The Development of Uninterruptible Power System Using Solar Energy for Earth's Electromagnetic Monitoring Application

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Abstract – **Most activity of earth electromagnetic monitoring activity involves the installation of the equipment (magnetometer) in remote areas with limited power supply from grid system. Most devices and application for remote monitoring purposes are suffering with the problem of power supply disruption. Therefore the development of interruptible power system is crucial to solve this issue. This paper discusses the uninterruptible power system using solar as a main source of power supply for electromagnetic monitoring. This system will supply power to the magnetometer. From the designed system, the magnetometer will fully depends on the solar input as the main source during daytime. During night time or when the voltage of solar panel is lower than the assigned threshold voltage, it will switch to the lead acid 12V (4.5 AH) battery which acts as a secondary power supply. In order to control the switching transition process, of power supply from solar to battery, a switching controller circuit has been deployed. The charging process is controlled by solar charge controller to avoid overcharge which can cause damages to the battery. The system is working properly to continuously operate the magnetometer by using both solar panel and battery. The development processes, troubleshooting and measurements are explained thoroughly in this technical paper.**

***Keywords*-solar energy, interruptible power system, magnetometer, switching, charge controller**

I. INTRODUCTION

Interruptible power supply is very critical for many sectors when there is a need of continuous power supply. To achieve this, the system should have secondary power as a backup. Additionally, automatic switching controller should be embedded to the system. A conventional power system is fully depends on grid system. However, for any continuous monitoring application at remote area, the most common problem faced is limited power supply due to the location that is very far from the grid-based power supply. Therefore, we have developed a system which can supply power continuously by using solar panel with battery as a backup power. A power supply that incorporates a renewable source of energy that involve in this project provides a feasible option to deal with the interruption of work in progress due to power failure. In generating electricity, it cannot be denied that there are varieties of methods available but using this solar panel will benefits all parties involved be it the producer or the consumer. Solar energy is a promising source of energy since it has been proven that there is more than enough solar radiation to meet the demand of this kind of energy. On a global average, each square meter of land is exposed to enough sunlight to produce 1,700 kWh of power every year [1].

A magnetometer is an electromagnetic monitoring device that is used in mostly in space based research and navigation. The typically used fluxgate magnetometer is said to be robust, reliable and have considerable space heritage [2]. An anisotropic magnetoresistive magnetometer has a significantly lower mass, volume and to a lesser extent power compared to fluxgate in its measuring capability.

The main components to this interruptible solar power system include solar panel, a rechargeable battery, solar charge controller, a voltage regulator and a switching circuit [3]. The interruptible solar power system in this study is made to operate automatically with provision for recharging the battery from the solar energy consumed by a 17.5V 5W solar panel. Internal switching control using relay as a switch will allow automatic use of the primary power when it is available as well as recharging the battery and operating the load.

II. SYSTEM DESIGN AND OPERATION

The system is designed as in Figure 1. The system consists of 5W 17.5V solar panel, 12V 4.5AH lead acid battery, voltage regulator, solar charge controller, a switching circuit and an anisotropic magneto resistive magnetometer as the load. The first step in the development of interruptible power supply is to determine the size of the power of solar panel. In this project, a 5W 17.5V solar panel is used as the primary input. During daytime, solar panel will supply power to the load as well as recharging the battery by means of solar charge controller circuit. When the power of 6V-19V is consumed by the solar panel, the voltage regulator needs to regulate 5V voltage to be supplied to the load because the magnetometer only needs 5V. The power supply will go through the switching circuit if there is enough power to supply to the load, if the voltage is below than 5V, it will switch to the secondary power supply which is the battery. There is another voltage regulator at the output of the battery to regulate the output voltage of the battery to 5V in order to meet the required voltage of the load.

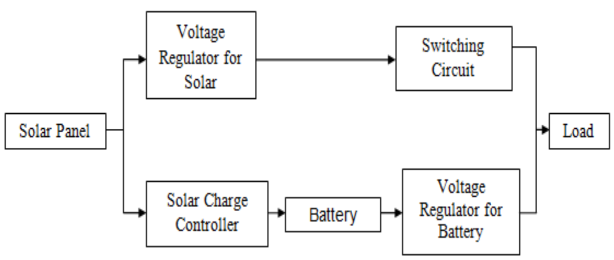
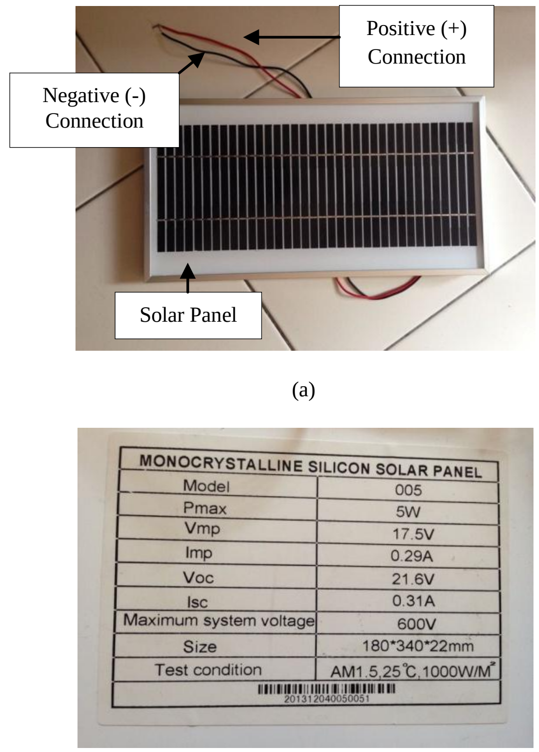


Figure 1: The interruptible solar power system block diagram

A. *Solar panel*

Solar panel photovoltaic cell is the one that is used to trap the sunlight and convert it into electricity. Silicon is used in producing photovoltaic cell because it is a semiconductor material and today's technology has made the silicon to be positive and negative charge carriers which is fundamental for electric cell or battery [4]. Photovoltaic material of solar panel works by converting photon from the sunlight that is accumulated in the photovoltaic cells into electrical energy.

Based on figure 2, Solar panel used in this power system is a 17.5V 5W solar panel. It gives a maximum voltage of 21.4V. This voltage indicates how much of input will the solar get on a very shiny day to supply to the panel and be regulated before getting to the load.



(b)

Figure 2: Photos of (a) solar panel and (b) technical specifications of solar panel

B. *Solar charge controller*

A solar charge controller circuit is placed in between the solar panel and the battery to regulate the current and voltage coming from the solar panel. Using solar panel, the most important thing to be taken into consideration is not to overcharge the battery since the amount of sunlight entering the solar panel cannot be controlled. In order to achieve this, a charge controller is designed using pulse width modulation (PWM) technique. PWM is the most practical method to attain constant voltage battery charging by controlling the amount of charge to the battery and slows down the charging process as the battery nears fully charged state [5].

This charge controller uses its PWM algorithm to control the charging process without overheating [6]. The charging process using PWM is done by using the Arduino Uno board in which consists of ATmega328 microcontroller. Arduino Uno board consists of 16 digital input/output pins where 6 pins are made to be use as PWM output. This analog output pins of PWM is 8 bits, so the maximum range of values is between 0 – 255 ($2^8 = 256$). Hence the value of 255 will indicate full power on PWM pin at which 100% duty cycle takes place. In this charge controller, it has been set in the coding when the battery voltage falls below 12V PWM duty cycle is 50% which means boost charging process. Otherwise, when battery voltage is higher than 10V, 10% duty cycle charging takes place.

The voltage sensor in this charge controller is implemented by using voltage divider. This controller used 1k ohm and 4.7k ohm resistor for both battery and solar voltage dividers. This will give the output of 3.158V for solar and 3.997V for battery. The output of this voltage divider must be less than 5V because the analog pin output of the arduino board is controlled to 5V. This is done by using equation (1).

$$V_{out} = \left(\frac{R_2}{R_1 + R_2}\right) * V \quad (1)$$

Based on the schematic diagram of the solar charge controller, power is supplied from the solar panel by using diode D1 and capacitor C1 is used to remove undesirable noise. The output from voltage divider R1 and R2 is connected to Arduino pin A0 to sense the output voltage from solar panel. The output from voltage divider of battery is connected to Arduino pin A1. MOSFET Q1 is placed to make sure that the power coming from the panel will not goes directly to the battery until it is switch by using PWM signal on pin -6 of Arduino board. Only when the transistor is on, then the charging process will start.

Regarding the software which is the coding that has been programmed for this solar charge controller, it will first detect the solar voltage, only if it is greater than the battery only then it will send the PWM signal to MOSFET Q1 in order for charging process to start. After that, the program will check the battery voltage, if it is below 12V boost charging will start with 70% PWM signals duty cycle.

The Solar Voltage and the battery voltage are displayed using LCD in which it is connected to the arduino. The charging process and fully charged state of the battery are indicated by the green and red LED respectively. Green LED will blink during charging process while red LED will light up when the battery is fully charged.

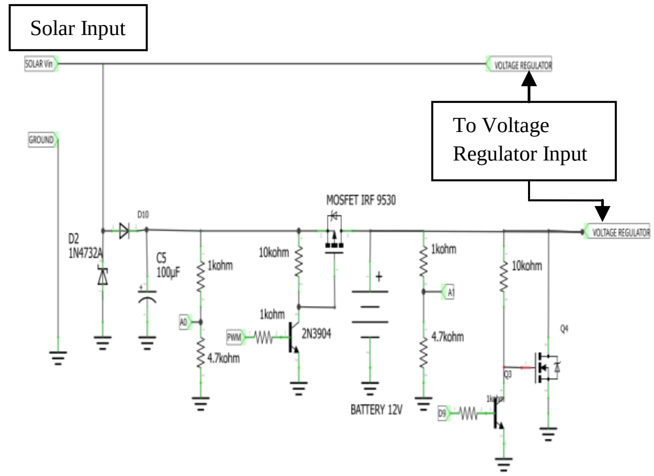


Figure 3: Circuit of Solar Charge Controller

C. Battery

Based on figure 4, A 12V (4.5AH) Sealed Lead Acid battery is used in this system as the backup power supply when the primary power supply fails. Sealed lead acid is chosen due to its high charging efficiency. a battery of lower voltage than the solar panel voltage need to be used in order for solar panel to charge the battery.

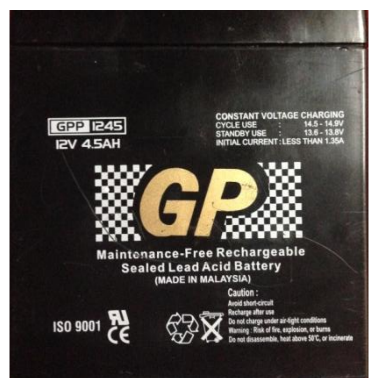


Figure 4: 12V (4.5AH) Sealed Lead Acid Battery

D. Voltage regulator

During the day, the power coming from the solar panel will drive the load and at the same time will charge the battery. To prevent voltage from solar panel goes directly to the load with the amount of voltage that may cause damage to the load, a voltage regulator is used. This voltage regulator used is LM7805 which gives out a fixed 5V to the load. So, any input voltage that is higher than

6V will give the output of 5V to supply to the load. This voltage regulator is designed by using two capacitors 1μF and 10μF. two voltage regulators are constructed to be put in between the solar panel and the load and the other one is in between battery and the load. LM7805 can receive the input voltage up to 35V which make it suitable to use for both battery and solar panel.

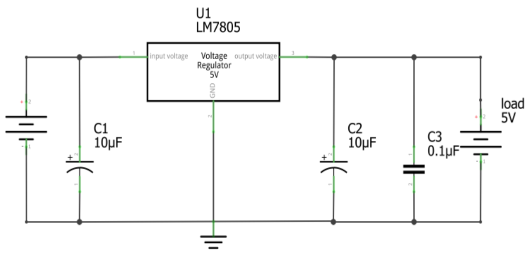


Figure 5: Circuit of Voltage Regulator

E. Switching circuit

Figure 6 shows the switching circuit built on a breadboard. The switching circuit is placed at the output of the voltage regulator for battery and solar. This switching circuit consists of relay and Arduino Uno to drive the relay. Relay acts as a switch based on the order given from programmable microcontroller chip. There is a built in 10-bit analog to digital converter (ADC) that able to sense the voltage drop from primary power source and automatically switch to the secondary power source which is the 12V 4.5AH battery. This circuit is able to supply to any appliances that operate standard 5V direct current (DC). The output of this switching circuit will go directly to the load.

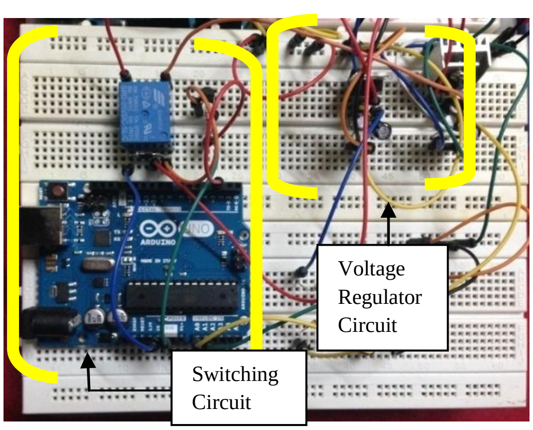


Figure 6: Switching Circuit

F. Magnetometer

Figure 7 show the magnetometer used in this study acts as a load that need 5V of power supply. Magnetometer is a device that measures the earth magnetic fields [7]. The magnetometer for this project is an anisotropic magneto resistive magnetometer used in space weather studies to see how the solar activity affects the earth magnetic field. For that reason, the magnetometer needs an interruptible power to make sure that when the disruption of power does not take effect on the magnetometer reading.

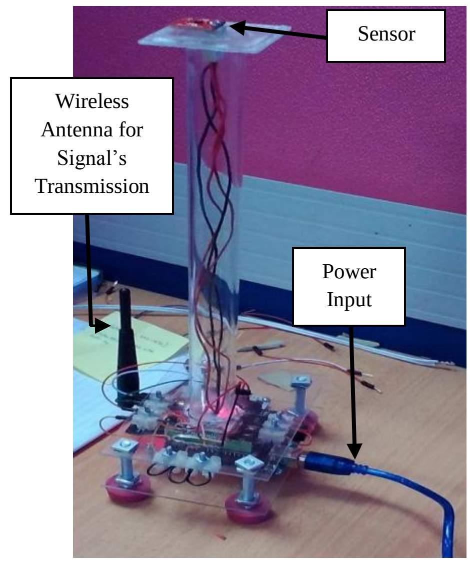


Figure 7: A magnetometer

III. METHODOLOGY

A. Project Development

During the very early stage of this project referring to Figure 8, the background of the related scope has been studied for data collection purposes and to generate the idea. The first step of this study was the research of the device used in electromagnetic monitoring activity. The result of the research shows that most of the existing magnetometers used are powered grid based supply which caused problem to the device that needs continuous monitoring. Based on the studies on solar system, the existing solar charge controller systems have the limitation where they are fully depending on the battery to drive the load. The main function is only for battery charging and will turn on the load during night time. Most of the solar charge controller used to automatic turn on the light during night time. The existing systems do not make full use of the solar energy. After doing some research and studies of how the limitations of the current systems can be upgraded, the idea was proposed. The idea is to design an uninterruptible power system using solar and rechargeable battery as a secondary supply. Once the proposal has been proved, the next step is to design the overall system including the system functionality and specification. At this stage, the type of solar charge controller and switching system that will be used were decided. The size of solar panel and type of battery according to the specification is chosen. The next step is to work on hardware and software development. At this stage, a lot of problems have been faced. The software is developed using IDE MPlab Software in which has been programmed to drive the solar charge controller circuit and the switching circuit. The hardware development consists of solar charge controller, voltage regulator circuit and the switching circuit using relay as a switch. It took about 4 months to develop the hardware and software. When it is done, the system is interfaced between hardware and software. At this time, the objective and system specification should meet the goal and requirement. The next step is system testing and troubleshooting. There is a lot of trouble found in the system includes the hardware and software. The details will be discussed in the testing and troubleshooting section. 1 month is spent to solve the problems occurred on the system. The developed system is then tested again whether it is properly functioning to meet the objective. The analysis of the system is done to obtain the result for technical paper writing. The analysis is divided to three parts. They are solar panel voltage analysis, the charging process and the switching process from the solar panel to the battery. By doing this, the efficiency of the system will be discovered.

B. Testing and Troubleshooting

The testing and experimental design of the circuit has been tested on the breadboard. The fist problem encountered was the voltage sensing for both battery and solar panel of the voltage divider in the charge controller circuit. This circuit has been implemented to restrict the output of the voltage dividers to 5V because the output of it is connected to arduino pin. The problem encountered when the output voltage not sensing the desired voltage. This problem is then solved by doing a few calculations has been made and the value of resistors used in the voltage divider has been changed to 1k ohm and 4.7k ohm. However, when a smaller value of resistors are used, the current at the load increase, thus to solve this problem, a resistor is used at the load to reduce the current. A problem in the software also occurred at the charge controller where it did not display the right value of voltage for both solar and battery. The problem is then solved by adjusting the coding for voltage sensing part.

Another problem encountered at the switching circuit. The microcontroller and voltage regulator becomes overheat when the supply voltage is high. For the microcontroller the overheat is caused by high current at the adc input of the Arduino. To solve this, voltage divider is used to reduce current to the input of Arduino. On the other hand, heat sink is used to overcome the overheat problems of voltage regulator.

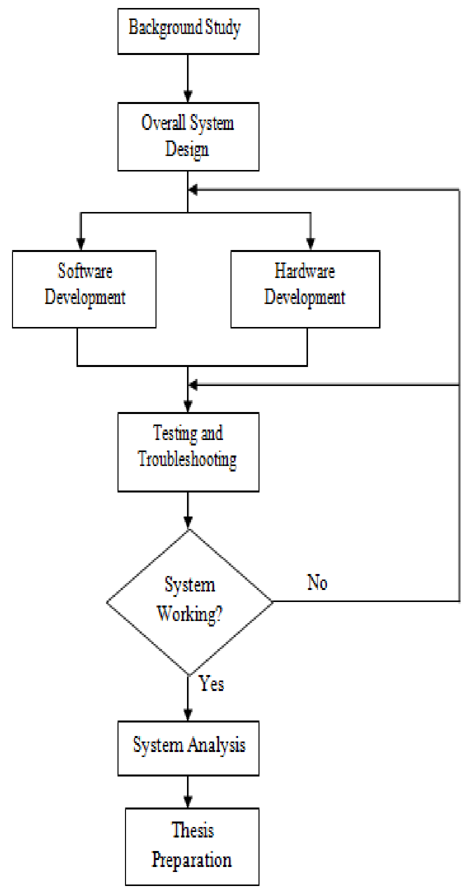


Figure 8: Project Development Flow Chart

IV. RESULT AND DISCUSSION

Several analyses conducted on this interruptible solar power system to test working capability of this system. The results are shown below.

The measurement of the open circuit voltage of the solar panel is done under the bright sunlight for three days. This test is to observe the maximum voltage that can be absorbed by the solar panel where the specification of open circuit voltage of solar panel is 21.4V. The result shows that the highest voltage is during 1300 hour at which the input voltage is 20.13V indicating the highest voltage recorded. Figure 9 shows the result of the solar panel voltage. The variation of the solar input voltage is due to the cloud blocking the sun and the variation of the light intensity.

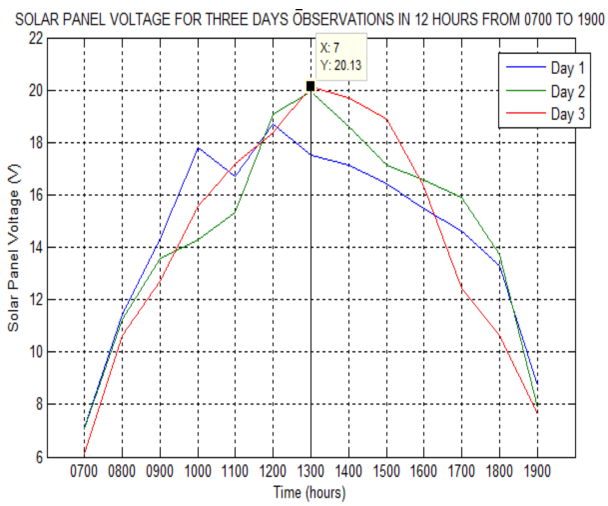


Figure 9: Solar panel voltage versus time

Figure 10 shows the graph of solar panel charging lead acid battery of 12V. The observation was made in 24 hours period from 6 pm until 5 pm. From the result obtained, during (i) which is the initial state, there is a drastic voltage drop of solar panel from 11.32V at 6pm to 0V at 9 pm. The battery voltage is higher than solar panel voltage which makes it impossible for the solar to charge the battery. There is no charging process at (i) therefore the PWM duty cycle is 0.

The solar panel voltage at (ii) was decreased to 0V. This is from 9 pm to 5 am where there is no sunlight at all. The battery voltage becomes lower as it reaches 5 am because the load now is driven by the battery and no charging process occurred here. PWM duty cycle is recorded to be 0.

Based on the graph at region (iii), from 5 am to 8 am, the solar panel voltage is starting to increase but still no higher than the battery voltage. Hence, there is also no charging process here.

The charging process of the battery by the solar panel started from 9 am at which solar voltage becomes higher than the battery voltage. It can be seen at region (iv) where the solar voltage increase to 12.47V surpassing the battery voltage of 7.23V. In this region, the duty cycle of PWM signal is 70% because the battery voltage is lower than 12V.

During (v), there is still charging process but has been reduced to 10% PWM duty cycle because the battery voltage at this hour is 12.02V at which higher than 12V. This command is already been set in the microcontroller.

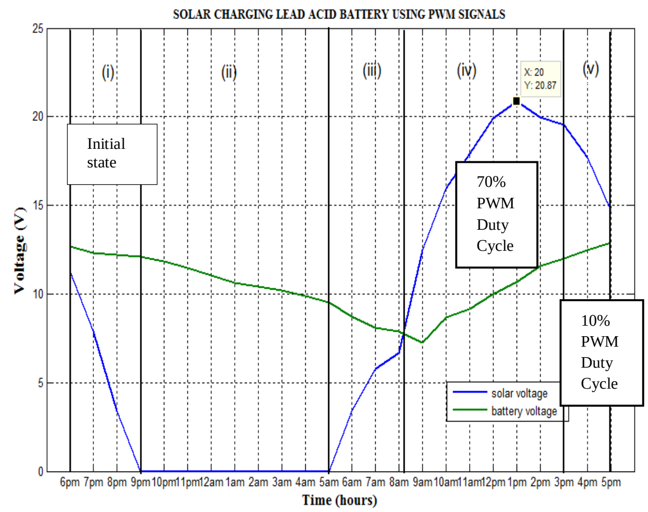
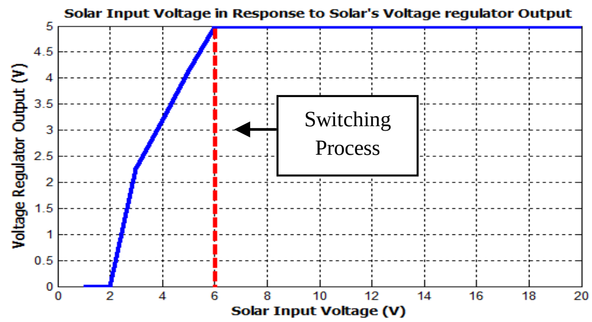


Figure 10: The solar charging process of 12V lead acid battery versus time

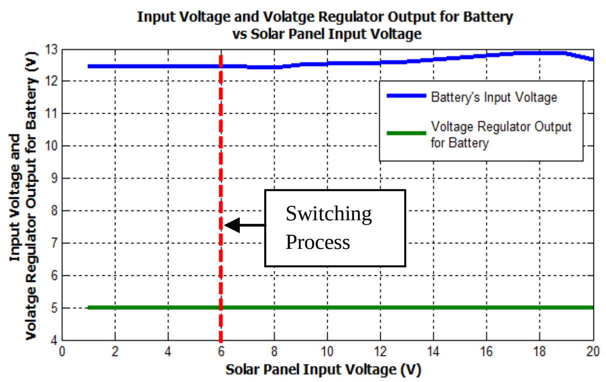
Regarding the switching process of this system, from primary power supply to secondary power supply which is the battery, results of the transition process is recorded below. This test is conducted by using dc power supply to replace the solar panel input power. Based on the solar panel voltage result that has been done, the dc power supply is set from 1V to 20V to see the response of the voltage regulator output using the dc tracking stabilizer.

Figure 11 (a) shows the solar input voltage responding to voltage regulator output. Referring to the figure, when the solar input voltage is lower than 6V, the output of the voltage regulator is in between 0 to 4.14V. However, the load input voltage is 5V (Figure 11 (c)) which is enough to drive the load by using secondary power supply (battery). At this time, the battery voltage is 12.45V (Figure 11(b)).

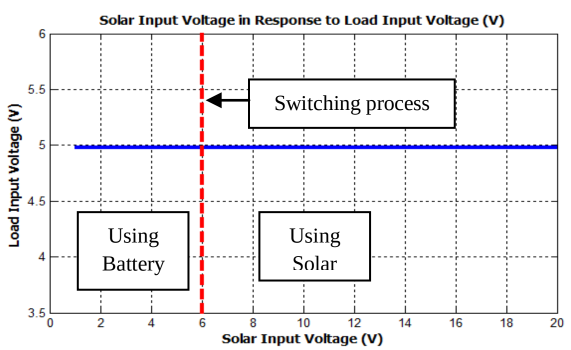
The switching process from battery to the main power supply occurs when the solar input voltage reach 6V. Although battery voltage is still enough to supply power to the voltage regulator, the load will be driven by the solar as it is the main power supply. As can be seen from figure 11(b), battery input voltage only varies a little and there is no voltage drop. This is because, the measurement is not done using real time as the voltage for solar input has already been set using dc tracking stabilizer.



(a) Solar input voltage in response to voltage regulator output voltage.



(b) Battery input voltage in response to voltage regulator output voltage.



(c) Input voltage at load.

Figure 11 (a) (b) (c): The switching process of the system from main power supply to the backup power.

V. CONCLUSION

It can be concluded that the interruptible solar power system has been developed and tested to drive the anisotropic magnetoresistive magnetometer. For application that needs a constant value of voltage supply, a suitable voltage regulator need to be used. By using this Uninterruptible power system using solar for electromagnetic monitoring activity, the system can operate continuously without any power failure. Besides this uninterruptible solar power system is not only limited to the usage of earth electromagnetic monitoring application, it can be used to drive any 5V appliances.

VI. FUTURE RECOMMENDATION

A lot of modifications can be done to this uninterruptible solar power system to make it more efficient and increase its mobility. A smaller solar panel can be use to make it more mobile. The system is limited to devices and appliances that take 5V to function. It can be improved by using a different voltage regulator according to the load demands. A different rechargeable battery type can be used to make it more efficient and easy to use. Lastly, another improvement that can be added to the system is an inverter. An inverter will perform a conversion from direct current (dc) output of the solar panel to alternate current (ac) which will then directly applied to the electrical grid system.

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