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Emergency Portable Solar Power Supply

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Abstract- This paper proposes an emergency portable solar power supply (EPSPS) by using a renewable energy source. The proposed EPSPS can be used in contingency conditions or in a rural area with non-electric power sources. The system architecture is similar to the existing photovoltaic (PV) system with a portable and user-friendly design. EPSPS comprises a solar panel, battery, charge controller, inverter, sensors, relays and Arduino Uno with Bluetooth module. The output voltage of EPSPS is 12 V and operate for 2 days without charging. The battery has required a minimum of 6 hours of charging. Based on the obtained results, the system supplied maximum up to 100 W of DC/AC power load.

Indexed Terms - Portable Solar Power Supply, renewable energy, solar energy, Arduino.

I. INTRODUCTION

Emergency Portable Solar Power Supply is a product that uses renewable energy source (sunlight) as the main source of electricity. According to World Energy Outlook (WEO) 2018, the percentage of renewable energy used as a source to generate electricity grew by 17% higher than the 10-year average and solar energy contributed more than a third despite accounting for just 21% of the total. Due to the vast usage, petroleum will be depleted faster than natural gas and coal [14, 15]. After 14 years, natural gas and coal will replace petroleum as fossil fuel and coal will then be the major fossil fuels. Based on the results from Hubbert Peak Theory [1, 2], the rate of production of petroleum has reached the maximum level in 2004 and started to decline since that time. According to WEO, [3], the percentage of renewable energy used to generate electricity grew by 17% higher than the 10-year average and solar energy contributed more than a third despite accounting for just 21% of the total.

By converting solar energy into electrical energy by PV installations is the most recognized way to maximize the use of solar energy. Since solar photovoltaic cells are semiconductor device, they have a lot in common with processing and production techniques of other semiconductor devices such as computers and memory chips. As it is well known, the requirements for purity and quality control of semiconductor devices are quite large. With today's production, which reached a large scale, the whole industry production of solar cells has been developed and, due to the low production cost, it is mostly located in the Far East. Today, photovoltaic cells that produced by the majority of producers are mainly made of crystalline silicon as a semiconductor material [4], which resulted in an increase of power, high reliability, durability and low noise in devices for producing electricity [5]. The fuel for the photovoltaic cell is free. The sun is the only resource that is required for the operation of PV systems, and its energy is almost inexhaustible.

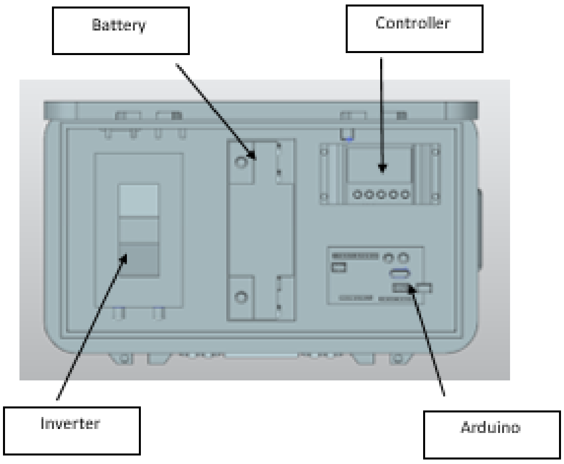
Typical photovoltaic cell efficiency is about 15%, which means it can convert 1 per 6 of solar energy into electricity. Photovoltaic systems produce no noise, there are no moving parts and they do not emit pollutants into the environment. Taking into account the energy consumed in the production of photovoltaic cells, they produce several tens of times less carbon dioxide per unit in relation to the energy produced from fossil fuel technologies. A photovoltaic cell has a lifetime of more than thirty years [6] and is one of the most reliable semiconductor products. Most solar cells are produced from silicon, which is non-toxic and is found in abundance in the earth's crust [7, 8]. Photovoltaic systems (cell, module, network) require minimal maintenance. At the end of the life cycle, photovoltaic modules are almost completely recycled. Photovoltaic modules bring electricity to rural areas where there is no electric power grid and thus increase the lifetime value of these areas. Photovoltaic systems will contribute to future development in a direction to become a key factor in the production of electricity for households and buildings in general. Besides that, these systems also can be used if there is a contingency and also contribute to reducing energy consumption in buildings. A series of legislative acts of the European Union in the field of renewable energy and energy efficiency have been promoted, particularly promoting photovoltaic technology for achieving the objectives of energy savings and CO_2 reduction in public, private and commercial buildings. Also, photovoltaic technology, as a renewable energy source, contributes to power systems through diversification of energy sources and security of electricity supply.

In Malaysia, the usage of solar energy is very low compared to other country, where the solar energy only produced 0.007% of the total in generated electricity in Peninsular Malaysia based on a report in 2012 [16] but based on the Sustainable Energy Development Authority of Malaysia (SEDA) on July 2016, around 9,406 of 9,586 applications are approved under Feed-in-Tariff program only for solar PV alone. It shows the growth of solar energy use in the general public of Malaysia. Based on data in 2007 the capacity of solar energy is 7 MW but it continues to increase till 233 MW in 2016 while for the total generation of solar energy it produces at 8 GWh in 2007 and it continues to increase rapidly until 253 GWh in 2015 but unfortunately in 2012, the generation of solar energy is dropping dramatically at 5 GWh. Based on data, the use of solar energy in Malaysia is increasing each year and it shows consumer in Malaysia realize important of solar energy.

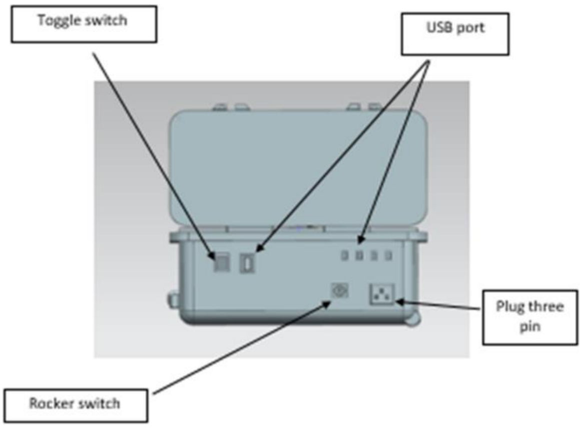
By the introduction of incentives for the energy produced by renewable sources in all developed countries, photovoltaic systems have become very affordable, and timely return of investment in photovoltaic systems has become short and constantly decreasing. This paper aims to design and implement an emergency portable solar power supply (EPSPS) that is more reliable, portable, and user-friendly system with green technology. The rest of the paper is organized as follows: Section II describes the research methodology. The proposed system is described in Section III. Section IV model validation with results are presented. Finally, a conclusion is highlighted in section V.

II. RESEARCH METHODOLOGY

Several phases were adopted to conduct this research. Starting from prototype design using NX 10 software and following by materials selection, system architecture design and implementation and ending by testing and validation phase. The NX 10 software was used to design this system. The design of the box to put all the component is a rectangular shape. Then the material of this box is ultra-high impact copolymer. The material is highly durable and often used to make gun case and pistol case. Then, this box is designed with a pair of a wheel, as it will make it easy to carry in motion. The box is heavy; due to the material used. The expected mass as all the components are summed in the box is up to 10 kg. The box will have a battery at the center inside and this battery will be covered by an aluminum plate. The box also contains controller, inverter, solar mat and Arduino. As shown in Figure 1, the front of the box will have five USB port. One for connecting to the solar panel and the rest for fast charging and for standard charging. The rocker switch also will be padded in front of the box, functioning as the on and off button. Next, a plug three-pin used to supply the current to the electric appliance and the toggle switch was used to control the type of power supply supplied, DC or AC power supply. Both plug three-pin and toggle switch were placed in the front of the box and for cooling down the system, a small fan was attached at the sides of the box.



(a)



(b)

Figure 1. EPSPS exterior view (a) Top View (b) Front View

After designing the casing of the proposed system, the components are then installed and connected to form complete system architecture. Then, the testing phase was conducted to ensure the batteries are charged by the solar panels, verifying the accuracy of the proposed battery monitor, and connected to multiple electric appliances such as four lamp, standard phone charger or fast charger and radio charged safely from the battery bank. Before the final implementation of the EPSPS, the testing phase was carried out in multiple steps. Firstly, the circuit was tested by using a solar panel to charge the batteries. Then the circuit that is used to charge the electric appliance from the batteries will be tested by connecting a load to the circuit to ensure that they are charging efficiently. After precautions are taken to protect the electric appliance, verification that electric appliance will be charge correctly is conducted. Throughout these tests, the microcontroller will be tested by having it connected to the batteries and monitoring their life. If all of these functions are considered working after they have been thoroughly tested, the design will be considered a success. After the testing phase was finalized, the next stage is wiring installation. In the next phase, all components of the EPSPS were assembled and connected to the Arduino microcontroller.

The proposed system uses a solar panel as the main source to get electricity. The solar panel gets the energy from the sun. It also calls the photovoltaic effect, this process causes electrons to become quite disrupted from their normal atomic orbit. This action alone creates an electrical power in the panels (also called DC), which then is sent to the battery. Then, the inverter is connected to the battery and it will automatically convert the DC into AC. Next, after the battery is fully charged or while charging we use it to charge the lamp and fan. All the component in the system is controlled by a controller.

Table 1. List of Nomenclature

V	Voltage
A	Ampere
DC	Direct current
AC	Alternate current
WEO	World Energy Outlook
W	Watt
PV	Photovoltaic
CO2	Carbon dioxide
Wh	Watt-hour
STC	Standard Test Condition
Ah	Ampere hour
SoC	State of charge

2.1 Load Determination

In this paper, the electrical appliances that used for drawing power from the solar system are DC table fan and AC lamp. The quantity that needs to use for both electrical appliances is one but with different wattage. The wattage of the table fan is 50 W and for the lamp is 16 W and the usage of the load is 8 hours and 6 hours per day respectively.

Table 2. Calculation of Electrical Appliances (Load)

Item	Quantity	Wattage	Total Watt	Hours per Day	Total Watt Hours per Day
Table Fan (DC)	3	6W	18	6	108
Lamp (AC)	2	3W	6	5	30
		∑ of total watt	24W	∑ of Total Wh/day	138 Wh/day

2.2 Battery Selection

The battery type recommended for using in a solar PV system is deep cycle lead-acid battery. Deep-cycle lead-acid battery is specifically designed to be discharged to low energy level and rapid recharged or cycle charged and discharged day after day for years [9]. The battery should be large enough to store sufficient energy to operate the appliances at night and cloudy days. Hence, a 12V battery is chosen as it will be optimum for the system.

- Voltage of battery = 12 V
- Total Watt. Hour/day = 138 Wh/day
- Efficiency of battery = 80% (batteries are not 100% efficient)

$$\text{Battery Capacity (Ah)} = \left(\frac{\text{Total Watt}-\text{hours per day used by appliances}}{(\text{ efficiency } \text{ x nominal battery voltage})}\right) \tag{1}$$

$$= \left(\frac{138 \text{ Wh/day}}{(0.8 \text{ x } 12\text{V})}\right) = 14.4 \text{ Ah}$$

Total Ampere-hours required is 14.4 Ah. So, the battery should be rated at 12 V, 14 Ah.

2.3 Solar Panel Selection

According to Table 2, the summation of the total watt-hours per day will be used by the system is 138 Watt-hour per day. The energy that needs to generate by the system must more than the energy that wants to use. Let assume 6 hours of effective sunlight which will generate the rated power due to the location of the sunlight which is not uniform during the 12-hour daytime.

Total power output of Panels = $12\ V$ x 14 Ah = $168Wh$ (2)

Power to be generated per hour = $168Wh\ /\ 6h$ =$28\ W$ (3)

Compensate for system inefficiencies. Every part of a solar-powered system has some inefficiency in it. The rule of thumb is used when there has an inverter (to produce AC) which makes the total system inefficiency become 30%. For systems that will be using the DC voltage directly from the battery bank, the inefficiency factor is 20%. So, the sizes of the solar panel need to be multiplied with 1.3.

Total of solar panel watts needed = $28\ W$ x 1.3 =$36.4\ W$ (4)

In order to determine the number of solar panels needed, divide the total of solar panel watts needed with the rated power output (watts) of the solar panel that has been chosen.

Total number of solar panel needed = $\frac{\text{Total of solar panel watts needed}}{\text{Solar panel rated output}}$ (5)

$$= \frac{36.4\text{W}}{20W} = 1.82$$

In conclusion, this system should be powered by at least 2 modules of 20 W, 12 V solar panel.

2.4 Charge controller Selection

The solar charge controller is typically rated against Amperage and Voltage capacities. So the current of the charge controller is calculated. Since this system is rated at 12V, the charge controller is also 12V.

Current rating = $\frac{\text{Power output of Panels}}{\text{Voltage}} = \frac{28\text{ W}}{12\text{ V}}$ =2.33 A (6)

For safety factor, the size of the controller needs to be multiplied by 1.25.

New controller size = 2.33 A x $1.25 = 3$ A (7)

2.5 Inverter Selection

The size of the inverter depends on the total watt of appliances. But for the safety issue, the size of the inverter should be 25 – 30% bigger than the total watt of the appliances. But it is not advisable if the watt of the inverter is too high because it will eventually decrease the efficiency of the system. Since the total watt for appliances is 24 W, thus the inverter size will be calculated as below:

Inverter size = $(0.30\ \text{ x } 24\text{ W}) + 24\text{ W} = 31.2\text{ W} \approx 100\text{W}$ (8)

III. PROPOSED SYSTEM

The purpose of this research is to develop a portable solar energy power supply for emergency situations. The system should become more reliable to the user, able to apply green technology, and able to utilize Arduino microcontroller with sensor and Bluetooth module to send data to a smartphone via Virtuino App. It is very important to make sure the product was able to run smoothly without any disturbance or problem. If the components were choosing wrong, the problem to run the product may occur. So, the main task was to integrate all components of EPSPS and validate its functionalities. With a better understanding of the electrical component in the project, it makes more easily on modification in the product itself without any problem. Therefore, the last phases of this research are the arrangement of the utilized components of the product. The sponge was used to hold the component to make sure the components are not move around because if the component has involved in many movements, it will damage the system and make the product to do maintenance in short period.

Unlike the conventional solar power supply, the proposed EPSPS utilized Arduino Uno with Bluetooth module and voltage sensor to get the voltage readings and update to the Virtuino mobile application. A relay board also is exploited to switching the outlet power ports. The first thing to improve the product is added Bluetooth module in the product where's connect to the mobile phone to control on and off the product, and able to monitoring the system and the battery percentage by used Arduino board as a platform to control the product to long-distance and voltage sensor was used to monitoring the system and battery percentage, thus making the system more user-friendly. Figure 2 depicts the connection of Arduino microcontroller with sensor, relays and Bluetooth module.

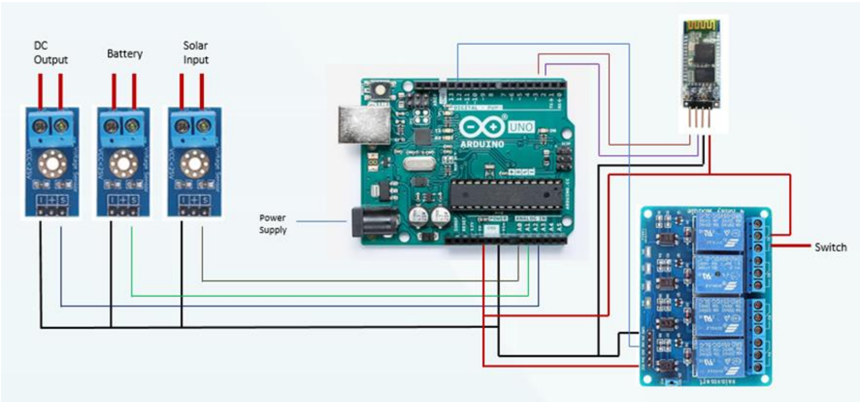


Figure 2. Arduino Controller connection of EPSPS.

IV. MODEL VALIDATION

After all the component was assembled and arrange the position, the validation of system functionalities was carried out. The overall system architecture is displayed in Figure 3 which shows the connections between main system parts and solar panels.

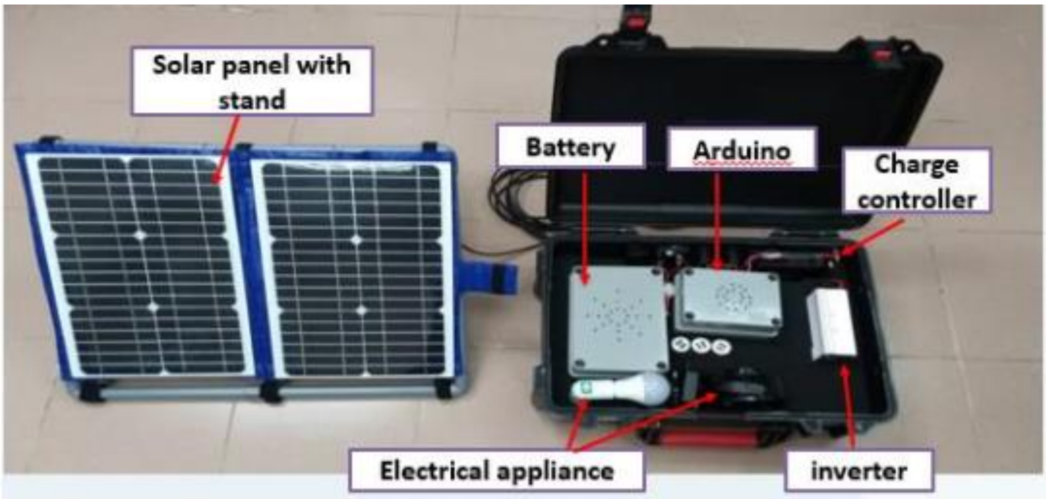


Figure 3. The architecture of EPSPS.

Table 3 shows the value of voltage and current at certain of irradiance. The value of irradiance was taken in three times and the average of the irradiance was calculated. Based on Table 3, a graph was linearly plotted which is called an "I-V curve", and it refers to the module's output relationship between current (I) and voltage (V) that produce from the solar panel when placed under the halogen lamp. Based on Figure 4, it shows that the number of current is directly proportional to the voltage.

Table 3. Various Voltage and Current Produced by Solar Panel at Difference Irradiance

Voltage (V)	Current (A)	Power (W)	Irradiance (W/m^2)			
			1	2	3	Average
12.32	0.13	1.60	737.7	739.9	709.9	729.2
12.48	0.14	1.75	936.0	851.9	938.5	909.8
12.67	0.16	2.03	852.6	1116.5	997.9	989.0
12.72	0.17	2.16	942.1	943.5	1109.8	998.5
12.75	0.18	2.29	1102.1	994.3	959.5	1018.6
12.79	0.18	2.30	1166.5	977.9	1095.3	1079.9
12.8	0.19	2.43	952.6	1150.1	1205.4	1102.7

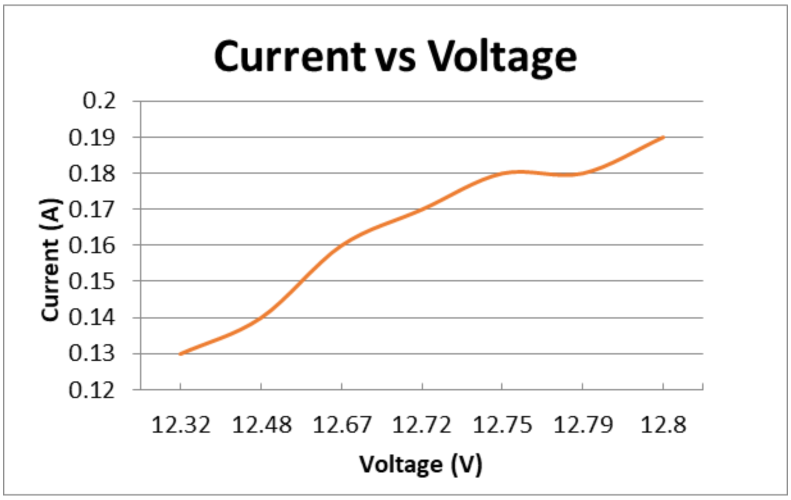


Figure 4. I-V Characteristic of PV module

The basic measure of solar panel energy output is calculated by testing the panels under average conditions, known as Standard Test Condition (STC) [10]. The STC measure the solar panel's energy output using common conditions of light exposure, orientation, and panel temperature. Under STC, a 250 W panel produces 250 W of electricity when the sunlight (or "solar irradiance") on the panel is 1000 W/m^2 and the panel is operating at 25°C. All manufacturers must produce panels that meet or surpass their advertised wattage under STC.

$$\eta_{max} = \frac{\boldsymbol{P_{max}}}{\boldsymbol{E \times A_C}} \times \mathbf{100}\% \; \frac{20\,W}{1000\frac{W}{m^2}\times 0.1176m^2} \times 100\% \;\; = 17\% \tag{8}$$

The solar panel that has been used has 17% of efficiency each. According to Glenn, the average standard efficiency of solar panel falls between 15% - 18%. The highest efficiency of solar panels can reach almost 23% efficiency [11]. Many internal and scientific factors play in the solar cell efficiency equation. But two major components are:

- Reflectance efficiency
- Thermodynamic efficiency

Reflectance efficiency is determined by how much sunlight is reflected back instead of absorbed and put to use. The less reflection in solar cells, the better. Silicon reflectance can be as much as 38 per cent, though most solar cells have a slight micro-pyramid shape [12]. This reduces reflectance to about 11 per cent [12].

There are ways to reduce reflectance, such as anti-reflective coatings which can bring reflectance down to just 1 or 2 % [12]. Thermodynamic efficiency is the maximum efficiency possible. It's the height at which the sun's energy could be converted into electricity. This number is right around 86 per cent, the thermodynamic efficiency limit. The way photons interact with solar cells, they can only generate electricity from the sun's energy up to a certain point. After that point (86 per cent) thermal energy, or heat, is created [13]. One way to improve thermodynamic efficiency is to construct multi-junction or tandem solar cells [11]. This improves efficiency by dividing the solar spectrum into smaller areas, which raises the efficiency limit for each section.

For the battery, charging time has been calculated from the following formula:

$$\text{Charge time} = \frac{\boldsymbol{Amp-hour\ of\ battery \times 1.15}}{\boldsymbol{Charge\ Rate}} \tag{9}$$

Where, charge rate = $\frac{40(W)}{12\ (V)}$ = 3.33 A

Charge time = $\frac{14\times1.15}{3.33}$ = 4.83 h

Table 4 shows that the state of charge based on voltage by referring to the initial and final voltage of the battery. The value of SoC is started from 40% - 90%. To determine the percentage of SoC based on the voltage, the interpolation method is used below.

Initial SoC of Battery at 40% = 11.97 V
Final SoC of battery at 90% = 12.7V
Interpolation = $\frac{12.7V-11.97V}{5} = 0.146$
Thus, at 50% of SoC: 11.9V + 0.146V = 12.12 V

Table 4: Relationship between State of Charge (SoC) and voltage

SoC (%)	Voltage (V)
40	11.97
50	12.12
60	12.27
70	12.41
80	12.56
90	12.70

Figure 5 shows after the voltage of the battery achieve around 60% SoC the value of voltage slightly increase from time to time. This means that the closer the battery to fully charge, the lower the value of voltage increases.

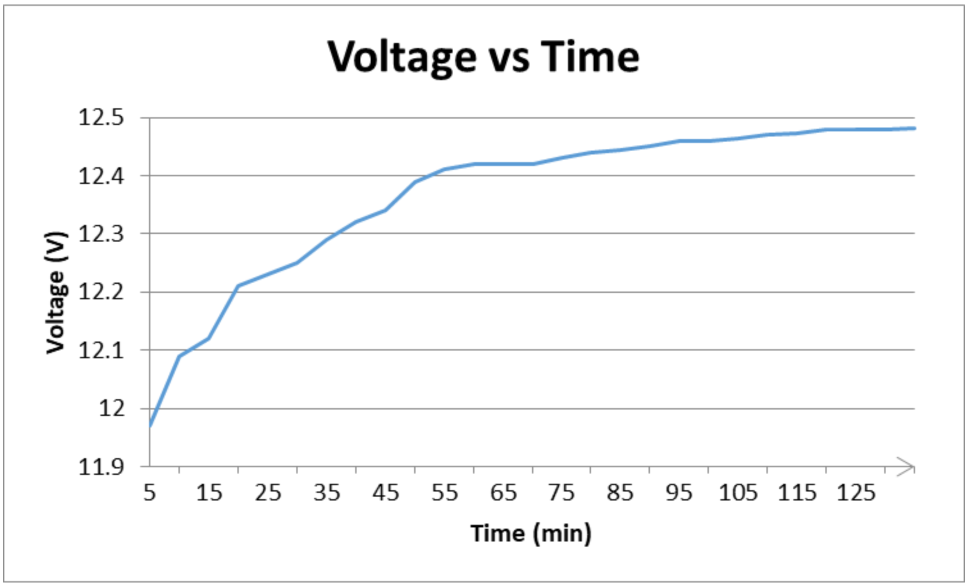


Figure 5. Relationship between Voltage and Time Taken of Battery Charge

V. CONCLUSIONS

In conclusion, this portable solar power supply can supply electricity collected from non-conventional energy sourced which is from solar power. This product can supply electricity to DC and AC appliances and power up to 100W at one time. The system can supply electricity which lasted for 2 days without the need for charging. This is sufficient enough to be used during contingency happens where the electricity interruption might happen.

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