AUTOMATIC BATTERY CHARGER FOR MOBILE APPLICATION USING SOLAR PV MODULE

By

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FINAL YEAR PROJECT II

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Universiti Teknologi PETRONAS

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Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Automatic Battery Charger for Mobile Application Using Solar Photovoltaic (PV) Module

by,

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13691

A project dissertation submitted to the
Electrical & Electronic Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfillment of the requirement for
Bachelor of Engineering (Hons)
(Electrical & Electronic)

Approved by,

____

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May 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and the original work contained herein have not been undertaken or done by unspecified source or persons.

(Asroy Angkoi)

ABSTRACT

This project aims to upgrade the efficiency and reliability of traditional charging by introducing an automatic battery charger using solar photovoltaic (PV) module where light radiation from the sun which is converted into electricity acted as power source and is harvested through the introduction of a small solar photovoltaic modules. This new introduction of automatic battery charger emphasizes on automatic charging and termination in order to ensure the battery is not endangered. This project will be carried out starting with the grasp of theoretical analysis, then move into the simulation phase with the aim to identify best circuit design for the project, and lastly the prototype construction phase. The end result of this project will involve a functional prototype that will be able to charge a mobile phone when exposed to the sun. The successfulness of this project will have a huge impact on the mobile application industry and media interactions businesses.

ACKNOWLEDGEMENT

First and foremost, I would like to convey my greatest gratitude to God for providing me with great condition, health, and well-being throughout the process of completing the project successfully. I also would like to express my gratitude to all the parties that involve in contributing towards project completion neither directly nor indirectly. Throughout the duration of Final Year Project (FYP), I have learnt a lot and gain precious experiences that will surely benefit me in the future.

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LIST OF ABBREVIATIONS

BC:	Battery charger
PV:	Photovoltaic
OTA:	Operational transconductance amplifier
FYP I:	Final year project I
FYP II:	Final year project II
V:	Voltage
A:	Ampere
AC:	Alternating current
DC:	Direct current
IC:	Integrated circuit

CHAPTER 1: INTRODUCTION

In order to fully understand the whole picture and execution of this project, the introduction is divided into separate sub categories, where firstly the background of study of this project is detailed out. Next, the problem statement is mentioned and few objectives are made clear to tackle the problems. To ensure the project does not deviate from the objectives, scope of study of this project will be elaborated. Significance and feasibility of the project in term of cost and time will also be discussed in this chapter.

1.1 Background of Study

1.1.1 Automatic Battery Charger

A battery charger is defined as a circuit or a device to put energy into a rechargeable battery in which is widely used in mobile phone nowadays[1]. Battery chargers are important in order to make sure those mobile applications stay active through charging process in a way that power are constantly provided. Traditional charging involves adapters and dependable charging circuitry. Automation of charging process is not fully researched and studied. Based on a circuit designed by [2]as in Fig. I below, the automation of charging process is driven by electric components known as relay for charging start and stop, voltage comparator IC2 and a voltage referencing Zener diodes, ZD. As the capacity of a battery falls under the voltage of the referencing diode, charging will commence through the contact of relay. At a particular time when the battery capacity gets higher than the reference voltage, charging will stop and the relay will break the circuit thus avoid overcharging. However, in order to achieve an efficient and reliable charger circuitry for a much lower range of voltage, a suitable voltage comparators needs to be used and thorough study towards the battery management which includes the charging profile and battery control loop as suggested by [3].

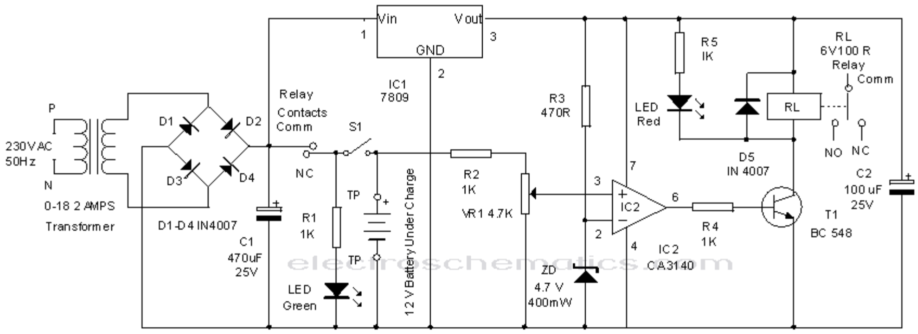

Fig.1: Schematic of automatic battery charger circuit[2]

1.1.2 Mobile Application

With revolution of technology, the function of mobile application has become more powerful and very complex. The designs of most mobile applications are compact and thus not many functions are available due to size consideration. For extra function, devices will need to have external devices in which raise the dependability on that particular device. As stated by [4], the mobile application in market attracts impressive cash flow and success stories and thus the demand for mobile application has greatly increased. The aim of this project is to focus on mobile applications due to its proven success stories globally. This project will explore the possibility of integrating a new function which is automatic charging with PV modules. According to [5], the question on how far automation is effective in a mobile application is raised. However the study by [5] only involve preliminary critical analysis on automation and suggested a deeper and mature study shall be continued in that area.

1.1.3 PV Module

This project will explore the design of a photovoltaic (PV) module. A PV module is a group of PV cells which are electronically grouped to form a pixel and are connected to DC-DC converter block. The study on PV modules in this project will concentrate on determining the size of a pixel, configuration of solar cells (series/parallel), and power electronics circuitry. The main deliverable is to achieve a high quality output voltage.

1.2 Problem statement

The integration of photovoltaic systems into a battery charger circuit has not been extensively explored. At this time, only a stand-alone power generation from photovoltaic system is used. Therefore main challenge is to design an efficient converter circuit. To achieve this, good selection of photovoltaic modules and materials must be emphasized. The size of the PV system is also taken into consideration to cut cost and for user conveniences.

Other than that, other challenge that is encountered is also the reliability and efficiency of the battery charger circuit itself. Since the charging process is in automatic mode, suitable electronic component for the circuit design have to be taken into consideration.

1.3 Objectives

In order to achieve the desired result for the project, few objectives are made clear and as a benchmark for the progress of the report. The preliminary objectives of the project are as follows;

1.3.1 To understand:

- 1.3.1.1 Battery charger for low voltage mobile application
- 1.3.1.2 Automation of charging process
- 1.3.1.3 Operation of PV module and selection of PV materials

1.3.2 To model and simulate:

1.3.2.1 PV charger

1.3.2.2 Charging profile

1.3.3 To design and validate an automatic PV charger prototype

1.4 Scope of study

The main of this project is to design and validate a battery charger resulting from the integration of photovoltaic modules with a controller circuit. This project will focus on extra low voltage application where the voltage range used in the project is below 120V[6] specifically a mobile phone which voltage ranging from 3.7V to 4.5V and current characteristic from 1A to 2A. Thus the selection of PV materials which act as power source in this project is very important. Detail understanding of the rated output power, voltage, and current will is crucial. In addition, details understanding of PV system will aid in the materials selection and size decision.

Since the final objective of this project involve a prototype fabrication, multiple simulations using LT Spice V4.2, MATLAB V7.12, and lab experimental works will be carried out in order to understand and come out with the most efficient and reliable PV charger circuit design. Based on data obtained in each simulation and experiment, conclusion on the relationship of the integration can be determined and thus on its final stage, a functional prototype is achieved.

1.5 Significance of the project

Common known charging involves a frequent unplugging mechanism from power adapter and through the use of external devices such as power banks. It can be considered as the traditional way to charge and make sure a mobile application stays active for routine usage that serves many purposes. Looking forward into the future, it is very significant to resolve limited battery lifetime problem especially when the world engages into intensive multimedia services. Thus, this project will look into the possibility of solar photovoltaic (PV) module in generating a small circuitry to be embedded into a battery charger of an application. In addition, the project also aims to cut users' dependability on charging the mobile application for example through adapters and power banks. Hence, the successfulness of this project will indirectly give a boost and lift up the mobile applications industry.

1.5 Feasibility of the project

15.1 Timeframe

The project will involve simulations and the fabrication of a prototype. The time frame allocated for this project which is two semesters is feasible to complete the project. The final outcome of this project will be a construction of a prototype and this will be achieved in FYP 2 which falls on August 2014. During FYP 1, the focus will mainly to perform simulation and analyze the data obtained and acquisition of materials. During FYP 2 on the other hand, the focus will shift to construct and troubleshoot the prototype.

15.2 Cost

The fabrication of prototype for this project will incorporate a small in size solar panel and few electronic components. Some of the electronic components are provided within the department's facility. Thus, it is feasible to conduct the project within the allocation of budget by the department.

CHAPTER 2: LITERATURE REVIEW & THEORY

Due to vast development in the information and manufacturing technologies, performances of portable gadgets and mobile applications are greatly enhanced. Power requirement and consumption of these gadgets therefore also increase. These applications are normally equipped with rechargeable batteries due to its cost efficiency over its lifetime. However, due to the great power consumption, users have to deal with limited battery lifetime through routine task called human-battery interaction[7].This will eventually impair the user to communicate, perform works, share ideas, and interact effectively. Survey has been conducted all over and showed that majority of the user demand increase in their battery lifetime. Over the years, significance research and approach are explored to improve the battery lifetime. Thus, in this chapter, journals, books and research papers are referred to conduct a literature review for the details of the project. The literature review are divided based on the objectives outlined earlier in the report.

2.1 To understand basic theory and fundamentals of the project (Objective 1)

In this section, the fundamental concept of battery chargers, automation of charging process and operation of PV modules is studied and understood.

2.1.1 Battery charger for low voltage application

In any portable products, battery charger (BC) and any charging circuitry play an important in keeping devices stay active when needed especially when it comes down to interactive multimedia services nowadays. BC is a device that is used to apply energy into a rechargeable battery through current flow. A BC is made up materials that include a plate and a cell. The plate in the charger will draw a charge when direct current flow through it, and then eventually produces certain amount of electric current[8].A conventional BC is able to charge only one type of battery. However, in a research by [9], he introduces a BC that able to accept wide range of input and supply wide range of voltage for any portable application. As stated in the scope of study, the project will focus on extra low voltage application which is below 120V. The power for the charging is fed by various power sources which can be summarize in Table I.

Table I: Type of controlled charging[10]

Controlled Charging	Description
AC supply	Typical appliances and application will draw power from the grid through voltage step-down by transformers. The applications will be connected to AC adapters through cabling.
Regulated DC battery supply	Power is supplied through special installation for a specific purpose.
Special Chargers	Power is drawn through various portable sources such as solar panels.

A charger has three main functions. First is the charging stage, where charge is supplied to a battery. The charging can be through various methods either constant voltage, constant current, taper current and many more depending on the users requirement[10].Secondly, it involves optimizing the charging rate (stabilizing) through close monitoring to the charging process and performance of the battery. Thirdly, the function of BC is to know when to stop the charging. This is important to preserve the battery life from unwanted overcharging. Charging termination can be done manually for example through unplugging from power source or automatically depending on the circuit configuration. The choice of a charger depends on applications, users' preference, and ultimately cost. Some examples of BC are shown in Table II.

Table II: Type of battery chargers[10]

Type	Working theory	Advantage	Disadvantage
Switch mode regulator	Use pulse width modulation to control voltage	Lower power dissipation over wide variation of input	Size
Series regulator	Use voltage dropping transistor and compare power between supply and output voltage	Less complex, small in size, low noise interference	Require heat sink to dissipate heat
Shunt regulator	Charging is controlled by a switch or transistor connected in parallel with special chargers (solar panel)	Protection mechanism, cheap, easy to design	Power efficiency due to external power source such as solar panel
Universal Serial Bus (USB)	Power are provided by host device(computer) and provide 5 volt power	Simple design, cheap.	Connection of USB can lead to non-standard variants. In spite of charging, data connection happen
Inductive Charging	Input (primary coil) of the charger is connected to main AC power and involves a step-down transformer, while secondary coil is in the battery itself. (wireless charging)	No physical connection, more user convenient	Expensive, complex design

2.1.2 Automation of charging process

Automation of charging or also known as smart charging is define as the process of charging a rechargeable battery at a similar rate as a battery self-discharging, thus maintain the battery at nominal capacity and at the same time do not endanger the battery itself from overcharging. Simplified charging circuitry as suggested by [11] is shown in Fig. 2 for the automatic circuit topology. The circuit consists of 4 major blocks which are a subtreshold operational transconductance amplifier (OTA), a 4.2 voltage reference, a current gain stage and end-of charge detector.

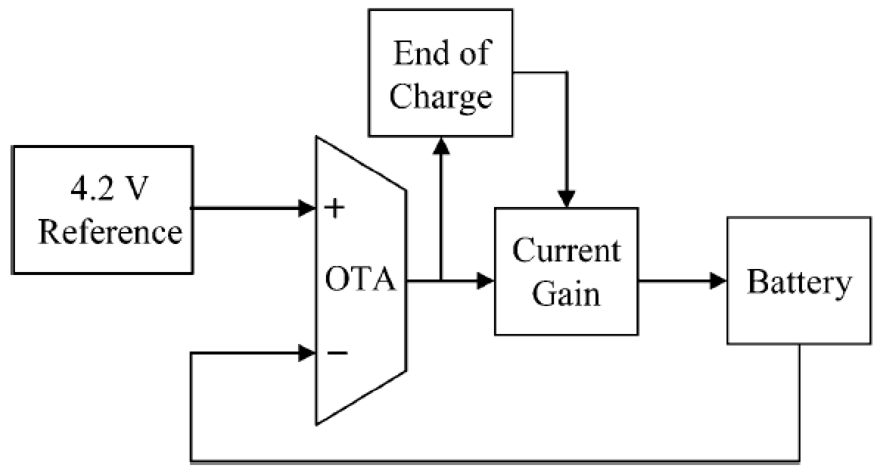

Fig.2: Simplified battery charger block diagram.[11]

The OTA in the Fig.2 generates an output current profile as a function of the instatenous battery voltage relative to the 4.2 voltage bandgap reference [11]. Optimizing charger design for battery longevity places tight design tolerance on the end-of-charge detection, over a range of operating temperature and supply voltages. As long as the battery capacity falls under the voltage reference voltage the charging process will resume. The current gain stage shown in Fig. 2 acts to increase output of OTA from few amps to the appropriate charging current for the battery. Lastly, the end-of-charge detector compares function to terminate the charging by comparing the end-of-charge input to a reference current. The design achieves and average power efficiency of 89.7% over 3.0V to 4.2V [11] range of battery voltage.

Automation of charging process in this project will be done through a controller circuit specifically LT1529-5, a low dropout regulator with micropowerr quiescent current and shutdown. The minimum voltage requirement to be feed to the component is 5V. The output of this component is adjustable from 3.3V to 14V. The voltage level can be adjusted through the use of variable resistor for the output voltage level.

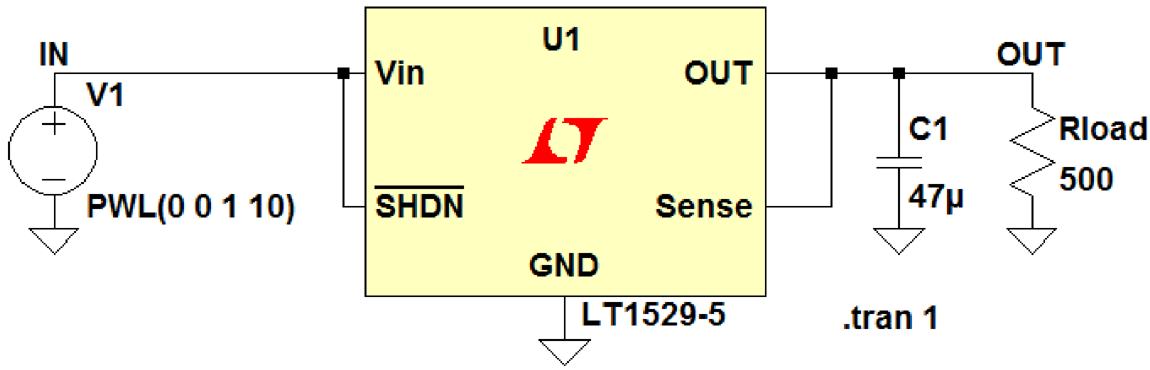

Fig. 3: Macro-model of LT1529-5[12]

As suggested by[13], the LT1529-5 is suitable for medium and low voltage application and is very practical to be used in battery-powered systems. The components mainly act as a current and voltage limiter. It limit the current and voltage level at the output prior to be supplied to any load. With sense or feedback function built in, it also act as current and voltage comparator and thus able to start and terminate supply to the load at any time depending on the project requirement. However, the parameters of the connected load must be specified and determined to ensure the comparison function to be utilized.

2.1.3 Photovoltaic (PV) system

Power can be harvested through various methods and sources. In this project, the power is harvested from exposure to solar radiation (sun) through solar panels. In this section of the literature review, how energy is harvest and converted to electricity, the system of PV, and selection of suitable materials for the solar panel are discussed. PV system is defined as arrangement of components for the purpose of supply electrical power using the sun (radiation) as the power source [14, 15]. Typically, the are two types of arrangement for PV system which are grid-tie and off-grid. These arrangements are further divided into with or without battery storage. Arrangement of the system that will be used in this project is off-grid configuration and without battery storage. The typical off-grid system with battery storage is illustrated in Fig. 4.

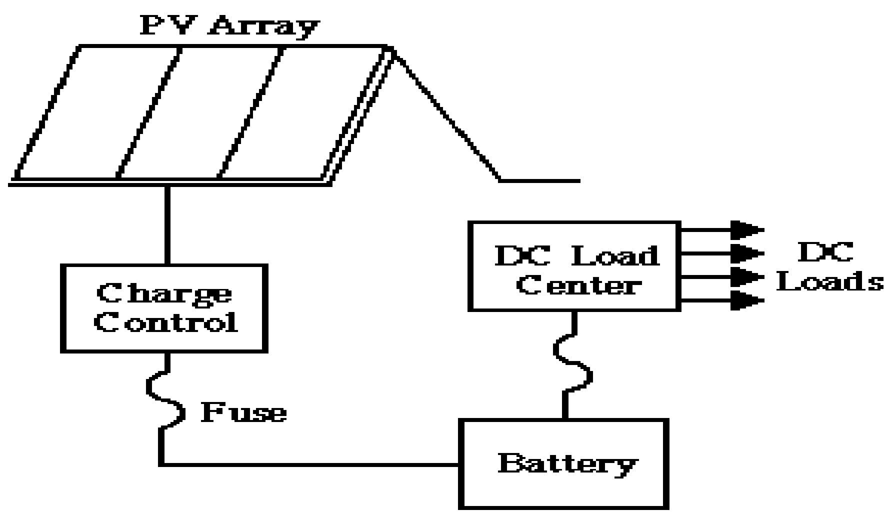

Fig 4: Photovoltaic system [14]

PV employs solar panels that are comprised of multiple solar cells. These solar cells convert energy from the sun through an effect called photovoltaic effect. Sun radiation that hits the solar panel contain of photons. These photons will excite electron into higher state of energy which then allow them to act as charge carriers for an electric current. On the other hand, selection of the right materials for the semiconductor of a solar cell plays an important role for better output power efficiency. Among the materials are monocrystalline silicon, amorphous silicon, and many more. However, taking into consideration of cost, amorphous silicon is choose for the prototype fabrication. For a small circuitry project, the amorphous silicon materials will suit the requirement of the project.

According to [16], a design with a low-cost, compact and feasible and power efficient is proposed. The proposal includes a battery protection controller design in which a power comparator component will connect and disconnect the solar panel from the charging circuit when the desired battery capacity is achieved. This feature protects the rechargeable battery from the adverse overcharging and undercharging. The limitation to the proposal is that the overall concept only applies during a consistent solar radiation which is during sunny day and luminance of approximately 50,000 lux [17]. This limitation is however addressed by [17] where they conducted experiments on solar cell efficiency under the indoor where the average luminance ranges from 100 to 1,000 lux [17] . The result of their experiments varies with the lighting condition. With a halogen light, the solar panel can generate energy in the amount of 1/3 of the ordinary battery and this can support minimal to moderate use of an application, while under normal fluorescent lighting, the solar panel generate energy only 1/20 of the ordinary battery which is too small to produce a meaningful amount of power to a mobile application.

2.2 To model and stimulate (Objective 2)

Through a solid understanding on the fundamentals of the project scope, the circuitry of the project is being constructed and simulated through simulation software which will be discussed further in this section. The main aim of this section is to come with a successful simulation that is able to meet the expected outcome of this project.

2.2.1 Photovoltaic (PV) panel

PV system requirement used in this project will not be very complex since the required power and voltage level is very small. Thus charger controller and battery storage will not be needed. Prior to material acquisition for the prototype construction, the performance of the PV panel need to be evaluated in order to select the best PV material. PV panel representation in simulation software is limited and too generic, thus in order to simulate one, an equivalent circuit can be constructed. According to[18], any PV panel can be simulated using an equivalent circuit shown in Fig. 5. The parameter R1, R2, C1, and D1 is determined depends on the desired output and hence, in this project, the parameter determination will be determined in chapter 3.

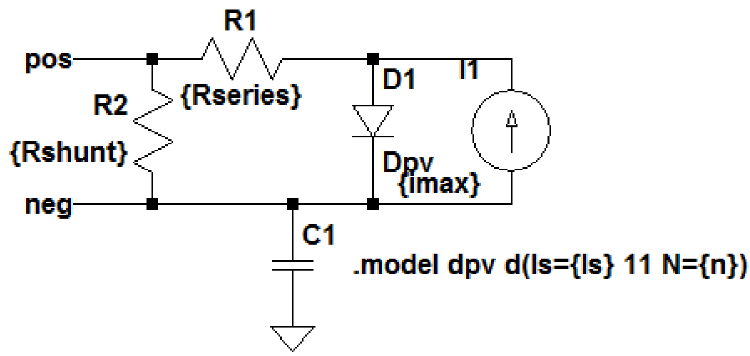

Fig.5: PV panel equivalent circuit[18]

The parameter R1, R2, C1, and D1 is determined depends on the desired output and hence, in this project, the parameter determination will be determined in chapter 3.

2.2.2. Controller circuit

Automation of charging process in this project will be done through a controller circuit specifically LT1529-5, a low dropout regulator with micropowerr quiescent current and shutdown. The main function of this controller is to control the input to the battery charger. This is also where the automation of the supply power to the battery is implemented. However, at the moment, the main focus is on the controller design to control input to the battery charger. Fig. 9 shows the preliminary design of a controller where LT1529-5 is specifically used for this project at which allowed maximum voltage input is 10V. Thus the parameter values (C1, C2, C3, R1, R2 and R3) shown in the figure are built-in values. This component is mainly used in solar related project and it has an output voltage that is very stable over ranges of temperature. Besides that, it is also act as a current limiter that prevent the output current from reaching 160mA and it is protected with thermal shutdown. Thus, IC is very suitable to be used in the project. The parameter of the controller circuit will be further discussed in chapter 3.

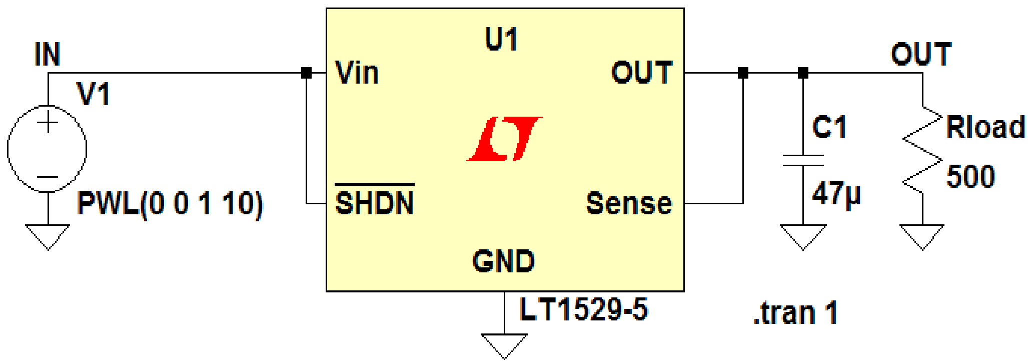

Fig.6: Macromodel of LT1529-5[12]

Table following Table III shows the summary of literature review that is completed until the time of writing.

Table III: Summary of literature review

No.	Authors	Ref. no	Tittle	Discussion	Results/Findings
1	I. Y. W. Chung and Y. C. Liang	[7]	A low-cost photovoltaic energy harvesting circuit for portable devices	Efficiency of solar energy harvesting, MPPT, battery protection system	Achieve higher efficiency of 89-90% of energy harvesting.
2	L. Chengliu, J. Wenyan, T. Quan, and S. Mingui	[8]	Solar cell phone charger performance in indoor environment	Experiment on solar efficiency under indoor environment	During cloudy and normal fluorescent light, solar cell does not produce enough power
3	B. Lawson.	[9]	Battery Charging Methods	Discuss on various charging methods	
4	B. Do Valle, C. T. Wentz, and R. Sarpeshkar	[10]	An Area and Power-Efficient Analog Li-Ion Battery Charger Circuit	Feedback loop for charging control	OTA, voltage reference, charging termination
5	Y. Yusof, S. H. Sayuti, M. Abdul Latif, and M. Z. C. Wanik	[11]	Modeling and simulation of maximum power point tracker for photovoltaic system	Stand-alone PV system	Power flow controller, charging controller
6	I. Y. W. Chung and Y. C. Liang	[12]	A low-cost photovoltaic energy harvesting circuit for portable devices	MPPT converter circuit, MPPT principle	Harvests maximum power regardless of solar insolation levels
7	I. Y. W. Chung and Y. C. Liang	[13]	A low-cost photovoltaic energy harvesting circuit for portable devices	Efficiency of solar energy harvesting, MPPT, battery protection system	Achieve higher efficiency of 89-90% of energy harvesting.
8	L. Chengliu, J. Wenyan, T. Quan, and S. Mingui	[14]	Solar cell phone charger performance in indoor environment	Experiment on solar efficiency under indoor environment	During cloudy and normal fluorescent light, solar cell does not produce enough power

CHAPTER 3: METHODOLOGY & PROJECT WORK

This section will elaborate more on the methods and procedures used in this project to achieve the objectives of this project.

3.1 Research Methodology

Table IV shows the project activities that are covered in this project.

Table IV: Methodology and project activities

Objective(s)	Methodology	Project activities
Objective 1.	Research and extensive literature review	Research are carried out to understand how battery charger and solar photovoltaic works. Literature review is to relate this project with previous works and researches done through variety of references.
	Extended proposal writing and defense	Background, objectives, and problem statement are stated concisely and clearly. The scope of study for the project must be relevant and the project is feasible to be carried out with specified duration of two semesters.
Objective 2.	Experimental design	Circuit is designed for simulation stage through detail mathematical calculations and thorough technical interpretation.
	Simulation	Simulations are carried by using Proteus simulator, Pspice, and MATLAB. The results of each simulation are gathered and analyzed.
	Design improvement and modification	If data gathered from the simulation does not meet the project requirement, modification and improvement are made to the design and simulation is carried out again. The process is repeated until satisfactory results are obtained.
Objective 3.	Prototype fabrication	Upon multiple simulations and when satisfactory result is obtained, fabrication of the prototype for will start.

3.2 Gantt chart

Table V show the Gantt chart for the project and its deliverables during FYP I and FYP II.

: To be executed

: Achieved

Table V: Gantt chart for FYP I and FYP II

		Final year project 1 (FYP 1)														**Final year project 2 (FYP 2)**												
Week(s)		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	25	26	27	28
Gantt Chart																												
Task(s)	**Obj.**																											
FYP title and supervisor confirmation	Obj. 1																											
Detail Understanding about the project																												
Equipment and components survey																												
Familiarization with schematic capture automation tools																												
Draft of circuit design	Obj. 2																											
Simulation and data collection																												
Components and materials acquisition																												
Prototype fabrication	Obj. 3																											
Output validation and modification																												

3.3 Key Milestones

Fig. 7 shows the key milestones that are completed during FYP I.

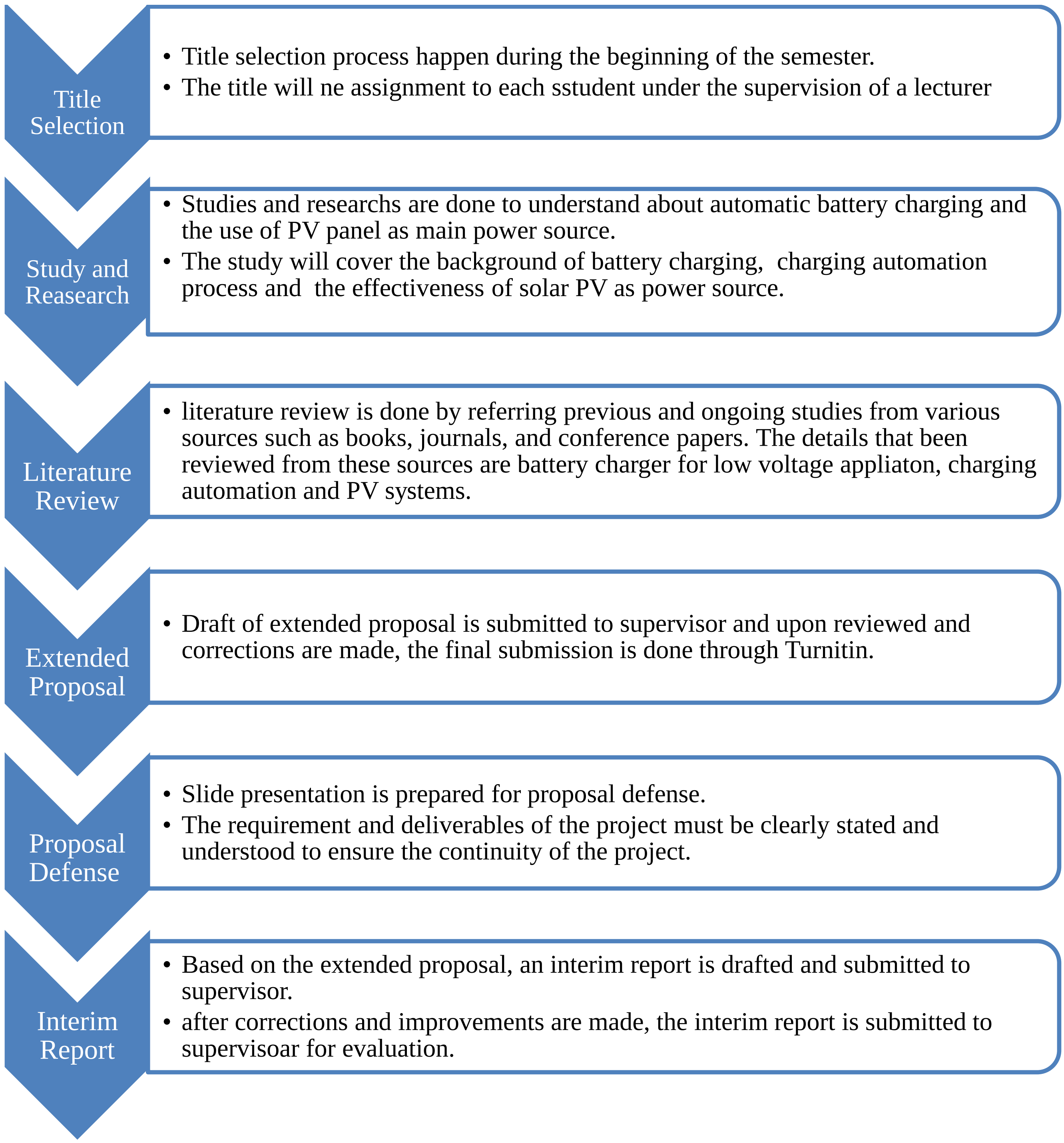

Fig. 7: Key milestones for FYP I

Fig. 8 shows the key milestones that will be completed during FYP II.

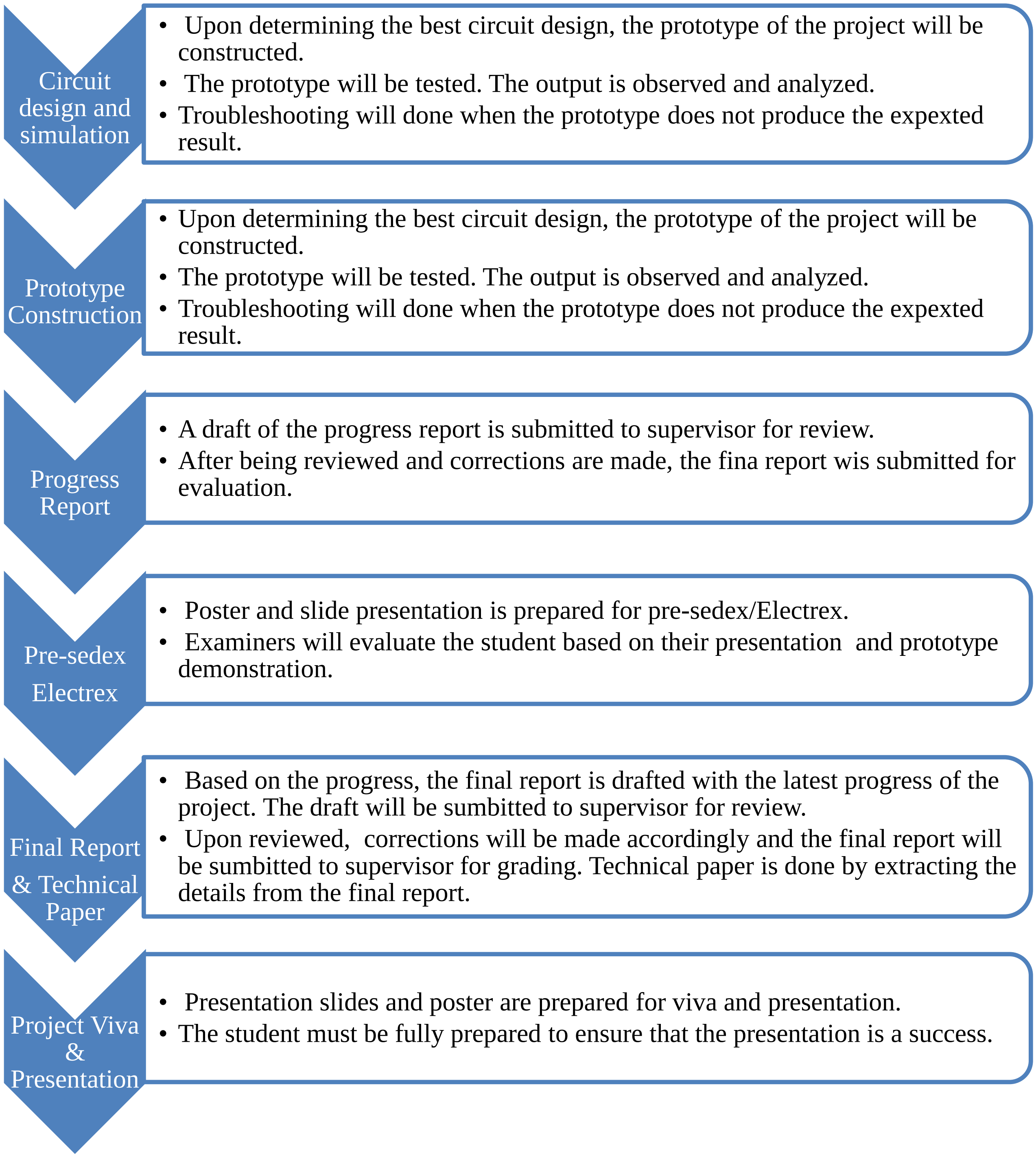

Fig. 8: Key milestones for FYP II

3.3 Flowchart

Fig. 9 shows the project flowchart for the whole duration of FYP I and FYP II. The project procedures will follow this flowchart.

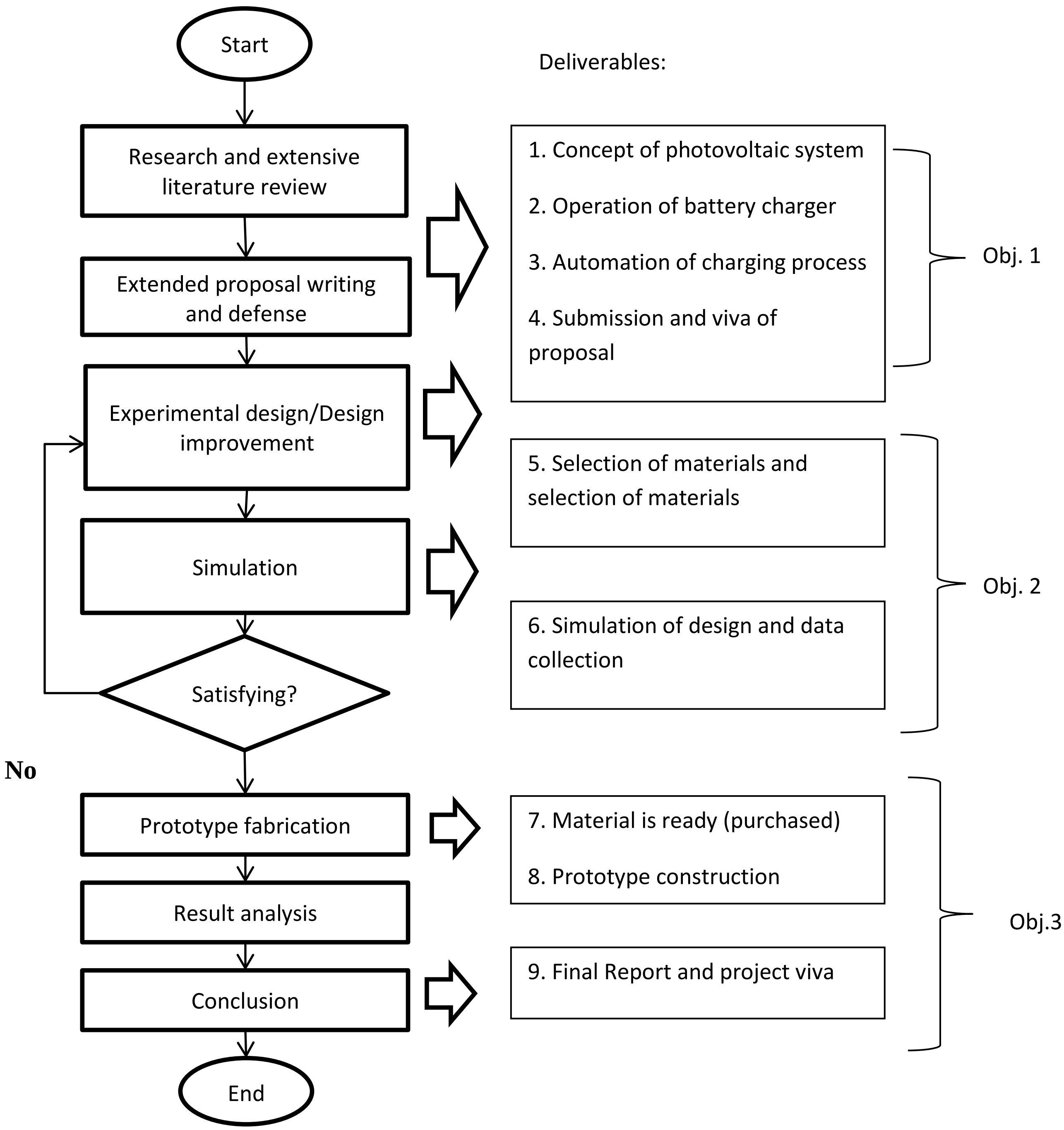

Fig. 9: Flowchart of FYP I & II

3.5 Tool & Software required

Tools and software that required throughout the implementation of this are:

1. Personal computer/ Laptop
2. Digital multi-meter
3. Proteus simulator 8
4. LT Spice Version V4.2
5. MATLAB V7.12
6. Pspice
7. Microsoft office 2010 tools (Excel & Word)
8. Electronic components (capacitors, resistors, voltage regulators, ICs)

3.6 Proposed topology

To complete this project, a set of procedures is drafted to obtain the required output and requirement of this project. The procedures is concluded and illustrated in Fig. 10.

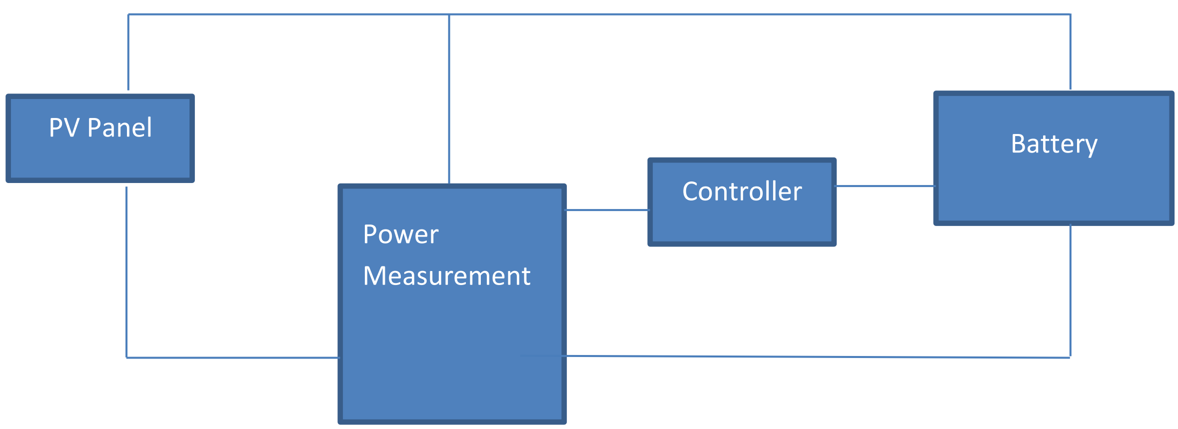

Fig. 10: Overall block diagram

Fig.10 detail out that the PV panel will act as power supply. As the input might differ with different exposure to light radiation, a power measurement block is set up to monitor the characteristics of the output power from the PV panel. The controller act as a input control to the battery charger to charge a Li-on battery. The controller battery will also comprise of a battery protection scheme to protect the battery charger from any voltage attenuation.

3.7 Preliminary design

In this section, the main elements of the project which are PV panel, controller circuit, and battery representation is treated individually to determine the respective parameters prior to prototype construction. After determining the parameters, the circuit is then simulated in LT Spice V4.2 to evaluate and analyze the performance.

3.7.1 PV Panel

Fig. 11 shows the solar PV equivalent circuit which is simulated to match the output voltage and rated power of the solar panel that is going to be used during the prototype construction. The equivalent circuit shown in Fig. 11 is proposed by [19]. In this simulation though, the circuit is modified to match a low voltage application. Thus the parameter value will be change accordingly. The output power, voltage and current characteristics will be discussed further in results and discussion on chapter 4.

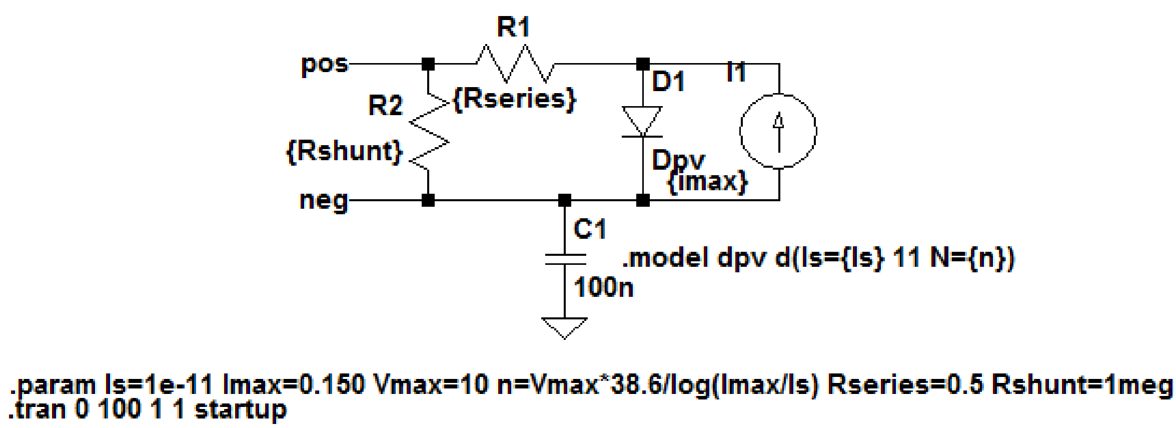

Fig. 11: Solar PV equivalent circuit in LT Spice V4.2

Traditionally, A PV module (Nm) is comprised of several cell connected together in parallel. In each module, a given of PV cells (Nc) are connected in series. The circuit parameters of the circuit is summarize as shown in Eq.(1) to Eq. (4) below[20, 21].

$$Vpv = Nc * Vcell \quad (1)$$

$$Ipv = Nm * Icell \quad (2)$$

$$Rseries\ (R1) = \frac{Nc}{Nm} * Rseriescell \quad (3)$$

$$Rshunt\ (R2) = \frac{Nc}{Nm} * Rshuntcell \quad (4)$$

The value of *Nc, Nm, Rseriescell,* and *Rshuntcell* can be obtained through the technical description given by the manufacturer. And thus, with given parameter, the value of *Rseries(R1)* and *Rshunt(R2)* can be calculated. From the datasheet values as follows are provided. *Rseriescell* = 1ohm, *Rshuntscell* = 4Mohm, *Nc* =12 and *Nm* = 48, thus by utilizing Eq. (3) and Eq.(4):

$$Rseries = \frac{12}{48} * 2\ ohm = 0.5\ ohm$$

$$Rshunt = \frac{12}{48} * 45Mohm = 1Mohm$$

The output current and voltage of this simulation is determine though Eq.(5) below,

$$I = IL - ID - Ish \quad (5)$$

Where *IL* is the current generated in the cell, *ID* represent the voltage-dependent current lost to combination, and lastly *Ish* is the current drop due to shunt resistance. Eq.(6) and Eq.(7) shows the equation to obtain the current and voltage of the of the PV panel.

$$ID = Io\ [\exp\left(\frac{V+IRs}{nVT}\right) - 1\ ] \quad (6)$$

$$VT = \frac{kTc}{q}, \quad (7)$$

$where\ k\ (boltzmann'sconstant) = \frac{1.381x10^{-23}J}{K} and\ q(charge) = 1.602x10^{-19}C$, and by using Eq.(6) and Eq.(7), the value for current and the voltage can be obtained.

$$I = IL - ID - Ish = 0.932A$$

$$VT = \frac{kTc}{q} = \frac{1.381x10^{-23}(309)}{1.602x10^{-19}} = 0.03\ V$$

From the value of current and thermal voltage of the solar, the output voltage of the solar PV can be calculated using the formula below:

$$ID = Io\ [\exp\left(\frac{V + IRs}{nVT}\right) - 1\ ]$$

$$100mA = 1.05uA\ [\exp\frac{(V + (0.932A * 0.5ohm))}{1(0.03)} - 1] = 9.622\ V$$

The calculated (ideal) value of current and voltage are slightly different from the simulated value. However such difference is to be expected since the internal resistance of components in the circuit is neglected.

1.7.2 Controller circuit

Fig.12 shows the design of the controller circuit.

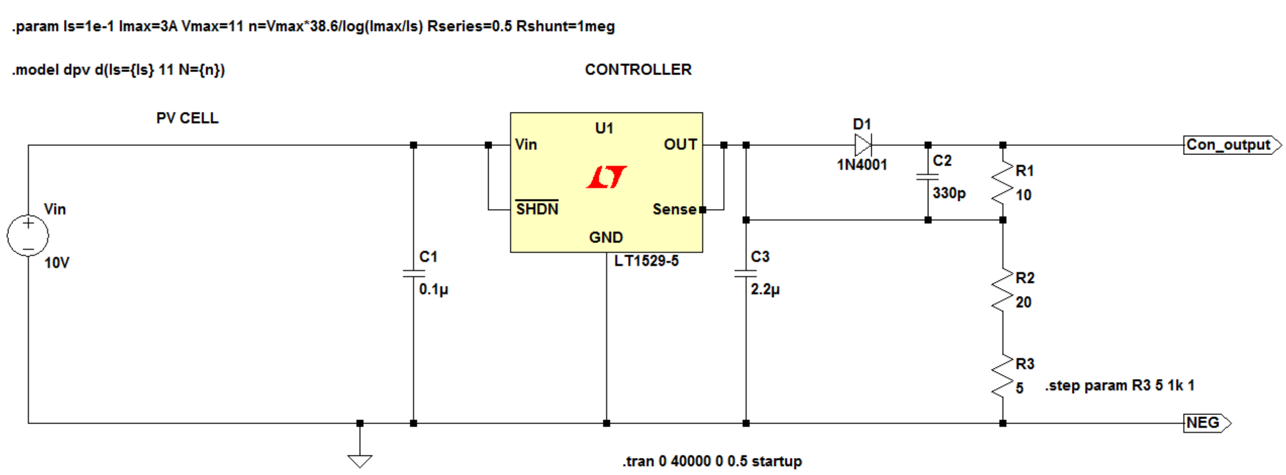

Fig. 12: Controller LT Spice V4.2 design

The circuit shown in Fig.12 was designed in way that the limit of charging is up to 160mA and a voltage set point of 4.2 V (+/- 0.025V). Besides that, it is also act as a current limiter that prevent the output current from reaching 160mA and it is protected with thermal shutdown. The input power source of the circuit (V1) as shown above is supply from solar PV which is discussed earlier. The output voltage of 3.7V of this circuit which is denoted at V2 is set through the resistor values shown in Fig. 9 where R1 = 10ohm, R2 = 20ohm and R3 = 5ohm. The resistor values can be identified using the formula V=IR. At the controller, the output voltage will vary from 4-6.5V. Table VI shows the resistors values in accordance to different level of output voltage.

Table VI: Resistor range in accordance to output voltage level

Voltage values (V)	Resistor values (ohm)
3.7	34
4	42
5	50
Thus, R1 and R2 value is keep fixed at 10 and 20 ohm respectively. R3 values varied accordingly, thus a variable resistor is used for R3.	

A diode (D1) is set to ensure there is no backflow of current when input power source is removed or when the battery is at maximum which can act as a power source too.

3.8 Costing

The Table VII summarizes materials acquisition and the costing. These are the materials that are required to fabricate the project prototype which will commence in semester 2.

The item specifications are obtained from: RS Malaysia, Elements14, MyDuino, and Lelong.com

Table VII: Material specification and cost

Item(s)	Description	Price (RM)	Quantity	Total
Solar Panel	Cytron technology 12V, 833.3mA	38.90	1	RM38.90
Resistor	Metal film type 10ohm-10Kohm	0.15 (per 10)	20	RM0.30
Breadboard	Breadboard Prototyping Board -39 x 173 x 9mm	43.37	1	RM43.47
Voltage regulator	Low Dropout Voltage Regulator, 0.1A, 5V (LP2951/LT1529-5) ±3.8%, 3-Pin TO-220 Status: Awaiting delivery	4.89	2	RM9.78
	Low Dropout Voltage Regulator, Adjustable 5A, 1.25 to 28.5V, 3-Pin TO-3P	49.22	1	RM49.22
Capacitor	Aluminium Electrolytic Capacitor Status: Available	2.46	3	RM7.38
Nokia 1200	Li-Ion 800 mAh battery (BL-5CB)	108.00	1	RM108.00
Total				RM257.05

CHAPTER 4: RESULTS & DISCUSSION

During the period of FYP 1 and early period of FYP 2, a preliminary circuit design has been constructed in LT Spice V simulation tool and multiple simulations has been carried out since to ensure that the project progress is right on track before proceeding to the construction of the prototype. A complete circuit design and further recommendation will be detailed out towards the end of FYP 2. Referring to Gantt chart discussed in the earlier in the project work and methodology, some of the milestone has and objective has have been achieved. In this chapter, the results are discussed for the simulation and the prototype itself.

4.1. Result for completed simulation

4.1.1. PV simulated circuit

The output power, current and voltage of the circuit in Fig. 11 is shown in Fig. 13.

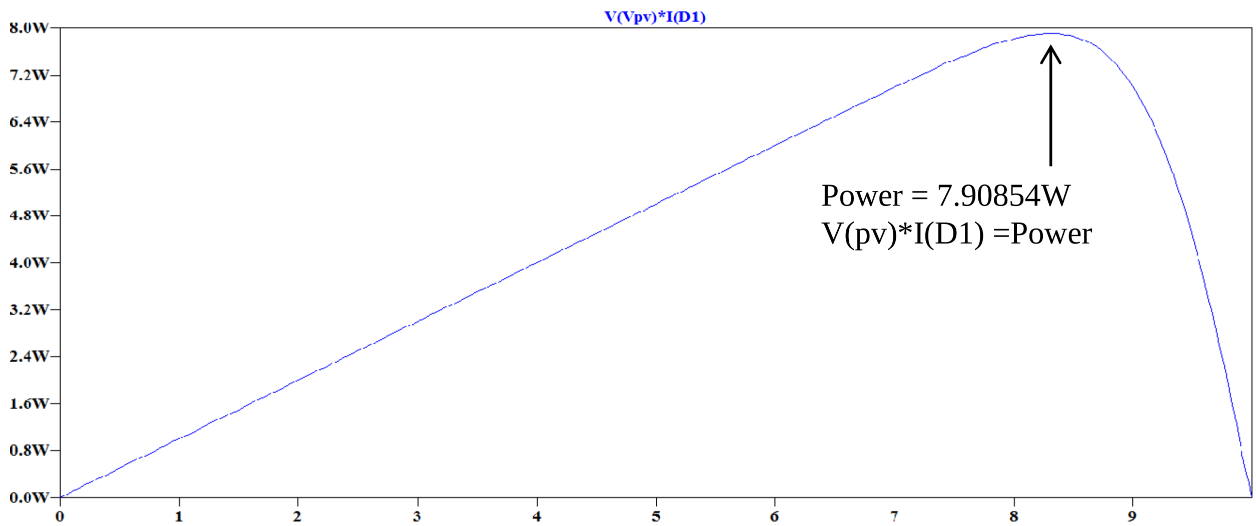

Fig. 13 Output power of the circuit in Fig.11

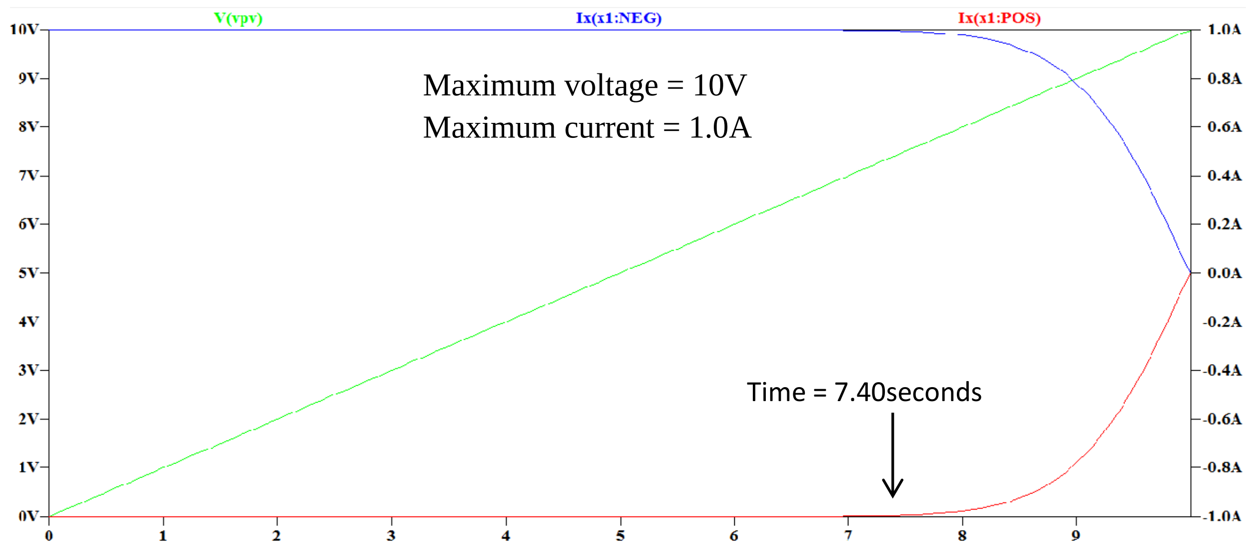

Fig. 14 Voltage and current output of Fig. 11

Referring to Fig. 13, the output power of the PV panel rise slowly rises from 0 watt to its maximum value of 7.90854W in 8.2 seconds. With the rise of output power, the voltage supplied also slowly increase and reach maximum value of 10V in 10 seconds. At 0 seconds, the current at the output negative terminal is 1A and the current at the output positive terminal is -1A. However, when the output voltage level reach the value of 7.40V, current is triggered and thus the current at the output negative terminal starts to fall and the current at the output positive terminal starts to rise.

The aim of this simulation is to ensure that the PV panel is able to provide enough power, voltage and current for the controller circuit. PV panel in this simulation is treated as ideal in which it is assumed that the solar radiance to be constant and efficiency is 90%, and thus explains the consistent and linear output obtained. The results obtained are analyzed and compared to the expected result of this project. The analysis is summarized in Table VII.

Table VIII: Result analysis summary of PV panel

Simulated result	Output requirement	Difference	Way forwards
Voltage = 10V	5-10V	0%	The voltage and current characteristics of PV panel is fulfilled.
Current = 1A	1-2A	0%	
Power = 7.90854W	10W	20.91%	Acceptable output.

Based on the analysis summary, the expected result of output voltage and current level of the PV panel is fulfilled. However, the power delivered by the PV panel is at 7.90854W in which it differs 20.91% from the expected result of the project. This is due to thermal and physical resistance that are neglected when the simulation is carried out.

4.1.2. Controller simulation

Current and voltage characteristics of controller in Fig.12 is shown in Fig. 15.

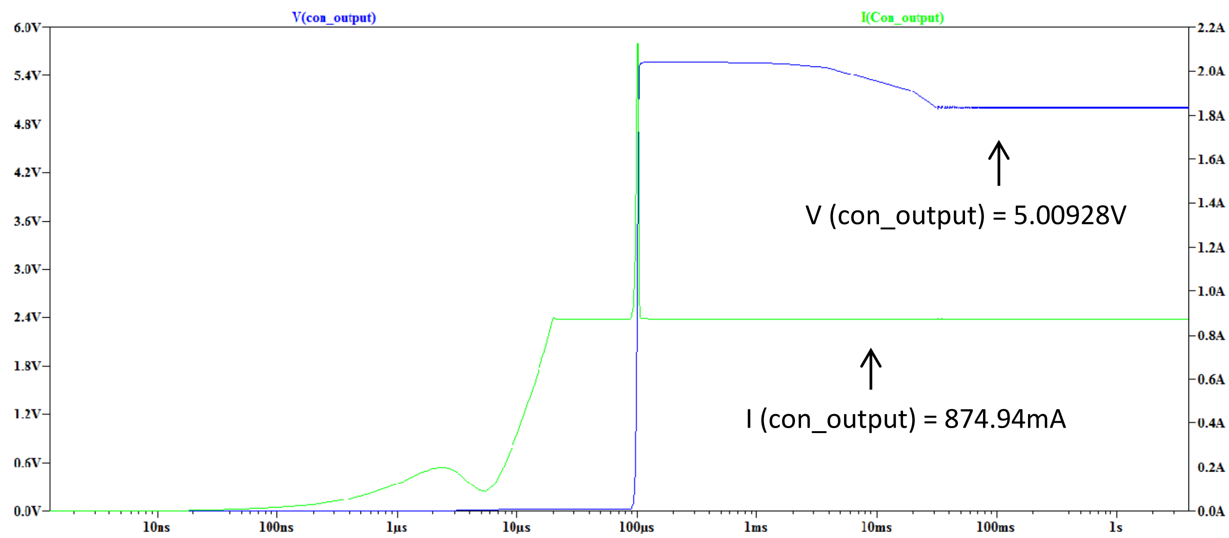

Fig. 15: Voltage and current output of Fig. 12

The controller circuit is supplied with constant DC voltage from the PV panel as indicated in Fig. 12. The performance of the controller is then observed and analyzed at the controller output. Referring to Fig.13, the voltage,V(con_output) and current, I(con_output) measured at the controller output is 5.00928V and 874.94mA respectively.

The output is obtained during the duration of 10s of the simulation. The voltage and current is observed almost instantaneously which is at 100ns.

The aim of this simulation to show that the controller is able to draw suitable current and voltage level from the PV panel. As observed during the simulation, the results are favorable when compared to the output requirement of the project. The summary of the analysis is summarized in Table IX.

Table IX: Result analysis summary of controller circuit

Simulation result	Output requirement	Way forward/comment
Source (voltage) = 10V	10V	The supplied voltage is fulfilled.
Controller output voltage = 5.00928V	3.7V-5V	Output voltage and current fall within the range of the expected output requirement. Thus the controller circuit design in Fig.9 is chosen as the best circuit design.
Controller output current =874.94mA	0.8A-2A	

It can be concluded that the controller circuit simulation is able to produce the expected result by using the IC LT1529-5.

4.2. Prototype

Upon parameters determination in the methodology, a battery charger circuit is designed and simulated in LT Spice V simulation software. The simulated circuit design based on Fig.12 is able to produce a satisfactory result when compared to project output requirement. Thus, the prototype of the project will be constructed based on the parameters and components used during the simulation. Fig.16 below shows the picture of the prototype.

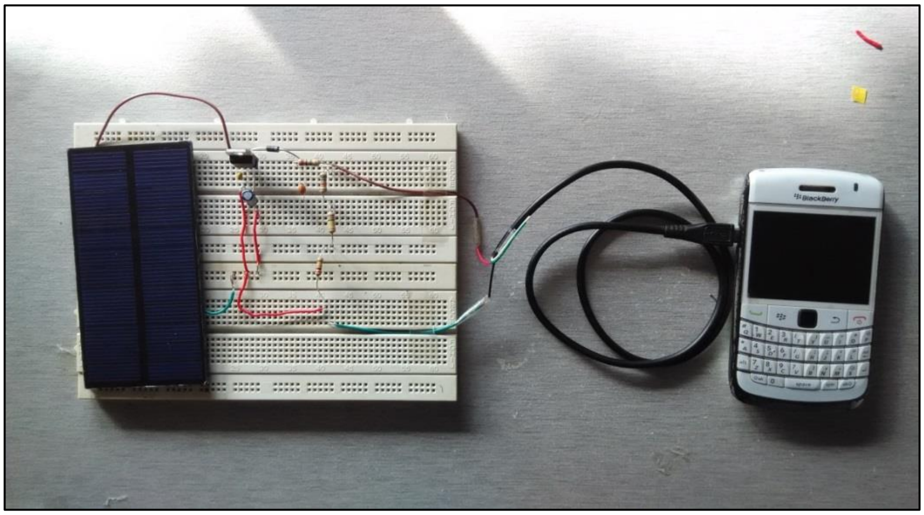

Fig. 16: Project prototype

Upon a complete construction, the prototype is tested and result is observed and tabulated for analysis. The result of the prototype is divided into two parts which are the performance of the PV panel and the output voltage and current at the controller output. Table IX show the performance of solar PV panel when tested during normal sunny day. The output voltage and current are measured and is represented in Fig. 17.

Table X: PV panel performance.

Time (24-hour system)	Voltage (V)	Current (A)
1200	6.213	0.289
1230	6.453	0.325
1300	6.298	0.539
1330	6.210	0.612
1400	6.476	0.232
1430	5.879	0.612
1500	5.544	0.631
1530	4.975	0.643
1600	4.512	0.598
1630	5.110	0.548
1700	4.786	0.460
1730	4.483	0.357
1800	4.101	0.366

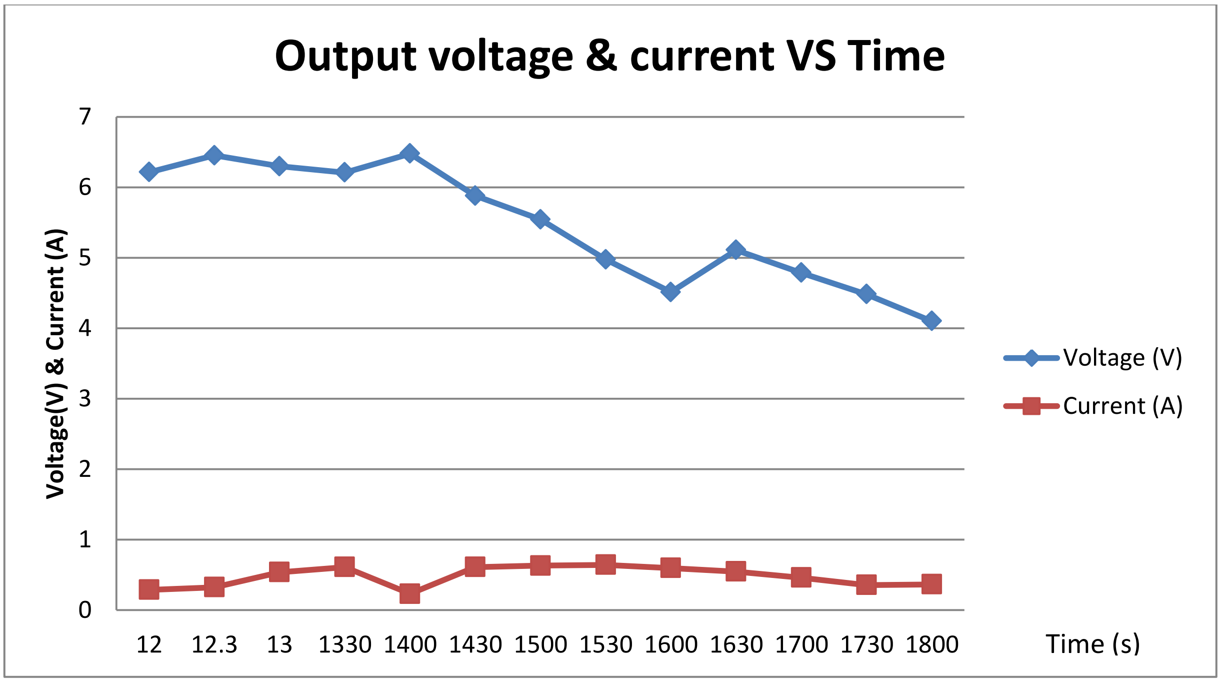

Fig.17: PV panel performance

The measured voltage and current from the PV panel are not consistent due to weather condition and thus the behavior of the PV panel is unpredictable. With the data obtained the power can be measured using the equation, P=VI. The power delivered by the PV panel is calculated and compared in Table X.

Table XI: Power delivered from PV panel

Time (24-hour system)	Power delivered P=VI	Expected output power	Percentage difference (%)
12.00	1.79556	10W	82.04443
12.30	2.09723		79.02775
13.00	3.39462		66.05378
1330	3.80052		61.9948
1400	1.50243		84.97568
1430	3.59795		64.02052
1500	3.49826		65.01736
1530	3.19893		68.01075
1600	2.69818		73.01824
1630	2.80028		71.9972
1700	2.20156		77.9844
1730	1.60043		83.99569
1800	1.50097		84.99034

The output power from the PV is very low compared to the expected output power of 10W with percentage difference at average is 74.087%. The expected output power of 10W as indicate in the technical description of the PV panel is achievable due to the assumption that the PV panel is tested and standard test condition (STC). However, when tested under real life condition, the performance of the PV panel is very poor and thus lead to the small output power. This is due to inconsistent solar radiated by the sun. Thus in order to achieve the expected 10W power; a PV panel of higher power delivery should be used. However, due to size consideration and the feasibility of project in term of cost, the PV panel of higher power rating is not possible.

The power fed to controller is very low and thus it is not enough for the controller to produce the expected voltage and current level of 1V-5V and 1-2A respectively. Measurements observed at the output of the controller are summarized in Table XII below.

Table XII: Output voltage and current at controller output

Time (hour)	Voltage (V)	Current (A)
1200	4.03845	0.1734
1230	4.19445	0.195
1300	4.0937	0.3234
1330	4.0365	0.3672
1400	4.2094	0.1392
1430	3.82135	0.3672
1500	3.6036	0.3786
1530	3.23375	0.3858
1600	3.9328	0.3588
1630	3.3215	0.3288
1700	3.1109	0.276
1730	2.91395	0.2142
1800	2.6656	0.2196

The tabulated data on the Table XII is the average data summarized from multiple data collection. Fig. 18 shows the graphical representation of data in Table XII.

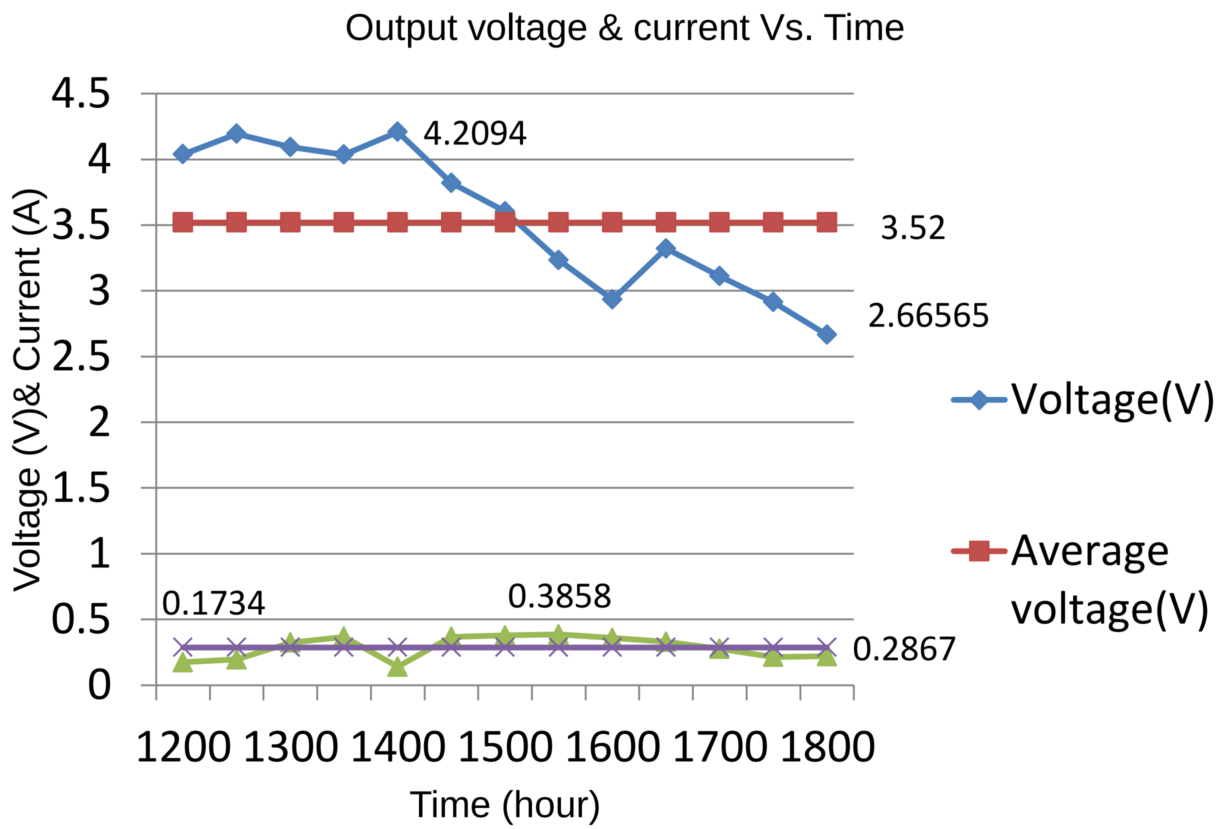

Fig. 18: Output voltage & current characteristic of controller output

From Fig. 18, the maximum and minimum output voltage observed at the controller output is 4.2094V and 2.6656V respectively. In average, the voltage at the controller output is 3.52V. Meanwhile, for the current level at the controller output, it is observed that the maximum and minimum level achieved are 0.3858A and 0.1734A respectively. Taking the average, the output current at the controller is 0.2867A.

Furthermore, the main IC used in the simulation that is able to control the voltage and current level at the controller output is not available for the prototype construction. In the prototype construction, LP2951 is used instead of LT1529-5. Technical descriptions of LP2951 specify that the IC will only be able to provide voltage and current sensing for charging automation when the supplied current is at 3A minimum.

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CHAPTER 4: CONCLUSION & RECOMMENDATION

The approach of explore the possibility of embedding the application of solar PV in generating a small scale circuitry power generation into a battery charger of mobile applications is very good counter to the problem of limited battery lifetime that is issued by users. In this project, A PV panel is used as a power supply to the battery charger circuit. In the battery charger circuit, a controller is used to regulate the voltage and current level for charging purposes. In the simulation, it is found that the output power from the PV panel is maximum at 7.90854W with maximum current and voltage at 1A and -1A at both positive and negative cycle and 10V respectively. After the prototype is tested, it is observed that the output power of the PV panel is very low at 2.5913W in average compare to the expected power requirement of 10W. Due to this low power output, the controller circuit is unable to regulate the voltage and current to meet the minimum requirement of voltage and current for charging which is 3.7V and 1A. Thus no charging process is observed.

For future works, it is recommended that the selection of PV module of higher performance and high efficiency when tested under real weather condition is required and necessary to achieve the main objective of the project. It is also recommended that the PV system that is introduced in the project is included with battery storage. This is to ensure that the power supplied to the controller is constant and the controller is able regulate voltage and current level accordingly.

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