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# Research Performance of Lithium-Ion Battery for Off-Grid Solar System

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**Abstract**: There are certain specifications that must use while comparing solar battery options, which includes how lengthy the solar battery will be remaining or how a great deal electricity it is able to provide. The goal of this study is to gain a better understanding of how effectively lithium-ion batteries operate within the context of the system as a whole. It is discussed how lithium-ion (Li-ion) batteries have the potential to fulfil the role of the primary energy storage component. The first step in the development project process is to identify the components used for the project. The types of solar panel, solar charge controller, lithium-ion batteries and power converter. This is important to ensure the smooth flow of the project in hardware development. There is discussion regarding the capability of lithium-ion (Li-ion) batteries to function as the primary source of energy storage in off-grid renewable energy systems. A longer lifespan in comparison to other technologies, as well as higher energy and power densities, are the two aspects of lithium-ion batteries that stand out as the most beneficial aspects of these batteries. It's possible that lithium-ion batteries will become the standard for energy storage. Since lithium-ion batteries are capable of providing more cycles than lead-acid batteries, they are an excellent choice for providing ancillary services to the grid.

**Keywords**: Lithium-Ion Battery, Off-Grid Solar System, Charge Controller, Inverter

## 1. Introduction

Lithium-ion batteries are one of the most popular forms of energy storage in the world, accounting for 85.6% of the energy storage systems introduced in 2015. Lithium-ion batteries are composed of positive electrode lithium metal oxide and negative electrode carbon that can store lithium ions. A lithium salt dissolved inorganic carbonate is used as an electrolyte. Lithium-ion batteries work by

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*Corresponding author: fadly@uthm.edu.my* moving lithium ions in two phases. Li-ion batteries do not require temperature monitoring to ensure effective operation. The large demand for Li-ion batteries is due to their accessibility and reliability.

Many technologies rely on lithium-ion batteries, such as portable devices, hybrid electric vehicles, and electric vehicles. The advantages of Li-ion batteries may lead to their use in the production of largescale storage systems, even if such storage will be expensive. Although Li-ion batteries have the highest price among all the battery-type energy storage devices, they offer the capability to store renewable energy because of their low cost per cycle.

The purpose of this project is to find out more about the performance of lithium-ion for the system. The ability of lithium-ion (Li-ion) batteries to be the primary energy storage in off-grid renewable energy is presented. A longer lifespan than different technology together with better energy and power densities are the maximum favourable attributes of Li-ion batteries. The Li-ion may be the battery of first preference for energy storage.

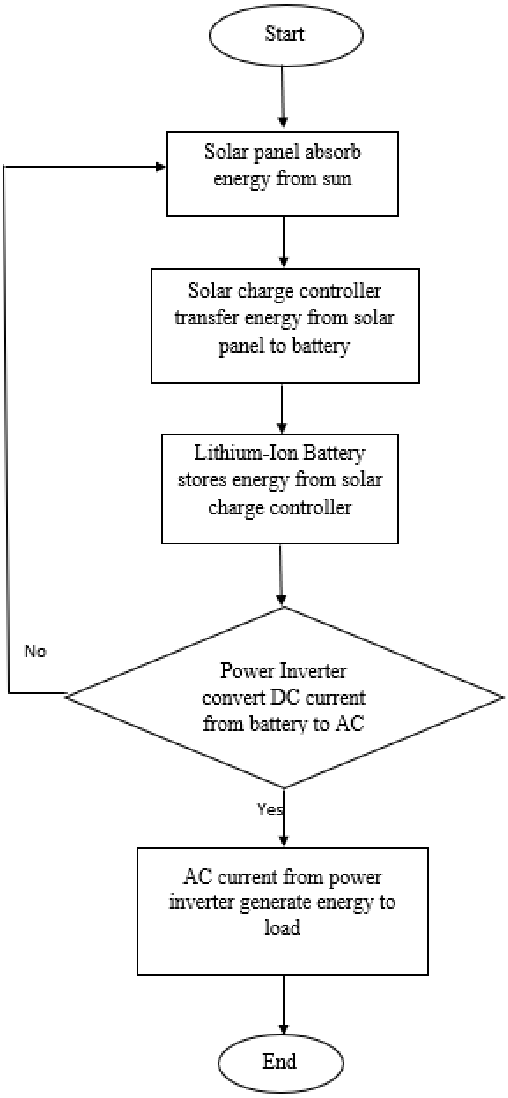
## 2. Materials and Methods

This discusses the method of development of this project consisting the detailed information regarding workflow, strategy, and approach in a precise and well-organized structure.

### 2.1 Operation Flowchart

The flow chart shows in figure 2.1 the operation of the Off-Grid Solar System Based Lithium-Ion Battery from beginning to end.

**Figure 1: Operation Flowchart**



## 2.2 Block Diagram

A block diagram in figure 2.2 is used to represent the layout and structure of the system that is involved. The design of the project will be described and highlighted in each chapter.

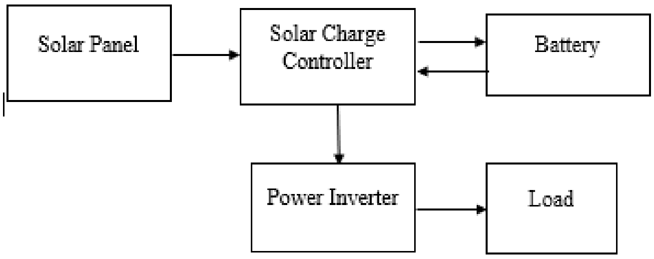


**Figure 2: Block Diagram of the Project**

## 2.3 Hardware Development

**Table 1: List of components to develop off-grid solar system**

| Item | Descriptions |
|---|---|
| Monocrystalline Solar Cell (Mono-Si) | • High-efficiency<br>• Smaller installation area needed in comparison with other types.<br>• Long life-span (25-year warranty)<br>• Good performance under low irradiation conditions. |
| MPPT Solar Charge Controller | • System voltage: 12V automatic<br>• Rated charging current: 10A 20A<br>• Rated discharge current: 10A 20A<br>• The highest photovoltaic voltage 10A-30A: 12V system |
| Lithium Iron Phosphate Battery | • Load: 1C<br>• Capacity: 38AH<br>• Voltage: 12V<br>• Built in bms:<br>• Over load protection<br>• Over charge protection - 14.6v (Advisable to set 14.4v cut off)<br>• Over discharge protection - 8.4v (Advisable to set 12v cut off)<br>• Short circuit cut off protection. |
| Pure Sine Wave Power Inverter | • DC 24V TO AC 230V<br>• 300W continuous power inverter 600W Peak Power<br>• With USB port 5V 1A<br>• Charger current: 5A<br>• No Load Current Draw: <0.6A<br>• Efficiency: > 88%<br>• Pure sine wave output<br>• Input Voltage: 21V-30V<br>• Output voltage: AC 230V<br>• Frequency: 50HZ+2<br>• Low battery alarm:21+0.5V<br>• Low battery shut down: 20V DC±0.5V<br>• Over voltage shut down: 30.5V+0.5V |

## 2.4 Design circuit

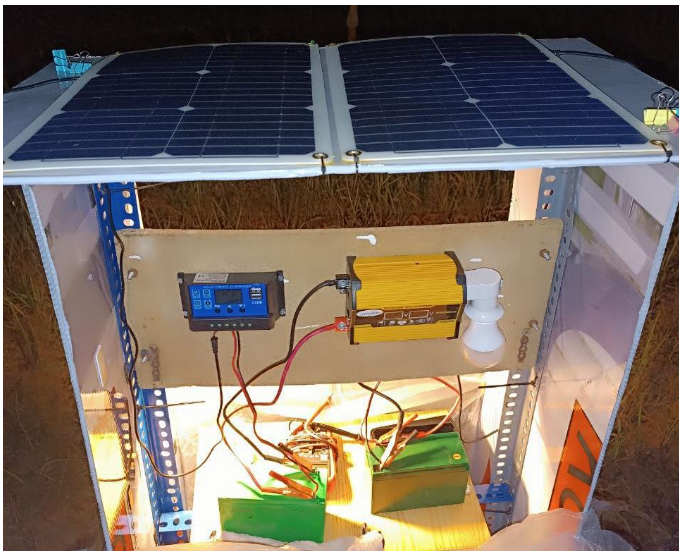


**Figure 3: Full hardware development**

## 3. Results and Discussion

The results and discussion perform tests after the system has been fully developed to ensure that all electrical components are functioning properly. The results obtained were tabulated, analyzed for differences, and compared with theoretical values based on previous literature.

### 3.1 Charge and Discharge Result Analysis

After the system has been fully developed, the voltage and current will record as follow:

**Table 2: The condition that had been observed**

| Condition | Explanation |
|---|---|
| A | Battery charging and current flow |
| B | Battery discharging and current flow |
| C | Ambient temperature condition |

### 3.1.1 Condition A: Battery Charging

The data for charging the lithium-ion battery is recorded for about 10 hours per day in 6 days. The result of voltage and current were tabulated and graphs plotted to see the charge state of charge of the lithium-ion battery from 9:00 until 18:00 for the day 1, day 3, day 5. Then, from 9:30 until 18:30 on the day 2, day 4, day 6. The table of the result and graph as shown below.

**Table 3: Charge voltage against times at 9:00 until 18:00 on day 1, day 3, day 5**

| Date | 1 | 3 | 5 |
|---|---|---|---|
| Time | Voltage Charge (V) | Voltage Charge (V) | Voltage Charge (V) |
| 9:00 | 11 | 8.3 | 8 |
| 10:00 | 12.2 | 9.7 | 9.5 |
| 11:00 | 12.4 | 11.5 | 10.7 |
| 12:00 | 12.42 | 11.8 | 11.3 |
| 13:00 | 12.5 | 12 | 11.5 |
| 14:00 | 12.7 | 12.1 | 11.9 |
| 15:00 | 12.75 | 12.2 | 12 |
| 16:00 | 12.75 | 12.2 | 12 |
| 17:00 | 12.76 | 12.2 | 12.1 |
| 18:00 | 12.77 | 12.1 | 12.2 |

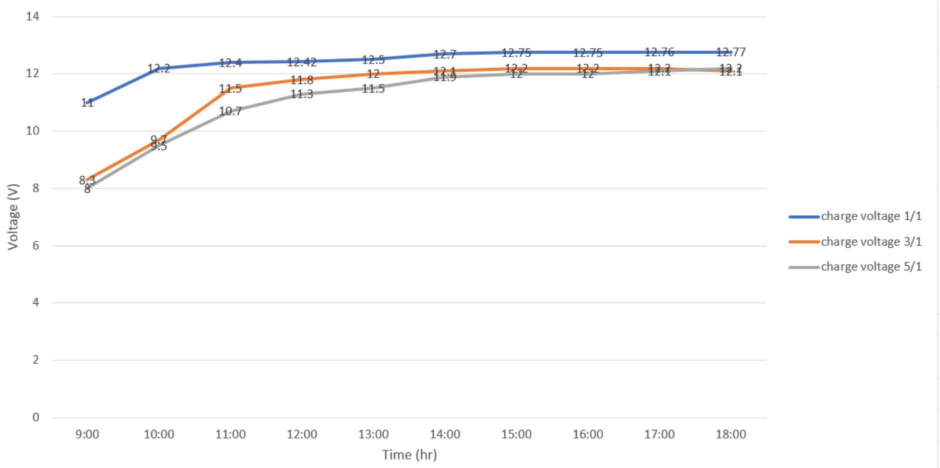


**Figure 4: Graph of charge voltage against times at 9:00 until 18:00 on day 1, day 3, day 5**

**Table 4: Charge voltage against times at 9:30 until 18:30 on day 2, day 4, day 6**

| Date | 2 | 4 | 6 |
|---|---|---|---|
| Time | Voltage Charge (V) | Voltage Charge (V) | Voltage Charge (V) |
| 9:30 | 10.79 | 9.7 | 8.5 |
| 10:30 | 11.35 | 10.1 | 9.3 |
| 11:30 | 11.5 | 11.1 | 10.1 |
| 12:30 | 11.9 | 11.5 | 11.2 |
| 13:30 | 12 | 11.5 | 11.7 |
| 14:30 | 12 | 11.7 | 12.2 |
| 15:30 | 12 | 12 | 12.2 |
| 16:30 | 12.1 | 12 | 12 |
| 17:30 | 12.2 | 12 | 12 |
| 18:30 | 12.2 | 12 | 12 |

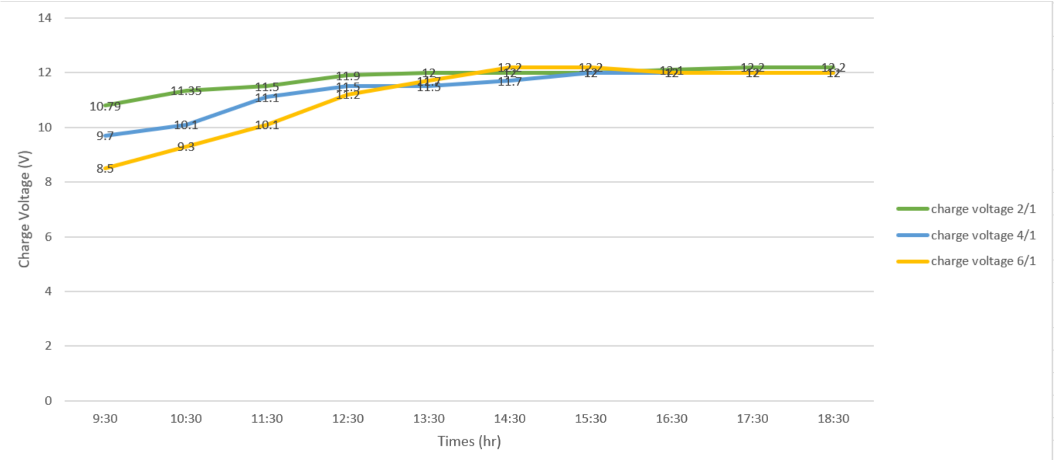


**Figure 5: Graph of charge voltage against times at 9:30 until 18:30 on day 2, day 4, day 6**

### 3.1.2 Condition B: Battery Discharging

The data for discharging of lithium-ion battery is recorded also about 4 hours per day in 6 days. The result of voltage and current were tabulated and graphs plotted to see the depth of discharge of the l lithium-ion battery from 19:00 until 22:00 for the day 1, day 3, day 5. Then, from 19:30 until 22:30 on the day 2, day 4, day 6. The table of the result and graph as shown below.

**Table 5: Discharge voltage against times at 9:00 until 18:00 on day 1, day 3, day 5**

| Date | 1 | 3 | 5 |
|---|---|---|---|
| Time | Voltage Discharge (V) | Voltage Discharge (V) | Voltage Discharge (V) |
| 19:00 | 12.5 | 12 | 12.3 |
| 20:00 | 11.9 | 11.6 | 11.6 |
| 21:00 | 11.3 | 11.2 | 11.4 |
| 22:00 | 9 | 8 | 8 |

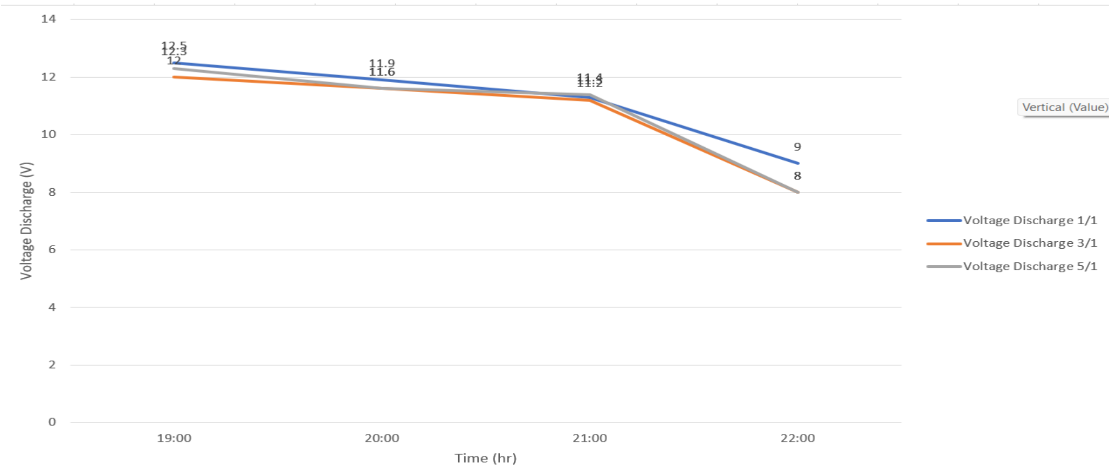


**Figure 6: Graph of discharge voltage against times at 9:00 until 18:00 on day 1, day 3, day 5**

**Table 6: Discharge voltage against times at 9:30 until 18:30 on day 2, day 4, day 6**

| Date | 2 | 4 | 6 |
|---|---|---|---|
| Time | Voltage Discharge (V) | Voltage Discharge (V) | Voltage Discharge (V) |
| 19:30 | 12.1 | 11.8 | 12 |
| 20:30 | 11.6 | 11.4 | 11.8 |
| 21:30 | 11.2 | 10.5 | 11.5 |
| 22:30 | 8 | 8 | 8 |

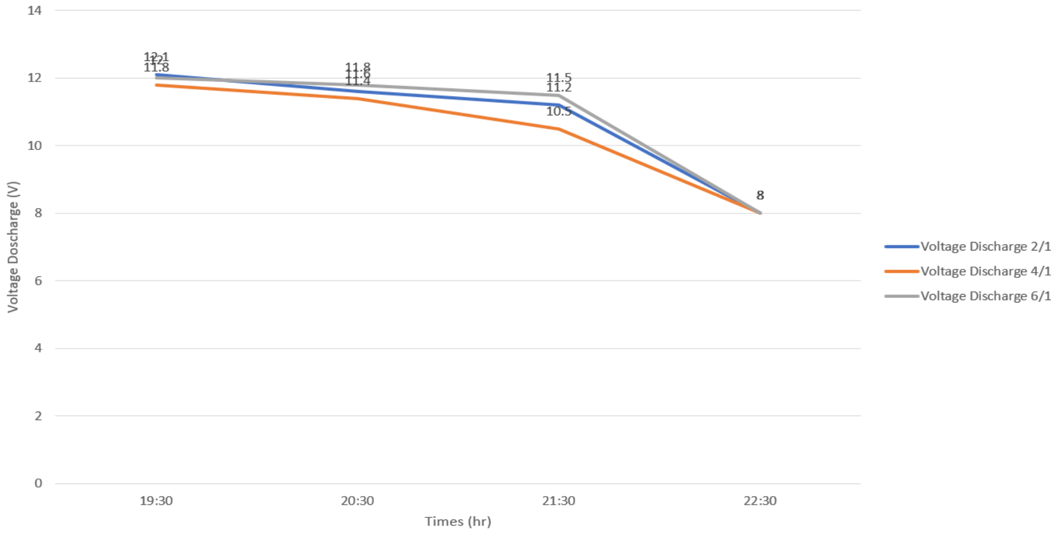


**Figure 7: Graph of discharge voltage against times at 9:30 until 18:30 on day 2, day 4, day 6**

### 3.1.3 Condition C: Ambient Temperature Condition

The ambient temperature condition was recorded by taking the temperature of panel and weather temperature every 10 hours. The data recorded divided to two sections, such as in day 1, day 3, day 5 are recorded by 9:00 until 18:00 and in day 2, day 4, day 6 are recorded by 9:30 until 18:30. The graph and table as shown below.

**Table 7: Temperature of solar panel compares to temperature of weather against time at 9:00 until 18:00 on day 1, day 3, day 5**

| Date | Day 1 | Day 1 | Day 3 | Day 3 | Day 5 | Day 5 |
|---|---|---|---|---|---|---|
| Time | Panel temp | Weather temp | Panel temp | Weather temp | Panel temp | Weather temp |
| 9:00 | 36 | 26 | 38.7 | 26 | 41.3 | 25 |
| 10:00 | 41.3 | 27 | 40.8 | 28 | 42.6 | 27 |
| 11:00 | 44.5 | 28 | 46 | 30 | 44.3 | 28 |
| 12:00 | 46.7 | 30 | 53 | 30 | 46.7 | 29 |
| 13:00 | 47.3 | 31 | 54 | 33 | 51.7 | 30 |
| 14:00 | 47.7 | 32 | 54.8 | 35 | 50.2 | 30 |
| 15:00 | 48.2 | 33 | 51.6 | 33 | 48.5 | 31 |
| 16:00 | 41.5 | 30 | 45.3 | 31 | 40.2 | 29 |
| 17:00 | 40.7 | 28 | 38.4 | 29 | 37.6 | 28 |
| 18:00 | 39.8 | 27 | 35.2 | 27 | 33.5 | 27 |

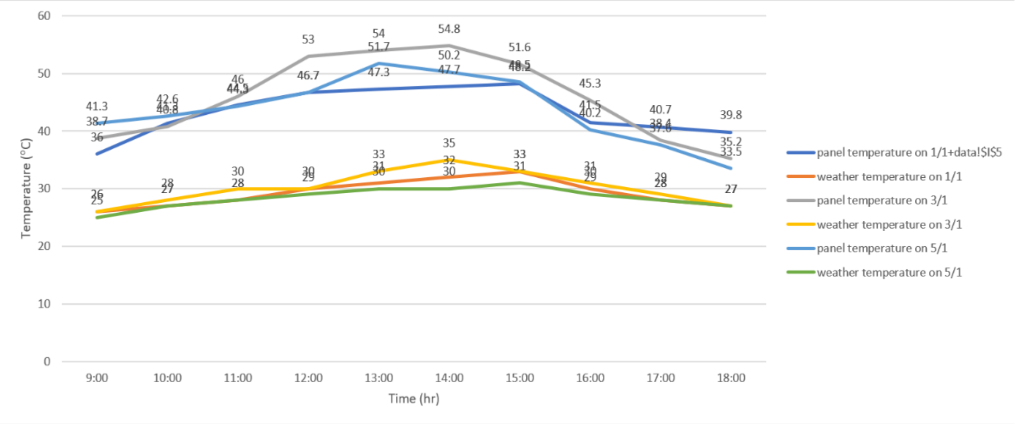


**Figure 8: Graph of temperature of solar panel compares to the temperature of weather against time at 9:00 until 18:00 on day 1, day 3, day 5**

**Table 8: Temperature of solar panel compares to the temperature of weather against time at 9:30 until 18:30 on day 2, day 4, day 6**

| Date | 2 | 2 | 4 | 4 | 6 | 6 |
|---|---|---|---|---|---|---|
| Time | Panel temp | Weather temp | Panel temp | Weather temp | Panel temp | Weather temp |
| 9:30 | 42.6 | 27 | 34.5 | 26 | 42.3 | 26 |
| 10:30 | 45.5 | 28 | 38.5 | 28 | 43.2 | 27 |
| 11:30 | 48.5 | 29 | 42.9 | 29 | 45.6 | 28 |
| 12:30 | 50.8 | 31 | 44.8 | 30 | 46.5 | 29 |
| 13:30 | 51.5 | 32 | 45 | 31 | 47.3 | 30 |
| 14:30 | 53.5 | 32 | 45 | 31 | 50.2 | 31 |
| 15:30 | 46.1 | 32 | 46 | 31 | 48.4 | 31 |
| 16:30 | 36.4 | 30 | 36.2 | 37 | 45.6 | 29 |
| 17:30 | 35.7 | 29 | 31.9 | 34 | 35.7 | 28 |
| 18:30 | 33 | 28 | 30 | 30 | 35.2 | 27 |

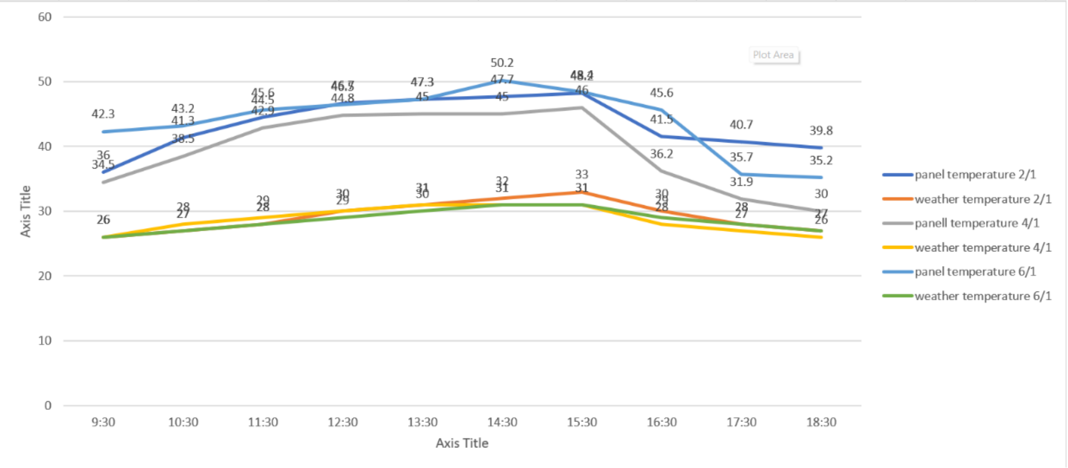


**Figure 9: Graph of temperature of solar panel compares to the temperature of weather against time at 9:30 until 18:30 on day 2, day 4, day 6**

This result shows that solar panel temperature will be a higher temperature than weather temperature. The temperature of the solar panel increases according to the weather temperature. The charging of a lithium-ion battery via a solar system can be affected by temperature. High temperatures can reduce battery capacity and lifespan, whereas low temperatures can increase internal resistance and reduce charging efficiency. To ensure optimal performance and longevity, lithium-ion batteries should be charged within a specific temperature range, typically between 0 and 45 degrees Celsius.

### 3.2 State of charge (SOC) Lithium-Ion battery vs Lead-Acid battery

The result below shows that lead-acid batteries can reach 13V, this is because the capacity of lead-acid batteries is bigger than lithium-ion batteries. The charge voltage against time is similar due to charge in the same time, place, solar panel temperature, and weather conditions. From the current charge against times, a lithium-ion battery seems more stable than a lead-acid battery.

**Table 9: Lithium-Ion voltage vs Lead-Acid voltage**

| Date | Lithium-Ion | Lead-Aid |
|---|---|---|
| Time | Voltage (V) | Voltage (V) |
| 9:30 | 10.79 | 10.8 |
| 10:30 | 11.35 | 12.9 |
| 11:30 | 11.5 | 12.8 |
| 12:30 | 11.9 | 13 |
| 13:30 | 12 | 12.7 |
| 14:30 | 12 | 12.8 |
| 15:30 | 12 | 12.7 |
| 16:30 | 12.1 | 12.7 |
| 17:30 | 12.2 | 12.8 |
| 18:30 | 12.2 | 12.6 |

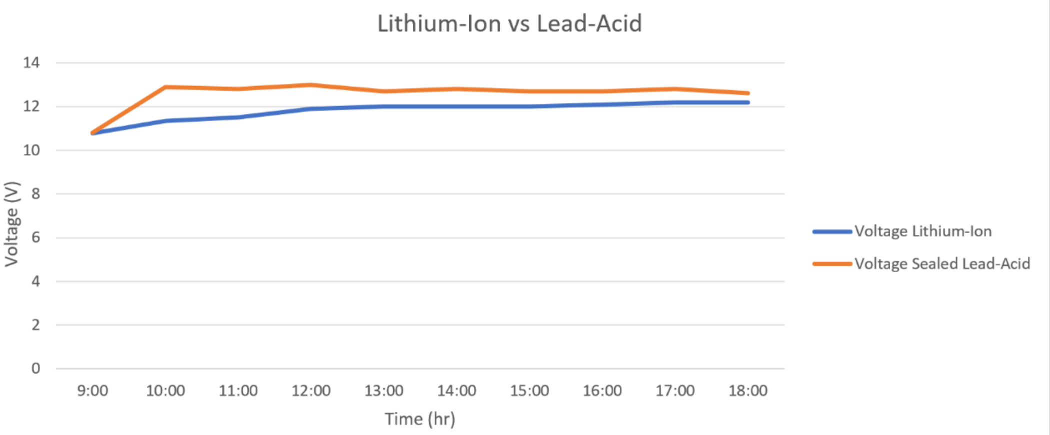


**Figure 10: Graph of Lithium-Ion voltage vs Lead-Acid voltage**

**Table 10: Lithium-Ion Current Vs Lead-Acid Current**

| Date | Lithium-Ion | Lead-Aid |
|---|---|---|
| Time | Current (A) | Current (A) |
| 9:30 | 1.1 | 1.4 |
| 10:30 | 1.2 | 1.21 |
| 11:30 | 1.2 | 1.5 |
| 12:30 | 1.1 | 1.5 |
| 13:30 | 1.2 | 1.2 |
| 14:30 | 1.3 | 1.61 |
| 15:30 | 1.4 | 1.13 |
| 16:30 | 1.23 | 1.4 |
| 17:30 | 1.25 | 1.3 |
| 18:30 | 1.26 | 1.52 |

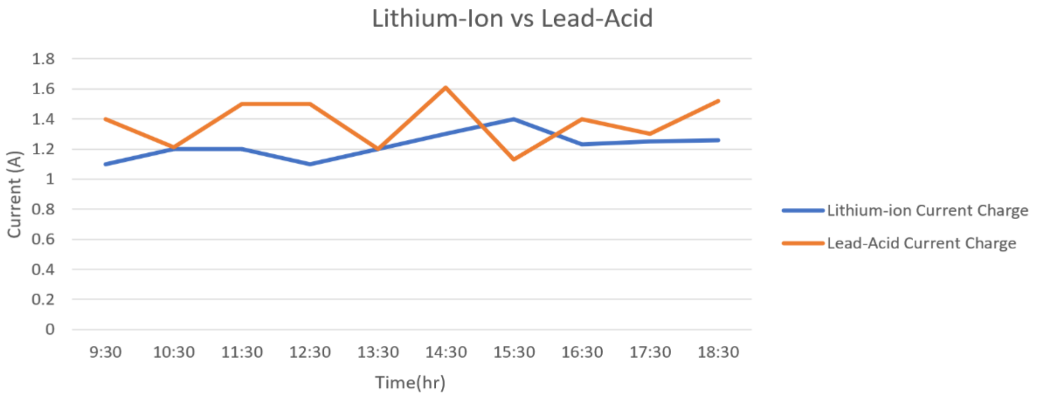


**Figure 11: Graph of Lithium-Ion Current vs Lead-Acid Current**

### 4.2 Depth of discharge (DOD) Lithium-Ion battery vs Lead-Acid battery

From result below shows that lead-acid batteries can drain faster than lithium-ion batteries. The lithium-ion battery can light up the bulb in 10W in 3 hours, such as 12V at 19:30, 11.6V at 10:30, and 11.2V at 21:30, when the voltage turns 8V at 22:30, the bulb and inverter were turned off. While lead-acid can light up the bulb of 10W only for 1 hour, such as 12.4V at 19:30, and when the voltage reaches 9.5V at 20:30 the bulb and inverter were turned off. Based on the comparison of the discharge current below, the lithium-ion battery can generate more energy better than lead-acid batteries. For example, lithium-ion current at 19:30, the current was 0.238A dropped to 0.125A at 20:30 and the current dropped from 0.065A to 0.045A at 21:30 to 22:30, while for lead-acid current dropped from 0.198A to 0.064A on 19:30 to 20:30 and from 0.051A to 0.029A on 21:30 to 22:30.

**Table 11: Lithium-ion discharge voltage vs Lead-acid discharge voltage**

| Date<br>Time | Lithium-Ion Discharge<br>Voltage (V) | Lead-Acid Discharge<br>Voltage (V) |
|---|---|---|
| 19:30 | 12 | 12.4 |
| 20:30 | 11.6 | 9.5 |
| 21:30 | 11.2 | 6.5 |
| 22:30 | 8 | 5.6 |

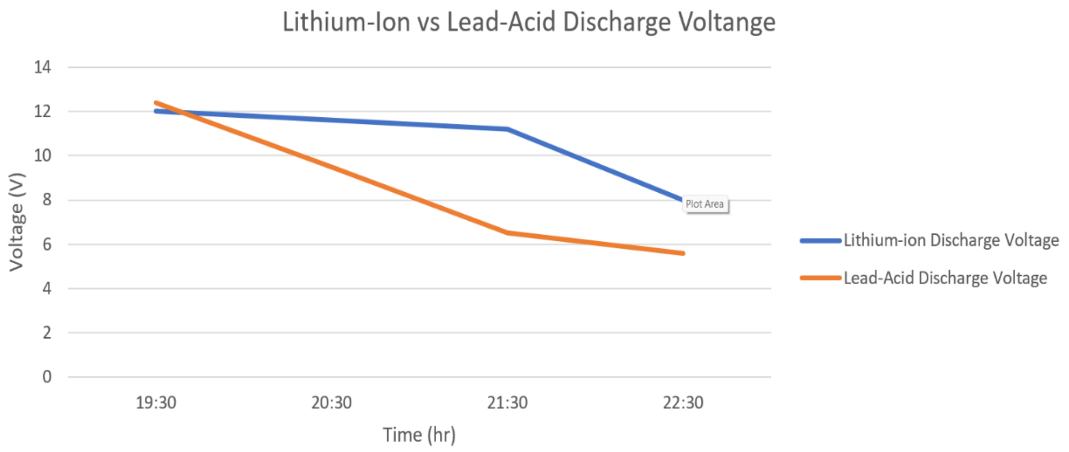


**Figure 12: Graph of Lithium-ion discharge voltage vs Lead-acid discharge voltage**

**Table 12: Lithium-ion discharge current vs Lead-acid discharge current**

| Date<br>Time | Lithium-Ion Discharge<br>Current (A) | Lead-Acid Discharge<br>Current (A) |
|---|---|---|
| 19:30 | 0.238 | 0.198 |
| 20:30 | 0.125 | 0.064 |
| 21:30 | 0.065 | 0.051 |
| 22:30 | 0.045 | 0.029 |

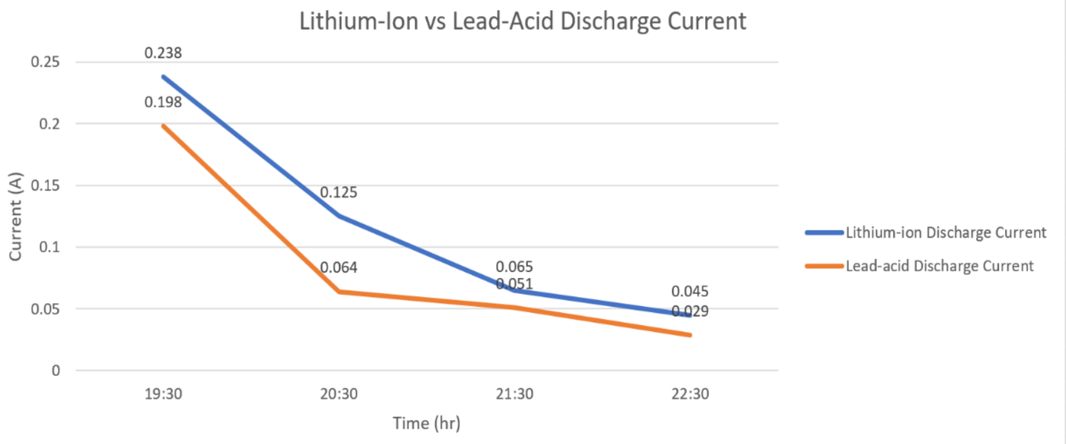


**Figure 13: Graph of Lithium-ion discharge current vs Lead-acid discharge current**

## 4. Conclusion

Based on the data collected, when the lithium-ion reaches full capacity, the voltage will reach 12V based on the solar charge controller. 12V can reach generally on 10:00 on day 1, 13:00 on day 3, 15:00 on day 5, 13:30 on day 2, 15:30 on day 4, 14:30 on day 6. Because the solar panel received great efficiency of energy from the sun. The weather that day was sunny and the temperature of the solar panel received the optimum temperature to perform well.

### 4.1 Recommendation and Future Work

The recommendation for future work is to create a solar tracking system. The solar tracking system can attain maximum light source from the solar panel. The more energy efficiency that is collected from the sun, the faster the state of charge for lithium-ion batteries.

## Acknowledgement

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