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Designing A Solar Charge Pack Battery Management System Integration for Enhanced Charging Performance

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Abstract

This study aims to improve the current portable solar charge pack by implementing battery management system to enhanced the charging performance by increasing the lifespan of the battery and safety. The study also aims to improve the previous solar powered backpack that has limited power production because of the low efficiency in converting sunlight energy into electricity during travelling by implementing manually adjustable tilt angle mechanisms to help increase the solar panel efficiency during travelling. This project will use solar panel attached to a backpack using manually adjustable tilt angle mechanisms, then it will be connected to solar charger controller and battery management system that has been designed for the battery. Lastly, it will be connected to a USB power output to charge electronic device. The result will be simulation for comparison of charging circuit with and without cell balancer for three batteries in series. This simulation shows that the charging circuit with BMS has balanced soc percentage between the battery and the voltage does not exceed the battery full voltage. Next, the comparison of power generated by solar power at different tilt angle. The manually adjustable tilt angle has been proven to increase power generated by solar panel.

1. Introduction

In this era of renewable and sustainable energy, the need for reliable and efficient power source is needed for personal electronic that has seen increasing usage among the people. Outdated way such as power banks and charger often struggling in supplying the electrical power needed in remote or off-grid locations. This increase the needs for innovative solution that provide continuous and renewable energy [1]. This can be done by improving the previous solar powered backpack which mainly designed to be use when stationery while still be portable enough to be carried around. This solar powered backpack project aim to design a backpack that can be used while travelling in sunny area and also can be used in stationery place while resting. This project will also incorporate battery management system to enhanced charging performance of the backpack. Based on previous research of solar powered backpack [2-4]. It is shown that precious research is more focusing on the internet of thing and smart system. Most of the solar powered backpack lithium ion battery does not have protection for cell balancing. This give me an idea to design a solar powered backpack with battery management system. The component of the solar powered consist of battery management system (BMS), solar panel, lithium ion battery and solar charger controller. The Battery management systems (BMS), is a technology dedicated to monitoring a battery pack commonly used in lithium-ion battery packs. Lithium-ion battery have a high energy density, they can have tight safe operating rating for all the value such as current, temperature and voltage. The several main factor for the overall construction and safety features included in battery management systems is affected by the

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costs, complexity, and size of the battery pack. The Battery management system will monitor and control the current of each battery pack. This will allow the battery management system to prevent the operation of the battery pack current to go outside of the peak current for charging and discharging [5,6]. For battery management protection for voltage, the main factor that need to be implemented is protection against overvoltage. For overvoltage protection, the overvoltage protection mainly protects the battery from overvoltage mainly caused by charging the battery. This is because battery will have imperfection in their construction that will lead to imbalance charging between the battery [4-7]. The type of architecture used is distributed BMS architecture. This architecture is a battery management system that distribute the BMS for each battery or a node the node will communicate with each other to coordinate their action and collectively manage the entire battery pack [8].

2. Methodology

Fig. 1 shows the overall flow chart of the work.

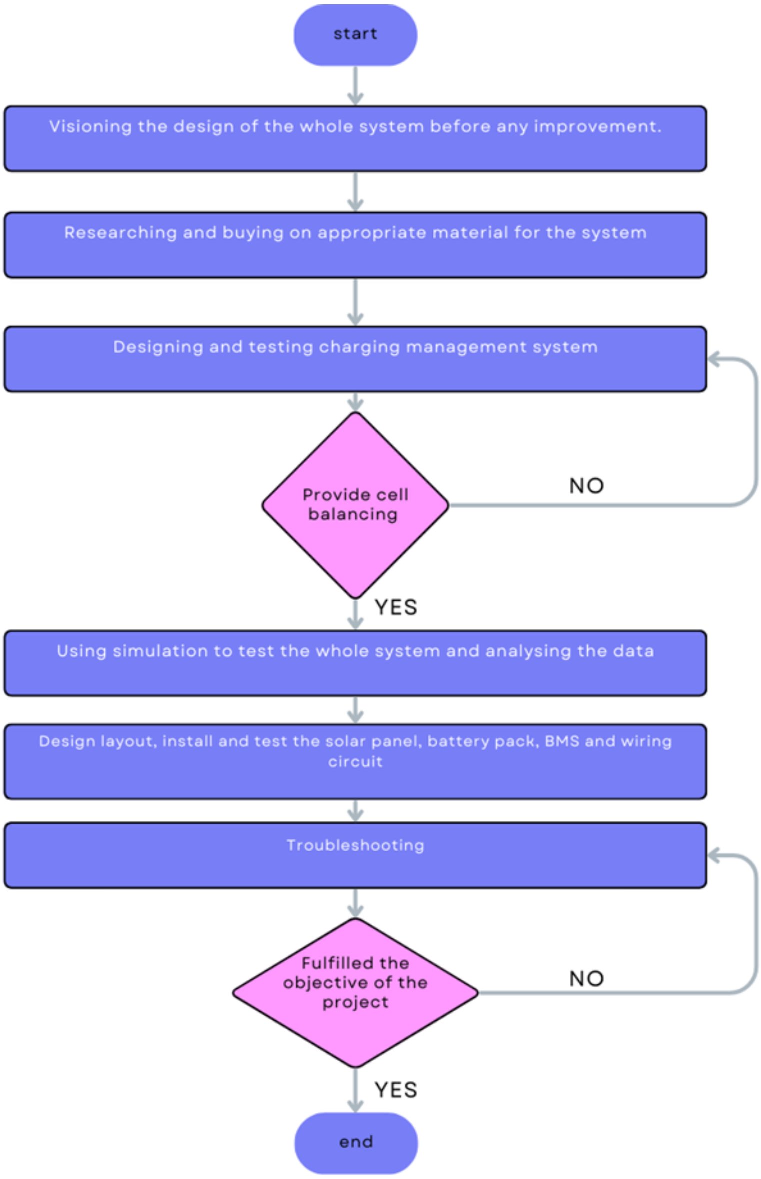


Fig. 1 *Whole flowchart of the work*

2.1 Device Structure

The hardware configuration for this project start with the solar panel as the power source. This solar panel material is made of semi – flexible monocrystalline solar cell without the steel outer frame reinforcement. This will decrease the weight of the solar panel compared to normal solar panel with steel frame. Then it will be attached to the back of the backpack. This backpack will be used to house all the components used in the project.

The solar panel will be attached to a wooden base to improve the strength of solar panel, this wooden base is thin and light to reduce the weight of the system. Then the solar panel will be connected to the battery management system. This battery management system is used to provide protection to the battery pack. One of the protections is input overvoltage protection. This will limit the input voltage to the batteries to 12.6V. Next, this battery management system will have current management protection. This current management system will protect the battery from overcurrent issue that can occur during charging process. This is done through limiting the input current to 600mA. The battery management system also has a cell balancing function which will balance the voltage of the battery during charging process. This cell balancer will balance the battery voltage during charging. The system then will be connected to the battery that has an arrangement of three 3.7V batteries in series with total voltage of 12.6V. Finally, the battery will have output port to charge the load. This output port will have 15W output. Fig. 2 and 3 show the hardware flow chart and the design of the solar powered backpack.

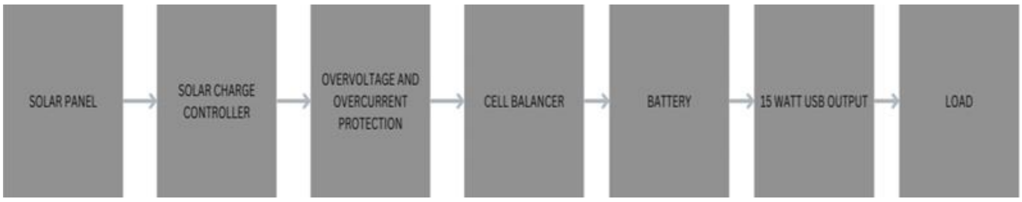


Fig. 2 *Hardware flowchart*

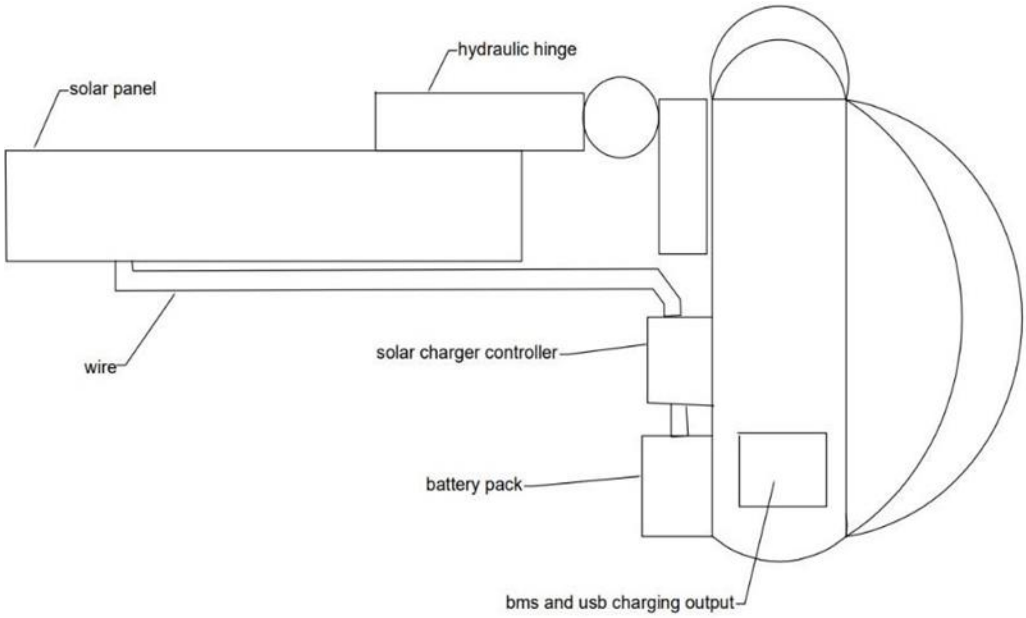


Fig. 3 *The design of the solar charge pack from side view*

2.2 Battery Management Systems

The battery management system consists of 3 component which is overvoltage protection to limit to keep the input voltage to the battery not higher than the battery full charge voltage, overcurrent protection to limit the current input to the battery during charging and cell balancer for equalizing battery voltage during charging. Fig. 4 shows the overvoltage circuit and formula. Fig. 5 shows the overcurrent circuit and formula.

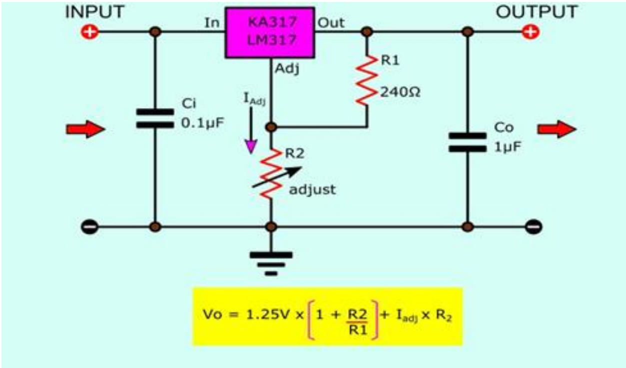


Fig. 4 *Lm317 voltage regulator circuit design and calculation*

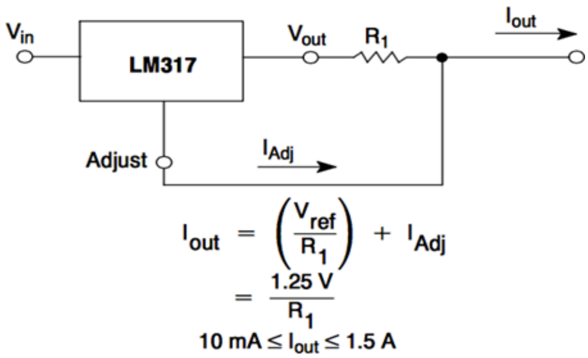


Fig. 5 *Lm317 current regulator circuit and its formula*

For the cell balancer for one unit battery, the battery positive terminal will be connected to collector junction of the transistor and the reference diode that been set to 4.2V. The base of the transistor will be connected to the positive of reference diode. This reference diode will remain open when the voltage does not reach 4.2V. When the battery is charging the voltage will remain under 4.2V. Then when the battery is full and reach 4.2V. The reference diode will close and allowed the NPN transistor to closed. When the transistor is closed this will allow the current to pass though the transistor and go through four diodes in series that act as a load and will bypass the battery. Fig. 6 shows the circuit of cell balancer for a unit battery.

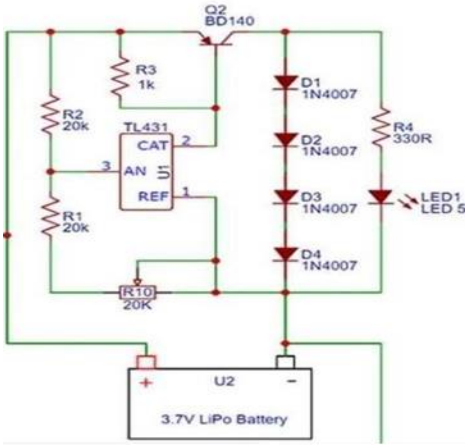


Fig. 6 *5 stages order for 2.4 GHz RF rectifier*

The circuit that will be used for charging the battery pack in this project is a charging circuit with 3 units battery in series. This circuit will be equipped with a cell balancer for each battery. This circuit for 3 units battery in series will provide 12.6V output for the battery pack. The cell balancer circuit in Fig. 7 can be use in 3 units battery in series configuration by putting the cell balancer circuit in parallel configurations to the battery. This means that each battery will have a cell balancer in parallel configurations. For the voltage and current regulator. The voltage regulator will be set to limit voltage input to 12.6V by changing the resistant value. This will allow the system to have 16V to 20V input voltage from the power source without damaging the battery. As for the current regulator, it will still be set at 600 mA. Fig. 6 shows the full circuit of the battery management system that will be used in this project.

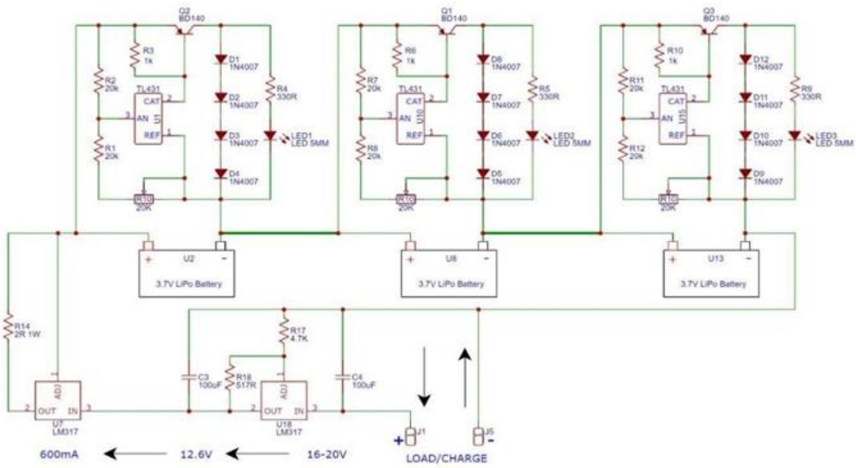


Fig. 7 *5 stages order for 2.4 GHz RF rectifier*

Based on Fig. 8 and Fig. 9, The solar panel will be attached to wooden base. Then the wooden base will be attached to the hydraulic hinge. This hinge has 3 different opening angles which are 90°, 45° and 0°. This hinge will enable the solar panel to open to 90° for optimum solar panel operation and be closed when not in use or for storage purposes. This can improve the portability of the solar charge pack as this feature will increase the convenient in using this project.

Fig. 8 *Hydraulic hinge*

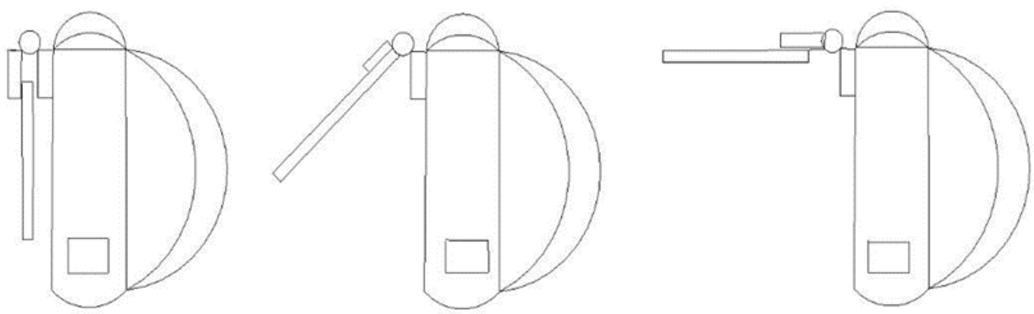


Fig. 9 *The side view of the backpack. From the left is 0° tilt angle, the middle is 45° tilt angle and from the right is 90° tilt angle*

3. Result and Discussion

This section will discuss the simulation result of 3 units of battery connected in series in battery charging circuit with and without cell balancer. Next, it will discuss the comparison of battery charging using pulse width modulation (PWM) and maximum power point tracking (MPPT). Then, the testing result of the battery management system that consists of input overcurrent protection, input overvoltage protection and cell balancer for 3 units battery in series. After that, the output of the charging module will be tested. Lastly, the result and discussion of tilt angle of the solar panel using the manually adjustable tilt angle mechanisms.

3.1 Project Design

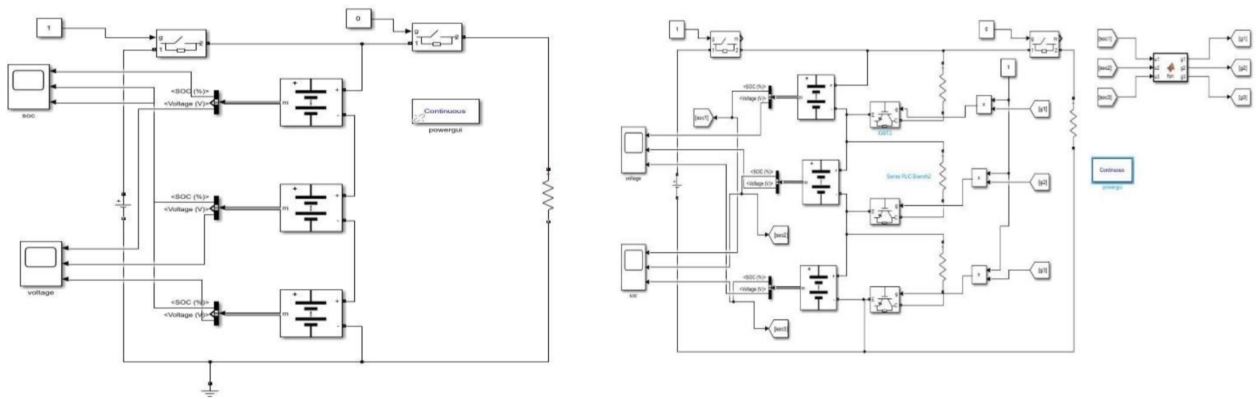
The design for this project is that the solar panel will be attached to the back of the backpack by using wooden base. The connection point between the wooden base to the backpack will be using hydraulic hinge that can be manually adjusted to obtain multiple tilt angle for the solar panel. Then, the solar panel will be connected to MPPT solar charger controller for avoiding reverse flow of current during cloudy conditions and managing the current flow to the output terminal. Next, the solar charger controller will be connected to battery management system (BMS) to provide overvoltage protection, overcurrent protection and balancing individual voltage of the bttery. Lastly, the output of the charging module can produce charging power of 15 watt from the battery. Fig. 10 shows the design of the project.

(a) (b) (c) (d) (e) (f)

Fig. 10 *Solar powered backpack design. (a) and (b) is front view, (c) and (d) is left view, (e) and (f) is right view*

3.2 Comparison of The Simulation of The Charging Circuit for 3 Battery in Series with and Without Cell Balancer

This experiment aims to study the charging behavior of three battery connected to a charging circuit in series with different initial state of charge (SOC). The SOC of the battery is, battery A at 25%, battery B at 23% and battery C at 28%. The main objective is to understand the battery behavior with and without cell balancer. The simulation setup for each circuit is 3-unit battery connected in series. The voltage source is 12.6V. The 3 units battery in series total voltage is 12.6V. The duration of the simulation is 1 hour. The initial soc of battery A is 25%, battery B is 23% and battery C is 28%. The type of cell balancer will be used is active cell balancer. The charging circuit in Fig. 10 (a) is not equipped with cell balancer and the charging circuit in Fig. 11 (b) is equipped with active cell balancer.



(a) (b)

Fig. 11 *The simulation setup (a) charging circuit without cell balancer; (b) charging circuit with cell balancer*

The simulation shows that the charging time for each battery is different. The battery C will reach full charge first followed by battery B and last battery A. Fig. 12 shows the SOC for the circuit without the cell balancer. The battery circuit with the cell balancer resulting in battery B which started at 23% SOC to be balanced with battery A which started at 25% SOC reaching an equal SOC of 50%. After Battery A and Battery B reached 50% SOC, the active cell balancer then worked to balance these two batteries with Battery C. Electric charge was transferred from Battery C to both Battery A and Battery B until all three batteries reached an equal SOC of 90%. Then it proceed to charge the C battery until 100% SOC. Fig. 13 below show the SOC for the circuit with the cell balancer. Fig. 14 shows the voltage for 3 units series battery charging without BMS and Fig. 15 shows the Voltage for 3 units series battery charging with BMS.

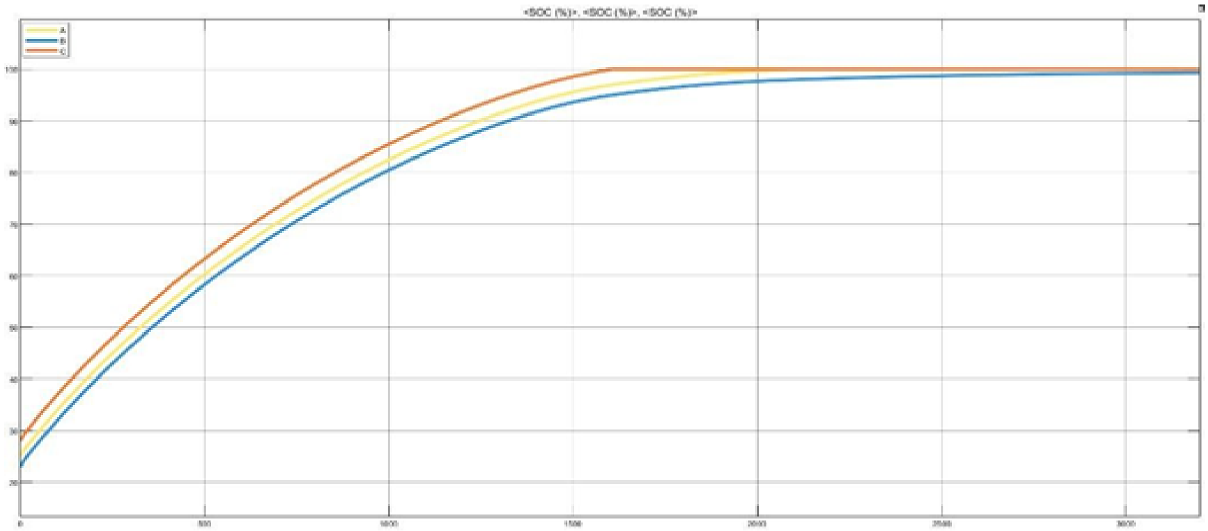


Fig. 12 *SOC for 3 units series battery charging circuit without BMS*

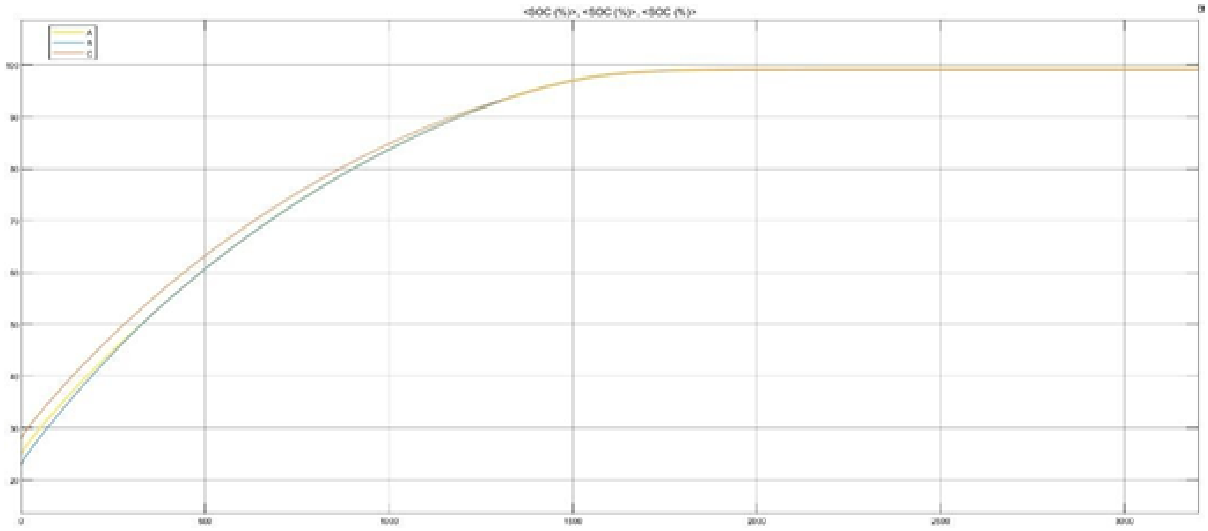


Fig. 13 *SOC for 3 units series battery charging with BMS*

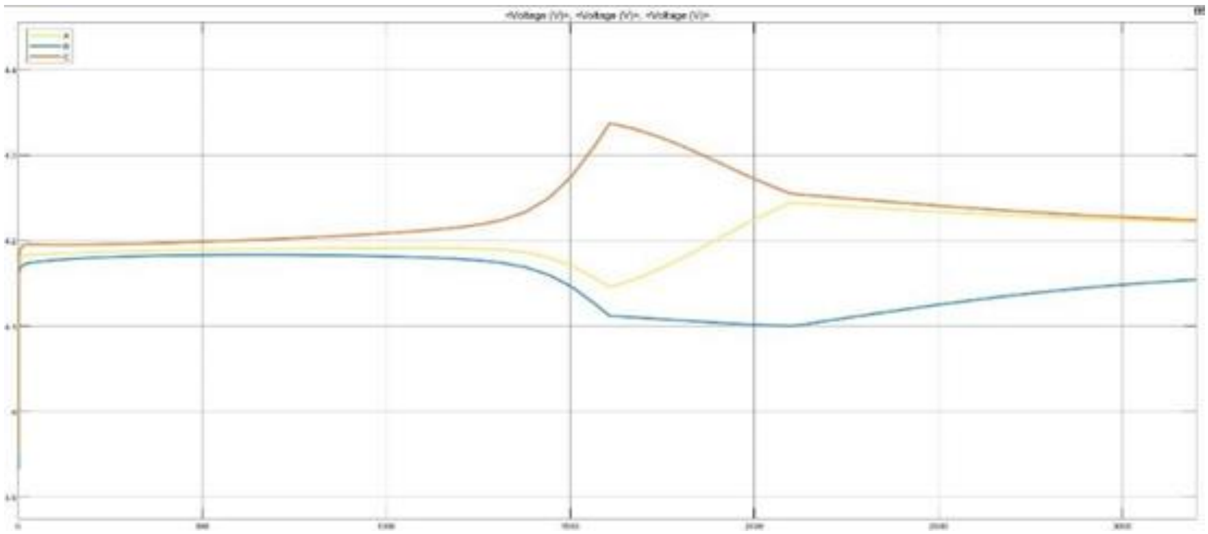


Fig. 14 *Voltage for 3 units series battery charging without BMS*

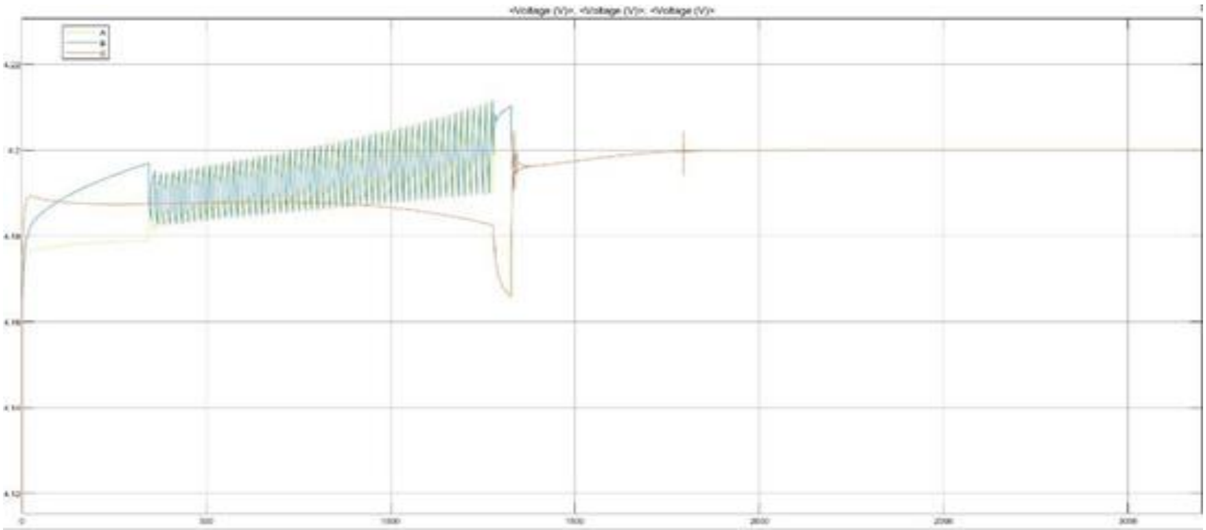


Fig. 15 *Voltage for 3 units series battery charging with BMS*

3.3 Battery Management Systems

This battery management system testing will be separated into three individual testing which is overvoltage protection, overcurrent protection and cell balancer. Fig. 16 shows the overvoltage protection testing. Fig, 17 shows overcurrent protection testing and Fig. 18 cell balancer circuit testing.

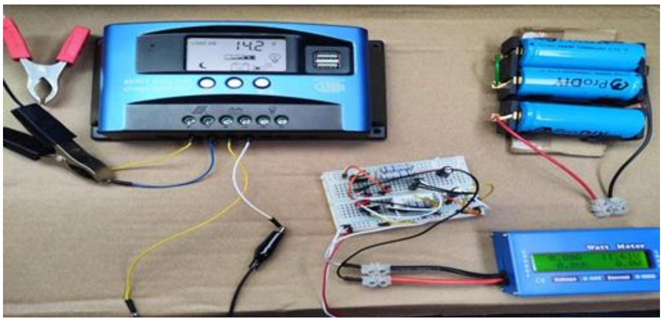
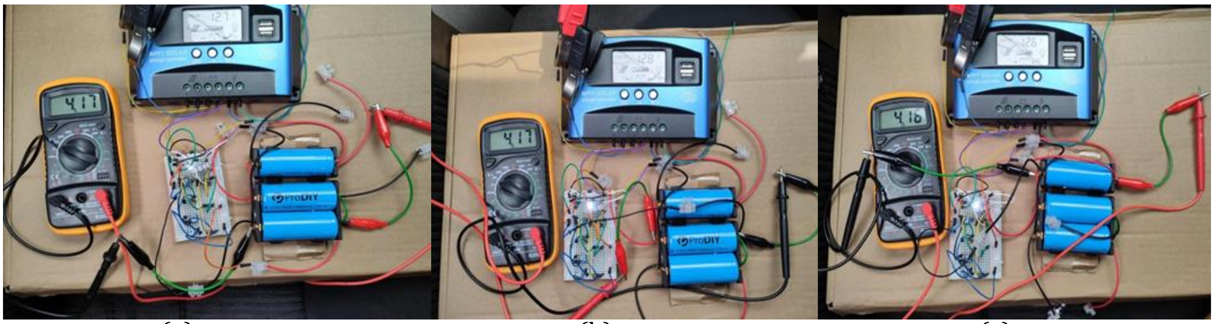


Fig. 16 *Overvoltage protection testing circuit*

Fig. 17 *Overcurrent protection testing circuit*



(a) (b) (c)

Fig. 18 *Cell balancer testing (a) Battery A cell balancer testing; (b) Battery B cell balancer testing; Battery C cell balancer testing.*

3.4 Comparison of Power Generated Between Different Tilt Angle

This experiment aims to learn the difference between power generated at different solar panel tilt angles. The tilt angle used in this experiment is 15°, 45° and 90°. Fig. 19 shows the solar placement at different tilt angle.

(a) (b) (c)

Fig. 19 *Solar placement on the backpack (a) 15° tilt angle; (b) 45° tilt Angle; (c) 90° tilt angle*

The solar panel with 15° tilt angle generated the less amount of power compared to solar panel with 45° and 90° tilt angle. The average power generated for solar panels with 15°, 45° and 90° tilt angle is 8.6W, 22.1W and 29.1W respectively. The percentage increase between solar panel with 45° and 90° tilt angle compared to 15° is 156% and 238% respectively. The percentage increase between solar panel with 90° tilt angle compared to solar panel with 45° tilt angle is 31.7%. This data show that the angle of solar irradiance hitting the solar panel is important to increase the efficiency of the solar panel. The data coincides with the theory which the solar panel will produce the highest amount of power when the solar panel is 90° to the sun. Fig. 20 shows the data collected in this experiment.

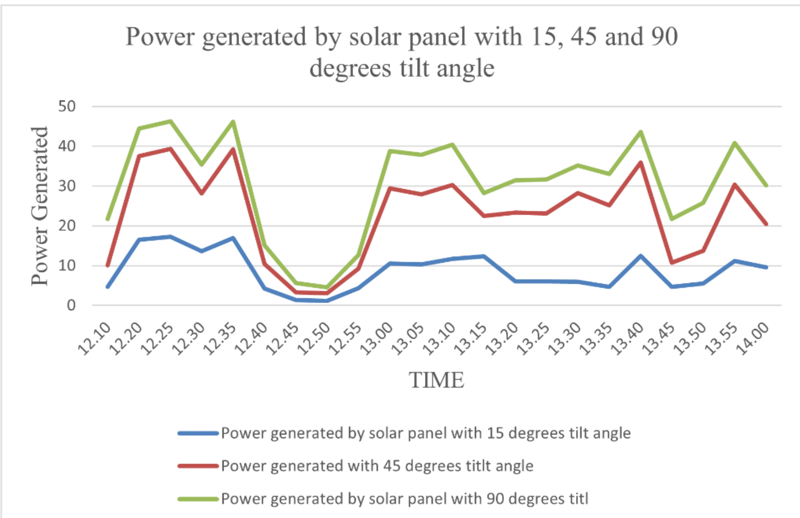


Fig. 20 *Graph for power generated by solar panel with 15°, 45° and 90° tilt angle*

4. Conclusion

The battery management system integration into the solar power backpack has been proven to increase the charging performance in aspects of safety for the component and the user. This is shown in the result of the simulation of the 3 units battery charging circuit with and without the cell balancer. This is proven when the battery in charging circuit without the cell balancer reach above the maximum full voltage while the battery in charging circuit with the cell balancer mostly under the maximum full voltage .The addition of the manually adjustable tilt angle mechanisms has been proven to increase the amount of power the solar panel can captured from the sunlight, thus improving the effectiveness of the solar panel in supplying electricity to the solar charge pack.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The author attests to having sole responsibility for the following: planning and designing the study, data collection, analysis and interpretation of the outcomes, and paper writing.

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