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

Detailed Design Review and Test Plan

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.

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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 1.5.2.1 displays one of the steering tests (the slalom test) that the car must undergo to qualify for the competition.

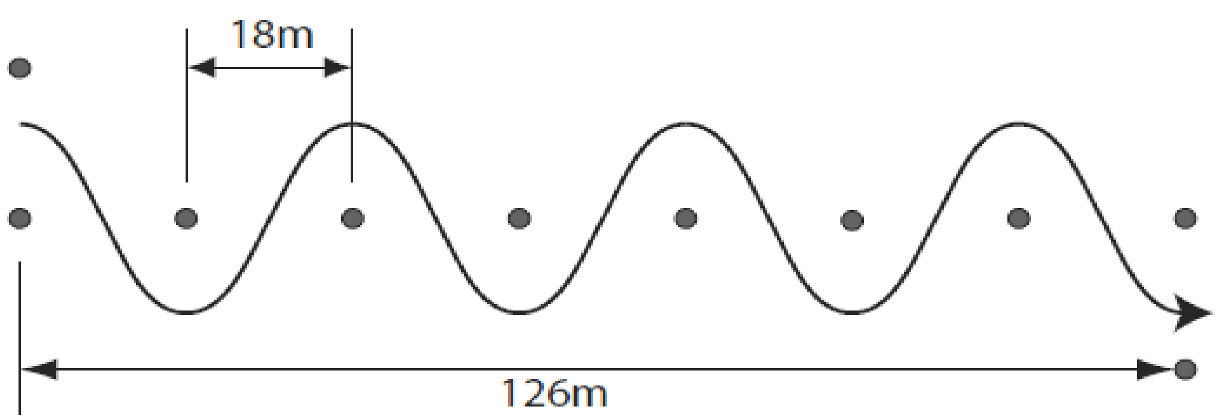


Figure 1.5.2.1 – Slalom Test Diagram

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 1.5.2.1 and Figure 1.5.2.2.

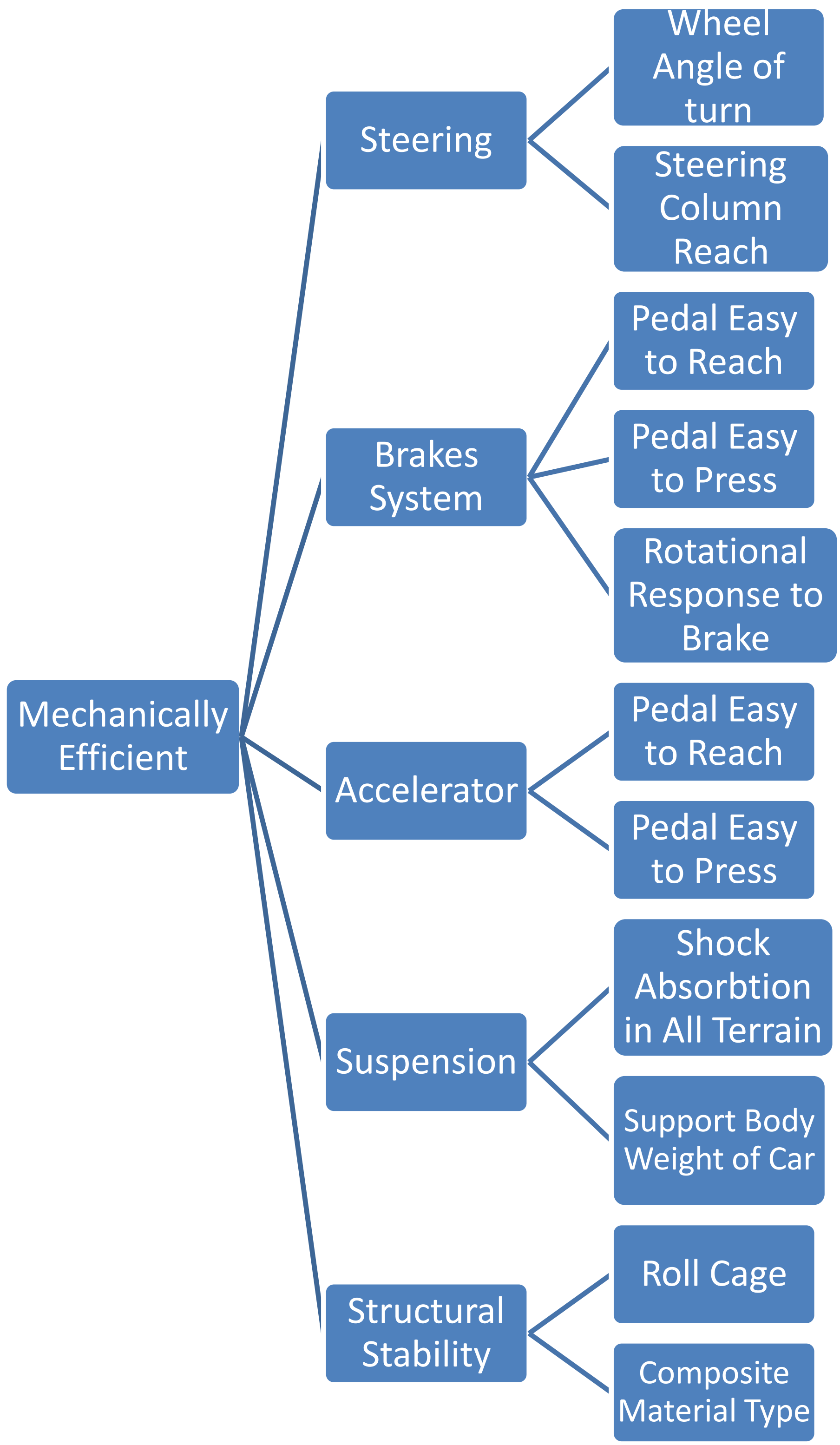


Figure 1.5.2.1 – Mechanical System

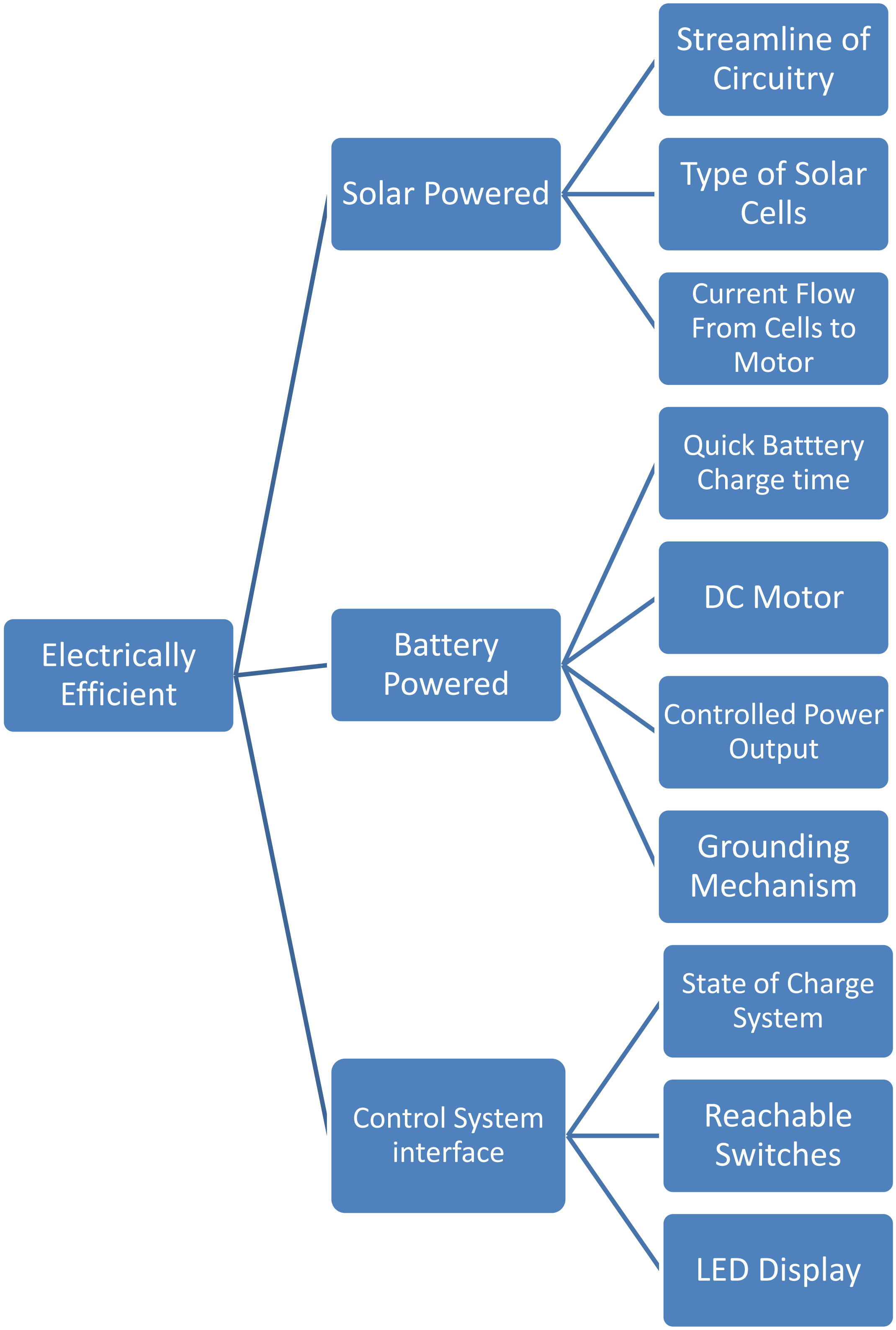


Figure 1.5.2.2 – Electrical System

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. A state of charge device that contains a voltmeter, temperature gauge, shunt line, and a battery fuel gauge will be used. This device will provide the driver with all the information necessary to make safe decisions in operating the vehicle. The simplicity of this device will make integration with other systems much simpler.

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.

2.5 Overall Risk Assessment

There are two major risks to the overall success of the project. They include a budget risk which is almost inevitable, but like most engineering projects there is never as much money as the individuals working on the project would like. The other major risk is having enough time to complete the project.

While there is still over two months left in the project which would seem like plenty of time there is always difficulty with other coursework and schedules which will divide the time of each member of the team. The time risk will be all about each member managing their individual schedule to try to maximize the amount of time that they can spend working on the project. Besides these two major risks, which are risks to almost any project in any field (not just engineering), there are wide variety of technical and safety risks involved with the project.

The biggest safety risk will be working with the batteries. As the batteries have a huge amount of energy stored in them an accidental short circuit is very dangerous if not lethal. When performing any of the work with the batteries or wiring a member will have to be very careful and should wear rubber gloves if possible. The other safety risks will involve when the car is actually in operation. The driver will have to be able to get out of the car quickly in the event of an electrical fire. This risk can be overcome by designing the body of the car to separate as easily as possible. The other risk will be operating the vehicle on roads. Despite the length and width dimensions of the car being quite large, the short height of the car may make it difficult for other motorists to see the solar car. To prevent an unnecessary risk a chase vehicle will be needed whenever driving the car on the street.

The technical risks for this project all involve designing a system or integration incorrectly. Due to the magnitude of the project there is a higher potential of error. These risks will be combated by having other project members, with similar technical skills, review any design work produced. During the fabrication phase it will also be necessary to have multiple team members present to verify that a design is being implemented correctly.

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.

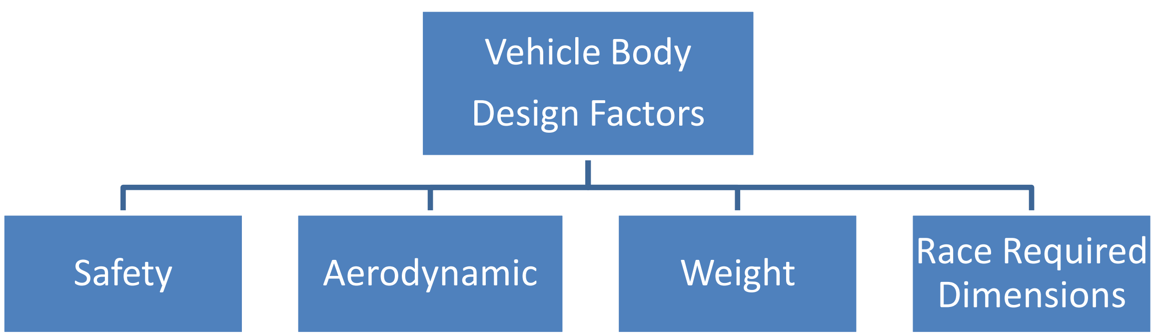


Figure 0.1---Vehicle Body Design Factors

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

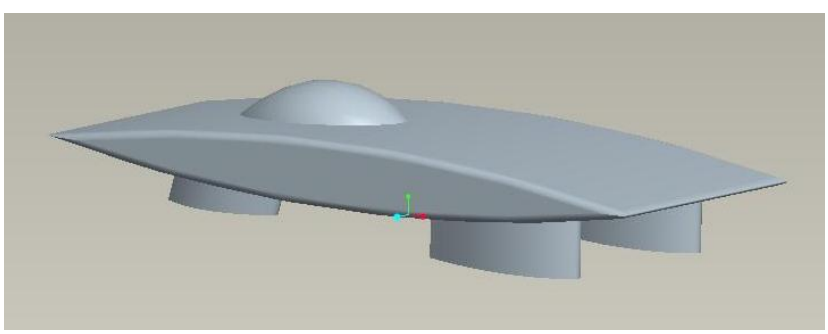


Figure 3.1.2.2 – Proposed Aerofoil Design

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 3.1.3.1---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 3.1.3.2---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.

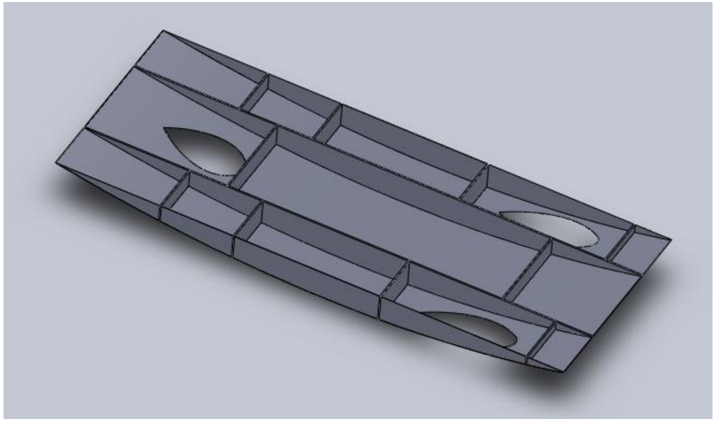


Figure 3.1.3.3---Proposed Monocoque Bottom Half

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 3.1.3.1.

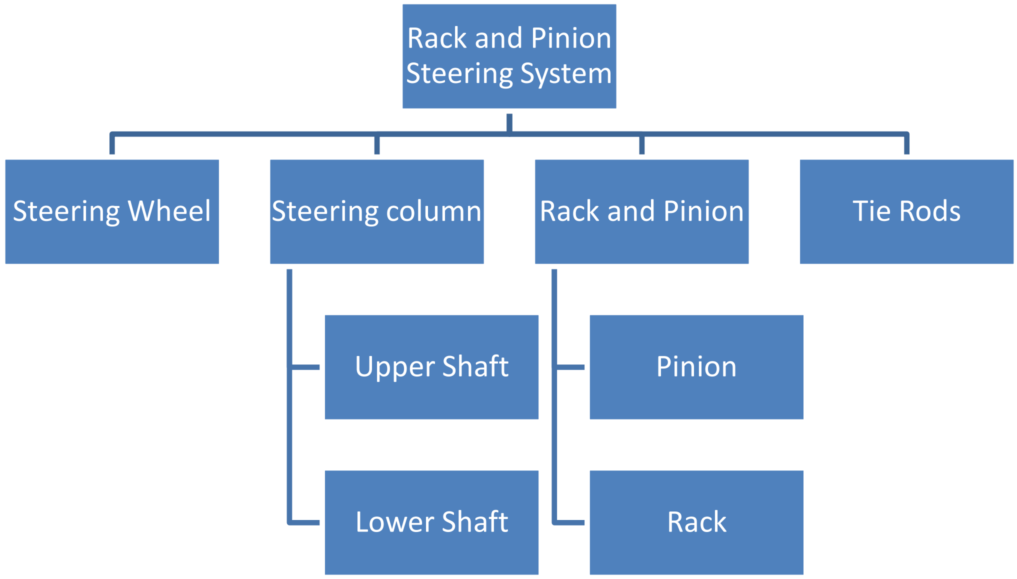


Figure 3.1.3.1 – Steering System Block Diagram

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 3.2.2.1 is an example of a steering shaft assembly.

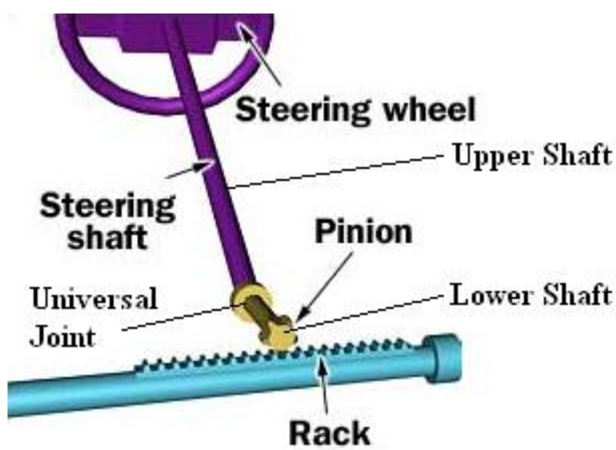


Figure 3.2.2.1--- Steering shaft. (Nice, How Car Steering Works, 2001)

3.2.3 Rack and Pinion

The rack and pinion, as shown in Figure 3.2.3.1 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 3.2.3.1 – Rack and Pinion Gear (Rack and Pinion)

3.3 Braking

Shown in Figure 3.2.3.1 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.

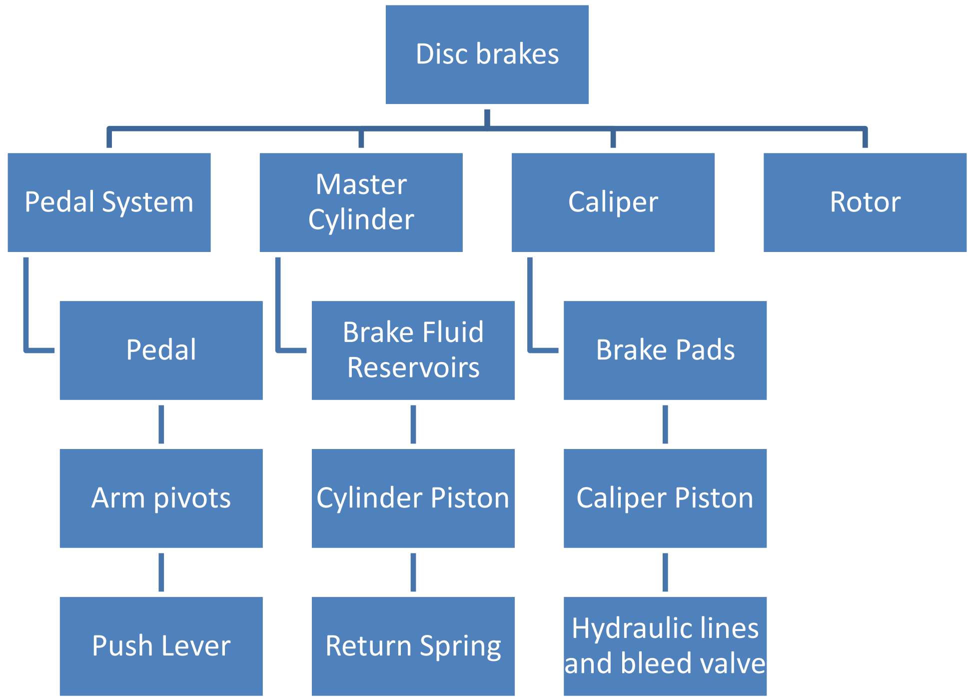


Figure 3.2.3.1– Hydraulic disc braking system block diagram

3.3.1 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 3.3.1.1 is the force diagram of the pedal system.

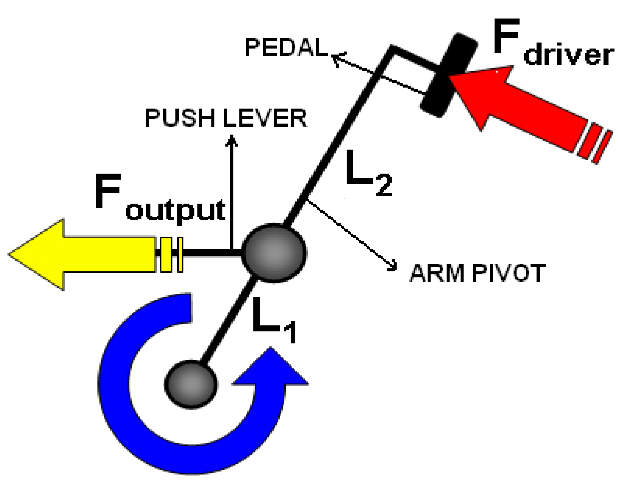


Figure 3.3.1.1 – Brake pedal system (Brake pedal setup)

3.3.2 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 3.3.2.1 is a schematic of a master cylinder.

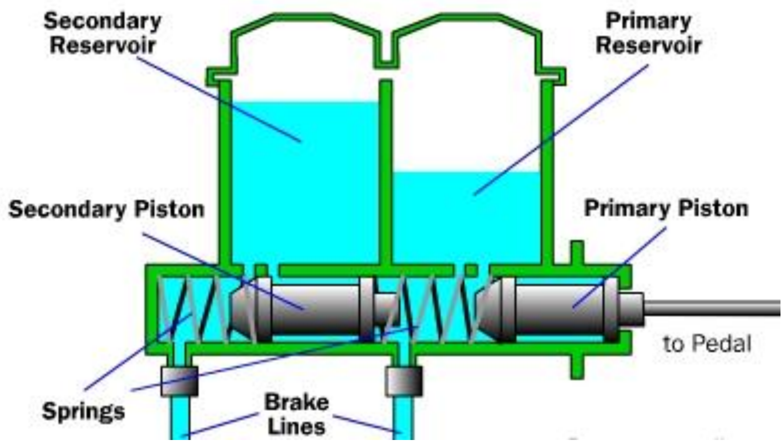


Figure 3.3.2.1 – Master Cylinder Schematic (Master Cylinder System)

3.3.3 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 3.3.3.1 shows a brake caliper assembly mounted on a rotor.

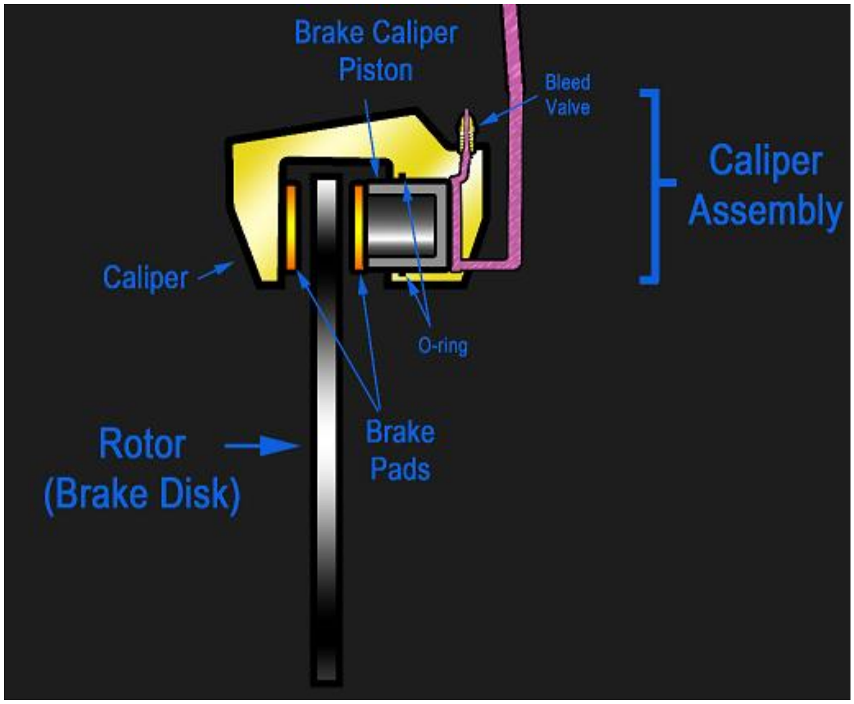


Figure 3.3.3.1 -- Brake Caliper assembly (Hydraulic Brake Diagram)

3.3.4 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 3.3.4.1 is brake rotor with cooling vanes.

Figure 3.3.4.1 -- Rotor with cooling vanes (Brake Rotor)

3.3.5 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 3.3.1 is the decision matrix of the braking system.

Table 3.3.1 – 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

3.4 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, ***Error! Reference source not found.***, 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).

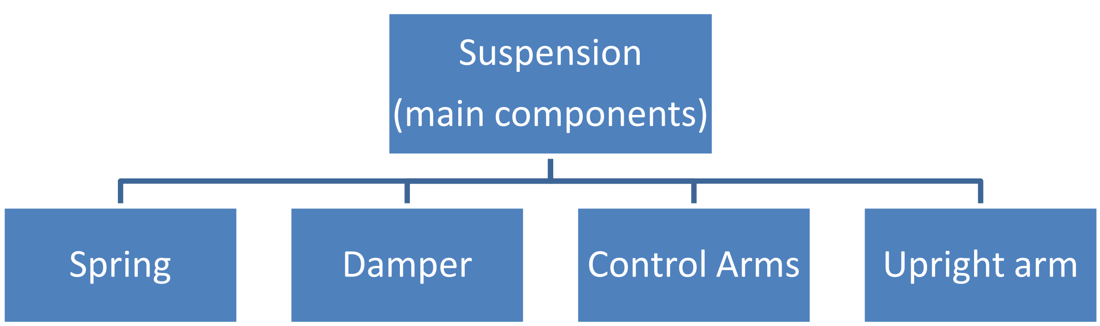


Figure 3.3.5.1 – Suspension Main Components

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 3.3.5.2 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.

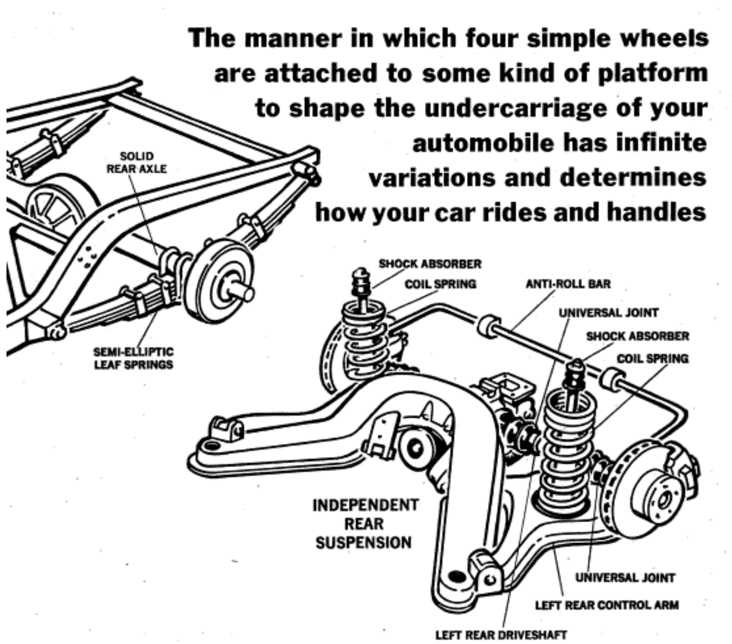


Figure 3.3.5.2 – Non-independent Suspension (Temple, 1969)

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 3.4.1*, can be used to calculate the force exerted by the springs.

Equation 3.4.1

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.

3.4.1 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 3.4.1.1, 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 3.4.1.1 – 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 3.4.1.2, usually ending with positive camber.

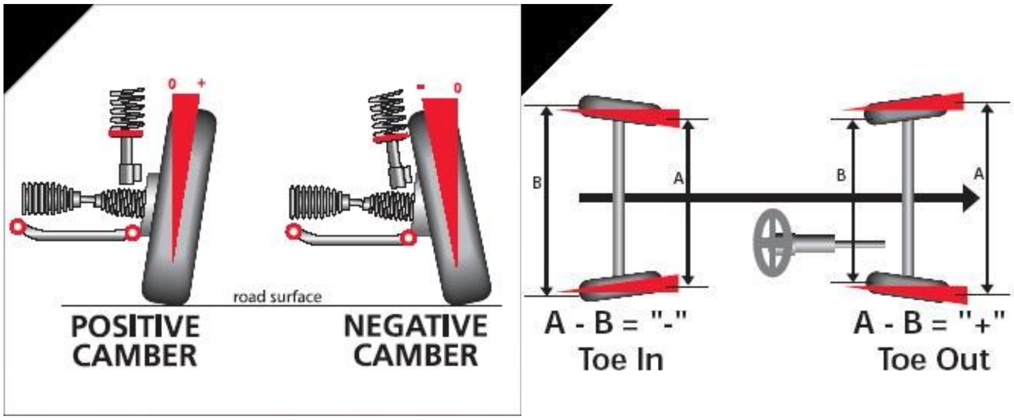


Figure 3.4.1.2 – Camber Angle and Toe Angle (Barrys Tyre & Exhaust Centre, 2010)

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 3.4.1.3, 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 3.4.1.2) 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.

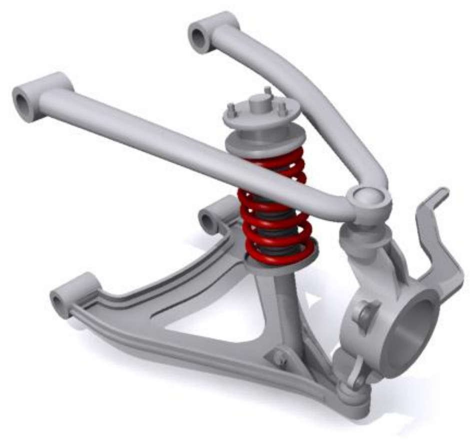


Figure 3.4.1.3 – Double Wishbone Suspension (Longhurst, 2010)

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.

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. The designed control arms have a clearance of twelve (12) inches between each point of contact with the car's frame rib, as shown in Figure 3.4.1.4.

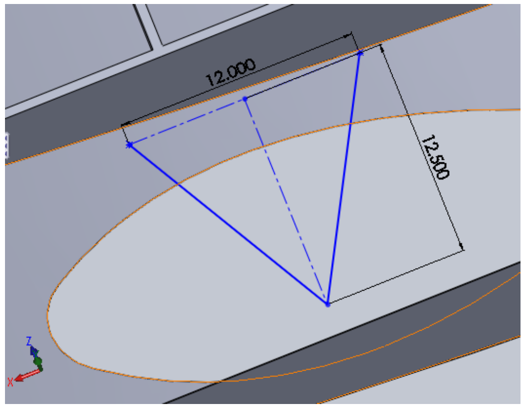


Figure 3.4.1.4 – Front Suspension Linear Sketch in Inches

However, the perpendicular length from the midpoint between both points of contacts to the ball joint linking the control arm to the upright, shown by the dashed line in Figure 3.4.1.4 – Front Suspension Linear Sketch in Inches, differs for both lower and upper control by 0.5 inches. The upper control arms have a length of twelve (12) inches whereas the lower control arms have a length of 12.5 inches. The short/long control arm design was created to keep the position of the contact patch in a straight vertical line under bump and rebound conditions. Also, the arms will not be positioned parallel to one another to prevent excessive tire scrubbing occurring due to large variation in track width as the wheel moves off the neutral position. A drawing of the lower control arm is shown in Figure 3.4.1.5.

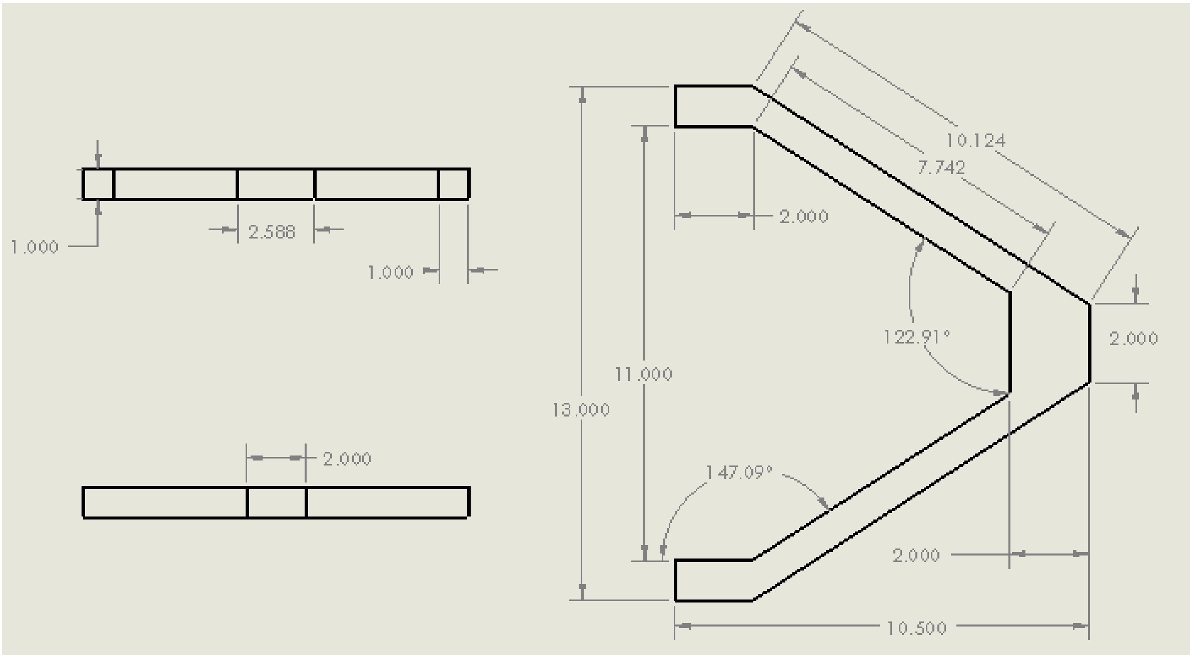


Figure 3.4.1.5 – Lower Control Arm Drawing in Inches

The control arms will be connected to the ribs using heim joints (Figure 3.4.1.6) and to the upright using ball joints.

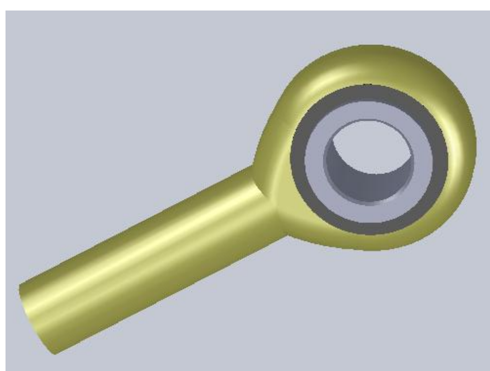


Figure 3.4.1.6 – Heim Joint

Assuming a total car weight of 520 lbs, a desired displacement of two (2) inches, using Hooke's Law (*Equation 3.5.1*), the calculated spring constant for each left and right front shock is .

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°.

3.4.2 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 3.4.2.1, 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.

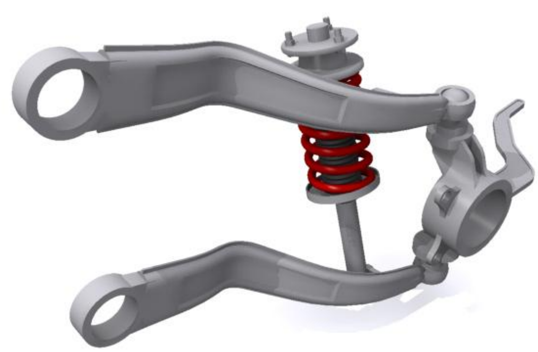


Figure 3.4.2.1 – Trailing Arm Suspension (Longhurst, 2010)

Last year's trailing arm design had the swing arm holding the wheel on one side as shown in Figure 3.4.2.2. 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.

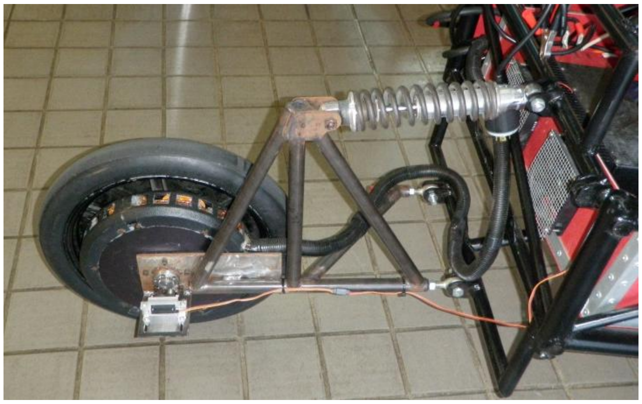


Figure 3.4.2.2 – 2009-2010 Solar Car Trailing Arm Suspension

After the front suspension is fully designed, the rear suspension will be designed. 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 3.4.2.3.

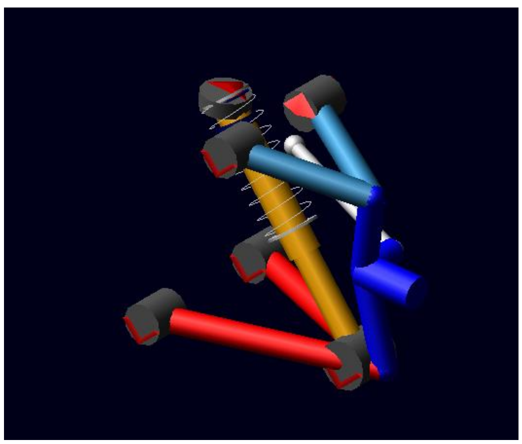


Figure 3.4.2.3 – Double Wishbone Design in MSC ADAMS/Car

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.

3.5 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 3.4.2.1 below displays the overview of the power generation system.

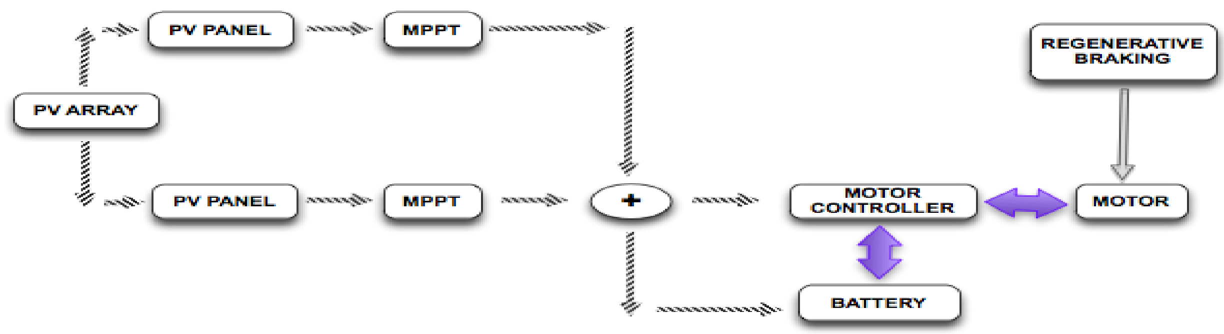


Figure 3.4.2.1 – Overview of Power Generation System

3.5.1 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 3.5.1.1 below displays the functional block diagram of the solar array system.

Figure 3.5.1.1 – Top level 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.

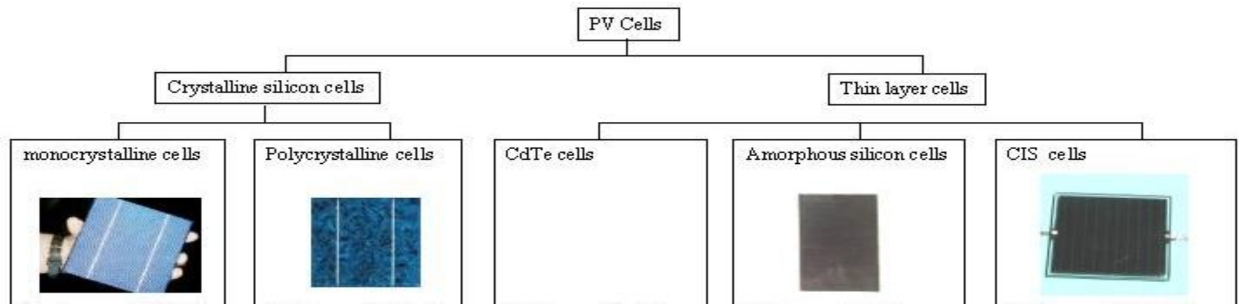


Figure 3.5.1.2 – Types of silicon solar cells

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 3.5.1 : Comparison between single junction and amorphous multi-junction solar cell

Table 3.5.1 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. The following are the factors affecting the performance of any solar cell.

- Insolation = 1000 W/m^2
- Semiconductor (Si, GaAs)
- Temperature
- Position of Sun
- Weather

The insolation or solar irradiance level in Tallahassee fluctuates between 600 W/m^2 to 800 W/m^2; 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 (V_{oc}), short-circuit current (I_{sc}), and efficiency. Voc and I_{sc} 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 3.5.1.3 below. The current from the solar cell is at best equal to the short-circuit current.

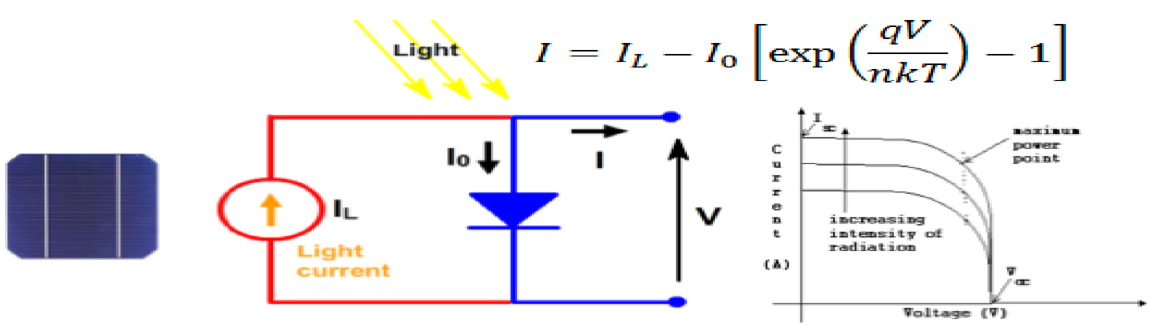


Figure 3.5.1.3 : A solar cell

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 3.5.1.4 below displays the modular structure of solar array system.

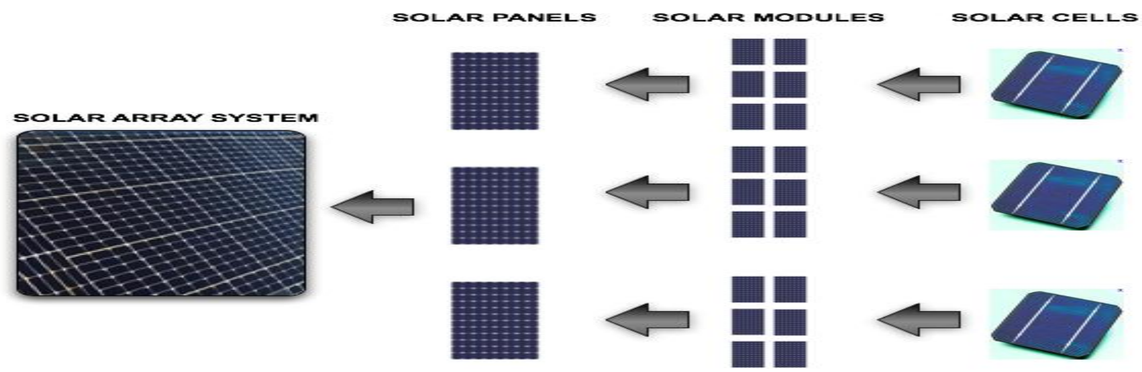


Figure 3.5.1.4: General structure of a solar array system

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.

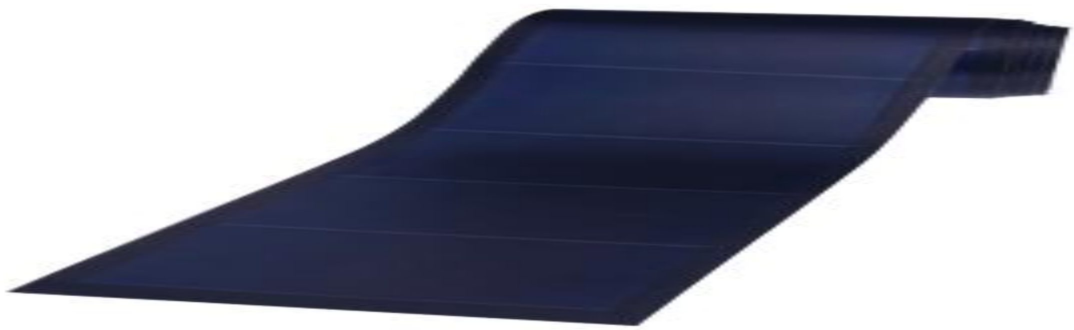
The preliminary design calculations were based on single junction multi-crystalline silicon solar cells. This assumption was made because of its commercial abundance and low price. Table 3.5.2 below depicts a datasheet from a solar cell supplier.

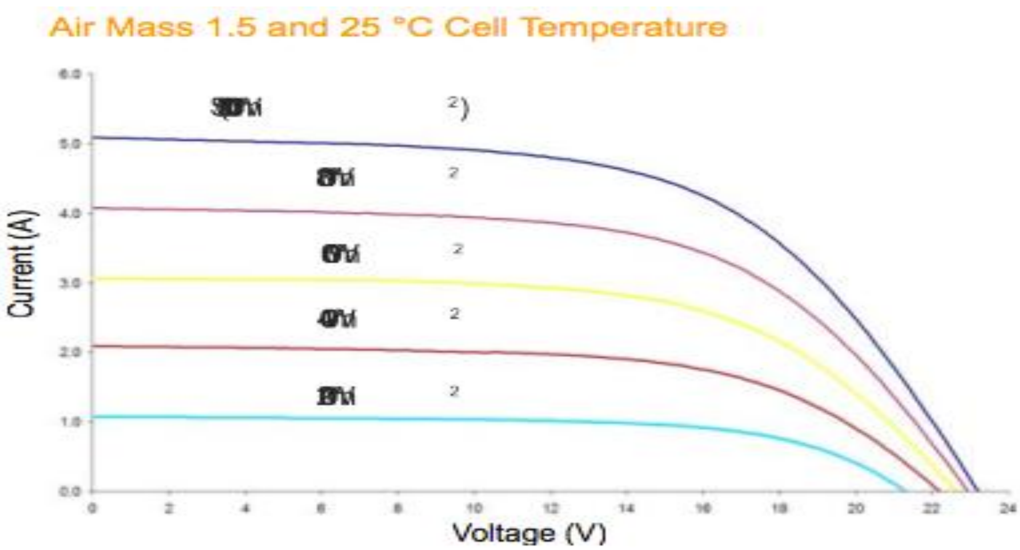
Product ID	**SPI-C156-365M2**	**SPI-C156-359M2**	**SPI-C156-353M2**	**SPI-C156-347M2**
Efficiency (%)	15.24--15.00	14.99--14.75	14.74--14.50	14.49--14.25
Power (W_P)	3.71--3.65	3.64--3.59	3.58--3.53	3.52--3.47
Max Power Current (typ)	7.19	7.11	7.03	6.95
Max Power Current (min)	6.92	6.84	6.76	6.69
Max 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 3.5.2 : Datasheet of various single junction multi-crystalline solar cells

Table 3.5.2 displays the differences in efficiency, power, I_{sc}, and V_{oc} 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.

Due to monetary constraints, the purchase, design, and completion of the solar array system cannot be completed during this phase. As such, with the money allocated, the team has opted to purchase several modules of triple junction amorphous thin film flexible solar cells from Unisolar. It is a 68 W module termed PVL-68. Our preliminary cost analysis limits us to a maximum of 2 such solar modules. The datasheet of the 68 W is presented in **Error! Reference source not found.** below.





Electrical Specifications

STC

(Standard Test Conditions)

(1000 W/m², AM 1.5, 25 °C Cell Temperature)

Maximum Power (P_{max}): 68 W
Voltage at Pmax (V_{mp}): 16.5 V
Current at Pmax (I_{mp}): 4.13 A
Short-circuit Current (I_{sc}): 5.1 A
Open-circuit Voltage (V_{oc}): 23.1 V
Maximum Series Fuse Rating: 8 A

NOCT

(Nominal Operating Cell Temperature)

(800 W/m², AM 1.5, 1 m/sec. wind)

Maximum Power (P_{max}): 53 W
Voltage at Pmax (V_{mp}): 15.4 V
Current at Pmax (I_{mp}): 3.42 A
Short-circuit Current (I_{sc}): 4.1 A
Open-circuit Voltage (V_{oc}): 21.1 V
NOCT: 46 °C

Figure 3.5.1.5 – Datasheet of PVL-68; a 68W solar module from Unisolar (9.4 ft * 1.3 ft)

The design of our solar panel is based on PVL-68 with an average I_{sc} (A) of 5.1 and an average V_{oc} (V) of 23.1, thus an average of 118 Watt of maximum theoretical power per unit module. We are limited to an area of 6 sq. meters for the solar array. This corresponds to around 5 modules for the whole car. Each cells in the solar module has a built in bypass diode circuitry configuration. Our battery system has a minimum of 72 V, maximum of 126 V, and nominal of 100 V. With 5 PVl-68 modules in series, we get a V_{oc} (V) around 116, Isc (A) of around 5.1, and maximum theoretical power of 340 W. of about want each panel to have a minimum Voc of 150 V (20% more than maximum battery bank voltage). The manufacturer's datasheet also displays the performance of the PVl-68 module at its nominal operating cell temperature. Drivetek MPPT has variable input and output voltage ranges but is restricted to a minimum of 9 A input current; the current from the solar module will not exceed the MPPT current restriction. The battery voltage and solar array components pertaining to the final design have been briefly summarized below. The power, voltage, and current data refer to standard test conditions, and are derived from the manufacturer's datasheet. The computations and Figure 3.5.1.6 below displays the power calculation and the overall solar array system schematic.

PVl-68 solar module:

V_{oc} (V) = 23.1 V

I_{sc} (A) = 5.1 A

V_{max} (V) = 16.5 V

I_{max} (A) = 5.1 A

P_{max}(W) = 68 W

Battery :

30 cells in series

V_{min} (V) = 72 V

V_{max} (V) = 126 V

$V_{nominal}$ (V) = 100 V

Solar Array:

5 PVl-68 solar modules in series

V_{oc}(V) = 115.5 V

I_{sc}(A) = 5.1 A

$P_{theoretical}$ = 580 W

V_{max} (V) = 82.5 V

I_{max} (A) = 4.13 A

Array_Power(W) = 340 W

8 A series fuse

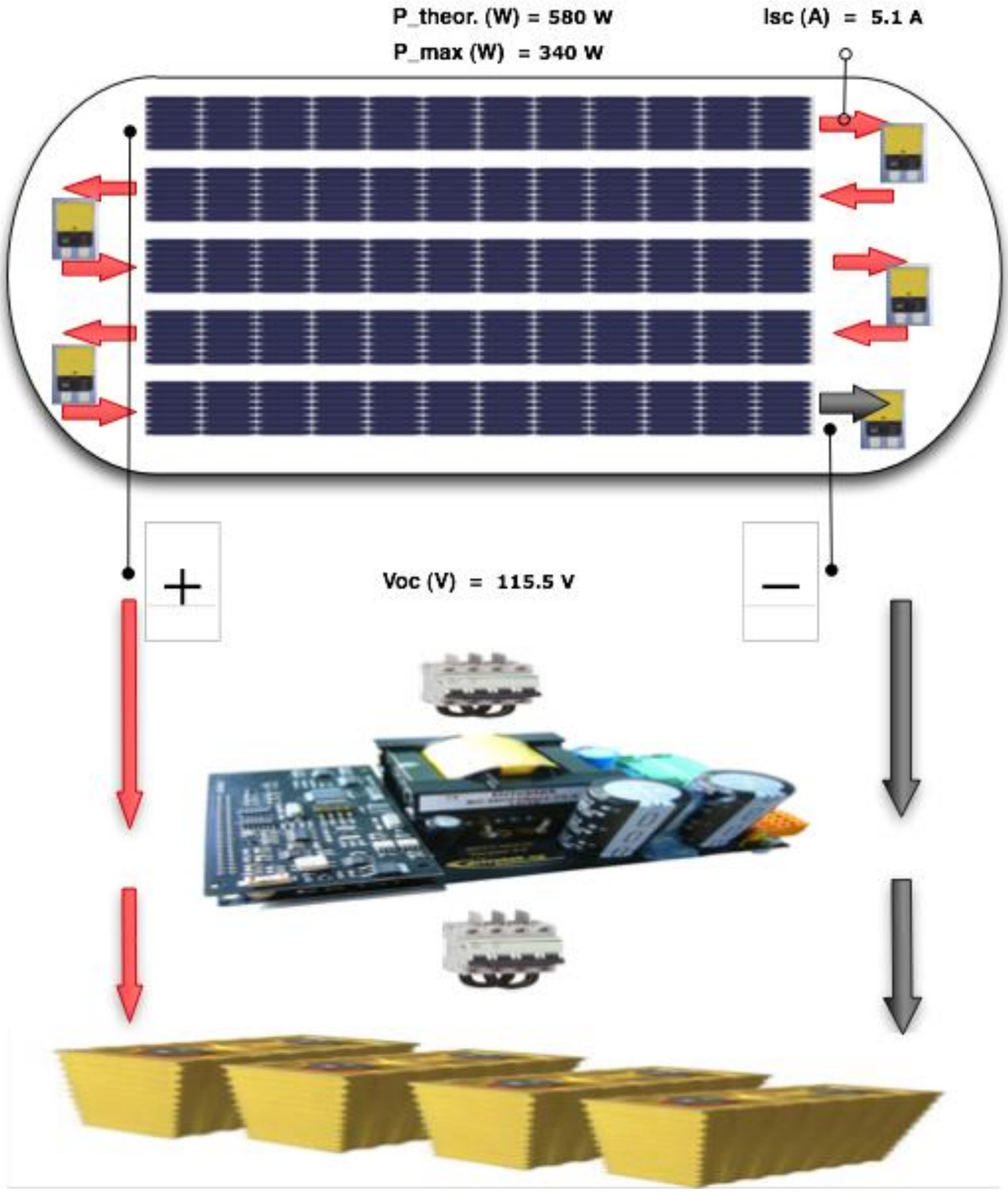


Figure 3.5.1.6: Design of solar array system

3.5.2 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 below depicts the block diagram of an MPPT along with a picture of Drivetek AG MPPT; then follows with a table comparing the previously mentioned two different types of MPPT suitable for high voltage solar car application.

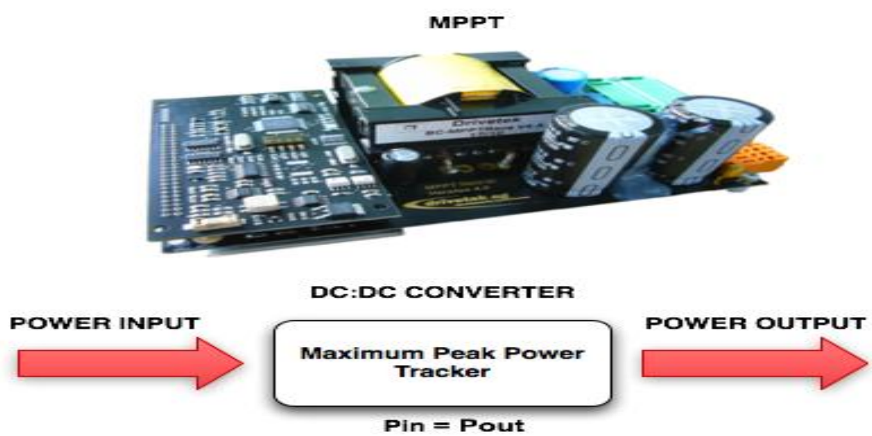


Figure 3.5.1.7 : Maximum Peak Power Tracker

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	

Table 3.5.3: Comparison between Drivetek RACE and AERL 600 B MPPT

Figure 3.5.1.7 and Table 3.5.3 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 3.5.1.8 below depicts a component diagram of this system. It is followed by Figure 3.5.1.9 which displays a top level shunt type interconnection schematic for the charge controller and the MPPT.

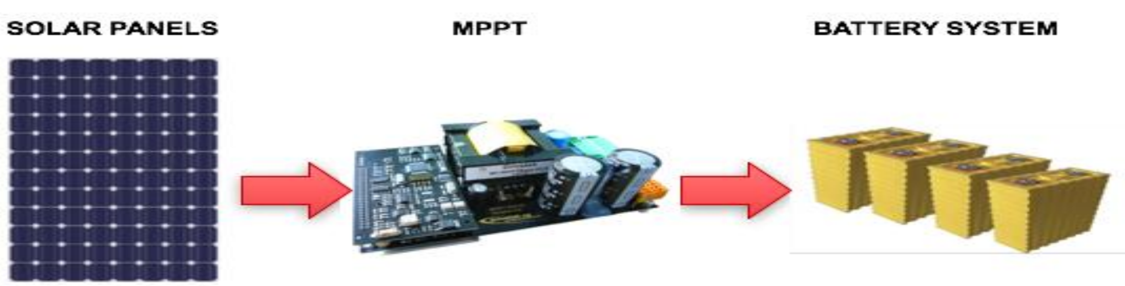


Figure 3.5.1.8: Component diagram of MPPT with solar panel and battery system

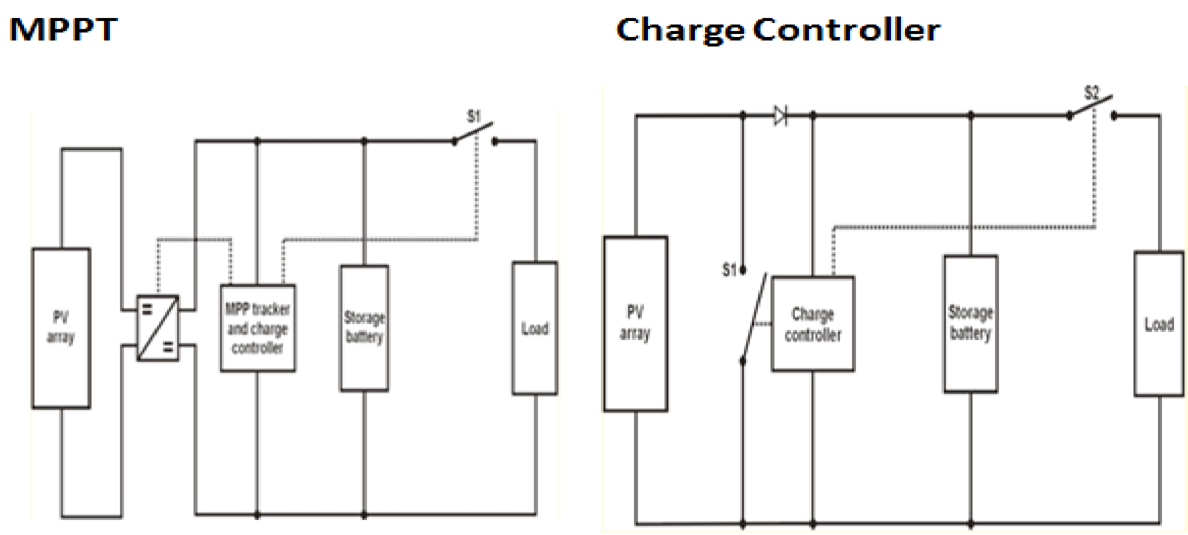


Figure 3.5.1.9: MPPT and charge controller top level component integration

3.5.3 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 or on the side of the driver; the regenerative braking system will be asserted when the driver pulls the handle towards him/her-self. Our "handle-type" design will be interconnected to a microcontroller. The microcontroller will process the analog regenerative signal and convey digital regenerative signal to the motor controller. The motor controller, upon receiving the signal from the microcontroller will enable the regenerative braking action in the motor; this will result in storage of charge in the battery system. Table 3.5.4 displays the preliminary versus final design options for regenerative braking system under consideration. It is followed by Figure 3.5.1.10 which 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.

Table 3.5.4: Preliminary versus final option for implementing 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

The final chosen option was the "Handle-type" regenerative braking system. This system is easy to implement, it is independent to the frictional brake, and the signal is processed by a microcontroller.

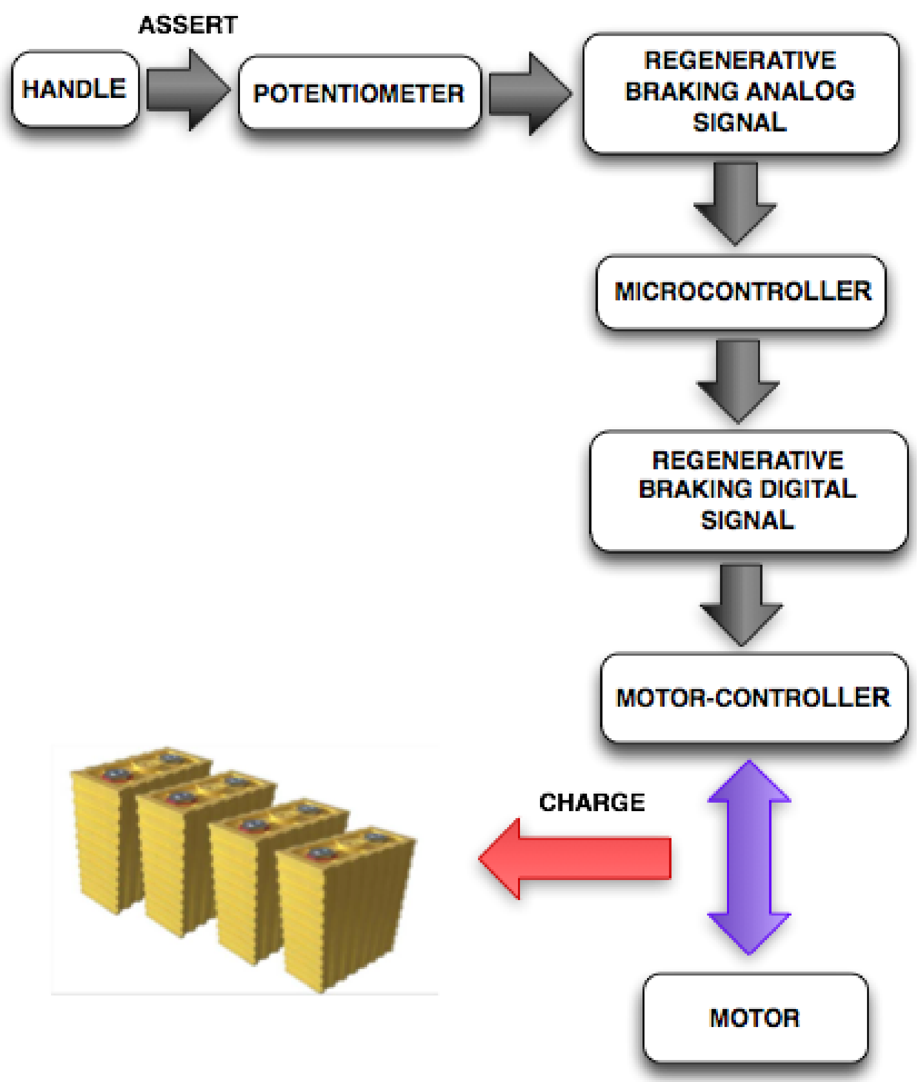


Figure 3.5.1.10: Regenerative braking system

3.6 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 3.5.1.1 shows the dashboard from the previous year's design.

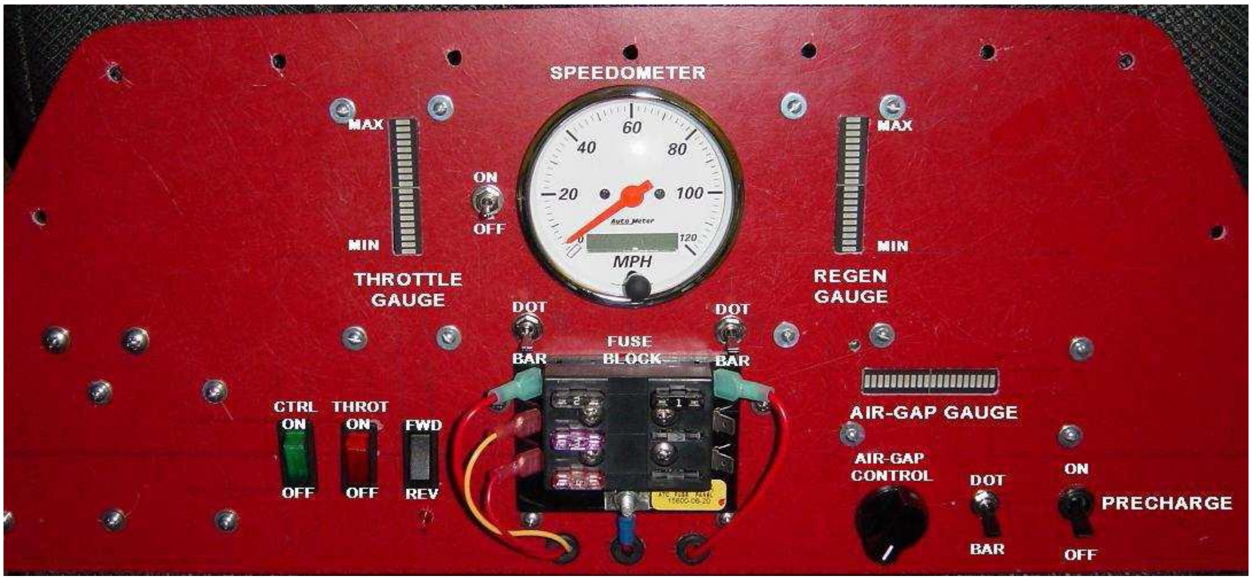


Figure 3.5.1.1 – Phase I Dashboard

3.6.1 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 3.6.1.1. 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.

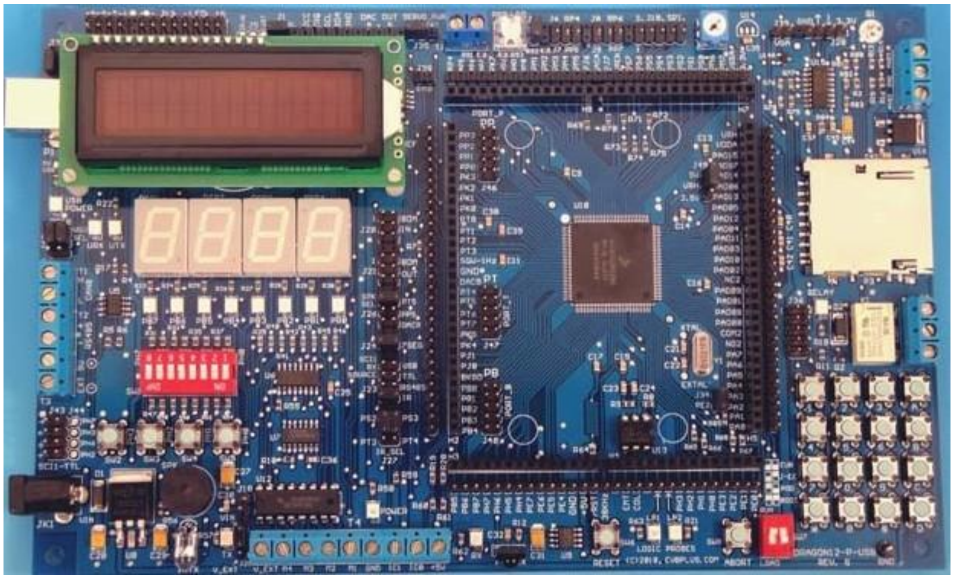


Figure 3.6.1.1 – Wytec Dragon12 Plus-USB

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.

3.6.2 Lights/Horn

The vehicle needs to be equipped with at least six lights, two front 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 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 electronic flashers will be used to control the turn indicator lights.

3.6.3 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 3.6.3.1 shows an example of a discrete control configuration for a motor controller.

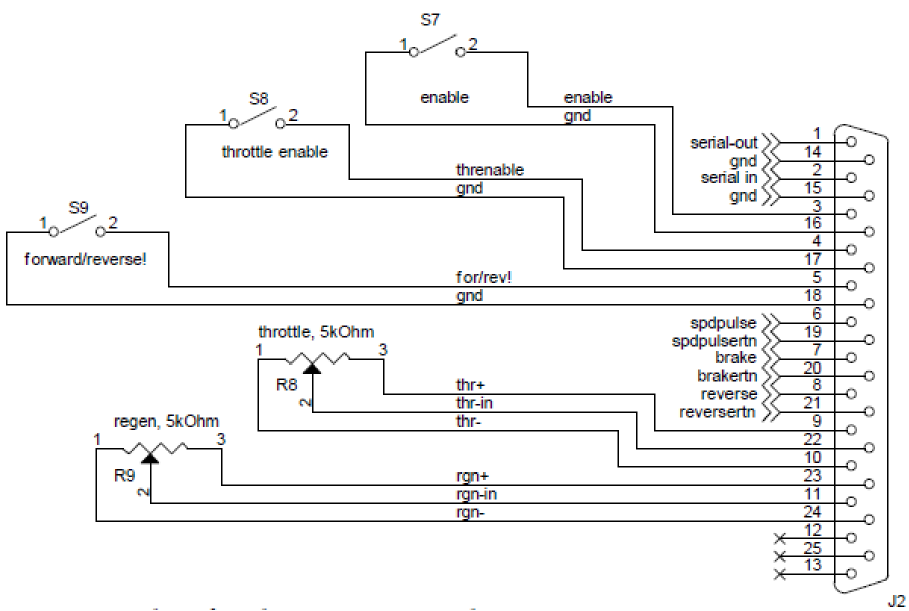


Figure 3.6.3.1 – Motor controller discrete control configuration

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.

3.6.4 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 3.6.4.1 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 3.6.4.1 – 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 3.6.4.2 shows the diagram for the main power system supplying power to the dashboard seen in the diagram in Figure 3.6.4.3.

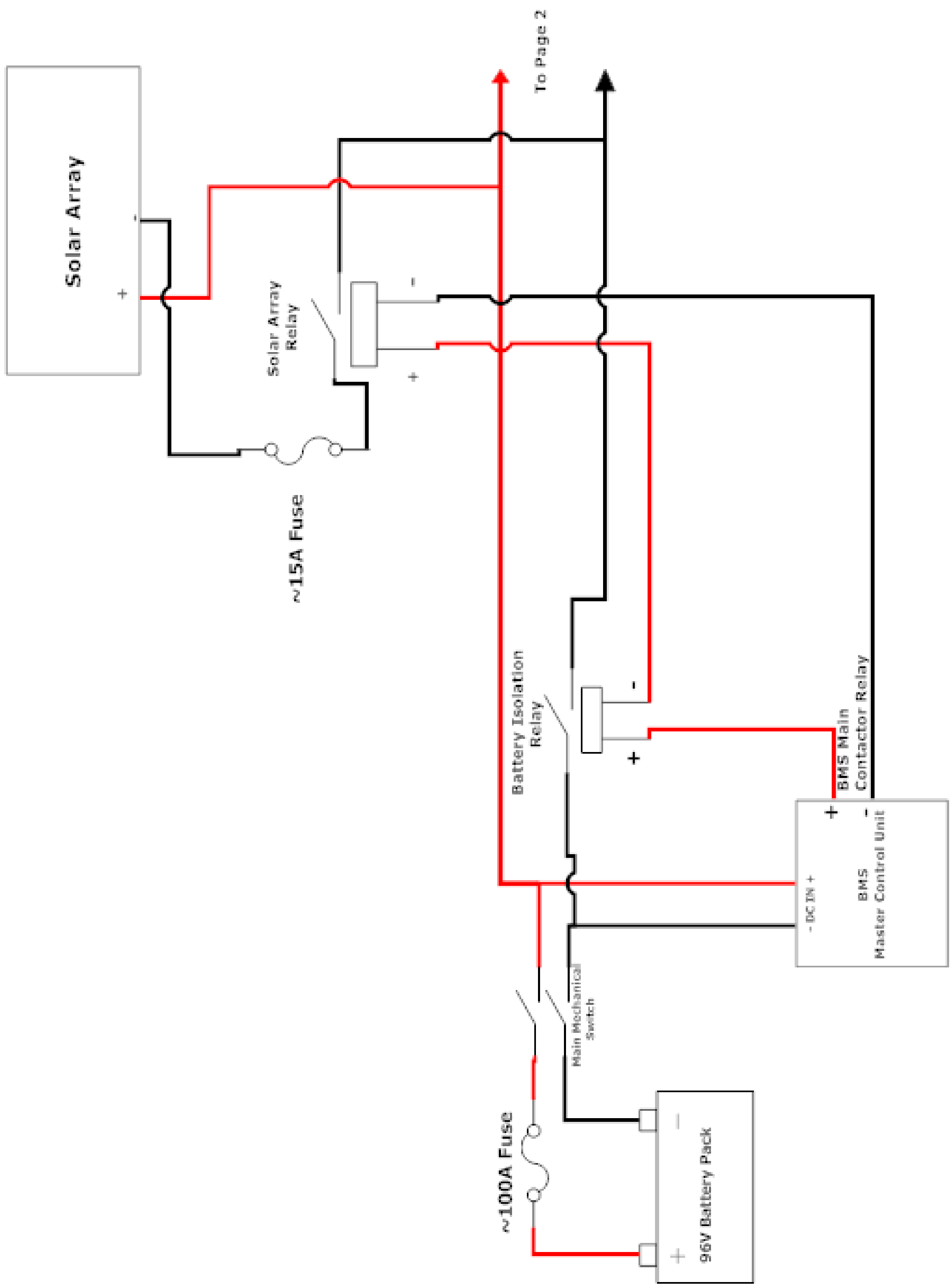


Figure 3.6.4.2 – Main power system design

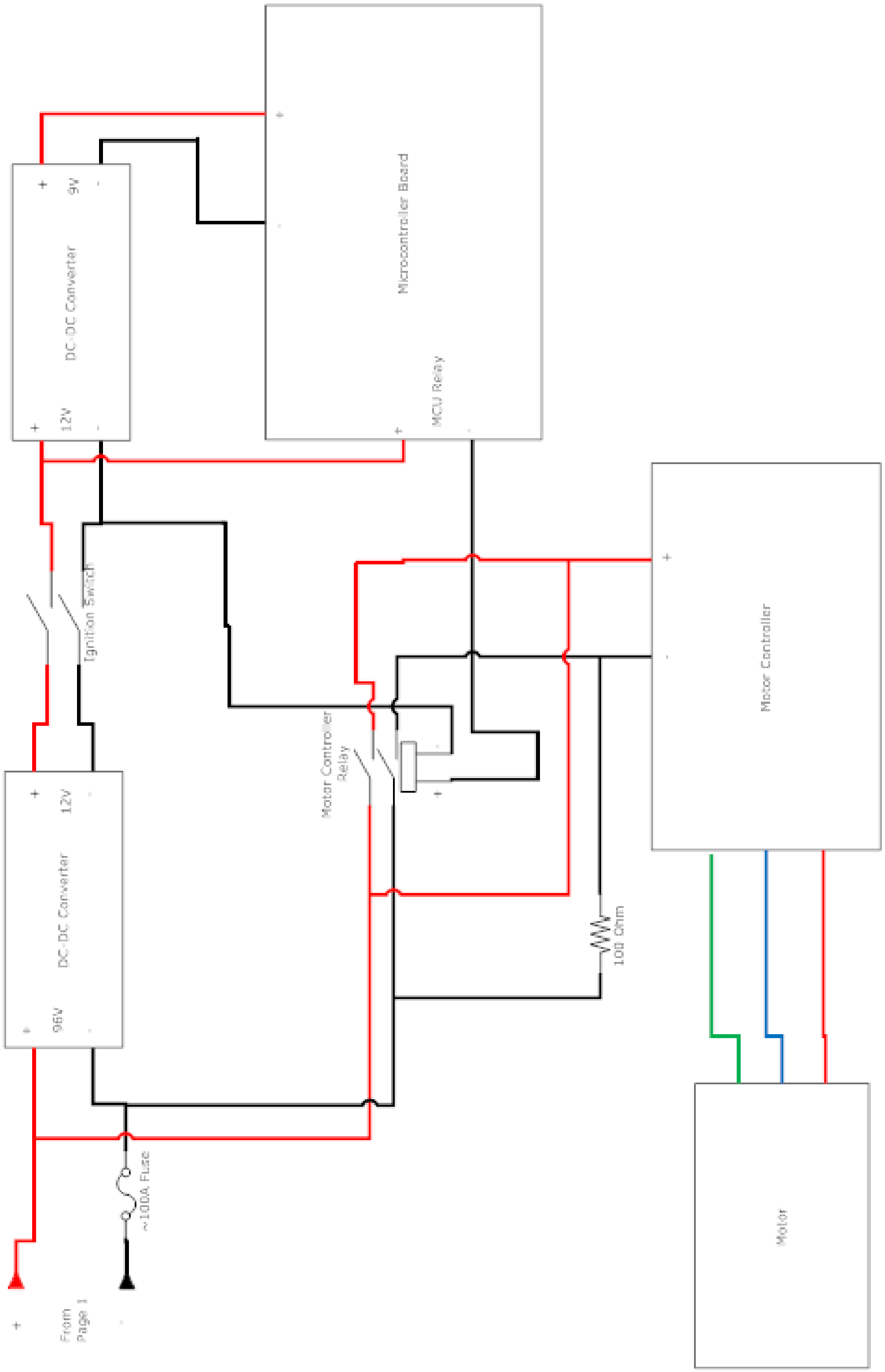


Figure 3.6.4.3 – Dashboard power system design

The new dashboard will look similar to Figure 3.6.4.4. 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.

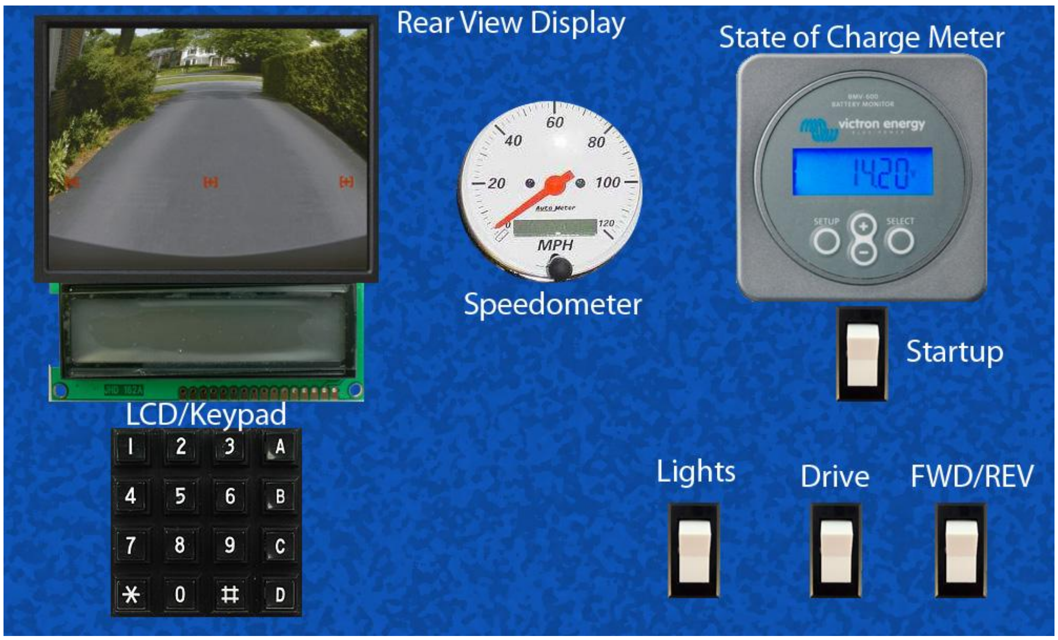


Figure 3.6.4.4 – New Dashboard Design

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.

3.7 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 3.6.4.1 shows the layout of the management system, the green blocks have already been completed in the previous phase.

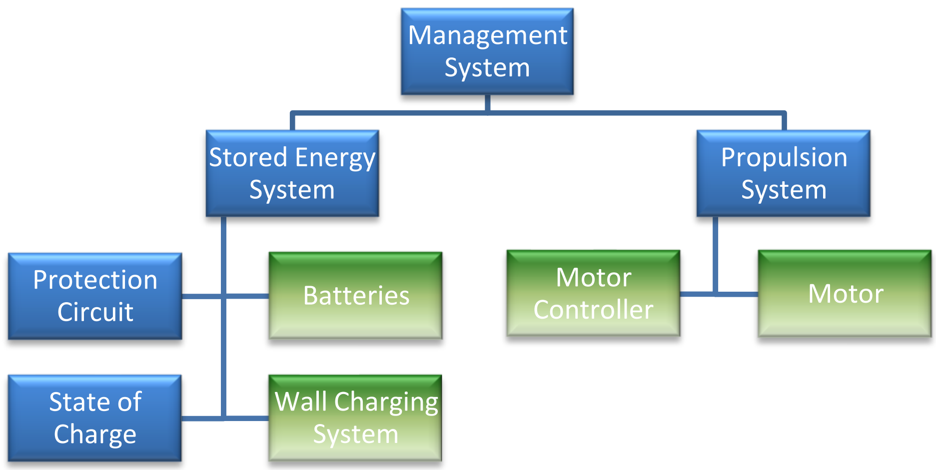


Figure 3.6.4.1 – Management Power System block diagram

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 3.6.4.2 shows the discharge cycle of the Thundersky batteries.

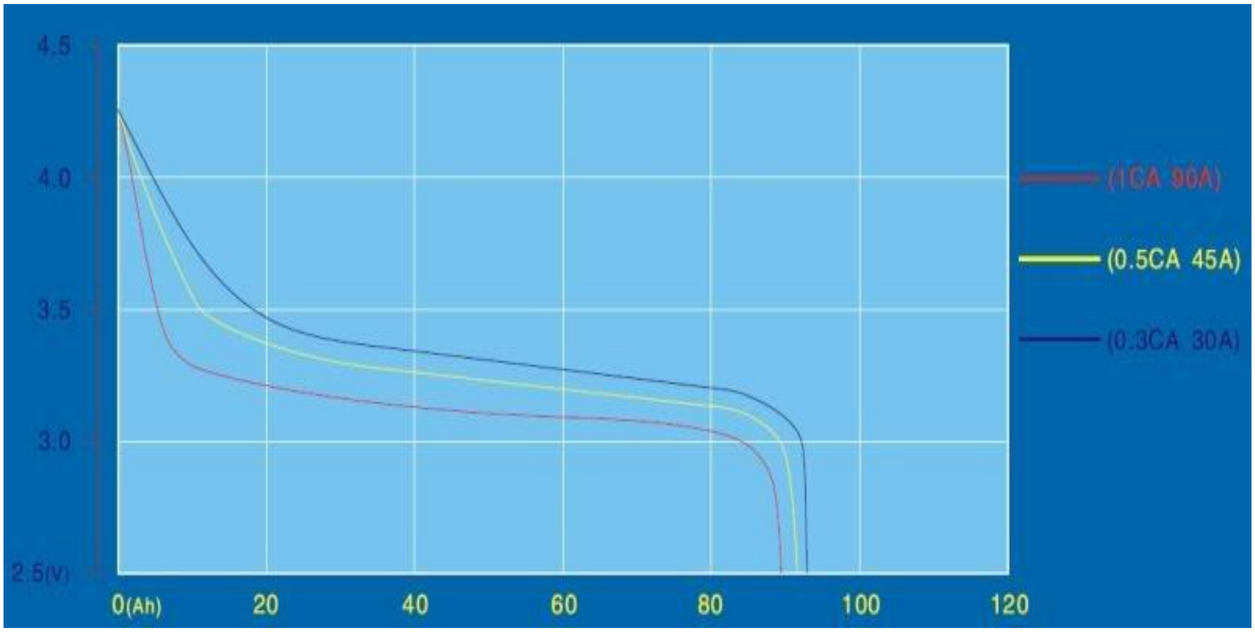


Figure 3.6.4.2 – Graph of Thundersky battery discharge cycle (Endless-Sphere)

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 3.7.1.

Table 3.7.1 – 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. The voltage will also be measured through a voltmeter device connected to a state of charge device which can be seen in Figure 3.6.4.3.

Figure 3.6.4.3 -- TBS Electronics E-Xpert Pro (Evolve Electrics: TBS Electronics E-Xpert Pro)

To measure the current out of the batteries a shunt line will be used. A shunt line will be a connection across the wires from the batteries and will be capable of measuring the current in those wires. This information will be delivered to the state of charge device in the dashboard so that it can be displayed. The information will also be delivered to the microcontroller, interpreted, and then delivered to the BMS. This way if for some reason the current exceeds the value rated for the batteries (120 A) then the BMS can perform he shut down sequence as before.

Originally a thermistor was going to be implemented in order to provide the temperature control for the batteries. The inherent problem with using the thermistor was the difficulty in determining the exact temperature because most thermistors operate similar to a switch, in that once the cutoff temperature is reached the resistance rises drastically. Since the temperature was some of the information that would certainly be helpful for the driver to know the state of charge device again will be implemented to provide this information to the dashboard display as well as to the microcontroller for processing.

Since the state of charge device will be capable of measuring the voltage level of the batteries and the current coming out it will be capable of giving an estimated fuel gauge for the batteries. This information is highly desirable for any vehicle, imagine driving to drive a car without knowing how much gas is left in the tank. Utilizing this information will also allow the driver to notice power trending, such as how much power is used during accelerating or at certain speeds. This information can be used by the driver to get the most mileage out of the car, by choosing to drive at speeds where the current flow is at its lowest. It is unclear whether the state of charge system will recognize power being placed back into the batteries through the power generation systems. Ideally it would read a negative current value and make corresponding corrections to the fuel gauge. This information will have to be determined through testing after the part has arrived.

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 Test Plan

A test plan document was created by the members of the previous phase as seen in Figure 3.6.4.1. In order to keep consistency this phase of the project will also implement the same test plan document. This template displays all the pertinent information about each test, including what is being tested, the goals of the tests, and final results. A well organized system for testing will yield a more successful product in the end.

Scheduled Test Reporting Form – Solar Car Team '09

TEST ITEM (TITLE):

TEST CASE #: (ex: BS-001) TEST DATE/TIME: (ex: 01/01/10 – 11:30 AM)

TEST CASE DESCRIPTION: TEST TYPE: ☐ TEST ☐ RE-TEST

include Objective and Requirement(s)

EXPECTED RESULTS:

ACTUAL RESULTS:

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

Figure 3.6.4.1 -- Blank Test Plan Format

4.1 System and Integration Test Plan

4.1.1 Mechanical Part Integration

For streamline integration, it is imperative for part to be assembled and tested before implementation into the vehicle. Testing of all parts will be performed for fit, strength and proper performance. Each test plan will be conducted using proper documentation as per requirements. Some parts may require construction to be tested; notes will be made with an estimated test date.

4.1.2 Electrical Part Integration

The electrical system integration will begin with the testing of the main power system, ensuring that all of the components are thoroughly tested for correct wiring and are receiving power. The System will then be configured to operate the motor in discrete mode to verify the functionality of the motor and motor controller. After the motor has been fully tested, the motor controller will be integrated with the MCU and retested using the serial mode controls.

4.2 Test Plan for Major Components

4.2.1 Body

To ensure strength in the carbon fiber material, a tensile test will be performed on a strip of test material. The test will be conducted using a one inch strip of the 12K carbon fiber material pregnated with the polyester blend of resin to be used on the bottom portion of the body. Again, to ensure proper strength, another tensile test will be done on the 3K carbon fiber material with the same polyester blend resin for the top half of the body.

4.2.2 Steering

For the steering system, the rack and pinion gear needs to be tested. The rack and pinion will be transferred from the previous year's car and be re-implemented into the new car design. Once installed there are various components of the system that must be checked.

Figure 4.2.2.1 – Tie Rod

The location of the rack and pinion will be positioned behind the suspension so the tie rods need to be checked to ensure they reach the steering arms on the wheel. If they do not reach the tie rods can be adjusted so they will reach the wheel.

The new geometry of the steering system may affect the steering capabilities of the rack and pinion gear. Once the gear has been installed, the vehicle must perform several maneuverability tests in order to compete in the race. The car must be able to make a U-turn in either direction, without backing up such that all wheels remain within a 16 m wide lane.

The rack and pinion gear must be tested to ensure that the gears mesh well with each other. The gear must translate the rotational motion of the steering column into linear motion of the rack. The rack and pinion must also be able to push the tie rods effectively to ensure proper steering.

Figure 4.2.2.2 – Rack and Pinion Gear

4.2.3 Braking

Several braking components are to be purchased from Wilwood Engineering. The parts include two brake calipers, two master cylinders, and a parking brake. Each of these components must be tested to ensure that they all integrate into an efficient braking system.

Two master cylinders are to be purchased from Wilwood Engineering. Once the Master Cylinders have been obtained they must be tested to ensure they provide adequate fluid pressure to each caliper assembly. Figure 4.2.3.1 shows the master cylinders to be purchased.

Figure 4.2.3.1 -- Wilwood Master Cylinder

Once installed, the master cylinder must be tested to ensure it can apply hydraulic pressure to the brake calipers. To test this, pressure will be applied to the brake pedal to force fluid through the brake lines. This also tests the integrity of the brake lines. Any leaks in the lines will be found by applying pressure to the pedal. If there is a leak in the line, the brake line must be adjusted or changed in order to keep hydraulic pressure.

Two brake calipers are to be purchased from Wilwood Engineering. These calipers are shown in Figure 4.2.3.2. Once the obtained the calipers must be tested to ensure they can effectively push the caliper piston. When hydraulic fluid is pumped to the caliper, the piston must move towards the brake rotor to stop the vehicle. Once pressure is released from the caliper, the piston must retract smoothly away from the rotor.

Figure 4.2.3.2 -- Wilwood brake calipers

The brake rotor will be fabricated at the machine shop. This custom rotor must be tested to ensure it effectively be used to stop the car as friction is applied to it. As friction is applied to the brake rotor, heat is generated throughout the component. The rotor must be tested to ensure it can dissipate heat effectively. If heat is not dissipated from the rotor, rotor failure is imminent. To prevent this, the heat transfer capabilities of the rotor will be tested by using finite element analysis. Figure 4.2.3.3 shows a brake rotor undergoing finite element analysis.

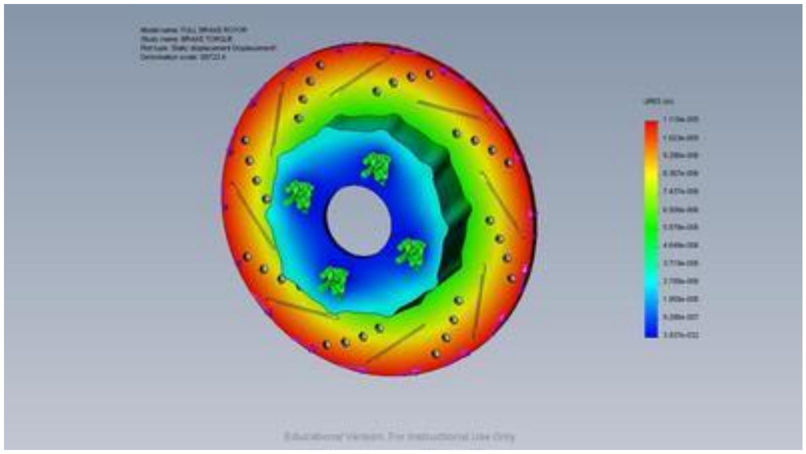


Figure 4.2.3.3 -- FEA on brake rotor

4.2.4 Suspension

Tests will be performed on the suspension's components and as a whole system to ensure desired and efficient performance.

4.2.4.1 Components

Finite element analysis will be performed on each of the suspension's components to observe the stress points and their deflections under the transferred forces it will experience from the wheel under bump and rebound conditions. This testing will also check for part failures by performing analysis at various nodes of the virtual mesh. The components to be tested include: mounting brackets, heim joints, control arms, and upright arms for both front and rear suspension systems. Refer to Test Plan Appendix section. Figure 4.2.4.1 shows an example of finite element analysis on a double wishbone suspension.

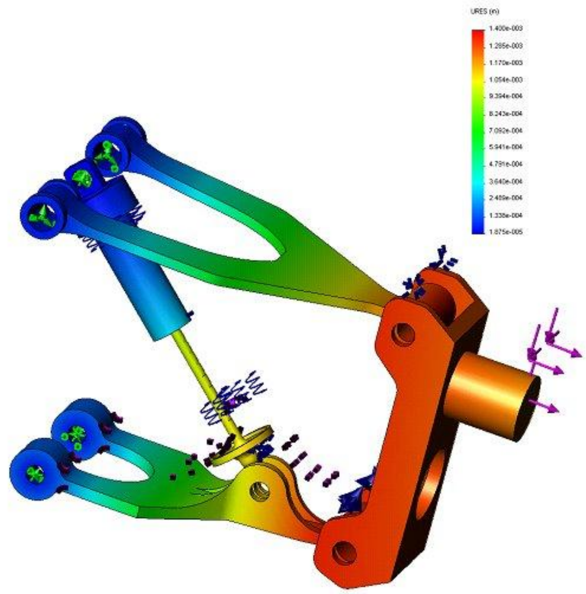


Figure 4.2.4.1 – Double Wishbone Suspension Finite Element Analysis

4.2.4.2 Suspension System Virtual Simulation

The assembled suspension system will be analyzed and simulated in MSC ADAMS/Car. These simulations will provide us with the data needed to observe the suspension's behavior and adjust the dimensions to achieve the desired results. Opposite, parallel, and single wheel travel, and steering simulations will be performed to observe the behavior of the designed suspension. The results obtained by these simulations include camber angle change, toe angle, as well as static loads and forces acting on the system. This test will be done independently from the front and rear suspension systems then as a whole.

4.2.5 Power Generation Test Plan

The test plans for power generation system consists of testing the solar array system, MPPT, and the regenerative braking. The solar array system will be tested for proper configuration (series and\or parallel); it will also be tested for manufacture rated open-circuit voltage and short-circuit current. The efficiency of the solar cell and insolation level of Tallahassee will be taken into account when measure these parameters. The MPPT is basically a DC: DC converter; so it will be tested for input and output voltages. The current coming from the MPPT into the battery shall be tested and measured using the state of charge device. The regenerative braking system will be tested to ensure the brake is applied when the system is asserted; it will also be tested to ensure if charge is being supplied to the battery system when the regenerative brake is asserted. Most of the testing will be performed using a digital multi-meter; care should be taken to ensure proper settings in the multi-meter before measurement.

4.2.6 Control Systems

Some of the major components were tested in the previous phase but will need to be retested upon integration into the new system. The MCU will need to be thoroughly tested in order to verify that all of the MCU software is functioning properly. Most of the MCU tests will be performed using simulations.

The Dashboard system components will need to be tested prior to integration. The speedometer and state of charge meter can be tested for functionality, but further tests will need to be performed after electrical system integration. The discrete electrical components will be tested using switches.

The serial functionality of the motor controller and the MCU will be tested using a serial terminal program on a PC before integration. After the MCU and motor controller functionality have been verified, a simple test program will need to be implemented to test the integration functionality.

4.2.7 Management System

There are only two new subsystems which will be added to the overall management system and these systems will have to be tested thoroughly during the integration phase. It will also be necessary to test the old subsystems as well before any integration. These tests will be necessary to verify that no damage occurred to the system during the summer and also to verify the systems were tested correctly in the first place. For this reason testing of the management system began with the battery and propulsion subsystems.

The batteries when first examined were tested for charge. The anticipated charge for a battery was 3.3 V and each of the batteries was tested using a volt meter. Out of the thirty batteries only one of the batteries was below this value. To correct this problem that battery was hooked up to an iCharger that allows the charge of an individual battery instead of charging all the batteries in series. The battery was again tested after using the iCharger and was verified to be able to hold a charge. The other important subsystem that was tested involving the batteries was the wall charging system. This subsystem was tested as a whole due to the thoroughly with which the first phase of the project tested this subsystem. The batteries were able to be charged successfully using the wall charging unit.

The propulsion system was rather simple to test. After the batteries were tested and reinstalled in the car the propulsion test began. It consisted of getting the car started and hitting the accelerator. This however did encompass a preliminary test of the existing dashboard systems as well. The car did run properly on the battery power once it was turned on responding to all the existing controls, which includes the steering and braking systems. The motor controller uses a D25 cable for all its input and output. While the input into the motor controller works properly because the car has motion, it was noted that some of the output were not working properly. The signal that send information about the speed of the car, which in turn was supposed to be used by the speedometer on the dashboard, was not working properly. By reading information about the motor controller all of the output signals should range between 0 V and 5 V, but using a multimeter the largest potential that was seen was around 2.4 V. To attempt to discover the source of this error there will be piecewise testing that will occur to test every device that interacts with this signal. This will include testing the D25 cable, breakout board, and speedometer itself. If it is determined that the source of the error is just a weak signal then it may be possible to boost the signal through an amplifying circuit.

The subsystems that will be added during this phase can be tested more rigorously during the different stages of development. The state of charge system is comprised of several smaller components and each of these components will have to be tested before integration. Testing the state of charge system's ability to measure potential will be simple because the information can be verified with any multimeter device without causing any damage to the system. Verifying a current measurement may require setting up a simple circuit by which to perform the tests, because generic measurement devices such as multimeters, are not designed to measure currents as high as 80 A. The final test will be the temperature sensor device on the state of charge device. Since the temperature sensor works on the ambient temperature around it, it can simply be tested by hooking it up and verifying that it is reading room temperature. It will need to be further verified at higher temperatures using a thermometer as gauge to measure accuracy.

Once the state of charge systems are all correctly working then the integration with the rest of the system will have to be tested. This will include sending information to the microcontroller, such as the current use and temperature. This information will be important is needed by the microcontroller as a means of battery protection. The microcontroller will take this information and communicate it to the BMS, which will ensure that the batteries are always operating in the designated safe ranges. A small program will be written to display the information obtained from the state of charge system on the development board's LCD screen. Then this information will be compared with the information on the display of the state of charge system. Once it is verified that the information is correctly communicated and with little delay it can be fully integrated into the system.

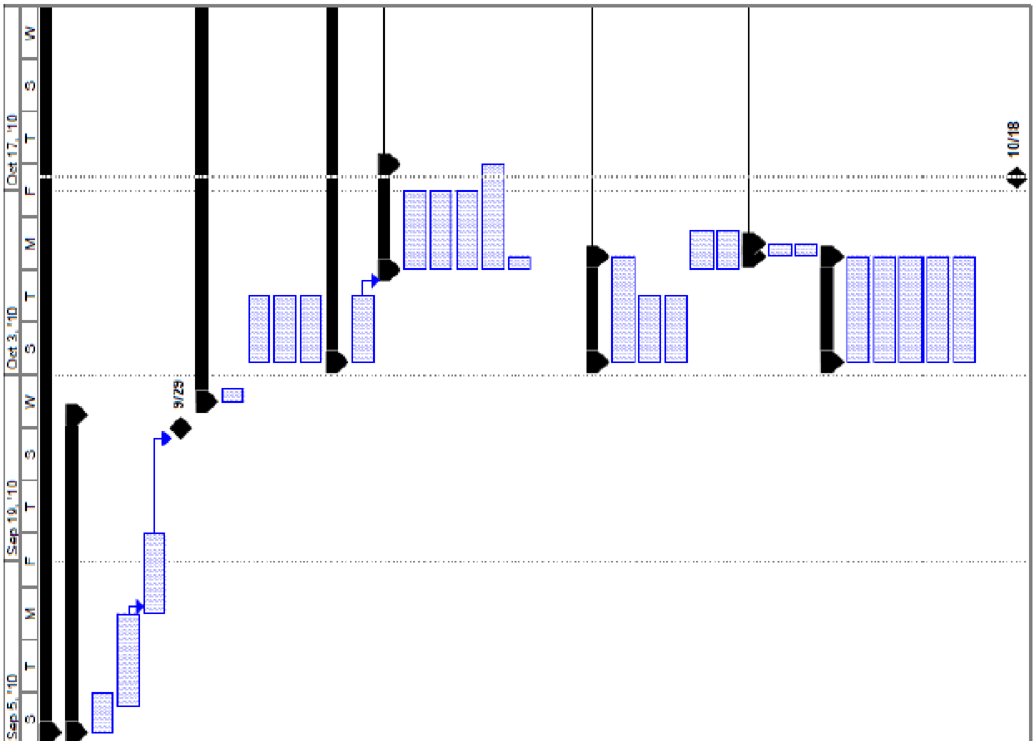
4.3 Summary of Test Plan

The following table shows a summary of the tests to be performed on the different components and systems of the car.

Test	Test Case #	Result
Carbon fiber tensile test	BD-001	TBD
Rack and pinion steering test	SS-001	TBD
Brake rotor	BS-001	TBD
Master cylinder	BS-002	TBD
Brake line	BS-003	TBD
Brake Caliper	BS-004	TBD
Hiem joint	SP-001	TBD
Control arm structure	SP-002	TBD
Mounting Brackets	SP-003	TBD
Upright arm	SP-004	TBD
Front Suspension	SP-005	TBD
Rear Suspension	SP-006	TBD
MCU power test	CS-001	TBD
Dashboard power test	CS-002	TBD
Power Relay	CS-003	TBD
Motor Relay	CS-004	TBD
Solar modules Vos/Isc	TP-001	TBD
Solar array Vos/Isc	TP-002	TBD
MPPT voltage	TP-003	TBD
Charge battery from solar array	TP-004	TBD
Regenerative braking (stopping)	TP-005	TBD
Regenerative braking (charging)	TP-006	TBD
Temperature Sensor	MS-001	TBD
Current shunt line sensor	MS-002	TBD
State of Charge to microcontroller interface	MS-003	TBD

5 Schedule

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



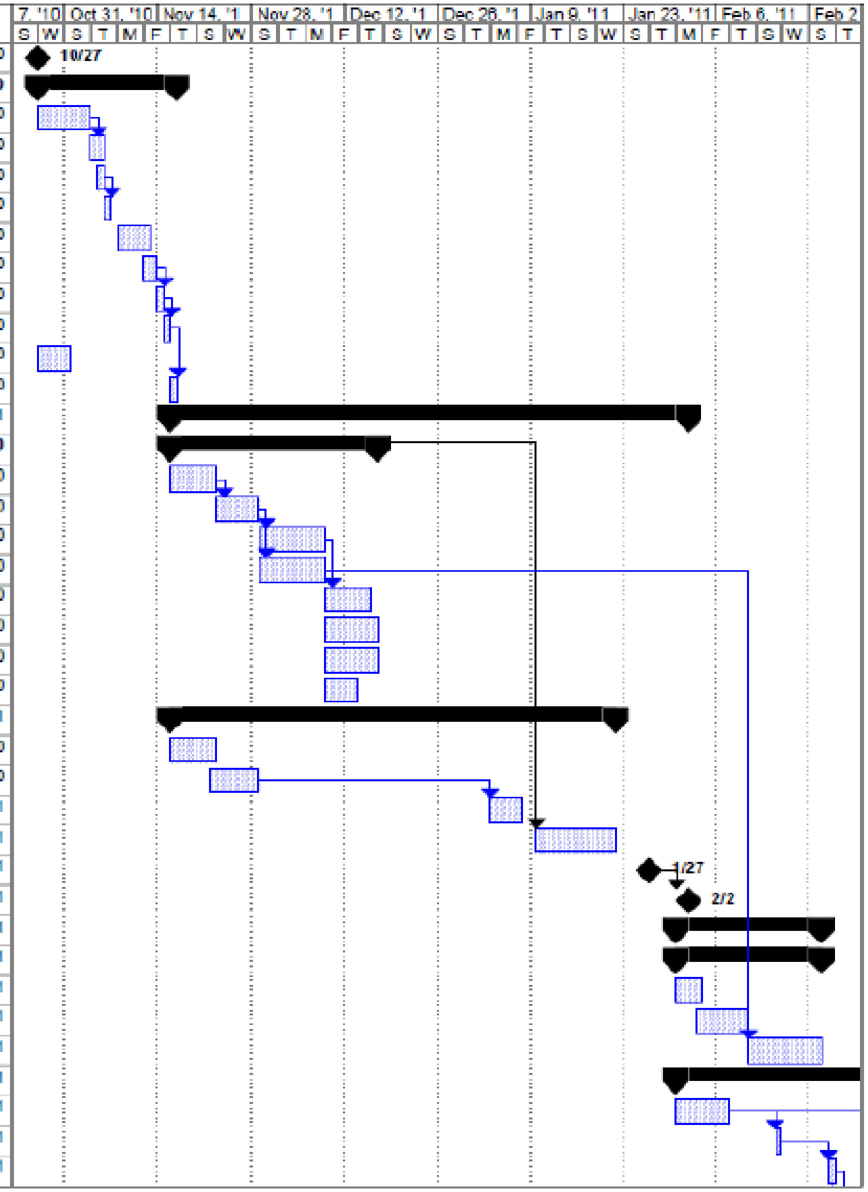
ID	Task Name	Duration	Start	Finish
1	**Solar Car**	**170 days**	**Mon 9/6/10**	**Fri 4/22/11**
2	**Needs Assesment Presentation**	**18 days**	**Mon 9/6/10**	**Wed 9/29/10**
3	Research race constraints	3 days	Mon 9/6/10	Wed 9/8/10
4	Research race requirements	5 days	Wed 9/8/10	Tue 9/14/10
5	Develop system 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	Regeesearch 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 | Milestone | External Tasks
Split | Summary | External Milestone
Progress | Project Summary | Deadline

Page 1

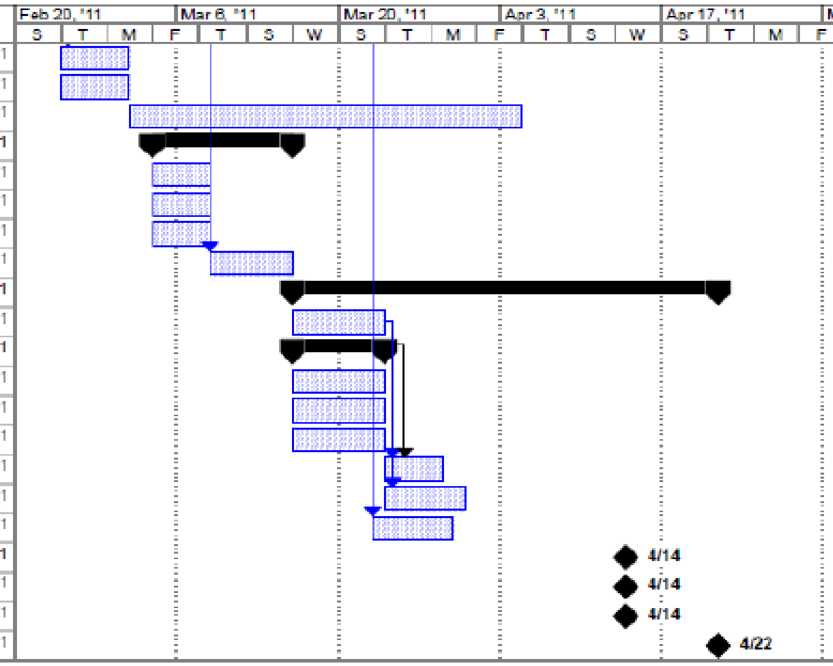
ID	Task Name	Duration	Start	Finish
39	Presentation	0 days	Wed 10/27/10	Wed 10/27/10
40	**System Level Design Review**	**17 days**	**Wed 10/27/10**	**Tue 11/16/10**
41	Develop Top Level Design	6 days	Wed 10/27/10	Wed 11/3/10
42	Analyze Top Level Desgin	2 days	Thu 11/4/10	Fri 11/5/10
43	Modify Top Level 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

6 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.

6.1 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**

6.2 Expenses

ELECTRICAL					
Item	**Quant.**	**Unit Cost**	**Total**	**Reference**	**Reference**
12V:9V DC:DC	1	$30.75	$30.75	website	powerstream
Relay	3	$105.25	$315.75	website	tecknowledgey
Micro controller	1	$188.00	$188.00	website	evb plus
Wires	1 set	$99.00	$99.00	website	mcmaster carr
Serial cable	1	$20.00	$20.00	local	radio shack
State Of Charge	1	$424.00	$424.00	website	evolve electrics
PVL-68 module	1	$249.00	$249.00	phone	unisolar
Fuses	10	$100.00	$100.00	wesbite	mcmaster carr
Breakers	2	$100.00	$100.00	website	mcmaster carr
Subtotal			$1,526.50		

MECHANICAL					
Item	**Quant.**	**Unit Cost**	**Total**	**Reference**	**Vendor**
Brake Kit	2	$125.00	$250.00	website	wilwood
Springs	3	$300.00	$900.00	website	van rc
Wood/Boards	1	$330.00	$330.00	local	home depot
Foam	10	$50.00	$500.00	phone	minco auto
Lumber	1	$15.21	$15.21	local	machine shop
Wax	2	$10.00	$20.00	local	home depot
C-Fiber 12k	197 yds	$20.00	$3,940.00	phone	hexel
C-Fiber 3k	50 yds	$16.80	$842.25	local	machine shop
Resin	10 gallons	$25.00	$250.00	local	composites one
Lantor Soric	1	$439.00	$439.00	local	machine shop
Fiberglass	1	$200.00	$200.00	website	mcmaster-carr
Solidworks	9	$150.00	$1,350.00	phone	solidworks
Subtotal			$9,036.46		
INDUSTRIAL					
Item	**Quantity**	**Unit Cost**	**Total**	**Reference**	**Vendor**
Driver seat	1	$500.00	$500.00	website	
Subtotal			$500.00		
Total Expenses			**$11,062.96**		

6.3 Overhead

Overhead Cost	
PERSONNEL	$133,747.00
EXPENSES	$11,062.96
DIRECT COST	$144,809.96
Total at 45%	**$65,164.48**

6.4 Equipment

Item	Quantity	Unit Cost	Total	Reference	Vendor
MPPT	1	$1,320.00	$1,320.00	phone	Drivetek ag
Total			**$1,320.00**		

6.5 Total Budget

TOTAL BUDGET	
PERSONNEL	$133,747.20
EXPENSES	$11,062.96
OVERHEAD	$65,164.48
EQUIPMENT	$1,320.00
Total Project Cost	**$211,294.64**

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. Ten gallons of polyester resin to for the production of the body was donated by Reichhold Composites.

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.

The team finished the production of the outer shell for the bottom of the car. The production of the ribs for the bottom of the body is currently underway. The control arms of the suspension have been designed and front shock selection is being made. Once the bottom of the body is complete, the installation of the electrical and mechanical systems will be added.

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9 Appendix

9.1 Calculation

$W_{total} := 520lb$

$x := 2in$

L . R = Left and Right

k = Spring constant

x = Displacement

W = Weight

$F = -k \cdot x$

$W_{L.R} := \frac{W_{total}}{4}$ $\quad W_{L.R} = 130 \cdot lb$

$k_{L.R} := \frac{W_{L.R}}{x}$ $\quad \boxed{k_{L.R} = 65 \cdot \frac{lb}{in}}$

$W_{rear} := \frac{W_{total}}{2}$ $\quad W_{rear} = 260 \cdot lb$

$k_{rear} := \frac{W_{rear}}{x}$ $\quad \boxed{k_{rear} = 130 \cdot \frac{lb}{in}}$

$L_s := 7.875in$ $\quad \theta := 30deg$ $\quad L_2 := 12.5in$

$h := L_s \cdot \sin(\theta)$ $\quad h = 3.937 \cdot in$

$L_1 := L_s \cdot \cos(\theta)$ $\quad L_1 = 6.82 \, in$

$F_s := \frac{W_{L.R} \cdot L_2}{L_1 \cdot \sin(\theta)}$ $\quad \boxed{F_s = 476.543lb}$

$k := \frac{F_s}{x} = 238.272 \frac{lb}{in}$

9.2 Test Plans

Test Plan – Solar Car Team '11

TEST ITEM (TITLE): 12K Carbon Fiber, 3K Carbon Fiber

TEST CASE #: BD-001 (ex: BS-001)

TEST DATE/TIME: 02/04/2011 (ex: 01/01/10 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: TEST ■ RE-TEST ☐

The objective of this test is to determine the ultimate tensile strength of the carbon fiber we will be using in the vehicle. The 12K carbon fiber will be used on the bottom half of the car for higher strength. The 3K carbon fiber will be used on the top because of the light weight properties. A sample strip of each will be cut and used in a tensile testing machine.

EXPECTED RESULTS:

The carbon fiber composite will exceed the minimum force requirements.

ACTUAL RESULTS:

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

Test Plan – Solar Car Team '11

TEST ITEM (TITLE): Rack and Pinion Steering System

TEST CASE #: SS-001 (ex: BS-001)

TEST DATE/TIME: TBD (ex: 01/01/10 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: TEST ■ RE-TEST ☐

The rack and pinion will need to be tested to see if it can provide accurate steering for the new body design. The rack and pinion should not lock up and it must provide a smooth transition from rotational to linear motion as the steering wheel is turned. The rack and pinion must also be able to push the tie rods so the effectively turn the wheels.

EXPECTED RESULTS:

The rack and Pinion will function properly and give the vehicle proper steering

ACTUAL RESULTS:

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

Test Plan – Solar Car Team '11

TEST ITEM (TITLE): Brake Rotor

TEST CASE #: BS-001 (ex: BS-001)

TEST DATE/TIME: TBD (ex: 01/01/10 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

A custom brake rotor will be fabricated in order to better suit the light weight of the vehicle. As the brake pads apply a frictional force to the brake rotor, the energy is transformed into heat. The rotor will need to be tested to ensure it can effectively dissipate heat, to reduce the chance of rotor failure. This can be done by performing FEM analysis on the rotor in order to see its heat transfer capabilities.

EXPECTED RESULTS:

The brake rotor will perform exceptionally.

ACTUAL RESULTS:

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

Test Plan – Solar Car Team '11

TEST ITEM (TITLE): Master Cylinder

TEST CASE #: BS-002 (ex: BS-001)

TEST DATE/TIME: TBD (ex: 01/01/10 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

The purpose of the master cylinders is to translate the force from the brake pedal into hydraulic fluid pressure to push the pistons in the caliper assembly. Test must be performed to meet race regulations.
Orders have been placed for two Master Cylinders from Wilwood Engineering.

EXPECTED RESULTS:

The master Cylinder will be able to provide sufficient hydraulic pressure to the calipers.

ACTUAL RESULTS:

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

Test Plan – Solar Car Team '11

TEST ITEM (TITLE): Brake Lines

TEST CASE #: BS-003 (ex: BS-001) TEST DATE/TIME: TBD (ex: 01/01/10 – 11:30 AM)

TEST CASE DESCRIPTION: TEST TYPE: ☒ TEST ☐ RE-TEST

The brake lines transport the brake fluid from the master cylinder to the caliper assembly. The lines must be checked to ensure no leaks are present in the lines, which will decrease hydraulic pressure to the calipers

EXPECTED RESULTS:

The brake lines will have no leaks.

ACTUAL RESULTS:

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

Test Plan – Solar Car Team '11

TEST ITEM (TITLE): Brake Caliper Assembly

TEST CASE #: BS-004 (ex: BS-001)

TEST DATE/TIME: TBD (ex: 01/01/10 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ☒ TEST ☐ RE-TEST

The brake caliper will apply a clamping force onto the brake rotor to generate friction force onto the rotor. The caliper contains a piston which pushes the brake pads onto the rotor. The pistons must be checked to ensure the piston does not lock up, which will cause frictional force to be constantly applied to the rotor. This may lead to rotor failure

EXPECTED RESULTS:

Caliper piston is able to apply pressure to the rotor and return freely to its original position.

ACTUAL RESULTS:

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

Test Plan – Solar Car Team '11

TEST ITEM (TITLE): Heim Joints Structural Testing

TEST CASE #: SP-001 (ex: BS-001)

TEST DATE/TIME: TBD (ex: 01/01/10 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

The objective of this test is to verify that the part can structurally hold under loading.
This part will be tested in SolidWorks using the Finite Element Method analysis built in the program.
The test will provide displacement and Von Misses stress analysis.

EXPECTED RESULTS:

The heim joint will not have any deformation during the force analysis.

ACTUAL RESULTS:

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

Test Plan – Solar Car Team '11

TEST ITEM (TITLE): Control Arm Structural Testing

TEST CASE #: SP-002 (ex: BS-001)

TEST DATE/TIME: TBD (ex: 01/01/10 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

The objective of this test is to verify that the part can structurally hold under loading.
This part will be tested in SolidWorks using the Finite Element Method analysis built in the program.
The test will provide displacement and Von Misses stress analysis.

EXPECTED RESULTS:

The control arm will not have any deformation during the force analysis.

ACTUAL RESULTS:

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

Test Plan – Solar Car Team '11

TEST ITEM (TITLE): Mounting Brackets Structural Testing

TEST CASE #: SS-003 (ex: BS-001)

TEST DATE/TIME: TBD (ex: 01/01/10 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

The objective of this test is to verify that the part can structurally hold under loading.
This part will be tested in SolidWorks using the Finite Element Method analysis built-in the program.
The test will provide displacement and Von Misses stress analysis.

EXPECTED RESULTS:

The mounting bracket will not have any permanent deformation during the force analysis.

ACTUAL RESULTS:

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

Test Plan– Solar Car Team '11

TEST ITEM (TITLE): Upright Arm Structural Testing

TEST CASE #: SP-004 (ex: BS-001) TEST DATE/TIME: TBD (ex: 01/01/10 – 11:30 AM)

TEST CASE DESCRIPTION: TEST TYPE: ☒ TEST ☐ RE-TEST

The objective of this test is to verify that the part can structurally hold under loading.
This part will be tested in SolidWorks using the Finite Element Method analysis built-in the program.
The test will provide displacement and Von Misses stress analysis.

EXPECTED RESULTS:

The upright arm will not have any deformation during the force analysis.

ACTUAL RESULTS:

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

Test Plan – Solar Car Team '11

TEST ITEM (TITLE): Front Suspension (Left and Right)

TEST CASE #: SP-005 (ex: BS-001) TEST DATE/TIME: TBD (ex: 01/01/10 – 11:30 AM)

TEST CASE DESCRIPTION: TEST TYPE: ■ TEST ☐ RE-TEST

The objective of this test is to verify that the system can structurally hold under loading.
This system will be tested in SolidWorks using the Finite Element Method analysis built-in the program.
The test will provide displacement and Von Misses stress analysis.

EXPECTED RESULTS:

The left and right front suspension will not have any deformation during the force analysis as a whole.

ACTUAL RESULTS:

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

Test Plan – Solar Car Team '11

TEST ITEM (TITLE): Rear Suspension

TEST CASE #: SP-006 (ex: BS-001)

TEST DATE/TIME: TBD (ex: 01/01/10 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ☒ TEST ☐ RE-TEST

The objective of this test is to verify that the system can structurally hold under loading.
This system will be tested in SolidWorks using the Finite Element Method analysis built-in the program.
The test will provide displacement and Von Misses stress analysis.

EXPECTED RESULTS:

The rear suspension will not have any deformation during the force analysis as a whole.

ACTUAL RESULTS:

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

Test Plan – Solar Car Team '11

TEST ITEM (TITLE): Test Solar Modules for rated Voc (V) and Isc (I)

TEST CASE #: TP-001 (ex: BS-001)

TEST DATE/TIME: TBD (ex: 01/01/10 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

Each solar module in the car should be tested for rated Voc (V) and Isc (A). The data for these values are provided in the manufacturers datasheet. For example, the PVl-68 solar module from Unisolar is expected to output a Voc (V) of 23.1 V and Isc (A) of 5.1 A. The open circuit voltage (Voc) is measured using a digital voltmeter. To measure the current, the solar module should initially be covered (safety reason – spark could occur when multi-meter is probed) to prevent sunlight. The short –circuit current is measured using a digital ammeter. A digital multimeter can be used to measure voltage and current, but care should be taken to ensure correct settings.

EXPECTED RESULTS:

The Voc (V) and Isc (A) measured from the solar module the rated value confirms with the values provided in the manufacturer's datasheet.

ACTUAL RESULTS:

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

Test Plan – Solar Car Team '11

TEST ITEM (TITLE): Test Solar Array System for rated Voc (V) and Isc (I)

TEST CASE #: TP-002
(ex: BS-001)

TEST DATE/TIME: TBD
(ex: 01/01/10 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ☒ TEST ☐ RE-TEST

The solar array system of the car should be tested for rated Voc (V) and Isc (A). The data for these can be computed using simple calculations from the data provided in the manufacturers datasheet of the modules used for the solar array system. For example, if 5 solar modules (PVl-68 model from unisolar in series configuration) are to be used, then the solar array system is to output a Voc (V) of 115.5 V and Isc (A) of 5.1 A. PVl-68 solar module from Unisolar is expected to output a Voc (V) of 23.1 V and Isc (A) of 5.1 A. The open circuit voltage (Voc) is measured using a digital voltmeter. To measure the current, the solar array should initially be covered (safety reason – spark could occur when multi-meter is probed) to prevent sunlight. The short –circuit current is measured using a digital ammeter. A digital multimeter can be used to measure voltage and current, but care should be taken to ensure correct settings.

EXPECTED RESULTS:

The Voc (V) and Isc (A) measured from the solar array confirms with the rated values calculated using the manufacturers datasheet.

ACTUAL RESULTS:

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

Test Plan – Solar Car Team '11

TEST ITEM (TITLE): Test MPPT for input \ output voltage

TEST CASE #: TP-003 (ex: BS-001)

TEST DATE/TIME: TBD (ex: 01/01/10 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

The MPPT is a DC: DC converter that maximizes the power point of the solar array system. The Drivetek MPPT that is currently being sought by the team has a certain input \ output voltage ranges. The MPPT has to be tested to ensure than its operation within these voltage ranges. The data regarding the voltage ranges are provided from the manufacturers datasheet. A digital multimeter or a voltmeter can be used to test the voltages.

EXPECTED RESULTS:

The MPPT functions in its safe operating voltage ranges; the voltage ranges can be obtained from the manufacturers datasheet.

ACTUAL RESULTS:

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

Test Plan – Solar Car Team '11

TEST ITEM (TITLE): Test charge of battery from the solar array system

TEST CASE #: TP-004 (ex: BS-001)

TEST DATE/TIME: TBD (ex: 01/01/10 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ☒ TEST ☐ RE-TEST

The current and the voltage output from the solar array system should charge the battery system via the MPPT converter. A state of charge system is being shopped around for monitoring the energy capacity of the battery bank. Most state of charge systems are able to display the voltage of the battery bank, capacity of the battery bank, and the magnitude of the input current to the battery system. The state of charge system comes with a shunt line that is inserted in series between the MPPT and the battery bank. As such, the current reading is readily displayed in a lcd screen. The second option under consideration is the hall effect sensor. If implemented, testing should be done to conform proper installation, alignment to the magnetic field, proper circuitry connections. Noise and disturbance greatly reduce the performance of these sensors. The hall effect sensor should be tested for output voltage under various different load conditions (full load – no load); these voltage signals need to be converted by a microcontroller to current amperage and displayed for diagnostics. The state of charge option is highly probable.

EXPECTED RESULTS:

The solar array system is capable of charging the battery system.

ACTUAL RESULTS:

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

Test Plan – Solar Car Team '11

TEST ITEM (TITLE): Test regenerative braking signal when the regenerative braking handle is asserted

TEST CASE #: TP-005 (ex: BS-001)

TEST DATE/TIME: TBD (ex: 01/01/10 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ☒ TEST ☐ RE-TEST

The regenerative braking system is to be asserted through a handle connected to a potentiometer. The signal is connected to the potentiometer to create a scaling effect from 0-5 V max; this signal needs to be tested using a digital multimeter, because each voltage on the scale equates to a desired signal for the given range. The analog signal will be connected to the microcontroller that will signal the motor controller on the amount of braking throttle force. The program code for this process will also be tested. The regenerative braking system as a whole will be tested for its functionality upon complete assembly on the body of the car.

EXPECTED RESULTS:

The regenerative signal is detected by the microcontroller when the regenerative braking handle is asserted.

ACTUAL RESULTS:

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

Test Plan – Solar Car Team '11

TEST ITEM (TITLE): Test regenerative braking system charges the battery

TEST CASE #: TP-006 (ex: BS-001)

TEST DATE/TIME: TBD (ex: 01/01/10 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ☒ TEST ☐ RE-TEST

The regenerative braking system is to be asserted through a handle connected to a potentiometer. The analog signal is received by a microcontroller that will be programmed to assert the digital regenerative braking signal to the motor controller. The kinetic energy received by the motor due to the motion of the vehicle is expected to charge the battery system. The state of charge device will be used to test and thus, measure the magnitude of the current received by the battery system upon assertion of the regenerative braking system. The program code for this process will also be tested. The regenerative braking system as a whole will be tested for its functionality upon complete assembly on the body of the car. The car can also be loaded on a jack and the motor throttled to a certain limit, then the regenerative braking system can be applied; the state of charge system will detect the magnitude of current generated due to the braking force on the motor.

EXPECTED RESULTS:

The regenerative braking system provides some amperage to the battery system.

ACTUAL RESULTS:

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

Test Plan – Solar Car Team '11

TEST ITEM (TITLE): MCU Power Test

TEST CASE #: CS-001 (ex: BS-001)

TEST DATE/TIME: TBD (ex: 01/01/10 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ☒ TEST ☐ RE-TEST

Test to ensure that the MCU is receiving power from the main power system through the 12->9V DC-DC converter.

EXPECTED RESULTS:

The MCU should power on when the ignition switch is set to ON position.

ACTUAL RESULTS:

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

Test Plan – Solar Car Team '11

TEST ITEM (TITLE): Dashboard Power Test

TEST CASE #: CS-002
(ex: BS-001)

TEST DATE/TIME: TBD
(ex: 01/01/10 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

Test to ensure that the dashboard systems are receiving power from the 100V->12V DC-DC Converter.

EXPECTED RESULTS:

The Speedometer, SOC Meter, and rear-view camera should power on when the ignition switch is set to ON position.

ACTUAL RESULTS:

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

Test Plan – Solar Car Team '11

TEST ITEM (TITLE): Power Relay Test

TEST CASE #: CS-003 (ex: BS-001)

TEST DATE/TIME: (ex: 01/01/10 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

Test to verify proper function of main BMS relays and corresponding power system relays. Power is supplied to the BMS which will activate the internal main contactor relay that supplies power to the battery isolation relay and the solar power relay to close them. A multimeter will be used to measure the current across the terminals of the relays to determine the state of each relay before and after BMS power on. When one of the BMS signals is wires is cutoff, the internal BMS relay will close after 10 seconds. The state of the Relays will again be evaluated after the BMS internal Relay is closed.

EXPECTED RESULTS:

Before power is supplied to the BMS, the relays should both be open. After power on, the relays should be closed. When the BMS signal wire is opened, the relays should open after 10 seconds

ACTUAL RESULTS:

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

Test Plan – Solar Car Team '11

TEST ITEM (TITLE): Motor Relay Test

TEST CASE #: CS-004 (ex: BS-001)

TEST DATE/TIME: TBD (ex: 01/01/10 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

Test to verify proper function of motor relay. When MCU is powered on, the MCU relay will activate after 10 seconds which should close the motor relay. A multimeter will be used to determine the state of the relay.

EXPECTED RESULTS:

Before power is supplied to the BMS, the relays should both be open. After power on, the relays should be closed. When the BMS signal wire is opened, the relays should open after 10 seconds.

ACTUAL RESULTS:

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

Test Plan – Solar Car Team '11

TEST ITEM (TITLE): Temperature Sensor

TEST CASE #: MS-001 (ex: BS-001)

TEST DATE/TIME: TBD (ex: 01/01/10 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

This test will be designed to test the temperature sensor for the state of charge device. Initially the test will be performed at room temperature to verify operation. Then a thermometer will be used in conjunction under various conditions (outside or in a heated room) with the thermometer to verify accuracy.

EXPECTED RESULTS:

Since the device is prepackaged with the temperature sensor there are no reason, except device malfunction, that this device will not operate correctly with a high degree of accuracy.

ACTUAL RESULTS:

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

Test Plan – Solar Car Team '11

TEST ITEM (TITLE): Current Shunt Line Sensor

TEST CASE #: MS-002 (ex: BS-001)

TEST DATE/TIME: TBD (ex: 01/01/10 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

This test will be designed to test the shunt line current sensor for the state of charge system. This test will be performed with a small simple circuit in order to protect the batteries. Since the final connection will be across the batteries themselves it is important to ensure correction operation before integrating it into the car itself. The shunt line will be used along with an ammeter as a means of verification for the accuracy of the device.

EXPECTED RESULTS:

Since the device is prepackaged with the shunt line sensor there are no reason, except device malfunction, that this device will not operate correctly with a high degree of accuracy.

ACTUAL RESULTS:

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

Test Plan – Solar Car Team '11

TEST ITEM (TITLE): State of Charge to Microcontroller Interface

TEST CASE #: MS-003 (ex: BS-001) TEST DATE/TIME: TBD (ex: 01/01/10 – 11:30 AM)

TEST CASE DESCRIPTION: TEST TYPE: ■ TEST ☐ RE-TEST

This test is designed to develop the sharing of information between the state of charge system and the microcontroller. A preliminary code will be written to display the information on the LCD. This information will be compared to the information seen on the display for the state of charge system. It will be important to verify that not only does the information match but also that there is little delay in the information sharing.

EXPECTED RESULTS:

Since the state of charge system is designed to share information through the use of signals there should be little problems passing the information.

ACTUAL RESULTS:

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS: