Paper Neutrino

by Kurriawan Pranata

SOC (STATE of CHARGE) THREE-CELL LEAD DYNAMIC BATTERY MODEL

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ABSTRACT

The 3-cell dynamic lead acid battery as the latest development of conventional secondary batteries has been successfully manufactured and carried out by 10 cycles of charge-discharge treatment with a variety of state of charge (SOC) 100% (Fullcharge 5100 mAh), 50% (2550 mAh), 25% (1275 mAh) and discharge current of 0.8 A. The purpose of this experiment was to analyze the treatment of SOC conditions on the performance of the three-cell lead acid dynamic battery. The 10-cycle cyclicality test was carried out using a Battery Management System (BMS) by applying an electric current of charging 1 A and discharging 0.8A. The results of the experiment through the treatment of the SOC charging conditions of 100%, 50%, 25% respectively gave a difference in the value of voltage efficiency of 84%, 87%, 88%, capacity efficiency values of 84%, 80%, 69%, energy efficiency values of 70%, 70%, 62%. Based on these results, the 100% and 50% SOC treatments showed better performance performance and battery energy than the 25% SOC treatment. This can be used as a recommendation that the designed battery can be used periodically even though the charging condition does not reach full charge. However, if the battery is charged less than 50%, the battery is designed to give poor performance.

Keywords: Lead acid battery, State of charge, Discharge current, Efficiency

Introduction

The need for electrical energy in Indonesia is estimated to continue to increase from year to year. Based on the projection results of PLN, the number of customers consuming electricity from the household, business, public, industrial sector in 2018 reached a total of 71,046 customers. The reference for the results of 2018 is also predicted by PLN in 2027 that the number of customers consuming electricity will continue to increase until it reaches 92,974 customers.[1] Therefore, the use of new and renewable energy must be the main concern of the Indonesian government not only as an effort to reduce the use of fossil energy but also to realize clean or environmentally friendly energy.[2] However, this clean energy has been faced with the constraints of inconsistent energy fluctuations, which can damage the energy storage system.[3]

Dynamic Battery or Redox Flow Battery (RFB) is a promising energy storage technology because it has a large storage capacity, is relatively cheap and is reversible.[4,5,6] In contrast to conventional batteries, dynamic battery electrolyte is made to flow through the electrolyte tank outside the battery system using a low power pump.[7,8] An electrochemical reaction occurs

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when the electrolyte flowing from the tank interacts with the electrodes when it is pumped.[9] Based on the electrolyte flow, there are two types of dynamic batteries,[10] namely single electrolytic dynamic batteries[11,12] and dual electrolytic dynamic batteries.[13] Single electrolyte dynamic battery using one type of electrolyte is accommodated in a reservoir which is circulated to the battery cell unit such as lead acid dynamic battery.[14] Meanwhile, the double electrolyte dynamic battery uses two types of electrolytes which are accommodated in two different reservoirs.[15] Usually these electrolytes are called analoyte electrolytes and cataloyte electrolytes.[16] In this study, a single electrolyte lead acid dynamic battery design has a low economic value with reduced electrolyte costs and no ion separation membrane.[17] In addition, this lead acid dynamic battery also has a higher energy density and cell voltage.[18] The lead acid battery uses H_2SO_4 as an electrolyte with Pb (Anode) and PbO (Cathode) electrodes. The following is a description of the electrochemical reaction of lead acid batteries during the Anode and Cathode processes:[19]

$$Pb + SO_4^{2-} \leftrightarrow PbSO_4 + 2e^- \qquad 1$$

$$Pb^{2+} + 2H_2 \leftrightarrow PbO_2 + 4H^+ + 2e^- \qquad 2$$

During the charging process, lead (II) (Pb^{2+}) is reduced to lead (Pb) at the negative electrode and oxidized to lead dioxide (PbO_2) at the positive electrode. On discharge (discharge), lead (Pb) and lead dioxide (PbO_2) dissolve, forming lead (II) (Pb^{2+}), which again dissolves in electrolytes.[15]

RFB battery charging that is too high (Over charge) can be dangerous because it produces hydrogen gas. Hydrogen gas generated by electrolysis can cause fires and, in extreme cases, explosions.[20] Therefore, battery management is needed to balance the battery cells so as to minimize damage. The important parameter in battery management is SoC, Charging condition of SoC is defined as% capacity in battery.[21] A 100% SoC indicates that the battery is fully charged.[22]

In 2017, previously reported that the time difference resulted in different capacity values, it was shown that the highest capacity was obtained 3838 mAh on 2.5 hours charging with the resulting voltage 2.12 V and requiring discharge time of 13779 s, while the lowest capacity was obtained 630 mAh at 0 charging, 5 hours with a voltage of 2.17 V and requires discharging time of 1988 second.[23] So it is known that% SoC capacity has a different effectiveness and is expected to affect battery performance in the next cycle.[22]

In this study, the estimation of the state of charge is very important to do so that the battery does not experience a dangerous condition (works in a safe operating area) and minimizes a decrease in performance, so testing the effect of SOC variation of 100%, 50% and 25% on dynamic lead acid batteries and cycle repetitions.

Methods

The study used a dynamic three-cell lead acid battery.[24] The 3 cell battery is made by making modifications to the 3 cell accumulator sold in the market where there are 4 positive electrodes and a negative electrode with a size of 4.5 x 7.5 cm^2. The battery is then connected to an 800 mL electrolyte tank which is flowed to the electrodes using a pump as shown in Figure 1.

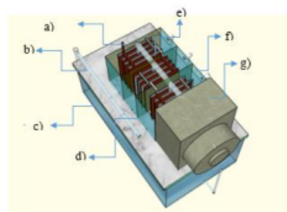

Figure 1. Design of three cell lead acid dynamic battery system a) Electrolyte inlet b) Electrolyte outlet c) Electrolyte tank d) Electrode tank e) Electrode f) Drain g) Peristaltic Pump

SoC value cannot be determined instantly.[25] Therefore, a SoC value of 50% 25% is obtained from the average percentage value of the full charge condition over many cycles. 10 cycles of data were collected using Turnigy Accucell-6 and Software ChargeMaster2.02. The data displayed is a graph of capacity, voltage and current. This research was conducted by applying a constant charging current of 1 A and a constant discharge current of 0.8 A. The charging pattern of using a current that is greater than the discharge current is expected so as not to quickly damage the electrode condition of the battery during the periodic use of the charge-discharge cyclability test.

Result and Discussion

The battery is discharged first as a result of the spontaneous reaction that occurs between the sulfuric acid electrolyte and the two electrodes as shown in Figure 2. Discharging is carried out using a constant current of 0.8 A with a discharging time of eight hours. This is done to find out how much voltage (OCV) is generated and the battery capacity contained in the 3 cell dynamic battery that has been made. The greater the open voltage value (OCV), it can be seen that the energy stored or the battery capacity is also getting bigger.

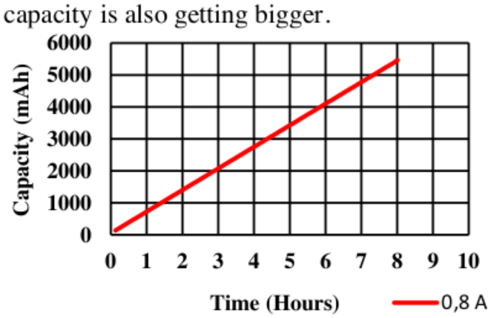

Figure 2. Initial discharge of 3 cell dynamic battery with discharge current of 0.8 A.

Figure 2, the graphical display of battery capacity has a linear graphical function with respect to time, which shows that battery capacity is the amount of charge stored over time. The result of this discharge has a final discharge capacity value of 5331 mAh. Figure 3, a 3-cell dynamic battery is charged 1A to the full until the voltage reaches 7.21 Volts and Figure 4 discharges 0.8A to the final voltage of 5.40 Volts. This filling-discharging treatment is carried out for 10 cycles and is applied to 100% SoC conditions. Then the 50% and 25% SoC variations were taken from the full charged state (SoC 100%). Then an experiment was carried out to characterize the filling of the SoC 50% and SoC 25% as shown in Figure 3.

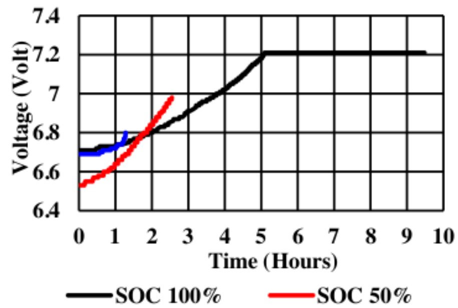

Figure 3.Charging current 1 A on a 3 cell sweetened battery with SOC variations of 100%, 50% and 25%

100% SoC value is a fully charged condition (full charge). Furthermore, the SoC value of 50% and SoC 25% is the value of 50% of the full charge condition and 25% of the full charge condition.[26] The average full charge capacity of the test 10 cycles of the battery with a discharge current of 0.8 A is 5100 mAh. Then the SOC 50% value is determined to be 2550 mAh (50% of 5100 mAh) and SOC 25% to be 1275 mAh (25% of 5100 mAh). Meanwhile, the SOC variation of 50% and 25% used a discharge current of 0.8 A.

Figure 3, at constant charging current of 1 A, the lead acid dynamic battery has a cutoff voltage of 7.21 V when it reaches full charge. Whereas in the process of charging the SOC battery 50% the cutoff voltage is 6.98 V and SOC 25% the cutoff voltage is 6.86 V. This affects the open circuit voltage (OCV) value shown in Table 1.

Table 1.Operating voltage state of the SoC 100%, 50%, and 25%

No	SOC	Vcutoff	OCV	Capacity
1	100%	7,21	6,54	5100 mAh
2	50%	6,98	6,50	2550 mAh
3	25%	6,86	6,17	1275 mAh

The open voltage (OCV) is the battery voltage when it is not given an external load. Table 1 shows that the greater the charging cutoff voltage has a value proportional to the open circuit voltage. At SOC 50% and 25% have an OCV value smaller than SOC 100%. This is because when charging does not reach the full charged condition. The amount of charge stored in the battery has an impact on the OCV (Open Circuit Voltage) value. The greater the stored charge, the higher the battery's OCV value.

When charging 1 A, 100% SOC or full charge takes longer than other SOCs as in Figure 3.Furthermore, Figure 4 also shows that the greater the battery SOC, the longer time required for constant current discharge is 0.8 A due to the amount of charge. which is emptied is bigger. During the discharge process 0.8 A the Vcutoff value of each SOC 100%, 50%, 25% is the same, namely 5.41 V.

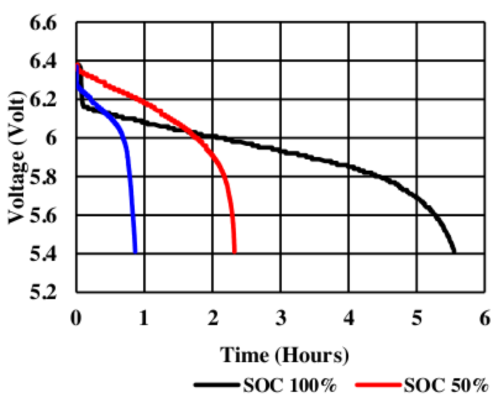

Figure 4. Voltage versus time curve for each SOC on discharge with a constant current of 0.8 A

Figure 4 shows the length of time for the discharge of SOC of 100%, 50% and 25% for 5.6 hours, 2.3 hours and 0.9 hours, respectively. This different length of time indicates that the stored charge at the higher SOC condition is proportional to the amount of charge. High SOC also larger payload amount. This statement is also supported by evidence of quantitative data shown in Table 1. SOC 100%, 50% and 25% each have a charge of 5100 mAh, 2550 mAh and 1275 mAh, respectively. As a physical equation representative as shown in equation 5.

$$i = \frac{dq}{dt} \quad (3)$$

$$\int_0^t dq = \int_0^t i\, dt \quad (4)$$

$$q_t = \int_0^t i\, dt \quad (5)$$

Figure 4 is in accordance with the physical statement of equation 5, the greater the amount of battery charge, then it is proportional to the length of discharging time. So that the SOC action treatment has 100% effect on the amount of charge stored in a battery.

It has been shown in Figure 2 above that the initial battery capacity is 5331 mAh. However, this value is not used as a condition for the full charge of a battery. As a test to determine the full charge value of a battery, 10 charge-discharge cycles of a battery with a constant charge current of 1 A with a constant discharge current of 0.8 A have been tested, the results of the test treatment are as shown in Figure 5.

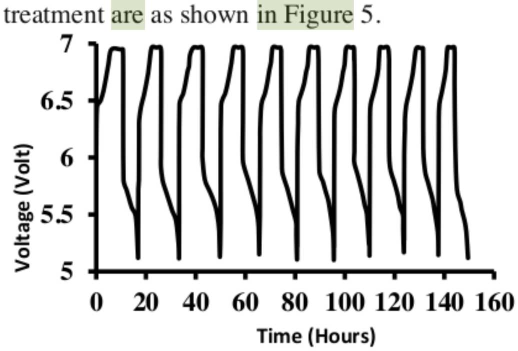

Figure 5.Ten cycles of 100% SOC constant current charge 1 A and constant current discharge 0.8 A.

Figure 5 shows a display of 10 battery discharge cycles, the time function takes a travel time of 149 hours. The 10 cycles form a curve that has an identical trend but the width of the curve is narrower if you pay attention to the condition pattern of five cycles and above. In the 10th cycle, the area of the curve is getting narrower which identifies the decreasing energy density of the battery which can be strengthened by the battery capacity value data from the 10 cycle test results as shown in Figure 6.

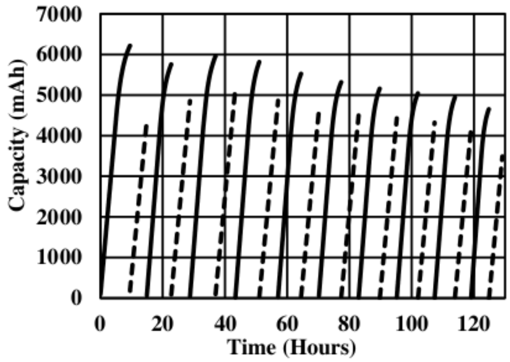

Figure 6.Ten cycles of 100% SOC capacity constant current charge 1 A and constant current discharge 0.8 A.

Figure 6 shows 10 charge-discharge cycles in the representation of battery capacity time function. It has been shown that the value of the battery capacity in the 10th cycle has decreased the charging capacity and discharging capacity. This reinforces that on the 10th cycle the battery has decreased performance. The results of the 100% SOC discharge capacity of 10 cycles were carried out on an average of 5100 mAh. These results are used as a basic reference that the capacity of the SOC condition is 100% full charge of 5100 mAh. So it can be ascertained that the SOC 50% is determined to be 2550 mAh (50% of 5100 mAh) and SOC 25% of 1275 mAh (25% of 5100 mAh). To confirm this statement, a 10-cycle SOC 50% test was carried out through the Turnigy Accu Cell device with a battery capacity setting point of 2550 mAh. This means that when charging has reached a capacity of 2550 mAh. Then the turnigy will automatically stop the filling process. The test results for 10 cycles of 50% SOC are shown in Figure 7.

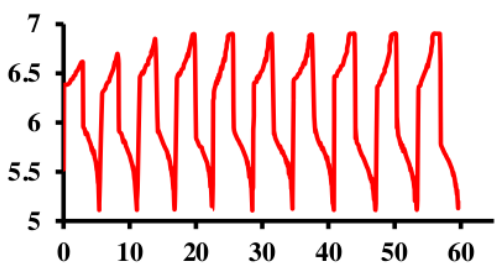

Figure 7.Ten cycles of 50% SOC charge constant current 1 A and constant current discharge 0.8 A.

Figure 7. The total time required for 10 cycles with 50% SOC charging is 52 hours. The average time per cycle was 5.2 hours. Although the SOC value of 50% is determined and constant each cycle. charging time for subsequent cycles has increased, although it is not very significant. In the first cycle, the time required for 2550 mAh charging is 2.5 hours while the last time on the 10th cycle is 2.9 hours. The increase in the travel time of this cycle means that the value of the battery discharge capacity is getting bigger as shown in Figure 8.

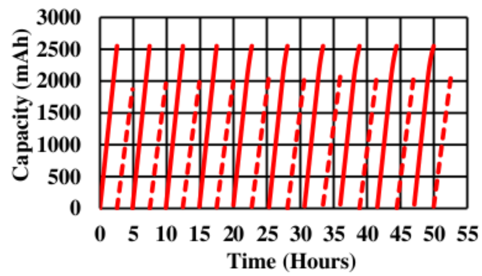

Figure 8.Ten cycles of 50% SOC capacity constant current 1 A charge and 0.8 A constant current discharge.

Figure 8. Shows the trend graph of the capacity of the 10 cycles of time function shows that the value of the battery capacity from the first cycle to the 10th cycle has increased over time. This indicates that it is identified that there is a charge remaining from the previous cycles. While the average discharge capacity from the measurement results is 2048 mAh which is still relatively close to the SoC charging capacity value of 50% (2550 mAh). That way, the three-cell dynamic battery that is made is proven to have good performance even though it is only given a charge of 50% of the full charge state.

Next to make sure the SOC is 25% of 1275 mAh from the calculation of (25% of 5100 mAh). A test of 10 cycles of constant current charging of 1 A and constant discharge of 0.8 A has been carried out in order to provide evidence of the statement of the calculation of the SOC value of 25%

from 5100 mAh of 1275 mAh. The test results are as shown in Figure 9.

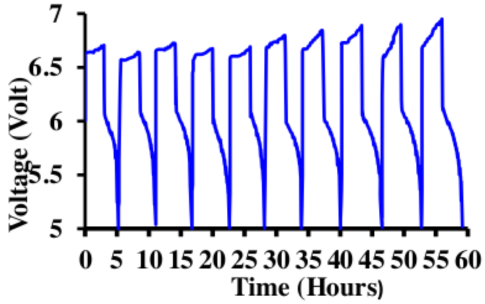

Figure 9. Ten cycles of 25% SOC constant current 1 A charge and 0.8 A constant current discharge.

The 25% SOC battery has a travel time of 10 cycles the fastest because the number of SOCs given is the smallest than the others. The time to take 10 cycles of the SOC 25% or 1275 mAh battery is 23.6 hours with an average per cycle of 2.36 hours. In contrast to the 50% SOC battery. The time required for the charging process tends to be stable for the following cycles, which is 1.27 hours. Like the 50% SOC battery, the 25% SOC battery which is also not in full charge has an increase in the value of the output capacity during the discharging process as shown in Figure 10.

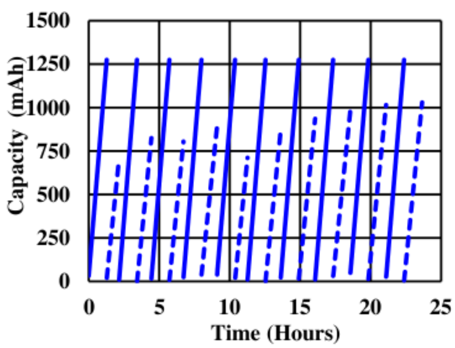

Figure 10.Ten cycles of 25% SOC capacity constant current charge 1 A and constant current discharge 0.8 A.

The results of the SoC's discharge capacity of 25% are 10 cycles of 876 mAh. This result is relatively far from the calculation that has been determined by the SOC 25% which is determined to be 1275 mAh (25% of 5100 mAh). That way, the three-cell dynamic battery that is made is proven to have poor performance when given a charge of 25% of the full charge state. So in fact, the dynamic three-cell battery that is made is not able to be applied by charging it briefly.

Figure 10 shows the SOC discharge capacity of 25% at cycles 1, 3, 5 fluctuating. However, in the 6th to 10th cycles, the trend of the capacity value graph increased significantly. These results indicate that the treatment of SOC 25% discharging current of 0.8 A in the cycle range 1-5 the battery capacity is not at full full. The results of the three tests of 10 cycles of SOC 100%, 50%, and 25% were analyzed by calculating the voltage efficiency, capacity efficiency, and energy efficiency as in the previous study[27] to review battery performance from the 100%, 50% and 25% SOC treatment. %. The results of the calculation analysis of the voltage efficiency, capacity efficiency and energy efficiency of 10 cycles have been shown in the form of a histogram in Figures 11, 12, 13.

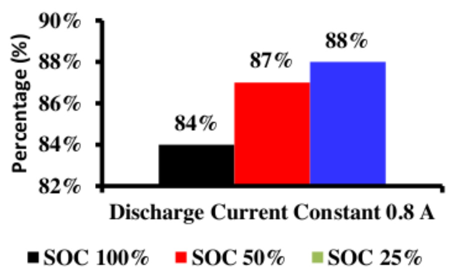

Figure 11. Voltage efficiency 0.8 A discharge current

Figure 11. The stress efficiency tends to experience a reverse ratio in value with increasing SOC treatment. These results indicate that when the SOC is 100% the average discharge voltage is smaller than the average charging voltage value.

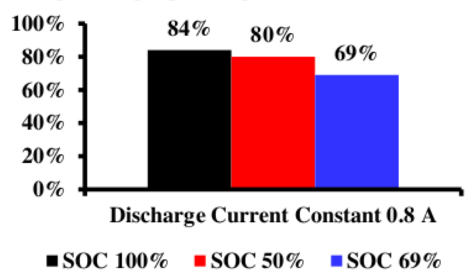

Figure 12. Discharge current capacity efficiency 0.8 A.

Figure 12. Capacity efficiency has a value proportional to the greater SOC value. This is indicated when a larger SOC treatment is carried out, the battery can store a larger charge, which means that the full-charged battery has the maximum mutant storage performance. This result is also supported by his research[23] which states that a battery with full charge has a better average capacity efficiency value than a battery that is not in full charge or SOC 50% and SOC 25%. This means that a battery with a longer charge has a greater capacity efficiency value

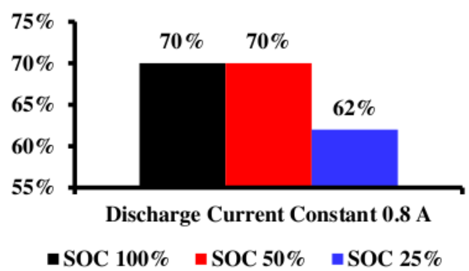

Figure 13. Energy efficiency 0.8 A discharge current

Figure 13.Energy efficiency at 100% and 50% SOC conditions has the same energy density performance, which means that it can be used as a recommendation that a battery that is designed even if the charging condition is carried out at 50% of the total battery capacity provides maximum electrical energy if used under usage conditions. . However, if the battery is carried out, the SOC condition is 25%, which means that it is less than 50% the condition for charging the battery which is designed is still not optimal for regular use.

Conclusion

Treatment of SOC conditions for analyzing battery performance is viewed from the analysis of the efficiency of voltage, capacity, and energy at full charge and half of the full charge state. Based on the research conducted, it has been concluded as follows:

1. Estimated initial battery capacity of 5331 mAh through the initial discharge test of the battery capacity with a constant current of 0.8 A.
2. When pre-charging with a constant current of 1 A at SOC 1005, 50%, and 25%, the battery is designed to have a charger cutoff voltage in the operating voltage range of 6.86-7.21 V.
3. When discharging with a constant current of 0.8 A at each SOC treatment of 100%, 50%, and 25% the voltage drops at the same value, namely at the value of 5.41 V. However, the length of the discharge range is longer at 100% SOC , then followed by SOC 50%, then 25% which took about 5.6 hours, 2.3 hours and 0.9 hours, respectively.
4. In the cyclibility test of 10 cycles of charging 1 A and discharge of 0.8 A, the graph of the voltage function of the 100% SOC battery takes a long time of 149 hours, 50% SOC requires 52 hours, 25% SOC requires 23.6 hours.
5. In the cyclability test of 10 charging cycles of 1 A and discharge of 0.8 A, the battery capacity graph is the 100% SOC time function giving the train discharge capacity of 5100 mAh, SOC 50%, with an average discharge capacity of 2048 mAh, and 25% of 876 mAh. The results of the 25% SoC test treatment showed a decrease in poor capacity performance and too far from the SoC 25% charging capacity target of 1275 mAh.
6. The energy efficiency of 100% and 50% SOC batteries provides the same good battery performance as indicated by the same 100% and 50% SOC energy efficiency values which can be used as a recommendation that a battery that is designed can be operated periodically even though the charging condition is 50 % of the full charge.

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