Solar Energy Harvesting for Wireless Sensor Network

By

TIMOTHY NGI ING HONG

FINAL PROJECT REPORT

Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

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CERTIFICATION OF APPROVAL

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Approved:

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Dr. Micheal Drieberg
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
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December 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 that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Timothy Ngi Ing Hong

ABSTRACT

Typically wireless sensor motes are operated by using small batteries because batteries are small in size and able to provide the sufficient energy for the motes. However batteries could not sustain the energy for the motes to operate for a long period. This is because the degradation of batteries could reduce the useable lifetime of the motes system. Besides that, batteries have limited energy capacity which could used up eventually. Aside from relying on the batteries to power up motes, one of the way to sustain the system is to harvest the sources of energy from the environment such as light, vibration, and thermal. These energies are renewable energy which does not cause pollution to the environment. In this project, solar energy harvesting have been proposed to sustain the energy requirement for the motes to operate. Experiments have been conducted to observe the solar panel charging characteristic to improve the efficiency and effectiveness of charging circuit to minimize the power loss. There are three main element in solar energy harvesting which are photovoltaic (PV) modules, solar charge controller and also energy storage. Based on the calculation, suitable PV modules, charging circuit and batteries are determined. Maximum Power Point Tracking (MPPT) technique are used for the charging circuit to maximize the efficiency conversion of the energy harvested from solar panel to charge the rechargeable lithium ion battery .

ACKNOWLEDGEMENTS

My completion of Final Year Project will not be a success without the help and guidance from my supervisor and colleagues. Hereby, I would like to acknowledge my heartfelt gratitude to those I honor.

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LIST OF ABBREVIATIONS

WSN: Wireless Sensor Networks

PV: Photovoltaic

MPPT: Maximum Peak Power Tracking

IC: Integrated Component

DC: Direct Current
NiCd: Nickel Cadmium

NiMH: Nickel Metal Hydride

Li+: Lithium Ion

FYP: Final Year Project

Chapter 1
INTRODUCTION

1.1 Background

Wireless sensor network (WSN) is a promising modern technology which has enabled applications that require low cost, low power, remote monitoring and ease of deployment. WSN are used in several applications such as military applications, environmental monitoring, health care monitoring, security monitoring and so on. Due to the characteristic of low power, remote monitoring and relative small motes, small batteries are normally used to operate WSN.

1.2 Problem Statement

WSN nodes or also known as motes are typically powered by small batteries. This is because small batteries provide sufficient power for WSN to operate. However, the energy capacity of AA batteries such as alkaline batteries are relative small which is approximately 3000mAh. Therefore, the battery source will eventually be depleted and needed for replenishment frequently[1]. Consider that there are hundreds of motes placed within an area, it is difficult to replace the used batteries by know the location of each motes[2]. Besides, WSN required to operate for several years, replacing batteries is a time-consuming and cost prohibitive exercise.

1.3 Objectives

This project aims

1. To design an efficient solar energy harvesting system as an alternative way to power WSN nodes by using Maximum Peak Power Tracking(MPPT) method.
2. To sustain the energy of wireless sensors so that it can be operate for a long period of time.
3. To reduce the cost of batteries replenishment which batteries also acts as an energy limitation for WSN.

1.4 Scope of study

The main focus of the project is to design an efficient solar energy harvesting system to charge rechargeable batteries. Due to the limitation for solar energy harvesting at night, it is essential to use rechargeable batteries to operate the motes at night. So, rechargeable batteries act as the energy storage for the motes to operate days and nights. Besides, comparison between other sources of energy harvesting is also included. Lastly, best type of solar panels and rechargeable batteries to be used in this project is also further studied.

Chapter 2

LITERATURE REVIEW

2.1 Wireless Sensor Network

WSN node is a small device that used to monitor certain types of condition such as environment temperature, pressure, humidity and weather. Besides that, it also can be used as surveillance system in an organization[2]. Typically, motes consists of batteries, processor, transceiver and sensor[2]. Batteries are used to provide power for the motes. Processor is the core of the motes just like a CPU in a computer. Without processor, the mote could not perform any task. Transceiver is used to receive or send the data to the other nodes. There are different type of sensor being used in motes depending on motes' application. Some motes coped with extra features such as GPS and power generator. Motes consume µA in sleep mode and might reach mA in active mode during high data transferring or receiving rate[3]. Gateway is the central point among all the motes. Gateway helps to store and process the received data from the motes through a server or computer.

Figure 1: WSN Components, Gateway, and Distributed Nodes[2]

2.2 Types of Renewable Energy Harvesting in WSN

Several types of renewable energy harvesting are being proposed. Among them are solar, piezoelectric, vibration and thermoelectric energy harvesting[1].

2.2.1 Solar Energy Harvesting

Solar energy is a type of exhaustible and clean renewable energy. The source of the energy is from the sun. Sun radiate heat and energy to the Earth by photons. When photons hit the surface of solar panels, its' energy is absorbed by photovoltaic(PV) materials to create free charge carrier[4]. Then, separation of positive(hole) charge and negative(electron) charge through a p-n junction semiconductor causes current to flow in one direction across the terminals which leads to a voltage difference. The power generated by PV modules is depending on the irradiance, temperature, weather condition, geographical location and angle of solar panel in respect to the sun[5].

Irradiance greatly influence the performance of solar array. In terms of PV modules, It defines as the incident density of radiation energy absorbed by the solar array over its area. The S.I unit for irradiance is watts per square meter (W/m2). Ideally, a typical solar panel can get an irradiance of 100mW/cm2[5].

Temperature of PV modules affect the efficiency of power generation. It is normally rated at module temperature which is 25°C. When the temperature of PV modules is too high or too low(in degree Celsius), efficiency of power generation drops. Research has been done that every degree C increase, the efficiency of PV modules drop 0.5%[5].

Due to it is unavailable to function during night time, rechargeable batteries is needed to be the storage to store energy generated by PV modules during day time so that the WSN is able to function around the clock.

2.2.2 Piezoelectric Energy Harvesting

The piezoelectric effect converts mechanical strain into electricity which is produced by vibrations, human motion, and acoustic noise. The power harvested by using this method is relatively low (in µW/cm3)[1]. However, it is enough to power certain low power applications such as self-winding wristwatches.

2.2.3 Vibration Energy Harvesting

Energy harvested by this method is also adopt from piezoelectric effect. The mechanical strain models used to create vibration are damper, spring and mass[6]. However, this type of energy harvesting also generate small amount of power (in µW/cm3)[1]. Normally, this type of energy harvesting are used in micro systems applications.

2.2.4 Thermoelectric Energy Harvesting

Thermoelectric effect converts the thermal gradient between two surfaces into electricity. The higher the thermal gradient between the two surface, the higher power is generated. Charge carriers in the material to diffuse from the hot surface to the cold surface and thus electricity is generated. The advantages of this effect is that no material replenishment is require. Besides, it can be a heating or cooling application when voltage is supplied. The downsides of thermoelectric effect is the low efficiency of energy conversion which is approximately 10%

Table 1: Power Densities of Harvesting Technologies[1]

METHODS	POWER DENSITY
Solar cells	15 mW/cm3
Piezoelectric	330 µW/cm3
Vibration	116 µW/cm3
Thermoelectric	40 µW/cm3

From the Table 1, it is obvious that solar cells has the highest power densities of harvesting technologies.

2.3 Types of Energy Storage in WSN

Table 2: Type of Energy Storage[1, 3]

Energy Storage	Figures	Advantages	Disadvantages
Nickel Cadmium (NiCd)		Deliver full rated capacity	Temporary capacity loss, High discharge rate
Nickel Metal Hydride (NiMH)		High energy density	Lower life cycle
Lithium Ion (Li+)		Longer life cycle, Low self-discharge	Expensive, Complicated charging circuit
Ultra-Capacitors		High power density, High life cycle	High self-discharge rate, Low capacity
Thin film		Higher cell voltage, Long lifetimes	Low capacity, High internal resistance

Table 2 is the comparison among the batteries which can be used in WSN. NiCd are less being used nowadays because of its high self-discharge rate and also have the memory effect. However, it is still used by the cameras because it can always deliver full rated capacity. Although Li+ battery are preferable choice due to its long life cycle and low self-discharge rate, it is more costly compared to other type of batteries. Both ultra capacitor and thin film have longer lifetime than batteries, however, due to its low energy capacity, they can only be used as a short term energy storage. Lastly, NiMH is the most desirable choice due to its high energy density and most commonly used technology, but the downsides of it is it has lower life cycle.

2.4 Maximum Peak Power Tracking (MPPT)

Most of the energy harvesting method use this technique to obtain Maximum Power Point Tracking (MPPT). MPPT is used because it can provide the highest energy conversion efficiency especially when the efficiency of the renewable energy harvesting is very low. Since the voltage and current generated by the renewable energy vary from time to time, MPPT technique help to adjust the output current with respect to voltage automatically to produce the highest power output[7].

Without using MPPT will result in wasted power. This can causes more solar panel needed to be installed to meet the same minimum power requirement for the battery charging circuit. Besides that, using battery connected directly to the solar panel result in battery capacity loss. This is because there circuit does not have a proper end-of-charge batteries' procedure. All these disadvantages results in higher installation cost due to more units are needed to provide same power requirement.

With a proper solar charge controller such as adopting MPPT technique, we do not need to install extra 30-50% units of PV modules to get the same power requirement which make this technique very attractive to the researchers. Even using the simplest MPPT algorithm, it is guaranteed that the energy conversion efficiency of battery charging circuit will be at least 90%.

2.4.1 Solar Panel MPPT

MPPT algorithms helps to automatically find the most suitable operating voltage with respect to input current from the PV modules to maximize the output power. Figure 2 shows the typical I-V characteristic of solar panels at given irradiance of sunlight. Figure 3 shows the open circuit voltage (VOC) to the right of maximum power point at given irradiance of sunlight. We can observe each maximum power point is at the knee of given irradiance. The short-circuit current (ISC) is another important parameter because that is the absolute maximum current can be drawn from the solar panel.

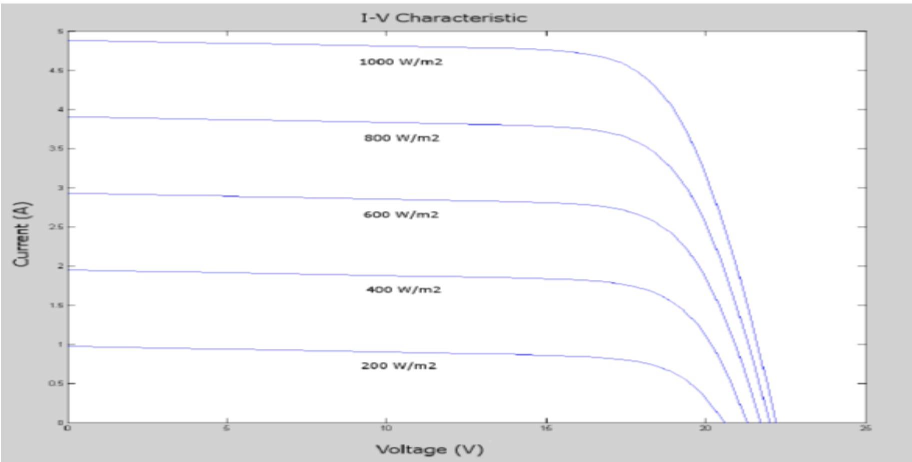


Figure 2: I-V Characteristic[8]

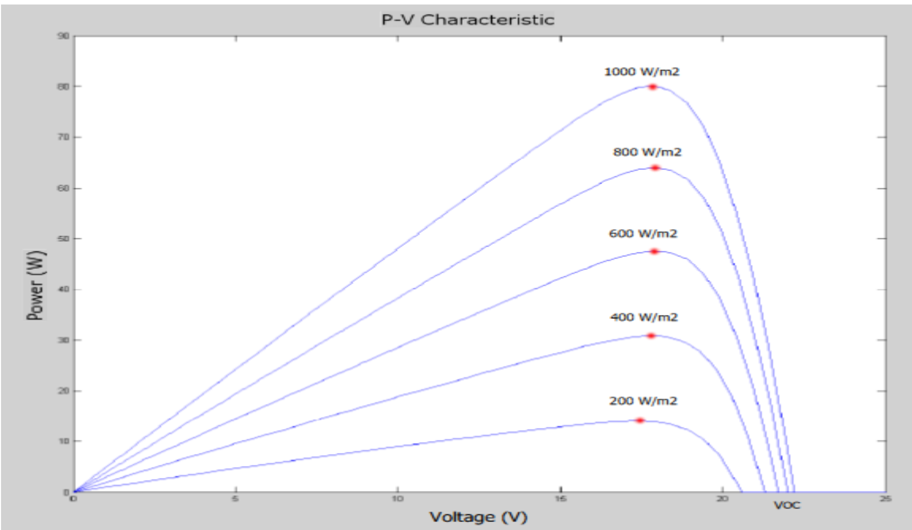


Figure 3：P-V Characteristic[8]

Chapter 3

METHODOLOGY

WSN motes used in this project is MICAz MPR2400CA. It is a 2.4GHz IEEE 802.15.4 tiny wireless measurement system which can be use for security monitoring, temperature, pressure, light intensity measurement. This mote also can be a base station if it is connected to gateway board or PC interface. The block diagram and specification for this mote is shown below.

Figure 4: MICAz Mote and Mote Interface Board[10]

Table 3: WSN Specification

Processor/Radio Board	MPR2400CA
Processor Performance	
Program Flash Memory	128K bytes
Configuration EEPROM	4K bytes
Analog to Digital Converter	10 bit ADC
Current Draw	8mA (active)
	< 15 µA (sleep)
RF Transceiver	
Frequency band	2400 MHz
Transmit (TX) data rate	252kbps
RF power	24 dBm to 0 dBm
Outdoor Range	75 m to 100 m
Indoor Range	20m to 30m
Current Draw	20mA (active)
	20 µA (sleep)
Electromechanical	
Battery	2X AA batteries
External Power	2.7 V - 3.3 V

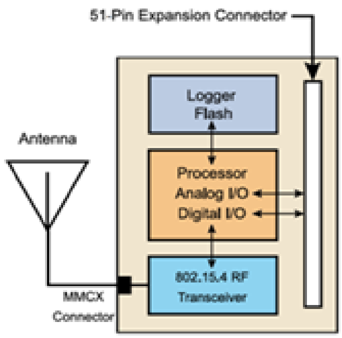


Figure 5: Block Diagram[10]

3.1 Calculation

3.1.1 Selection of solar panel and battery

Total current draw from the mote in active mode and sleep mode is 30mA and 35μA respectively. To calculate average current draw in a day, let's consider that the mote is in active mode for 4 hours and sleep mode for 20 hours.

$$I_{avg(day)} = 30\text{mA} * 4(\text{hr}) + 35\ \mu\text{A} * 20(hr)$$

$$\approx 120.7\text{mA / day}$$

Assume the energy capacity for Li ion battery is 2500mAh and all the capacity is consume by the mote without any losses. The maximum day for the mote to operate is:

$$t_{day} = \frac{2500mAh}{120.7mA}$$

$$\approx 20 \text{ days}$$

The minimum requirement for selecting a solar panel from the calculation is to select a solar panel which can generate at least 121mAh/day. Li ion battery of larger than 2500mAh is recommended.

3.2 Solar Energy Harvesting Block Diagram

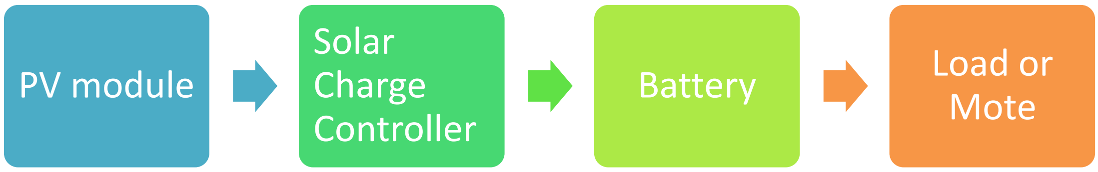


Figure 6: Solar Energy Harvesting Block Diagram

The process of solar energy harvesting is shown in Figure 5.PV module converts photons from the sunlight into DC electricity. The electricity produced is then flow into solar charge controller which helps to regulate the voltage and current to the rechargeable battery and prevents battery from overcharging which may result in shorten battery lifetime. Battery is used to store energy and load, in this case, mote is connected to the solar PV system for WSN operations.

3.3 Circuit design

The Integrated Circuit (IC) used in this project is LT3652 from the Linear Technology Corporation. The feature and applications are shown in the table below:

Table 4: LT3652 Features and Applications

Features
Input Supply Voltage Regulation Loop for MPPT
Input Voltage Range from 5V to 32V
Programmable Charge Rate Up to 2A
Resistor Float Voltage Up to 14V
Applications
Solar Powered Applications
Remote Monitoring Applications
Portable Instruments
Low Voltage Automotive Systems

The LT3652 is a step-down battery charger with input voltage range operate from 5V to 32V. It provides a constant-current or constant-voltage charge characteristic, with maximum charge current up to 2A. The charger employs a 3.3V float voltage feedback reference, so any desired battery float voltage up to 14V can be programmed with a resistor divider.

The LT3652 have the feature of input voltage regulation loop. When the input voltage falls below programmed level, the charge current will be reduced with respect to input voltage, by setting with a resistor divider.

Before designing solar charge controller circuit, calculations are needed to determine a suitable solar panel. Then, calculations on the component parameters are also needed to design the solar charge controller circuit.

To determine a suitable solar panel, we need to calculate the minimum requirements for open circuit voltage (Voc), peak power voltage (Vpmax), and peak power current (Ipmax). Besides that, 15% of Lithium battery charging is predetermined for low intensity start-up and operation.

$$V_{OC} = (V_{BAT(FLOAT)} + \mathrm{V_{FORWARD(D1)}} + 3.3\mathrm{V} * 1.15$$
$$= (3.7 + 0.5 + 3.3) * 1.15$$
$$= 8.625\mathrm{V}$$

$$V_{P(MAX)} = \left(V_{BAT(FLOAT)} + \mathrm{V_{FORWARD(D1)}} + 0.75\mathrm{V}\right) * 1.15$$
$$= (3.7 + 0.5 + 0.75) * 1.15$$
$$= 5.693\mathrm{V}$$

$$I_{P(MAX)} = I_{CHARGE} \times \frac{V_{BAT(FLOAT)}}{n.VP(MAX)}$$
$$= 0.1 \times \frac{3.7}{0.8 \times 5.7\mathrm{V}}$$
$$= 0.081\mathrm{A}$$

From the calculations, the minimum requirement for the solar panel to operates the solar charge controller circuit are shown below:

Voc =8.625, Vp(max)=5.6925 and Ip(max)=0.081A

Then, current sensing resistor R_{SENSE} is determined for maximum charging current $I_{CHARGE(MAX)}$.

$$R_{SENSE} = 0.1/I_{CHARGE(MAX)}(\Omega)$$

Maximum charging current $I_{CHARGE(MAX)}$ is predefined at 0.1A,

$$R_{SENSE} = 0.1/0.1$$

$$R_{SENSE} = 1\Omega$$

To compensate input bias current error, the Thevenin's equivalent resistance are set to 250k. Then, this resistance value in substituted into output feedback voltage divider network to find R_{FB1} and R_{FB2}. The V_{FB} pin reference voltage is set at 3.3V.

$$R_{FB1} = \frac{V_{FLOAT} \times 250K}{3.3V}$$

$$R_{FB1} = \frac{3.7V \times 250K}{3.3V}$$

$$R_{FB1} = 280K\ \Omega$$

Let, $R_{FB1} = 270K\Omega$

$$R_{FB2} = \frac{R_{FB1} \times 250K}{R_{FB1} - 250K}$$

$$= \frac{270K \times 250K}{270K - 250K}$$

$$= 3.3M\Omega$$

The voltage divider network of R_{IN1} and R_{IN2} are used to set the MPPT voltage.

$$\text{Let } \mathrm{R_{IN2}} = 200\mathrm{K\Omega}$$

$$\mathrm{R_{IN1}} = \frac{\mathrm{V_{P(MAX)}} - \mathrm{V_{FORWARD(D1)}} - 2.74\mathrm{V}}{2.74} \times 200\mathrm{K}$$

$$= \frac{5.7\mathrm{V} - 0.5\mathrm{V} - 2.74\mathrm{V}}{2.74} \times 200\mathrm{K}$$

$$= 180\mathrm{K\Omega}$$

The following equation is used to calculate the minimum and maximum MPPT voltage:

$$V_{REG(MIN)} = \left(2.67 \times \frac{R_{IN1} + R_{IN2}}{R_{IN2}}\right) + V_{F(D1)}$$

$$V_{REG(MIN)} = \left(2.67 \times \frac{180 + 200}{200}\right) + 0.5V$$

$$= 5.57V$$

$$V_{REG(MAX)} = \left(2.74 \times \frac{R_{IN1} + R_{IN2}}{R_{IN2}}\right) + V_{F(D1)}$$

$$V_{REG(MAX)} = \left(2.74 \times \frac{180 + 200}{200}\right) + 0.5V$$

$$= 5.71V$$

Finally, The parameter for shutdown voltage's resistance, R_{SHDN1} and R_{SHDN2} is determined using voltage divider network formula.

$$R_{SHDN1} = R_{SHDN2} \times \frac{\left(V_{REG(MIN)} - V_{F(D1)}\right) - (V_{SHDN(MAX)} - V_{SHDN(HYST)})}{V_{SHDN(MAX)} - V_{SHDN(HYST)}}$$

The V_{SHDN} rising threshold is 1.2V±$50mV$with hysteresis of 120mV.

$$\text{Let, } R_{SHDN2} = 47K\Omega$$

$$R_{SHDN1} = R_{SHDN2} \times \frac{\left(V_{REG(MIN)} - V_{F(D1)}\right) - (V_{SHDN(MAX)} - V_{SHDN(HYST)})}{V_{SHDN(MAX)} - V_{SHDN(HYST)}}$$

$$= 47 \times \frac{(5.57 - 0.5) - (1.25 - 0.12)}{1.25 - 0.12}$$

$$= 160K\Omega \ \ [9]$$

3.4 Schematic Diagrams

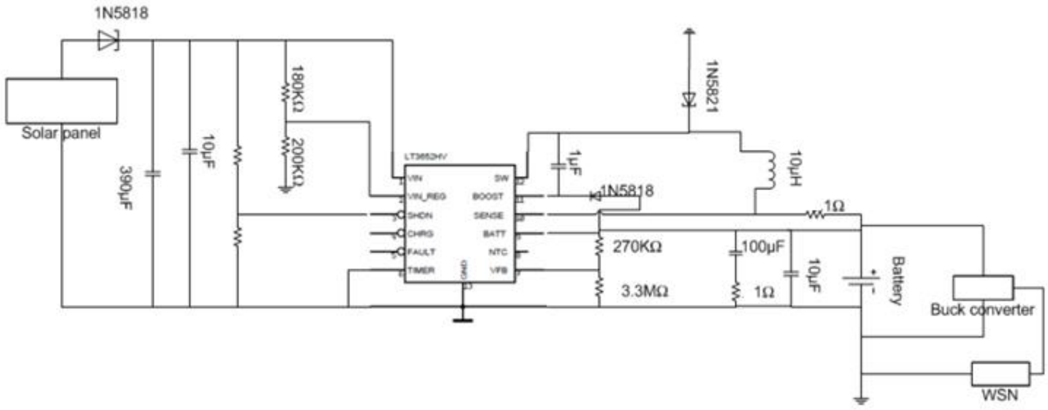


Figure 7: Solar Energy Harvesting System

Figure 7 shows the schematic diagrams for solar energy harvesting by using a software named LTspice. LT3652 is an solar charge controller IC which optimize the energy harvested from the solar panel by using MPPT technique. The capacitors, inductors and resistors parameters are calculated in Section 3.3.

Solar panel which acts as the source converts the solar energy to electrical energy. A diode is installed next to the solar panel is to prevent the reverse current flow from the battery to the solar panel at night due to the higher voltage at the battery which become the source and lower voltage at the solar panel which become the load. Then the solar charge controller IC reduce the output voltage to 3.7V by using voltage divider technique to charge the Lithium Ion battery. This IC also helps to track the maximum peak power that can be generated at a given irradiance. Since the sensor motes can only be functioning at the range of 2.7V-3.3V, the Lithium Ion battery is stepped down from 3.7V to 3.0V by using IC LTC3440 Boost-Buck Converter.

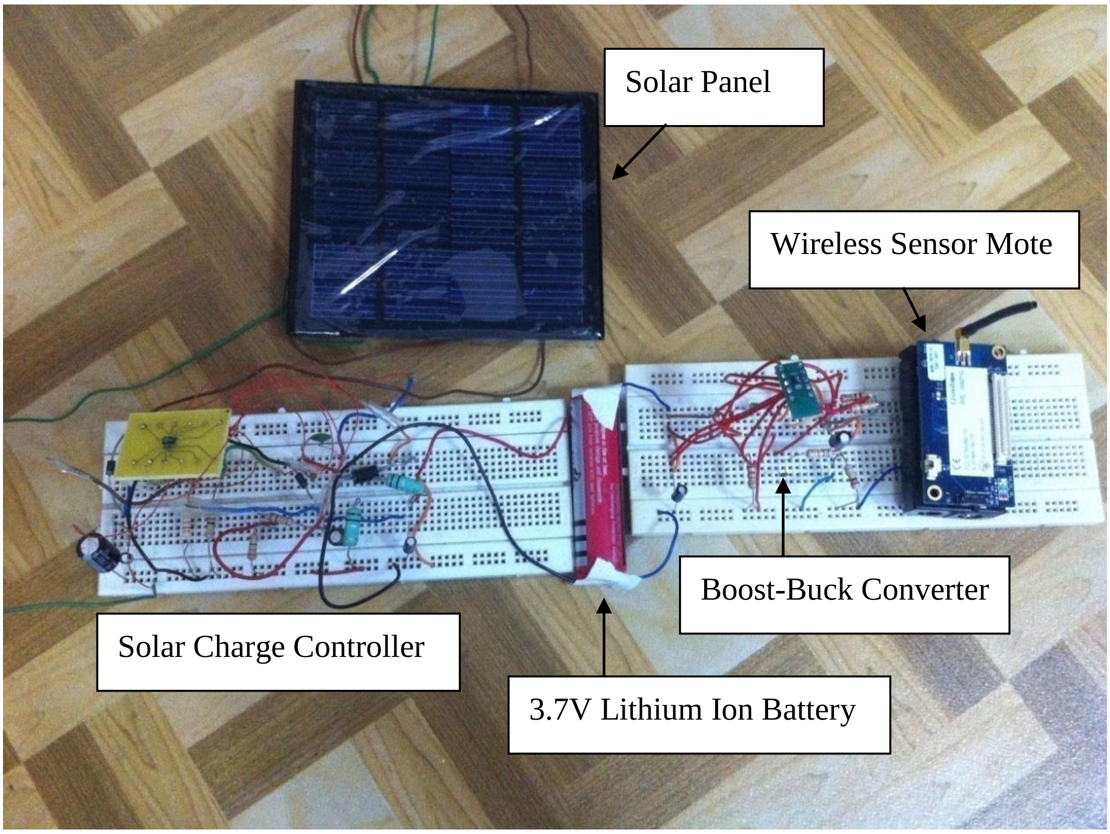
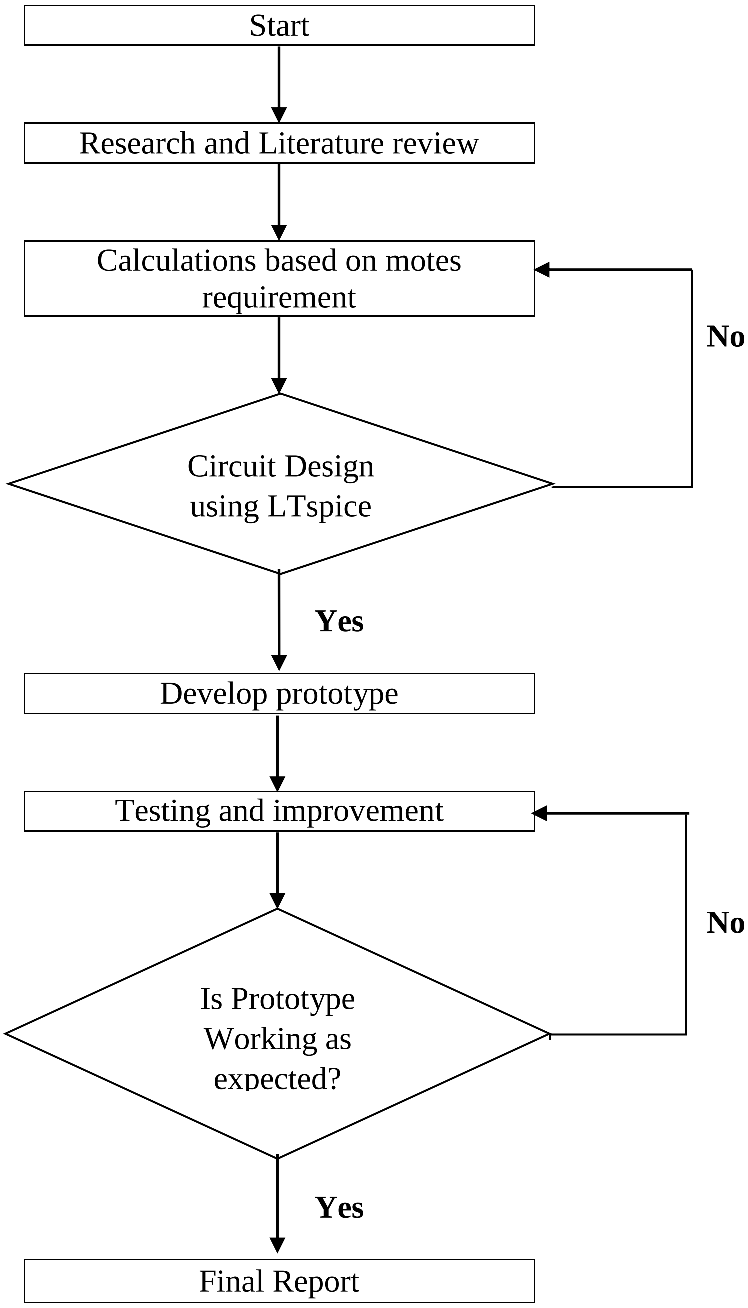


Figure 8: Prototype of Solar Energy Harvesting System

3.5 Project Flowchart



3.6 Project Activities

The following items shows the progress of the project conducted in a sequential manner.

3.6.1 Choosing a Title

A project title is chose based on interest from supervisor. Then discussion is done with supervisor to know the requirement and the overall objective of the project. The title for this project is Solar Energy Harvesting for Wireless Sensor Network.

3.6.2 Read Journals, Conference Papers, Magazines, and E-books

Search for project related journals, conference papers, magazines, and E-books. Then, go through it and understand the concepts. After that, choose the most suitable designing technique for solar energy harvester among them.

3.6.3 Calculations based on Motes and Solar Panel Requirement

First of all, mote minimum and maximum operating requirement is determined. Then a suitable solar panel is chosen base on the mote requirement. Finally, a solar charging circuit is designed based on the chosen solar panel.

3.6.4 Software Testing

A simulation circuit is designed using LTspice to check if everything run smoothly. If the simulation circuit run without any problems, the real circuit will be assembled.

3.6.5 Prototype Design, Testing and Improvement

After done checking with the simulation circuit, a prototype will be designed based on the calculated parameters. This prototype will be designed on the breadboard. This prototype will be tested and improved repeatedly to obtain the expected results. Prototype may not be working as expected as the simulation circuit due to the tolerance errors of the electronic components. Besides that, experiments on the influence of irradiance towards the output voltage and current of the solar cell are also conducted.

3.6.6 Final Report

This is the end of the Final Year Project 2. After everything had settled such as ELECTREX/SEDEX and VIVA, a overall final report will be written and submitted in softcopy, hardcopy and compact disc.

3.7 Software and tools

The software and tool used in this project:

- PV Module
- LT3652
- LT3440
- Lithium Ion Battery
- Lithium Ion Battery Charger
- Electrical Components
- LTspice
- Pasco Capstone
- KIMO Solarimeter
- Voltage Sensor
- Current Sensor
- Multimeter
- Soldering tools
- Breadboard

3.8 Key Milestone and Gantt Chart

3.8.1 Gantt Chart for FYP1

Table 5: Gantt Chart for FYP1

Phase	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Choosing project title	■	★												
Read journals,magazines,conference paper related to project title			■	★	■	■								
Write extended proposal					■	★								
Finding information and making comparison on solar charger controller						■	■	★						
Proposal Defence									★					
Come out with the suitable solar charger controller and the suitable algorithm.										★	■			
Design a circuit of solar charger controller with solar panel and battery bank.											★	■		
Interim Report Draft												■	★	
submission of Interim Report													■	★

★ **Indicate Key Milestone**

3.8.2 Gantt Chart for FYP2

Table 6: Gantt Chart for FYP2

Phase	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Design suitable experiment to check suitablity of solar panel.	■	★	■											
Design a circuit of solar charger controller with solar panel and battery bank.			■	■	★									
Simulate a solar charger controller circuit on Ltspice and check for circuit performance					■	■	★							
Implement the circuit with motes.							■	■	★					
Observe for compatibility of motes with the circuit and also improvement									■	■	■	★		
Final implementation of the compatible motes and circuit.													★	

★ **Indicate Key Milestone**

Chapter 4

RESULTS AND DISCUSSIONS

4.1 Experimenting on Solar irradiance

Experiments has been conducted to observe the behavior of solar irradiance of a chosen solar panel for several days in UTP. Two random days of solar irradiance data is selected for analyzing. These data is recorded by using Data Taker.
The solar irradiance graphs is shown below.

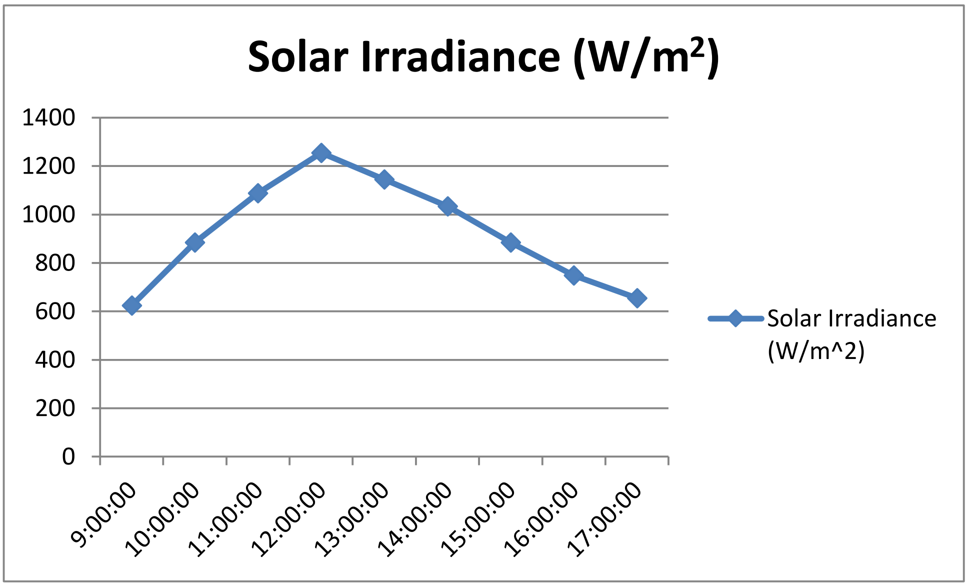


Figure 9: Solar irradiance on June 25th

The graph above shows the solar irradiance, watt per meter square on 25 June 2014 from 9am to 5pm in UTP. From the graph, it shows that the solar irradiance increases gradually from 9am (624 W/m^2) to 12pm(1254 W/m^2) and starts decreasing linearly from 12pm(1254 W/m^2) to 5pm(654 W/m^2).

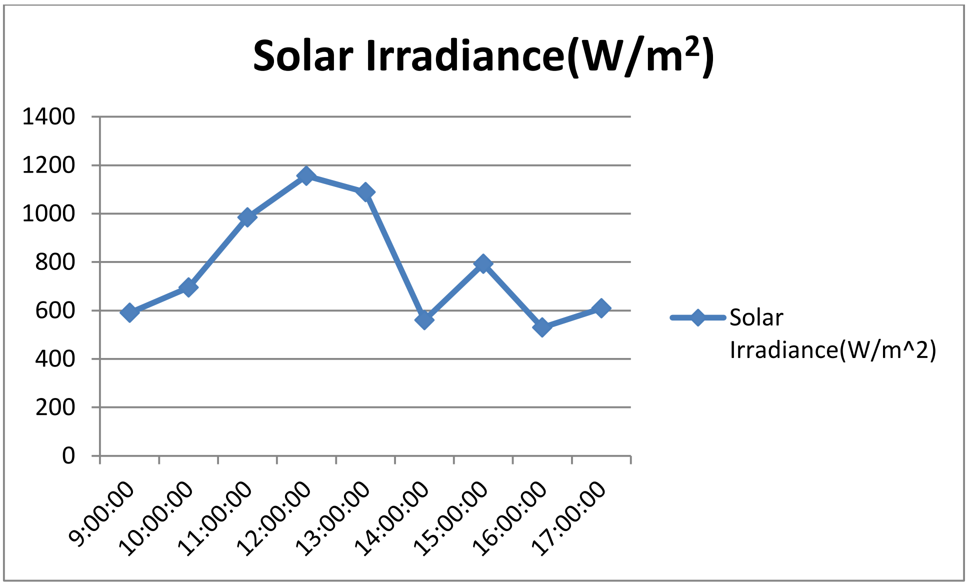


Figure 10: Solar irradiance on June 30th

The graph above shows the solar irradiance, watt per meter square on 30 June 2014 from 9am to 5pm in UTP. On this day, the solar irradiance also increases gradually from 9am to 12pm. Due to the weather changing inconsistently in the afternoon (mostly cloudy), the solar irradiance does not shows a good result.

From the statistic of the graph we can conclude that the solar irradiance will be increases from morning until peak at 12pm noon, then it starts to decreases slowly in the afternoon. Besides that, the solar irradiance are very dependent on the weather during daytime. So, we may not always get the expected results. Due to the characteristic of solar panel which are time and solar irradiance varying, it is inappropriate to directly connect solar panel to the wireless sensor motes as it may spoil the motes and also the motes could not function at night.

4.2 Voltage, Current and Power Characteristics of Solar Panel.

The figure below shows the setup to test the characteristics of solar panel between voltage, current and power by varying the solar irradiance values. Way to vary the solar irradiance values is by adjusting the distance between the solar simulated light bulb and the solar panel. Two different solar irradiance parameters had been selected which are 200 W/m^2 and 300 W/m^2 to observe the voltage, current and power characteristics of solar panel.

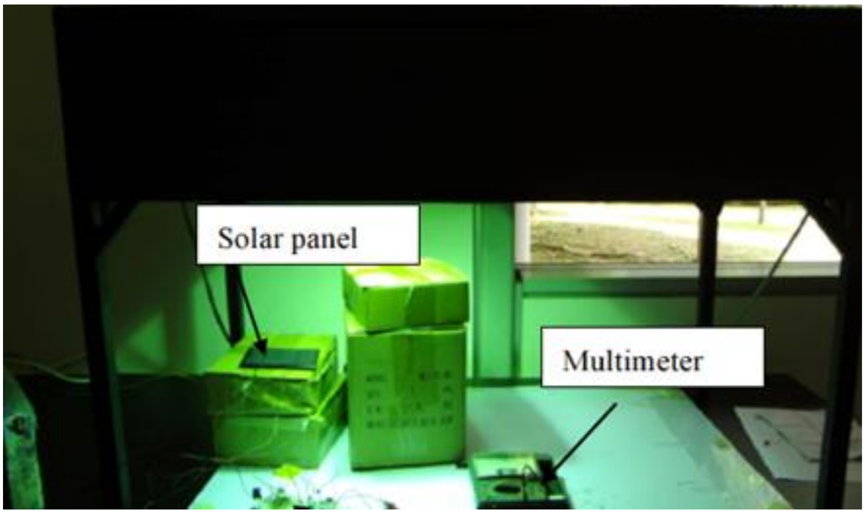


Figure 11: Experiment Setup for I-V and P-V Characteristics of Solar panel

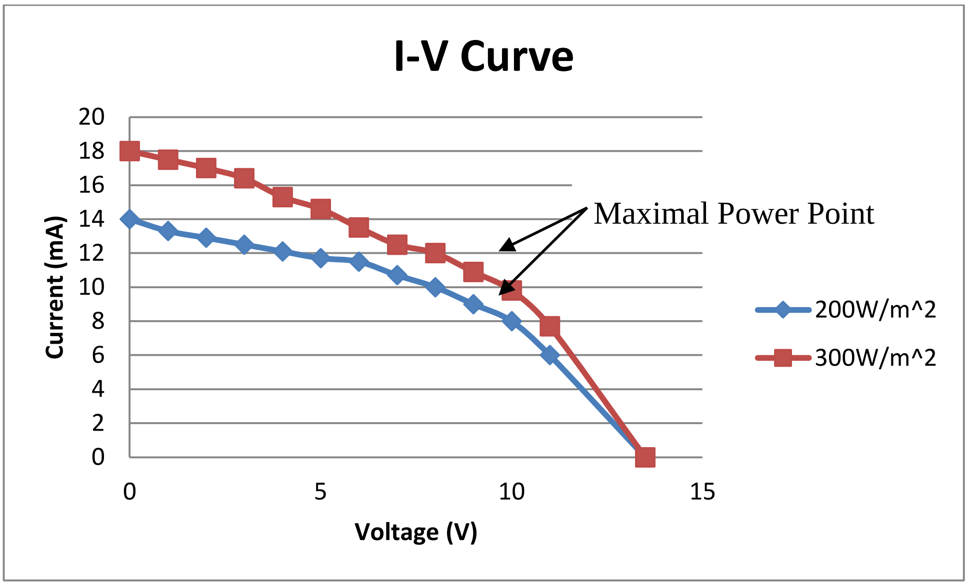


Figure 12: I-V Curve of Solar Panel

Figure 12 shows the current versus voltage curve of solar panel with solar irradiance at 200W/m^2 and 300W/m^2. The current is at highest when the voltage is 0V(short-circuit) and 0A(open circuit) when voltage is at maximum. As the voltage increases, the current starts decreasing regardless the solar irradiance. The MPP for both solar irradiance of 200W/m^2 and 300W/m^2 is around 9V.

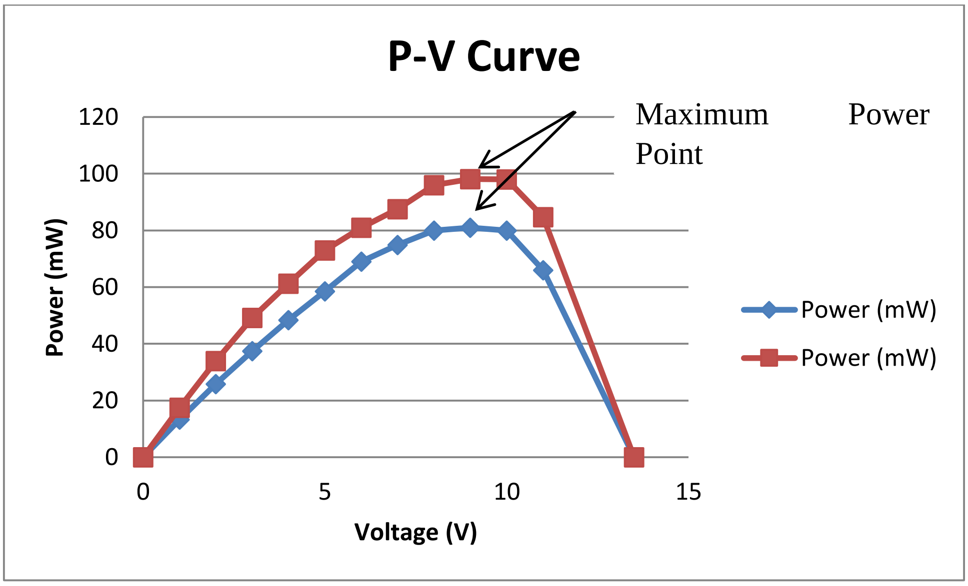


Figure 13: P-V Curve of Solar Panel

Figure 13 shows the P-V curve of solar panel with solar irradiance at 200W/m^2 and 300W/m^2. Both solar irradiance of 200W/m^2 and 300W/m^2 had increasing output power as the voltage increases until a maximal power point, then it starts decreasing The MPP for both solar irradiance of 200W/m^2 and 300W/m^2 is around 9V.From Figure 10 and 11, it can be concluded that the MPP is at the knee of the graph. At this point, the output power is at the maximum for this solar panel. Besides that, it is proven that the solar panel acts as voltage-limited current source. Short-circuit current increases when solar irradiance increases.

4.3 LTSpice Software Simulation

In this section, a solar energy harvester system is simulated to check the compatibility of this system. The schematic diagram consist of solar charger (LT3652HV), battery storage, boost-buck converter (LTC3440) and Load (resistor).

4.3.1 Solar Charger (LT3652HV) Schematic Diagram

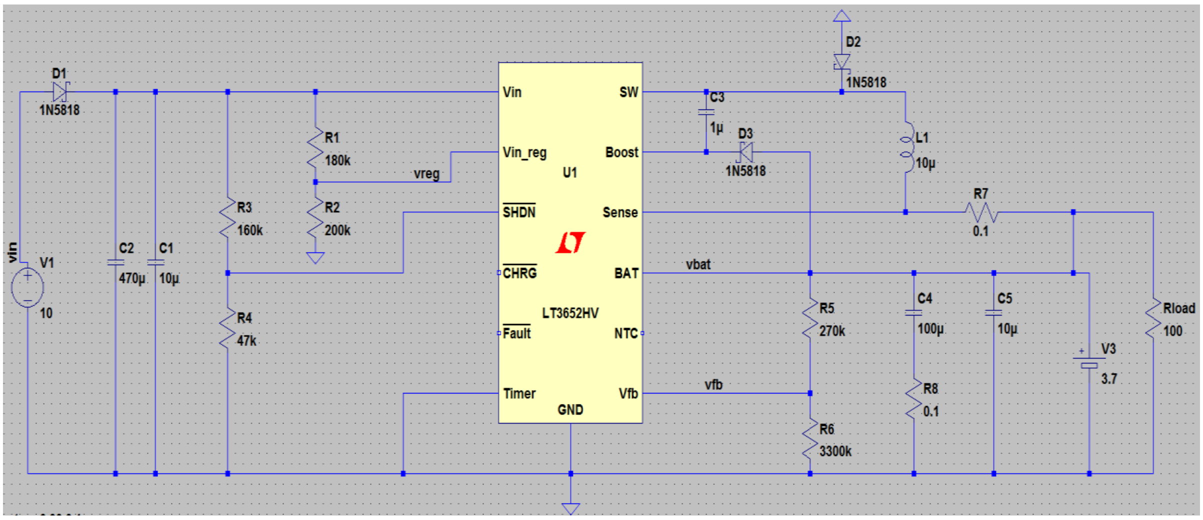


Figure 14: Solar Charger (LT3652HV) Schematic Diagram

4.3.2 Boost-Buck Converter (LTC3440) Schematic Diagram

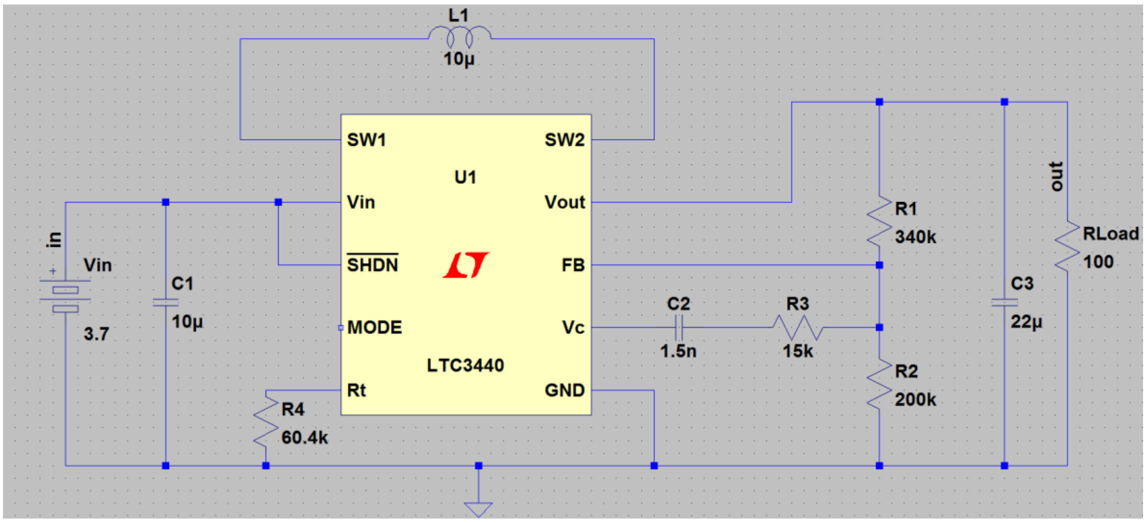


Figure 15: Boost-Buck Converter (LTC3440) Schematic Diagram

4.3.3 Solar Harvester System Schematic Diagram

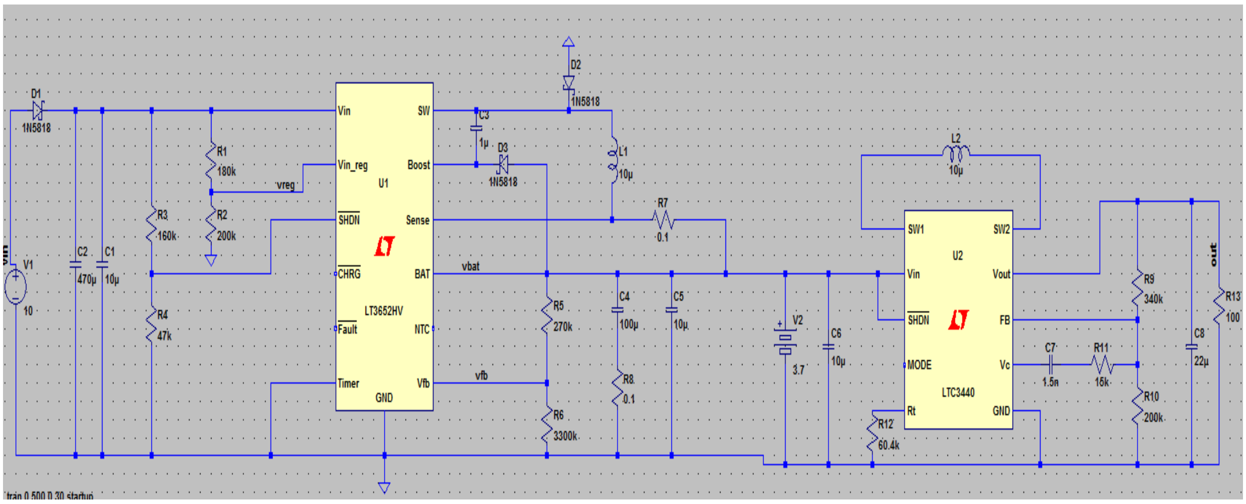


Figure 16: Solar Harvester System Schematic Diagram

4.3.4 Solar Harvester System Input and Output Voltage

Figure 17: Graph of Voltage Input and Output for Solar Harvester System

Figure 17 shows the input and output voltage of solar harvester system. The input voltage(Vin) is 10 volts which act as solar panel input voltage. The output voltage from the solar charger (Vbat) which used to charge the battery is 3.7volts. Vfb is the Battery Float Voltage Feedback Reference and it is set default at 3.3volts. Vout is the output voltage from the boost-buck converter which step down the voltage to 3.0volts. Since the operating voltage for the motes is between 2.7Volts-3.3Volts, this circuit is compatible to power up the wireless sensor motes.

4.4 Charging Lithium Ion Battery with Solar Charge Controller

In this section, a nominal voltage of 3.7V Lithium ion battery will be charged by using the designed solar charge controller. The irradiance used in this charging experiment is 400W/m^2 and the charging period is around 3 minutes. A software called PASCO Capstone is used to record the charging battery in real time.

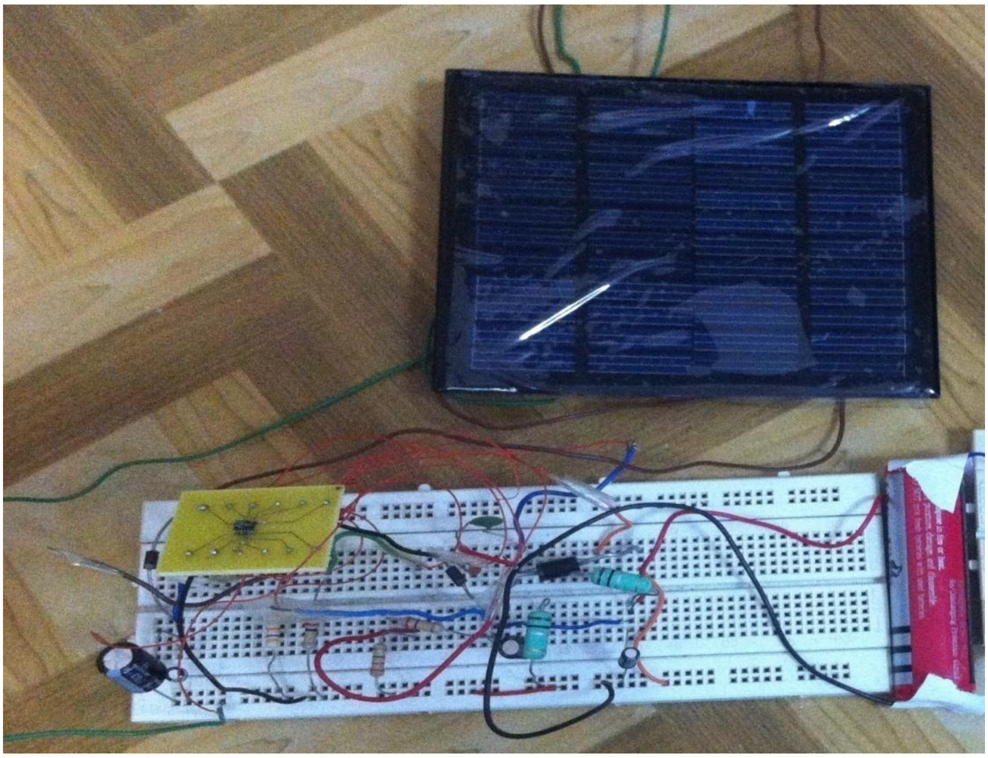


Figure 18: Solar Charge Controller System

4.4.1 Lithium Ion Battery Charging Graph of Voltage over Time

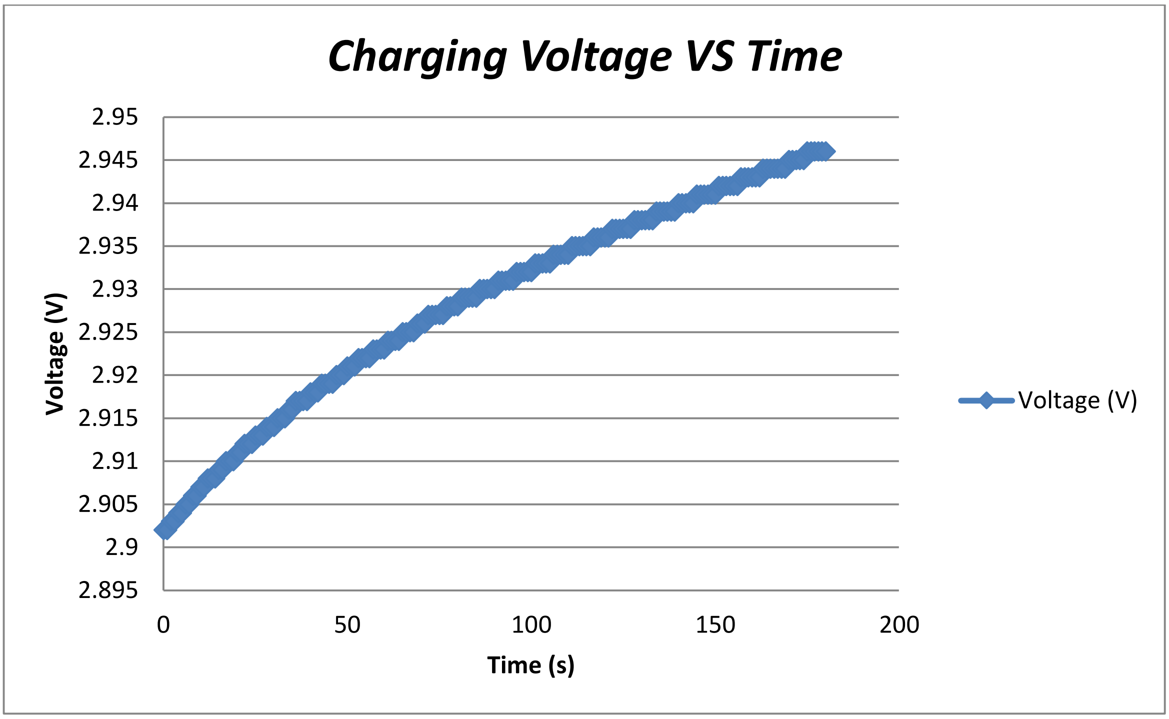


Figure 19: Graph of Charging Voltage VS Time

Figure 16 shows the Lithium Ion battery charging graph of voltage over time. The input of the charging voltage is regulated by the solar charge controller at 3.7V. The irradiance are set at a constant value of 400W/m^2 during the experiment. From the graph, it shows that the initial voltage of the battery is around 2.9V and the battery is being charged for 3 minutes. From the graph, it is obviously shows that the voltages increases exponentially during the charging period, voltage increment from 2.9V to 2.945V. However, this charging circuit could not fully charged the 3.7V Lithium Ion battery due to the lack of input charging voltage. To fully charged a Lithium Ion battery, a input voltage of 4.2V is required. However, Lithium Ion battery does not need to be fully charged as it does not affected by "memory effect" which may reduce the total capacity of a battery. Besides that, overcharging a Lithium Ion battery is not encouraged as it causes cell oxidation which reduces battery lifetime.

4.4.2 Lithium Ion Battery Charging Graph of Current over Time

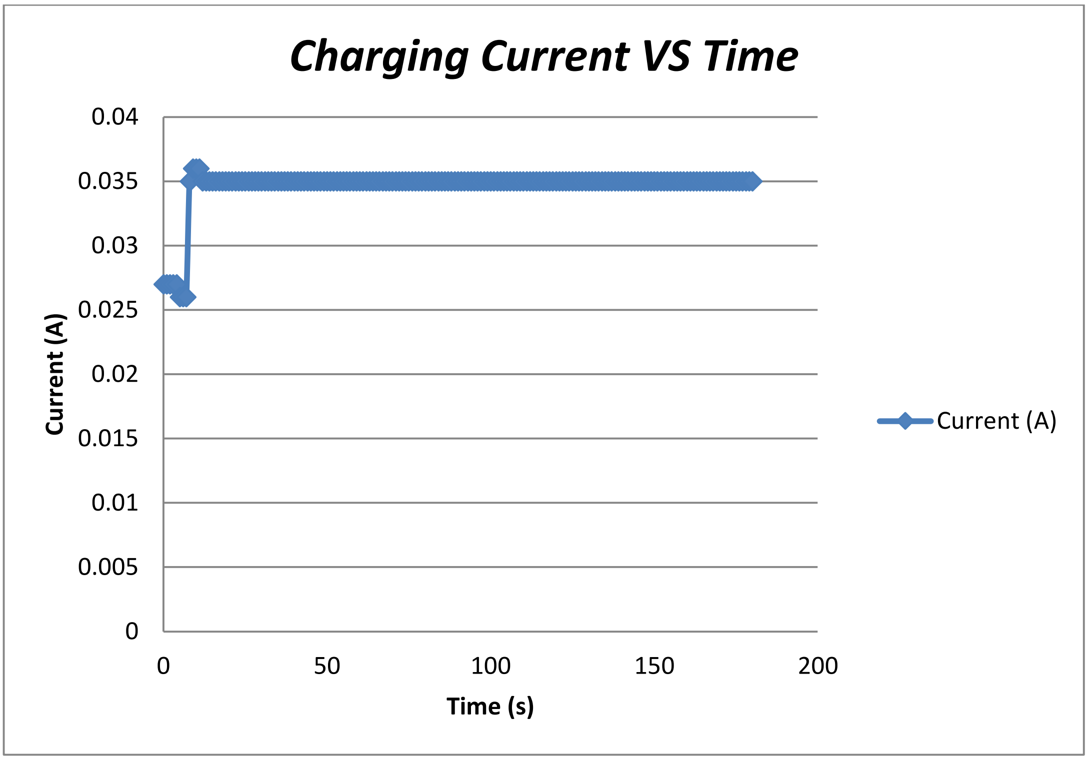


Figure 20: Graph of Charging Current VS Time

Figure 17 shows the graph of charging current over duration of 3 minutes. The irradiance is set constant at 400W/m^2. From the graph, it shows that the charging current is stabled 35mA when the irradiance is constant at 400W/m^2. However, the output current from the solar charge controller also varies as the irradiance changes. Higher irradiance produce higher output current.

4.5 DC-DC Boost-Buck Converter

As the voltage of Lithium Ion Battery is rated at 3.7V, the voltage must be stepped down to the normal operating range of sensor motes which is 2.7V to 3.3V. IC LTC3440 boost-buck Converter is used to step down the voltage to 3V by using the voltage divider technique.

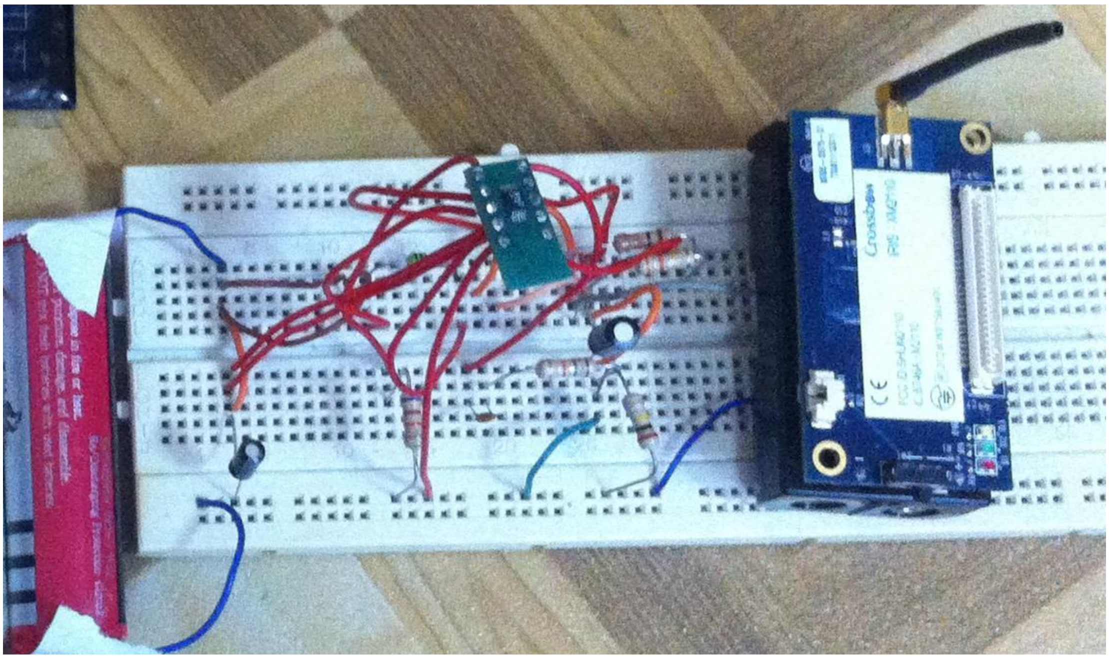


Figure 21: DC-DC Boost-Buck Converter System

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

Recently, green energy becomes an alternative option for power sustainability. In this report, a solar energy harvester is designed to charge Lithium Ion battery for powering up wireless sensor nodes. To maximize the power transfer of charging circuit to the battery, a technique called Maximum Peak Power Tracking (MPPT) technique is used. By using this technique, it helps to reduce the unwanted power loss for charging the battery due to the non-linear I-V curve from the solar panel.

Some issues arise when designing the solar charger when the input and output voltage in real world does not match with the calculated requirements. One of the reason is because it is hard to find a solar panel that meets the calculated requirements in Malaysia. Another reason is due to the weather conditions. Weather condition will directly interrupt the performance of the solar charger. It is hard to conduct the experiments when the weather is cloudy or rainy day.

Safety is very concerning when designing a circuit to charge a rechargeable battery. Different type of batteries have different charging characteristic. So, the batteries must be well handled when designing a battery charging circuit to prevent unwanted accidents happening. Overcharging a battery may shorten the lifetime of the battery and in a worst case scenario it may cause explosion.

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APPENDICES

APPENDIX A

RESULT FOR THE SOLAR IRRADIANCE ON 26 JUNE 2014

Time	Solar Irradiance (W/m^2)
9:00:00	624
10:00:00	884
11:00:00	1088
12:00:00	1254
13:00:00	1145
14:00:00	1034
15:00:00	884
16:00:00	748
17:00:00	654

APPENDIX B

MAXIMUM POWER POINT OF THE SOLAR PANEL

Irradiance (W/m^2)	Voltage (V)	Current (mA)	Power (mW)
200	0	14	0
200	1	13.3	13.3
200	2	12.9	25.8
200	3	12.5	37.5
200	4	12.1	48.4
200	5	11.7	58.5
200	6	11.5	69
200	7	10.7	74.9
200	8	10	80
200	9	9	81
200	10	8	80
200	11	6	66
200	13.5	0	0

APPENDIX C

MAXIMUM POWER POINT OF THE SOLAR PANEL

Irradiance (W/m^2)	Voltage (V)	Current (mA)	Power (mW)
300	0	18	0
300	1	17.5	17.5
300	2	17	34
300	3	16.4	49.2
300	4	15.3	61.2
300	5	14.6	73
300	6	13.5	81
300	7	12.5	87.5
300	8	12	96
300	9	10.9	98.1
300	10	9.8	98
300	11	7.7	84.7
300	13.5	0	0

APPENDIX D

Voltage Increases while Charging a Lithium Ion Battery over 3 Minutes with Irradiance of 400W/m^2

Time (s)	Voltage (V)
0	2.902
1	2.902
2	2.903
3	2.903
4	2.904
5	2.904
6	2.905
7	2.905
8	2.906
9	2.906
10	2.907
11	2.907
12	2.908
13	2.908
14	2.908
15	2.909
16	2.909
17	2.91
18	2.91
19	2.91
20	2.911
21	2.911
22	2.912
23	2.912
24	2.912
25	2.913
26	2.913
27	2.913
28	2.914
29	2.914
30	2.914
31	2.915
32	2.915
33	2.915
34	2.916
35	2.916

Time (s)	Voltage (V)
61	2.924
62	2.924
63	2.924
64	2.924
65	2.925
66	2.925
67	2.925
68	2.925
69	2.926
70	2.926
71	2.926
72	2.927
73	2.927
74	2.927
75	2.927
76	2.927
77	2.928
78	2.928
79	2.928
80	2.928
81	2.929
82	2.929
83	2.929
84	2.929
85	2.929
86	2.93
87	2.93
88	2.93
89	2.93
90	2.93
91	2.931
92	2.931
93	2.931
94	2.931
95	2.931
96	2.932

Time (s)	Voltage (V)
121	2.936
122	2.937
123	2.937
124	2.937
125	2.937
126	2.937
127	2.937
128	2.938
129	2.938
130	2.938
131	2.938
132	2.938
133	2.938
134	2.939
135	2.939
136	2.939
137	2.939
138	2.939
139	2.939
140	2.94
141	2.94
142	2.94
143	2.94
144	2.94
145	2.941
146	2.941
147	2.941
148	2.941
149	2.941
150	2.941
151	2.942
152	2.942
153	2.942
154	2.942
155	2.942
156	2.942

36	2.917
37	2.917
38	2.917
39	2.917
40	2.918
41	2.918
42	2.918
43	2.919
44	2.919
45	2.919
46	2.919
47	2.92
48	2.92
49	2.92
50	2.921
51	2.921
52	2.921
53	2.922
54	2.922
55	2.922
56	2.922
57	2.923
58	2.923
59	2.923
60	2.923

97	2.932
98	2.932
99	2.932
100	2.932
101	2.933
102	2.933
103	2.933
104	2.933
105	2.933
106	2.934
107	2.934
108	2.934
109	2.934
110	2.934
111	2.935
112	2.935
113	2.935
114	2.935
115	2.935
116	2.935
117	2.936
118	2.936
119	2.936
120	2.936

157	2.943
158	2.943
159	2.943
160	2.943
161	2.943
162	2.943
163	2.944
164	2.944
165	2.944
166	2.944
167	2.944
168	2.944
169	2.944
170	2.945
171	2.945
172	2.945
173	2.945
174	2.945
175	2.946
176	2.946
177	2.946
178	2.946
179	2.946
180	2.946

APPENDIX E

Constant Current while Charging a Lithium Ion Battery over 3 Minutes with Irradiance of 400W/m^2

Time (s)	Current (A)
0	0.027
1	0.027
2	0.027
3	0.027
4	0.027
5	0.026
6	0.026
7	0.026
8	0.035
9	0.036
10	0.036
11	0.036
12	0.035
13	0.035
14	0.035
15	0.035
16	0.035
17	0.035
18	0.035
19	0.035
20	0.035
21	0.035
22	0.035
23	0.035
24	0.035
25	0.035
26	0.035
27	0.035
28	0.035
29	0.035
30	0.035
31	0.035
32	0.035
33	0.035
34	0.035
35	0.035
36	0.035

Time (s)	Current (A)
61	0.035
62	0.035
63	0.035
64	0.035
65	0.035
66	0.035
67	0.035
68	0.035
69	0.035
70	0.035
71	0.035
72	0.035
73	0.035
74	0.035
75	0.035
76	0.035
77	0.035
78	0.035
79	0.035
80	0.035
81	0.035
82	0.035
83	0.035
84	0.035
85	0.035
86	0.035
87	0.035
88	0.035
89	0.035
90	0.035
91	0.035
92	0.035
93	0.035
94	0.035
95	0.035
96	0.035
97	0.035

Time (s)	Current (A)
121	0.035
122	0.035
123	0.035
124	0.035
125	0.035
126	0.035
127	0.035
128	0.035
129	0.035
130	0.035
131	0.035
132	0.035
133	0.035
134	0.035
135	0.035
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147	0.035
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149	0.035
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157	0.035

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60	0.035

98	0.035
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101	0.035
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114	0.035
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116	0.035
117	0.035
118	0.035
119	0.035
120	0.035

158	0.035
159	0.035
160	0.035
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162	0.035
163	0.035
164	0.035
165	0.035
166	0.035
167	0.035
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169	0.035
170	0.035
171	0.035
172	0.035
173	0.035
174	0.035
175	0.035
176	0.035
177	0.035
178	0.035
179	0.035
180	0.035