Estimating the state of charge on lead acid battery using the open circuit voltage method

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Abstract. This research investigates one of the methods to estimate the State of Charge (SoC) of a lead-acid battery with an Open Circuit Voltage (OCV) method. Determining the battery voltage in open circuit condition with standard temperature (25°C). Observing the OCV of the battery on the discharging cycle then compare with the increasing and decreasing of the battery voltage in open circuit condition (OCV) that can show the SoC battery to determine the capacity of the battery. Then using the Coulomb Counting method to compare the estimated SoC by OCV method. The result shows that there is a different value measured by these two methods at the early and later stages during the discharge cycle of a lead-acid battery.

1. Introduction
The number of the life cycle of a battery is one of the important parameters of a battery. This shows how long it can be used before the battery capacity drop from the rated capacity. Many aspects that affect this parameter. One of the aspects that can make the battery life reduced quickly is the level of the Depth of Discharge(DoD)[1]. Therefore we need to monitor the capacity of the battery so we can prevent the DoD so high that it can result in the battery lifetime reduced so quick. In estimating the SoC (State of Charge) of a battery several methods can be done[2-4]. Among those methods, One of them is by using a method of measuring the battery voltage in an open circuit or open circuit. This method is done by measuring the voltage value of the battery when the battery is not connected to an electrical load. Then the voltage value becomes a parameter for estimating the SoC by comparing the OCV value with the maximum open-circuit voltage and minimum open-circuit voltage of the battery. Unfortunately, this method is hard to implement to the battery that is charged or discharged because of the nature of this method that needs the battery in an open circuit condition for a while after being charged or discharged[5].

2. Literature Review
2.1 State of Charge (SoC)
SoC (State of Charge) is a parameter of a secondary battery that functions to avoid excessive charge and
discharge which can reduce battery life faster. SoC is usually expressed as a percentage (%) that when the SoC has a value of 0% it indicates the battery capacity is empty, and vice versa 100% indicates full battery capacity.

2.2 Depth of Discharge

The alternative to the SoC is the DoD (Depth of Discharge) shown in figure 1 which is the opposite of the SoC. The higher DoD level, the lower the battery capacity and vice versa, the lower the DoD level, the higher the battery capacity.

![Relationship between SoC and DoD](image)

**Figure 1. Relationship between SoC and DoD.**

The higher the DoD level, the lower the battery lifetime. So this must be prevented by periodically monitoring the battery SoC level. These parameters are very important to consider in maintaining battery life because the deeper the depth of discharge can cause battery damage and the lower the battery lifetime, shown in figure 2.

![Relationship battery life cycles and DoD](image)

**Figure 2. Relationship battery life cycles and DoD[5].**

2.3 Open Circuit Voltage

OCV (Open Circuit Voltage) shown in figure 3 is a power supply voltage value when not connected to load (load) so that no current will open circuit or there is no current flowing in the circuit (Icircuit = 0).

\[ I = \frac{V}{R} \]  \hfill (1)
In ideal conditions, an open circuit has a very high value of resistance \((R = \infty)\) so that no current will flow in the circuit \((I_{\text{circuit}} = 0)\). This can be proven by using Ohm's law shown in equation (1).

\[
I = \frac{V}{\infty}
\]

\[
I = 0
\]

**Figure 3.** Open circuit.

Where \(I\) is the value of the current flowing in the circuit, then \(V\) is the voltage value of the power supply, and \(R\) is the resistance value in the circuit. In this case, the air that has a very large resistance value or can be considered infinite. Then the values are entered into Ohm's law, equation (2) and equation (3)

\[
I = \frac{V}{\infty}
\]  

\[
I = 0
\]

In this situation, the value of \(V\) is the value of OCV. This voltage value can be used as a parameter to estimate to determine the State of Charge of a battery[6].

2.4 *SoC Estimation using OCV method*

The value of the voltage obtained when measuring battery voltage in open circuit conditions used a reference for estimating SoC. Another test that has been done measures the value of OCV batteries to determine the SoC of a battery. Can be seen in figure 4 above is an example of an analysis of the relationship of 12 V lead-acid battery voltage and state of charge of a battery at room temperature.

**Figure 4.** The relationship of the SoC level to the voltage on a 12V lead-acid battery[6].
The advantage of the OCV method for estimating SoCs is a simpler method because only the voltage parameters are the reference for determining the battery SoC. However, the disadvantages of the OCV method are hard to implement for practical use, because the battery must first be open circuit.

2.5 SoC Estimation using the Coulomb Counting method
Coulomb counting is one method of calculating the state of charge from a battery. This method works by measuring current in a certain period of time to calculate the incoming and outgoing energy of this calculation, usually measured in Ampere-hours. Where SoC can be found with the following equation.

\[ \text{SoC} = \left( \frac{KQ_{\text{rated}}}{Q} \right) \times 100 \% \] (4)

3. Experiment

3.1 SoC Estimation using the Open Circuit Voltage
The experiment was done by discharging the battery and calculating the open voltage then using the characteristics of open circuit voltage to get the SoC value. Tests are carried out in a room with a temperature of ±24°C, and second attempt to discharge done to see the consistency of the measurement of the SoC.

3.2 SoC Estimation using the Coulomb Counting method
At the same time using the coulomb counting method to get the value of the SoC. Using the formula to calculate how much the SoC that lost during the discharge. Then, compare the value with the value of the open circuit voltage during that discharge time.

\[ \text{SoC} = 1 - \left( \frac{^\wedge}{V} \right) \times 100 \% \] (5)

**Figure 5.** Graph of The open circuit voltage and the OCV SoC first cycle  
**Figure 6.** Graph of The open circuit voltage and the OCV SoC second cycle
Where the value of $Q_d$ is equal to the capacity of discharge (Ah) and the $Q_{\text{rated}}$ is the value of the rated capacity given by the battery manufacturer.

### 3.3 The Comparison of the two methods

The following graphs show the value of the open-circuit voltage compared with the 2 SoC method. The graph above shows that there are differences in the value of battery capacity in the form of percent between the first and second cycles with the average difference in the SoC reading of 3.7794%. As for the capacity calculated using the coulomb counting method still shows ± 15% in the last calculation is different from the OCV method which shows the capacity has reached ± 5%. We can assume that lead-acid is not exactly worth 9 Ah, because according to Peukert's law that says the battery capacity will increase when the discharge flow is reduced [7-8].

Cause the calculation using the assumption that the 100% capacity of the battery is worth 9 Ah which causes the calculation of the Coulomb counting method used in this test is not too precise. SoC is <10% with an open voltage of ± 11V, when the battery is connected to the load, the battery voltage drops to ±
8V and the current flowed also decreases. Makes the battery is not optimal to become a 12V power supply can be seen when testing is done 9W 12V LED lights to become dim, and the movement of DC motors becomes slow.

4. Conclusion
The estimated capacity of the battery SoC using the open circuit voltage method has a fairly precise value with differences in the calculation of the average first and second cycles of 3.77%. But over time the accuracy level will decrease due to the characteristics of the battery which has a reduced voltage in the open circuit. The two methods show the different values of SoC estimation at the early and later stages during the discharge cycle of the battery. For the coulomb counting method, there are still many errors due to the loss of energy and the Peukert’s law that have not been included in the calculation parameters during this test.

5. References
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