DEVELOPMENT OF SOLAR ENERGY HARVESTING FOR WIRELESS SENSOR NETWORK

By

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Electrical & Electronics Engineering Programme
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Approved by,

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Dr. Micheal Drieberg

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TRONOH, PERAK

January 2016

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.

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ABUZAR MOHAMED ABDALLA ELTAYEB

Abstract

To have a successful wireless sensor networks (WSN), we should have an energy supply which provided by batteries. Batteries have small size and provide sufficient energy for the motes, but batteries cannot sustain the energy for the (WSN) to operate long time. The reason is that the batteries have limit storage capacity and it used up by time. So to save the sustainability of the system we harvest energy from surrounding environment such as light, thermal, or vibration. All these are renewable and green types of energy that does not cause pollution to the environment. In our project, a solar energy harvesting system have been introduced to provide energy requirement for the (WSN) to operate. A photovoltaic (PV) module, solar charge controller and energy storage are elements that used for the solar energy harvesting system. And according to calculations, a suitable PV module, batteries, and solar charging circuit are determined. On the other hand to get the highest and the maximum efficiency of the energy harvested, we use a maximum peak power tracking or maximum power point tracking technique (MPPT), to charge our rechargeable batteries which for our project is lithium-ion battery.

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1. Introduction

1.1Project background

Among all types of renewable energy sources such as hydropower, wind power, solar energy, geothermal energy, piezoelectric energy, and tidal energy, the solar energy consider to be the most promising widely applied in a lot of different applications and have been used in a lot of practices, and that is due to several advantages such as; very low maintenance cost, friendly to the environment, inexhaustible power supply, wide applications, and also easy to build and construct.

Wireless sensor network (WSN) have experienced a rapid development in recent years due to the advancement in power electronic technology and massive research conducted worldwide. Efforts in the field let to enlargement of wireless sensor nodes applications in various fields. It is customary nowadays to notice sensor nodes in civilian applications (such as communication networks, building security systems, etc.) beside implementation for military usage. Nowadays, batteries represent the ultimate component to supply wireless sensor nodes with electricity. However, limited capacity of batteries and necessity to recharge presented a great challenge. Moreover, nodes are sometimes placed in difficult to access area such as dense woods and that has added to the burden. To solve the problem researchers started to harvest energy from surrounding environment.

1.2 Problem statement

Nowadays batteries are commonly used in wide range to power wireless sensor network. Due to the fact that batteries has finite stored energy, so it must be replaced or recharged continuously after specific periodic time. However, the replacement of the batteries becomes not possible because many sensor nodes being deployed in the field, and almost very difficult to access to the WSN in different environmental conditions. To solve this problem, the energy harvesting from near environment seems to be good solution to extend the life time for the wireless sensor network.

1.3 Objective

1. To develop solar energy harvesting system that is integrated with the wireless sensor motes.
2. Simulate the system using LT-spice and evaluate the effectiveness of the system in term of the efficiency, robustness and network lifetime.
3. Compare the actual results with the simulated one.

2. Literature Review

The researches that have been done on solar energy harvesting for wireless sensor networks are quite recent. Several studies and solutions have been conducted and represented in the last a few years, but Prometheus and Heliomote for sure were the first proposal to supply power for the motes with help of small PV module. These solutions proposed do not applying any MPPT algorithm, but only direct connection between the PV cell and the batteries (storage device) was applying for recharging the batteries. In addition, to protect the PV panel, an adoption of diode has been used but that does not helps because the PV module only work when the PV panel voltage is higher than the buffer voltage which in this case the diode will be forward biased. Also appear that the amount of power that provided by the PV module depends on the energy buffer level (Vbat or Vcap). On the other hand, the direct connection between the PV cell and the storage device forces the operation point of the solar module to the voltage of the capacitor Vcap which is usually far from the optimal value, reducing the output power of the PV panel too much.[1].

2.1 Wireless sensor network (WSN):

For our project we must understand what is wireless sensor network definition and applications, A WSN can be defined as a network of tiny devices, called sensor nodes, which are spatially distributed and work cooperatively to communicate information gathered from the monitored field through wireless links. The data gathered by the different nodes is sent to a sink which either uses the data locally or is connected to other networks, for example, the Internet (through a gateway). The Following Figure1 illustrates a typical WSN.

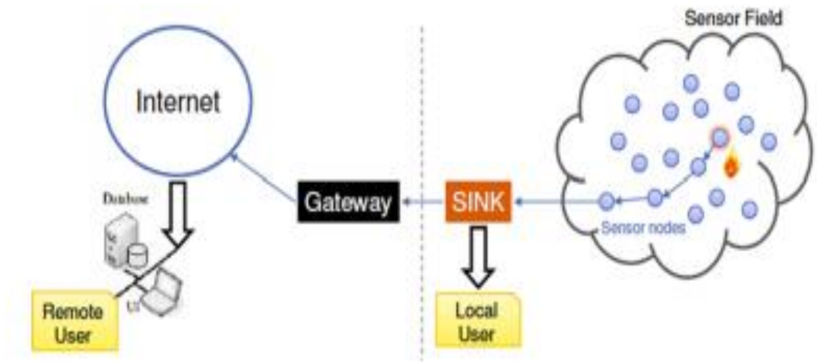


Figure 1: WSN.

2.1.1 WSN applications

The WSN motes may consist of many different types of sensors such as seismic, low sampling rate magnetic, thermal, visual, infrared, acoustic, and radar, which are able to monitor a wide variety of ambient conditions that include the following:

- Temperature.
- Humidity.
- Vehicular movement.
- Lightning condition.
- Pressure.
- Soil makeup.
- Noise levels.
- The presence or absence of certain kinds of objects.
- Mechanical stress levels on attached objects.
- The current characteristics such as speed, direction.

2.2 Types of renewable energy harvesting in (WSN)

1. Solar energy harvesting.
2. Piezoelectric energy harvesting.
3. Vibration energy harvesting.
4. Thermos energy harvesting.
5. Acoustic-noise energy harvesting.

2.2.1 Solar Energy harvesting

Solar energy is exhaustible and clean renewable energy which produced from the sun. the photons transfer the sun radiate heat and energy to the Earth so when the photon hits solar panel's surface and , its' energy is absorbs by photovoltaic (PV) materials to produce free charge carrier [4]. After that the separation of positive (hole) charge and negative (electron) charge through a p-n junction semiconductor causes one direction current which across the terminals that leaded to a voltage difference. The power generates by PV modules depends on the temperature, weather condition, irradiance, geographical location and angle of solar panel.

2.2.2 Piezoelectric energy harvesting:

The mechanical strain can be converted to electricity due to piezoelectric effect. This electricity produced by vibrations, acoustic noise, and human motion so that the power harvested is low. However, specific amount of this power enables to work some applications like self-winding wrist watches.

2.2.3 Vibration Energy Harvesting:

This sort of energy harvesting produced by piezoelectric effect and models of mechanical strain which create vibration are damper, spring and mass [6]. However, vibration energy harvesting can generate small amount of power [1] and it is usually used in micro systems applications.

2.2.4Thermoelectric Energy Harvesting:

The thermal gradient between two surfaces can be converted by thermoelectric effect. The power generated can be increase with the increasing of the thermal gradient between the two surfaces, the charge carriers inside the material moves from the hot surface to the cold surface and this is how the electricity generated and thermoelectric effect's advantage is not requirement of material replenishment. When voltage supplied this can be used in heating or cooling application while thermoelectric effect's disadvantage is that energy conversion has low efficient (10% approximately).Below table shows a variety of energy harvesting technologies:

Table 1: Energy Harvesting Technologies

Methods	**Power Density**
Solar cells	15mW/cm^2
Piezo-electronics	330uW/cm^3
Thermo-electric	40uW/cm^3
Vibration	116uW/cm^3
Acoustic-noise	960nW/cm^3

Table 2: Types of storage device:

Battery Type	**Advantages**	**disadvantages**
1. Nickel Metal Hydride (NiMH)	Has high energy density	Lower life cycle
2. Nickel Cadmium (NiCd)	It’s deliver full rated capacity	Temporary capacity loss, High discharge rate
3. Ultra Capacitors	Have a high power density, High life cycle.	High self-discharge rate, Low capacity
Lithium Ion (Li+)	Longer life cycle, Low self-discharge	Expensive, Complicated charging circuit

2.3. Maximum Peak Power Tracking (MPPT)

In this project we use maximum peak power tracking mechanism to get best value of power. This method usually used to adjust automatically the voltage and with the current, and the reason why we need to adjust because the current and voltage coming from our PV panel is not constant [3].

Advantages of using MPPT method:

- Get highest value of the power from the PV panel.
- To avoid battery failure and power loss.
- Reduce the cost by installing less panels.

2.4. Solar panel MPPT

As mention in part 2.3 to get the highest power output we are using MPPT method, figure2 and figure3 below shows the I-V characteristics and the open circuit voltage respectively.

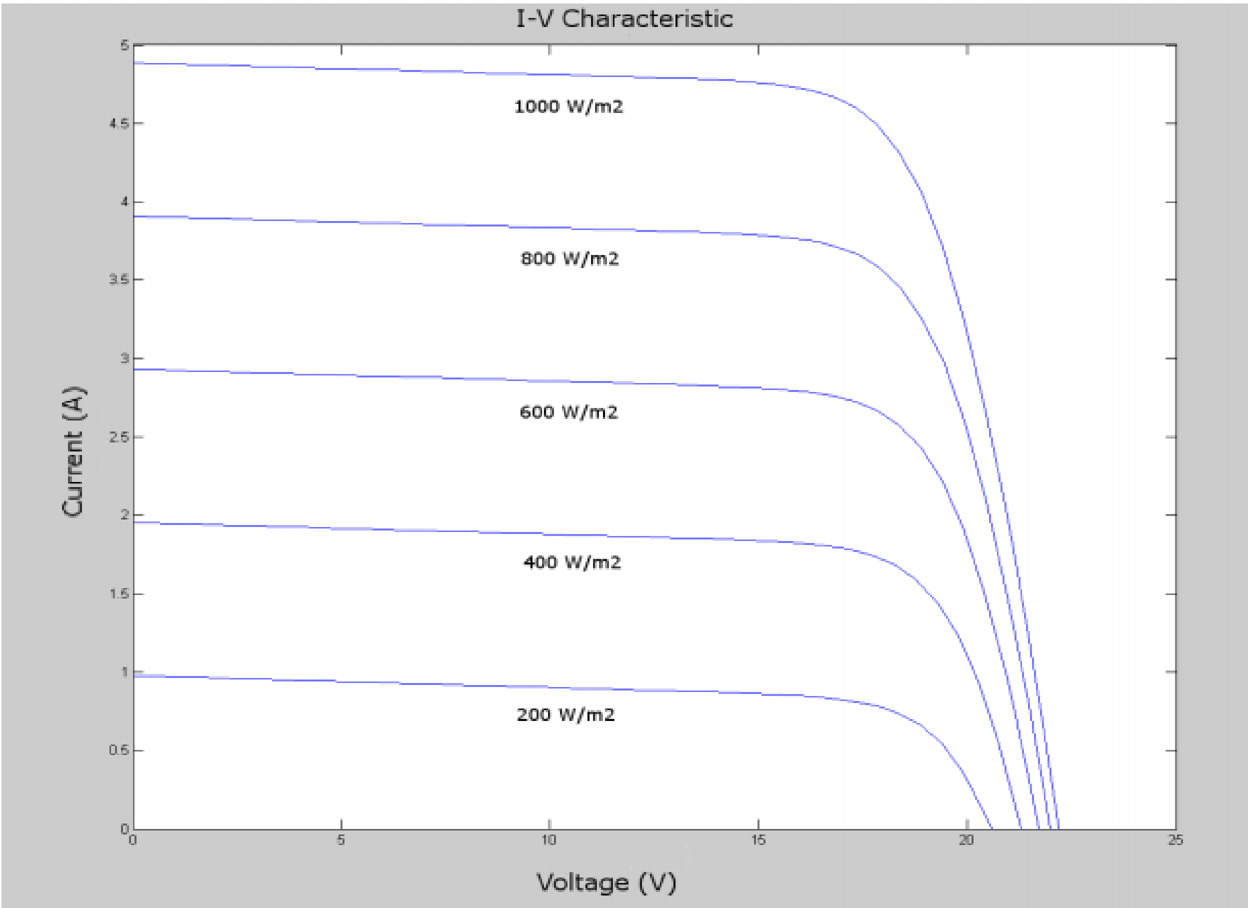


Figure 2: I_V characteristic.

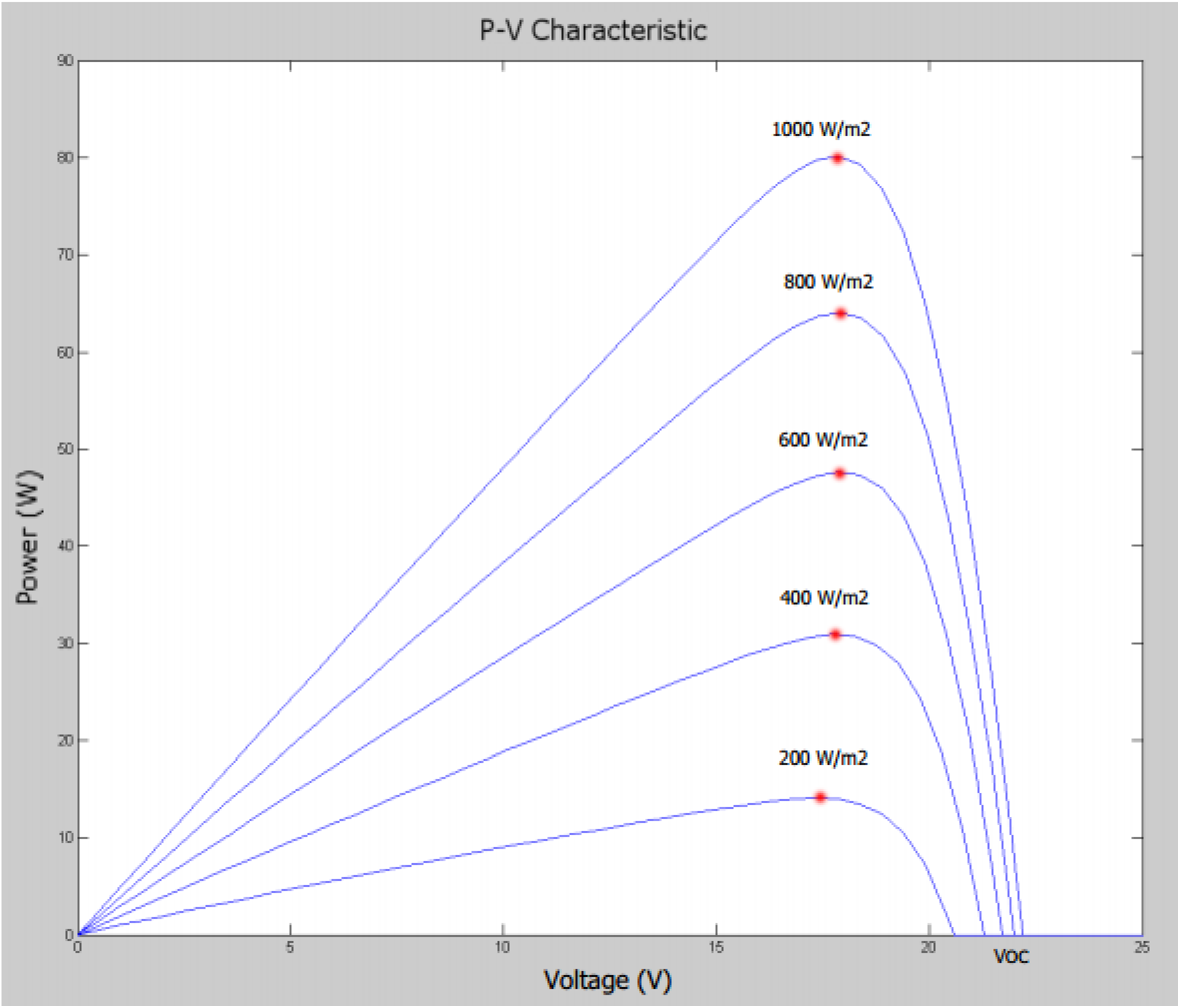
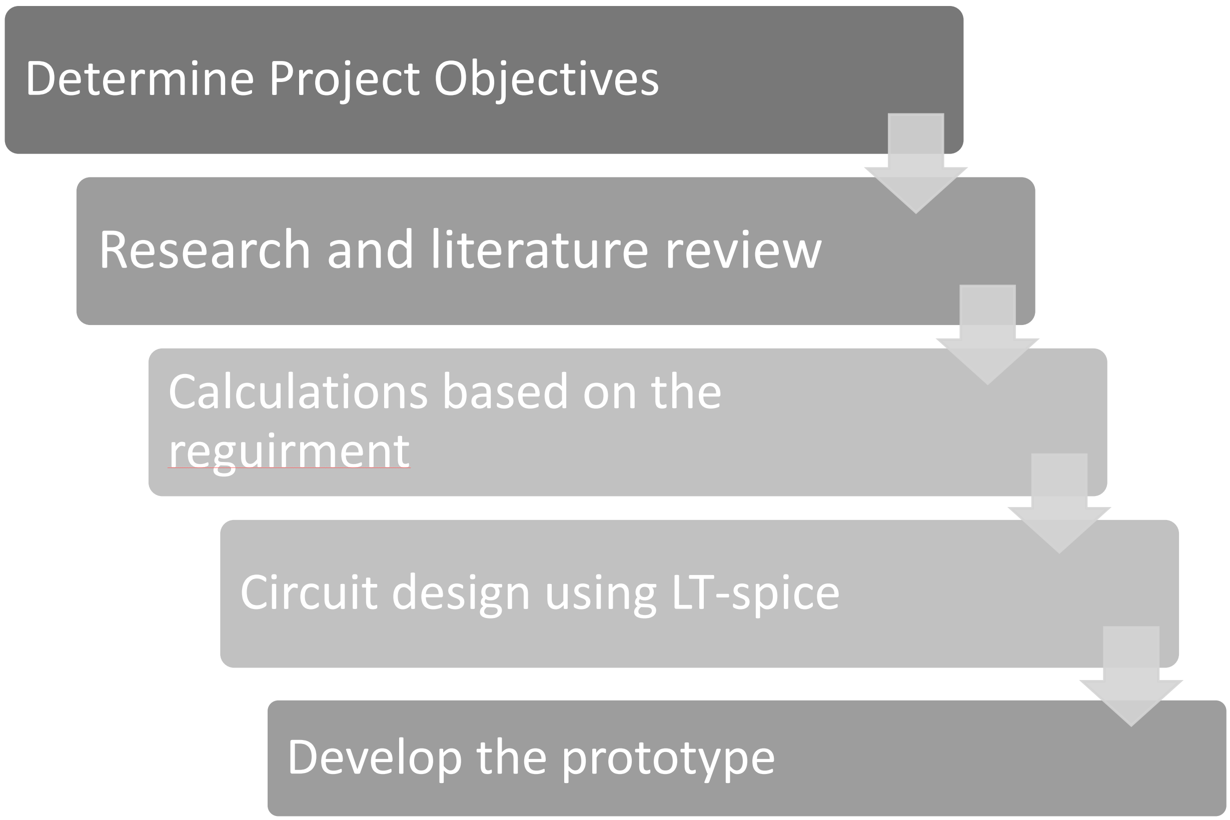


Figure 3: the open circuit voltage.(Voc)

3. Methodology

In our methodology part every step is clearly signed, and also calculations is done for selecting suitable component for our solar harvesting system, and the figure below shows the steps.



3.1. Scope of study and feasibility of the project

During the semester for FYP1 the researcher plans to concentrate on reviewing the literature, model the system, then list and find all the design parameters. In addition to that the researcher plans to simulate the designed structure in the LT-spice software by the end of this semester. FYP2 semester will held optimizing the design through the software, as well as fabricating the final solar harvesting system and make necessary testing. In a paramilitary view all needed equipment for the experiments are available in Universiti Teknologi PETRONAS laboratories. The two semesters are expected to enable the researcher to complete the project. Shown below proposed Gantt charts.

Activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14
FYP Briefing	■	■												
Literature reviewing discussion with SV		■	■	■	■									
Extended Proposal Submission						■								
Prepare the complete design							■	■						
Simulation									■					
Collect and discuss simulation results								■	■	■	■	■	■	
Proposal Viva									■					
Interim report submission														■

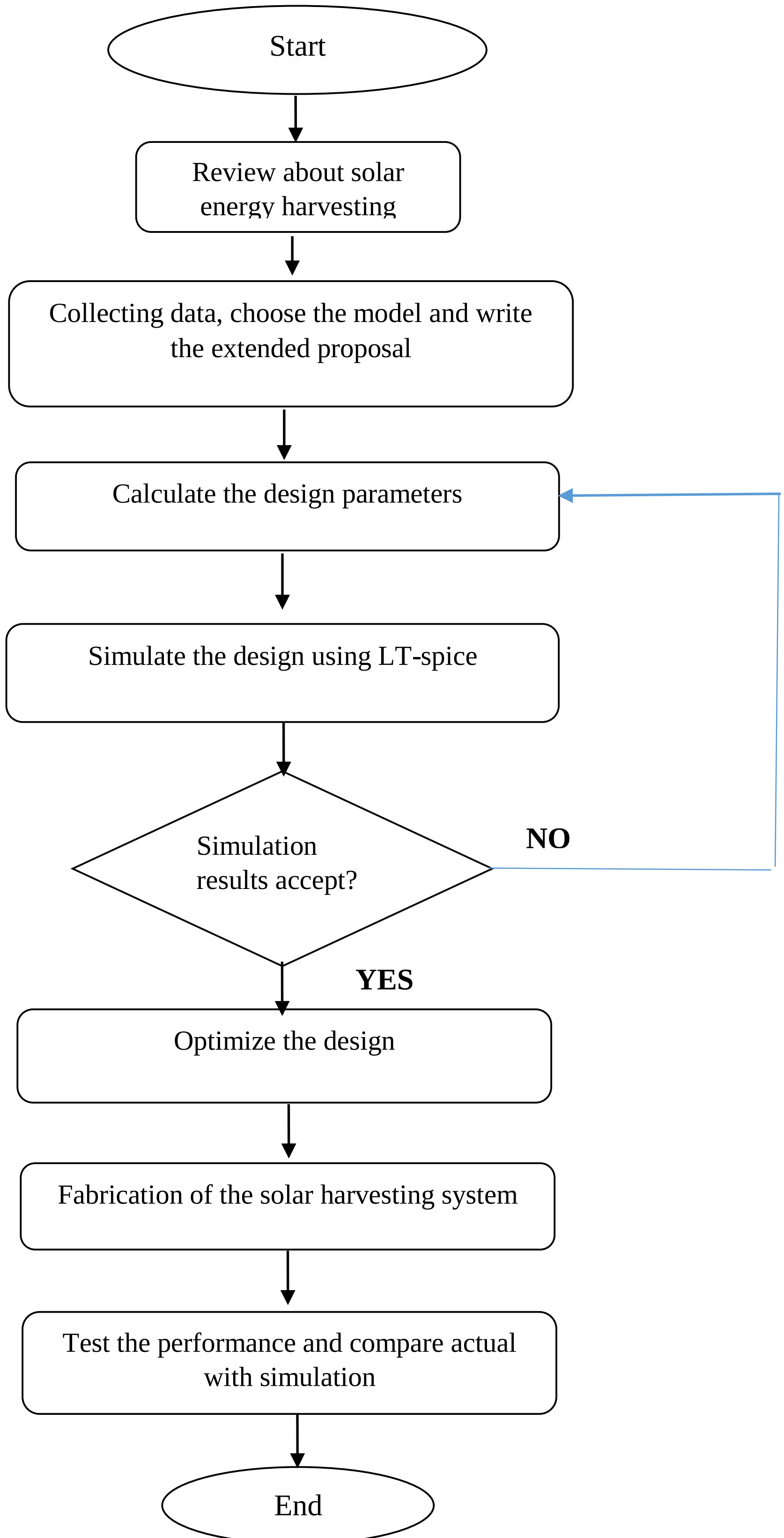
Figure 4 **Gantt chart of FYP-1**

Activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Optimize the design	■	■												
Fabrication		■	■	■	■									
Testing, result gathering and analysis						■								
Progress report submission							■	■						
Pre-SEDEX									■					
Dissertation submission (Soft bound &technical)								■	■	■	■	■	■	
Oral presentation									■					
Project Dissertation submission(Hard bound)														■

Figure 5: Gantt chart of FYP-2

The red color represent project key milestones.

3.2 Project flow chart



3.3 procedure

1. **Research and information collection:**

Before designing the system, student have to study previous researches and finding what other researchers has achieved, mainly about solar energy harvesting system construer, as well as complete design parameters, and the resultant output from the design, that will help student to know exactly what result does he looking for.

2. **Data and collection design:**

After looking at different modeling methods and designs, student will choose the one that suites his time frame, capabilities, and the tools and equipment available. After selecting the suitable model, then the design is ready to simulation stage.

3. **Simulation stage:**

This stage will be done by the help of LT-spice, after designing the solar harvesting system, this software help the student to build the model and check the performance before going into fabrication stage.

4. **Fabrication:**

The researcher plan to optimize the design from simulation to build a prototype of solar harvesting system associated with WSN, with the help of PCP lab specialist the design can be done, also testing the actual performance can be done.

5. **Experimental tools:**

In a preliminary look, the tools include in the design are available at UTP laboratories and nearby markets also some component available online, tools can be divided into:

Hardware components: such as PV cells, batteries, WSN, boost converter, charge controller, resistance, etc.

Software ware: LT-spice, eagle to design PCP, Microsoft word and Microsoft office

3.4 Calculations

3.4.1. Solar panel module:

The solar panel module consist of a current source, single diode connected in parallel with shunt resistor Rsh, and all connected in series with shield resistor.as shown in figure(6) below.

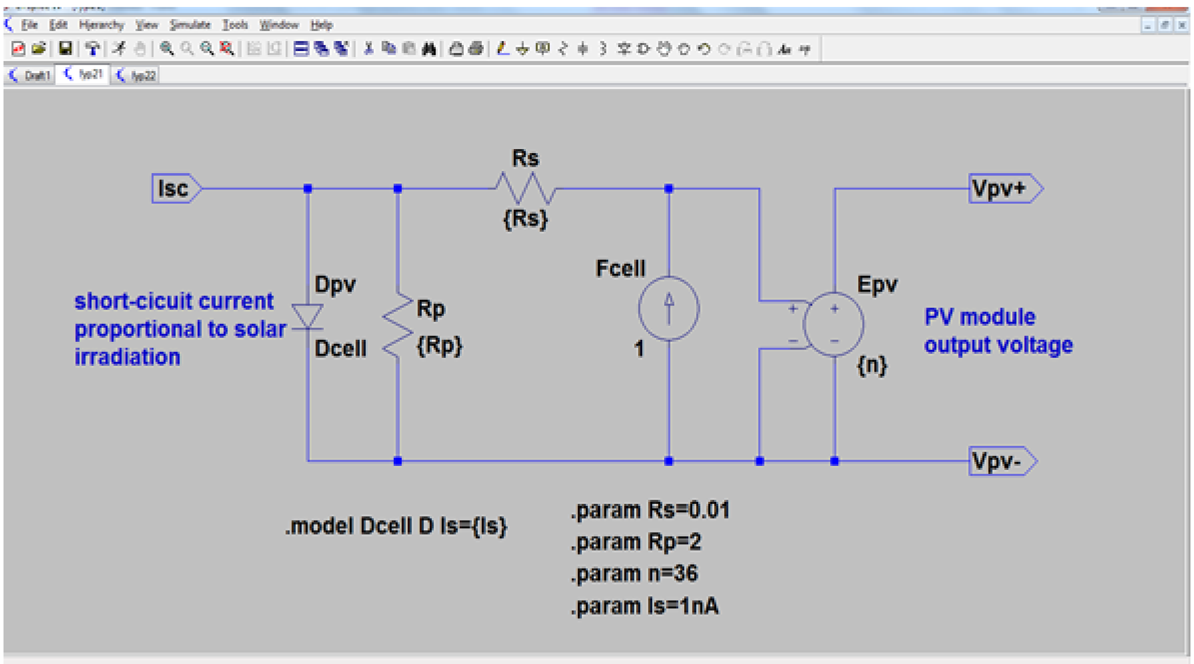


Figure 6): solar panel module.

Figure5 represents the solar model panel that consist of one (1) diode and series and parallel resistance and also the cell current source (Fcell), the basic diode include only one parameter (IS), then the cell voltage is multiplying by the number of cells (n) in series through the voltage control Epv, and that how we get the output voltage terminals of the panel.

Selecting the (PV) solar panel and the batteries:

To design a successful system, calculations must be done to determine the suitable PV cell, and the type of battery we should use.

Base on the fact that the current that consuming by the motes in active mode is 30mA and 30UA in sleep mode. Hence, we can make the calculation for one day, let us assume that the mote is in active mode for 4 hours and in sleep mode for the rest of 20 hours, then:

$$Iavr(day) = 30mA * 4(hr) \ + \ 30uA * 20\ (hr) = 120\ .6\ mA/day$$

And by assuming the total capacity of lithium ion battery is 2600 mAh, and all this capacity consumed during one day, then the maximum days for mote operation using this battery will be:

$$time(days) = \frac{2600mAh}{120.6mA} = 21.6\ days$$

So select a solar panel then can generate more than 120.6 mA/day, and Li ion battery has capacity more than 2600mAh.

The circuit design:

For the solar charge controller an integrated circuit (IC) id using for this project which is LT3652, with next specifications;

- Input voltage range from 5V to 32V.
- Provide a constant current and constant voltage characteristics, the maximum charge current is up to 2A.
- 3.3 V float voltage feedback references.

But we must first calculate all components and parameters values to design a successful solar charge controller, we must find the value of: open circuit voltage (Voc), Peak power voltage (Vpmax), and peak power current (Ipmax).

$V(oc) = Vbat(float) + Vforword(D1) + 3.3V * 1.15 = 8.63V$

$Vp(max) = (Vbat(float) + (VforwordD1\ +\ 0.75V) * 1.15 = 5.93V$

$Ip(max) = Icharge * \frac{Vbat(float)}{n.Vp(max)} =\ 0.1 * \frac{3.7}{0.8*5.7} =\ 0.081A$

Then determine the current sensing resistor R(sense) for maximum charge current Icharge(max):

Icharge(max)= 0.1 A

$$R(sense) = \frac{0.1}{Icharge(max)} = 1\Omega$$

To find R(FB1), and R(FB2), the Thevenin's equivalent resistance is set to be 250 KΩ, and reference voltage V(FB)= 3.3V.

Let assume R(FB1)= 260KΩ

$R(FB2) = \frac{(R(FB1)*250K)}{R(FB1-250k)} = 6500K$

Also by using voltage divider network of Rin1 & Rin2:

$Rin1 = \frac{Vp(max)-Vforword(D1)-2.74V}{2.74} * Rin2$

And let Rin2 = 100K then Rin1 = 90KΩ

Then calculating the maximum and minimum MPPT voltages:

$$V(min) = (2.67 * \frac{Rin1 + Rin2}{Rin2} + Vforeord(D1) = 5.57V$$

$$V(max) = (2.47 * \frac{Rin1 + Rin2}{Rin2} + Vforeord(D1) = 5.7V$$

Lastly, we calculating the shutdown resistances, Rshdn1, and Rshdn2:

$$Rshdn1 = \frac{(Vmin - Vforword(D1) - (Vshn(max) \; - \; Vshdn\,(HYST))}{Vshdn(max) - Vshn(HYST)} * Rshdn2$$

Let, Rshdn2 = 50K, then Rshdn1 = 400K.

4. Result and Discussion

First we test the PV panel module to get I-V characteristics by using PV module symbol we got from figure5 and also using test circuit as below:

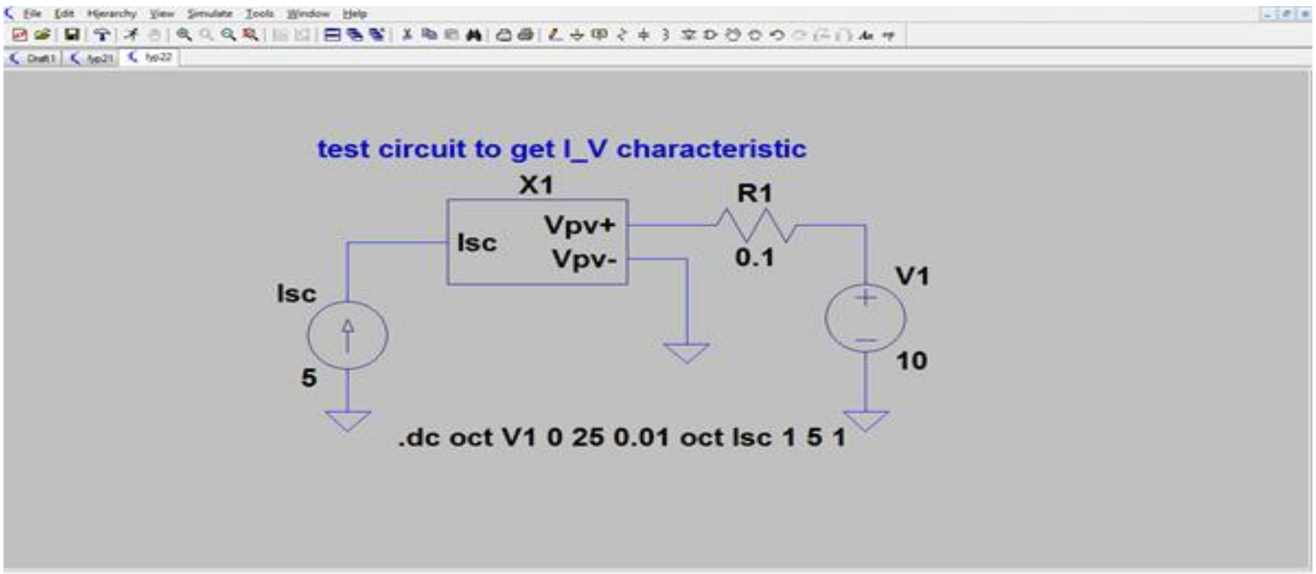


Figure 7: test circuit

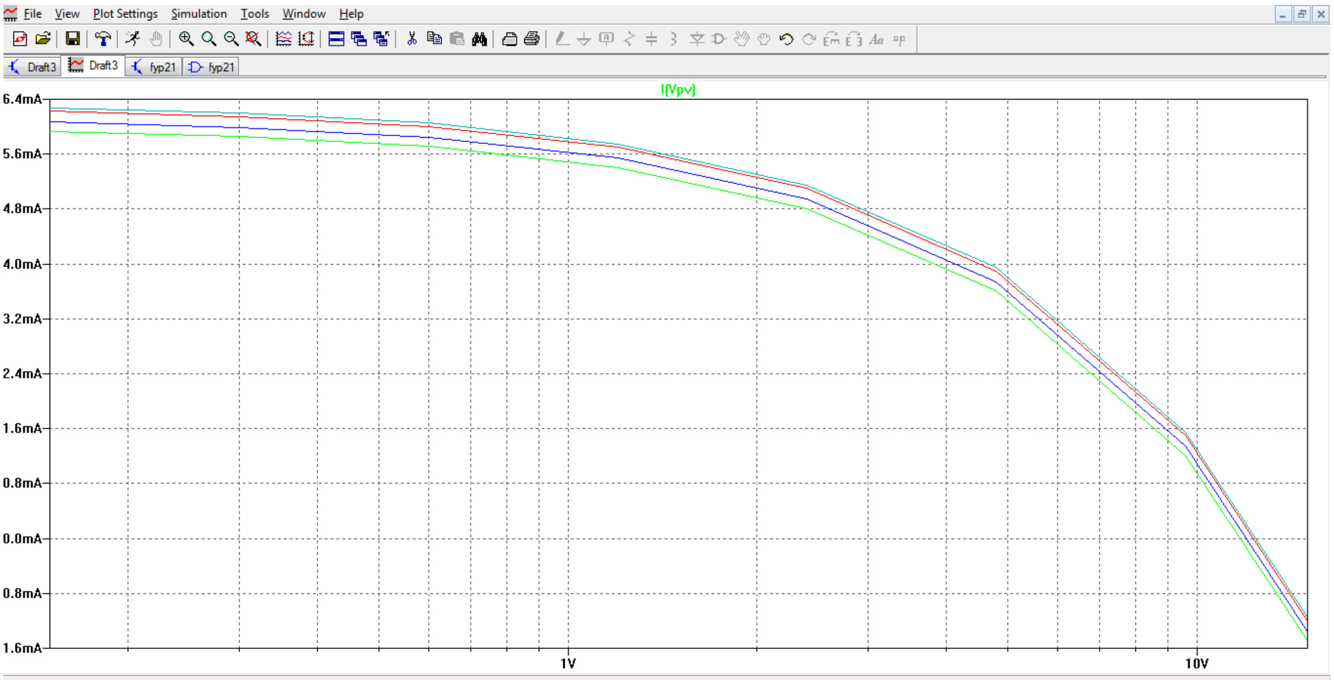


Figure 8: IV characteristics using the PV module

Above figure (8) represent the IV characteristics by using the PV panel module, and the curves represent four types of short circuit current and the horizontal axis represent the PV voltage producing from the PV cell.

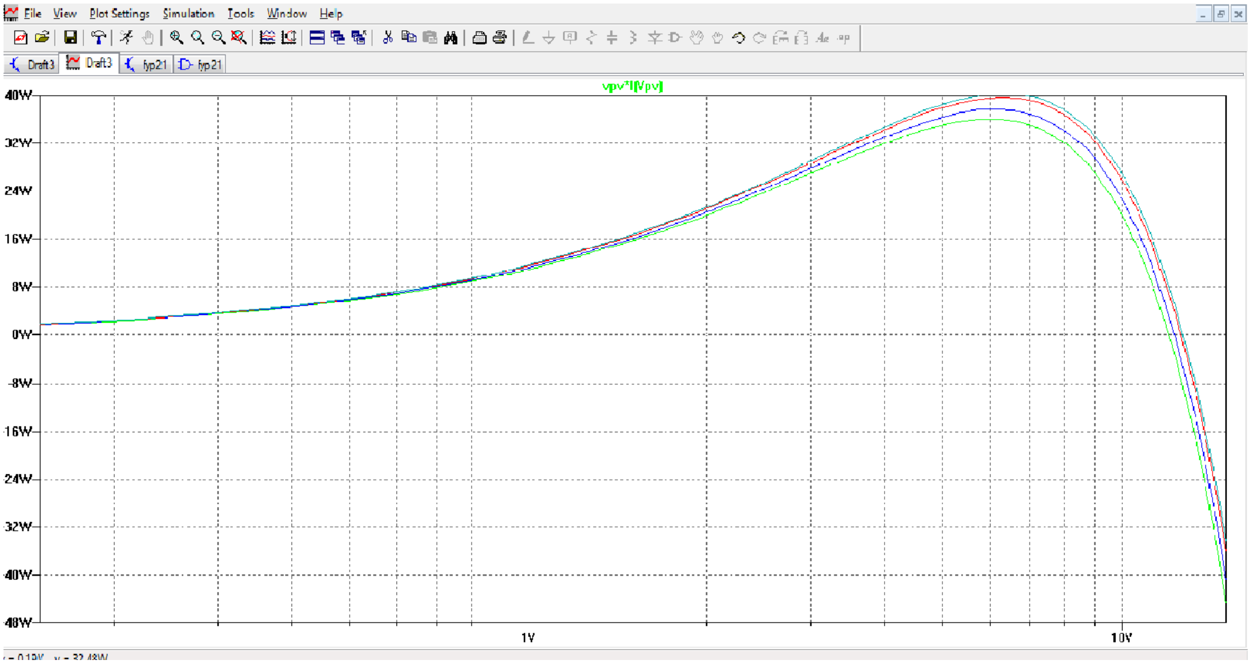


Figure 9: output power

Above figure (9) represents the output power resulting from our PV panel associating with the same different families of short circuit currents.

The simulation using LT-spice have been done according to calculation done in methodology part and the result as fellow:

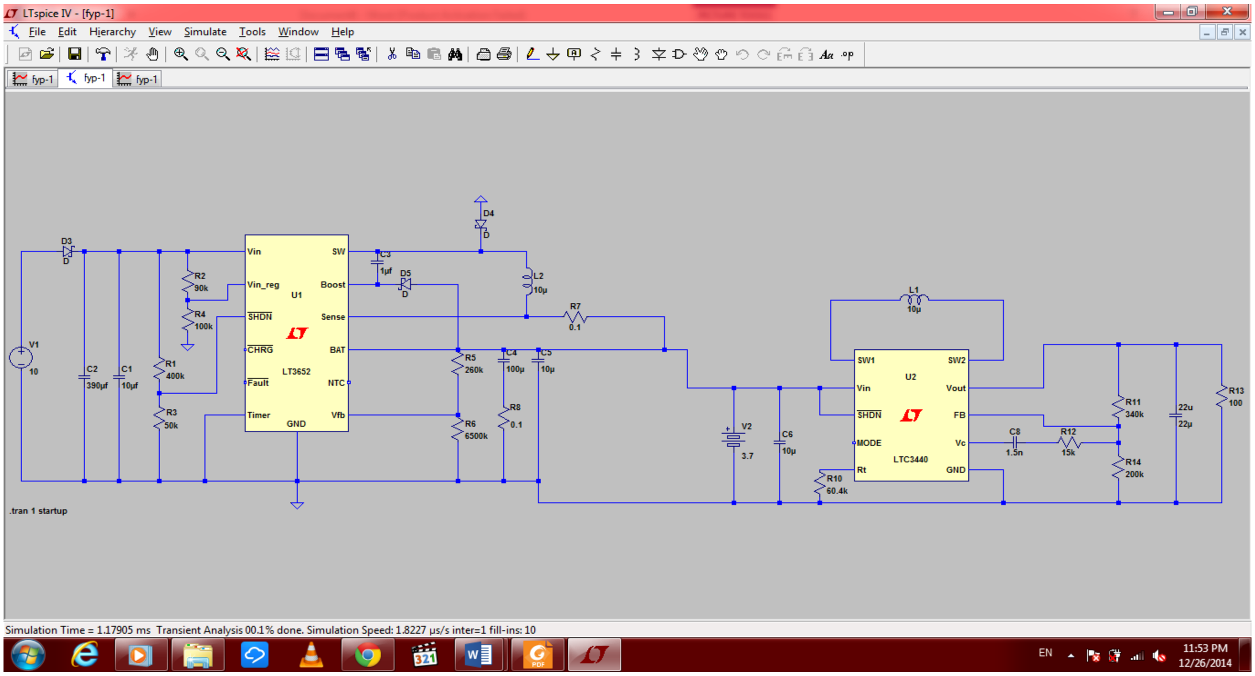


Figure 10: full circuit schematic

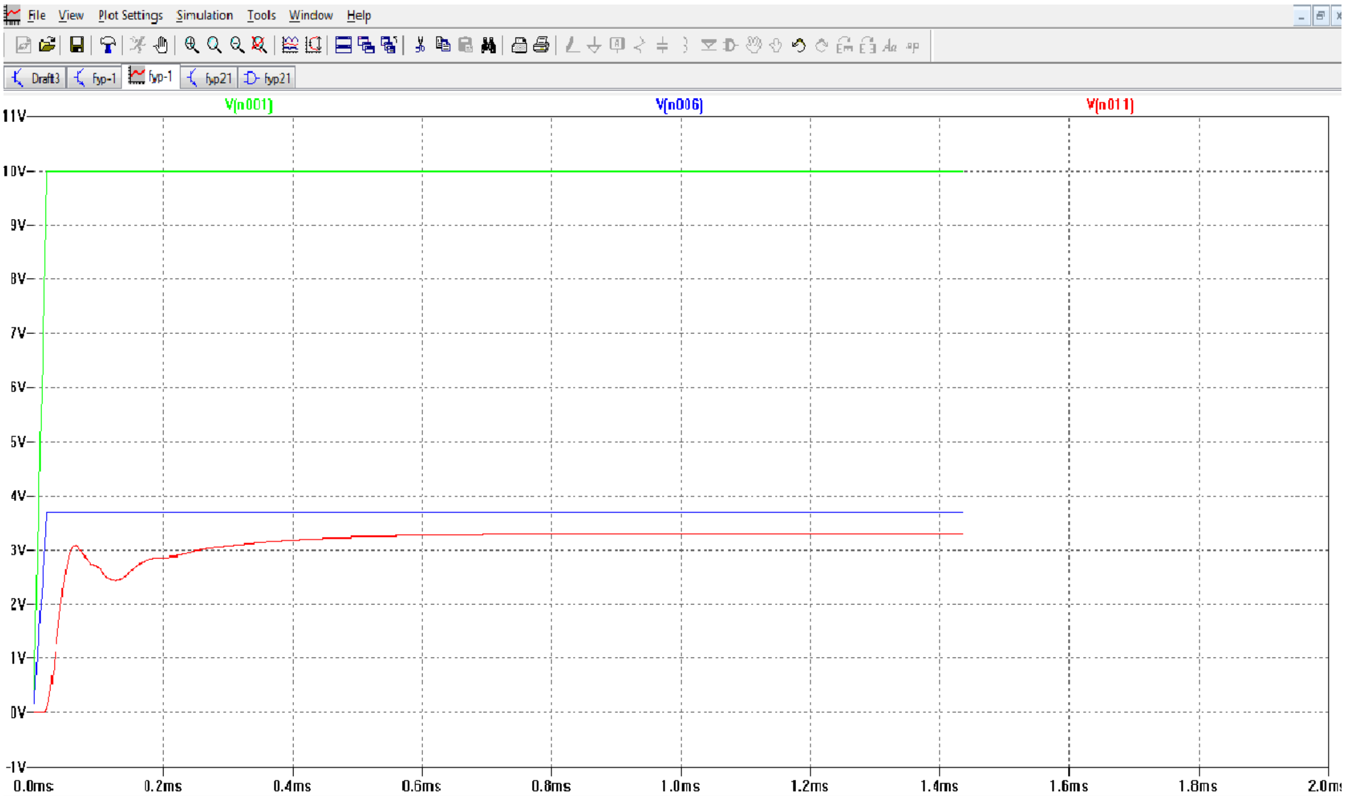


Figure 11: output voltage

Figure(11), shows the output voltages, the green waveform shows the input voltage from our source the PV panel, the waveform in blue color shows the output voltage after using LT3652 solar charge controller which steps down the value of the voltage to 3.7V which is required to charge our battery, then the IC LT3440 (boost-buck converter) is used to step down the voltage from 3.7v to 3.2v which appear in figure(11) in red color waveform, and we need step down this value because the motes operating voltage is from 2.2v to 3.3v.

5. Conclusion

As a conclusion for our project, firstly the literature review has been done as well as methodology part, in literature review the Maximum peak power tracking (MPPT) technique has been clearly explained as well as the solar panel (MPPT) with I-V characteristic curve and open circuit voltage curve. In Methodology part the PV circuit module has been constructed by using basic diode as shown in part 3.4.1. Finally in the result part, the PV module shown as run using LT-spice software firstly we used PV panel module to get the I-V characteristic and P-V characteristics as well by using test circuit, finally we got output voltage of 3.2v which required to operate the sensor motes.

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