be at least 70 cm off the ground and provide 100 degrees of view to the right and the left
4. A roll cage will be protecting the driver in the event of a rollover collision
5. The electrical systems must be isolatable so that power can be immediately cut by either the driver or an onlooker from outside the car
6. The car will have to pass a series of safety and performance tests outlined in the American Solar Challenge guidelines and the finished project of this phase should have a car capable of passing all these tests

1.6 Expected End and Other Deliverables

The most important deliverable will be the completed solar car from this phase of the project. This will not be delivered until the end of the project time as will be illustrated below in the schedule. The other deliverables for the project will include several design papers which will include updates as to the current design and any modifications made from previous reports. A website will be created for the purpose of displaying information about the solar car, progress to date, and will include a section for all the papers and presentations. Finally a user manual for the safe operation of the vehicle will be completed.

2 Systems Design

2.1 Overview of the System

Due to the amount of exposure to vehicles in today's society the top level design of the solar car is fairly fundamental. There are basics that every 'car' has that will also be required in the end result of the solar car. The car will need a means of motion for not only the vehicle but also for the driver. Although motion is a good start it is almost worthless if the motion cannot be controlled and directed. The control means that the driver has to be able to slow down and speed up as desired and also has the ability to change the direction of travel. It would also be ideal for the driver to have information about this travel and control readily available (ie, speedometer). As it is a solar car it will need a means of power generation through the sun's radiant energies. This energy will have to be stored at times because the driver may want to move the car during times when solar radiation is not available. While this is far from a summation of the goals that the solar car will need to achieve it is a basic overview of the standards to which the car will be held.

2.2 Major Components of the System

Due to the magnitude of the project it has been broken up into two sections, mechanical and electrical, mainly as a means to describe the functionality of the system or component and further dictate the primary party responsible. Each section has been further subdivided into multiple systems to allow the design work to be placed in the hands of a specific engineer on the project.

The mechanical systems of the car will include the body, steering, braking, and suspension. The body of the car will be just that, the housing for all components as well as structural support for the entire vehicle. As can be inferred, the steering will be the system that will provide directional control over the vehicle with driver input. The braking system will be the means by which the driver slows the car down. Finally the suspension will be the system that will further facilitate driver control over the vehicle and provide a smoother more comfortable ride for the driver.

The electrical systems that will be present in the final design of the car include: power generation, control systems, management system, and propulsion system. The power generation system refers to the two methods of generating power in the car. The first of these methods is solar energy, which is an integral component to any solar powered device. The alternative method for power generation is through the regenerative braking energy that can be produced by the motor. Controlling these two methods of power generation will be the primary function of the power generation system. The control system will be the devices that allow the driver to view information about the car, such as current speed and state of charge, and to turn on and shut down the car through electrical relays. The management system's primary goal will be to keep the batteries of the car in a safe operating range at all times. Finally the propulsion system refers to the means by which the car will move, the electric motor for the car, and all devices that provide control for this device.

2.3 Performance Assessment

Each of the systems will have to be evaluated to ensure not only correct performance but ideal performance under the wide variety of conditions that the car will be exposed to. This evaluation will begin during the design phases and continue through fabrication and implementation through testing.

The body of the car will be graded against three major standards: aerodynamics, strength, and weight. Due to the very low efficiency of utilizing solar energy everywhere power can be saved will be absolutely necessary. For this reason the aerodynamics of the body may be one of the most important design phases for the entire project. Through the use of CAD programs, different types of models can be tested and the overall drag coefficient for the vehicle can be calculated. The strength of the car will also be incredibly important as if the body breaks it could not only cause serious damage for the components but also to the driver of the car. However since the motor will have to propel all the weight of the car, it will also be necessary to keep the body as light as possible. The material of the body will have to be chosen on these two factors.

The steering of the car will provide the direction control over the motion of the vehicle. As the anticipated end result of the solar car is the end up in the American Solar Car Challenge (ASC), there are certain restrictions on the degree of control the steering must be able to provide. This is not the design limit for the car however and more control would be ideal unless if comes at the cost of friction or other power losses. Figure 2.3.1 displays one of the steering tests (the slalom test) that the car must undergo to qualify for the competition.

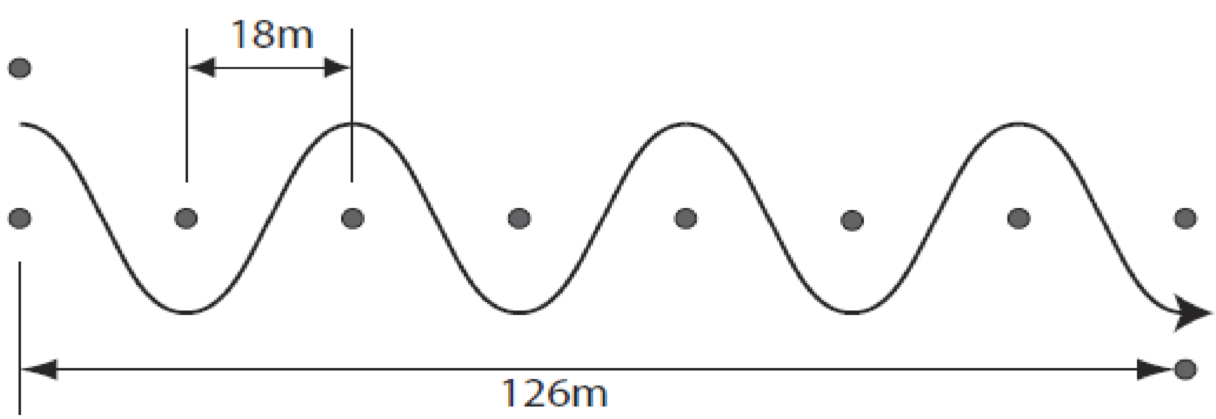


Figure 2.3.1 – Slalom Test Diagram

Similar with the braking system, the ASC has stipulated requirements on quickly the car must decelerate (4.72 m/s^2), but that is in no way a limit. Therefore the design of the braking system will be to meet the needs of the competition and if it is possible to efficiently surpass these bounds than the system will be designed as such.

The suspension of the car will provide some impact protection for various road conditions that the car will encounter during operation. This protection will keep the body from unnecessary damage and also provide the driver a more comfortable ride. Once the final weight and size of the vehicle is determined there will be a maximum displacement for the suspension to be designed around.

The power generation system will also be limited by the ASC regulations, allowing a maximum of 6 m^2 of surface area for the solar arrays. The performance of these solar cells will be measured by the fill factor, the ratio of theoretical power to actual power, solar efficiency, and thermal efficiency. Along with the solar cells, power point trackers (PPT) will need to be utilized as well. PPTs will be chosen based on the power rating and the overall efficiency with the solar cells utilized.

The control system’s primary component will be the microcontroller. The microcontroller’s performance will be determined by comparing the needs of the project to the specifications of the microcontroller. When a few microcontrollers are found that will meet the needs of the project, with a little extra for possible design changes, then the search for the most cost effective one will take place.

The management system’s performance will be based upon how well the state of charge information is monitored, both through the BMS and also the information displayed for the driver. It will also be important to verify that the information seen by the driver will correspond to the information that will be seen by the BMS, primarily as a means of checking that both systems are working properly.

2.4 Design Process

The solar car team has been provided with three industrial engineers to act as subcontractors for the project, allowing for a wider variety of design input. The industrial engineers were able to greatly facilitate the design process through their methodologies as shown in Figure 2.4.1 and Figure 2.4.2.

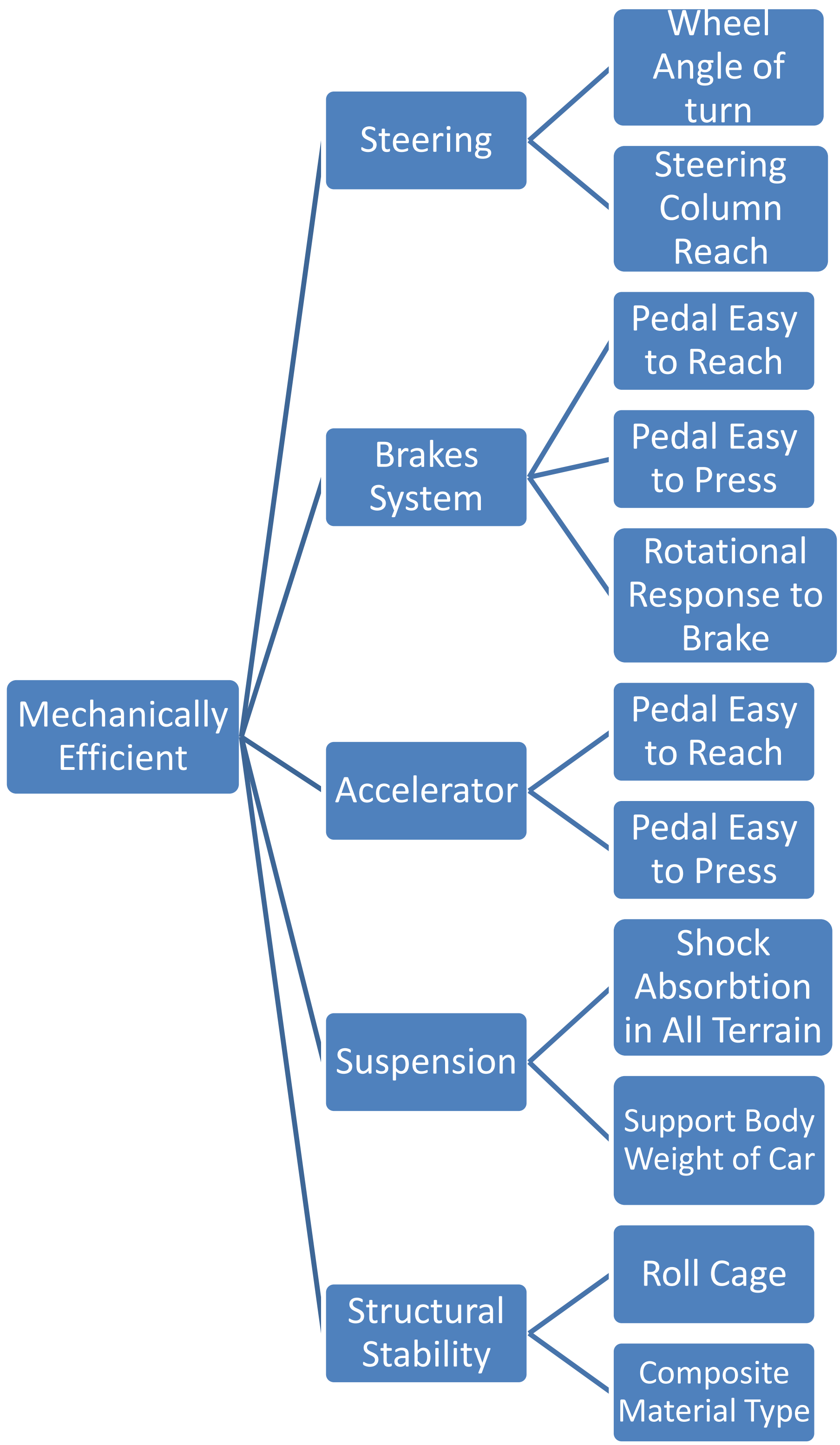


Figure 2.4.1 – Mechanical System

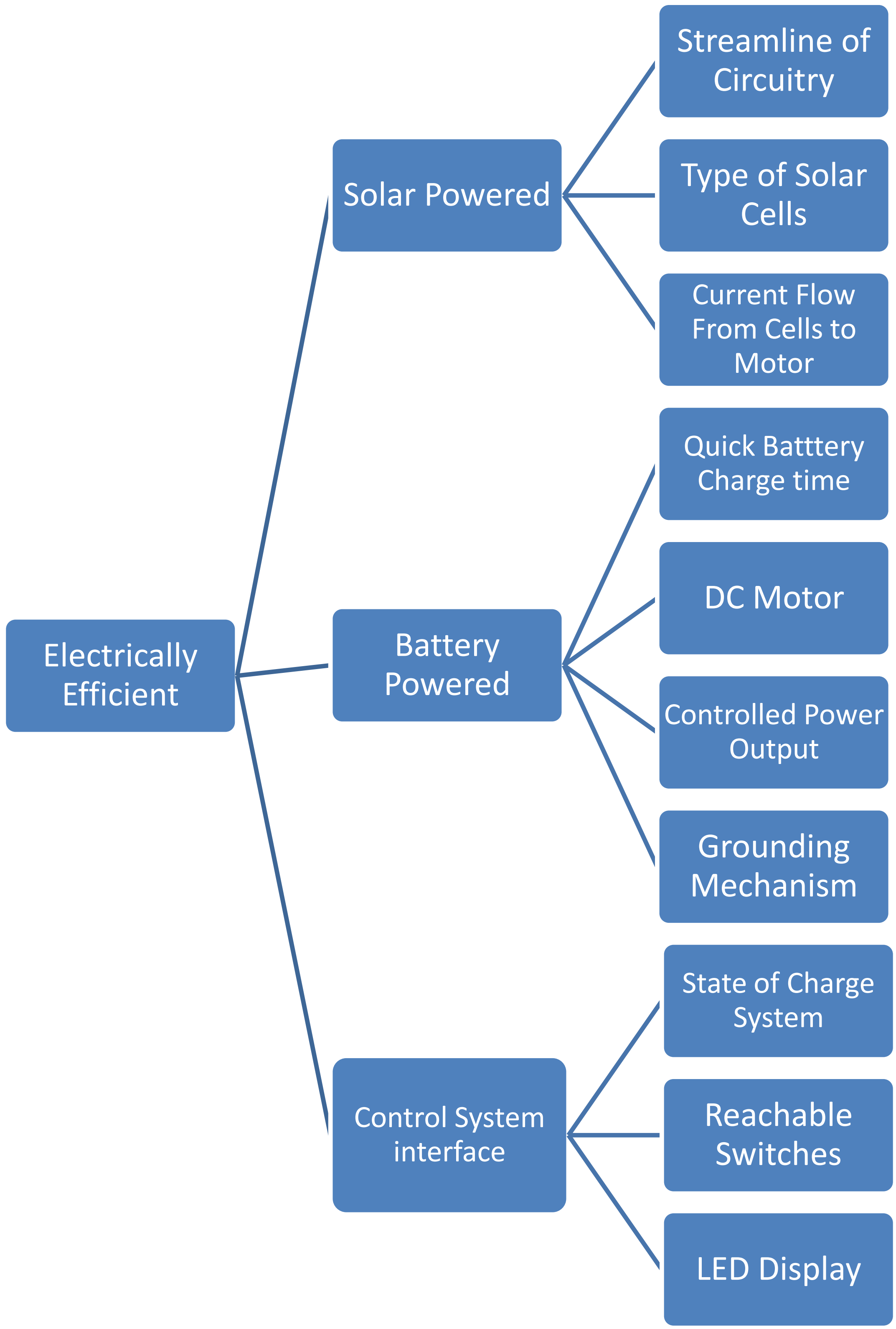


Figure 2.4.2 – Electrical System

These figures helped ensure that all factors were taken into consideration while going through the other design stages. It was this process that helped to create the major component areas for our project.

For the power generation system the most important decision was the type of solar cells that would be utilized in this design project. The options that were considered were silicon and amorphous silicon. The major difference between the two is that the amorphous silicon are self encapsulated and flexible while the regular silicon cells would have to be laminated to the body and, due to lack of flexibility, are much more fragile. The advantages of the regular silicon cells are cost and a higher solar efficiency despite a lower fill factor. Taking these factors into consideration it was determined that the amorphous would be a better option mostly because of the durability. As none of the members of the team have a great deal of experience with solar cells there was a fear that during installation a few might break, which increase the cost for having to replace the cells. The flexibility of these solar cells will also allow them to molded to the curvature of the body unlike the regular silicon cells, which would have to be tiered and increase the overall drag of the car.

The control system had to make a decision about which microcontroller would meet all the needs of the design project. It was important to keep in mind that if the capabilities of the microcontroller greatly exceeded the needs of the project it would most likely cost more money as well. The microcontroller chosen for the project is the Dragon12 Development Board, which contains more than enough I/O pins for the entirety of the project. The programmable memory on this board is rather large which should surpass the simple application for the dashboard displays.

The most difficult design portion of the management system will involve implementing a state of charge system for the car. This state of charge will be measuring the voltage potential across the batteries and current out of the batteries. Measuring the voltage is a rather simple task but in order to measure the current a special device would have to be used. Three options for measuring the current presented themselves that would be capable of measuring such high currents without damage to the device itself: a current transformer, Hall Effect sensor, and a shunt line device. The current transformer will be chosen for this application for two reasons: one is the previous group experience in utilizing these devices and second because of the devices found for purchase online, the current transformers consistently had simpler microcontroller interfaces. This simplicity in integration will go a long way to helping complete the project.

These are only a few of the major decisions that each system has already made on the way to completing the design for the project. It is likely that many of these decisions will have to continue to be made throughout the entire project, including the fabrication phase. However if a similar approach is implemented then a sound decision can be made further ensuring the overall success of the project.

3 Design of Major Components

3.1 Body

The design for the body of the solar car has many factors when designing an efficient body with very little frictional losses. When considering the design, the team has to keep in mind a few very important factors. The first is the safety of the driver, which must meet the race regulations. The race regulations state that the driver must be encapsulated in a roll cage for rollover protection. Dimensioning the vehicle to fit the roll-cage has to be considered. The next factor that has to be considered is the overall shape of the vehicle to keep air resistance at a minimum. Frictional loss from air resistance can be a huge variable when driving at speeds reaching 70 mph. The final factor that must be considered is the weight of the vehicle. The race states that the driver must weigh 80kg, making this the minimum the total car can weigh. When considering rolling frictional loss in the tires, the main variable is the downward force between the tires and the road, also referred to as the overall weight of the vehicle. This design must be drawn in SolidWorks CAD software to be analyzed for structural integrity.

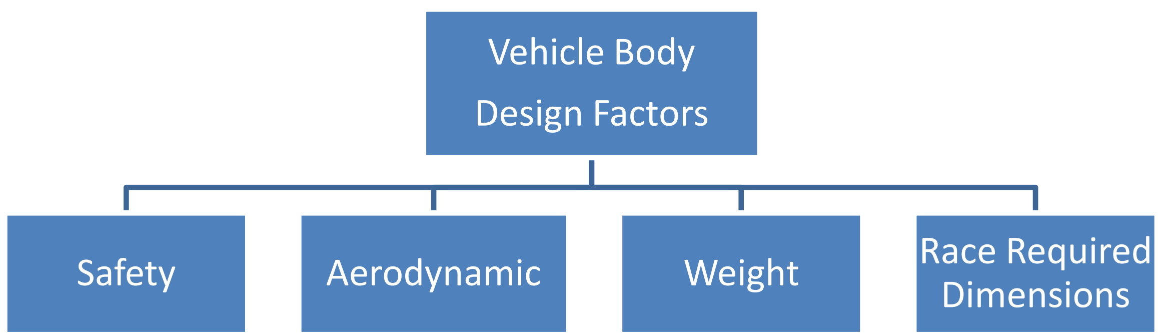


Figure 3.1.1---Vehicle Body Design Factors

3.1.1 Safety

According to the race regulations, the solar car must have a roll-cage to protect the driver in a crash situation. To achieve the maximum amount of safety, a roll cage must be designed in conjunction with the body to provide for the most effective design. When considering the roll-cage, the team had to decide between a cage that has double bars over the drivers' helmet or a design using one bar over the drivers' helmet and one bar over the lap of the driver. The factors for deciding between the two designs are the effectiveness, whether it is easy to escape the car and the weight comparison. The team chose to use the design of the double bars over the helmet of the driver because it would be much easier to escape from the car in the case of an accident or fire. The bars will be made from chromoly tubing because it is lightweight and very strong.

3.1.2 Body Shape

The body of the Solar Car must have as little air drag as possible. This makes for a more streamline design reducing the force it takes to cut through the air. Through extensive research, the proposed design takes the shape of a water droplet falling through the air which is commonly known as the basic most aerodynamic object. At the bow of the vehicle, the design mimics the parabolic shape of the bottom end of a water droplet. This is so there is no separation between the air and the body. When separation of the air and the body occurs, there is a pocket of low pressure air that acts against the direction the vehicle is moving. At the aft of the vehicle, the upper and lower halves of the body converge to a single line. This, again, is to reduce the separation of air from the body reducing the chance for the low pressure air pocket to be generated. When calculating the drag an object produces, the two variables that can be controlled are the cross sectional area (A) and the drag coefficient (C_D) of the vehicle, as seen in the *Equation 3.1.1*.

– *Equation 3.1.1*

Other Solar Car teams have tried using different radical shapes, as seen in Figure 3.1.2, but the standard aerofoil shape, Figure 3.1.3 has been proven to work the best in the solar car application.

Figure 3.1.2 – Radical Design from American Solar Challenge 2010 (Änderung, 2009)

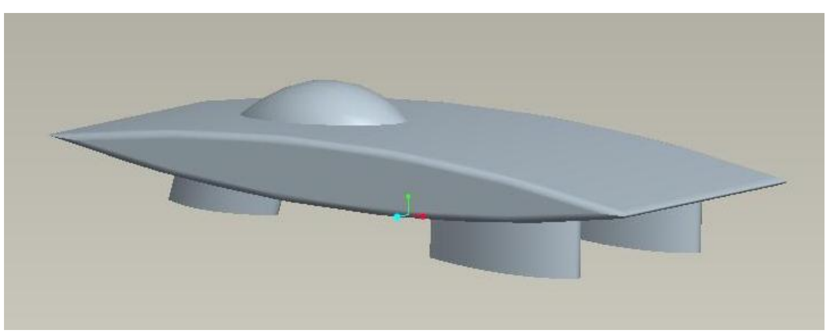


Figure 3.1.3 – Proposed Aerofoil Design

3.1.3 Body Weight

The overall goal of the car is to make the body and its components as light as possible. This is because frictional loss between the tires and the road and the frictional loss in the wheel bearings is a function of the weight. Weight is also known as the Normal force (N_f) exerted to hold the car above the ground. When determining the rolling friction lost between the road and the tires, *Equation 3.1.2* is used: where C_{rr} is the coefficient of rolling friction for Michelin solar car/eco-marathon tires.

Equation 3.1.2

For reduction of overall weight of the body, there are two major components that have to be considered, first of which is the design of the frame. Previously, solar cars were made using space age aluminum framing and covered with a fiberglass shell as seen in Figure 3.1.5. The use of a frame adds considerable weight making it less desirable.

Figure 3.1.4---Aluminum Frame with Outer Shell (Cyber, 1999)

The design chosen uses the idea of a monocoque construction which utilizes the shell of the body as the load bearing structure as seen in Figure 3.1.6. It eliminates the aluminum tubing frame making for a much lighter design.

Figure 3.1.5---Monocoque Body (Kruschandl, 2005)

The monocoque body can be made of either fiber glass or carbon fiber fabric. It is desirable to use the carbon fiber fabric because it is 40% lighter than fiber glass and much stronger. The only drawback is that it is considerably more expensive. The proposed design, Figure 3.1.7, is to use carbon fiber to make the solar car as light as possible to reduce the frictional losses.

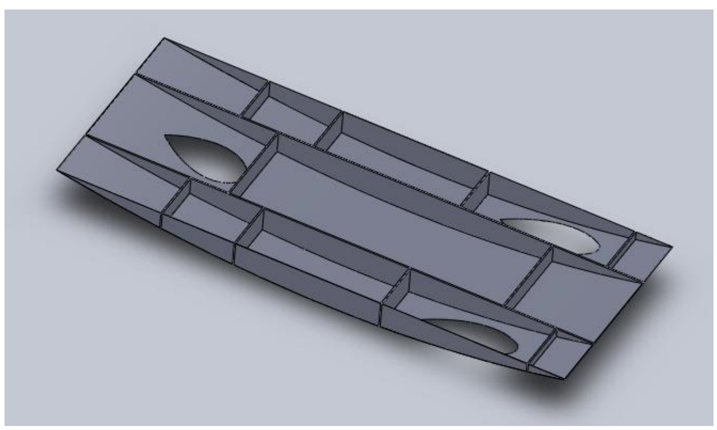


Figure 3.1.6---Proposed Monocoque Bottom Half

3.2 Steering

The steering system from the previous year's solar car will be salvaged and implemented into the current solar car design. The only new component will be selection of a new gear box to give to vehicle its required steering characteristics.

The major components of a rack and pinion steering system are the steering wheel, steering column, rack and pinion gear, and the tie rods. This is depicted in a block diagram in Figure 3.2.1.

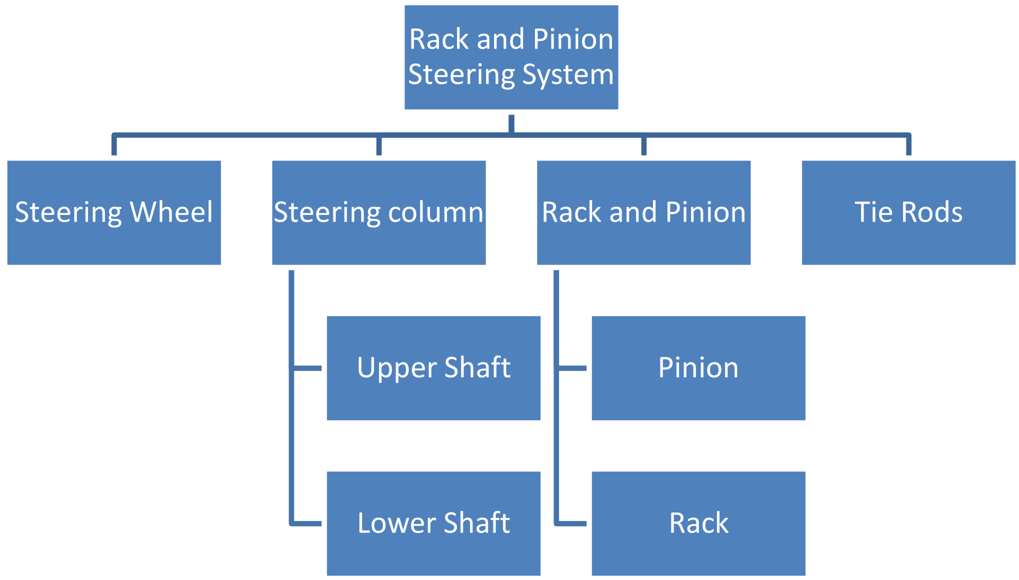


Figure 3.2.1 – Steering System Block Diagram

3.2.1 Steering Wheel

The steering wheel is the input device for the steering system. As the driver turns the wheel it rotates the steering column in order to turn the wheels in the desired direction.

3.2.2 Steering Column

The Steering column consists of two parts, the upper and lower shaft. The upper shaft is attached to the steering wheel so as the steering wheel is turned, the upper shaft rotates proportionally to the wheel. The lower shaft is positioned parallel to the road and is connected to the upper shaft using a universal joint. Shown in Figure 3.2.2 is an example of a steering shaft assembly.

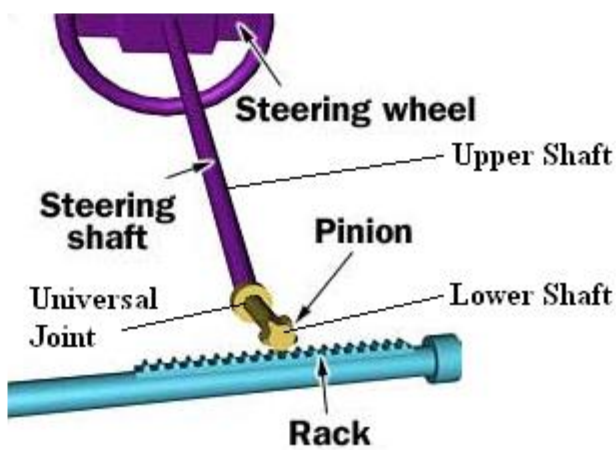


Figure 3.2.2--- Steering shaft. (Nice, How Car Steering Works, 2001)

3.2.3 Rack and Pinion

The rack and pinion, as shown in Figure 3.2.3 is the main component of the steering system. It consists of a pinion gear, which is attached to the lower shaft that is in mesh with a rack. The rotational motion of the pinion is converted to a linear motion by the rack gear. As the rack moves linearly it moves the tie rods which turn the wheels.

Figure 3.2.3 – Rack and Pinion Gear (Rack and Pinion)

3.3 Braking

Shown in Figure 3.3.1 is the block diagram for the hydraulic disc braking system. The main components of the system are the pedal system, master cylinder, caliper, and brake rotor.

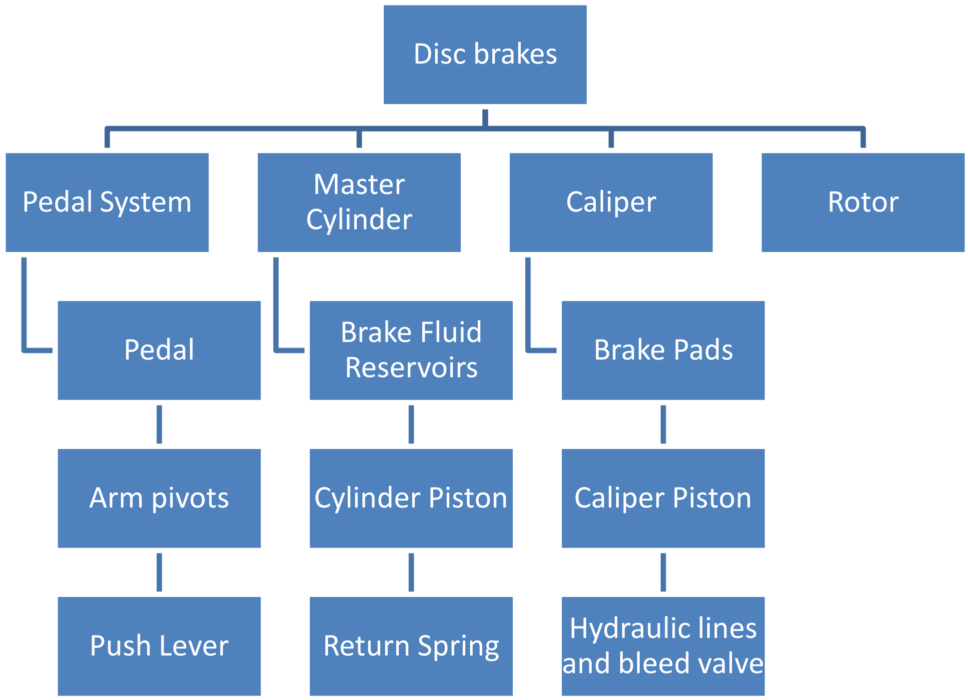


Figure 3.3.1– Hydraulic disc braking system block diagram

3.4 Pedal System

To initialize the braking system of the car, a brake pedal will be installed in the car so when pressure is applied to the pedal it rotates the arm pivot around a point to activate the push lever, which is connected to the master cylinder and is responsible for applying pressure to the pistons in the master cylinder to drive the hydraulic fluid. Shown in Figure 3.4.1 is the force diagram of the pedal system.

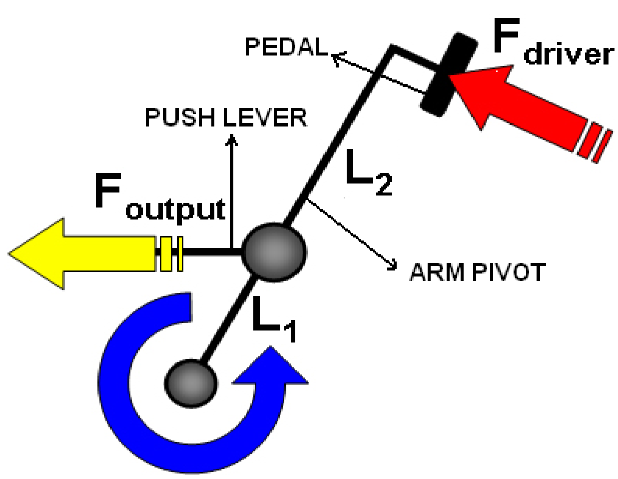


Figure 3.4.1 – Brake pedal system (Brake pedal setup)

3.4.1 Master Cylinder

The master cylinder is a crucial component of a disc braking system. The master cylinder is a control device that converts the pressure from the push lever into the hydraulic pressure needed to stop the vehicle. The master cylinder is comprised of the main cylindrical body, which encases two pistons and two return springs, and a reservoir for the brake fluid. When the brake pedal is pressed it moves a the primary piston. As the primary piston moves, hydraulic pressure builds in the cylinder and pushes a second piston. The built pressure from these pistons gets transferred into the brake lines which go to the respective brake caliper systems. When pressure is taken off the brake pedal, the return springs return springs bring both pistons back to their respective rest states relieving pressure in the master cylinder. Shown in Figure 3.4.2 is a schematic of a master cylinder.

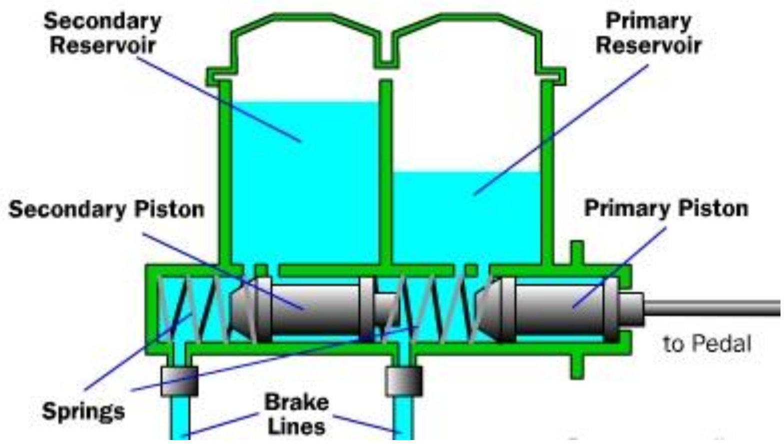


Figure 3.4.2 – Master Cylinder Schematic (Master Cylinder System)

3.4.2 Caliper

The actual device that applies the frictional force on to the rotor to stop the vehicle is the brake caliper. The brake caliper is an assembly that contains brake pads, caliper piston. The caliper fits over the brake rotor like a clamp. Inside the caliper there are frictional pads placed on both inside faces of the caliper. When pressure is applied to the brake pedal, brake fluid is sent from the master cylinder to the brake caliper causing hydraulic pressure on the caliper system. This hydraulic pressure on the piston forces the brake pads against the motor, which in turn stops the vehicle. Figure 3.4.3 shows a brake caliper assembly mounted on a rotor.

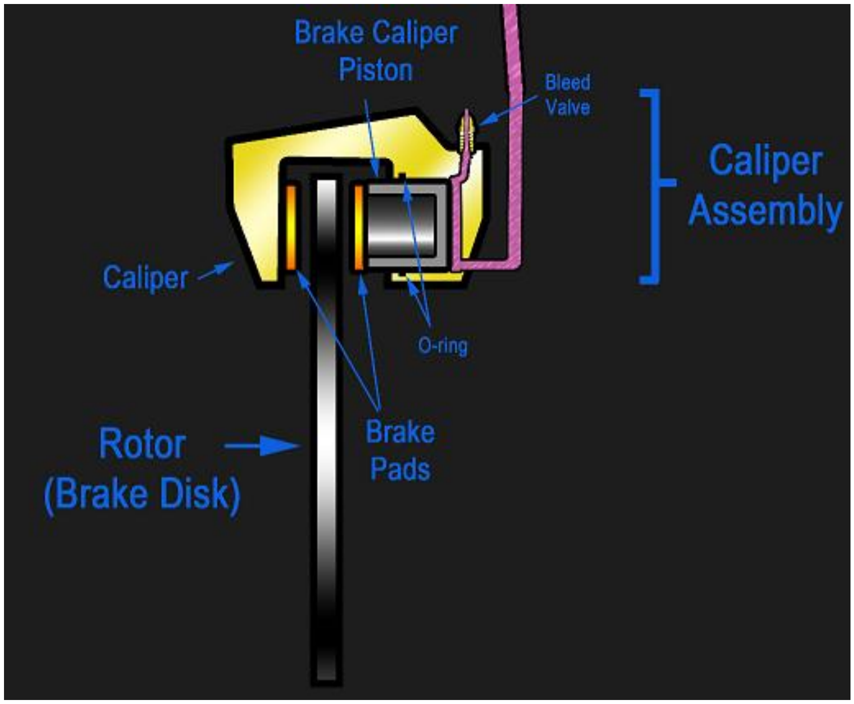


Figure 3.4.3 -- Brake Caliper assembly (Hydraulic Brake Diagram)

3.4.3 Rotor

The rotor serves two purposes, the first of which is actually stopping the vehicle. As the brake calipers clamp onto the brake rotor, a frictional force is generated on the rotor in the direction opposite of the vehicles motion. This frictional force is what enables the car to stop or slow down. Another purpose of the rotor is to dissipate heat which is created as a result of friction. As friction is applied to the rotor, the kinetic energy of the moving rotor is converted to thermal energy. To help keep the rotor cool, rotors have cooling vanes machined in them to suck in cool air as it rotates. Shown in Figure 3.4.4 is brake rotor with cooling vanes.

Figure 3.4.4 -- Rotor with cooling vanes (Brake Rotor)

3.4.4 Brake System Selection

When selected the braking system to use, a decision need to be made between the disc and drum braking system. Looking at the drum braking system, although it is a cheap system it can be complex and difficult to fix. The internal components of the drum brake can become inefficient when the brakes are applied repeatedly over a period of time. The drum brakes do not dissipate heat as efficiently as disc brakes do, so the efficiency of the drum brakes decrease drastically when heated. The disc brakes have the brake rotor exposed to open air so he can be dissipated efficiently without compromising the efficiency of the braking system. Overall a drum brake is cheaper than the disc braking system, however last year's solar car has various components which can be salvaged to reduce the cost of the system. Taking these considerations into account a decision matrix was constructed to aid in the decision making process. Shown in Table 3.4.1 is the decision matrix of the braking system.

Table 3.4.1 – Brake System Decision Matrix

Brake System Decision Matrix						
	Cost	Efficiency	Durability	Complexity	Manufacturability	Total
Disc brakes	5	4	4	4	2	19
Drum Brakes	2	2	3	2	3	12

From the decision matrix it was an obvious choice to go with the disc brakes over the drum brakes. When selecting the actual disc brake system to use, the required braking force for each tire is to be calculated. This can be done by using *Equation 3.4.1.*

Equation 3.4.1

Where F_friction is the frictional force the rotor applies to oppose motion, Fclamp is the force applied by the caliper clamp onto the rotor; the equation for F clamp is shown in *Equation3.4.2*, where is the coefficient of friction between the rotor and the brake pad.

Equation 3.4.2

3.5 Suspension

The suspension in the car will help maximize the friction between the tires and the road surface, and provide steering stability with good handling to ensure the comfort of the driver. Main components of a suspension, Figure 3.5.1, include spring, damper, control arms, and upright. Most suspension designs use a passive spring to absorb impact and a damper to control spring motion. A study found that humans perceive a ride to be comfortable when the bouncing frequency is 1 to 1.5 Hz; after 2Hz, most people feel the ride to be tough. Therefore, the ride quality is controlled by the selection of appropriate springs and dampers (Wan, 2000).

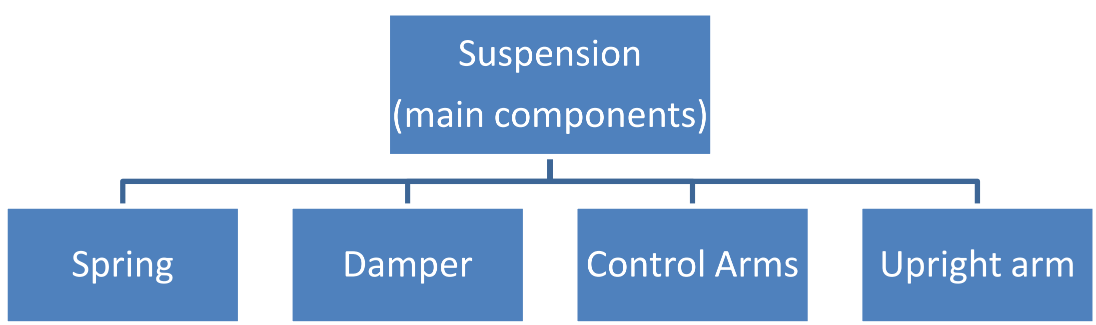


Figure 3.5.1 – Suspension Main Components

A car's suspension can be non-independent or independent. In a non-independent suspension, a rigid axle fixed is between the left and right wheels, and the body is suspended by leaf springs or coil springs on the axle. Consequently, the wheels are not independent and when one wheel rides on a hump, the shock is transferred to the other wheel. In contrast, in an independent suspension, the wheels' suspension systems are independent of each other (Shiota, 2010). This will provide the rider with a more comfortable ride isolating the vehicle by its points of contact from the road and eliminating the disadvantages of the beam axle. Some of these disadvantages include loss of friction by the wheels, small maximum spring deflection, no control of the steering system, and over-steer. Due to the advantages of an independent suspension system, the solar car will feature an independent suspension system for each of the three wheels.

Figure 3.5.2 compares an independent and non-independent suspension design. It shows a solid rear axle held by leaf springs for the non-independent suspension, and a spring and damper combination for the independent suspension design.

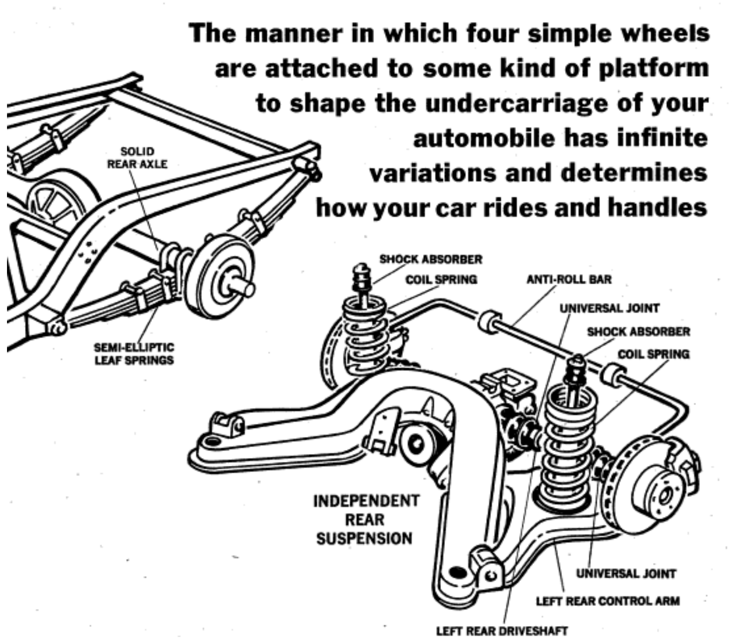


Figure 3.5.2 – Non-independent vs. Independent Suspension (Temple, 1969)

Important parameters to take in consideration in the suspension design include: spring rate, damping, travel, roll center height, and body dimension constraints. The spring rate or spring coefficient, k, is a ratio measuring how resistant a spring is to being compressed or expanded during the spring's deflection with units of lbf/in. or N/mm. Damping controls the movement of the car; un-damped cars oscillate, whereas a damped car settles back to the equilibrium state in a minimal time. A car's travel must be established to set the spring's displacement, *x*, and prevent the car from bottoming. Hooke's Law, *Equation 3.5.1*, can be used to calculate the force exerted by the springs.

Equation 3.5.1

The roll center height is important to body roll and stiffness distribution for both front and rear of the car. Lastly, after analyzing the final design of the bottom shell of the car’s body, points on the body and ribs will be chosen to connect the control arms of the suspension.

3.5.1 Front Suspension

The front suspension is linked to the steering system, thus some of the design parameters are constrained by the steering design. Two suspension designs, the MacPherson strut and double wishbone suspension systems, were analyzed and compared to choose the best fit for the front suspension. The MacPherson strut, as shown in Figure 3.5.3, is a simple system comprised of a strut-type spring and shock absorber combo pivoting on a ball joint on the single, lower arm.

Figure 3.5.3 – MacPherson Strut (Longhurst, 2010)

The telescopic shock absorber also serves as a link to control the position of the wheel as well as the load bearing member, thus replacing the upper control arm making it compact. However, this design does not offer very good handling as body roll and wheel's movement lead to variation in camber (degree to which the wheel tilts in and out), shown in Figure 3.5.4, usually ending with positive camber.

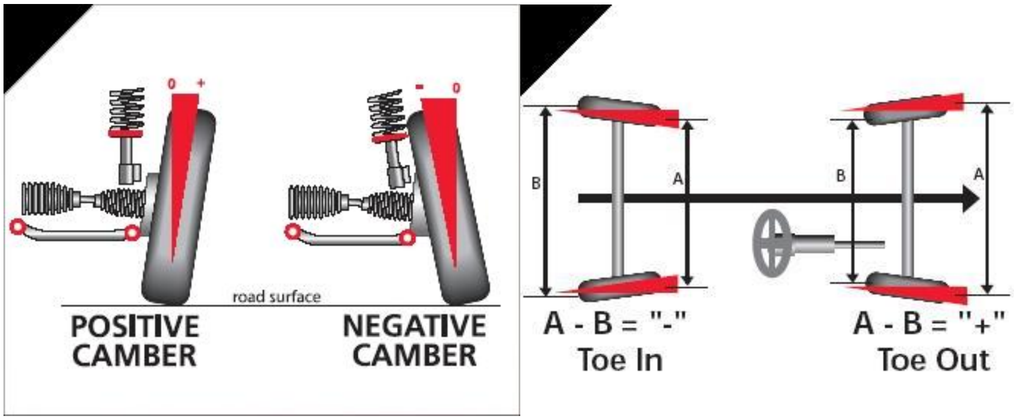


Figure 3.5.4 – Camber Angle and Toe Angle (Barrys Tyre & Exhaust Centre, 2010)

Consequently, the control arm will experience expansion rather than the ideal state of compression. This gives engineers less freedom to adjust the camber angle and roll center. It’s high overall height requires a higher hood line, which is not desirable in the design of the solar car body as it will increase drag and decrease its streamline body design.

A double wishbone suspension design, shown in Figure 3.5.5, is regarded by many designers as the most ideal suspension. It includes two (2) links forming a wishbone shape where one end is fixed to the frame of the car and the other end to the lower and upper ball joints supporting the upright arm that holds the wheel. A coil spring and damper combination is fitted between the two wishbones. It’s parallelogram design allows the wheels to travel vertically up and down and a slight side-to-side motion know as scrub. There are two other wheel movements relative to the body produced by this suspension: toe angle (Figure 3.5.4) or steer angle (difference in the distance between the front of the tires and the back of the tires), and camber angle or lean angle. This results in a complex system, but it provides engineers the freedom to adjust the kinematics minimizing roll or sway resulting in a more consistent steering feel. Moreover, this design always maintains the wheel perpendicular to the road surface, irrespective of the wheel's movement ensuring good handling.

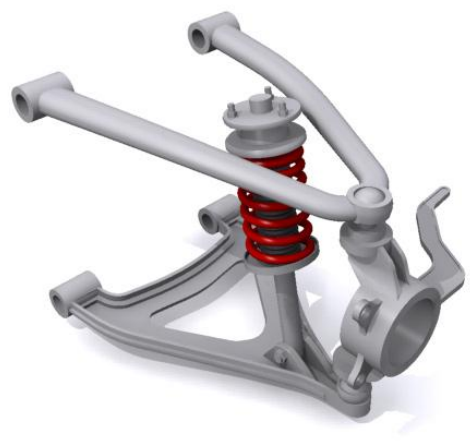


Figure 3.5.5 – Double Wishbone Suspension (Longhurst, 2010)

Table 3.4.1 shows a comparison table between the two (2) suspension designs.

Table 3.4.1 – MacPherson Strut vs. Double Wishbone Suspension

MacPherson Strut		Double Wishbone	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
Compact	Average handling	Ideal camber control	Complex
Cheap	High overall height	Good handling	Space engaging
Simple	Camber angle change	Easily tuned kinematics	Costly
	Expensive replacement	Optimized lightweight parts	

After comparing the two (2) suspension designs, a double wishbone design was chosen as the best fit to the front suspension of the solar car. The double wishbone design gives the freedom to adjust camber and toe angles, as well as scrub radius, and allows a vertical wheel movement perfect for the constrained airfoil shaped wheel enclosure. Also, the control and upright arms will be manufactured in the college's machine shop as this design allows for optimized lightweight parts, another advantage in achieving a light weight car. Simulations in MSC ADAMS/Car such as opposite, parallel, and single wheel travel, and steering will be performed to observe the behavior of the designed suspension. Also, using MSC ADAMS/Car, we will be able to change the design parameters to obtain the desired camber angle of 0° and toe angle of -1° to 0°.

3.5.2 Rear Suspension

The rear suspension system will be supporting the single rear wheel as well as the motor connected to it. We will be using the same suspension design of a single trailing arm suspension as it was used in last year's Phase I of the solar car project. However, calculations and analysis on this design will be done again using the constraints of the new design.

A trailing arm, or swing arm, suspension shown in Figure 3.5.6, is similar to that of a motorcycle. It has an arm joined at the front to the chassis that allows the rear to swing up and down, a suited motion for the single rear wheel. This prevents side-to-side scrubbing allowing only vertical motion, thus no change in the camber angle. The spring and damper system will be connected to the lower arm on one end and to the body on the other end.

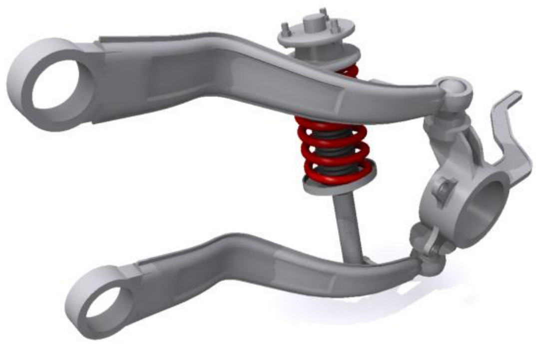


Figure 3.5.6 – Trailing Arm Suspension (Longhurst, 2010)

Last year's trailing arm design had the swing arm holding the wheel on one side as shown in Figure 3.5.7. This created a torque on the wheel making it bend and not be perpendicular to the road surface. To prevent torque and moment from developing, the control arm will be fork-shaped to hold the wheel and motor on both sides.

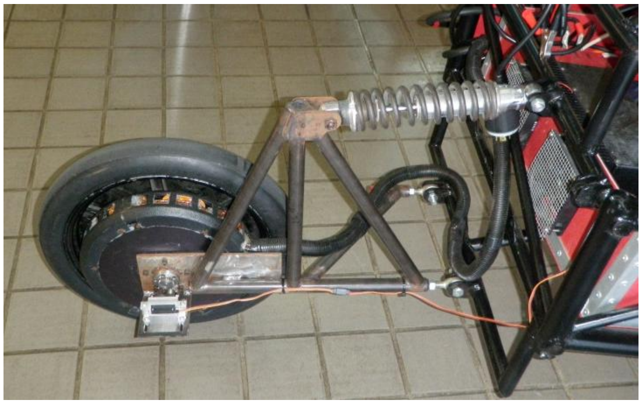


Figure 3.5.7 – 2009-2010 Solar Car Trailing Arm Suspension

The front suspension of the car will be designed before the rear suspension. Now that the final design of the bottom shell of the body is complete, the wheel base measurements as well as the center of the car will be used to sketch the front suspension. Once the rough sketch is done in SolidWorks, it will be imported into MSC ADAMS/Car to analyze it and perform simulations. These simulations will provide us with the data needed to observe the suspension's behavior and adjust the dimensions to achieve the desired results. An example of a double wishbone suspension design in MSC ADAMS/Car done by Eric Afyouni, a student in the Vehicle Design class, is shown in Figure 3.5.8.

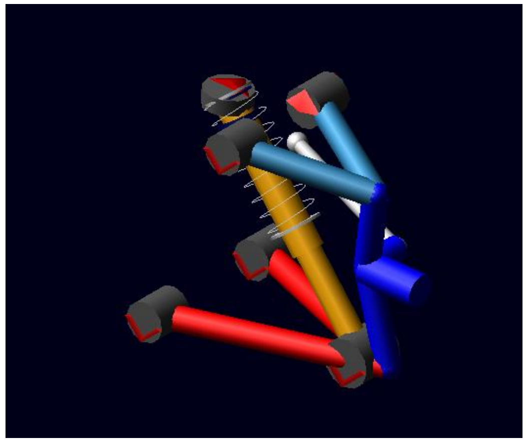


Figure 3.5.8 – Double Wishbone Design in MSC ADAMS/Car

The spring and damper combination will be chosen depending on the total weight of the car and the expected car behavior under braking, normal, and cornering conditions modeled in the CAD software.

Some risks associated with the design of the suspension include: budget and schedule risks, wrong spring selection making the suspension too soft or stiff, wrong material selection to fabricate the control arms causing stress failure. These risks will be expanded in the Technical Risks section 4.

3.6 Power Generation

The power generation system will be composed of solar array system, regenerative braking system, and a maximum peak power tracker (MPPT). The solar array system will channel energy from solar radiation into electrical energy. This energy will either propel the vehicle, or charge the vehicle's battery system. The MPPT will optimize performance of solar array system to provide maximum amperage to either charge the batteries, or propel the vehicle. The regenerative braking system will charge the battery system through the motor controller, when asserted by the driver. The regenerative braking system and mechanical frictional braking system will provide total braking output. Figure 3.6.1 below displays the overview of the power generation system.

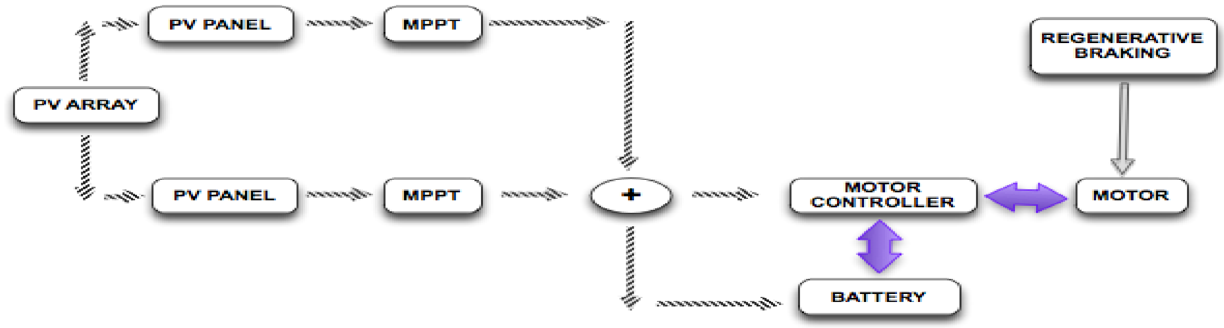


Figure 3.6.1 – Overview of Power Generation System

3.6.1 Solar array system

The solar array system is an important component in the solar car. It is responsible for conversion of electromagnetic radiation energy of the sun into electrical energy. It is an array of solar cells configured to provide an output power suitable to propel the vehicle, or charge the battery.

The solar array is designed to input solar radiation energy and output electrical power. The fundamental unit of this system is a solar cell. A solar array is parallel and/or series configuration of solar cells. Figure Figure 3.6.2 below displays the functional block diagram of the solar array system.

Figure 3.6.2 – Top-level block diagram of the Solar Array System

There are many types of silicon based solar cells. They vary in size, material, number of junctions, efficiency, price, weight, and various other factors. The team is focusing on two different kinds of solar cells – Single Junction Multi Crystalline or Multi Junction Amorphous. Figure 3.5.1.2 below depicts various different types of solar cells, and the table following depicts the differences between the two primary solar cells the team is aiming to get.

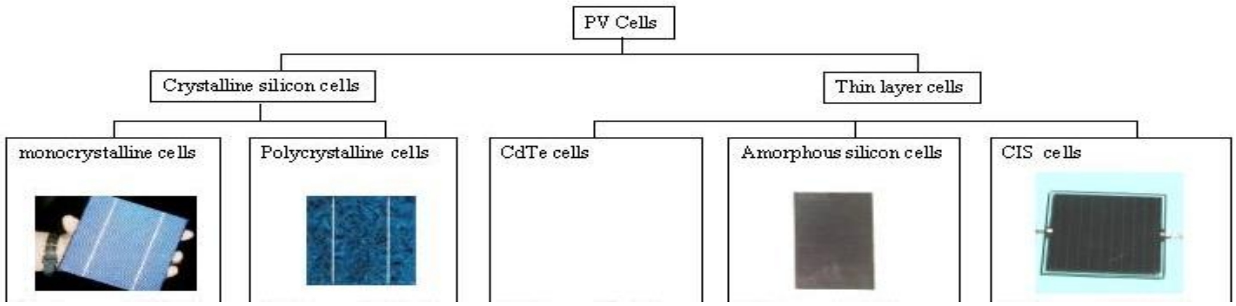


Figure 3.6.3 – Types of silicon solar cells

Table 3.6.1 – Comparison between single junction and amorphous multi-junction solar cell

Single Junction Silicon	Amorphous Multijunction Silicon
Cheap	Expensive
Efficiency = 14-16%	Efficiency = 10-12%
Fill Factor > 0.4	Fill Factor = 0.67-0.75
V_{OC}, I_{SC}	V_{OC}, I_{SC}
Non-flexible	Flexible
Easily broken	Durable
Non-waterproof	Waterproof

Table 3.6.1 lists the differences between single junction multi-crystalline and amorphous multi-junction solar cells. The team is aiming to have amorphous multi-junction solar cells to be donated though a company (UNISOLAR). These cells are waterproof, durable, and flexible; thus, they can easily adhere to the shape of the body. They have a high fill factor than single junction solar cells. Fill factor is the ratio of maximum attainable power to maximum theoretical power. The major drawback of amorphous solar cells is lesser efficiency and higher costs than multi-crystalline solar cells. The highest grade of solar cells is made up of gallium arsenide (GaAs) semiconductor; however, besides budgetary constraints, the use of GaAs based solar cells is prohibited by the regulations of American Solar Challenge, 2012. Performance factors for solar cells include: insolation, type of semiconductor, temperature, position of the sun, ad weather conditions.

The insolation or solar irradiance level in Tallahassee fluctuates between 600 W/ sq. m to 800 W/sq. m; it is higher during winter and spring season than summer seasons. As such, testing of solar panels will be performed in the spring semester (January – March). Silicon and Gallium Arsenide are the two most common semiconductor material used to fabricate solar cells. Gallium Arsenide solar cells have efficiency of up to 40%, while silicon shows efficiencies ranging from 6-20%. Solar cells display higher performance in lower temperatures; they operate at higher voltage in lower temperatures and lower voltages at higher temperature. The layout of solar cells should be designed to minimize its operating temperature. The team has three basic ideas of approach for this problem: increase airflow by placing solar array on a platform an inch above the body, or purchase high heat resistance composite, or insert a system of small fans and holes to generate airflow. The solar cells will have to be tilted at a certain angle to the sun. This angle, termed angle of incidence, is the angle between the outward normal of a solar cell and the incident ray of the sun. This angle should be in between 20-25 degrees. Weather is also a factor that affects the performance of solar cells; it is also a factor beyond our control. The design should ensure reliability and safety in the most extreme of conditions like rainfall, haze, clouds, snow, potholes, etc.

The three most important parameter of solar cells are open-circuit voltage (Voc), short-circuit current (Isc), and efficiency. Voc and Isc vary with the irradiance level. This leads to fluctuations in power output. A solar cell is electrically characterized as a current source in parallel with a diode. The electrical schematic of a solar cell, and the I-V curve (with respect to different irradiance levels) of the solar cell along with its equation is displayed in Figure 3.6.4 below. The current from the solar cell is at best equal to the short-circuit current.

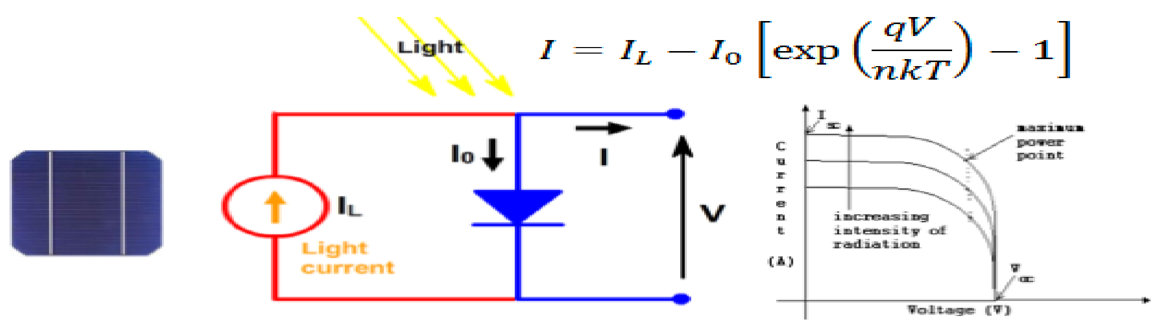


Figure 3.6.4 – A solar cell

In designing a solar array system from solar cells, a modular structure is generally followed. A solar module is a chain of solar cells (series configuration). Parallel and/or series combination of solar modules makes up a solar panel. An array of parallel solar panels makes up a solar array. Figure 3.6.5 below displays the modular structure of solar array system.

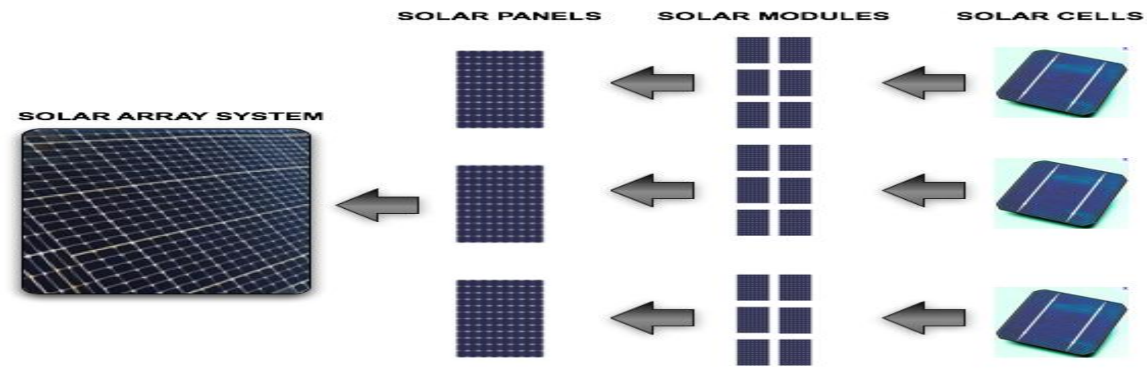


Figure 3.6.5 -- General structure of a solar array system

The solar array system is designed for voltage potential greater than the battery system voltage. The battery system has a minimum and maximum safe operating voltage region. An array of solar panels in parallel configuration makes up a solar array. So, each panel will be designed with open-circuit voltage greater than the battery voltage. Due to inefficiencies, we will design an array with an open-circuit voltage (Voc) 20- 30% greater than the maximum voltage of the battery bank.

The preliminary design calculations are based on single junction multi-crystalline silicon solar cells. This assumption has been made because of its commercial abundance and low price. Table 3.6.2 below depicts a datasheet from a solar cell supplier.

Table 3.6.2 – Datasheet of various single multi-crystalline solar cells

Product ID	SPI-C156-365M2	SPI-C156-359M2	SPI-C156-353M2	SPI-C156-347M2
Efficiency (%)	15.24--15.00	14.99--14.75	14.74--14.50	14.49--14.25
Power (W_P)	3.71--3.65	3.64--3.59	3.58--3.53	3.52--3.47
Max Power Current (typ)	7.19	7.11	7.03	6.95
Max Power Current (min)	6.92	6.84	6.76	6.69
Max Power Voltage (typ)	0.512	0.509	0.506	0.503
I_{SC} (A)	7.69	7.61	7.55	7.50
V_{OC} (V)	0.612	0.610	0.608	0.606

Table 3.6.2 displays the differences in efficiency, power, Isc, and Voc between different models of solar cells. Greater values of these parameter represent greater power output, which naturally translates to higher solar cell per unit costs. A decision has to be made between desired power output of an individual cell versus cost per unit cell.

The design of our solar panel is based on a single junction multi-crystalline solar cell with an average Isc (A) of 6.00 and an average Voc (V) of 0.6, thus an average 3.5 Watt of maximum theoretical power per unit cell. We are limited to an area of 6 sq. meters for the solar array. This corresponds to around 2300 standard sized solar cells (with standard size of a solar cell being 4 sq. in). Each solar module will be composed of 36 cells and 2-3 bypass diode (schottky); this corresponds to Voc of 21.6 V, Isc of 6 A, and power of around 130 W per module. Our battery system has a minimum of 72 V, maximum of 126 V, and nominal of 100 V. So, we want each panel to have a minimum Voc of 150 V (20% more than maximum battery bank voltage). This corresponds to around 7 modules per panel. If we chain all modules in series we will have per module: Voc of 150V, Isc of 6 A, and power of 900 W. Our MPPT has variable input and output voltage ranges but is restricted to a minimum of 9 A input current, therefore there is parallel solar module configuration is not present (as this will lead to an input current of 12 A. The battery voltage and solar array components pertaining to the initial design have been briefly summarized below. Figure 3.6.6 below displays the I-V curve of a standard 20V solar module with reference to different irradiance level. It also shows displacement in I-V curve of the module with reference to varying temperature. The calculations in Table 3.6.3 show that the solar array is capable of an output power of approximately 1000 Watts.

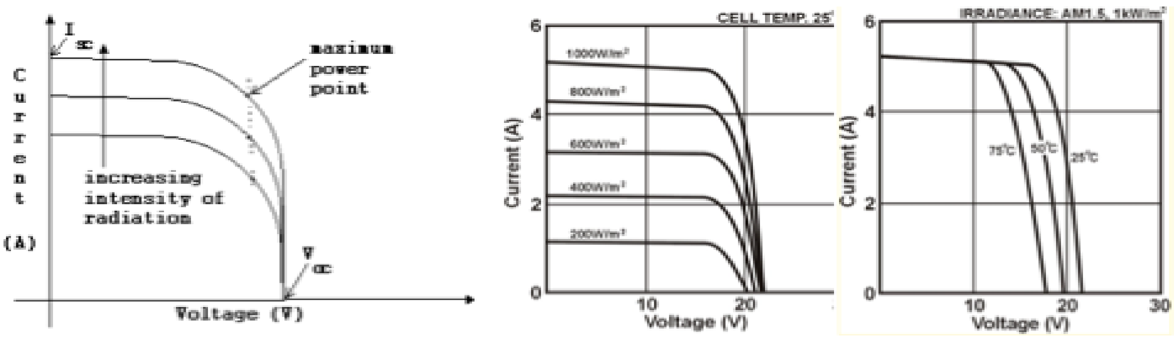


Figure 3.6.6 – Standard 20V solar module

Table 3.6.3 – Calculated steps for solar array design

Average Solar Cell	ISC (A) = 6.00 A
	VOC(V)=0.60 V
	Pmax(W)= Isc *Voc = approximately 3.5 W
Solar Module	36 solar cells in series
	2 bypass diode (schottky)
	Voc (V) = 21.6 V
	Isc (A) = 6 A
	Pmax(W) = approximately 130 W
Battery	30 cells in series
	Vmin (V) = 72 V
	Vmax(V) = 126 V
	Vnominal(V) = 100 V
Solar Panel	Voc, min desired (V) = Vmax + 0.2*Vmax 150 V
	7 solar module in series per panel (252 solar cells)
	Isc (A) = 6 A
	Pmax (W) = approximately 900 W
Solar Array	2363 solar cells allowed; 252 solar cells per panel
	9 panels per array in parallel configuration
	Voc(V) = 150 V per panel
	Isc(A) = 6 A per panel
	Pmax(W) = 9 panels * 900 W per panel * 0.125 (efficiency)
	Array Power(W) = approximately 1000 W

3.6.2 Maximum Peak Power Tracker

Solar cells have a non-linear I-V relationship; this relationship varies widely with respect to solar irradiance level. This causes fluctuations in output power. The MPPT is basically a DC:DC converter. It has an efficiency of 92-97%. Its main mode of operation is optimization of power output from the solar panels to provide maximum amperage to the system. One MPPT per solar panel is an ideal configuration. MPPT's provides protection to the battery and solar array. There is a loss of power due to efficiency of the component (MPPT). MPPT's are known to have efficiencies from 92-97%. Our design team has looked at two MPPTS: Drivetek AG MPPT-Race V 4.0 from a company in Germany and AERL RACEMAX 600B from Australia. The figure, Figure 3.6.7, below depicts the block diagram of an MPPT along with a picture of Drivetek AG MPPT; Figure 3.6.8 then follows with a table comparing the previously mentioned two different types of MPPT suitable for high voltage solar car application.

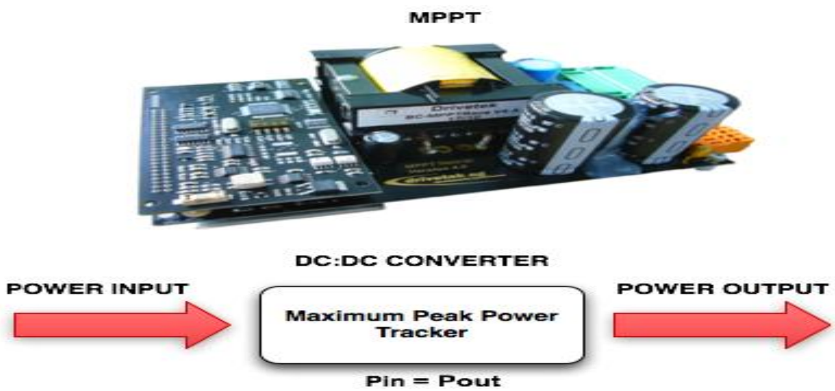


Figure 3.6.7 – MPPT

DRIVETEK RACE

Parameter	Unit	Minimum	Typical	Maximum
Input Power Continous	W	5		800
Input Power Peak[3]	W			1250
Input Current	ADC			9
Peak Efficiency[2]	%		99	
Input Voltage Range	VDC	36		144
Output voltage Range[4]	VDC	40		200
Output Shutdown Voltage[7]	VDC			236
Input to Output Voltage Ratio[6]	-	1.05		4

AERL 600 B

Parameter	Max
Maximum ambient air temperature	50°C
PV panel short circuit current - constant	6A
PV panel short circuit current – transient	8A

Parameter	Min	Max
Solar panel peak power	0W	600W
PV panel open circuit voltage	40V	135V
Efficiency @ 6A, 100Vmp, & 25Camb	98.00%	-
Battery Voltage (Selectable)	72, 96, 120, 144, 168V	

Figure 3.6.8 – Comparison between Drivetek RACE MPPT and AERL 600 B MPPT

Figure 3.6.8 above shows Drivetek RACE V 4.0 MPPT provides a wider range of power handling capability, greater input current, and wider input/output voltage range than AERL 600B MPPT. AERL 600B MPPT is also limited to a battery selectable voltage level of 72, 96, 120, 144, 168V. It should be noted that AERL 600B has a lower cost than Drivetek RACE V 4.0. Commercial market does offer basic charge controllers and PWM charge controllers (Pulse Width Modulated). However, they are not able to track maximum power point of solar panels, or offer protection to the battery and solar array system. They are only able to charge the batteries until they are "full", then the charge controller disconnects the battery from the solar array. On the other hand, MPPT operates the PV array at a voltage which can deliver maximum output power at the prevailing solar irradiance.

Drivetek MPPT has a maximum input current of 9 (A) DC. The current output from solar panel cannot exceed 9 (A). The MPPT is a component that connects the solar panels with the battery system of the solar car. Figure 3.6.9 below depicts a component diagram of this system. It is followed by Figure 3.6.10which displays a top level shunt type interconnection schematic for the charge controller and the MPPT.

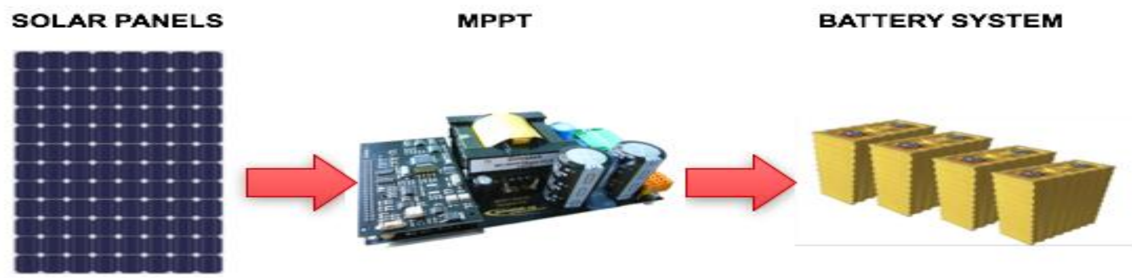


Figure 3.6.9 – Component diagram of MPPT with solar panel and battery system

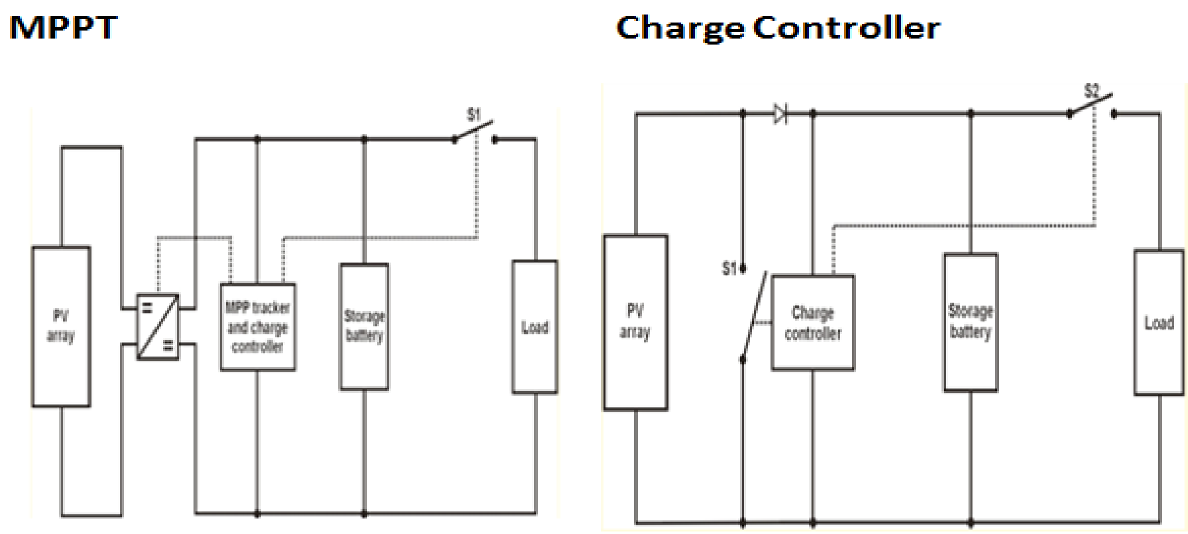


Figure 3.6.10 – MPPT and charge controller top level component integration

3.6.3 Regenerative Braking

The regenerative braking system will convert kinetic energy of motion into electrical energy. This electrical energy is stored as charge in the battery bank. The regenerative braking system, upon asserted, will change the polarity of the motor; as such, the motor essentially behaves like a generator. Regenerative braking along with mechanical friction will provide total braking output.

The regenerative braking will be either a “handle-brake” type or integrated with the mechanical braking. The regenerative braking signal will be an input to the motor controller. When the signal is “on”, the regenerative braking system will be asserted. Commercial electric vehicles show 60-70% efficiency in their regenerative braking system.

In the “handle-type” brake design of the regenerative braking system, the handle will be behind the steering wheel and assert the regenerative braking system when the driver pulls the handle towards him/her-self. In the microcontroller based design, the regenerative brake and mechanical brake will be coupled to the brake pedal (present at the feet of the driver), their action will be controlled by a microcontroller and will be proportionate to the force on the braking pedal. The regenerative braking system will be asserted when force is applied on the brake pedal until a certain angle is reached between the pedal and ground, when this angle is exceeded the microcontroller will trigger mechanical frictional braking. Ideally we want total braking output to be a sum of regenerative braking and mechanical braking. This design concept does not fulfill this, but does provide the extra electrical charge that cannot be provided by mechanical braking. The other type of design which is beyond the scope of the project is a brake controller. The brake controller is a microcontroller based design which monitors and controls the mechanical and regenerative brake to give total braking output. It requires complex algorithms and a lot of time. The team is currently inspecting the feasibility of the microcontroller based design. The “handle-type” design is easy to implement and will be used if problems are encountered in the microcontroller based design. Figure 3.6.11 below displays the Regenerative Braking system block diagram. The electrical charge generated from the motor will be transferred to the battery system through the motor controller. The figure is followed by Table 3.6.4 which lists the three options for regenerative braking system under consideration.

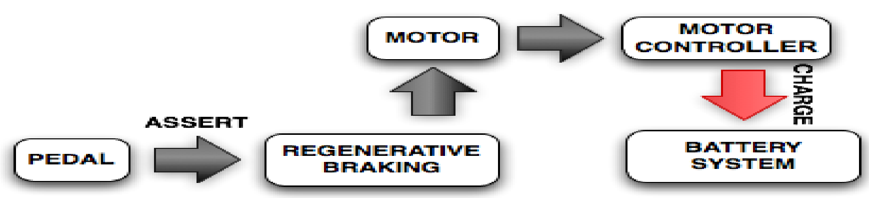


Figure 3.6.11 – Regenerative Braking System

Table 3.6.4 – Different options for implementing the regenerative braking system

“Handle-type”	Micro-controller based	Brake controller
Easy to implement	Programming required	Intense programming required
Independent to frictional brake	Regenerative brake applied for “soft” braking only	Coupled mechanical and regenerative brake

3.7 Control Systems

The primary task of the control system is to provide a means to the operator to control the car and make available to the operator the current status of the car’s components. The driver must have full control of all the systems of the vehicle during operation, and must also be provided with telemetry information and the status of system components. Figure 3.7.1 shows the dashboard from the previous year's design.

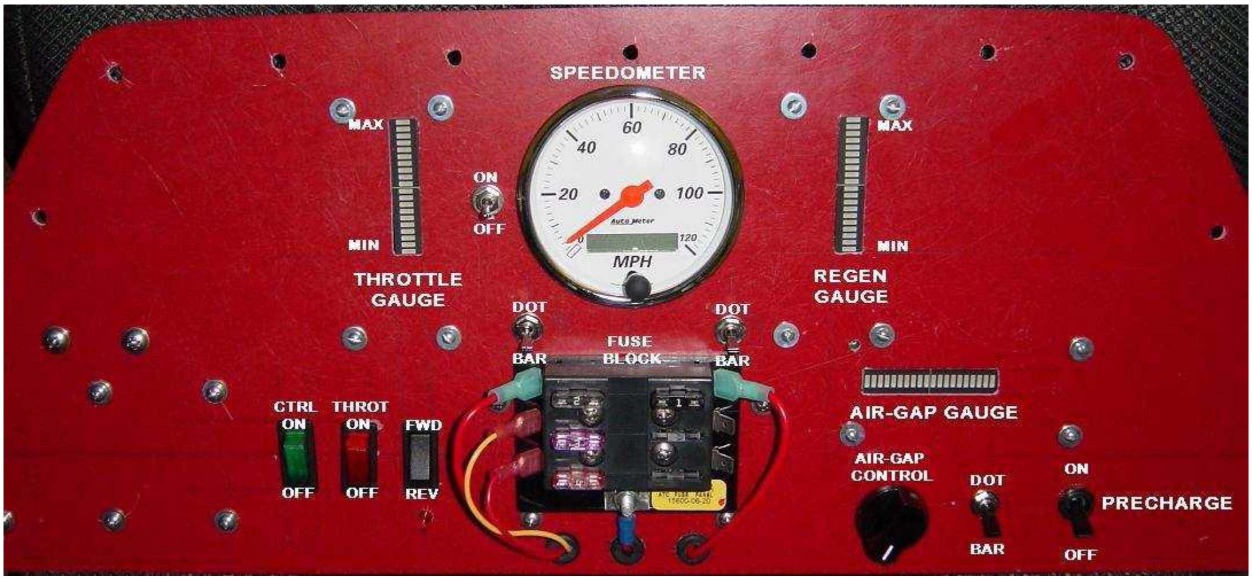


Figure 3.7.1 – Phase I Dashboard

3.7.1 Master Control Unit

The master control unit (MCU) will function as the interface between the driver, the motor controller, and the battery management system (BMS). The MCU needs to be able to communicate serially with the motor controller. It is also needed to control the lights in the car.

The microcontroller chosen is the Wytec Dragon12 Plus-USB development board shown in Figure 3.7.2. The Dragon12 Plus uses a Freescale HCS12 16-bit Microprocessor which is designed for use in automotive applications. This board was chosen because it was the only board that could be found that contains all of the I/O components need for the process.

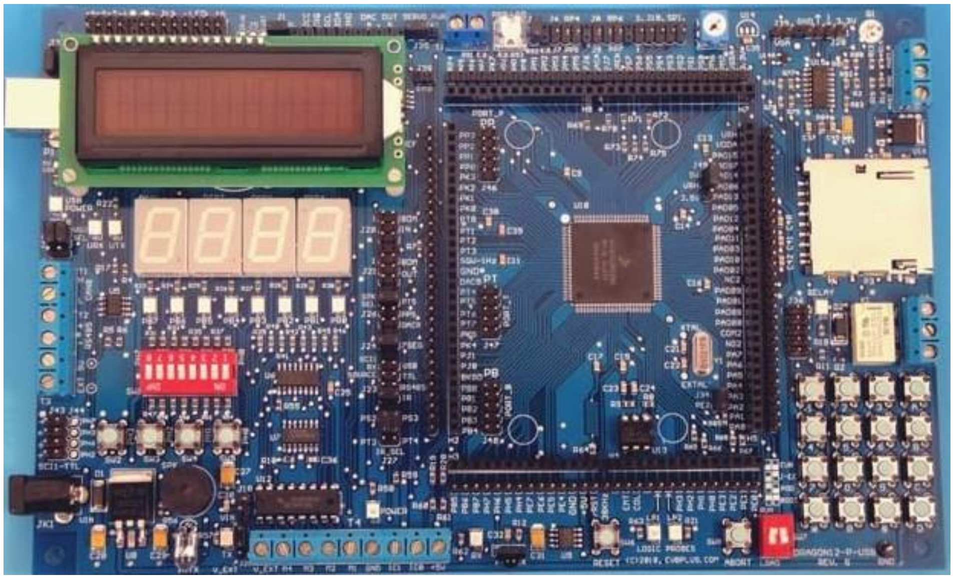


Figure 3.7.2 – Wytec Dragon12 Plus-USB

The code for the microcontroller will be written using the Freescale CodeWarrior IDE software. CodeWarrior is offered for free by Freescale for use in development of applications using Freescale's products. Using an IDE will increase productivity and provide simulation, debugging, and programming capabilities in order to decrease development time.

The functions that the MCU will perform include but are not limited to:

- Activating the motor controller relay after the motor controller has had time to pre-charge
- Use an algorithm to automatically adjust the air gap in the motor
- Activate the lights and horn
- Provide a menu based input system for the driver to change the settings of the motor controller and view car status information

The Board is powered by a 9V source, so a means of providing the power must be found. The options explored thus far include the incorporation of the existing 100V to 12V DC-DC Converter with a 12V to 9V DC-DC converter, and using a 100V to 12V DC-DC converter. The 12V to 9V DC-DC is more widely available and cheaper, although the current DC-DC converter may need replacing in the future. Ideally, the team would like to use a single DC-DC converter that has 24V, 12V, and 9V output with 100V input if such a converter exists.

3.7.2 Lights/Horn

The vehicle needs to be equipped with at least six lights, two front lights, two rear lights, two rear brake lights and two turn indicators. The brake lights can be combined with the turn indicators for a total of six lights. The lights need to be able to controlled by the MCU. The output ports cannot supply enough power to the lights, so a relay is needed between the lights and the output of the MCU. A relay board such as the one in Figure 3.7.3 needs to be designed or bought to enable control of the lights directly by the MCU

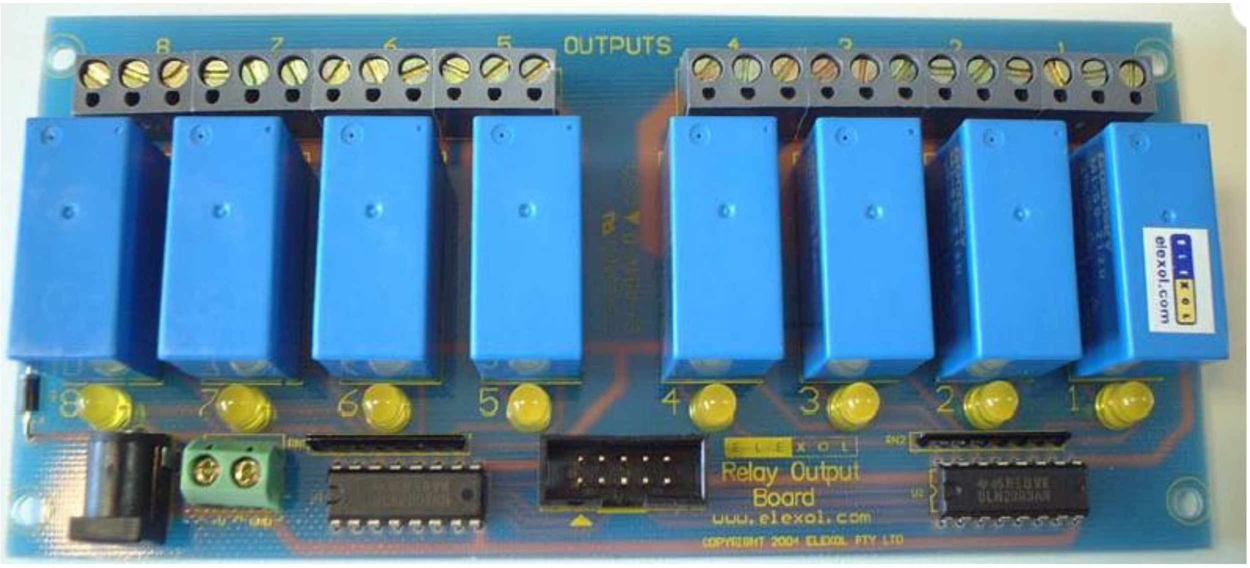


Figure 3.7.3 – Relay Board

The main lights will be controlled by a switch on the dashboard to control the front and rear lights. The brake lights will be activated by a signal sent from the motor controller to the MCU when the regenerative braking is activated. The turn signal lights will be either activated by a switch on the dashboard or by switches integrated into the steering wheel.

3.7.3 Motor Controller

The motor controller is used to power the motor. It is controlled by a microcontroller that can be accessed through a serial interface. The motor controller has two control modes, discrete control mode, and serial control mode. The car is currently configured to operate in discrete mode. The main advantage of discrete mode over serial mode is that is it easier to implement. However, in discrete mode, there is no access to the internal functions of the motor controller's microprocessor, which contains very useful diagnostic, and status data and motor control mode settings. Figure 3.7.4 shows an example of a discrete control configuration for a motor controller.

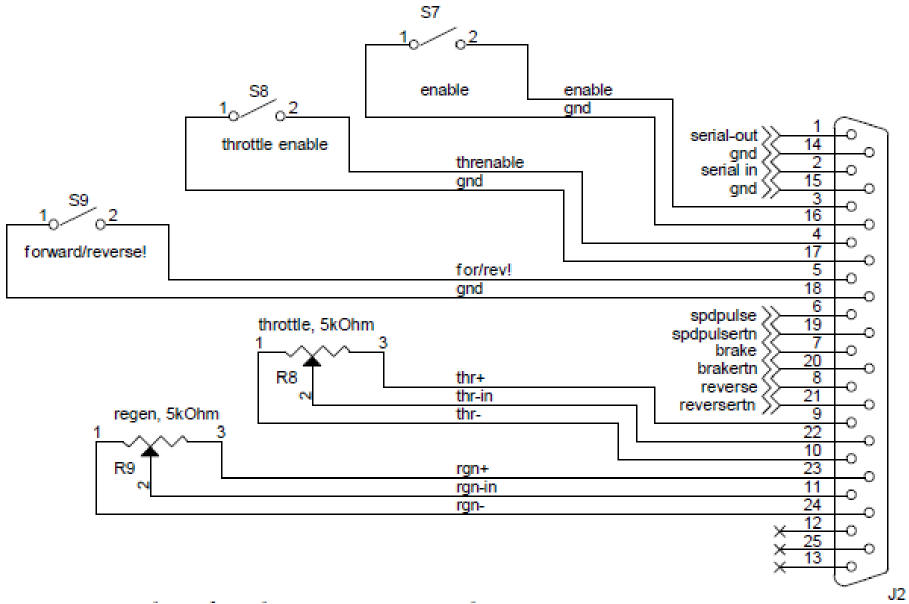


Figure 3.7.4 – Motor controller discrete control configuration

The motor controller will be reconfigured for a combined discrete and serial mode operation. The MCU will be connected to the motor controller through the serial interface. The throttle potentiometer will remain connected directly to the throttle input to the motor controller, but the microcontroller will read the data from the motor controller and use it to make adjustments to the air gap of the motor based on the data collected from the motor controller. All of the diagnostic data produced by the motor controller will be collected by the MCU and processed to be available to the driver. The forward/reverse switch and the throttle enable switch will be connected the MCU which will send the command to the motor controller serially.

3.7.4 Dashboard

The dashboard shall function as the I/O interface of the operator of the vehicle. It will display telemetry information, contain an input mechanism to send commands to the motor controller through the MCU, and display control status information.

Currently, the control system is discretely controlled manually by switches. The current startup sequence is somewhat complicated and cannot be performed by someone that does not have full knowledge of the car's design. The new system will replace these manual switches with High voltage DC rated electromagnetic contactors, as shown in Figure 3.7.5 that will be automatically activated by the Battery Management System (BMS) when the BMS is powered on. The BMS is designed to open these relays to actively isolate the batteries in situations of over-voltage, under-voltage, over-current, and over-temperature.

Figure 3.7.5 – High voltage DC rate contactor

Once the main switch is activated, power will be supplied to the 12V power source and the motor will begin to precharge. An ignition switch will be pressed to enable power to the dashboard systems and power on the MCU. The MCU will then activate the motor controller relay after the motor has had time to precharge. This configuration simplifies the startup sequence to turning on the main power switch and activating the ignition switch. Figure 3.7.6 shows the diagram for the main power system supplying power to the dashboard seen in the diagram in Figure 3.7.7.

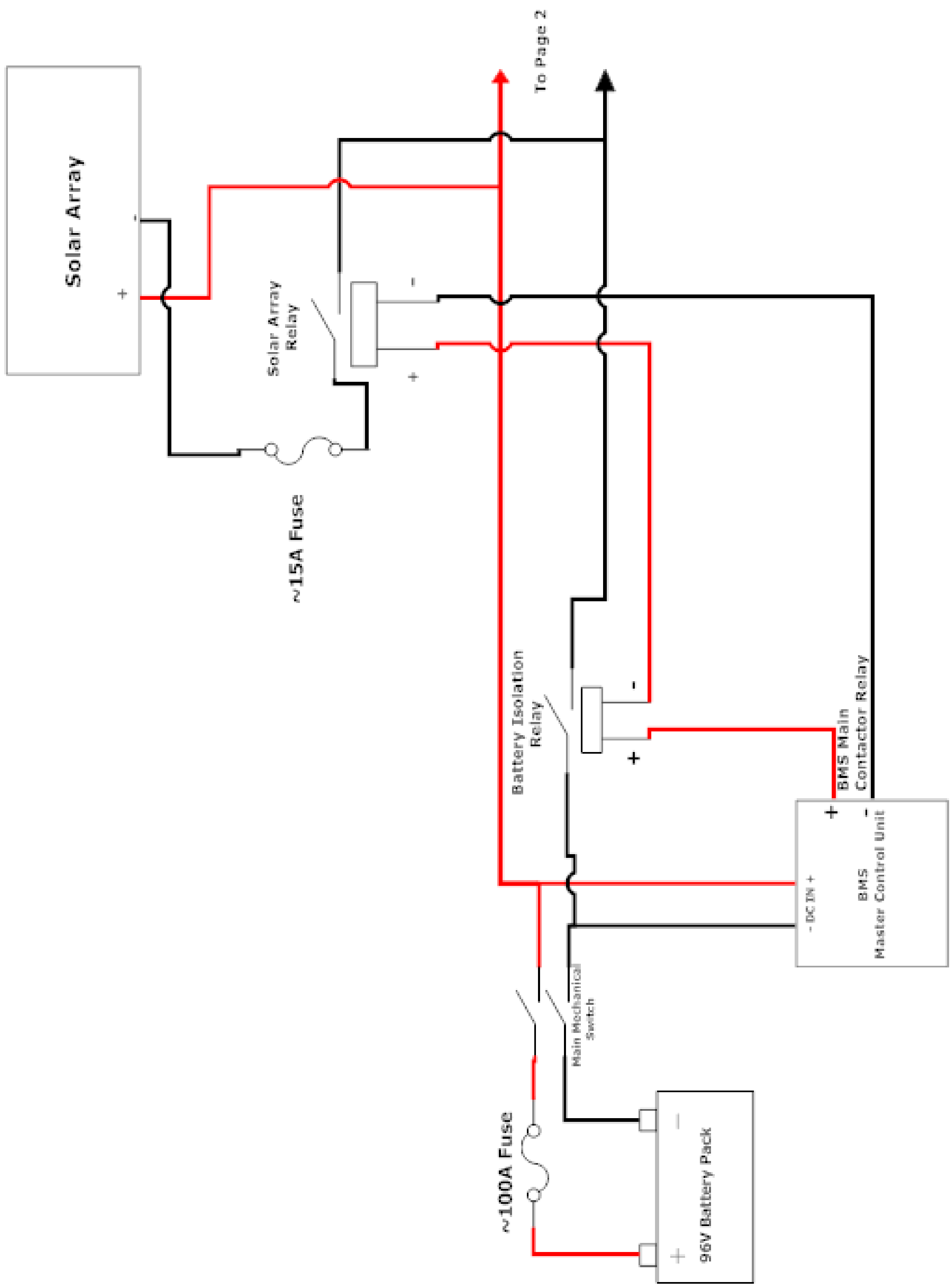


Figure 3.7.6 – Main power system design

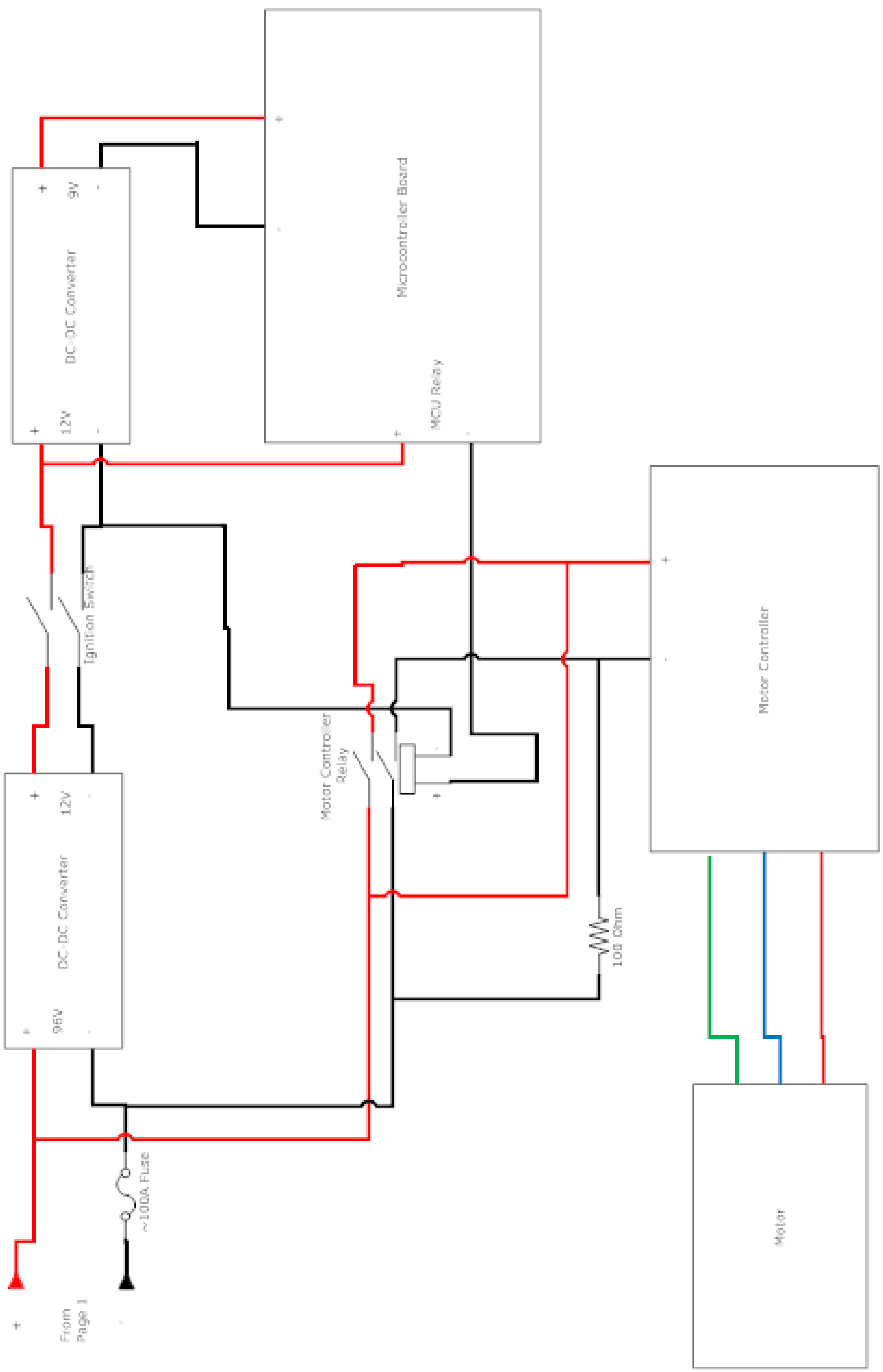


Figure 3.7.7 – Dashboard power system design

The new dashboard will look similar to Figure 3.7.8. Currently the dimensions of the dashboard area are unknown, so the placement of the components may change once this information is known.

The state of charge meter will be added to display the current and voltage levels of the batteries as well as an approximation of the available energy left in the batteries. An LCD Display with a keypad that is connected to the MCU will be used to input commands the MCU directly from the dashboard. The LCD display will display all of the information provided by the MCU.

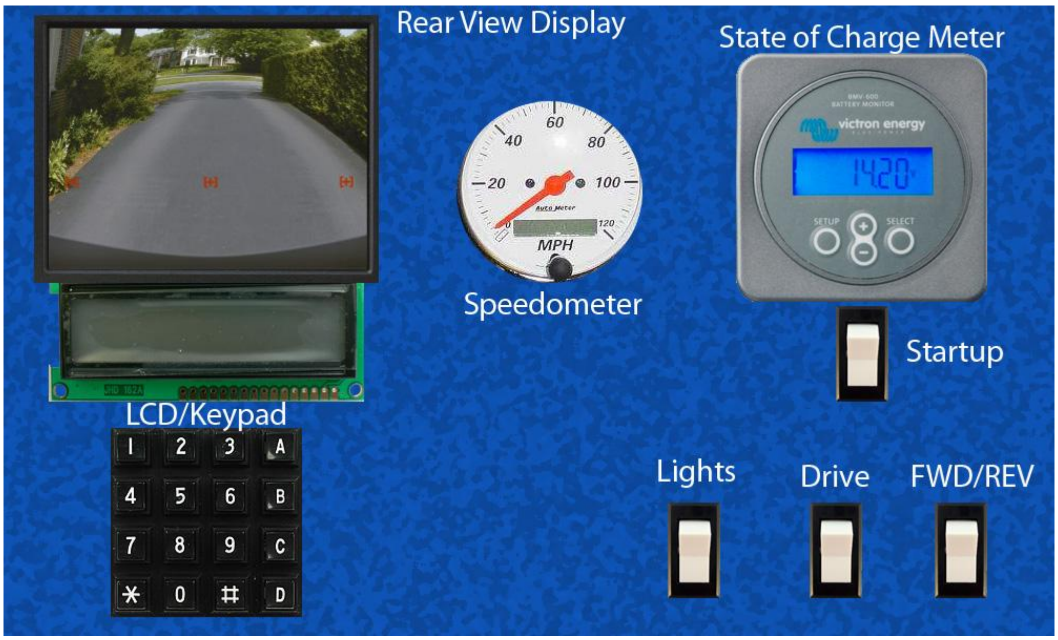


Figure 3.7.8 – New Dashboard Design

The speedometer that is currently in the car is not working, and the exact cause of the problem is unknown. The signal to the speedometer is not being sent from the motor controller properly. This is thought to be due a grounding problem or possibly from a malfunction in the motor controller. A proposed design to fix this problem is to use the MCU to read the speed data directly from the motor controller and use this information to send a signal to the speedometer.

A rear view mechanism will be needed to see behind the car because the driver will not have enough room to turn around inside the car. The two options explored so far are using a rearview mirror and using a rear camera with a display mounted on the dashboard. Using a mirror would be much cheaper, but it may not be possible depending on the final design of the body.

3.8 Management Systems

The management system will consist of the batteries, the battery management system, cell modules, and state of charge devices. The motor and motor controller is also an integral portion of this system because the motor controller is a management device. The first phase of the project was able to get bring the motor to a fully functioning state and because there are no foreseeable modifications necessary will not be discussed in this portion of the paper. The batteries for the system have already been purchased in the previous phases and will again be utilized during this phase of the project. Due to the importance of the batteries in the final product the rest of this system will be designed to meet the needs of these batteries. Figure 3.8.1 shows the layout of the management system, the green blocks have already been completed in the previous phase.

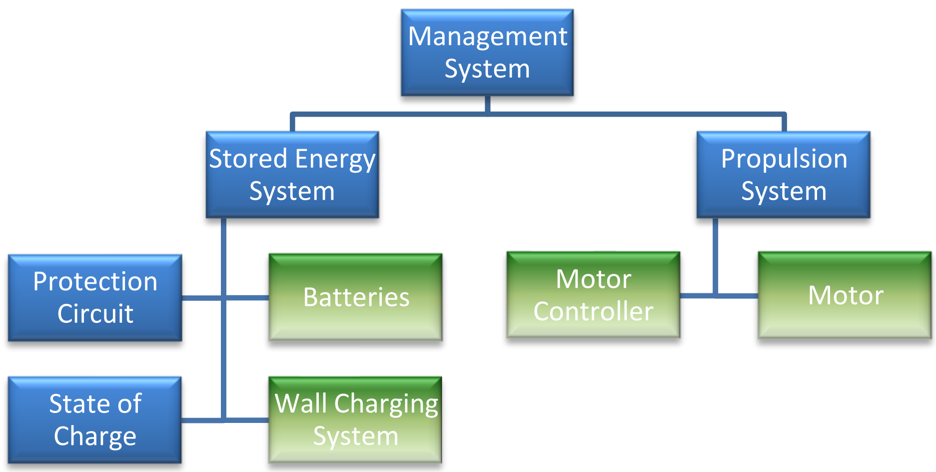


Figure 3.8.1 – Management Power System block diagram

Currently thirty Thundersky batteries have been implemented into the system. Each cell has an ideal operating voltage of 3.2 V and therefore the system as a whole will operate at 96 V. The only time that the batteries are outside of this range should be at a point of complete charge or at complete discharge. Figure 3.8.2 shows the discharge cycle of the Thundersky batteries.

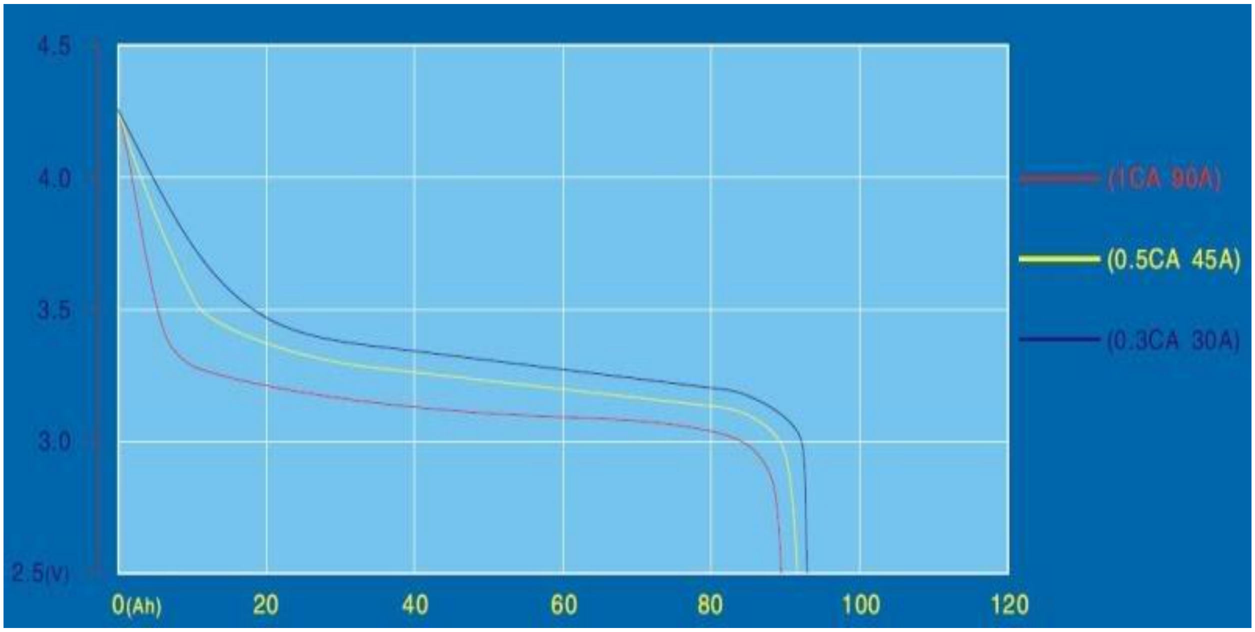


Figure 3.8.2 – Graph of Thundersky battery discharge cycle (Endless-Sphere)

The Thundersky batteries like all batteries have ideal operating parameters and must be kept in this range or risk causing damage to the batteries. A protection circuit will have to be implemented to keep the batteries in the safe range. The protection circuit will be designed to the ideal operating ranges displayed in Table 3.8.1.

Table 3.8.1 – Safe battery operating parameters

Protection Type	Restraining Value
Over Voltage	4.25 V
Under Voltage	2.5 V
Over Current	120 A
Over Temperature	75 °C

Several devices have already been purchased in conjunction with the batteries to simplify this state of charge monitoring. A battery management system (BMS) designed specifically for these batteries will be utilized as a means to isolate the batteries from the rest of the electrical system. The battery management system contains four signal wires through which passes a small current. As long as the signal circuits are closed then the BMS will allow operation of the batteries. As soon as one of the signals is broken then the BMS will slowly power down the batteries and finally separate them entirely from the rest of the system. This will be the controlling device to prevent batteries from out of bounds conditions.

The voltage protection for the batteries will utilize a cell module device attached to each of the batteries. The signal wire from the BMS will be run through each of the cell modules. During the operation of the vehicle the cell module will monitor the voltage potential of the individual battery that it is attached too. When the battery is in a safe operating range the cell module will be a closed circuit and when outside of this range the cell module will be an open circuit. If even one of the cell modules is an open circuit then the BMS will begin the shut down phase.

To measure the current out of the batteries a current transformer will be used. A current transformer is a series of looped coils which can be placed around a wire to measure the magnetic field generated by the current in the wire. This device will produce an output which can be interpreted through an algorithm to determine the current value in the wire. The microcontroller will control the signal to the BMS and break the signal when current exceeds the maximum. The current can also be used for display on the dashboard state of charge display.

The temperature will be monitored through a device called a thermistor. A thermistor is a circuit element whose resistance varies with temperature. For this application a positive thermal coefficient (PTC) thermistor will be used, where resistance increases with temperature. Through experimentation it has been discovered that the signal from the BMS can be broken with approximately 2400 ohms of resistance. Therefore the thermistor will be chosen to coincide with at least 2400 ohms resistance when ambient temperature reaches 75 degrees Celsius. The graph on Figure 3.8.3 – Graph of resistance values vs. temperature for a thermistor Figure 3.8.3 shows the behavior of these circuit elements.

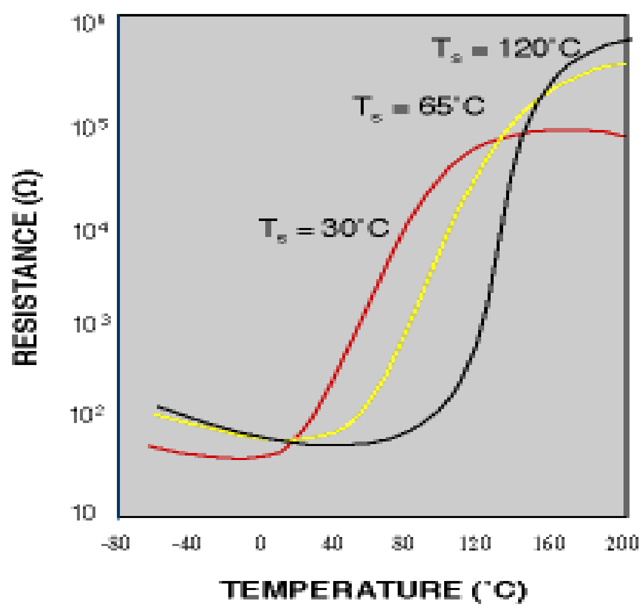


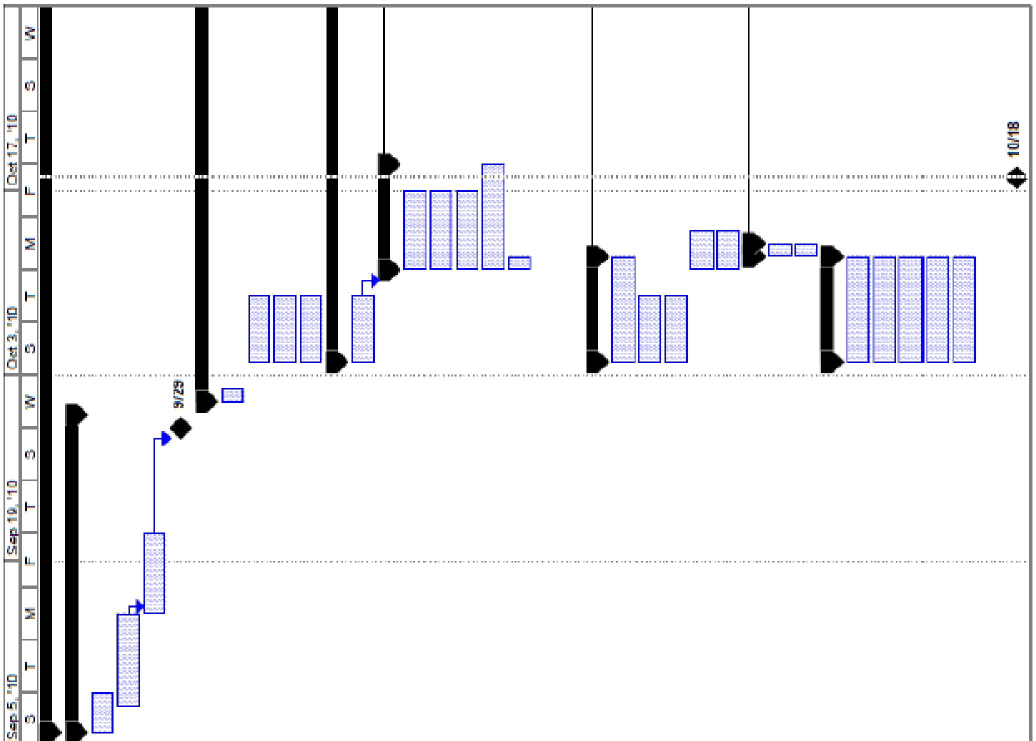
Figure 3.8.3 – Graph of resistance values vs. temperature for a thermistor (CR Magnetics, Inc.)

After the protection circuitry is completed and the BMS will automatically isolate the batteries when operating out of bounds the next major step will be to display this information for the driver. In order to accomplish this all the information will be given to the microcontroller to display this information on the dashboard. The current coming out of the batteries will be measured by the previously implemented current transformer. The voltage will be measured utilizing a voltmeter. Ideally the information from the voltmeter will go to the microcontroller and then be displayed on the dashboard. The other desirable function for this series of devices will be a fuel gauge for the batteries. In order to accomplish this, the batteries will have to be brought up to a full charge. Once the batteries are at a full charge the microcontroller will have to start measuring the discharge by the batteries, which can be calculated with the voltage and current. This will give the driver an approximate gauge of how much of the stored energy in remaining in the batteries.

Once the state of charge system and protection circuit is in place there is no reason that the batteries should ever be exposed to dangerous operating conditions. In the event that the BMS or some element of the protection circuit fails the driver, through the dashboard, should be aware of any danger to the operating environment of the batteries.

4 Schedule

Below is a copy of the Ghant schedule produced in Microsoft Project that must be followed to successfully complete the project on time.



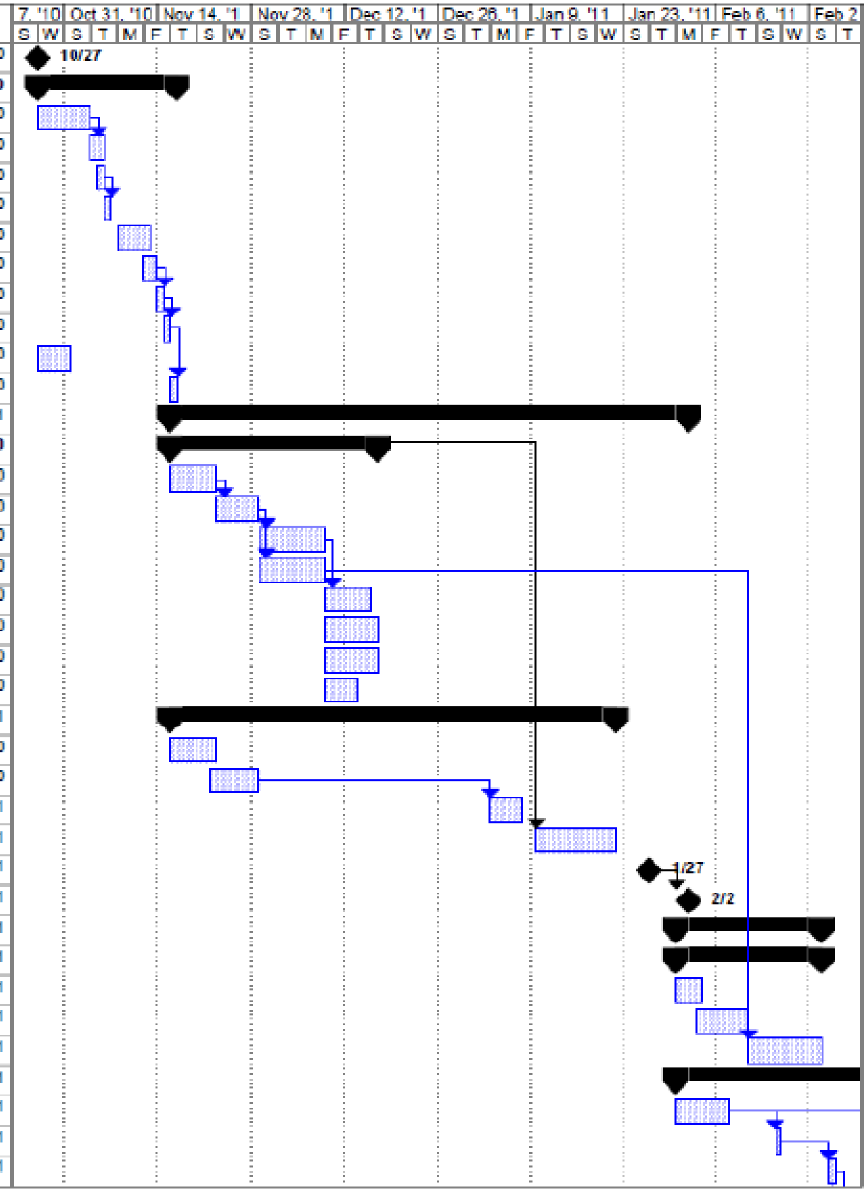
ID	Task Name	Duration	Start	Finish
1	**Solar Car**	**170 days**	**Mon 9/6/10**	**Fri 4/22/11**
2	**Needs Assesment Presentation**	**18 days**	**Mon 9/6/10**	**Wed 9/29/10**
3	Research race constraints	3 days	Mon 9/6/10	Wed 9/8/10
4	Research race requirements	5 days	Wed 9/8/10	Tue 9/14/10
5	Develop system test plans	4 days	Wed 9/15/10	Mon 9/20/10
6	Presentation	1 day	Wed 9/29/10	Wed 9/29/10
7	**Solar Car Project Proposal**	**62 days**	**Fri 10/1/10**	**Mon 12/20/10**
8	Assigned Project Tasks/ Roles	1 day	Fri 10/1/10	Fri 10/1/10
9	Research Solar Arrays	5 days	Mon 10/4/10	Fri 10/8/10
10	Research Power Trackers	5 days	Mon 10/4/10	Fri 10/8/10
11	Research Battery Protection Systems	5 days	Mon 10/4/10	Fri 10/8/10
12	**Research Suspension**	**58 days**	**Mon 10/4/10**	**Thu 12/16/10**
13	Research Current Technology	5 days	Mon 10/4/10	Fri 10/8/10
14	**Select Components**	**7 days**	**Mon 10/11/10**	**Mon 10/18/10**
15	Hub	8 days	Mon 10/11/10	Sat 10/16/10
16	Ball Joints	8 days	Mon 10/11/10	Sat 10/16/10
17	Loswer wishbone	8 days	Mon 10/11/10	Sat 10/16/10
18	Upper wishbone	7 days	Mon 10/11/10	Mon 10/18/10
19	Shocks/Damper	1 day	Mon 10/11/10	Mon 10/11/10
20	Model Suspension in Solid Works	12 days	Mon 11/15/10	Tue 11/30/10
21	FEM analysis of Component	12 days	Wed 12/1/10	Thu 12/16/10
22	**Research Brake Systems**	**6 days**	**Mon 10/4/10**	**Mon 10/11/10**
23	Research Braking Components	8 days	Mon 10/4/10	Mon 10/11/10
24	Research Composite Materials	5 days	Mon 10/4/10	Fri 10/8/10
25	Research Aerodynamic Design	5 days	Mon 10/4/10	Fri 10/8/10
26	Research Sensors	3 days	Mon 10/11/10	Wed 10/13/10
27	Regesearch Regentive Brakes	3 days	Mon 10/11/10	Wed 10/13/10
28	**Research Steering System**	**1 day**	**Tue 10/12/10**	**Tue 10/12/10**
29	research rack and Pinion Steering	1 day	Tue 10/12/10	Tue 10/12/10
30	Calculate appropriate Steering Ratio	1 day	Tue 10/12/10	Tue 10/12/10
31	**Select Components**	**6 days**	**Mon 10/4/10**	**Mon 10/11/10**
32	steering wheel	8 days	Mon 10/4/10	Mon 10/11/10
33	steering column	8 days	Mon 10/4/10	Mon 10/11/10
34	steering shaft	8 days	Mon 10/4/10	Mon 10/11/10
35	rack and pinion	8 days	Mon 10/4/10	Mon 10/11/10
36	steering stops	8 days	Mon 10/4/10	Mon 10/11/10
37	Develop Design Proposal	2 days	Fri 12/17/10	Mon 12/20/10
38	Project Proposal Report	0 days	Mon 10/18/10	Mon 10/18/10

Project: Solar Car Project
Date: Mon 10/18/10

Task | Split | Progress | Milestone | Summary | Project Summary | External Tasks | External Milestone | Deadline

Page 1

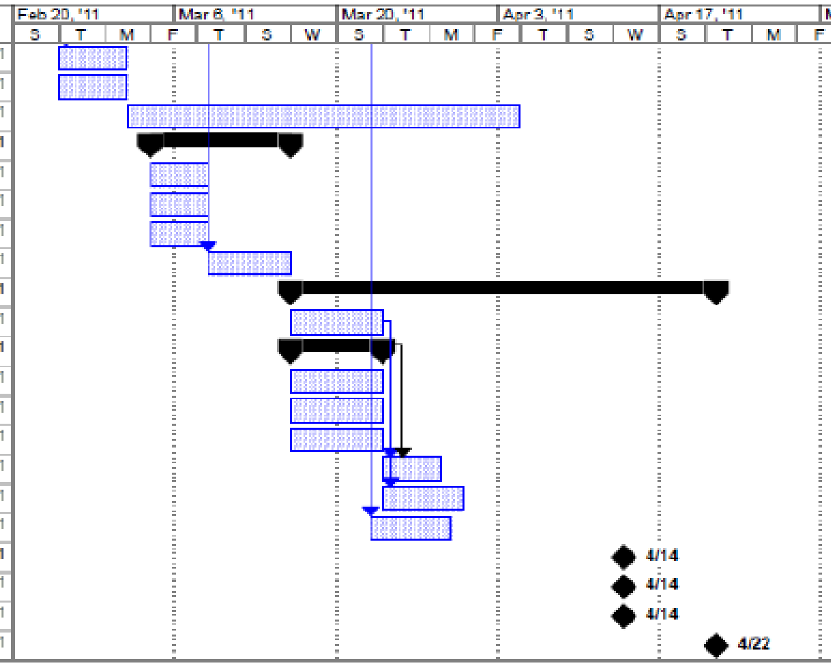
ID	Task Name	Duration	Start	Finish
39	Presentation	0 days	Wed 10/27/10	Wed 10/27/10
40	**System Level Design Review**	**17 days**	**Wed 10/27/10**	**Tue 11/16/10**
41	Develop Top Level Design	6 days	Wed 10/27/10	Wed 11/3/10
42	Analyze Top Level Desgin	2 days	Thu 11/4/10	Fri 11/5/10
43	Modify Top Level Design	1 day	Fri 11/5/10	Fri 11/5/10
44	Finalize Top Level Design	1 day	Sat 11/6/10	Sat 11/6/10
45	Develop Modular Level Design	5 days	Mon 11/8/10	Fri 11/12/10
46	Analyze Modular Lever Design	1 day	Fri 11/12/10	Sat 11/13/10
47	Modify Modular Level Design	1 day	Sun 11/14/10	Sun 11/14/10
48	Finalize Modular level Design	1 day	Mon 11/15/10	Mon 11/15/10
49	Research Vendors	3 days	Wed 10/27/10	Sun 10/31/10
50	Purchase parts	1 day	Tue 11/16/10	Tue 11/16/10
51	**Detailed Design Review and Test Plan**	**57 days**	**Tue 11/16/10**	**Wed 2/2/11**
52	**Lower Body Assembly**	**23 days**	**Tue 11/16/10**	**Thu 12/16/10**
53	Construct Lower Shell Mold	5 days	Tue 11/16/10	Mon 11/22/10
54	Construct Lower Body Shell	4 days	Tue 11/23/10	Sun 11/28/10
55	Assemble Front Suspension	8 days	Mon 11/29/10	Wed 12/8/10
56	Assemble Rear Suspension	8 days	Mon 11/29/10	Wed 12/8/10
57	Install Disc Brakes	5 days	Thu 12/9/10	Wed 12/15/10
58	Install Parking Brake	6 days	Thu 12/9/10	Thu 12/16/10
59	Install Regenerative Brake	6 days	Thu 12/9/10	Thu 12/16/10
60	Install Steering System	3 days	Thu 12/9/10	Mon 12/13/10
61	**Upper Body Assembly**	**50 days**	**Tue 11/16/10**	**Fri 1/21/11**
62	Construct Upper Body Mold	5 days	Tue 11/16/10	Mon 11/22/10
63	Construct Upper Composite Body	5 days	Mon 11/22/10	Sun 11/28/10
64	Construct Cockpit Canopy	5 days	Mon 1/3/11	Fri 1/7/11
65	Assemble Upper Shell to Lower Body	10 days	Mon 1/10/11	Fri 1/21/11
66	Detailed Design Review and Test Plan Report	0 days	Thu 1/27/11	Thu 1/27/11
67	Detailed design Review and Test Plan Presentation	0 days	Wed 2/2/11	Wed 2/2/11
68	**Lower Body Configuration**	**16 days**	**Mon 1/31/11**	**Mon 2/21/11**
69	**Re-install working components of management systen**	**16 days**	**Mon 1/31/11**	**Mon 2/21/11**
70	Batteries	4 days	Mon 1/31/11	Thu 2/3/11
71	Charging System	6 days	Thu 2/3/11	Thu 2/10/11
72	Motor	7 days	Fri 2/11/11	Mon 2/21/11
73	**Solar Array Installation**	**59 days**	**Mon 1/31/11**	**Fri 4/22/11**
74	Test Solar Cells	6 days	Mon 1/31/11	Mon 2/7/11
75	Combine Solar cells into modules	1 day	Tue 2/15/11	Tue 2/15/11
76	combine modules into panels	1 day	Wed 2/23/11	Wed 2/23/11



Project: Solar Car Project
Date: Mon 10/18/10

Task		Milestone		External Tasks	
Split		Summary		External Milestone	
Progress		Project Summary		Deadline	

ID	Task Name	Duration	Start	Finish
77	Test MMPT integration into the panels	4 days	Thu 2/24/11	Tue 3/1/11
78	Test Solar Array Protection System	4 days	Thu 2/24/11	Tue 3/1/11
79	Test Charging Capabilities	24 days	Wed 3/2/11	Mon 4/4/11
80	**Total Body Configuration**	**8 days**	**Fri 3/4/11**	**Tue 3/15/11**
81	Install Energy Storage System	3 days	Fri 3/4/11	Tue 3/8/11
82	Install Central Interface System	3 days	Fri 3/4/11	Tue 3/8/11
83	Install Propulsion System	3 days	Fri 3/4/11	Tue 3/8/11
84	Install Energy Generation System	5 days	Wed 3/9/11	Tue 3/15/11
85	**Final Testing Phase**	**27 days**	**Wed 3/16/11**	**Fri 4/22/11**
86	Test Steering System	6 days	Wed 3/16/11	Wed 3/23/11
87	**Test Braking System**	**6 days**	**Wed 3/16/11**	**Wed 3/23/11**
88	Regenerative Brake	6 days	Wed 3/16/11	Wed 3/23/11
89	Standard Brakes	6 days	Wed 3/16/11	Wed 3/23/11
90	Parking Brake	6 days	Wed 3/16/11	Wed 3/23/11
91	Test Car Maneuver test	3 days	Thu 3/24/11	Mon 3/28/11
92	Car Stability Test	5 days	Thu 3/24/11	Wed 3/30/11
93	Test Solar Capabilites	5 days	Wed 3/23/11	Tue 3/29/11
94	**Design Fair**	**0 days**	**Thu 4/14/11**	**Thu 4/14/11**
95	Final Report	0 days	Thu 4/14/11	Thu 4/14/11
96	Final Project Oral Presentations	0 days	Thu 4/14/11	Thu 4/14/11
97	Peer Evaluations and Course Review	0 days	Fri 4/22/11	Fri 4/22/11



Project: Solar Car Project
Date: Mon 10/18/10

Task | Split | Progress | Milestone | Summary | Project Summary | External Tasks | External Milestone | Deadline

5 Budget Estimate

An estimated budget on the design project was presented by the team in the project proposal report. The budget has been divided into Personnel, Expense, Overhead Costs, Equipment, and Total Project Cost. Every member in the team is subjected to a base salary rate of $30 per hour. Each team member will be assumed to work twelve hours per week for both the fall and spring semesters. Fringe benefit rate of 29% will be applied on all personnel. All supplies under $1000 will be documented under Expense. Quantity, unit cost, total cost, and a reference (store name or website) for each supply will be documented under Expense. Overhead costs of the project will be presented with an overhead rate of 45%. Items with cost over $1000 will be listed under Equipment. With respect to aforementioned costs, total costs necessary for successful completion of the project will be presented under Total Project Cost. The previous budget estimate is shown below.

5.1 Personnel Expenses

Name	Hours	Base Pay	Total
Barge, James	384	$30.00	$11,520.00
Cires, Adrian	384	$30.00	$11,520.00
Dalick, Keith	384	$30.00	$11,520.00
German, Nelson	384	$30.00	$11,520.00
Panther, Emiliano	384	$30.00	$11,520.00
Pradhan, Rajat	384	$30.00	$11,520.00
Prisland, Zachary	384	$30.00	$11,520.00
Rajbhandari, Shishir	384	$30.00	$11,520.00
Roberts, Amanda	384	$30.00	$11,520.00
Subtotal			$103,680.00
Fringe Benefit (29%)			$30,067.20
Total Personnel Cost			**$133,747.20**

5.2 Expenses

ELECTRICAL					
Item	Quant.	Unit Cost	Total	Reference	Reference
Battery				NAWS	(website)
SOC Monitor	1	$319.00	$319.00	NAWS	(website)
Connection Kit	1	$98.70	$98.70	NAWS	(website)
Temperature Kit	1	$64.25	$64.25	NAWS	(website)
Syringe	9	$10.00	$90.00	ONCE	
Weller	9	$60.00	$540.00	ONCE	
Iron Tip	9	$9.00	$81.00	ONCE	
Paste Flux	10	$10.00	$100.00	Marshall Indus.	
Mount Tape	3	$47/roll	$141.00	R.S. Hughes Co	
Heat Shrink	2	$98.88	$197.80	McMaster-Carr	(website)
Fuses	8	$3.50	$28.00	McMaster-Carr	(website)
Connector	16	$0.95	$15.00	McMaster-Carr	(website)
Wires	7	$35/ft	$245.00	McMaster-Carr	(website)
3-way toggle	2	$5.00	$10.00	McMaster-Carr	(website)
2-way toggle	2	$6.50	$13.00	McMaster-Carr	(website)
push button	2	$10.00	$20.00	McMaster-Carr	(website)
Speedometer	1	$15.00	$15.00	Bicycle Store	(local)
Digital Therm.	1	$15.00	$15.00	Amazon	(website)
Ammeter	2	$45.00	$90.00	Ebay	(website)
Volt meter	1	$45.00	$45.00	Ebay	(website)
Fuses	10	$3.50	$35.00	Autozone	(local)
Camera\lcd	1	$150.00	$150.00	Ebay	(website)
Icharger	1	$170.00	$170.00	Amainhobbies	(website)
Current protec.	1	$150.00	$150.00	All-battery	(website)
Over Vol protec.	1	$200.00	$200.00	Smartec	(china)
Cell Balance Brd	1	$200.00	$200.00	Smartec	(china)
Microcontroller	2	$125.00	$250.00	Xillinx	Website
Miscellaneous			$500.00		
Subtotal			$3,782.75		

MECHANICAL					
Item	**Quant.**	**Unit Cost**	**Total**	**Reference**	**Reference**
Suspension System					
Aluminum	12 ft	$9.00	$108.00	local	(local)
Front suspension					
Coil Spring	2	$60.00	$120.00	jpc cycles	(website)
Damper	2	$49.50	$99.00	US motoman	(website)
Rear Suspension					
Coil Spring	1	$60.00	$60.00	pitstopusa	(website)
Damper	1	$49.50	$49.50	pitstopusa	(website)
Nuts & Bolts		$25.00	$25.00	Motor Sport	(website)
Miscellaneous		$125.00	$125.00		
Brake System					
Brake Pads	4	$35.00	$140.00	Motor Sport	(website)
Calipers	2	$85.00	$170.00	J C Whitney	(website)
Rotors	2	$45.00	$90.00	Moto Store	(website)
Miscellaneous					
Steering sys		$125.00	$125.00		
Wheel	1	$150.00	$150.00	advance auto	(website)
Rack & Pinion	1	$265.00	$265.00	Cabela's	(website)
Steering Column	1	$169.00	$169.00	J C Whitney	(website)
Miscellaneous		$125.00	$125.00		
Subtotal			$1,820.50		
INDUSTRIAL					
Item	**Quantity**	**Unit Cost**	**Total**	**Reference**	**Reference**
Resins	1	$500.00	$500.00	local	local
Canopy	1	$150.00	$150.00	local	build
Seats	1	$150.00	$150.00	advance auto	local
Horns	1	$35.00	$35.00	advance auto	local
Head Lights	1	$50.00	$50.00	advance auto	local
Brake Lights	1	$25.00	$25.00	advance auto	local
Reverse Lights	1	$35.00	$35.00	advance auto	local
Indicators	1	$20.00	$20.00	advance auto	local
Painting	1	$500.00	$500.00	local	local
Supplies		$500.00	$500.00		

Subtotal	$1,965.00
Total Expenses	$7,568.25

5.3 Overhead

Overhead Cost	
PERSONNEL	$133,747.00
EXPENSES	$7,568.25
DIRECT COST	$141,315.25
Total at 45%	**$63,591.86**

5.4 Equipment

Item	Quantity	Unit Cost	Total	Reference	Reference
Solar Array	2363 cells	$6.50	$15,356.00	photonek.com	(website)
MPPT	2	$1,899.00	$3,798.00	AERL	(Australia)
Suspension	1	$1,100.00	$1,100.00	J C Whitney	(website)
Carbon Fiber	100 yds	$26.00	$2,600.00	solarcomposites	(website)
Total			**$22,854.00**		

5.5 Total Budget

TOTAL BUDGET	
PERSONNEL	$133,747.20
EXPENSES	$7,568.25
OVERHEAD	$63,591.86
EQUIPMENT	$22,854.00
Total Project Cost	**$227,761.31**

After further analysis and research, a more complete budget has been created. Donations in the form of Student Licenses have been acquired from SolidWorks and MSC Adams. These donations will help keep the team on schedule with the design and the analysis of the design. The design team has purchased 50 yards of 3K carbon fiber fabric at a discounted price and received an additional donation of 12K carbon fiber fabric at no additional cost. The steering system for last year's solar car is going to be salvaged leaving only a gearbox to be purchased to ensure proper steering of the vehicle. Shown below is the updated budget estimate, which is a more realistic and accurate budget for the project.

5.6 Personnel Expenses

NAME	Hours	Base Pay	Total
Barge, James	384	$30.00	$11,520.00
Cires, Adrian	384	$30.00	$11,520.00
Dalick, Keith	384	$30.00	$11,520.00
German, Nelson	384	$30.00	$11,520.00
Panther, Emiliano	384	$30.00	$11,520.00
Pradhan, Rajat	384	$30.00	$11,520.00
Prisland, Zachary	384	$30.00	$11,520.00
Rajbhandari, Shishir	384	$30.00	$11,520.00
Roberts, Amanda	384	$30.00	$11,520.00
	Subtotal		$103,680.00
	Fringe Benefit (29%)		$30,067.20
	Total Personel Cost		**$133,747.20**

5.7 Expenses

ELECTRICAL					
Item	**Quant.**	**Unit Cost**	**Total**	**Reference**	**Reference**
12V:9V DC:DC	1	$40.00	$40.00	Power Stream	(website)
Multi-meter	1	$45.00	$45.00	Ebay	(website)
Camera\lcd	1	$150.00	$150.00	Ebay	(website)
Soldering Kit	3	$130.00	$390.00	ONCE	(website)
Key switch	1	$20.00	$20.00	McMaster-Carr	(website)
Keypad	1	$20.00	$20.00	Bycicle Store	(local)
Digital Therm.	1	$15.00	$15.00	Amazon	(website)
Current Trans.	1	$100.00	$100.00	Ebay	(website)
Icharger	1	$170.00	$170.00	Amainhobbies	(website)
Microcontroller	1	$180.00	$180.00	Wytec	Website
SW-190 Relay	3	$115.00	$345.00	Curtis	(website)
Relay board	1	$70.00	$70.00	Curtis	(website)
PTC thermistor	1	$10.00	$10.00	Radioshack	(local)
Multi-crystalline Silicon Solar Cell	2300	$5.00	$11,500.00	Solar world	(website)
Miscellaneous			$500.00		(local)
Subtotal			$13,555.00		

MECHANICAL					
Item	**Quant.**	**Unit Cost**	**Total**	**Reference**	**Reference**
Suspension System					
Aluminum	12 ft	$9.00	$108.00	local	(local)
Front suspension					
Coil Spring	2	$60.00	$120.00	jpc cycles	(website)
Damper	2	$49.50	$99.00	US motoman	(website)
Rear Suspension					
Coil Spring	1	$60.00	$60.00	pitstopusa	(website)
Damper	1	$49.50	$49.50	pitstopusa	(website)
Nuts & Bolts		$25.00	$25.00	Motor Sport	(website)
Miscellaneous		$125.00	$125.00		
Brake System					
Brake Pads	4	$35.00	$140.00	Motor Sport	(website)
Calipers	2	$85.00	$170.00	J C Whitney	(website)
Rotors	2	$45.00	$90.00	Moto Store	(website)
Miscellaneous					
Steering sys		0	0		
Wheel	1	0	0	advance auto	(website)
Rack & Pinion	1	$265.00	$265.00	Cabela's	(website)
Steering Column	1	0	0	J C Whitney	(website)
Miscellaneous		0	0		
Subtotal			$1,251.50		
INDUSTRIAL					
Item	**Quantity**	**Unit Cost**	**Total**	**Reference**	**Reference**
Resins	1	$500.00	$500.00	local	local
Canopy	1	$150.00	$150.00	local	build
Seats	1	$150.00	$150.00	advance auto	local
Horns	1	$35.00	$35.00	advance auto	local
Head Lights	1	$50.00	$50.00	advance auto	local
Brake Lights	1	$25.00	$25.00	advance auto	local
Reverse Lights	1	$35.00	$35.00	advance auto	local
Indicators	1	$20.00	$20.00	advance auto	local

Painting	1	$1000.00	$1000.00	local	local
Supplies		$500.00	$500.00		
Subtotal			$2,315.00		
Total Expenses			$17,121.50		

5.8 Overhead

Overhead Cost	
PERSONNEL	$133,747.00
EXPENSES	$17,121.50
DIRECT COST	$150,868.50
Total at 45%	**$67,890.86**

5.9 Equipment

Item	Quantity	Unit Cost	Total	Reference	Reference
MPPT	2	$1,100.00	$2,200.00	AERL	(Australia)
Suspension	1	$1,100.00	$1,100.00	J C Whitney	(website)
Carbon Fiber	50 yds	$15.00	$750.00	solarcomposites	(website)
Total			**$4,050.00**		

5.10 Total Budget

TOTAL BUDGET	
PERSONNEL	$133,747.20
EXPENSES	$17,121.50
OVERHEAD	$67,890.86
EQUIPMENT	$4,050.00
Total Project Cost	**$222,809.56**

The new calculated budget is $4,951.75 less than previously estimated.

6 Overall Risk Assessment

6.1 Technical Risks

Technical Risk can be associated with every aspect of the design. Failure is high when certain design calculations depend on other parts of the design. A domino effect may occur, making the final design riddled with errors. To prevent from technical errors transpiring, the team must calculate and test the findings. Also, having more than one team member to check the results may help to avoid technical errors in the design.

6.1.1 Rollover

Risk	Rollover
Probability	Low
Consequences	Catastrophic
Strategy	• Ensure load testing is analyzed properly • Material properties can handle the load

The solar car will traveling on public roads and highways therefore there is the chance for a rollover accident. Even though there is a low probability for a rollover to occur the consequences can destroy the entire vehicle and can potentially harm the driver. To ensure driver and car safety, load testing must be considered on the roll-cage and body for optimal design.

6.1.2 Crash

Risk	Crash
Probability	Low
Consequences	Severe
Strategy	Ensure forces placed on body can withstand impacts at multiple places on the body

As stated above, the solar car will be traversing public roads across North America. Consequently, there is a potential for crash just like any other vehicle on the road. The solar car will be traveling with a lead car and car following protecting the bow and aft from other vehicles on the road, therefore making the probability of occurrence very low. In the case of an accident, the car must be able to withstand forces acting in places that are unexpected. With the use of SolidWorks CAD software, forces can be placed on any point or surface making it easy to analyze the body for optimal safety.

6.1.3 Rack and Pinion Malfunction

Risk	Rack and Pinion Malfunction
Probability	Low
Consequences	Severe
Strategy	Design steering system to prevent any overloading on gearbox

A malfunctioning gear box means the failure of the entire steering system. This is the most severe risk when implementing steering into a vehicle.

6.1.4 Tie Rod Fracture

Risk	Tie Rod Fracture
Probability	Moderate
Consequences	Severe
Strategy	Analysis of stresses on tie rod to prevent fracture

Table 3.2.2 shows the risk assessment for the tie rod component of the steering system. Tie rods are subject to many tensile forces, and have a moderate probability of failure. Fortunately the failed tie rod can be easily replaced and does not pose a huge threat to the overall steering system.

6.1.5 Wrong spring selection for the suspension

Risk	Wrong spring selection for the suspension
Probability	Low
Consequences	Minor
Strategy	Revise the suspension calculations and repeat simulations in CAD software as needed.

Choosing the wrong spring for the suspension has a very low probability since most of the calculations are performed by the CAD software MSC ADAMS/Car. However, human error could be present in inputting the gathered data for the analysis into the software causing the latter to produce the wrong results. Having the wrong spring will cause the suspension to be either too soft or too stiff. This consequence is minor since the springs can be easily replaced. In order to prevent this from happening, the gathered data will be revised by two mechanical engineers to ensure there are no discrepancies and the right information is inputted. Also, simulations will be repeated more than once.

6.1.6 Control arm stress failure

Risk	Control arm stress failure
Probability	Low
Consequences	Catastrophic
Strategy	Research material properties and perform a thorough Finite Element Analysis (FEA) on the control arms in SolidWorks

There is a low risk that the control arms will experience stress failure. Stress failure can be caused by choosing the wrong material to fabricate the control arms or by experiencing an unprecedented extreme force under abnormal road conditions. The consequences would be catastrophic; if the control arms fail while driving, the driver's life would be put in jeopardy. Moreover, other suspension parts could break, thus making the car inoperable. To prevent this from occurring, material properties will be carefully evaluated and the one with the highest yield strength will be chosen. Also, a thorough FEA will be performed on the control arm design in SolidWorks with the roll and vertical forces obtained from simulations in MSC ADAMS/Car.

6.1.7 Degradation and/or failure of photovoltaic array

Risk	Degradation and/or failure of PV array
Probability	Moderate
Consequences	Catastrophic
Strategy	• Design and interconnect solar cell modules to be easily disconnected from the solar array • Design and interconnect solar cells to be easily disconnected from solar cells • Replace degraded solar cells

6.1.8 Module glass breakage

Risk	Module glass breakage
Probability	Moderate
Consequences	Severe
Strategy	• Due to thermal stress, handling, wind, hail, or vandalism • Purchase triple-junction amorphous solar cells. They are durable, flexible, and waterproof

6.1.9 Short-circuited cells

Risk	Short-circuited cells
Probability	Moderate
Consequences	Severe
Strategy	Care should be taken to ensure proper cell interconnections. Pin holes or regions of corroded or damaged cell material increases probability of short-circuit between top and rear contacts.

6.1.10 Open-circuited cells

Risk	Open-circuited cells
Probability	Moderate
Consequences	Severe
Strategy	• Caused by thermal stress, thermal expansion, or "latent cracks" • Loop interconnections between cells to minimize cyclic effect • Use double-interconnects to protect against fatigue failure

6.1.11 By-pass diode failure

Risk	By-pass diode failure
Probability	Low
Consequences	Severe
Strategy	• Caused by over-heating, often due to undersizing • Will result in damage to PV module • Purchase diode rated to handle currents 20-30% higher than maximum current from the solar module design configuration

6.1.12 Encapsulation failure

Risk	Encapsulation failure
Probability	Low
Consequences	Severe
Strategy	• Caused by leaching and diffusion of encapsulating materials • Use UV absorbers and encapsulant stabilizers to ensure long life

6.1.13 Electrocution

Risk	Electrocution
Probability	Moderate
Consequences	Catastrophic
Strategy	• High voltage DC modules • Current arc generated due to faulty connections • Employ proper work procedure and safety precautions during installation • Employ rated fuses, and protective relay circuits

6.1.14 Unsuitable Input-Ouput MPPT range (V, I, efficiency)

Risk	Unsuitable Input-Output MPPT range (V, I, efficiency)
Probability	Low
Consequences	Severe
Strategy	• Purchase MPPT that has a wide input-output voltage range (DC) • Purchase MPPT that has a high input current (A) • Purchase MPPT with high efficiency

6.1.15 Overcharging the battery system

Risk	Overcharging the battery system
Probability	Low
Consequences	Moderate
Strategy	• Design and implement, or purchase an over-current protection component for the battery system • Implement the microcontroller to disable regenerative brake signal to the motor controller when the regenerative brake is implement while battery is at full capacity

6.1.16 Failure of Regenerative Brake

Risk	Failure of Regenerative Brake
Probability	Low
Consequences	Severe
Strategy	• Design primary mechanical frictional braking system for “back-up” • Monitor regenerative braking signal through microcontroller for diagnostics

6.1.17 Motor controller burns out

Risk	Motor controller burns out
Probability	High
Consequences	Catastrophic
Strategy	• Must charge the capacitor bank in the motor controller slowly for about 15 seconds after start up • Set up a pre-charge circuit using a parallel resistance • Ensure operation of the pre-charge circuit before giving full power to the motor

The motor controller being used for propulsion has a capacitor bank built into it. Before the motor can be operated this capacitor bank will need the charge to full capacity. If the user attempts to push power to the motor without this capacitor bank being charged, the capacitors will be damaged and prevent operation of the motor. Since the motor controller is the most expensive individual component on the entire car it would be catastrophic to the vehicle. Furthermore since the project is already under budget it would be impossible to replace.

6.1.18 Batteries operate under dangerous conditions

Risk	Batteries operate under dangerous conditions
Probability	Low
Consequences	Moderate to High
Strategy	• Test state of charge devices outside of implementation with battery • Test all four signal wires for BMS • Display correct information for driver allowing for manual shut down

The batteries being another important component to the success of the project must operate in their boundary condition for the duration of operation. As was previously discussed a protection circuit will be implemented to prevent these risks. This protection circuit will need to be tested rigorously however to ensure functionality under all circumstances.

6.2 Schedule Risks

Schedule risks directly impact the progress and completion of the project. When considering completion of the project, time management is the single most important thing to keep in mind. A well maintained schedule must be kept for best use of allotted time. Goals for certain portions of the project have been set and must be kept up with. The risk of failure is high, hence the team must stick to the schedule.

6.2.1 Large number of team members

Risk	Large number of team members
Probability	Low
Consequences	Moderate
Strategy	• Coordinating members of a large group is difficult • A proper schedule for team is designed to ensure all team member can meet at least once a week • A reference portal (dropbox) is developed to track weekly progress of the team; this source can be used to update members who missed team meetings • The team leaders of each discipline is in charge of conveying all relevant information to the members in their respective discipline • Team leaders of each discipline will meet with the project manager once a week

6.2.2 Schedule Conflict

Risk	Schedule conflict
Probability	High
Consequences	Severe
Strategy	• Assign independent tasks to each individual team member so they can work in their own time • Set team meeting in period (location, day, and time) when all team members are able to attend • Make a chart of school and work schedule of all team members

6.2.3 Illness

Risk	Illness
Probability	Low
Consequences	Minor
Strategy	• The member suffering with the illness should contact his/her team leader • The team leader will contact a member if prior notice of absence has not been presented by the member and the member is absent in team meeting • Any member suffering with illness need not attend meetings, their task will be uploaded in the Dropbox • The team leader of the member suffering with illness will monitor the progress of the ill member to ensure he/she is able to complete his/her task • If a member is suffering serious illness, his/her task will be subdivided between the team

6.2.4 Team members have to leave town

Risk	Team members have to leave town
Probability	Moderate
Consequences	Minor
Strategy	• The team member will inform their team leader or the project manager • The team member will be responsible of completing their allocated task • The team member will upload his/her completed task in dropbox • The team member will contact his/her team leader to ensure proper format, structure, and completion of their task

6.2.5 Delay in Shipment

Risk	Delay in shipment
Probability	High
Consequences	Severe
Strategy	• The team will compile money from team members and use a credit card to purchase parts below $200 • An order form for important parts and components (above $200) essential for basic project completion will be completed and sent to respective companies before the end of semester (fall 2010) • Depending on shipping cost, if budget allows, expedited shipping method will be implemented

6.2.6 Time

Risk	Time
Probability	Moderate
Consequences	Severe
Strategy	• Time is an important resource for completing the project; team members have to allocate their time for the project, school work, and personal jobs • Fundamental needs and requirements for project completion will be the primary focus of the team • A certain period of time (7 -10 days) is allocated for project work during breaks (winter break, spring break) • Processes such as solar module encapsulation will be outsourced (if budget allows) to spend more time on analysis and simulation of design

6.2.7 Unforeseen Circumstances

Risk	Unforeseen circumstances
Probability	High
Consequences	Severe
Strategy	• Design flaws are inevitable and results in an iterative process of initial design modification and re-testing • One and half week of time is allocated in schedule for component testing • One week of time is allocated in schedule for on-road testing • Analysis, simulation, and design integration will be rigorously tested to decrease the probability of "unforeseen circumstance" (example: speedometer stops functioning) • An emergency budget fund is set up to deal with this risk

6.3 Budget Risks

Most projects incur budget risks that may produce budget overruns. Budget overrun may occur due to additional support costs, unexpected material or equipment costs, component or system failures, and underestimation of costs. Currently our project is over budget by $84,062.36. This is mostly due to the extremely expensive solar cells needed to produce enough charge for the batteries, which are at an estimated $5 per watt, resulting in $11,500. As mentioned in the budget estimate, our current funding is $5000 with additional donations of materials and software. However, more funding is needed to be able to obtain the parts needed and complete the project.

6.3.1 Budget Overrun

Risk	Budget overrun
Probability	High
Consequence	Severe
Strategy	Increase fundraising efforts

As mentioned earlier, we are currently experiencing a budget overrun due to small funding and the costly solar cells needed. The consequence of this is very severe since it can halt the progress of the project due to the inability of obtaining the parts needed to complete the project. Also, this will result in a trade-off between cost and performance, hindering the expected outcome of the project by buying low cost materials and parts. To prevent this from happening, we will continue to increase our fundraising efforts and find sponsors to cover the overrun costs. A copy of our fundraising paper can be found in the appendix section.

6.3.2 Component Failure

Risk	Component Failure
Probability	Moderate
Consequence	Severe
Strategy	Ensure components are carefully chosen

Another risk is the failure of any component of the car. The probability of this happening is moderate since most parts will be ordered according to the required specifications. However, components are prone to failure and must be replaced thus increasing the budget if not covered by warranty. This consequence is severe since it will delay the progress of the design and building of the car by increasing the budget.

6.4 Summary of Risk Status

Due to the enormity of the solar car project there are bound to be a plethora of risks involved. The budget risk is the most daunting of the anticipated risks for the project. Even though the budget is listed as a risk, at this point it is more of a certainty. The project as a whole is grossly under budget. The team is seeking donations, both material and capital, to bridge this gap in estimated costs.

The technical risks for the project are also very real, though not necessarily as detrimental to the completion of the project. The industrial engineering team has introduced design methodologies that have greatly increased the scope of details for the project. This expanded view has facilitated every step of the design process and will reduce the chance of missing steps. The other side of the technical risks is the injury to individuals on the solar car project. These risks can be managed with utilizing proper safety techniques, such as using proper personal protective equipment (PPE) or utilizing material safety datasheets (MSDS) when working with materials, during any fabrication or integration stages.

Finally the schedule risks are the least likely to impact the success of the project. This is largely due to the fact that there are nine individuals and a graduate advisor working on this project. If one or even two members become ill it is possible that the group could divide up the work and still make steady progress towards the completion of the project. There are many risks to the success of the project but with proper planning and awareness the team as a whole should be able to confront any issues and prevent disaster.

7 Conclusion

Through much research into solar power production and solar vehicle fabrication, the proposed solar car has taken shape to be an efficient, well designed vehicle. The design allows for minor changes after testing to make the solar car very efficient and worthy to travel the highways of North America. Design concepts for each of the project objectives have been considered and decided upon using decision matrices for an optimal model. In addition to the design concepts, each portion of the design has been assessed for risks, therefore making less chance for problems and a higher chance for project streamline. In the near future, the design team will start fabrication of the solar car. This includes production of a mold for the body and laying the carbon fiber for the bottom and top half of the car.

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9 Appendix

9.1 Fundraising Paper

FAMU-FSU College of Engineering

2525 Pottsdamer Street Tallahassee, FL 32310

SOLAR CAR TEAM

Senior Deisgn Project

Project Executive Summary

The American Solar Challenge is a competition to design, build, and drive solar-powered cars in a cross-country time/distance rally event. The Solar Challenge hosted in 2012 will have teams competing in a 2400-mile course between multiple cities across the continent. It is hosted by Innovators Educational Foundation, an organization devoted to the applied learning in the areas of science, engineering, and technology. FAMU-FSU College of Engineering has set up a team of senior undergraduate students from multiple disciplines to design and build a solar powered car to compete in this challenge. The team consists of three electrical engineers, three mechanical engineers, and three industrial engineers.

The energy from solar radiation is the most abundant and potentially the greatest source of renewable energy. Research is constantly conducted around the globe aimed at increasing solar cell efficiency and may one day enable us to harness the full energy of the sun. The technical design project that we have undertaken is attempting to introduce senior engineering students to solve the problem of designing, building, and racing a safe and functional car that is powered via sunlight.

The objectives of the technical design project are as follows:

1. Design a composite body
2. Design solar array configuration
3. Design suspension system
4. Design electrical system
5. Optimize design
6. Test mechanical system
7. Test electrical system

The new car will be designed using the idea of a monocoque body, which incorporates the chassis into the body. The monocoque body will be made using carbon fiber and composite materials to reduce weight and increase aerodynamic efficiency. The design will consist of three wheels, as opposed to four wheels, to reduce the overall friction loss of the vehicle. The design will undergo stress analysis to ensure safety and stability of the vehicle. Low friction disc brakes will be used on the forward two wheels for proper stopping force necessary to decelerate the vehicle in the allotted space. A rack and pinion steering system will be designed to best fit the vehicle for a turning radius specified by the race regulations.

For propulsion, the driving force for the vehicle will produced by an in-wheel brushless DC motor. The motor will be mounted on the rear trailing wheel assembly. To control the input power to the motor, a motor controller will be used by taking the power from the batteries. Sensor readings, such as temperature, voltage, will be continuously gathered to protect the batteries, motor and driver from over-heating or over-charging. Also, a protection circuitry, including breakers and fuses, will be implemented in order to safeguard components from power surges or cross wiring. These will ensure safety to the driver and vehicle, which is the number one priority of the team.

A substantial amount of capital will be required in order to actualize our design goals. We implore your company for any possible funding for our technical design project. The cost of the solar power arrays, composite body and components for modification will exceed the current budget allocated to us by the university. Any contribution would be of significant help to us for attaining our mission objective. We thank you for your time and patience and wish you the very best.

Budget

The estimated total budget for the design and building of the solar car is $22,538. So far, the FAMU-FSU College of Engineering has donated $5,000 to the team.

SOLAR CAR BUDGET

ELECTRICAL

Item	Quantity	Unit Cost	Total
Solar Cells	2363	$ 6.50	$ 15,359.50
MPPT	2	$ 200.00	$ 400.00
SOC Monitor	1	$ 320.00	$ 320.00
Connection Kit	1	$ 100.00	$ 100.00
Syringe	9	$ 10.00	$ 90.00
Weller	9	$ 60.00	$ 540.00
Iron Tip	9	$ 9.00	$ 81.00
Paste Flux	10	$ 10.00	$ 100.00
Mount Tape	3	$ 47.00	$ 141.00
Heat Shrink	2	$ 98.88	$ 197.76
Fuses	8	$ 3.50	$ 28.00
Connector	16	$ 0.95	$ 15.20
Wires	7	$ 35.00	$ 245.00
Speedometer	1	$ 15.00	$ 15.00
Digital Thermometer	1	$ 15.00	$ 15.00
Ammeter	2	$ 45.00	$ 90.00
Volt meter	1	$ 45.00	$ 45.00

Fuses	10	$ 3.50	$ 35.00
Camera/Display	1	$ 150.00	$ 150.00
iCharger	1	$ 170.00	$ 170.00
Current Protection	1	$ 150.00	$ 150.00
Voltage Protection	1	$ 200.00	$ 200.00
Microcontroller	1	$ 250.00	$ 250.00
Miscellaneous		$ 500.00	$ 500.00
SUBTOTAL			**$ 19,237.46**

MECHANICAL

Item	Quantity	Unit Cost	Total
Aluminum 6061 (stock)	12	$ 9.00	$ 108.00
Coil Spring	3	$ 60.00	$ 180.00
Damper	3	$ 49.50	$ 148.50
Brake Pads	4	$ 35.00	$ 140.00
Calipers	2	$ 85.00	$ 170.00
Rotors	2	$ 45.00	$ 90.00
Rack & Pinion	1	$ 265.00	$ 265.00
Steering Column	1	$ 169.00	$ 169.00
Miscellaneous		$ 125.00	$ 125.00
SUBTOTAL			**$ 1,395.50**

INDUSTRIAL

Item	Quantity	Unit Cost	Total
Carbon Fiber (yards)	100	$ 18.00	$ 1,800.00
Resin (gallons)	10	$ 50.00	$ 500.00
Canopy	1	$ 150.00	$ 150.00
Seat	1	$ 150.00	$ 150.00
Horn	1	$ 35.00	$ 35.00
Head Lights	2	$ 15.00	$ 30.00
Brake Lights	2	$ 10.00	$ 20.00
Indicators	4	$ 5.00	$ 20.00

Paint (estimated)	1	$ 500.00	$ 500.00
Supplies		$ 500.00	$ 500.00
SUBTOTAL			**$ 1,905.00**

Electrical	$ 19,237.46
Mechanical	$ 1,395.50
Industrial	$ 1,905.00
TOTAL EXPENSES	$ 22,537.96

FUNDING

Donator	Amount
College of Engineering	$ 5,000.00

Sponsorship Levels

Platinum - $2000 +

- ✓ Priority logo location on all team vehicles, website, and apparel
- ✓ Promotion during public events
- ✓ Access to team members for company events and speeches
- ✓ Project updates via e-mail
- ✓ Invitation to all solar car events

Gold - $1000

- ✓ Logo on the front of all team vehicles, website, and apparel
- ✓ Promotion during public events
- ✓ Access to team resume book
- ✓ Project updates via e-mail
- ✓ Invitation to all solar car events

Silver - $500

- ✓ Logo on rear half of team vehicles, website, and apparel
- ✓ Project updates via e-mail
- ✓ Invitation to all solar car events

Bronze - $250

- ✓ Acknowledgement on deliverables and website
- ✓ Project updates via e-mail

Faculty Advisor	Project Manager	Mechanical Lead
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