POWER SYSTEM DESIGN FOR SOLAR CAR

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BACHELOR OF ENGINEERING
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FACULTY OF MECHANICAL ENGINEERING

We certify that the project entitled Power System Design for Solar Car is written by Sunil Shanaz bin Redzuan Perpinder. We have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. We herewith recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering with Automotive Engineering.

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Report submitted in partial fulfilment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering with Automotive Engineering

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Automotive Engineering.

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STUDENT’S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurently submitted for award of other degree.

Signature

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Dedicated to my loved ones who have

inspired me throughout these 22 wonderful years of my life

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I took a huge sigh of relieve as I finished the final bits of this report. Only God knows how thankful and delightful I am to have completed this project. I would to thank Him for His blessings throughout the whole time. It is very true that God helps people who help themselves.

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ABSTRACT

The solar car power system consists of three main subsystems which are the solar array, battery management and lastly, battery pack. It is arguably the most essential system of a solar car since it generates power for the car thus vastly influences the functionality of the car itself. This project was carried out to design a solar car power system that is feasible, cost effective and in compliance with the rules and regulations of the 2011 World Solar Challenge (WSC). The main objective of this project was to design an electrical layout of a solar car power system with components that are properly selected as well as carrying out analysis to determine the practicality and compatibilty of the design. The design of the power system was divided into four levels which were the selection of subsystems' mian components, design of the subsystems, the conditioning of the power system and finally, the design of the overall power system itself. These steps involved drawing of design, design calculations and analysis of compatibilty within the power system. The drawings involved in the design of the system were done via Solidworks 2010 and SmartDraw 2010 softwares. The finalized design delivered a power system that could generate a maximum power of 837.6W through its solar array designed by tabbed monocrystalline solar cells. The power generated would be stored in a battery pack which consists of five VRLA batteries with a combined power capacity of 6.4kWh. A buck type maximum power point tracker configures the input from the solar array to the battery pack. Motor controller of the actuation system would configure the power system to continuously supply 1kW to the motor. It is calculated that in ideal conditions, the power system can continously power the motor for at least 11.99 hours which is already sufficient for a day of solar racing. The results and discussion concluded that the design of the solar car power system is feasible to be implemented and is considerably cost effective, within the financial prowess of the university. Through proper justifications, the design is also proven to be compatible within the system itself. For further improvements in the future, this project should be conducted with a greater budget so that rather than coming up with a conceptual design, a fabrication or at least a better form of design simulation can be done. Besides that, with greater budget, better components that are more costly are then affordable.

ABSTRAK

Sistem kuasa kereta solar terdiri daripada tiga subsistem utama iaitu modul solar, pengatur cas dan sistem bateri. Ia boleh dianggap sebagai sistem yang paling penting bagi sesebuah kereta solar memandangkan ia menjana kuasa untuk kegunaan kereta tersebut dan oleh sebab itu, ia menentukan sejauh mana sesebuah kereta solar dapat berfungsi. Projek ini dilaksanakan untuk mereka sebuah sistem kuasa kereta solar yang praktikal, kos efektif dan mematuhi peraturan pertandingan World Solar Challenge 2011. Objektif utama projek ini adalah untuk mereka sebuah plan elektrikal bagi sistem kuasa kereta solar dengan menggunakan komponen-komponen yang dipilih secara teliti serta menjalankan analisis untuk menetukan kewajaran dan kesinambungan rekaan tersebut. Rekaan sistem kuasa ini dibahagikan kepada empat peringkat iaitu pemilihan komponen utama bagi setiap subsistem, rekaan subsistem, pemantapan sistem dan akhir sekali, rekaan sistem kuasa secara menyeluruh. Proses ini melibatkan lakaran rekaan, pengiraan serta analisis bagi menetukan kesinambungan sistem. Lakaran bagi rekaan sistem kuasa ini dihasilkan dengan menggunakan Solidworks 2010 dan SmartDraw 2010. Rekaan yang terhasil memberikan sebuah sistem kuasa yang mampu menjana kuasa maksimum sebanyak 873.6W melalui modul solarnya yang direka dengan menggunkan sel solar monokristalin. Tenaga yang terhasil disimpan di dalam sistem bateri yang terdiri daripada lima bateri VRLA dengan kapasiti 6.4kWh. Cas daripada modul solar ke sistem bateri diatur dengan menggunakan pengatur cas injak turun. Pengatur motor melaraskan agar 1kW kuasa dibekalkan secara berterusan ke motor. Maka, melalui pengiraan, di bawah keadaan sempurna, didapati bahawa motor boleh berfungsi secara berterusan selama sekurang-kurangnya 11.99 jam iaitu jangka masa yang mencukupi untuk sehari perlumbaan. Akhir sekali dapat disimpulkan bahawa sistem kuasa yang direka adalah praktikal untuk dilaksanakan serta didapati kos efektif iaitu setimpal dengan peruntukan universiti. Di samping itu, sistem yang dihasilkan juga terbukti akan kesinambungannya. Projek boleh ditambahbaikkan pada masa akan datang sekiranya dana yang secukupnya dapat diperuntukkan. Dengan itu, rekaan dapat dihasilkan bukan sahaja dari segi konseptual tetapi juga dari segi pembuatan atau sekurang-kurangnya simulasi yang lebih bersesuaian. Selain itu, komponen-komponen yang lebih baik juga mampu digunakan sekiranya dana bagi projek mencukupi.

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LIST OF SYMBOLS

A	Area
m	mass
V	Voltage
I	Current
P	Power
N	Number of Solar Cell / Panel / Module / Battery
N_{max}	Maximum Number of Solar Cell / Panel / Battery
V_{mp}	Maximum Voltage
I_{mp}	Maximum Current
t	Time
G	Solar Radiation
T	Temperature

LIST OF ABBREVIATIONS

AC	Alternate Current
Ag-Zn	Silver Zinc
$LiFePO_4$	Lithium Iron Phosphate
Li-ion	Lithium Ion
Li-polymer	Lithium Polymer
MPPT	Maximum Power Point Tracker
Ni-Fe	Nickel Iron
NiMH	Nickel Metal Hydride
Ni-Zn	Nickel Zinc
Pb-acid	Plumbum Acid / Lead Acid
PV	Photovoltaic
PVC	PolyVinyl Chloride
SWD	Switching Duty
VRLA	Valve Regulated Lead Acid
WSC	World Solar Challenge

CHAPTER 1

INTRODUCTION

1.0 Introduction

The global energy crisis started with the predicted shortage of crude oil. Due to insecurities regarding the future availability of petroleum, the main form of non-renewable energy, the whole world are looking for other energy alternatives. Renewable energy such as wind, solar, tidal, wave and biomass is definitely considered as a fraction of the remedy. Thus, more and more investment is pumped into the development of renewable energy (Anthony Hilliard et.al. 2008).

Nowadays, solar energy covers only 0.5% of the world's energy consumption. However, its significance as an energy source is predicted to further increase in the future. Solar energy is said to have a great potential in becoming one the main types of energy in the world (Rosaidi, 2009). One of the efforts done in order to fulfill the potential of solar energy is via integrating the use of solar energy with cars. These cars are called solar cars. Since its introduction, various solar cars were built and tested fo either racing or demonstrative purposes (Ivan Arsie et. al. 2006) In the year 1983, Hans Tholstrup and Larry Perkins crossed Australia in their solar car named the Quiet Achiever. From that point, the solar car technology continuously received encouragement thus developed and matured through racing events such as the World Solar Challenge. It is because of that, up until now, existing solar cars clearly inherit a race-bred history (A.Simpson et. al. 2002).

However, despite these achievements, solar cars are still some way off from conventional cars due to limitations such as inconsistency of solar cource availability and the need of minimizing weight, friction and aerodynamic losses. These limitations are basically among the aspects that need to be taken into consideration while designing a solar car. Besides, these limitations also outline the challenges which lie in the building of a solar car (Ivan Arsie et. al. 2006).

1.1 Problem Statement

One of the biggest hurdles faced by solar cars is the limitations posed by its power system. This is because photovoltaic (PV) technology is known to be expensive and the availability of solar energy vigorously depends on the weather and surroundings. Hence, the power system is arguably the most critical aspect of a solar car. A solar car power system has the main goal of harnessing ample energy to operate the vehicle. Many aspects has to be considered in the designing process of a solar car power system such as feasibilty of design, cost as well as safety measures. This study tries to deliver a proper solar car power system design that is cost effective, in compliance to the rules and regulations of the 2011 World Solar Challenge and most importantly, practical and compatible for use in solar vehicles.

1.2 Objectives

There are three objectives identified in this particular project. First of all is to design the electrical layout of a solar car power system from the solar array to the battery pack. The second objective is to select the suitable components that are to be used in the design of the power system. Last but not least, this project also requires analysis of the various aspects of the solar car power system with regards to the compatibility within itself as well as its practicality in production.

1.3 Scope of Study

The project scope is essential as it draws a guideline to ensure the project is conducted within its intended boundaries and remains in the right direction to achieve its objectives. There are several criterias in which the scope of this project covers. First of all, the type of solar cells, maximum power point tracker and batteries for the design of the power system is to be determined. The component selected must be of the ones available in the market. The solar car power system is to be designed according to the technical regulations of the 2011 World Solar Challenge. SmartDraw 2010 software is used to draw electrical circuits and diagrams of the power system design. As for components such as the battery box and the array stand, they are to be designed using Solidworks 2010.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

This chapter provides an academic review of facets related to solar car power system. It starts with the history of solar energy and the fundamentals of a photovoltaic system. Furthermore, it discusses the existing types of photovoltaic cells, maximum power point trackers as well as batteries in relevance to the topic of the study. The distinctions, advantages and disadvantages of each types are revealed.

2.1 History of Solar Energy

Solar energy exploration is said to have started a long time ago. Ancient Greeks and Romans saw great benefit in passive solar design, which is the use of architecture to make use of the sun’s capacity to light and heat indoor spaces. This art was further advanced by the Romans who covered south facing building openings with glass or mica to hold in the heat of the winter sun. Through calculated use of the sun’s energy, Greeks and Romans offset the need to burn wood that was often in short supply. In 1861, a steam engine powered entirely by the sun was developed (T.Mohd, 2009).

Solar energy continued to attract European scientists through the 19th century. Scientists developed large cone-shaped collectors that could boil ammonia to perform work such as locomotion and refrigeration. There was also a point when France and England hoped that solar energy could power the operations of their colonies in Africa and East Asia. Moving on, solar power could boast few major gains through the first half of the 20th century. In fact, Albert Einstein was even awarded 1921 Nobel Prize in physics for his research on the photoelectric effect. The photoelectric effect is a phenomenon referring to the generation of electricity through solar cells (T.Mohd, 2009).

Back then in the 1950s, solar photovoltaic (PV) cells were far from economically practical. The hope in the 1970s was that through massive investment in subsidies and research, solar photovoltaic costs could drop sharply and eventually become competitive with fossil fuels. By the 1990s, cost of solar energy dropped as predicted but costs of fossil fuels had also dropped. Thus the idea of solar technology being economically practical did not change quite as much. However, huge PV market growth in Japan and Germany from the 1990s to the present has reenergized the solar industry. Such progress has been creating economies of scale, thus steadily lowering costs. The PV market is currently growing at a blistering 30 percent per year, with the promise of continually decreasing costs (T.Mohd, 2009).

2.2 Photovoltaic System

Photovoltaic (PV) is the field of technology and research related to the application of solar cells for energy by converting sunlight directly into electricity. Due to the growing demand for clean sources of energy, the manufacturer of solar cells and photovoltaic arrays has expanded dramatically in recent years. Photovoltaic production has been doubling every two years, making it the world's fastest-growing energy technology (Suhaifiza, 2009). Solar energy has been used around the world for powering numerous applications. It works by converting energy from the sunlight directly into electricity (DC). The smallest part of a photovoltaic panel is called photovoltaic cell. Multiple solar or photovoltaic cells are connected to form a solar module and combination of solar module by series or parallel is called the solar array (Rosaidi, 2009).

The electricity from the solar cells is stored in the battery for immediate or later use. The role of the charge controller is to regulate the voltage and current from the solar cells before it is stored in the battery. It monitors the condition of the battery state of charge and protects the battery from being over-charged. The charge controller will also protect the battery from discharging below its lowest acceptable voltage. Where required, an inverter is used to change the Direct Current (DC) to Alternating Current (AC) to power most AC appliances (Rosaidi, 2009).

2.3 The Photovoltaic Effect

The photovoltaic effect is a phenomenon that converts the sun's electromagnetic energy directly to electricity. A junction of two dissimilar semiconductor materials is very effective in producing this phenomenon (Batcheller, 1993). As seen in Figure 2.1, solar cells consist of a p-n junction fabricated in a thin wafer or layer of semiconductor, usually silicon. They are specially created to form an electrical field, positive on one side and negative on the other. When solar energy in the from of photons hits the solar cell, electrons are knocked loose from the atoms in the semiconductor material creating electron-hole pairs. If electrical conductors are then attached to the positive and negative sides, forming an electrical circuit, the electrons are captured in the form of electric current, I_L in which in this case is known as photocurrent (Hafiez, 2009).

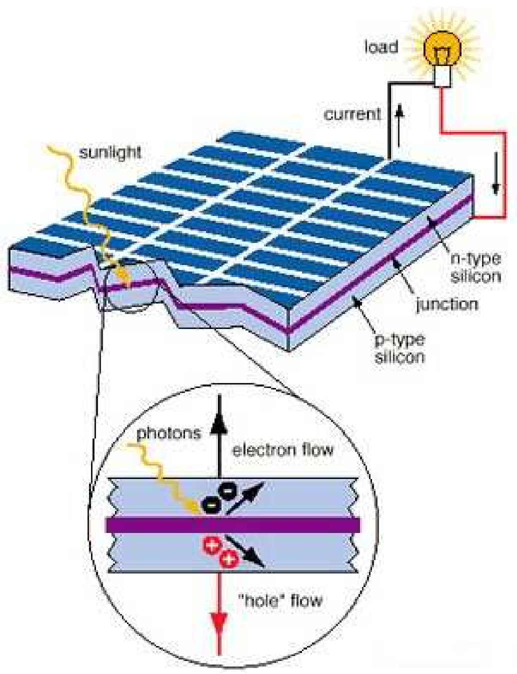

Figure 2.1: Photovoltaic effect

Source: Suhaifiza, (2009)

2.4 Types of Photovoltaic Cells

Solar cells are made up of various semiconductor materials, which become electrically conductive when supplied with heat or light. The majority of solar cells produced are composed of Silicon (Si) which exist in sufficient quantities and do not add any burden on the environment (Hafiez, 2009). The main purpose in the research and development of photovoltaic cells is to improve the energy conversion efficiency of solar cells as well as other related parameters in order to reduce the commercial cost of solar cells and modules. The continuous efforts of producing high efficiency solar cells at lower cost have helped to produce various photovoltaic technologies that are available in today's market. The three main classifications of solar cells are crystalline silicon, thin-film and multi-junction (Irwan, 2008).

2.4.1 Crystalline Silicon

Silicon is the most used type of semiconductor in the fabrication of solar cells. The two common types of solar cells that fall into this category are Monocrystalline Silicon and Polycrystalline Silicon (Irwan, 2008)

Monocrystalline Silicon

These cells are made from very pure monocrystalline silicon. The silicon has a single and continuous crystal lattice structure with almost no defects or impurities. A monocrystalline silicon solar panel can be seen as shown in Figure 2.2. Monocrystalline cells have an approximate efficiency of up to 18%. It is the first type of solar cell to be developed commercially. The manufacturing process required to produce Monocrystalline is complicated, thus causing in slightly higher costs than other technologies (Irwan, 2008) (William, 1992) (T.Mohd, 2009)

Figure 2.2: Monocrystalline silicon solar panel

Source: Irwan, (2008)

Polycrystalline Silicon

This cell, as shown in Figure 2.3, is produced using numerous grains of monocrystalline silicon. Polycrystalline, also known as multicrystalline cells, are cheaper to produce than monocrystalline ones, due to the simpler manufacturing process. However, they tend to be slightly less efficient, with average efficiencies of around 13%. Similar to monocrystalline cells, polycrystalline cells have long life-span (Irwan, 2008) (William, 1992) (T.Mohd, 2009).

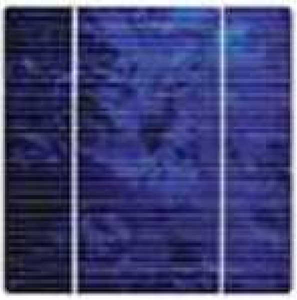

Figure 2.3: Polycrystalline silicon solar cell

Source: Irwan, (2008)

2.4.2 Thin Film

Thin film solar cells such as Amorphous Silicon, Copper Indium diselenide and Cadmium Telluride has relatively low efficiency of within the range of 6% to 12%. The advantages of thin film solar cells are their lightweight and their low cost due to less complicated manufacturing processes. Their low cost makes them ideally suited for many applications where high efficiency is not required and low cost is important. Examples of applications that use thin film cells are toys, calculators and watches (Irwan, 2008).

2.4.3 Multi-Juction Cell

Multi-junction cells are solar cells that are developed for very high efficiency. Given its very high efficiency, multi-junction solar cells are very expensive and currently, are only feasible for high cost applications such as in the Aerospace industry (Irwan, 2008).

2.5 Effects of Radiation and Temperature on Photovoltaic Cells

Output power produce by solar array depends on solar irradiation and temperature. It influences the I-V and P-V characteristics.

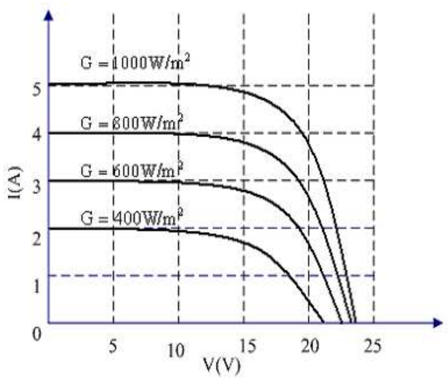

Figure 2.4: The effect of solar radiation, G on the I-V characteristic curve

Source: Rosaidi, (2009)

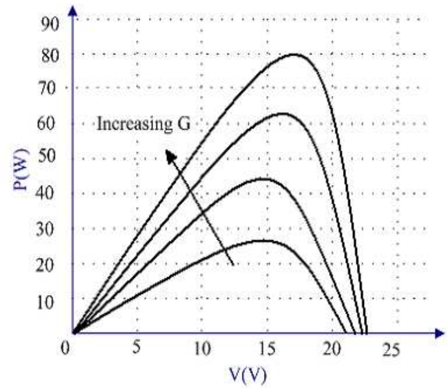

Figure 2.5: The effect of solar radiation, G on the P-V characteristic curve

Source: Rosaidi, (2009)

Both Figure 2.4 and Figure 2.5 above demonstrate that the short circuit current of a solar array is directly proportional to the solar radiation. This means that the greater the solar radiation is, the bigger the output current will be hence producing higher maximum output power (Rosaidi, 2009).

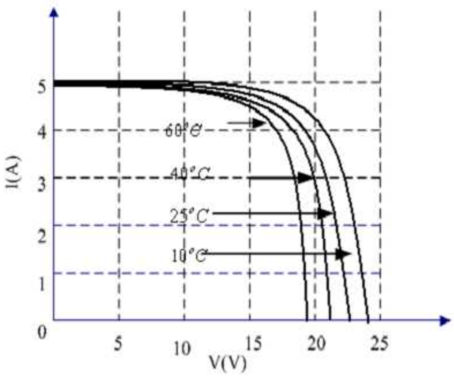

Figure 2.6: The effect of temperature, T on the I-V characteristic curve

Source: Rosaidi, (2009)

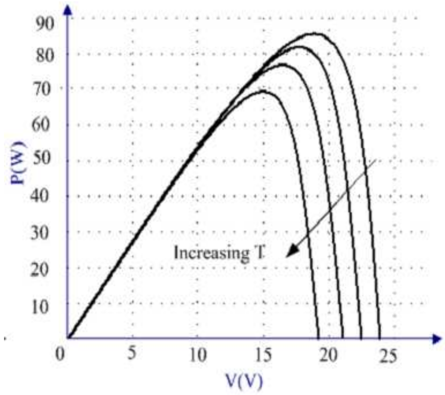

Figure 2.7: The effect of temperature, T on the P-V characteristic curve

Source: Rosaidi, (2009)

In the other hand, both Figure 2.6 and Figure 2.7 show that the temperature of the solar array is inversely proportional to the open-circuit voltage. Therefore, greater temperature of the solar array would result in lower output voltage hence causing lower maximum output power. Thus, these opposite effects of the variations of solar radiation and temperature on the maximum power output make it important to track the maximum power point efficiently (Rosaidi, 2009).

2.6 Operations of Maximum Power Point Tracker

Figure 2.8: Maximum power point tracker

Source: Stephanie et. al., (2003)

The Maximum Power Point Tracker (MPPT) is needed to optimize the amount of power obtained from the photovoltaic array to the power supply. The output of a solar module is characterized by a performance curve of voltage versus current, called the I-V curve as shown in Figure 2.9. The maximum power point of a solar module is the point along the I-V curve that corresponds to the maximum output power possible for the module. This value can be determined by finding the maximum area under the current versus voltage curve (Stephanie et. al. 2003)

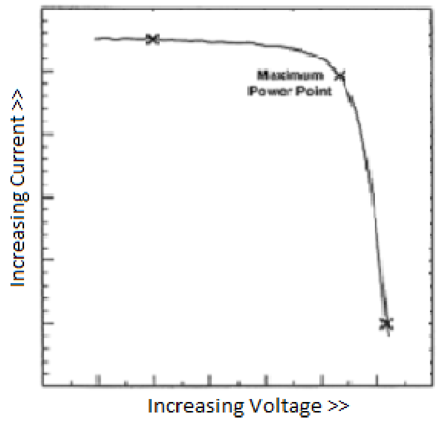

Figure 2.9: I-V characteristic curve

Source: Stephanie et. al., (2003)

As shown in Figure 2.10, the inputs of the MPPT consisted of the photovoltaic voltage and current outputs. The adjusted voltage and current output of the MPPT charges the power supply. A microcontroller was utilized to regulate the integrated circuits (ICs) and calculate the maximum power point, given the output from the solar array (Stephanie et. al. 2003).

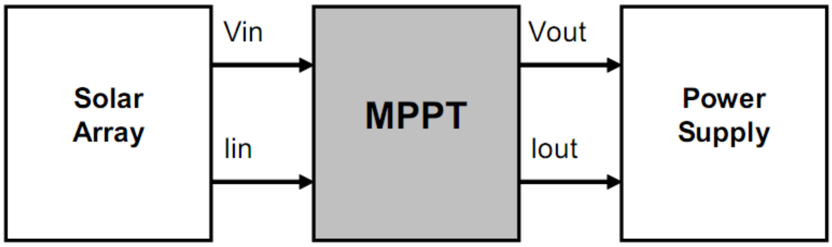

Figure 2.10: Basic block diagram of power system

Source: Stephanie et. al., (2003)

2.7 Topologies of MPPT

There are three common topologies for the MPPT which are the boost chopper, the buck chopper and the buck/boost chopper. Referring to Figure 2.11, the function of the chopper is to allow the photovoltaic supply to operate at the maximum power voltage independent of the operating voltage of the load, thereby transferring the maximum power from the photovolatic to the load. The feedback control continuously monitors the system and adjusts the ratio of the output voltage to the input voltage, N to ensure proper operating conditions (Batcheller, 1993).

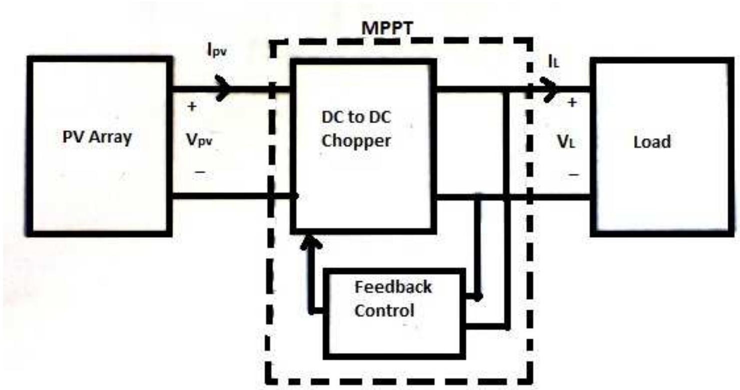

Figure 2.11: MPPT block diagram

Source: Batcheller, (1993)

2.7.1 Boost (Step Up) Chopper

The boost chopper steps the voltage up from the input to the output. Hence, N is greater than 1. The boost chopper topology is commonly used in a MPPT which is used in a stand-alone application where the minimum battery voltage is designed to be greater than the maximum power voltage, V_{mp} (Batcheller, 1993)

2.7.2 Buck (Step Down) Chopper

The buck steps the load voltage down relative to the photovoltaic array. Hence, N is less than 1. Due to the reason that the output voltage is stepped down relative to the photovoltaic array, the current on the load can be maximized. The buck chopper can also be used in stand-/alone application where the maximum battery voltage is less than the minimum photovoltaic maximum power voltage. A possible advantage of using the buck chopper over the boost chopper for stand-alone system is fewer power losses as a result of high operating voltages and lower operating currents of the photovoltaic supply (Batcheller, 1993).

2.7.3 Buck/Boost Chopper

The buck/boost MPPT is able to provide the load with a voltage level greater than or less than the voltage of the array. Therefore, it will work for all applications. However, this configuration is more complex, requires more electrical circuitry and less efficient. The buck/boost is typically not used for MPPTs since systems can be designed such that the output voltage will always be greater than the input voltage or vise-versa (Batcheller, 1993).

2.7.4 Comparison of Efficiencies

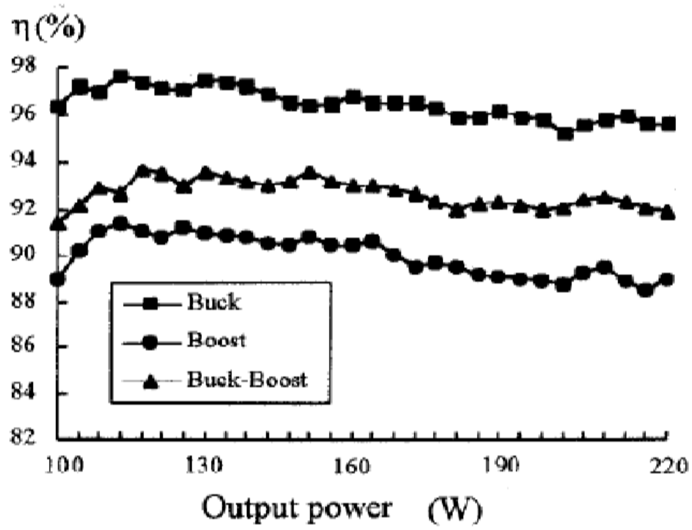

Figure 2.12: Efficiency of topologies

Source: Rosaidi, (2009)

Figure 2.12 shows the plots of efficiency against the output power for buck, boost and buck-boost converters. The plot shows the differences in the converters' efficiency for buck, boost and buck-boost converters. The efficiency of buck converter is a little bit higher than boost and buck-boost converters (Rosaidi, 2009).

2.8 Fundamental Concepts of Battery

Batteries are electrochemical devices which are used to supply energy for electrical and electronic product. Chemical energy stored in a battery is converted into electric current when battery is discharged. This electric current is produced directly by chemical reactions which occur within the battery. The quantity of electric energy made available is the function of chemical compositions and the amount material present in a cell. Many sets of different chemicals have been combined, with varying degrees of success, to make energy storage systems. Each type of battery couple has advantages and disadvantages with regards to its physical and electrical characteristics (Hafiez, 2009).

For a solar car, the primary energy source for the vehicle is the battery bank. The battery bank usually consists of a number of individual batteries connected in series or parallel. Each battery in the bank is typically amounts to a certain voltage and multiple batteries are connected in series or parallel to obtain the desired system voltage and capacity (Andrew et. al. 2008).

The capacity of a cell is measured typically in ampere-hours (Ah). The capacity is determined by a constant current discharge down to a defined end-of-discharge voltage. The capacity depends significantly on the discharge current and the temperature. Battery manufacturers can define the discharge current and the end-of discharge voltage on their own. Therefore, it is very important to check the reference conditions defined by the manufacturer while comparing the capacity of different products (Hafiez, 2009).

2.9 Types of Batteries

There are several types of batteries that are commonly used in solar cars. The types are lead acid, lithium ion and nickel-metal hydride. The common lead acid battery used in a solar vehicle is valve-regulated lead acid (VRLA) battery. Each type of battery has its own advantages and disadvantages. VRLA battery suits solar car teams that are just starting with their projects. This is because VRLA battery is very easily managed and does not require high maintenance unlike lithium ion and nickel-metal hydride batteries. VRLA battery is also far cheaper compared to the other two. Nickel-metal hydride and lithium ion batteries are expensive batteries and requires frequent monitoring and maintenance due to their sensitive nature. If wrongly treated, these batteries can be explosive. However, compared to lead acid, these batteries have greater energy density as well as being lightweight (Feinberg, 2006) (Connor, 2006).

CHAPTER 3

METHODOLOGY

3.0 Introduction

This chapter provides a discussion of the methodology used in conducting this project from starting until it is completed. It begins with the design of project study, where the general methodology used in conducting this project is discussed. Then it is followed by a more detailed explanation specifically for the the design and analysis procedures involved in this project.

3.1 Design of Project Study

Due to the general nature of the topic, a basis for the project is outlined in which the design of the solar car power system would be done following the guidelines of the 2011 World Solar Challenge (WSC). Hence, the progress of the project is continued with a thorough understanding of the rules and regulations of the tournament focusing to the ones related to the topic. Based on the understanding, all the fundamental requirements of the solar car power system according to the tournament regulations are listed down as follow:

i. The area of the solar array must not exceed $6m^2$.
ii. For energy storage system that is built from commercially-available rechargeable cells, the maximum allowable weight for the batteries is shown in Table 3.1:

Table 3.1: 2011 WSC Maximum Battery Weight Allowed

Type of Battery Chemistry	Maximum Weight (kg)
$LiFePO_4$	40
Li-polymer	22
Li-ion	21
NiMH	70
Pb-acid	125
Ni-Zn	75
Ag-Zn	40
Ni-Fe	100

Source: 2011 World Solar Challenge Technical Regulations, (2010)

iii. Battery packs must be housed in boxes with lids that are preferably transparent. The boxes must be removable from the vehicle in which they are installed.
iv. A maximum of only 2 battery packs are permitted per solar car.

Then, from the list of guidelines obtained, the project problem statement, project objectives as well as project scopes are finalized. These are very important features of the project as they provide definitions of the project. Moving on, the study continues with the literature review and report writing. These are continuous processes that go straight towards the end of the semester. The preparation of literature review improves the understanding of the project topic into greater depth. At the same time, the project also proceeds with the identification of the subsystems of the solar car power system and its main components. There are altogether three main subsystems of the power system. They are the solar array, battery management and battery pack. For each subsystem, the main components are solar cells, maximum power point tracker and batteries respectively.

After each and every individual main component is identified, the project proceeds with the selection for type of components to be used in the design of subsystems. The selection consists of the type of solar cell to be used for the array, type of maximum power point tracker and type of battery for the battery pack. The selection process involves processes of analysis and comparisons between the existing types for each component. With the end of the component selection, the project proceeds with the preparation of the project proposal which also signifies that Part 1 of the project is almost completed. The project proposal is presented to a group of panels and lastly, the project proposal is submitted to the supervisor. For the second part of the project, most of the work left is in terms of design and analysis. The project proceeds with the design of the individual subsystems which are the solar array, battery management and the battery pack. From the designs that have been created, analysis was done through either calculations, technical reasoning or comparisons. In order to further enhance the practicality of the system, the design proceeds with the conditioning of the system. In this step, the overall internal nature of the system is taken into consideration including its surroundings. This is done so that the vulnerability of the system in reference with its own nature as well as its external environment can be identified. From the identification of these vulnerabilities, the safety features of the system are determined. Next, the designing process of the power system continues with the overall design of the power system. In this case, the overall operation of the system is analyzed and synchronized so that the system is feasible for implementation. The finalized design is then reviewed before the project continues with the documentation of the results. The documentation process is done to ensure that the results are properly arranged in order to be presented in the final report. After the documentation process, the project proceeds with its conclusion. Through the conclusion, recommendations are made so that the in the future, the project can be further improved. With that, most part of the project is already completed and the preparation of the final report is started. The outcome of the project is presented to a group of panels followed by the submission of the final report in the form of a thesis. Thus the project is completed.

3.2 Flow Chart

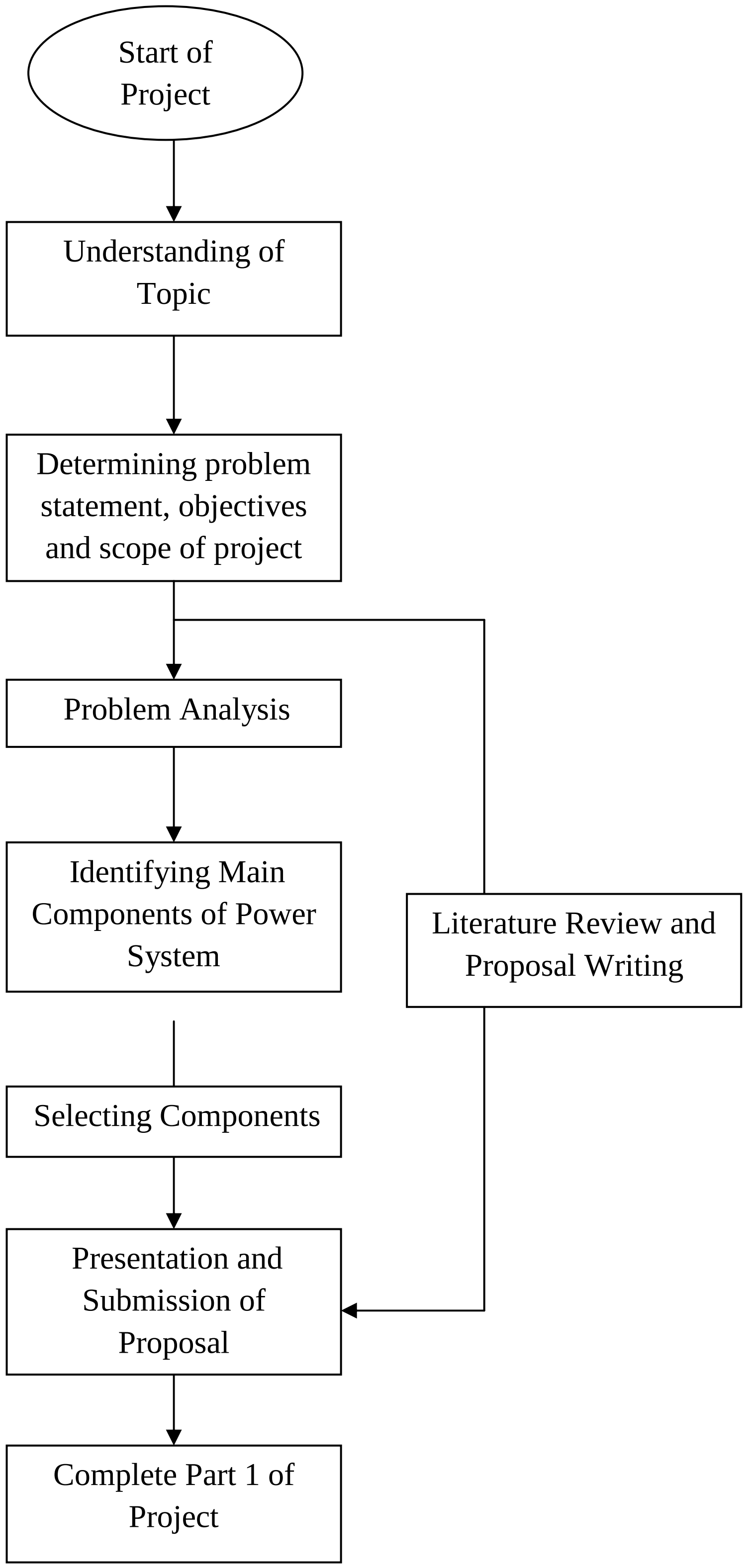

Figure 3.1: Flow Chart for Semester 1 Progress

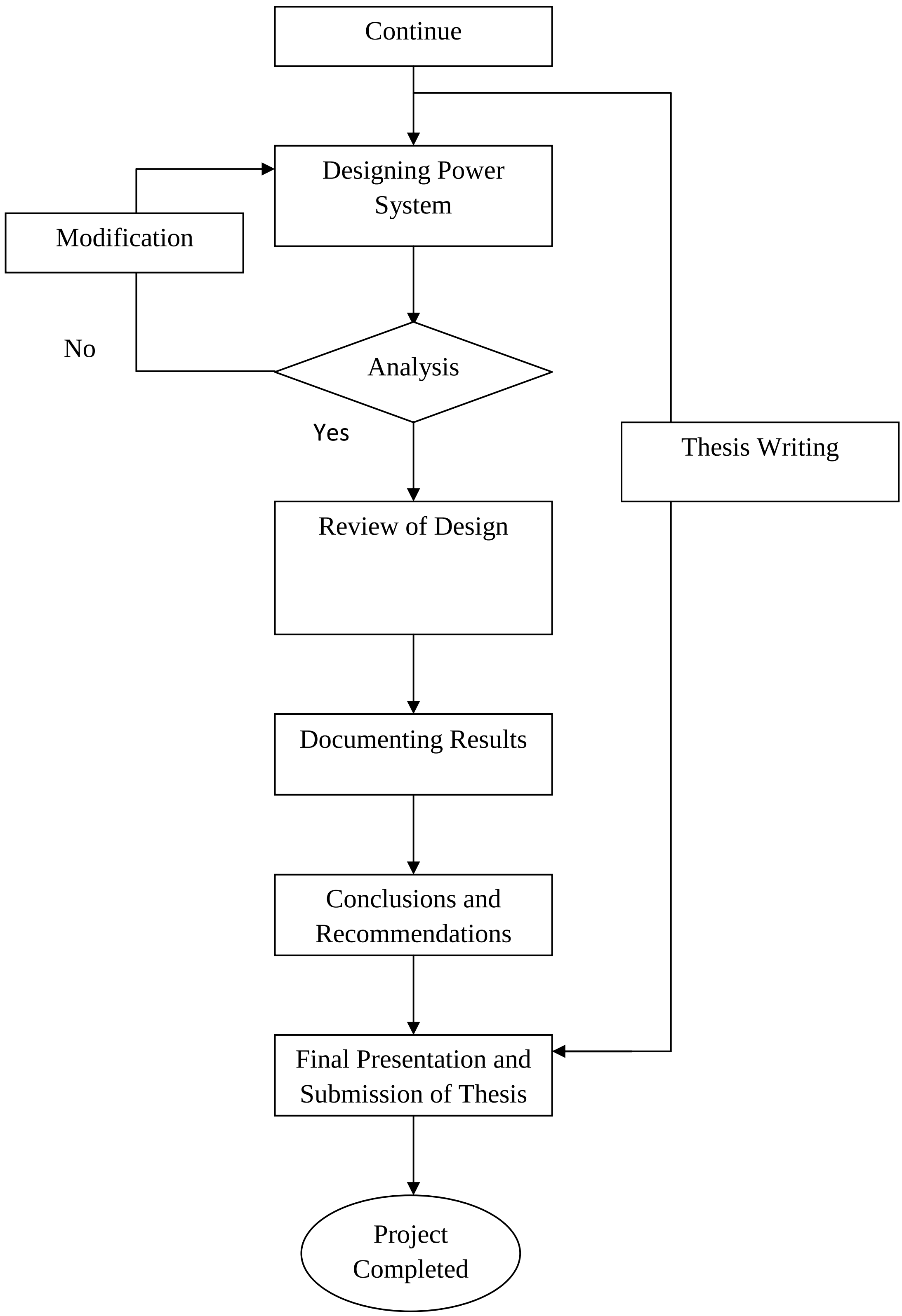

Figure 3.2: Flow Chart for Semester 2 Progress

3.3 Methods in Design and Analysis of Study

In this project, design and analysis is the most important procedure involved. This particular procedure can be broken into many levels. After the selection of subsystems' components, all subsystems are designed individually. After obtaining a bsic view of the power system from its subsystems, conditioning of the system is done. The conditioning focuses more on the way to enhance the practicality and the safety of the system. Lastly, the overall power system design is produced and compatibility within itself as well as between the actuation system of the solar car is analyzed.

3.3.1 Design of Solar Array

The solar array is designed via two methods. First method of designing the array is from the formation of commercially available solar panels and secondly, from the soldering of solar cells. The former is known as design A while the latter is design B. For both designs, first the number of solar panels or solar cells allowed has to be determined by dividing the maximum area of the solar array with the area of the solar panel or the solar cell as shown in equation 3.1.

$$Number\ of\ solar\ panels = \frac{6m^2}{Area\ per\ solar\ panel} \tag{3.1}$$

Then, the projected area, A of the designed solar array is calculated as well as its mass, m and cost.

$$Area\ of\ solar\ array, A = N \times Area, A\ per\ unit \tag{3.2}$$

$$Total\ mass, m = N \times mass, m\ per\ unit \tag{3.3}$$

$$Cost\ of\ solar\ array = N \times cost\ per\ unit \tag{3.4}$$

Next, the maximum output voltage and current of the solar array is calculated with the following equations;

$$Maximum\ output\ voltage, V_{mp} = N\ \times maximum\ output\ voltage\ per\ unit \quad (3.5)$$

$$Maximum\ output\ current, I_{mp} = N\ \times maximum\ output\ current\ per\ unit \quad (3.6)$$

N in all the above equations refers to the number of units used in system. After obtaining the above information, the maximum power output or the peak power, P_{max} of the solar array is calculated via equation 3.7.

$$Peak\ Power, P = Maximum\ voltage, V_{mp}\ \times Maximum\ current, I_{mp} \quad (3.7)$$

For design A, the schematic diagram of the solar array is sketched using SmartDraw 2010. As for design B, the schematic circuit of a single panel formed by the solar cells and the schematic diagram of the solar array are produced using SmartDraw 2010.

For both designs, the view of the placement of solar array on the upper body of the solar car is portrayed via Solidworks 2010. Besides, Solidworks 2010 is also used to design an array stand which is integral in the charging process of the solar array.

3.3.2 Design of Battery Pack

The battery pack is designed firstly by determining the type of battery to be used. Then using the maximum mass allowed for different types of batteries from Table 3.1, the maximum amount of batteries can be used is determined through the maximum mass of batteries allowed.

$$Maximum\ number\ of\ batteries, N_{max} = \frac{Maximum\ mass\ allowed}{Mass\ per\ unit} \quad (3.8)$$

Then the size of the battery pack is determined according to the suitability towards the system. After deciding the number of batteries to be used, the nominal voltage of the battery pack is calculated as well as its capacity.

$$Nominal\ voltage\ of\ battery, V = N\ \times nominal\ voltage\ per\ cell \quad (3.9)$$

$$Capacity\ of\ battery, Ah = N\ \times capacity\ per\ cell \quad (3.10)$$

Hence, the power capacity of the battery is calculated using equation 3.11.

$$Power, P = Voltage, V\ \times Capacity, Ah \quad (3.11)$$

The design of the battery pack is then continued with the design of the battery box. The battery box is drawn in Solidworks 2010 and the material that will be used to build the battery box is determined.

3.3.3 Design of Safety Features

The safety features of the power system is done via two levels which are electrical disconnects and wiring system. In terms of electrical disconnects, the most suitable electrical disconnect is chosen for the power system. The positions in which the electrical disconnects are located are also determined. In terms of wiring, the type of safe wiring is determined for the power system. In order to determine this, the internal and external natures of the power system are taken into consideration.

3.3.4 Design of Overall Power System

Last but not least, via the SmartDraw 2010 software, the block diagram of the system is built. The connections of the components in the power system are shown in the drawing. Analysis in terms of calculations and technical reasoning is done to test the compatibility of the system within itself and with the corresponding actuation system.

Chapter 4

Results and Discussion

4.0 Introduction

This chapter discusses various parts of the design with regards to the overall structure of the solar car power system. Therefore, the progress of this chapter is arranged according to the various parts of the design which are the solar array, battery pack, maximum power point tracker, wiring system, safety functions and lastly, the overall view of the system itself. Throughout the chapter, detailed analysis and calculations involved in the designing process are shown.

4.1 Solar Array

The solar array of the solar car is formed by monocrystalline solar cells. Monocrystalline type of solar cell is preferred compared to polycrystalline and amorphous mainly due to its higher efficiency. Hence, a monocrystalline solar cell can produce more power compared to polycrystalline and amorphous solar cells of the same size. A minor experiment is conducted to determine the efficiency of each type of solar cell. All solar cells used in the experiment are of the size of 125mm × 125mm with peak power output of 1 Watt. Table 4.1 shows the results of the experiment while Figure 4.1 portrays the efficiency of the cells as plotted in a graph.

Table 4.1: Relation between types of solar cells with power output

Time / Type	9.00am	12.00pm	3.00pm	Average Power (Watt)
	Power (Watt)			
Monocrystalline	0.57	0.88	0.75	0.73
Polycrystalline	0.43	0.70	0.62	0.58
Amorphous	0.36	0.59	0.44	0.46

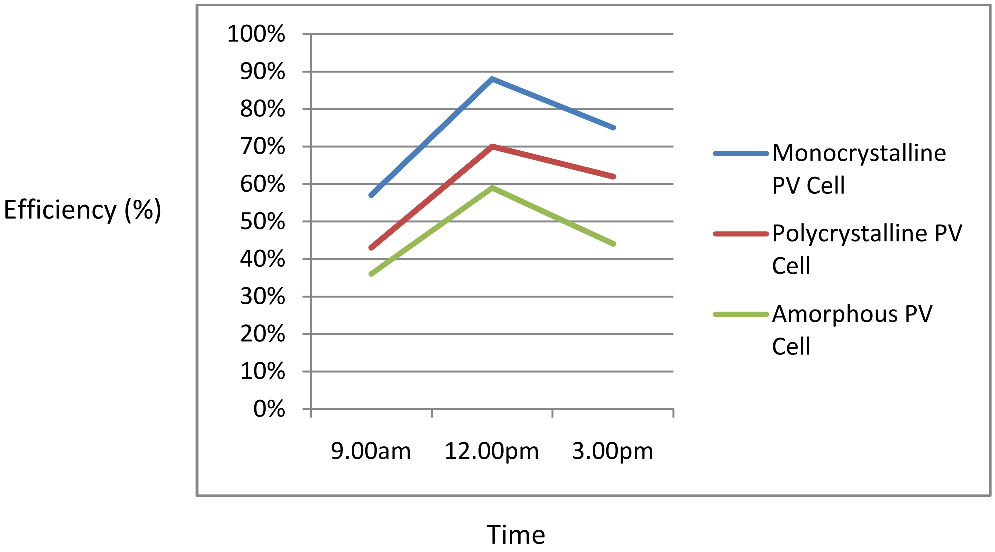

Figure 4.1 Graph of efficiency of different solar cells at different times of a day

From Table 4.1 and Figure 4.1, it is proven that monocrystalline photovoltaic cell has greater efficiency than its counterparts. At at dimension and peak power equal to the other cells, monocrystalline solar cell produces the highest power output. Through the results obtained from the experiment, it is also proven that the efficiency of solar cells varies according to the weather and time of the day. As observed, at noon, the solar cells are at their highest efficiency level compared to morning and evening mainly due to the location of the sun during that time.

The solar array of a solar car can either be formed quite directly from readily made solar panels which are commercially available or in the other hand, built from the soldering of solar cells. In the design of the solar array of this solar car power system, both methods are considered and a comparison of both methods is made.

4.1.1 Design A: Design of Solar Array from Commercially Available Solar Panels

The solar panel that is selected for this design is a product of SC Origin Sdn Bhd. It has a peak power of 50 watt with maximum power voltage and maximum power current of 18.22 volt and 2.75 ampere respectively. Furthermore, it weighs 6 kg with an area of 445 mm x 980 mm. The cost of one solar panel is at RM750.00. Taking into account that the 2011 World Solar Challenge rules and regulations state that a solar array can only occupy a maximum area of 6m^2, the amount of solar panels to be used in order to comply with this rule is:

$$Number\ of\ solar\ panels = \frac{6m^2}{Area\ per\ solar\ panel}$$

Therefore,

$$Number\ of\ solar\ panels = \frac{6m^2}{445\ mm\ \times 980\ mm}$$

$$Number\ of\ solar\ panels = 13.758$$

Since amount should be an integer, 13 solar panels should be used rather than 14. This is because if 14 solar panels are to be used, the total area of the solar array would be larger than 6m^2 thus breaching the rules of the competition.

However, in order to maximize the power output of the solar array with regards to the arrangements of the solar panels, only 12 solar panels are used. The 12 solar panels would consume an area of:

$$Area\ of\ solar\ array = 12\ \times 0.445m\ \times 0.98m =\ 5.233m^2$$

As for the approximate total mass of the solar array, a total of 12 solar panels would weigh:

$$Mass\ of\ solar\ array, m = 12\ \times 6kg = 72kg$$

Whereas, the calculated cost of the solar array consisting of 12 panels is approximately at:

$$Cost\ of\ solar\ array = 12\ \times RM750.00 = RM9000.00$$

The 12 solar panels are arranged in a 2 × 6 arrangement which means that there will be 6 sections with each section contains 2 solar panels connected in series to each other. These 6 sections are connected in parallel to each other. Hence, from this arrangement, the maximum voltage and maximum current obtained from the solar array are as follow.

$$Maximum\ voltage, V = 2\ \times 18.22\ Volt = 36.44\ Volt$$

$$Maximum\ current, I = 6\ \times 2.75\ Ampere = 16.5\ Ampere$$

From the calculated values of maximum voltage as well as maximum current of the solar array, the maximum power or peak power of the solar array is obtained through equation

$$Peak\ Power, P = Maximum\ voltage, V\ \times Maximum\ current, I$$

$$Peak\ Power, P\ of\ Solar\ Array = 36.44\ V\ \times 16.5\ A = 601.26\ Watt$$

The schematic circuit design of the solar panels arrangement is shown in Figure 4.2.

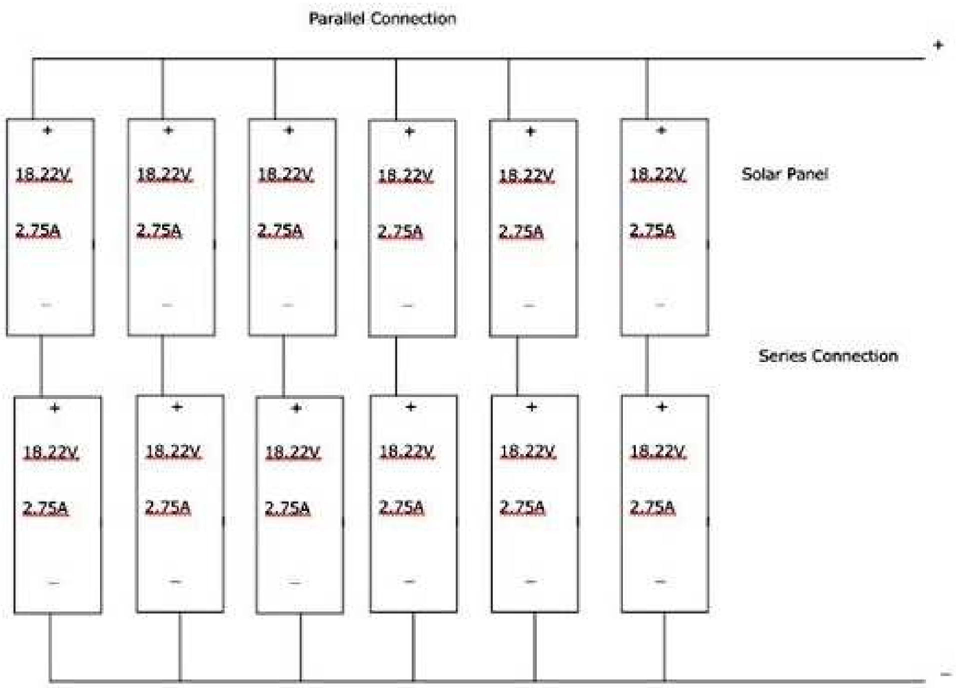

Figure 4.2 Schematic circuit design for series-parallel connection of solar panels

The position of the solar panels as designed on the upper body of the car is shown in Figure 4.3.

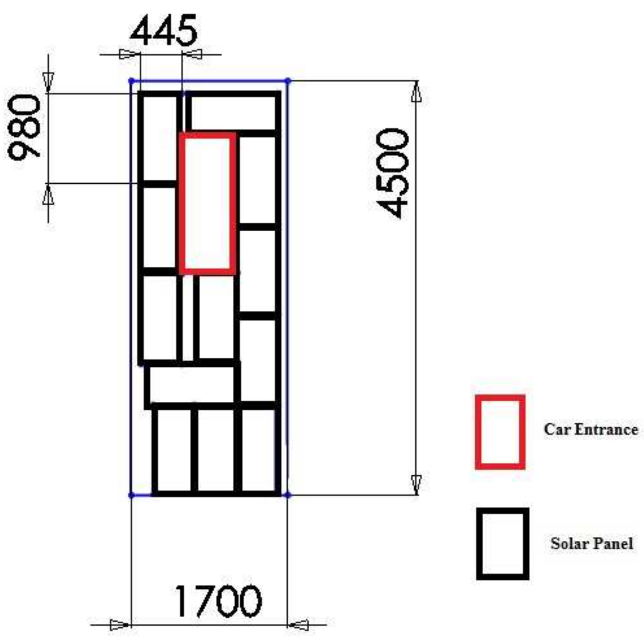

Figure 4.3: Design of solar panels placement on upper body

As witnessed in Figure 4.3, the position of the solar panels are quite untidy due to the fixed dimension of the solar panels. Solar panels of a particular fixed size have to be crammed within the space available on the upper body of the car. However, albeit the untidy arrangement, connection as portrayed in Figure 4.2 can still be done. For panels that are connected in series, they are connected at opposite terminals, meaning to say, positive to negative. As for panels that are connected in parallel, they are connected at the same terminals, meaning to say, positive to positive or negative to negative.

4.1.2 Design B: Design of Solar Array from Soldering of Solar Cells

The solar cell that is selected for this design is a product of Everbright Solar Incorporated, an American based photovoltaic company. For the purpose of easing the process of soldering, tabbed solar cells are used. The use of tabbed solar cells lessen almost half the work of soldering solar cells into a panel. Each tabbed solar cell has a peak power of 1.75 watt with maximum power voltage and maximum power current of 0.52 volt and 3.5 ampere respectively. Furthermore, each cell weighs approximately 60 grams and has a dimension of 80 mm x 150 mm. These tabbed solar cells are sold in bulks of 36, 108 or 500 cells. Since a solar array can only occupy a maximum area of $6m^2$, the amount of solar cells allowed to be used for the array is:

$$Number\ of\ solar\ cells = \frac{6m^2}{80\ mm\ \times 150\ mm}$$

$$Number\ of\ solar\ cells = 500$$

Therefore, the tabbed solar cells can be bought in a bulk of 500 cells. One bulk as such costs around RM2200. However, in the design of the solar array, only 480 cells are used in order to cater to the desired voltage and ampere output as well as make cover just in case if there are damaged solar cells. Solar cells are often damaged during shipping or soldering. The 480 solar cells would produce an array with an area of:

$$Area\ of\ solar\ array = 480\ \times 0.08m\ \times 0.15m =\ 5.76m^2$$

Taking into account just the mass of the solar cells, the approximate mass of the array is:

$$Mass\ of\ solar\ array, m = 480\ \times 0.06kg =\ 28.8kg$$

The 480 solar cells are being made into 10 solar panels with each panel having 48 solar cells connected in series. The schematic circuit design of the solar cells arrangement in a single solar panel is shown in Figure 4.4.

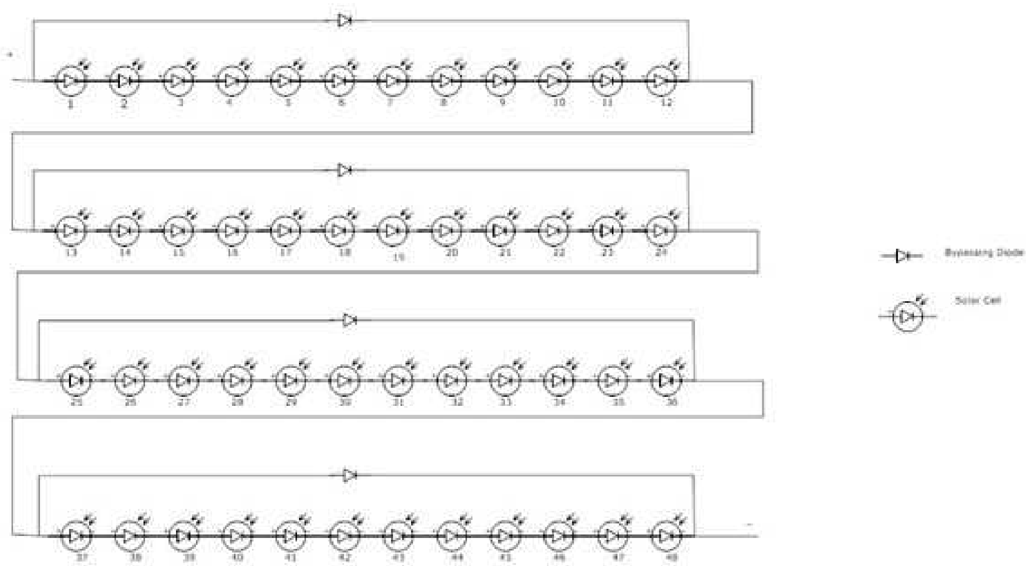

Figure 4.4: Schematic circuit design of solar cells arrangement per panel

Hence, from this arrangement, the maximum voltage and maximum current obtained from a single solar panel are as follow.

$$Maximum\ voltage\ per\ panel, V = 48\ \times 0.52\ Volt = 24.96\ Volt$$

$$Maximum\ current\ per\ panel, I = 3.5\ Ampere$$

In Figure 4.4, it is seen that the there is a bypassing diode attached parallel to every 12 solar cells connected in series. The purpose of the bypassing diode is to overcome the effect of shading. When part of the panel is shaded and thus disabled, the solar cells that are shaded become loads to the system with high resistance against the flow of current. Bypassing diodes create a path or least resistance around the disabled solar panel and help to protect solar panels from damage.

When solar cells are used to make an array instead of directly using commercially available solar panels, there is an extra process involved which is the soldering process. Soldering is done in order to connect solar cells and build them into a solar panel. Using wire cutters, wire strippers, a soldering iron and solder, each solar cells are attached to each other in the manner desired, series or parallel. After all solar cells are connected, it is covered with a layer of plexiglass that gives the cells protection from extreme weather, scratches as well as vulnerability of being damaged.

Hence, from the design of a single solar panel from solar cells as portrayed in Figure 4.4, 10 solar panels are made up. These panels are then connected in a series-parallel connection so that the desired maximum voltage and current of the solar array can be achieved. Figure 4.5 shows the schematic circuit design for the arrangement of the solar panels within the array.

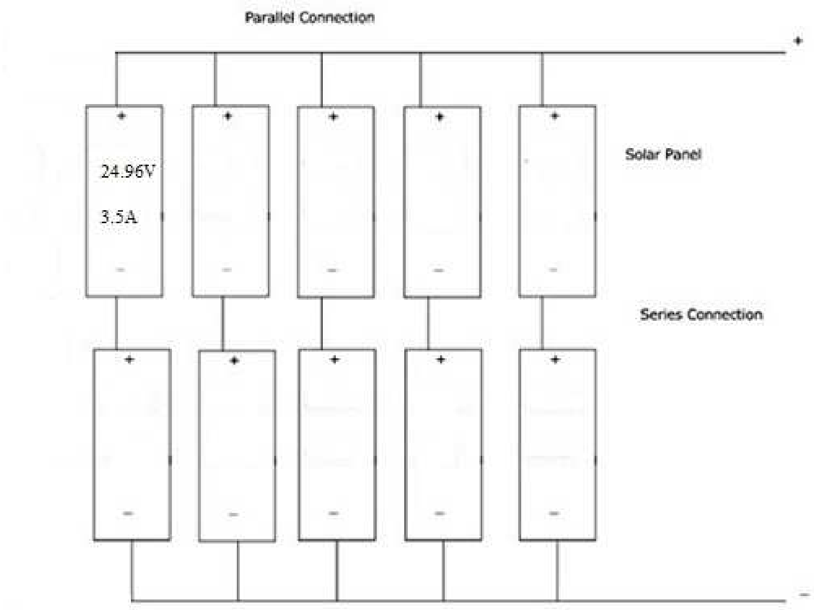

Figure 4.5: Schematic circuit design for connection of panels within solar array

Based on Figure 4.5, the maximum voltage and current of the solar array can be calculated.

$$Maximum\ Voltage, V = 24.96V \ \times 2 \ = 49.92V$$

$$Maximum\ Current, I = 3.5A \ \times 5 = 17.5A$$

From the calculated values of maximum voltage as well as maximum current of the solar array, the maximum power or peak power of the solar array is obtained through equation:

$$Peak\ Power, P = Maximum\ voltage, V \ \times Maximum\ current, I$$

$$Peak\ Power, P\ of\ Solar\ Array = 49.92\ V \ \times 17.5\ A = 873.6\ Watt$$

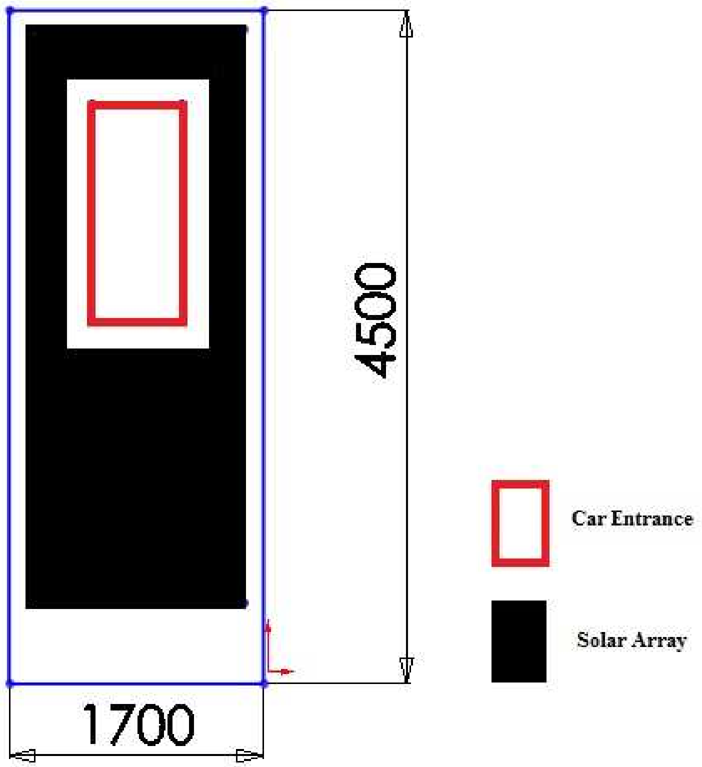

Figure 4.6: Design of solar array placement on upper body

The placement of the solar array on the upper body of the solar car is as shown in Figure 4.6. Due to the reason that the solar array is formed by individual solar cells, the placement of the solar array onto the upper body of the solar car can be customized during the soldering process of the solar cells. Hence, a more tidy outlook of solar array placement can be obtained.

4.1.3 Comparison of Solar Array Designs

After finishing with both designs, a comparison of the designs are made in order to determine the better method of building a solar array.

First of all, power output of the respective designs are taken into consideration. Design A yields a maximum power of 601.26 watt while design B yields 873.6 watt at maximum. The key to any solar power system is to produce as much power as possible. Hence, in terms of power output, design B prevails.

Secondly, comparing the mass of the two designs, design B is far lighter than design A. Design B weighs as much as only 28.8kg while design A weighs 72kg. One might argue that the calculated mass of design B does not includes encapsulation and soldering. But even if an overestimate value of 40kg is added into the mass of design B due to encapsulation and soldering, design A would still be the heavier one between the two. Mass of the solar array is an important attribute of a solar car since it plays a pivotal role in determining the speed in which the car can travel. The heaviear a car is, the more difficult it would be for the vehicle to travel faster.

Furthermore, in the approximate cost of the array, design B is by far cheaper than design A. Design A would cost at least RM9000. It is true that the cost of design B, which is RM2200, accounts only for the solar cells unlike design A which is already encapsulated. However, assuming that even if encapsulation and soldering consumes an additional RM5000, which is quite an overestimate, design B would still be relatively cheaper than design A.

Last but not least, when it comes to the process of mounting the solar array on the upper body of the solar car, design B is more preferred because when solar panels are built on our own, the shapes of the panels can be customized as desired. Hence, placement of solar array on the upper body is more arranged and neat. When readily made solar panels are used, altering the shape of the panels is quite redundant albeit possible. Hence, the mounting of the solar array has to comply with the fixed shape and dimension of the panels. As a result, a neat and tidy arrangement is hard to achieve. Table 4.2 summarizes the comparisons of design A and design B.

Table 4.2: Summary of designs comparisons

Criteria	Design A	Design B
Maximum Power Output	601.26W	873.6W
Minimum Mass	78kg	28.8kg
Minimum Cost	RM9000.00	RM2200.00
Flexibility of Design	Rigid	Flexible

4.1.4 Conclusion of Solar Array Design

Based on the comparisons made in part 4.1.3 as well as the summary shown in Table 4.2, it is decided that the better method of building the solar array of a solar car is through design B, which is from soldering of solar cells. Despite the additional work of soldering, which is known as very intricate, the end product is more suitable and rewarding than resorting to readily made solar panels. The use of tabbed solar cells lessen the work of soldering by half. Designing the solar array from tabbed solar cells is also cost effective, flexible to customization and most importantly, more efficient in the long run. The placement of solar panels onto the upper body is done by using double sided foam tape.

Hence, it is finalized that the solar array for this design of power system produces a maximum power of 873.6W at maximum voltage of 49.92V and maximum current of 17.5A.

4.1.5 Array Stand

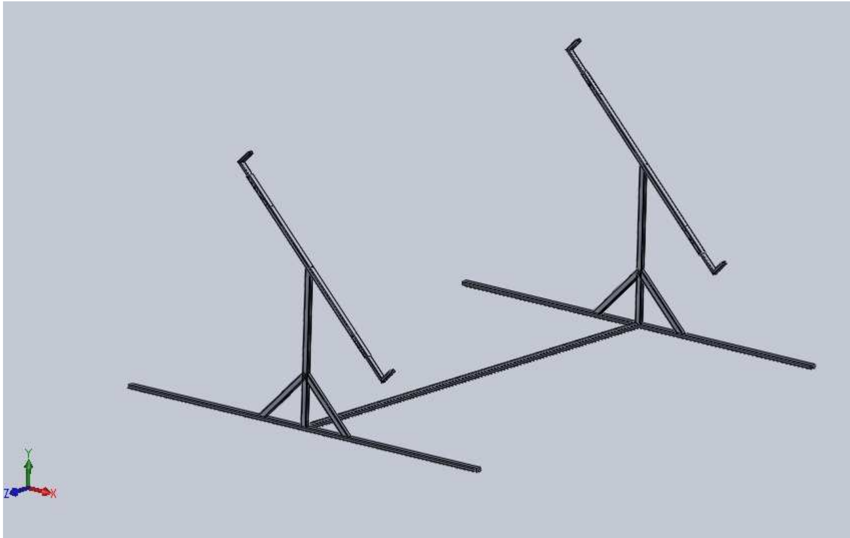

Figure 4.7: Array stand design

Figure 4.7 shows the isometric view of the designed array stand. A solar car race would go on for days and every day before the start of a race, teams are allowed to charge their power system. The array stand is used to hold the solar array for charging while the solar car is not in use. The material proposed for the array stand is low carbon steel due to its high strength. A material with high strength is important because the array stand would have to bear the heavy load of the solar car upper body whilst charging.

4.2 Battery Pack

The battery pack is a vital part of the solar power system since typically, a solar system is designed so that everything runs off the batteries. The solar panels are only replacing the electrical energy that has been stored in the batteries. In a solar car, a rechargeable, deep-cycle battery must be used. Deep-cycle batteries differ from other batteries in that their discharge rate is much slower. Deep cycle batteries have thicker lead plates and are designed to be discharged slowly. The process of designing a battery pack starts by determining the type of battery to be used, defining the attributes of the battery pack and last but not least, designing the battery box for the placement of the batteries.

4.2.1 Type of Battery

The type of battery chosen for the battery pack is a valve-regulated-lead-acid (VRLA) battery. Despite being heavy compared to lithium ion batteries, VRLA batteries has lower internal resistance and requires less maintenance. Lithium ion batteries are very sensitive in which they have to be handled with extra care due to their vulnerability in nature. Lithium ion batteries are also less durable compared to VRLA batteries. Most importantly, when it comes to a high cost project such as a solar project, cost reduction is very vital. In this case, VRLA batteries are way cheaper compared to lithium ion batteries. A cheaper battery would go a long way in saving plenty of money since in a solar car, a very large battery pack consists of many batteries is needed to run the system. Furthermore, the durability of VRLA batteries, mostly up to 10 years, means that replacement are not to be done frequently compared if less durable batteries are used.

In this battery pack design, the VRLA battery chosen is a product of Japanese based ABM. It is rated at 8V 160Ah. It also weighs 22.7kg and has a dimension of 281 mm × 195 mm × 323 mm.

4.2.2 Attributes of Battery Pack

Since the battery pack supplies electrical energy to the motor of the solar car, the operating voltage of the motor must be considered in order to determine the voltage of the battery pack. The motor selected for the solar car can be operated at a voltage within the range of 24V to 72V.

Based on the technical regulations of the 2011 World Solar Challenge as stated in Table 3.1, the maximum mass of lead acid batteries that can be used per solar car is 125kg. In order to maximize the amount of batteries used, the maximum number of batteries that caan be used for the battery pack design is calculated.

$$Number\ of\ batteries = \frac{Maximum\ mass\ allowed}{Mass\ of\ single\ battery}$$

$$Number\ of\ batteries = \frac{125kg}{22.7kg} = 5.5 \sim 5$$

The number of batteries to be used must be of an integer. Hence, in this case, based on the above calculation, five VRLA batteries will be used in the design of the battery pack. With five VRLA batteries making up the battery pack, the total mass of the batteries are:

$$Total\ mass\ of\ battery\ pack, m = 5\ \times 22.7kg = 113.5kg$$

In the design, all five batteries in the battery pack are connected in series. The series connection gives the battery pack a voltage of:

$$V_T = V_1 + V_2 + \cdots + V_n\ ; n = number\ of\ cells\ in\ series$$

$$Voltage\ of\ battery\ pack, V = 8V + 8V + 8V +\ 8V + 8V = 40V$$

Due to series connection of the batteries, its capacity remains the same which is 160Ah. Therefore, the power capacity of the battery pack is:

$$Power, P = 40V\ \times 160Ah = 6.4kWh$$

4.2.3 Battery Box

In the design of a battery box, there must be considerations that it needs to be light, strong, chemically resistant, corrosion resistant, electrically resistant, possess high impact resistance and relatively low cost. These characteristics are significantly related to the material of the battery box. Hence, the design of the battery box covers the material selection, drawing of the design and also the safety aspects of the design.

Material Selection

The battery box can be made of several materials such as fibreglass, aluminum, steel and polyethylene. Table 4.3 discusses the comparisons between the afore-mentioned materials:

Table 4.3: Comparisons of materials for battery box

Material	Strength (MPa)	Density (g/cm^3)	Yield	Corrosion Resistance	Electrical Resistance	Cost
Fiberglass	145.00	1.53	Can crack	Good	Good	High
Steel	250.00	7.85	Good	Poor	Poor	Low
Aluminum	400.00	2.70	Good	Average	Poor	High
Polyethylene	35.00	0.95	Good	Good	Good	Low

Source: Cameron Motor Works, (2005)

Based on Table 4.3, it is evident that each material has its pros and cons. Thus the most appropriate material has to be chosen for the battery box. By comparisons with other materials, aluminum is seen as the best material for the battery box. Despite its poor electrical resistance and considerably high cost, aluminum provides the perfect characteristics in terms of strength and material density. Since VRLA batteries are heavy and thus exert high load onto the surface of the battery box, in specific, aluminum 2024 is used because it has great realiability in bearing weight. Material density is important in the design of battery box because it defines the weight of the material. It is utmost vital for a solar car to minimize its weight as much as possible, hence the use of aluminum 2024 suits perfectly. As for the poor electrical resistance of aluminum, it can solved by using insulation on the surface of the battery box. Overall, although aluminum costs relatively higher than other materials, its advantages to the design outweighs its disadvantages.

Design of Battery Box

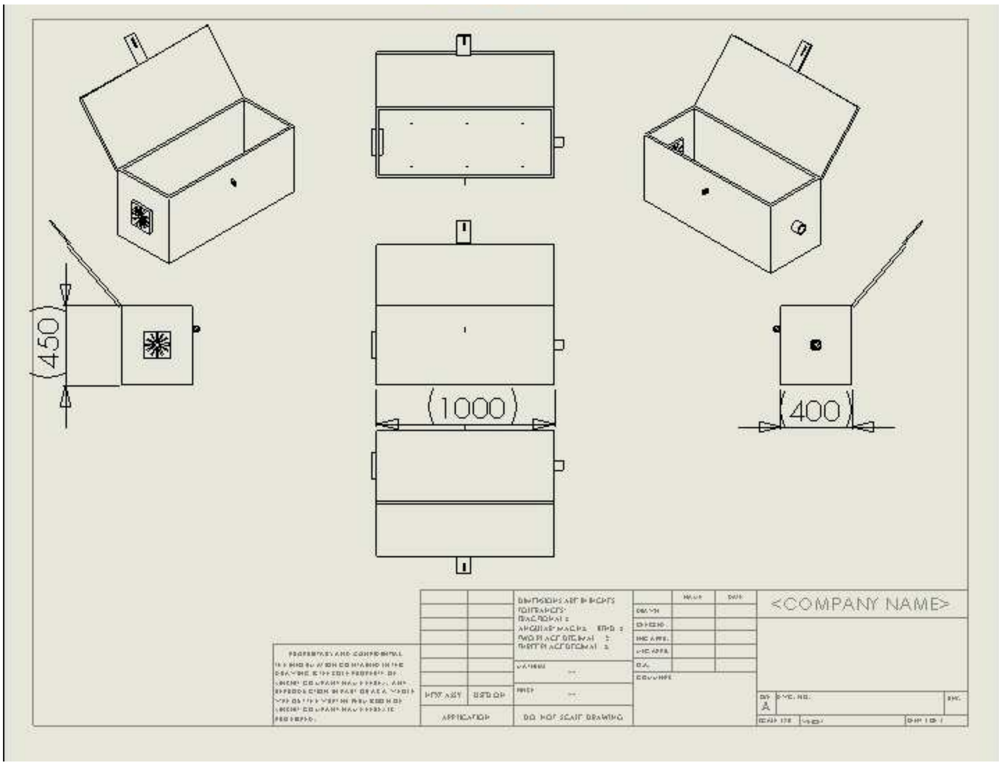

Figure 4.8: Drawing sheet of battery box

Figures 4.8 shows the drawing of the battery box. The battery box designed has a dimension of 1000mm × 400mm × 450mm. The dimension fits well with the space allocated by the frame of the solar car as well as provides enough room for the five batteries that make the battery pack. As stated earlier, the material used to build the battery box is aluminum 2024. However the lid of the battery box is made of a piece of rigid pvc sheet which is attached to the box via hinges. The battery box can be locked through the hinge that is existent on the front of its surface. The battery box is attached to the frame of the car via fasteners. One of the most important component of the battery box is the ventilation system of it. Through the drawings, it is evident that the battery box has a ventilation fan as well as a vent pipe in order to facilitate the movement of air within the battery box. Lead acid batteries has the tendency to discharge oxygen and hydrogen in which if the contents are high, can cause danger to the overall battery system. The ventilation fan used in this design is an ordinary computer system ventilation fan. The ventilation fan obtains electrical energy from the battery pack itself.

Proceeding with the design of the battery pack, the battery pack is formed by having the five batteries held inside the battery box by the holder as shown in Figure 4.9. The holder is made of low carbon steel, which is covered by paint in order to deter rust and corrosion so that its strength remains. The holder is fastened on the base of the battery box at both of its ends with the help of fasteners as portrayed in Figure 4.10.

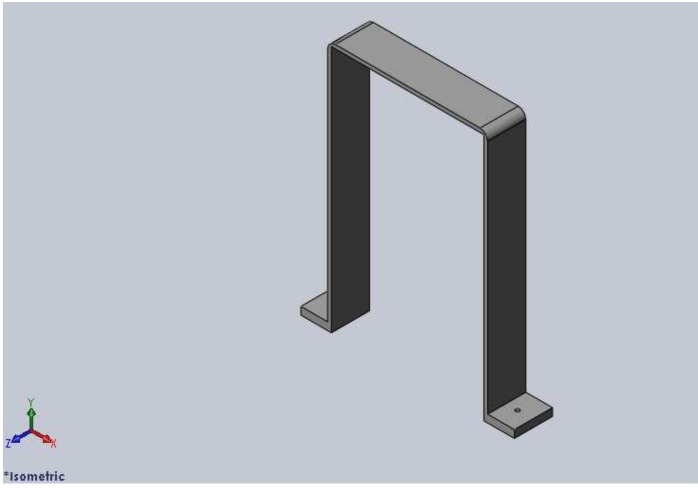

Figure 4.9: Isometric View of Battery Holder

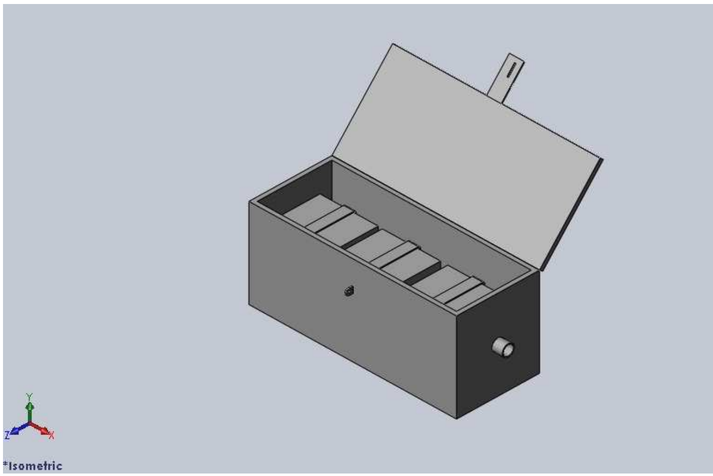

Figure 4.10: Isometric View of Battery Pack

4.2.4 Summary of Battery Pack Design

In a nutshell, the design of the battery pack consists of five VRLA batteries that weighs up to 113.5kg. The enormous weight of the batteries is coped by using high strength aluminum-2024 as the material for the battery box. The battery pack has a voltage of 40V and capacity of 160Ah. The power capacity of the battery pack is 6.4kWh.

4.3 Maximum Power Point Tracker (MPPT)

The MPPT that has been selected is TriStar MPPT 45, a product of US based company, MorningStar Corporation. The cost of the MPPT is RM1498.00 and it is distributed by a local solar company, SC Origin Sdn.Bhd.

4.3.1 Compatibility of MPPT with power system

The MPPT that is chosen is compatible with the power system in many ways. Firstly, the type of topology chosen for the MPPT is buck (step down) converter. There are several reasons on why the buck converter MPPT is selected. Since the photovoltaic source voltage is greater than the battery pack voltage, a step down mechanism is used to regulate the amount of voltage going into the battery pack. Therefore, although the voltage of the battery is only at 40V, maximum power from the solar array can still be stored into it by converting the excess voltage in current. Assuming that the solar array is producing maximum power, 873.6W will be produced. The MPPT would regulate the amount of voltage going into the battery pack to only 40V. Rather than wasting the extra voltages, the MPPT would convert it into current so that the all power generated can be stored in the battery pack. Hence, in this case, the amount of maximum current going into the battery pack is:

$$Maximum\ Input\ Current\ into\ Battery, I = \frac{P}{V}\ ; P = VI$$

$$Maximum\ Input\ Current\ into\ Battery, I = \frac{873.6W}{40V} = 21.84A$$

Based on the above calculation, the MPPT chosen must be able to bear the maximum current going into the battery. The TriStar MPPT 45 can bear up to a maximum 45A going into the battery pack. Therefore, again the MPPT is proven compatible in the sense that in can bear the maximum input current of the system which is 21.84A.

Besides that, there is an additional advantage using buck converter compared to other topologies because when using buck converter, the power dissipated or power losses from the system is reduced. Higher operating voltages and lower operating currents of the photovoltaic supply result in fewer power losses. The power losses can be demonstrated by Ohms Law;

$$P=I^2R \tag{4.1}$$

where I is the current through the wires and R is the resistance of the wire. By reducing the current through the wires by designing a system with high operating voltage, the amount of power dissipated is reduced.

4.4 Safety Functions

Safety functions of the solar car power system can be considered in my levels. In this section, safety of the solar car power system design is discussed in two levels which are electrical disconnects and wiring.

4.4.1 Electrical Disconnects

It is very important that every unit or device in the power system can be isolated electrically. Electrical disconnects play its role to protect the whole system as well as the user in case if something goes wrong with any particular part of the system. For this design, it is decided that there should be a disconnect between the solar array and the charge controller and between the connection of charge controller with the battery pack.

The disconnect chosen in this design is a DC rated circuit breaker. The DC rated circuit breaker protects the electrical circuit from damage due to short circuit overload. However in this design, a particular type of DC rated circuit breaker is used. The specific type of circuit breaker to be used in this design is the SWD DC-rated circuit breaker. SWD stands for switching duty. It means that in emergency times, the circuit breaker can be used as a switch in order to isolate the solar array and the battery from the entire system. The switch will then be made viable to the driver as well as to the exterior of the car in case of any emergency occurrence.

In order to size the circuit breaker, the regular current of the system must be known. In this design, the regular current is 17.5A. Hence, the the circuit breaker should be rated at:

$$Size\ of\ Circuit\ Breaker = 125\%\ (System\ Amps)$$

$$Size\ of\ Circuit\ Breaker = 1.25\ \times 17.5A = 21.875A$$

From above, the circuit breaker used must be rated at 43.75A. However, since there is no circuit breaker rated at that value, a 30A circuit breaker is used due to its common existence and best suitability.

4.4.2 Wiring

Since the solar car is a vehicle with very compact and limited space, the wiring of the car must be done safely in order to avoid any live wires dangling or within the contact of anyone. With this awareness, the wiring of the power system is designed to use PVC conduit, or to be more specific, schedule 40 PVC conduit.

Moreover, by using the PVC conduit, the wires are protected from extreme conditions such as heat or rain. Therefore, the durability of the wires can be susteained and at the same time, prevent any unwanted incident due to damaged wiring.

The use of PVC conduit is very convenient for the safety enhancement of the solar car power system because it is also light and the very easily manageable. The PVC conduit can be cut and glued easily. It is also very durable and does not fail under extreme conditions. One of the reasons of its durability is because it does not corrode easily. Hence, the strength of the material is quite easily mantained. Besides that, PVC conduit is also low in cost compared to metallic conduit.

4.5 Overall Power System Design

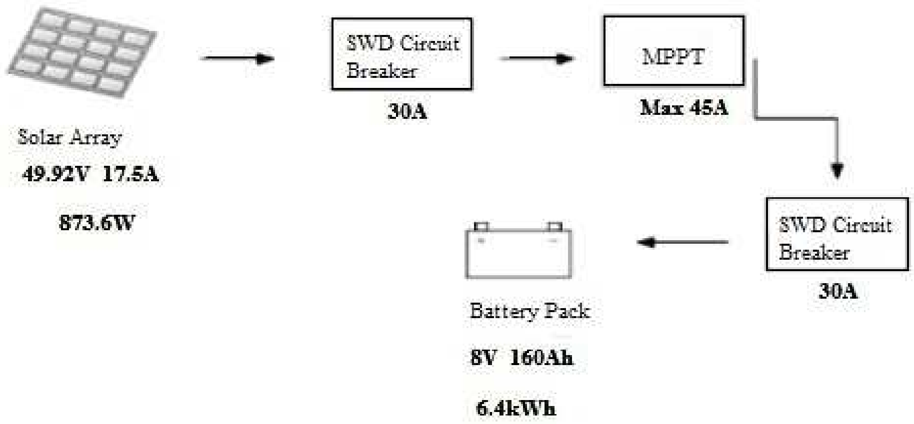

Figure 4.11: Power System Diagram

Figure 4.11 shows the overall view of the power system design. The solar array is designed to produce a maximum voltage and current of 49.92V and 17.5A respectively. At peak condition, the array designed produces a maximum power of 873.6W. From the solar array, the electrical energy passes through a 30A rated SWD circuit breaker which acts as an electrical disconnect to the connection between the solar array and the MPPT. If there is no problem encountered by the circuit breaker, the electrical energy generated by the solar array continuously flows into the MPPT.

The MPPT that is chosen for this design is TriStar MPPT, which operates as a buck converter. It can bear a maximum of 45A input current. Through calculation in part 4.3.1, the maximum input current of the system is 21.84A. The MPPT is of buck converter topology due to the reason that the maximum input voltage supplied by the solar panel is greater than the battery voltage. Hence, it will step down the input voltage and convert the excess voltage into current so that maximum amount of power produced is utilized in this power system design.

In between the connection of the MPPT and the battery pack, another 30A SWD circuit breaker is used. The battery pack is rated at a voltage of 40V and capacity of 160Ah. It gives a power capcity of 6.4kWh. The electrical energy flows all the way from the solar array into the battery pack in order to charge it. For this power system design, the amount of time for the solar array to charge the battery pack can be calculated.

$$Time\ to\ fully\ charge\ battery, t = \frac{Battery\ Capacity}{Maximum\ Input\ Current}$$

$$Time\ to\ fully\ charge\ battery, t = \frac{160Ah}{21.84A} = 7.33\ hours$$

4.5.1 Compatibility with Actuation System

The battery pack will supply electrical energy to the actuation system of the solar car. The actuation system starts with a motor controller which regulates the energy going into the motor. With the use of the motor controller, the input current to the motor is set at 25A so that 1kW of power is supplied to the motor continuously.

$$Power\ supplied, P = 40V\ \times 25A = 1kW$$

Therefore, from above, theoretically, the total time that will be taken by the battery before it is fully discharged is:

$$Time\ for\ battery\ before\ fully\ discharged, t = \frac{160Ah}{25A} = 6.4\ Hours$$

In the duration of 6.4 hours, assuming continuous peak power is produced by the array, the percentage of the battery already being charged can be calculated:

$$\%\ of\ Battery\ Charged = \frac{21.84A\ \times 6.4hrs}{160Ah} \times 100 = 87.36\%$$

The amount of time taken for a 87.36% charged battery to fully discharged is calculated as follow:

$$Capacity\ of\ battery = \frac{87.36}{100} \times 160Ah = 139.78Ah$$

$$Time, t = \frac{139.76Ah}{25A} = 5.59\ Hours$$

Therefore, with the present configuration of the power system, the motor of the solar car can run continously for:

$$Operating\ time, t = 6.4\ Hours + 5.59\ Hours = 11.99\ Hours$$

A particular solar race usually goes on for 10-12 hours per day, thus with this power system design, the solar car is most likely to go through the whole day of solar racing without facing power shortage.

CHAPTER 5

CONCLUSION

5.0 Introduction

This chapter discusses about conclusions and project recommendations. This chapter includes project summary, project findings and further recommendations to improve the project in the future.

5.1 Project Summary

This project requires a power system design of a solar car. The main components of the power system are the solar array, maximum power point tracker and battery pack. The main problems faced in the design of the solar car power system are the cost and the practicality of the design given that it has to bide by the rules and regulations of the World Solar Challenge. These are the main concerns throughout the progress of this project. The power system is designed in five levels which are the selection of the subsystems' main components, design of subsystems, conditioning of the system and lastly, the overall design of the power system itself. For the solar array, the array is decided to be formed by the soldering of tabbed solar cells rather than using commercially solar panels. An array stand is also designed in order to hold the array while charging out of a race. The material chosen for the array stand is low carbon steel which has great strength to uphold the upper body of the solar car. As for the maximum power point tracker, the type that is chosen for this power system design is the buck type which is the most efficient among the existing types of topologies. The battery pack is formed by five VRLA batteries which are cheap and durable despite its heavy nature. The batteries are supported in a battery box made of aluminum 2024. The battery box is equipped with ventilation as well as insulation using PVC sheets so that it is completely safe to be used. The safety features that are existing in the design are in terms of electrical disconnects and wiring system. The electrical disconnect that is used is a DC rated SWD circuit breaker which can also act as a manual switch in case of emergency. As far as the wiring system is concerned, the wiring is strenghten by a schedule 40 PVC conduit to protect the wires from damaging due to extreme conditions. The power system produces a maximum power of 873.6W, with 48V and 17.5A from its solar array. The battery pack with a full capacity of 6.4kWh stores the power generated. The power system is configured to supply continuous 1kW power to the motor. With this, under ideal conditions, the motor will be able to run continuously for at least 11.99 hours which is enough for a whole day's race. It is known that this particular design is just a conceptual design, based on theoretical values. However, it gives an essential view of the first steps in designing a solar car power system. Altogether, it is observed that the entire design has been able to minimize cost and whilst remains feasible to be produced. Besides, via proper justifications, the design is also proven compatible within the solar car system itself.

5.2 Recommendations For Future Research

There are a few things that can be done in order to improve this study. The very basic department in which improvement can be made is improvement in terms of the budget available to fund the project so that a proper fabrication of the design can be done instead of just a conceptual design. Furthermore, through a bigger budget, better components can be used in the system such as the use of lithium ion batteries instead of VRLA batteries. Besides that, this study can also be improved if there are other subsequent studies such as on the battery monitoring system or telemetry system. This is so that synchronizing of systems can be made and further improvements on the power system design can be done.

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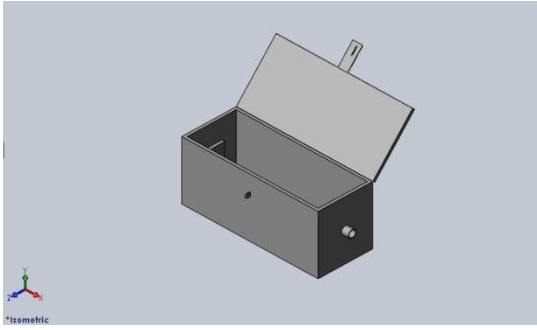
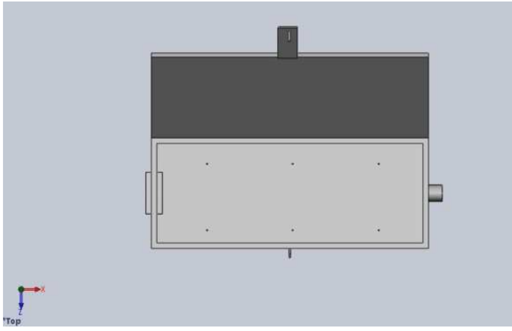
APPENDICES

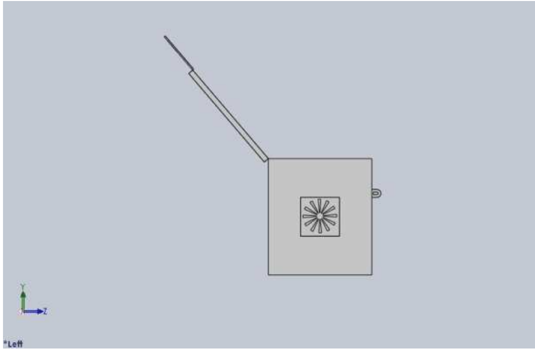
APPENDIX A: BATTERY BOX



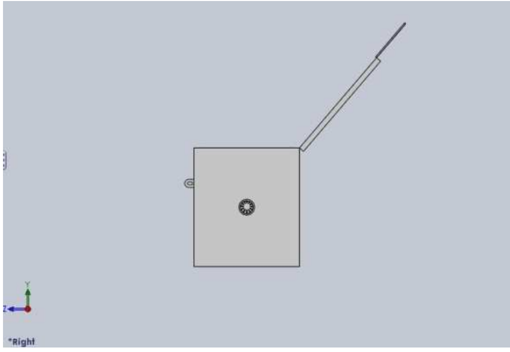
Isometric View



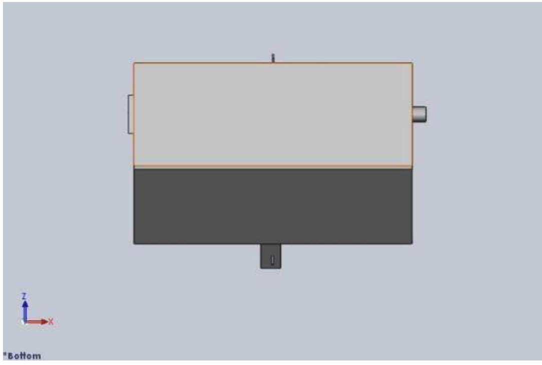
Top View



Left View



Right View



Bottom View

APPENDIX B: SPECIFICATIONS OF TRISTAR MPPT

TriStar MPPT	TS-MPPT-45
Maximum Battery Current	45 amps
Nominal Maximum Solar Input	
12 volt	600 Watts
24 volt	1200 Watts
48 volt	2400 Watts
Nominal System Voltage	12, 24, 36 or 48 volts DC
Maximum Solar Open Circuit Voltage	150 volts DC

APPENDIX C: SPECIFICATIONS OF SCORIGIN SOLAR PANEL

SPECIFICATIONS

Model type	ET-M53650	ET-M53655
Peak power(Pmax)	50W	55W
Weight	6.0kg (13.2lbs)	6.0kg (13.2lbs)
Dimensions	445×980×35mm 17.5×38.5×1.37inch	445×980×35mm 17.5×38.5×1.37inch
Maximum power voltage (Vmp)	18.22V	18.4V
Maximum power current (Imp)	2.75A	2.99A
Open circuit voltage (Voc)	21.96V	22.1V
Short circuit current (Isc)	3.04A	3.22A
Maximum system voltage	DC 1000V	DC 1000V
Temp. Coeff. of Isc (TK Isc)	0.06 %/ ℃	0.06 %/ ℃
Temp. Coeff. of Voc (TK Voc)	-0.397 %/℃	-0.397 %/℃
Temp. Coeff. of Pmax (TK Pmax)	-0.47 %/ ℃	-0.47 %/ ℃
Normal Operating Cell Temperature	44.4±2℃	44.4±2℃

Note: the specifications are obtained under the Standard Test Conditions (STCs): 1000 W/m² solar irradiance, 1.5 Air Mass, and cell temperature of 25℃.
The NOCT is obtained under the Test Conditions : 800 W/m2, 20°C ambient temperature, 1 m/s wind speed, AM 1.5 spectrum.

APPENDIX D: BATTERY