UNIVERSITI TEKNIKAL MALAYSIA MELAKA

FAKULTI KEJURUTERAAN ELEKTRIK

SOLAR HARVEST AND SUPERCAPACITOR FOR POWER STORAGE IN LOW POWER DEVICE

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A project report submitted in partial fulfillment of the requirement for the degree of Bachelor of Electrical Engineering (Industrial Power)

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2014

I hereby declare that I have read through this report entitle " Solar Harvest and Supercapacitor For Power Storage In Low Power Device" and found that is comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)

Signature : ………..…………………………….....

Name : WAN MOHD BUKHARI BIN WAN DAUD

Date :

I hereby declare this report entitle “Solar Harvest and Supercapacitor for Power Storage in Low Power Device” is the results of my own research except as cited in the references. The report has not been accepted for any degree and it is not concurrently submitted in candidature of any degree.

Signature : ………..……………………………..

Name : MUHAMMAD SYAHMI BIN AHMAD JOHARI

Date :

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Assalamualaikum,

I am feeling grateful to Allah for giving me the opportunity to accomplish my final year project, I would like to take this opportunity to express my gratitude to my dedicated project supervisor, Wan Mohd Bukhari bin Wan Daud for guiding and sharing valuable ideas and expertise. The knowledge shared help to solve issue and problem regarding to this final year project.

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ABSTRACT

Solar energy and photovoltaic (PV) was known as attractive solution as alternative power generation source that is sustainable. Despite of that, biggest limitation of solar energy is its avaibility. The reasons are the clouds and nightfall interrupt collection of energy, thus limit time and lack of efficient for solar to charge batteries during this situation. The purpose of this study is implementation of a solar energy using supercapacitor for power storage in application low power circuit devices. A supecapacitor is an energy storage device utilizes high surface area carbon to deliver much higher energy density than conventional capacitors. The supercapacitor balancing circuit use in this device as charging circuit and balance the voltage between two supercapacitors and thus protect them from overvoltage. In this study solar device performs maximum power solar energy collection from balancing circuit with under various light conditions, with high efficiency and low energy cost without using mechanical solar tracker. Much attention has been given to identify the power use in circuit component. The result shows that system maintains averagely 10V to charge the battery in any weather condition except nightfall. This system achieves low power consumption which maintained operation efficiency and reduce cost operation of solar energy.

ABSTRAK

Tenaga solar dan fotovoltaik (PV) adalah salah satu jalan penyelesaian yang menarik sebagai sumber alternatif. Walaubagaimanapun, had terbesar tenaga solar adalah kadar pencahayaan matahari. Ini disebabkan, cahaya matahari adalah terhad apabila berlaku perubahan cuaca seperti mendung dan hujan. Tujuan kajian ini melakasanakan sistem tenaga solar menggunakan superkapasitor sebagai simpanan dalam aplikasi voltan rendah. Superkapasitor adalah alat simpanan tenaga menggunakan karbon berkepadatan tinggi berbanding kapasitor konvensional. Litar pengimbang superperkapasitor digunakan bagi mengimbangi voltan di antara dua superkapasitor ketika dicaj dan melindungi litar daripada voltan terlampau. Dalam kajian ini, peranti tenaga solar melakukan pengumpulan tenaga secara optimum melalui litar pengimbang superperkapasitor di bawah pelbagai keadaan cuaca, dengan kecekapan yang tinggi dan kos tenaga yang rendah tanpa menggunakan tracker solar mekanikal. Perhatian yang lebih telah diberikan kepada mengenal pasti penggunaan kuasa dalam komponen litar. Hasilnya menunjukkan bahawa sistem mengekalkan 10V secara purata untuk mengecas bateri di bawah pelbagai keadaan cuaca. Sistem ini berjaya mencapai penggunaan tenaga yang rendah yang mengekalkan kecekapan operasi dan mengurangkan kos operasi tenaga solar.

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LIST OF SYMBOLS

Ω	-	Ohm
C	-	Capacitor
V	-	Volt
h	-	hour
mV	-	millivolt
A	-	Ampere
µV	-	microvolt
F	-	Farad
µF	-	microfarad
mA	-	milliampere
%	-	Percent

LIST OF ABBREVIATIONS

PV	-	Photovoltaic
LV	-	Low voltage
C	-	Capacitance
LV	-	Low Voltage
R	-	Resistance

CHAPTER 1

INTRODUCTION

1.1 Project Background

Solar power is renewable source of energy, which has become increasingly popular in modern times. There are lot of advantages over non renewable energy sources such as coal, oil and nuclear energy. It is non-polluting, reliable and can produce energy anywhere that there is sun shining, so its resources are not going to run out anytime soon. It also has advantages over other renewable energy sources, including wind and hydro power. Solar power is generated using solar panels, which do not require any major mechanical parts such as wind turbines. Energy storage is the key component in solar energy for creating sustainable energy systems. Currently, the dominating energy storage device is battery, particularly the lead-acid battery. The charge and discharge process in batteries is a slow process and can degrade the chemical compounds inside the battery over time. As a result, batteries have a low power density and lose their ability to retain energy throughout their lifetime due to material damage [1]. The supercapacitor uses a different storage mechanism. In the supercapacitor, energy is stored electrostatically on the surface of the material, and does not involve chemical reactions. Given their fundamental mechanism, supercapacitors can be charged quickly, leading to a very high power density, and do not lose their storage capabilities over time. Supercapacitors can last for millions of charge and discharge cycles without losing energy storage capability [2]. The battery behave like a slow and steady energy supplier for large energy demands, and the supercapacitor that charge and discharge quickly for low energy demands.

1.2 Project Motivation

In this study supercapacitors are used to store temporary energy to charge battery. They are attractive as they have a higher power density than batteries, do not require special circuitry, and have a long operational lifetime which is usually considered to be not effect to the number of charge and discharge cycles [2].

Many research efforts into the use of supercapacitors in second choice for power storage in low power device. From previous work the progress in low-power design, the research has greatly reduced the size and the power consumption in low power device, and the design of these systems can improve by use correct energy harvesting techniques and store the energy in supercapacitor. Nowadays, small solar panels suffice to ensure continued circuit operation, and several PV harvesting circuits have been recently proposed for low power device [3], [4].

Other works suggest using maximum-power-point tracking (MPPT) techniques in solar harvest for optimum supercapacitor charging. It stated that the output characteristics of a PV array vary nonlinearly when temperature or sun light conditions change. Therefore, maximum-power-point tracking (MPPT) techniques are use for adjusting the operating point of the solar panel in order to obtain the maximum output power from the PV module. So far, MPPT methods have been in small-scale PV power systems, usually without digital controllers. They are less accurate, but they are cheaper with advantageous cost efficiency in PV applications below 50 W for charging supercapacitor [5], [6].

1.3 Problem Statement

The biggest limitation of solar energy is sunlight avaibility. The reasons are the clouds and nightfall interrupt collection of energy, thus limit time and lack of efficient for solar to charge batteries during this situation. Solar power is used to charge batteries so that solar powered devices can be used at night or used in absent of light. The absent or less intensity sunlight prevent the solar energy charging the battery because during that situation the power collected not meet the charging voltage of battery.

1.4 Objective

The aim of this study is develop prototype a solar energy using supercapacitor for power storage in application low power circuit devices.

The objectives of this study are:

i. To design solar harvest using supercapacitor for power storage in low power device.

ii. To build a prototype solar harvest using supercapacitor for power storage in low power device.

iii. To analyze the performance of the design hycircuit by testing under various charging and discharging conditions.

1.5 Scope

The scope of this project is to study, understand and investigate the characteristic of supercapacitor and its advantage over commonly use. Hence the research is target to design energy using supercapacitor for power storage in application low power circuit devices. Then, the development of hardware prototype is implemented. The supercapacitor balancing circuit use in this device as charging circuit and balance the voltage between two supercapacitors and thus protect them from overvoltage. In this study solar device performs maximum power solar energy collection from balancing circuit with under various light conditions,. The performance of the circuit tested under various charging and discharging conditions. In addition, this prototype will be build based on simulation and testing that consist component of solar panel, supercapacitor and embedded system. The developed hardware will be test and analyze in term of it functionality.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

All the related topics and studies will be included in this chapter. In previous research and studies, all the information related to theory and characteristic of supercapacitor and photovoltaic have been collected either from IEEE journals, thesis, book and website.

Section 2.1.1 and 2.1.2 describe the theory and principles that involved in this project. Lastly Section 2.2 reviews the previous related work to this topic .

2.1.1 Photovoltaic

Photovoltaic is a method of generating electrical power by converting solar radiation into direct current electricity using semiconductor that exhibit the photovoltaic effect. Material presently used for photovoltaic includes monocrystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride and copper indium gallium selenide/sulfide.Open circuit voltage (Voc), is voltage developed as the terminals are isolated. The short circuit current (Isc), is current drawn as terminals are connected or with zero load resistance.

2.1.1.1 Limit in Photovoltaic Efficiency

The steady evolutionary progress of the PV industry is the result of increase in automation of engenderment of thin film solar cells with incremented efficiency and lower costs. The decider for revolutionizing breakthroughs in the PV industry is sometimes halted by the advancements in the PV materials and manufacturing technology leading to amendments in the cost competitiveness and the expansion of the PV market. By shattering the old limits of efficiency and cost by bringing about innovations by exploiting incipient understanding of physics and material science will become an expeditious paced revolution [7].

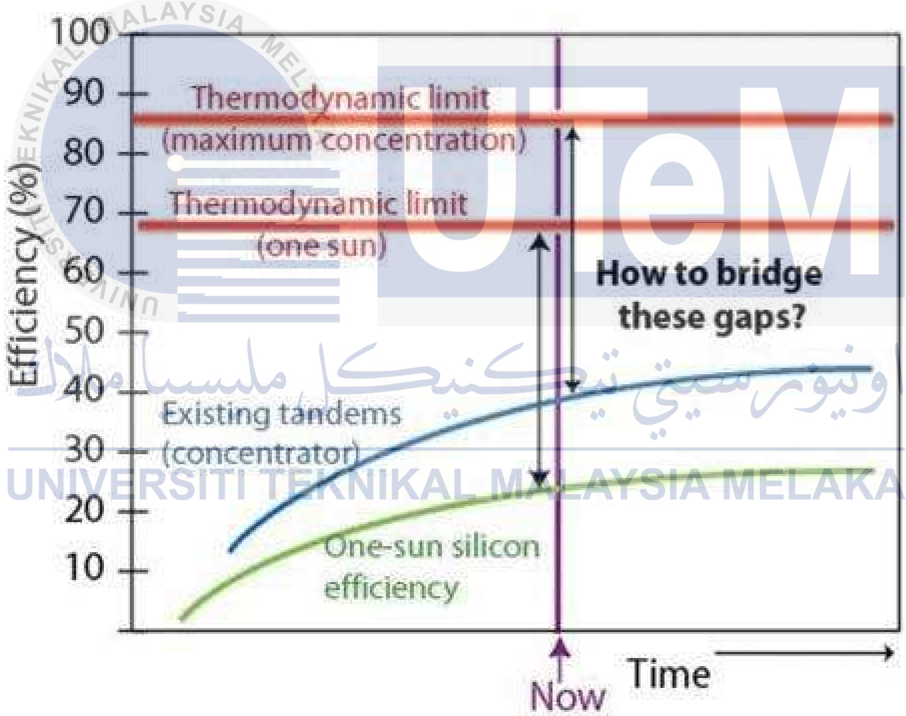

Figure 2.1: Narrowing gap between Existing and Theoretical PV efficiencies [7]

Figure 2.1 shows theorical for a solar intersection sun powered unit without daylight (one sun) is something like 31% made by the Schokley-Quiesser constrain. Under the most measure of daylight example. 50,000 suns a solitary intersection sun powered unit can have a greatest productivity of something like 41%. This productivity might be increased by using multi-intersection sun based cells by catching a greater amount of the sunlight based range.

Table 2.1: Data showing potential magnitude of future improvements in performance across device configurations [7]

Approximate Theoretical Limit Efficiency		Approximate Best Experimental Performance to Date	
Thermodynamic (concentrator)	87%	n/a	
Thermodynamic (1 sun)	68%	n/a	
Six-junction	58%	n/a	
Hot carrier	54%	n/a	
Triple-junction concentrator	64%	44%	III-V alloys, monolithic stack
Triple-junction (1 sun)	49%	15%	Thin-film amorphous silicon alloys
Double-junction concentrator	56%	30%	III-V alloys, monolithic stack
Double-junction (1 sun)	43%	12%	Thin-film amorphous silicon alloys
Shockley-Queisser single-junction (46,200 suns)	41%	30%	Crystalline silicon (500 suns)
Shockley-Queisser single-junction (1 sun)	31%	24% 20% 12% 6%	Crystalline silicon Thin multicrystalline silicon Dye-sensitized cell Organic cell

Table 2.1 shows data showing potential magnitude of future improvements in performance across device configurations , the best performance for PV thermodynamic concentrator by approximate theoretical limit efficiency 87%, the alternate configuration maybe the choice of triple-junction by approximate theoretical limit efficiency 64%. This configuration are specify by PV panel manufacture, solar panel best choose by it efficiency percentage.

2.1.1.2 Photovoltaic Working Principle

The point when light shines on a pn diode it created electron-opening combines over the entire device. Assuming that the apparatus is open circuited, the electron hole pairs generated near the depletion region tend to recombine with the charge in the depletion region, thus reducing the depletion region charge and eventually reducing the depletion region. The reduction in depletion region is equivalent of applying a forward bias to the device, this reduction in depletion region tends to develop a potential across the open terminals of the device. The maximum voltage that can be developed is the maximum forward drop across the device which theoretically is possible with the complete elimination of the depletion region. This maximum voltage that can be developed across the open circuited device is called the open circuit voltage represented by the point C in Figure 2.2. If the device is short circuited, the generated holes and electrons produce a current corresponding to the incoming photons. This current is called the short circuit current represented by the point A in Figure 2.2. When the pn device is used to drive an external load say 'R' the region of operation is somewhere in between these two points. The reason being a current, I flow through the device which creates a drop across the resistor and the direction of the current is such that the device comes into forward bias condition. As there is some drop across the load and the device the maximum output voltage is not equal to open circuit voltage. The forward bias conducts the device in the direction opposite to the current generated by the photons called the dark current. The presence of the dark current does not allow the device to operate at short circuit current. Thus the device operates in the fourth quadrant where the voltage is positive but the current is negative making the power negative, the device generates power using light as source.

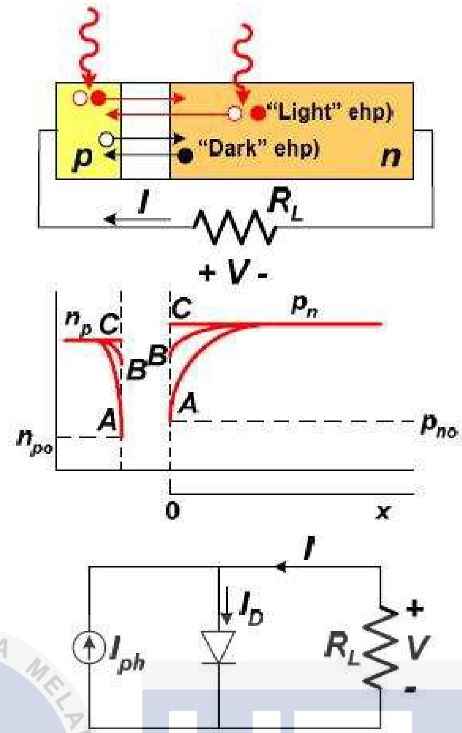

Figure 2.2 Working of a pn diode solar cell [7]

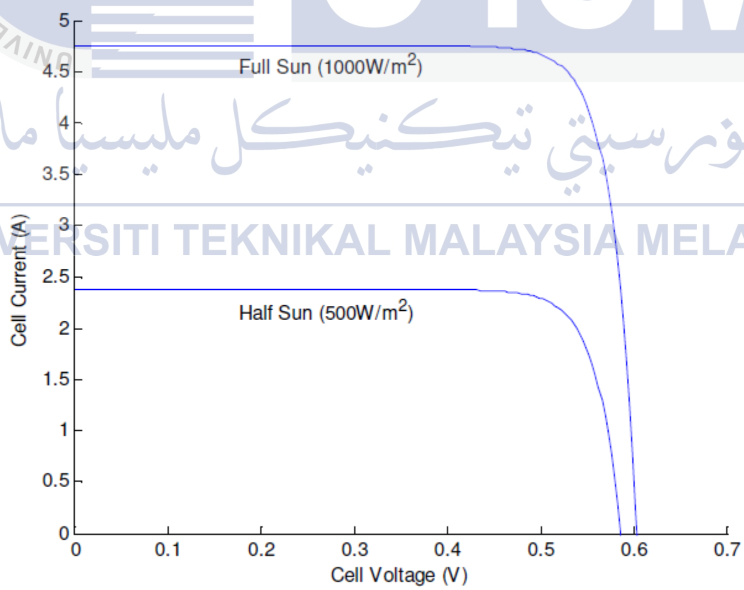

Figure 2.3: I-V plot of ideal PV cell under two different levels of irradiance [7]

The figure 2.3 show the current produce in two different weather condition, when the PV get full irradiance the cell current produce higher, this is limitation of PV depend on light intensity.

2.1.2 Supercapacitor

Supercapacitors also known ultracapacitor can be defined as energy storage device that stores energy electrostatically by polarizing an electrolytic solution. Unlike batteries no chemical reaction takes place when energy is being stored or discharged and so supercapacitor can go through hundreds of thousands of charging cycles with no degradation.

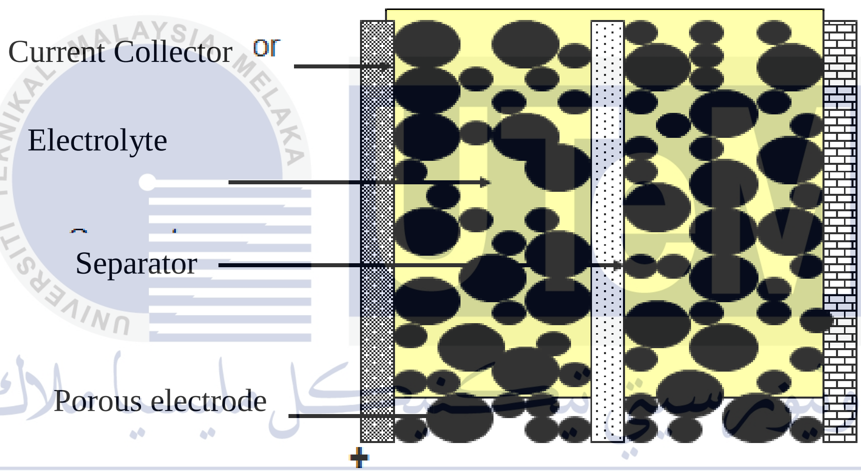

Figure 2.4: Supercapacitor electrode and electrolyte [2]

Figure 2,4 shows there are two carbon sheet separated by separator. The geometrical size of carbon sheet is taken in such a way that they have a very high surface area. The highly porous carbon can store more energy than any other electrolytic capacitor. When the voltage is applied to positive plate, it attracts negative ions from electrolyte. When the voltage is applied to negative plate, it attracts positive ions from electrolyte. Therefore, there is a formation of a layer of ions on the both side of plate. This is called 'Double layer' formation. For this reason, the ultracapacitor can also be called Double layer capacitor.

The ions are then stored near the surface of carbon. The distance between the plates is in the order of angstroms. Ultracapacitor stores energy via electrostatic charges on opposite surfaces of the electric double layer. They utilize the high surface area of carbon as the energy

storage medium, resulting in an energy density much higher than conventional capacitors. The purpose of having separator is to prevent the charges moving across the electrodes. The amount of energy stored is very large as compared to a standard capacitor because of the enormous surface area created by the (typically) porous carbon electrodes and the small charge separation (10 angstroms) created by the dielectric separator.

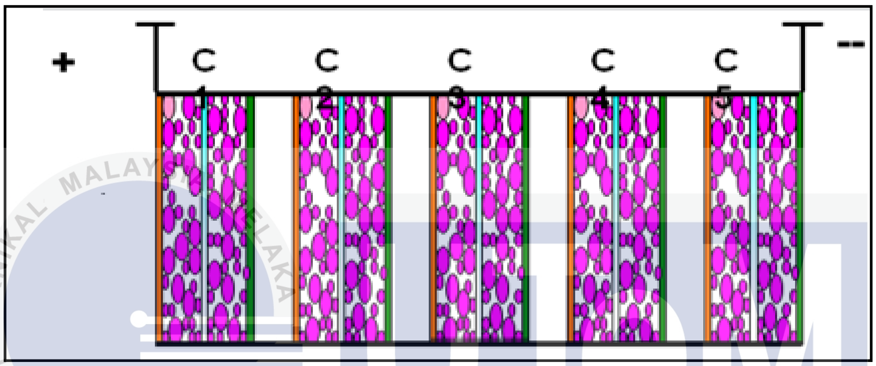

Figure 2.5: Supercapacitor Stack [2]

Supercapacitor consists of a porous electrode, electrolyte and a current collector (metal plates). There is a membrane, which separates, positive and negative plated is called separator. The following Figure 2.5 shows the supercapacitor module by arranging the individual cell.

Table 2.2: Advantages and limitations of supercapacitor [2]

ADVANTAGES	LIMITATIONS
Virtually unlimited cycle life - can be cycled millions of times.	Linear discharge voltage prevents use of the full energy spectrum.
Low impedance - enhances load handling when put in paralleled with a battery.	Low energy density - typically holds one-fifth to one-tenth the energy of an electrochemical battery.
Rapid charging - super capacitors charge in seconds	Cells have low voltages - serial connections are needed to obtain higher voltages. Voltage balancing is required if more than three capacitors are Connected in series.
Simple charge methods - no full-charge detection is needed; no danger of overcharge except lifetime deterioration.	High self-discharge - the rate is considerably higher than that of an Electrochemical battery.

The supercapacitor have advantage and disadvantage of its operation as shown in table, the main contribution is its rapid charging require on few second to full charge, it not require complex protection for overcharge voltage. Despite of that the supercapacitor got own weakness that get attention from engineering and education sector, the supercapacitor low energy density typically holds one-fifth to one-tenth the energy of an electrochemical battery.

2.2 Review Of Previous Related Works

A PV is the energy source in this project. These cells are used to convert solar energy into electricity. These cells are used to convert solar energy into electricity. This occurs when the photovoltaic cell are exposed to solar energy causing cells electrons to drift which in turn, produces an electric current. This current varies with the size of individual cells and the light intensity.

For light intensity, Bunea G, Wilson K, Meydbray Y, Campbell M and Ceuster DD was discuss in the Conference Record of the 2006 IEEE 4th World Conference on Photovoltaic Energy Conversion. The title of this paper is “Low Light Performance of Mono-Crystalline Silicon Solar Cells”. Changing the light intensity incident on a solar cell changes all solar cell parameters, including the short-circuit current, the open-circuit voltage, the fill factor, the efficiency and the impact of series and shunt resistances. Solar cells experience daily variations in light intensity, with the incident power from the sun varying between 0 and 1 kW/m2. At low light levels, the effect of the shunt resistance becomes increasingly important. As the light intensity decreases, the bias point and current through the solar cell also decreases and the equivalent resistance of the solar cell may begin to approach the shunt resistance. When these two resistances are similar, the fraction of the total current flowing through the shunt resistance increases, thereby increasing the fractional power loss due to shunt resistance. Consequently, under cloudy conditions, a solar cell with a high shunt resistance retains a greater fraction of its original power than a solar cell with a low shunt resistance.

The journal review super capacitors have an excellent power density, sometimes up to 100 times more than some batteries. Load characteristics are also very good with an efficiency of almost 100% compared with some batteries that only have 50-60%. The fact that they have pretty low energy density, up to 300 times less than some batteries, limits their use in Hybrid Electric Vehicle (HEV) to instant power assist.

Aging is not an issue for the super capacitor. Provided that it is not subjected to overvoltage, too large currents and too high temperatures its lifetime can be up to almost 80 years. It is also possible to deep cycle it more than 500000 times.When storing the super capacitor it is recommended to keep it in a cold place due to its high self discharge rate.

Capacitors store energy by charge separation. This energy is given by equation 2.1

$$\text{Energy store, } E = \frac{C \times V^2}{2} \tag{2.1}$$

Where *C* is its capacitance (Farads) and *V* is the voltage between the terminal plates. The breakdown characteristics of the dielectric material determine the maximum voltage of the capacitor. CV gives the charge Q (coulombs) stored in the capacitor. The capacitance of the dielectric capacitor depends on the dielectric constant (*K)* and the thickness (th) of the dielectric material and its geometric area (*A*).

$$\text{Energy capacitor, } E = \frac{K \times A^2}{th} \tag{2.1}$$

A super capacitor, sometimes referred as an electrochemical capacitor, is an electrical energy storage device that is constructed much like a battery. They utilize two electrodes immersed in an electrolyte with a separator between the electrodes. The electrodes are fabricated from high surface area, porous material having pores of diameter in the nanometer (nm) range. The surface area of the electrode materials (BET surface area) used in super capacitors, 500–2000 m2/g, is much greater than that used in battery electrodes being below 50 m2/g. Charge is stored in the micro pores at or near the interface between the solid electrode material and the electrolyte. Calculation of the super capacitors capacitance is much more difficult as it depends on complex phenomena occurring in the micro pores of the electrode. There are many sorts of super capacitor technologies; some examples are carbon double-layer capacitors, utilizing pseudo-capacitance capacitors, metal oxide capacitors, conducting polymer capacitors and hybrid capacitors

During charging the electrolyte anions and cations are drawn to electrodes of opposite polarity, Figure 2.6 shows where they accumulate into layers inside the activated carbon pores with a distribution governed by pore size. When charging, the electrolyte becomes depleted of ions.

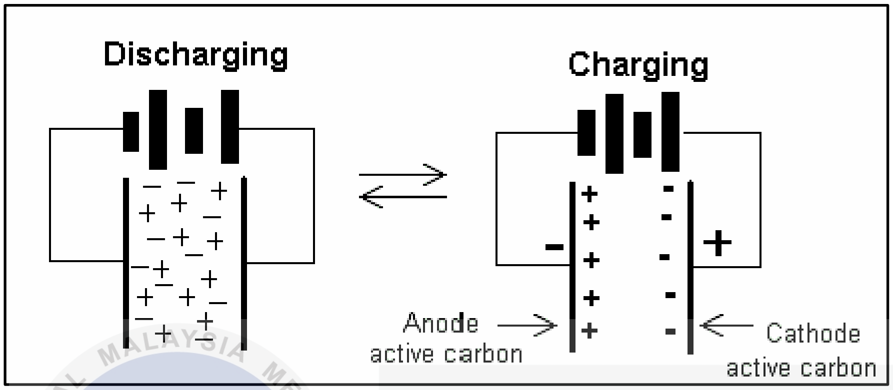

Figure 2.6: Distribution of electron and ion in the capacitor [2]

Various materials are proposed as electrodes and electrolytes. To increase the surface area of the electrodes and thus the energy density of the capacitor, the electrodes are made from materials such as activated carbon. In the sulphuric acid electrolyte system, activated carbon is used for the electrode material. In the organic electrolyte system, activated carbon or activated carbon fiber is used for the electrode material. Organic electrolyte systems are favorable because of keeping its decomposition voltage high.

Discotic liquid crystals (DLC) with organic electrolytes have voltage ratings of <3.0 V per cell whereas with aqueous electrolytes the voltage rating drops to <1.23 V per cell, typically 0.9 V. In all DLC's the terminal capacitance consists of the series combination of an anode DLC and the cathode DLC, so the net rated voltage is twice the value of the electrolyte decomposition voltage. Organic electrolyte DLC's have higher decomposition voltages and higher specific energy but higher resistance than aqueous types. The low conductivity of the organic electrolyte DLC results in higher ESR.

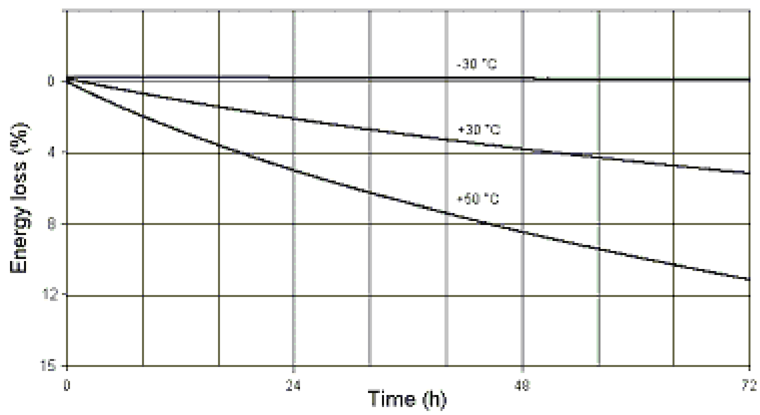

Figure 2.7 The self discharge rate of super capacitors at different temperatures [2]

The line graph in Figure 2.7 is from a double layer capacitor with symmetric carbon electrodes and with an organic electrolyte rated at 3600F.The reason why super capacitors have a higher self discharge rate than batteries is because of the fact that the super capacitors larger surface area favors oxidation of the electrolyte. This means that there is a larger leakage current in the super capacitor than in batteries [2].

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Methodology

This chapter will describe the method of implementation procedure and task of planning to design and develop hardware of solar harvest using supercapacitor for power storage in low power device in term of application. All the steps and techniques that had been used are recorded to be analyzed.

The voltage harvest from panel recorded in table and illustrate in a graph, the value recorded in two conditions. The PV data collection technique discuss in section 3.4.1. In section 3.4.2, the technique use for supercapacitor, the balancing circuit design for charging and balance purpose were explained.

Figure 3.1 show the flow of this study that begin from doing research on solar harvest using supercapacitor for power storage in low power device until the end of the report writing.

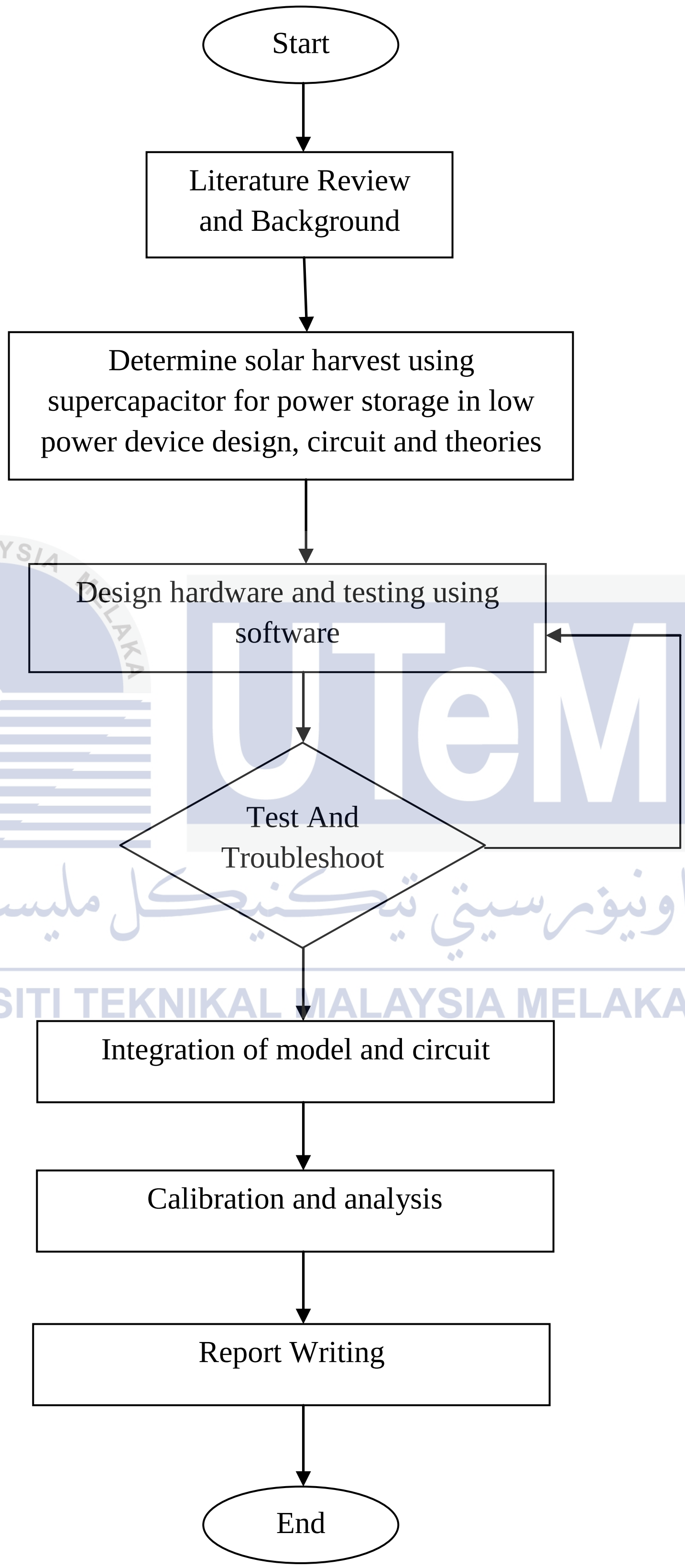

Figure 3.1: Flowchart of the project

3.2 Project Development Process Steps

The study for the project start with investigation through section, articles, journals and internet information to study, understand and investigate the characteristic of supercapacitor and its advantage over commonly use battery. This has been closely discussed in chapter 2.

After doing some extends research, a design for solar harvest using supercapacitor for power storage use in low power device is develop. The main component of the design is included of solar panel, supercapacitor, battery storage and led light as a load . The supercapacitor balancing circuit use in this device as charging circuit and balance the voltage between two supercapacitors and thus protect them from overvoltage. In this study solar device performs maximum power solar energy collection from balancing circuit with under various light conditions, with high efficiency and low energy cost without using mechanical solar tracker.

Then, the development of hardware prototype is implemented based on design. The performance of the circuit tested under various charging and discharging conditions. In addition, this prototype will be build based on simulation and testing the system. The hardware development was tested in terms of functionality and reliability. If any problems occurs, trouble shooting at the most suspected system will be done.

Once hardware development completed, the system need to follow process of calibration and analysis to make sure the system worked as in design.

3.3 Project Block Diagram

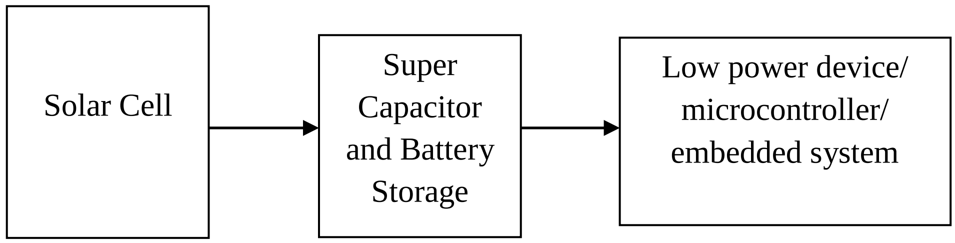

Figure 3.2: Solar Power Battery-less Wireless System Block Diagram

Figure 3.2 shows electrical energy are harvested from the sun irradiation by a solar cell. The energy harvest by solar cell then will be stored in the supercapacitor that acts as power storage. The power store in capacitor uses to operate the low power device such as microcontroller and embedded system.

3.4 Hardware Implementation

In this section the test and investigation of the use of solar panels and supercapacitors for the power supply and energy storage of the system. The use of supercapacitors will prove to be feasible if power consumption of the overall configuration below 10W. The general design of the power system that includes solar panels and super-capacitors Solar panels will be the power source of our system. They will provide a DC voltage (12, 24 or 48V possibly) when there is sunlight. A DC-DC step down converter receives power from the solar panels so that it decreases the voltage to a suitable value for the supercapacitors, since in most cases the voltage that a supercapacitor operates is around 2.5V. Larger voltages can damage the dielectric between the capacitor’s plates. Following the DC-DC step-down converter will be the capacitor tank, which will include a number of supercapacitors, connected in parallel, for energy storage. When there is sunlight, the supercapacitors will get charged and then remain fully charged. After the sun goes down, the solar panel will stop providing power and the supercapacitors will discharge and give their stored electric energy to the battery storage. A diode will be used between the step-down converter and the supercapacitor tank in order to avoid power leakage backwards. Since the voltage of the capacitors is relatively low compared to the system's voltage, a DC-DC step-up converter is also needed for increasing the voltage to an acceptable level for the system to work.

3.4.1 Photovoltaic

Figure 3.3 Photovoltaic panel

Polycrystalline Silicon PV panel in Figure 3.3 has been chosen as PV panel to produce energy from the sun. Unlike monocrystalline based solar panels, polycrystalline solar panels do not require the Czochralski process that discuss in section 2.1.1.1. Raw silicon is melted and poured into a square mold, which is cooled and cut into perfectly square wafers. The process used to make polycrystalline silicon is simpler and cost less. The amount of waste silicon is less compared to monocrystalline. Polycrystalline crystalline crystal is cut in a square rather than the rounder shape of the mono crystalline cell. This square shape means more of the solar panel area can actually be used to produce solar power as the available solar panel area is used space efficiently. Table 3.1 shows specification of solar panel use.

Table 3.1 Specification for Photovoltaic panel

Specification	
Type of panel	Polycrystalline
Solar Panel Power	6W
Open Circuit Voltage	12V
Dimension (mm):	356x267x3
Working temperature	-10°C to 50°C

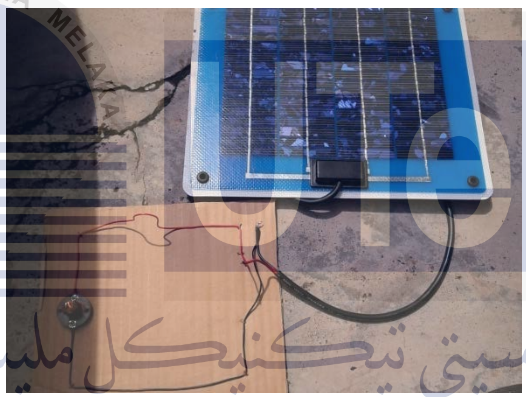

Figure 3.4 Testing and Measurement

For the testing and measurement the multimeter was used in every hour for voltage and current. The power will get from the theory P = IV. Figure 3.4 showstesting to get the reading voltage at bulb. To get the voltage and current for every hour, this photovoltaic was connecting to bulb voltage that must lower than photovoltaic. The rated of bulb is 24V and 5W. This data analyze if the panel is suitable for the system.

3.4.2 Supercapacitor

Supercapacitor has been use in this project as an energy storage to charge the battery. Battery is important as storage from photovoltaic. The low output current will increase time to charge the battery. Cooper Bussmann PowerStor supercapacitor type in Figure 3.5 has been used in this project. Its working voltage is 5.4V and nominal capacitance range is 0.47F. Table 3.1 shows the specification of this supercapacitor.

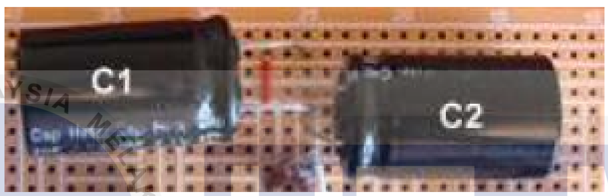

Figure 3.5 Couple Supercapacitor

Table 3.2 Specification for supercapacitor

Specification	
Working voltage (maximum)	5.4V
Surge voltage	6.0V
Nominal Capacitance range	0.47F to 5F
Capacitance tolerance	-10% to +30% (20˚C)
Operating temperature range	-40˚C to 65˚C
Extended operating temperature range	-40˚C to 85˚C (within linear voltage rating to 4.0 V @ 85˚C)

3.4.3 Led Light

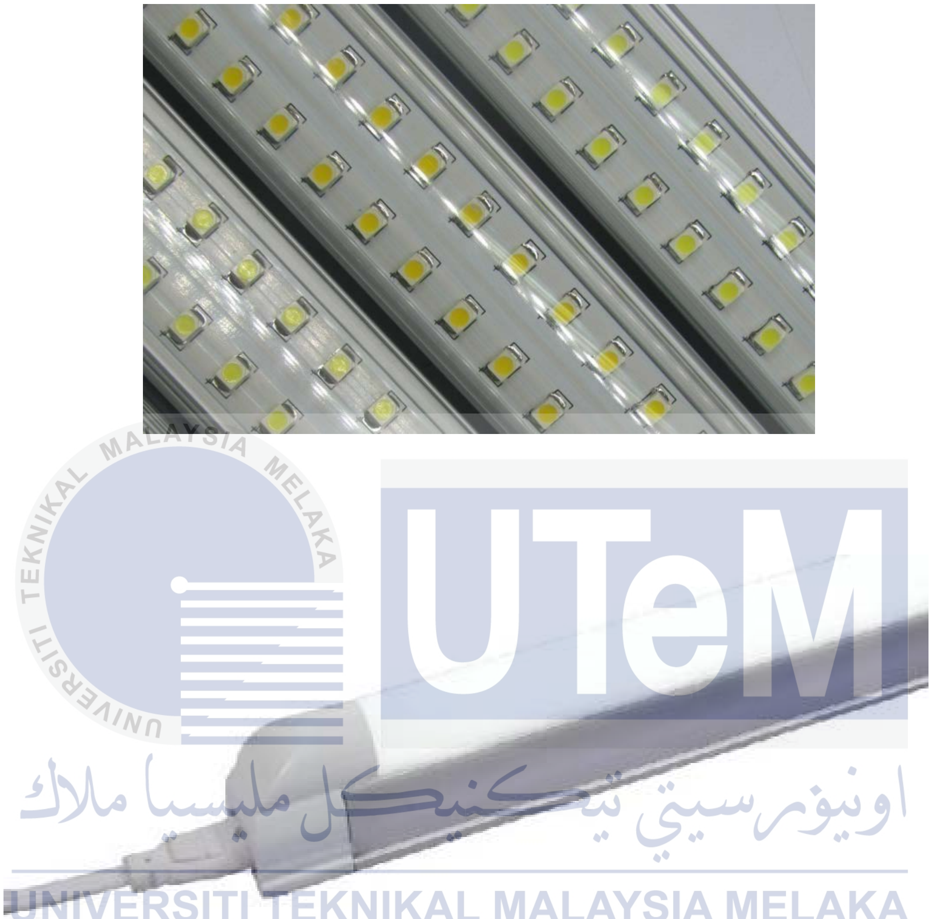

Figure 3.6 LED light 4w

Two pieces Light Emitting Diode (LED) light size 1 feet use in this study. This LED light consumes less electric power, every led light only rating 4 watt of power. In Figure 3.6 show the strip of led was installed in LED light to produce a bright light for certain size of space.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

Chapter 4 will discuss the result from data collected from simulation, test and experiment conducted. For the first result is the data from solar panel that connected in open circuit. The voltage recorded during bright and cloudy day. Second test conducted to find voltage charge and discharge a couple supercapacitor by using balancing circuit. The test is to find either the voltage in both supercapacitor balance or not during charging and discharging process.

4.1.1 Taking Reading Photovoltaic Voltage During Bright Day

The table 4.1 shows the reading of voltage from 6am until 7pm. At 6am. The voltage recorded every 30minutes. The reading taken during good weather with partially cloud movement.The data collected illustrated in graph figure of Figure4.1

Table 4.1 : Voltage reading during bright day.

Time(h)	Voltage(V)
6.30	4.2
7.00	4.1
7.30	4.3
8.00	5.0
8.30	4.9
9.00	7.0
9.30	7.1
10.00	11.2
10.30	10.9
11.00	11.5
11.30	11.4
12.00	11.8
12.30	11.4
13.00	11.5
13.30	11.8
14.00	11.8
14.30	11.6
15.00	11.3
15.30	7.4
16.00	8.3
16.30	8.6
17.00	8.4
17.30	5.9
18.00	6.0
18.30	6.4

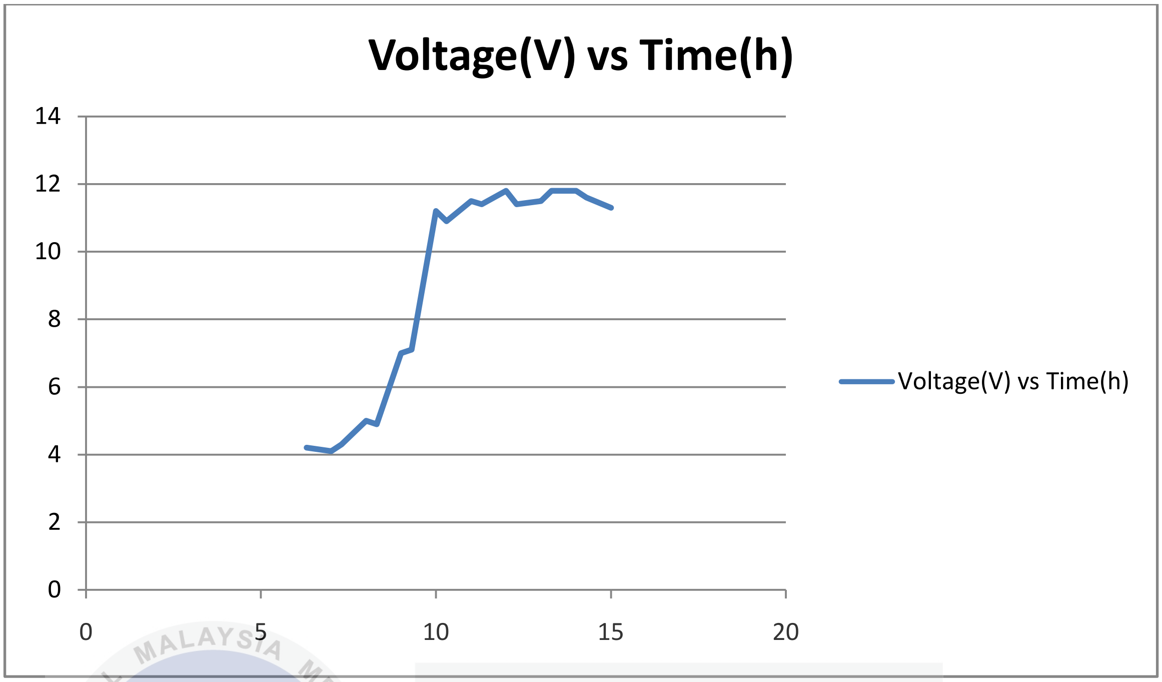

Figure 4.1 Voltage vs time During Bright Day.

Figure 4.1 shows the time for solar energy operation to charging only available 3 hours per day that is between 11.00 hour to 14.00 hour. The other hour the solar energy will not operate to charge battery.

4.1.2 Photovoltaic Voltage During Cloudy Day

Table 4.1 shows the reading of voltage from 6am until 7pm. At 6am. The voltage recorded every 30minutes. The reading taken during bad and cloudy weather with vigorous cloud movement. The data collected illustrated in graph figure 4.1

Table 4.2 : Voltage reading during cloudy day.

Time(h)	Volatge(V)
6.30	2.2
7.00	1.9
7.30	3.0
8.00	5.0
8.30	1.3
9.00	2.1
9.30	3.4
10.00	5.9
10.30	2.9
11.00	4.4
11.30	5.5
12.00	4.3
12.30	9.4
13.00	9.2
13.30	11.1
14.00	10.9
14.30	9.0
15.00	10.0
15.30	7.9
16.00	11.4
16.30	3.5
17.00	6.9
17.30	4.6
18.00	7.4
18.30	5.5

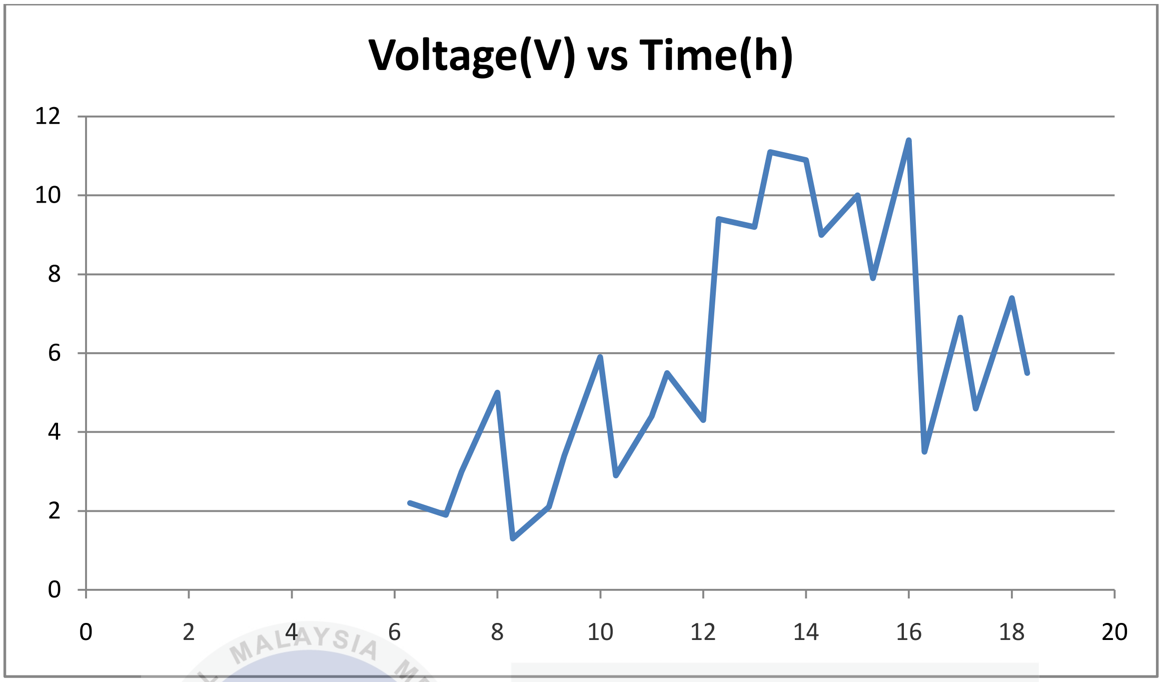

Figure 4.2 Voltage vs time cloudy day.

Form graph from figure 4.2 the time for solar energy operation to charging available less 2 hours per day that is between 11.00 hour to 14.00 hour. The worst case the voltage not consistently available to charge the battery. Most of other hour the solar energy will not operate to charge battery.

The Photovoltaic Panel averagely gives output 10V for both bright day and cloudy day operation. The Solar panel is not cost optimum for charging battery power storage. Normally the number solar panel will added to increase charge time for battery, so that it will increase cost operation per voltage harvest. The location of solar panel also important to avoid light obstacle reach photovoltaic surface. The direct sunlight to photovoltaic surface can give maximum power harvesting and avoid loses. The purpose of implementing supercapacitor balancing circuit capacitor really stabilizes the voltage capacitor to the battery charging operation. Hence, the number of photovoltaic panel can be reducing so the maximum cost operation can be benefit. This can avoid overvoltage waste as well as can reduce build cost.

4.2 Balancing the Voltage between Supercapacitors

The purpose of this circuit is to balance the voltage between two supercapacitors and help protect from overvoltage. When capacitor connected in series the voltage not always same. Usually two capacitor will share voltage but not same value this cause capacitor working not in rating voltage and cause damage to capacitor . Then the resistor RL will replace by DC-DC step up converter, to increase voltage for charging battery storage.

4.2.1 Balancing Circuit

The circuit includes two supercapacitors connected in series and a resistor (RL), which acts as a load shown in Figure 4.3. The circuit is balance by op amp MAX4770. The circuit runs in orcad pspice to monitor the discharge voltage.

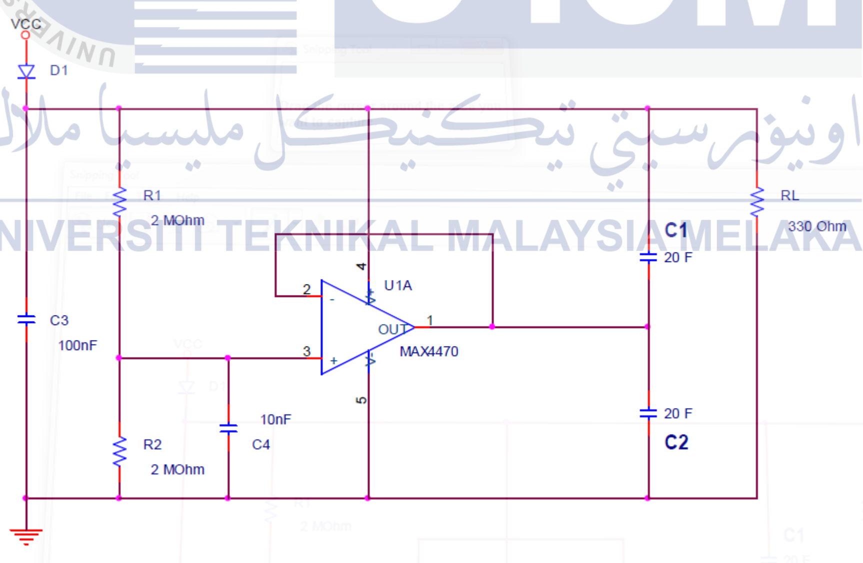

Figure 4.3 Balancing Circuit.

4.2.2 Simulation Result Balancing Circuit Capacitor Voltage Discharge without Load

From the Figure 4.4, the graph shows that the voltage out for discharge voltage of both capacitors without load. At beginning both capacitor fully charge then disconnected from supply. The value immediately recorded after supply is disconnected.

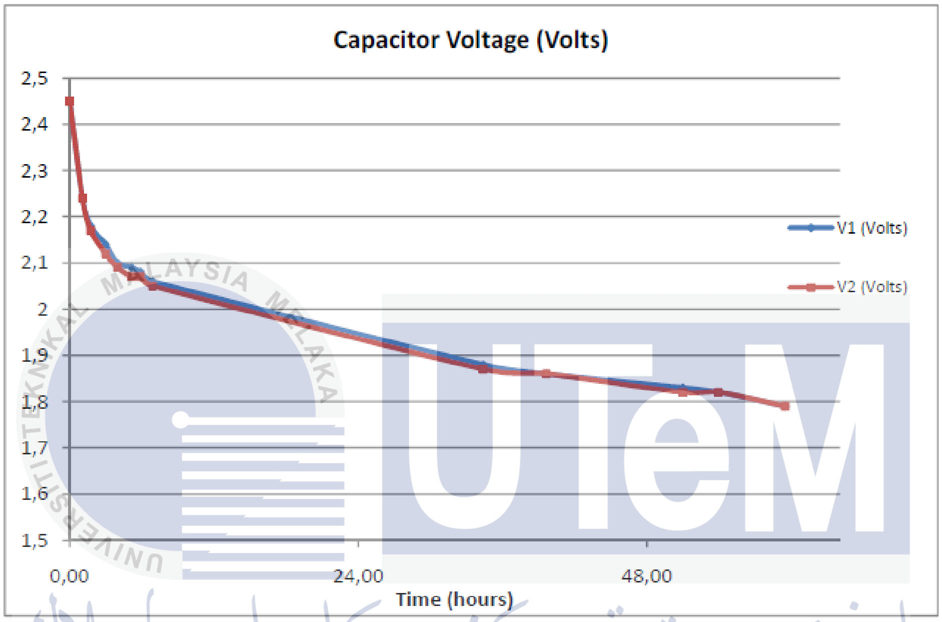

Figure 4.4 Voltage Capacitor C1 and C2

There is great drop from first hour and continue with steady discharge time. Average drop was at 0.03V per hour. The voltage in both capacitors is almost same because op-amp help balance voltage between capacitor. . Implementing balancing circuit capacitor really stabilizes the voltage between capacitor. The voltage collected show both supercapacitor have same value through discharging time. The supercapacitor can operate at optimum voltage without large different voltage between capacitor. This because the op amp MAX4770 will always operate amplified low side voltage to high side voltage during charging and discharging process. The supercapacitor will act as replace for battery during low voltage operation, the charge store can be use by DC-DC step up converter to charge battery.

4.3 Data Voltage Collected Supercapacitor Balance Circuit With Dc-Dc Step Up Converter During Bad Weather

Polycrystalline Silicon PV panel connected to supercapacitor Balance Circuit and the load replace by with Dc-Dc Step Up Converter. The condition weather are highly cloudy and the sun light very limited. The digital multimeterr was used to measure voltage. Table 4.5 show the results of this system

Table 4.5: Voltage reading of the system

Time(h)	Voltage(V)
8.00	10.1
8.30	11.2
9.00	9.8
9.30	9.7
10.00	10.9
10.30	11.3
11.00	9.0
11.30	10.1
12.00	11.5
12.30	11.6
13.00	11.1
13.30	11.1
14.00	11.9
14.30	10.9
15.00	11.3
15.30	11.3
16.00	9.7
16.30	10.8
17.00	11.7
17.30	10.6

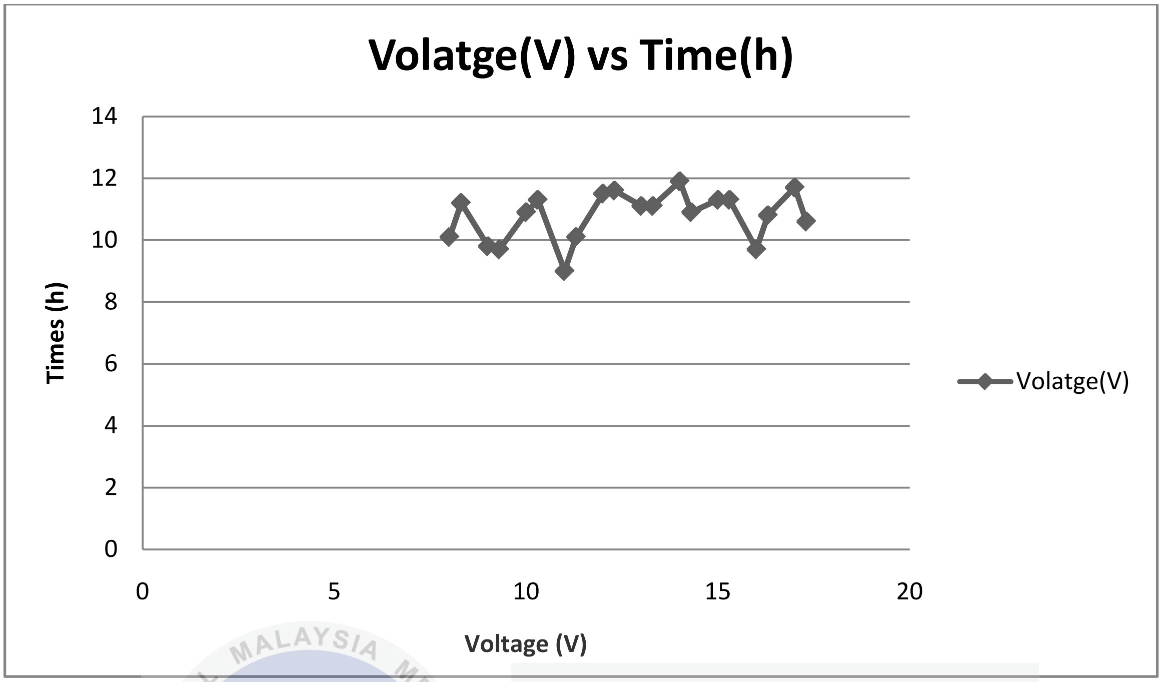

Figure 4.5 Voltage reading of the system

Form graph Figure 4.5 the time for solar energy operation available almost full half day that is between 8.00 hour to 17.30 hour. The base case the voltage consistently available to charge the battery. The main constrain is in night time when absent of light. The Photovoltaic Panel averagely gives output 10V for cloudy day operation. The Solar panel now in cost optimum operation for charging battery power storage. Propose implementing of supercapacitor balancing circuit capacitor really stabilizes the voltage capacitor to the battery charging operation. Hence, the number of photovoltaic panel can be reducing so the maximum cost operation can be benefit. This can avoid overvoltage waste as well as can reduce build cost.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

After two semester progress work, this project had met the objectives as mention in Section 1.4. Design of solar harvest using supercapacitor for power storage in low power device had test on Pspice simulation before building prototype. The design supercapacitor balancing circuit was created to charge and balance supercapacitor voltage during battery charging process. Then the prototype had been build to implement the design created, the prototype tested and analyze in term functionality and reliability. The prototype fully functional can be use for charging battery in various lighting condition, even the weather were bad. The third objective has been achieved which is to analyze the performance of the circuit by simulation and hardware testing under various charging and discharging conditions. The supercapacitor voltage shows that the value is adequate to operate low voltage device normally. The photovoltaic panel will provide enough power to charge the capacitor literally.

By building this system the limitation of solar energy for light irradiation can be improve, it is practically use to increase performance of solar panel, the panel will not require to install mechanical solar tracking hence can reduce cost and maintenance of solar energy. This prototype targeted for low power device and future study can improve the system to be used in more power demand application or connected in grid.

5.2 Recommendation

Nevertheless, there still many aspect and section can be study in the future. The further research may be pursued on the following aspects can be focused to make it operate for grid connected system. Next step for product development is to create system will be user friendly to use. The product can be more compact size for easy transportation. Finally, the next step for product development is to implement to embedded system such miniature robot or monitoring sytem for user daily device.

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APPENDICES

Solar Harvest by Using Supercapacitor for Power Storage in Low Power Device

Abstract-**Solar energy and photovoltaic (PV) was an attractive solution as a medium in producing sustainable and green power source for the society. The main objective of this paper is to implement a solar harvester platform using supercapacitor for power storage for the application in low power circuit devices. In this study, the solar harvest platform has performs the maximum power point tracking of solar energy collection under non-stationary light conditions by producing high efficiency and low energy cost without using mechanical solar tracker. The novelty of the study has been discovered since the non-stationary light condition has managed to generate power from solar energy. The design circuit was analysed by simulation and experimental testing under various types of charging and discharging conditions (bright day and cloudy day). Lots of improvements have been studied to identify the maximum power use in the circuit configuration. The result shows that the applied system performs achievable low power consumption and it is able to help the society in reducing the cost for power system utility in the future.**

Keywords: *Solar energy; Photovoltaic; Supecapacitor; Power storage; Low power device*

I. INTRODUCTION

The motivation of developing a device to store the energy harvest from the sun power for powering an embedded system was extremely increasing this time. Energy storage is the key component for creating sustainable energy systems. Currently, the dominating energy storage device remains the battery, particularly the lithium-ion battery. Lithium-ion batteries power nearly every portable electronic device, as well as almost every electric car. Batteries store energy electrochemically, where chemical reactions release electrical carriers that can be extracted into a circuit.. The charge and discharge process in batteries is a slow process and can degrade the chemical compounds inside the battery over time. As a result, batteries have a low power density and lose their ability to retain energy throughout their lifetime due to material damage [1]. The limited battery lifetime of electronic and mobile device require frequent battery replacement to make sure device work normally. A capacitor is similar to a battery because it can store and release electrical energy. But the way that capacitors work is very different from the way batteries work. Batteries are charged by chemical reactions. A capacitor does not use chemical reactions at all. Instead, the two terminals connect to two metal plates inside the capacitor. These plates are separated by a non-conductive material, which is called a "dielectric". This make supercapacitor can be charged and discharged almost an unlimited number of times, not affected by deep discharges as are chemical batteries, have a long lifetime which reduces maintenance costs and there is no danger of overcharging when fully charged the supercapacitor simply quits accepting a charge.

The supercapacitor uses a different storage mechanism. In the supercapacitor, energy is stored electrostatically on the surface of the material, and does not involve chemical reactions. Given their fundamental mechanism, supercapacitors can be charged quickly, leading to a very high power density, and do not lose their storage capabilities over time. Supercapacitors can last for millions of charge and discharge cycles without losing energy storage capability [2].

Many research efforts have been done in applying the supercapacitors for power storage. In [3] and [4], the small solar panels suffice to ensure continued circuit operation, and several photovoltaic (PV) harvesting circuits have been recently proposed. While the maximum-power-point tracking (MPPT) techniques in solar harvest for optimum supercapacitor charging has been proposed in [5-6]. The authors explained that the output characteristics of a PV array vary nonlinearly when temperature or sun light conditions change. Therefore, maximum-power-point tracking (MPPT) techniques are used for adjusting the operating point of the solar panel in order to obtain the maximum output power from the PV module. This method has been applied in small-scale PV power system without the digital controllers. But, the proposed technique is less accurate.

In term of light intensity, the authors in [7] has discussed regarding to the low light performance of Mono-Crystalline Silicon solar cells in details. The changing of the light intensity incident on a solar cell changes all solar cell parameters, including the short-circuit current, the open-circuit voltage, the FF, the efficiency and the shunt resistances. Solar cells experience daily variations in light intensity, with the incident power from the sun varying between 0 and 1 kW/m2. At low light levels, the effect of the shunt resistance becomes increasingly important. As the light intensity decreases, the bias point and current through the solar cell also decreases. Meanwhile the equivalent resistance of the solar cell may begin to approach the shunt resistance. When these two resistances are similar, the fraction of the total current flowing through the shunt resistance increases, thereby increasing the fractional power loss. Consequently, under cloudy conditions, a solar cell with a high shunt resistance retains a greater fraction of its original power than a solar cell with a low shunt resistance.

In this study, the supercapacitor concept for power storage has been applied in order to perform maximum power point tracking of solar energy collection under non-

Figure 8.1 Technical Paper of solar harvest using supercapacitor for power storage in low power device.

Figure 8.2 UTeMEX Silver Award.

Figure 8.3 I-ENVEX Bronze Award.