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Performance of Lead-Acid Battery for Off-Grid Solar System

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Abstract: The use of a storage device in applications using renewable energy plays a crucial role in ensuring effective functioning. In solar photovoltaic (PV) applications, a storage device is an essential component in order to continue supplying electricity to the load after the sun has set. In the course of this investigation, the information obtained from Lead-Acid type batteries will be evaluated in order to get a better understanding of such batteries' capabilities and performances, including the Depth of Discharge (DOD) and the State of Charge (SOC). If the performance of the battery can be improved, then not only will there be a notable decrease in the cost of the energy, but there will also be an increase in the system's level of dependability. A battery is required in a PV system in order to store the additional energy that is generated by the sun, which can then be released back into the system when it is required. To put it another way, to improve the performance of a system, we need to improve the performance of the battery. In this study, the factors that have been shown to have a significant influence in achieving optimal performance are analyzed. Temperature and load current are the two characteristics that have the most significant impact on the performance of the battery. It has been discovered that the capacity of the battery decreases when the discharge current is large, and that the opposite is true when the current is low.

Keywords: Performance of Lead-Acid Battery for Off-Grid Solar System, Sealed-Lead-Acid Battery, Lead-Acid Battery, Solar System

1. Introduction

Other than Lithium-Ion battery types, Lead-Acid batteries are the most common type of battery in solar systems. When compared to other battery types, lead-acid batteries have a long lifespan and affordable costs despite their low energy density, low efficiency, and high maintenance needs. As the most popular battery type for the majority of rechargeable battery applications (such as starting automobile engines), lead-acid batteries offer the distinct benefit of having a well-established, mature technical basis. In contrast to other battery types, lead-acid batteries have their own State of Charge

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(SoC) and Depth of Discharge (DoD). Each element also has a function and can affect how well the solar system functions. Terminal voltage and specific gravity are the two main methods for calculating the SoC for lead-acid batteries. Lead acid batteries should only be discharged by 50% for DoD purposes in order to prolong their life, which means that they should cycle between 100% and 50% [1].

Batteries are typically used in solar systems to store energy produced when the sun is shining. It is crucial to comprehend the particular needs of batteries while building a solar system. This includes being aware of how much energy will be lost while charging the batteries. Underestimating them results in unplanned load loss and the risk of damaging batteries due to a lack of supplying a periodic high state of charge, while overestimating them results in a larger PV array than is necessary. Battery charge efficiency is well known to be excellent (over 95%) at low charge levels but rapidly decreases as the battery gets closer to full charge. While there is general consensus that they fall off at higher stages of charge, actual battery charge efficiencies are occasionally stated as if they are linear across all levels of charge [2]. The ability to make educated judgements about battery capacity and daily depth of discharge would be made possible for solar system designers with the help of information on real charge efficiency as a function of state of charge (SoC) (DoD) [3].

There are four main objectives for this research which are to identify the properties and capabilities of lead acid type batteries on the solar system and study the effectiveness of Lead Acid type batteries on solar system. After that, to assess the level of charging and discharging of batteries using the solar system and the differences in the analysis of Lead-Acid type batteries with Lithium-Ion type batteries will be compared. In summary, using a larger battery (e.g., 300Ah) in a system with a daily load of 30Ah will keep the battery in a higher state of charge (90-100%) on average, but may require a larger solar array to compensate for increased charge efficiency losses. Lower charge rates result in better charge efficiency, so the larger battery will charge at a slower rate but may require more solar capacity. The appropriate solar array size should be determined based on the charge efficiency at the current charge rate [5].

According to [4], people nowadays want to save energy by using renewable energy as an alternative. Due to their low cost, lead-acid batteries are the most frequently used battery for solar systems, making them one of the best options for energy conservation. Although this varies from cycle to cycle, the maximum Depth of Discharge (DOD) for Lead-Acid batteries is typically at or below 50%. The DOD is important since adhering to it prolongs the battery's life. The nominal capacity of the batteries must be increased in order to prevent the requirement to discharge Lead-Acid batteries below 50% State of Charge (SOC) [6]. Depending on how quickly a battery was depleted, a lead-acid battery's capacity changes. Depending on the load, the life of a lead-acid battery can be three to four years. It's because Lead-Acid batteries need to cool off after charging because charging produces a lot of heat. Lead-Acid batteries are less effective at charging batteries other than solar batteries when using solar systems. Internal corrosion, sulfation, and electrolyte loss are three factors that contribute to a lack of effectiveness [8].

2. Materials and Methods

Throughout the project and development of the research performance of Lead-Acid battery for solar system, the project flowchart as shown in figure 1 is used to represent the overall workflow of the development process.

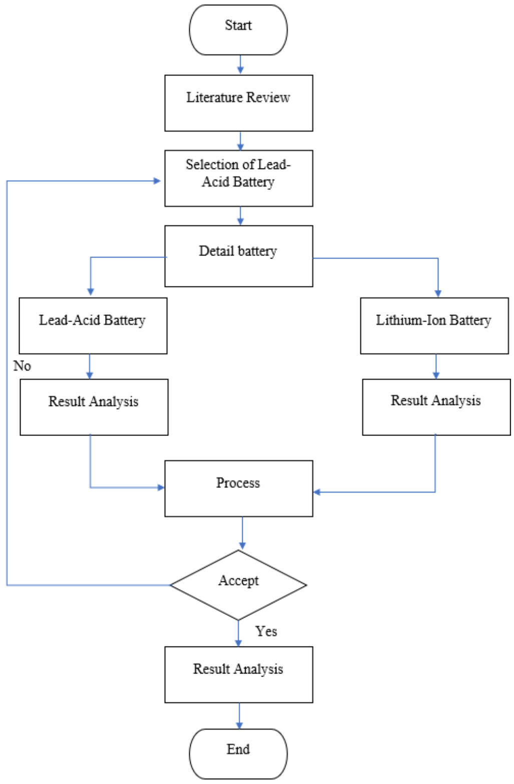

Figure 1: workflow of the development process

2.1 System Block Diagram

A block diagram is used to depict the operation or screen navigation of the entire system of research performance od Lead-Acid battery for off-grid solar system. Figure 2 depicts a simple block diagram of the solar panel, solar charge controller, inverter, Lead-Acid battery and output as a load.

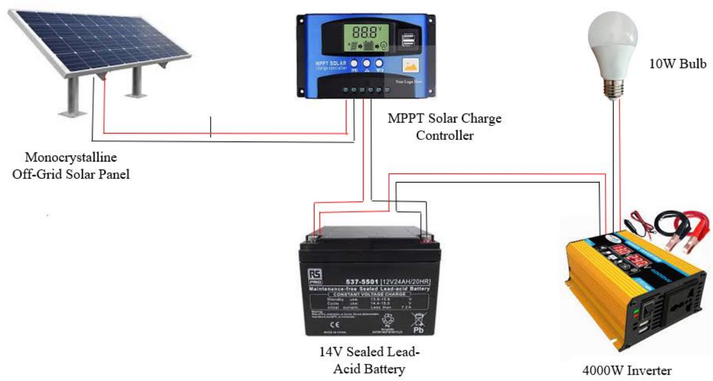

Figure 2: Simple system block diagram

Figure 2 displays the block diagram for the Research Performance of Lead-Acid Battery for Solar System, which entails solar panels using a charge controller to charge the battery. Energy loss is controlled by the charge controller. A controller, on the other hand, only functions when the SOC hits one of the extreme ends and has no impact on the discharge characteristics of a battery throughout its operational range. There are two output options: AC output and DC output. While the AC output comes via an inverter, the DC output is sent directly from the solar charger controller to the load.

The detail system block diagram is shown in the figure 2 above. The Sealed Lead-Acid battery was for charging and discharging process for this system because it can store a charging voltage which absorb by solar panel and discharging voltage which will use for load. The solar charge controller which is an electronic device that is used are connected to the off-grid solar panel and battery in order to optimize the power generated from a solar panel and charge a battery. The primary function of a solar charge controller is to monitor the voltage and current generated by the solar panel, and to adjust the electrical load on the panel to ensure that it is operating at its maximum power point. This can result in significant increases in the efficiency of the solar panel system, particularly in systems where the solar panel and battery are not located in close proximity to one another or where the voltage of the battery is different from the voltage of the solar panel. Furthermore, the battery also connected to the inverter is a device that converts direct current (DC) electricity into alternating current (AC) electricity. An inverter is capable of converting a DC power source, such as a battery, into an AC power source that can be used to power devices that use AC power, such as appliances, lights, and tools. The output of an inverter of AC power at a given moment in time, assuming that the DC input power is sufficient to support that level of output.

2.2 Monocrystalline Silicone Solar Panel (Mono-SI)

A 18W monocrystalline solar panel, also known as a Mono-SI panel, is a type of photovoltaic (PV) panel that uses monocrystalline silicon solar cells to convert sunlight into electricity. These cells are made from a single, continuous crystal of silicon, which gives them a higher efficiency than other types of solar cells, such as polycrystalline cells. Monocrystalline solar panels typically have a higher cost per watt than polycrystalline solar panels, but they are also more durable and have a longer lifespan [7].

These panels are often used in a variety of solar power applications, such as charging batteries for off-grid systems, powering remote telecommunication equipment, and providing electricity for homes and businesses. They are also widely used in outdoor solar powered appliances such as lamp and surveillance cameras. When combined in solar arrays, they can generate power on a larger scale [12].

The mentioned technology of diffused phosphorus on the surface, is a technique called 'emitter wrap through' (EWT) it helps to increase the overall efficiency of the panel and allows more light to be absorbed by the solar cells. As a result of it, more electricity is generated and power output increases [11].

2.3 100W MPPT Solar Charge Controller

One of the most crucial elements in the research is the solar controller. The 14V DC MPPT Solar Charge Controller with LCD display and 5V 2A USB output is the rating used for this component. An AC-DC converter called an MPPT charge controller increases a solar system's efficiency. By altering the voltage match between the batteries and solar panels, this is achieved. In the most effective and efficient way possible, this solar charger controller manages the energy flowing from the solar panel array and transfers it straight to the batteries. It will provide batteries the longest potential life. Charge controllers are becoming more common as energy storage technology develops and grows [4].

A 100W MPPT Solar Charge Controller is a device that regulates the charge of a battery bank using energy from a solar panel array with a maximum power point of 100 watts. It uses Maximum Power Point Tracking (MPPT) technology to optimize the amount of power captured from the solar panel and deliver it to the battery. This helps to ensure that the battery is charged efficiently and prevents overcharging or undercharging. The controller also includes safety features such as overcurrent and short circuit protection to ensure that the battery and solar panel are protected from damage [6].

2.4 Sealed Lead-Acid Battery

In this study, a single SLA battery unit will be utilized to provide voltage to the loads. While the common floating voltage range is 12.5V to 13.4V, the standard absorption voltage range for SLA batteries is 14.2 to 14.7V. This battery has many benefits over conventional Lead-Acid batteries because it doesn't require maintenance, which means that the electrolyte doesn't need to be topped out. SLA batteries are position-insensitive other from that. It's because we can put it wherever, whether it's high or low, unlike the conventional flooded Lead-Acid battery, which needs to remain upright at all times. A Sealed Lead-Acid battery may withstand 300 to 1200 cycles, depending on the kind. Actually, the answer depends on the battery's intended use, operating conditions, number of discharge cycles, and charging method [2].

The SLA battery typically self-discharges at a rate of 3.3% each month. Without being charged, it can be kept for up to six months, however this is not advised. To ensure that the remaining capacity is not used up and that sulfation doesn't take place, regular recharging is necessary. An unused SLA battery needs to be recharged every three months and kept in a cool, dry area with a temperature of no more than 75 degrees Fahrenheit (23 degrees Celsius) [5].

SLA batteries are often used as backup power sources for devices such as alarms, uninterruptible power supplies (UPS), and mobility scooters, and are also used in other applications such as golf carts, solar power systems, and backup generators. They have a relatively long lifespan and can be recharged multiple times, but they are less efficient than other types of batteries, such as lithium-ion batteries, and are more sensitive to temperature changes [3].

2.5 Pure Sine Wave Inverter

A 4000W Pure Sine Wave Inverter is a device that converts direct current (DC) electricity, which is typically stored in a battery, into alternating current (AC) electricity, which is the type of electricity that is used in most homes and buildings. The "4000W" rating refers to the maximum amount of power that the inverter can handle. This means that the inverter can supply up to 4000 watts of AC power at any given time [11].

Inverters are commonly used in a variety of applications, such as powering tools and appliances in vehicles, boats, and RVs, providing backup power during power outages, and powering remote equipment in locations where AC power is not available. The inverter is typically connected to the battery or batteries through wires, with the inverter rated for the highest amperage needed to power any given device. They can be connected in parallel or in series to get the desired voltage or power [6].

Inverters are also rated by their peak power, which is the highest amount of power they can supply for short periods of time. And also, they rated by their efficiency and they come in different designs, such as pure sine wave, modified sine wave and square wave. Pure sine wave inverters are more expensive but considered more efficient, clean and better for sensitive electronic devices compare to the other two types [9].

3. Results and Discussion

The outcomes and discussions from the expected result will be explained in this section. Figure will be used to provide a brief explanation of hardware development and system operation. When the battery is being charged or discharged, a reading of its voltage is made and stored. The Sealed Lead-Acid battery is often the key component on which to concentrate for this research after all the hardware has been assembled as shown in Figure 4.4. This study combines a sealed lead-acid battery with a solar system that includes a monocrystalline off-grid solar panel, a 4000W inverter, an MPPT solar charge controller, and a 10W bulb as a load. The 14V Sealed Lead-Acid Rechargeable Battery's voltage and current readings were recorded after six days of system operation observation.

Four different conditions have been noted. The voltage of a rechargeable 14V Sealed Lead-Acid battery when it is being charged with current during the day. The voltage of a rechargeable 14V Sealed Lead-Acid battery when it is being discharged with current flow is the second factor, and the ambient temperature condition is the third.

3.1 Analysis and Discussion for Charging and Discharging Voltage

3.1.1Battery Charging and Current Flow

The information was gathered for the battery charge over the course of around 10 hours, and the findings are displayed below. The data displays the battery voltage and current generated by solar panels between 9.00 p.m. and 6.00 p.m. on January 1, 3, and 5, 2023, and between 9.30 a.m. and 6.00 p.m. on January 2, 4, and 6. Due to the startlingly sunny weather on January 1, 2023, the voltage progressively increased till noon. Due to the sudden downpour of rain, the voltage drops slightly between Day 1 and Day 2 in the afternoon. Due to the cloud cover, battery voltage fluctuates slightly throughout the afternoon. At 5:00 p.m. that day, the highest voltage input is 13.52V. Other than that, when the battery is being charged by a solar panel, the current pattern gradually increases over time. The day's largest current gain was 1.61A at 2 PM, while the lowest was 1.2A at 1 PM.

According to Table 1, the third and fifth days' voltage charging on the battery increased gradually, and the information gathered from the voltage charging is nearly same on both days because of the cloudy weather from 9.00am to 11.00am. Because some of the sunlight cannot reach the solar panel's surface when it is cloudy, it is harder to see the sun when it is present. Because some of the sunlight has been reflected or absorbed by the clouds, the sunlight that does reach the surface of the solar panel on a cloudy day tends to be redder or orange in colour and seems less bright. Between the hours of 12 a.m. and 4 p.m. at that time, the solar charge controller charged the battery up to the regular pace; the maximum charging voltages were 13.3V on the third day and 13.1V on the fifth. According to Table 3, the pattern of change for the current input throughout those three days is a modest increase and drop between the range of 1.11A to 1.7A.

Table 1: Voltage reading during the charging state for Day 1, Day 3 and Day 5

Time, t	Voltage Day 1 (V)	Voltage Day 3 (V)	Voltage Day 5 (V)
9.00a.m	8.45	7.1	7.5
10.00a.m	12.7	8.4	9.9
11.00a.m	12.7	10.2	11.4
12.00p.m	12.9	12.7	12.8
1.00p.m	13.35	13.3	12.7
2.00p.m	12.4	12.8	13.1
3.00p.m	13.5	12.9	12.7
4.00p.m	13.26	12.6	12.3
5.00p.m	13.52	12.9	12.9
6.00p.m	13.2	12.5	12.6

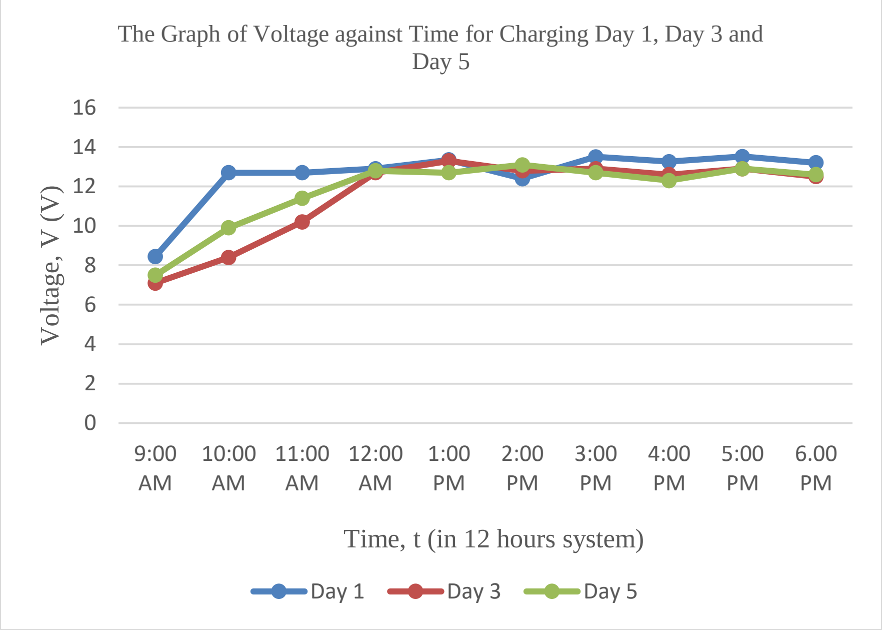

Figure 3: The Graph of Voltage against Time for Charging Day 1, Day 3 and Day 5

Table 2: Current reading during the charging state for Day 1, Day 3 and Day 5.

Time, t	Current Day 1 (A)	Current Day 3 (A)	Current Day 5 (A)
9.00a.m	1.4	1.5	1.11
10.00a.m	1.21	1.6	1.3
11.00a.m	1.5	1.5	1.3
12.00p.m	1.5	1.7	1.28
1.00p.m	1.2	1.7	1.4
2.00p.m	1.61	1.6	1.5
3.00p.m	1.13	1.6	1.4
4.00p.m	1.4	1.6	1.6
5.00p.m	1.3	1.4	1.42
6.00p.m	1.52	1.2	1.38

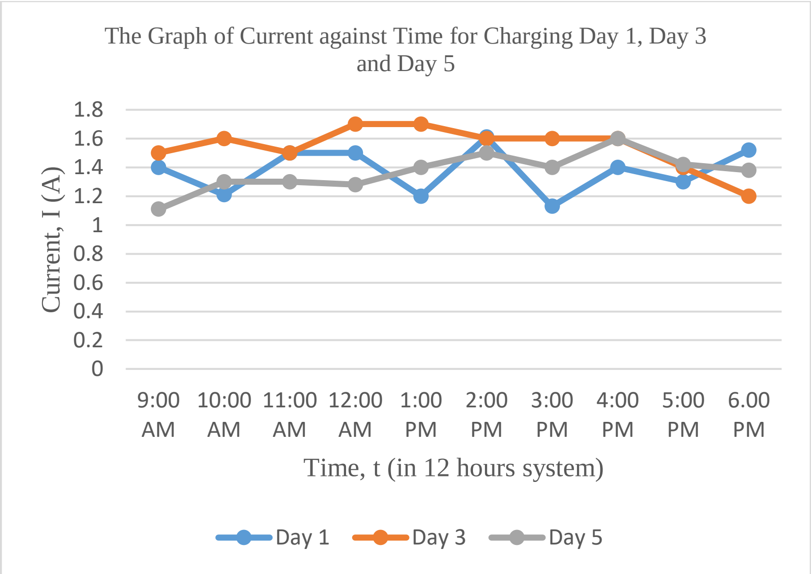

Figure 4: The Graph of Current against Time for Charging Day 1, Day 3 and Day 5.

The data collected on the second, fourth, and sixth day was taken from 9:30am to 6:30pm to observe the solar system's performance under different weather conditions, at different tim, and as the battery ages. This can give a better understanding of the overall performance of the system, including how it performs during sunny and cloudy weather, how it performs during different seasons, and how it performs as the battery ages. Additionally, it can show how the system performs under different loads at different times of day. On the second day, the weather was clear and sunny, which allowed for quick charging of the battery. The charging voltage on the battery started at 10.8V and increased sharply to 12.9V at 10.30am. Throughout the day, the charging voltage slightly increased and decreased until 6.30pm. The peak input current for the day was 1.6A, and the pattern of the current was slightly decreasing and increasing in correlation with the voltage charging.

The fourth day's weather started off overcast, remaining that way until 10:30am. The weather then became sunny and remained that way until the evening, causing the voltage charge to stay consistent as stated in Figure 5 below. At 5:30pm, the temperature increased, and the current input for that day did not change much and slightly decreased in the evening as sunlight became less visible starting at 4:30pm. On the sixth and final day of data collecting, the weather remained overcast and rainy until 1:30pm, resulting in a gradual increase in the battery's charging voltage. The current input which stated on Table 4 was slightly increased from 9:30am to 12:30pm, and drastically increased to a peak of 1.5A at 2:30pm. The increase in charging voltage led to an increase in current flowing into the battery, as per Ohm's law, but once the battery becomes fully charged, the current flowing into the battery will decrease, even if the charging voltage is still high.

Table 3: Voltage reading during the charging state for Day 2, Day 4 and Day 6.

Time, t	Voltage Day 2 (V)	Voltage Day 4 (V)	Voltage Day 6 (V)
9.30a.m	10.8	8.2	7.2
10.30a.m	12.9	10.4	8.5
11.30a.m	12.8	13.3	9.7
12.30p.m	13	13.2	9.9
1.30p.m	12.7	13.0	10.3
2.30p.m	12.8	12.9	12.9
3.30p.m	12.7	12.9	12.5
4.30p.m	12.7	13.3	12.6
5.30p.m	12.8	13.9	12.7
6.30p.m	12.6	12.5	12.3

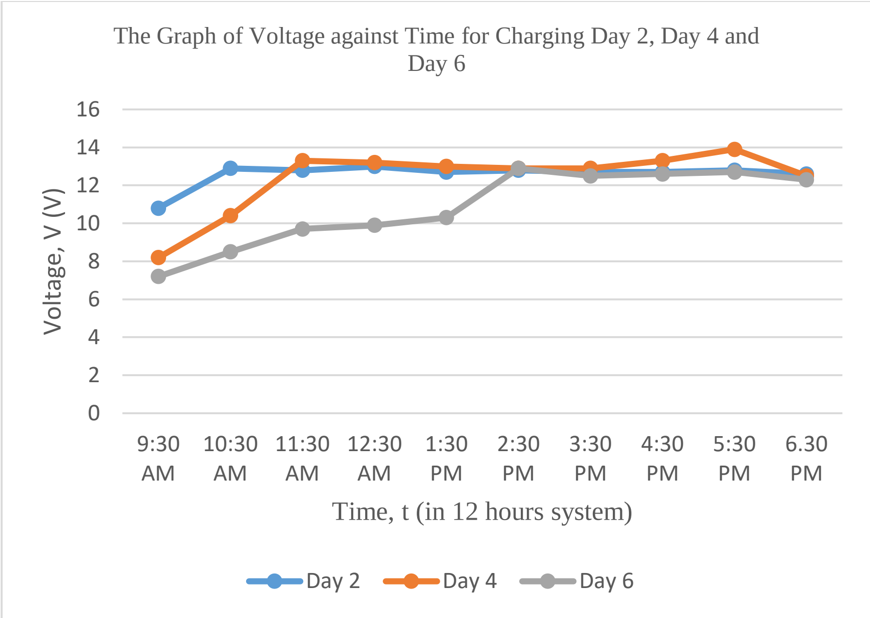

Figure 5: The Graph of Voltage against Time for Charging Day 2, Day 4 and Day 6.

Table 4: Current reading during the charging state for Day 2, Day 4 and Day 6

Time, t	Current Day 2 (A)	Current Day 4 (A)	Current Day 6 (A)
9.30a.m	1.3	1.4	0.9
10.30a.m	1.6	1.4	1.13
11.30a.m	1.41	1.5	1.2
12.30p.m	1.5	1.5	1.1
1.30p.m	1.3	1.4	1.1
2.30p.m	1.4	1.4	1.5
3.30p.m	1.4	1.3	1.34
4.30p.m	1.17	1.3	1.55
5.30p.m	1.21	1.1	1.4
6.30p.m	1.23	1.0	1.46

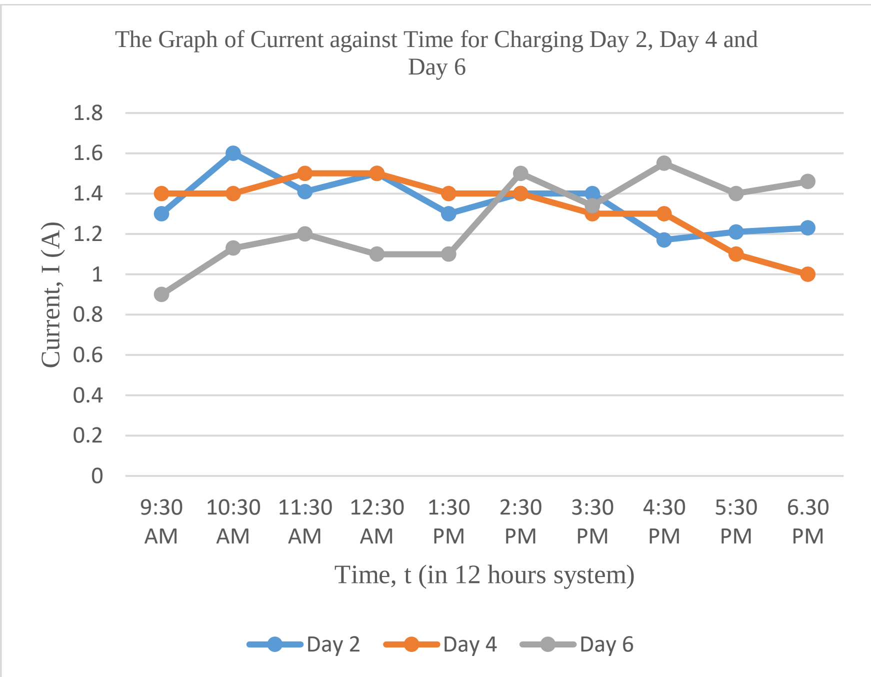

Figure 6: The Graph of Current against Time for Charging Day 2, Day 4 and Day 6

3.1.2 Battery Discharging and Current Flow

A 14V Sealed Lead-Acid battery is a common and relatively inexpensive type of rechargeable battery used in solar power systems, it has a long service life. It releases stored energy in the form of electrical current when discharging, which happens when connected to a load, in this research case, a 10W lamp. The current flow in a solar power system depends on the size of the load and the capacity of the battery. As the battery discharges, the voltage of the battery will drop. This rate of drop depends on the size of the load and the capacity of the battery. The larger the load or the smaller the capacity of the battery, the faster the voltage will drop. Once the voltage drops below a certain level, the load may not function properly and the battery will need to be recharged.

The data was collected for four hours on six days during the battery's discharging process. On the first, third, and fifth days, data was collected from 7:00pm to 10:00pm, while on the second, fourth, and sixth days data was collected from 7:30pm to 10:30pm. The results from the first, third, and fifth days are recorded in Table 4.5 and Table 4.6. The discharging process was done to observe the battery's durability when connected to a 10W lamp as a load. The voltage drop pattern on the first and third days is similar, with a drastic decrease from 12.3V to 6.3V on day 1 and 12.4V to 5.6V on day 3. On day 5, the discharging voltage drops slowly from 7:00pm to 9:00pm and drastically decreases at 10:00pm, the last data point for discharge.

According to Figure 4.9, the current output on the first, third and fifth days is slightly different. On day 1, the starting current output is 0.07A and drops over time, with the last reading of 0.035A. The current output on day 3 drops drastically compared to day 1 and day 5. The starting current is 0.084A and drops to 0.021A at 10:00pm. The difference in current output on different days can be due to environmental factors such as temperature and humidity, which can affect the battery's performance. If the temperature or humidity was significantly different on the three days when the data was taken, it could lead to a difference in the current output.

Table 5: Voltage reading during the discharging state for Day 1, Day 3 and Day 5.

Time, t	Voltage Day 1 (V)	Voltage Day 3 (V)	Voltage Day 5 (V)
7.00a.m	12.3	12.4	12.6
8.00a.m	9.4	9.5	10.1
9.00a.m	7.1	6.5	9.4
10.00p.m	6.3	5.6	6.1

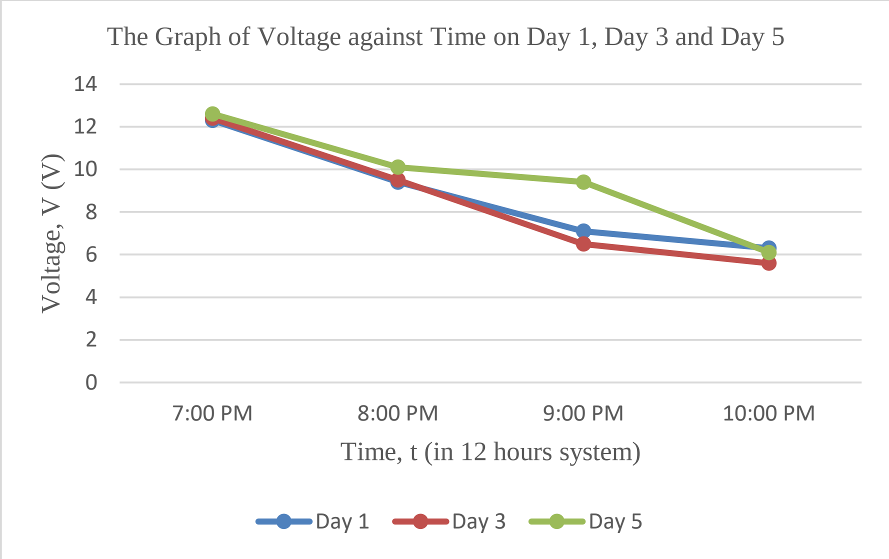

Figure 7: The graph voltage against time for discharging Day 1, Day 3 and Day 5

Table 6: Current reading during the discharging state for Day 1, Day 3 and Day 5

Time, t	Current Day 1 (A)	Current Day 3 (A)	Current Day 5 (A)
7.00a.m	0.07	0.084	0.085
8.00a.m	0.057	0.061	0.054
9.00a.m	0.049	0.045	0.047
10.00p.m	0.035	0.021	0.032

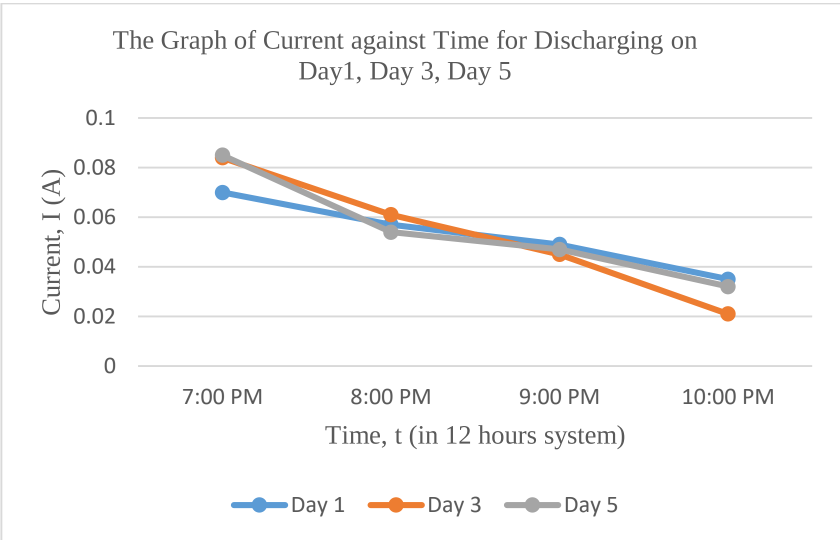

Figure 8: The graph current against time for discharging Day 1, Day 3 and Day 5.

The data in Table 4.8 shows the voltage of the battery at different times on three different days, with time on the x-axis and voltage on the y-axis. Day 4 has the highest battery voltage value because the weather was sunny and it allowed the solar panels to absorb more sunlight during charging. However, the voltage dropped excessively from 7:30pm to 8:30pm, from 12.7V to 8.1V, and the pattern of dropping was similar to day 2. On day 6, the voltage dropped linearly from 7:30pm to 10:30pm, from 12.4V to 5.3V. Overall, the data shows that the voltage of the battery decreases over time, and that there are some differences in the voltage measurements taken on different days.

Table 7: Voltage reading during the discharging state for Day 2, Day 4 and Day 6.

Time, t	Voltage Day 2 (V)	Voltage Day 4 (V)	Voltage Day 6 (A)
7.30a.m	12.2	12.7	12.4
8.30a.m	7.4	8.1	10.2
9.30a.m	6.0	6.0	8.2
10.30a.m	5.1	5.6	5.3

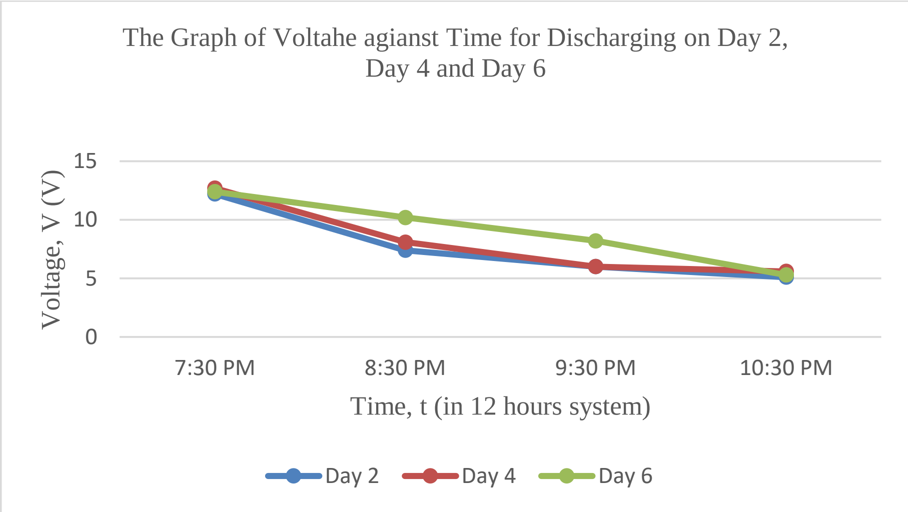

Figure 9: The graph voltage against time for discharging Day 2, Day 4 and Day 6.

Table 4.9 shows the current at various times over the course of day 2, day 4 and day 6 which collected from 7.30pm until 10.30pm. On day 2, the current was highest at 7.30pm at 0.198A and decreased later. On day 4, the current was lowest at 7.30pm at 0.128A and decreased later. On day 6, the current was consistently higher than day 2 and day 4, with a peak at 8.30pm at 0.086A. Overall, the data suggests that the current may vary based on the time of day and day of the week. The current output dropping pattern is similar from 7.30pm until 10.30pm. Other factors such as the state of charge of the battery or the discharge rate might contribute to the difference in the current output of a battery when data is taken on different days.

Table 8: Current reading during the discharging state for Day 2, Day 4 and Day 6.

Time, t	Current Day 2 (A)	Current Day 4 (A)	Current Day 6 (A)
7.30a.m	0.198	0.128	0.151
8.30a.m	0.064	0.069	0.086
9.30a.m	0.051	0.051	0.067
10.30a.m	0.029	0.042	0.034

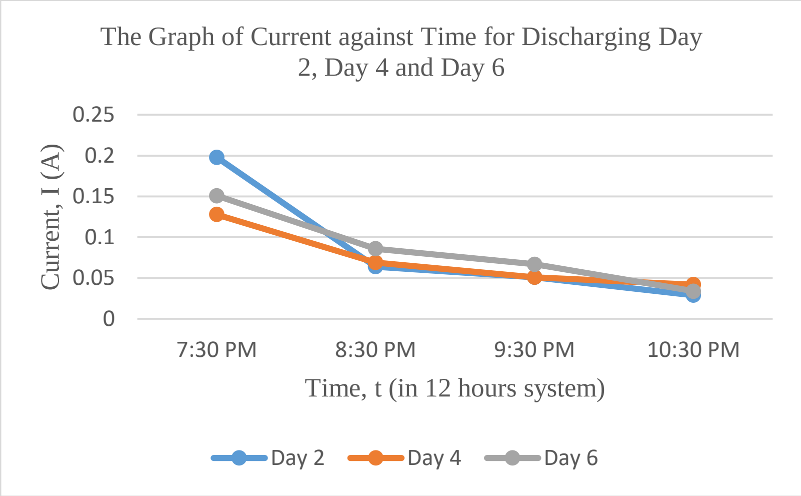

Figure 10: The graph current against time for discharging Day 2, Day 4 and Day 6.

3.2 Temperature Condition on Solar Panel

The information in this part was gathered to compare how well the system performed on the two days with the most extreme weather which is the hottest day and the coldest day. Between the six days in the data set, day 3 is the hottest, and day 6 is the coldest day with the least amount of visible sunlight. Anyone may comprehend how well the system functions in various weather circumstances by comparing the system's performance on these two days. They can also spot any potential areas for improvement.

3.2.1Temperature Condition on Solar Panel on Sunny Day

On day 3, the sun was visible and the weather was sunny beginning at 9:00 a.m. Based on the information in Table 4.10, the solar panel's temperature climbed from 2.00 PM, when it went from 29°C to 40°C, then from 41.3°C to 55.3°C after that. After that, the weather begins to cool off at 3 p.m. and continues to do so until 6 p.m. as a result of the weather being darker and less hot, which also lowers the temperature on the solar panel. Figure 11 shows the pattern of the temperature of the weather and the solar panel rising and falling. As a result, the charging voltage will be lower than it would be during the day. The ambient temperature of the area around a solar panel directly affects its temperature. The solar panel will be warmer when the temperature is higher and cooler when the temperature is lower. The reason for this connection is that solar panels are made to take in energy in the form of sunshine. Solar panels become heated as the sun's rays strike them. The solar panel will absorb more heat and heat up at a higher temperature when the ambient temperature rises.

Table 9: The temperature reading for weather and solar panel on day 3.

Time, t	Weather Temperature (°C)	Solar Panel Temperature (°C)
9.00a.m	29	41.3
10.00a.m	31	41.3
11.00a.m	32	45.5
12.00p.m	35	51.6
1.00p.m	38	53.4
2.00p.m	40	55.3
3.00p.m	36	48.5
4.00p.m	33	35.5
5.00p.m	31	32.9
6.00p.m	29	31.6

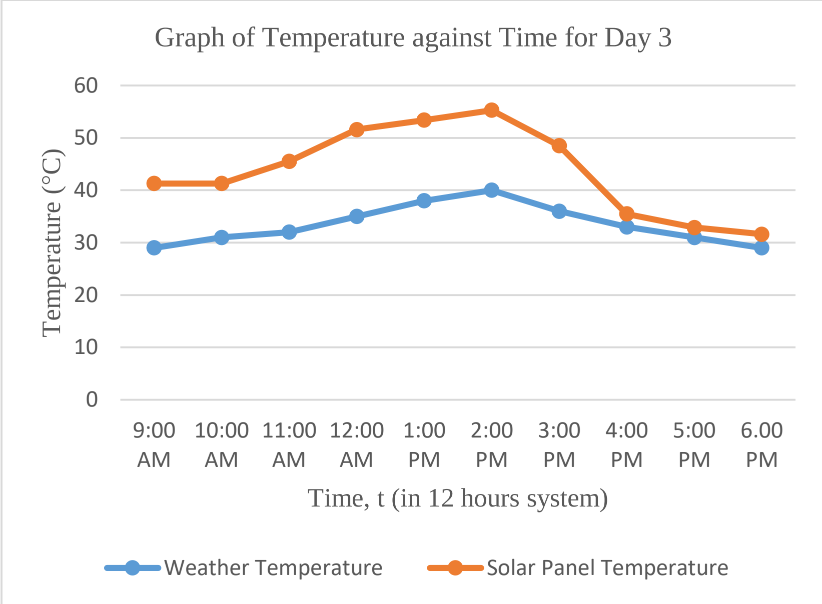

Figure 11: The graph of temperature against time for day 3.

3.2.2Temperature Condition on Solar Panel on Cloudy and Rainy Day

Data on a battery's charging voltage was gathered over the period of six days. It was noted that the weather on the sixth day was unsuitable for the charging procedure. When the initial data reading was taken in the early morning hours, it had already started to rain, and the bad weather continued all day. The rain and clouds can obstruct the sun's beams and lower the amount of solar energy that the panel can absorb, making this type of weather unsuitable for charging batteries. As a result, charging might go more slowly and ineffectively. It is generally better to charge a battery on days with clear, sunny weather, as this allows the solar panel to absorb more energy and charge the battery more quickly.

From 9.30 a.m. to 1.30 p.m. on Day 6, the weather was gloomy and damp, which made it impossible to see the sun and decreased the battery's rate of charge. The results in Table 10 show that over the first four hours, the solar panel temperature grew from 41.3°C to 51.6°C whereas the outside temperature only marginally increased, rising from 29°C to 35°C. The weather then turns sunny and hotter, which raises the temperature of the solar panel while the weather temperature begins to fall from its greatest value between 12.30 and 5.30 p.m. The rising and falling pattern of the solar panel temperature is depicted in Figure 12. Solar panels perform better in warmer climates as they absorb more heat and produce more electricity but can overheat and reduce performance and lifespan for the battery. To prevent this, cooling mechanisms such as air vents or fans are often used.

Table 10: The temperature reading for weather and solar panel on day 6.

Time, t	Weather Temperature (°C)	Solar Panel Temperature (°C)
9.00a.m	29	41.3
10.00a.m	31	41.3
11.00a.m	32	45.5
12.00p.m	35	51.6
1.00p.m	38	53.4
2.00p.m	40	55.3
3.00p.m	36	48.5
4.00p.m	33	35.5
5.00p.m	31	32.9
6.00p.m	29	31.6

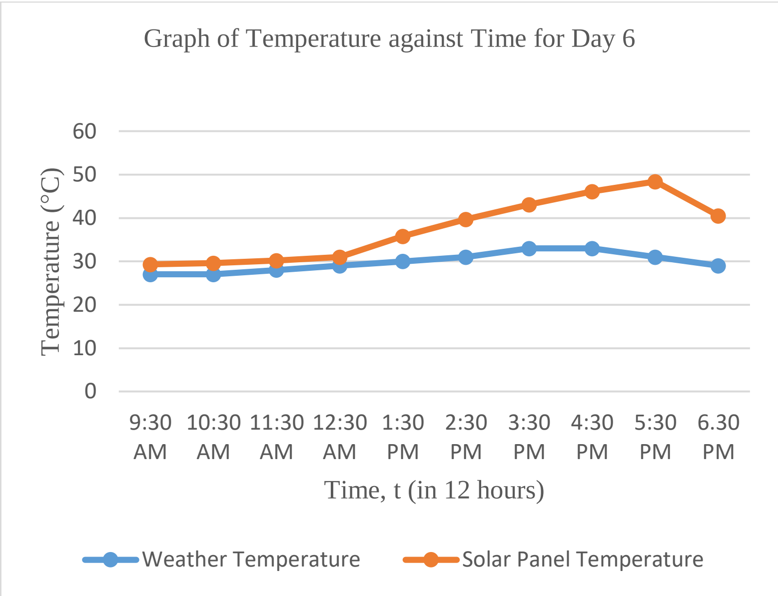

Figure 12: The graph of temperature against time for day 6.

4. Conclusion

Numerous efforts and sacrifices have been made throughout the course of this undertaking. The Performance of Lead-Acid Battery for Off-Grid Solar System is the name of the study. This study used an off-grid solar system to measure the battery's charging and discharging voltages and estimate the status of charging and depth of drain for sealed lead-acid batteries. This project references different publications and papers to fulfill its aim. The findings of previous studies are presented and comparisons are made. The positives and negatives of the topic are enumerated to make the information more accessible. Each completed project in the past has had both positive and negative aspects, and a discussion paper was drafted for each one. The project also discusses various software and hardware developed during the initial project.

This research study in Chapter 3 includes construction of a research flowchart, hardware study, and 3D modeling. It provides details on the items used during the project and includes a discussion and conclusion for each item. Chapter 4 includes data collection of a battery connected to a solar system, an analysis of the performance of a Sealed Lead-Acid battery and a comparison against a Lithium-Ion battery. The infrared thermometer and multimeter were used as measurement instruments to measure solar panel temperature and voltage charge and discharge for the battery, and the outcomes were documented as a result of the finished research.

The research objectives were met through hardware simulation tests and the performance of Sealed Lead-Acid battery was found to be as expected. The battery was thoroughly tested for charging and discharging over six days, and the solar system, with proper circuit connections, activated based on preference using the Sealed Lead-Acid battery to store charging and discharging voltage. The test results showed that the battery capacity depleted in around 10 hours of data collection while charging and 4 hours while discharging voltage operations.

4.1 Recommendations

A few issues were discovered whilst this research was being conducted. The predicted outcomes from the theory are not quite accurate enough to be taken as dependable in comparison to the actual experiment. The fixed location of the solar panels, which do not follow the path of the sun, is one of the causes. As a result, the battery receives energy at a lower pace than it might. Get a solar sun tracker to make sure the solar panel always follows the path in order to solve this problem.

4.2 Comparison between Sealed Lead-Acid Battery and Lithium-Ion Battery on Off-Grid Solar System.

4.2.1Comparison between Sealed Lead-Acid Battery and Lithium-Ion Battery during Charging Voltage

Lithium-ion batteries are more sensitive to sunlight and are able to start charging when the sun's rays are detected, even if the light is not very bright. This suggests that the lithium-ion battery may be more efficient and effective in charging from a solar panel system, at least under the conditions tested on day 1.

Table 11: The reading of charging voltage for Sealed Lead-Acid battery and Lithium-Ion battery on day 1.

Time	Charging Voltage for Sealed Lead-Acid Battery (V)	Charging Voltage for Lithium-Ion Battery (V)
9.00a.m	8.45	11.0
10.00a.m	12.7	12.9
11.00a.m	12.7	13.1
12.00p.m	12.9	13.42
1.00p.m	13.35	13.61
2.00p.m	12.4	13.55
3.00p.m	13.5	13.71
4.00p.m	13.26	13.69
5.00p.m	13.52	13.65
6.00p.m	13.2	13.67

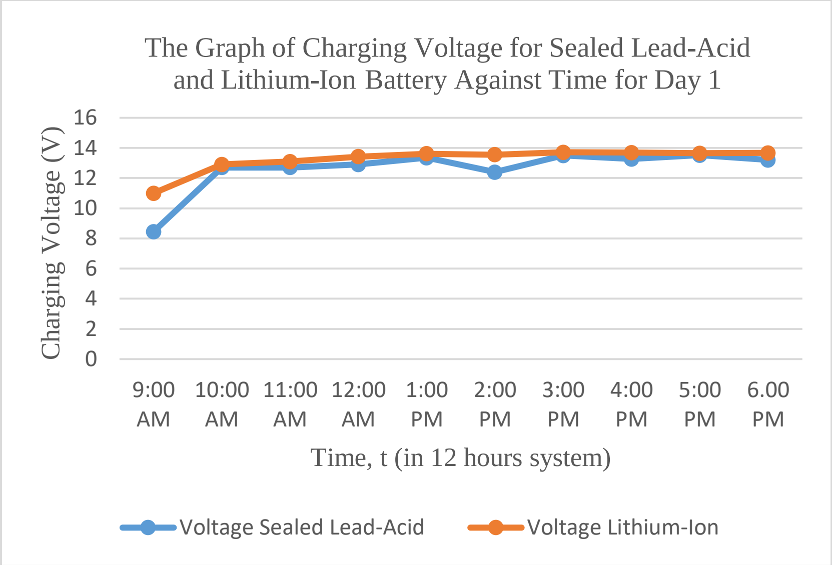

Figure 13: The graph of charging voltage for Sealed Lead-Acid and Lithium-Ion battery against time for day 1.

4.2.2Comparison between Sealed Lead-Acid Battery and Lithium-Ion Battery during Discharging Voltage

A few issues were discovered whilst this research was being conducted. The predicted outcomes from the theory are not quite accurate enough to be taken as dependable in comparison to the actual experiment. The fixed location of the solar panels, which do not follow the path of the sun, is one of the causes. As a result, the battery receives energy at a lower pace than it might. Get a solar sun tracker to make sure the solar panel always follows the path in order to solve this problem.

Table 12: The reading of discharging voltage for Sealed Lead-Acid battery and Lithium-Ion battery on day 1

Time	Charging Voltage for Sealed Lead-Acid Battery (V)	Charging Voltage for Lithium-Ion Battery (V)
7.00p.m	12.3	12.5
8.00p.m	9.4	11.9
9.00p.m	7.1	11.3
10.00p.m	6.3	9

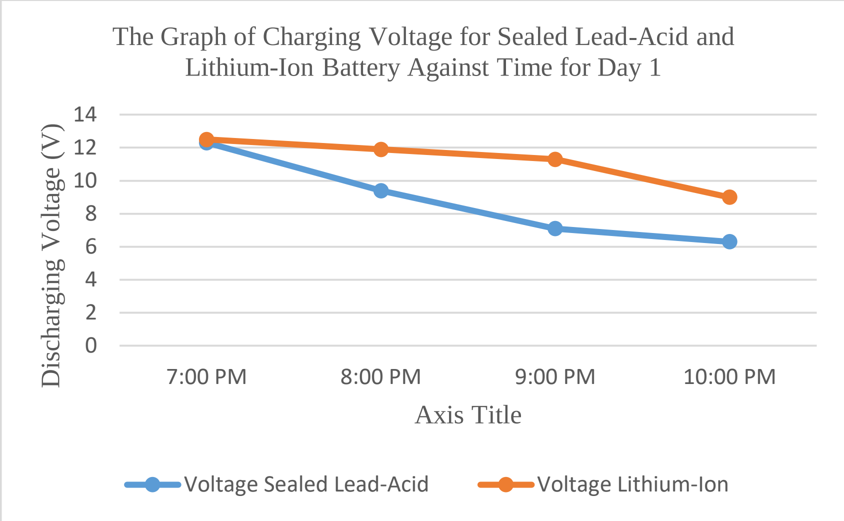

Figure 14: The graph of charging voltage for Sealed Lead-Acid and Lithium-Ion battery against time for day 1.

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