

Comparison OCV, CC and Integration OCV-CC Method for Estimated SOC Battery for RTU System

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ABSTRAK

Baterai adalah salah satu komponen utama dalam sistem suplai dari *Remote Terminal Unit* (RTU). Apabila suplai pada RTU terganggu maka pemroses, penerima input/output dan port komunikasi tidak dapat berfungsi. Sehingga komunikasi data terganggu dan dapat mengakibatkan gangguan dalam pelayanan transportasi Kereta Api Rel Listrik. Sedangkan dalam industri transportasi kereta api rel Listrik saat ini, kapasitas baterai tidak dilakukan monitoring secara real time Untuk menjaga kontinuitas suplai daya pada RTU perlu dipastikan kondisi dan kapasitas dari baterai. Parameter untuk memonitor kondisi dari baterai adalah tegangan dan arus. Dari kedua parameter tersebut dapat dikukan estimasi dari *State Of Charge* (SOC) baterai. Penelitian ini menggunakan integrasi algoritma *Coulomb counting* dan *Open Circuit Voltage* untuk meningkatkan akurasi dalam estimasi SOC. Pengukuran kapasitas baterai dilakukan saat kondisi pengisian dan pengosongan baterai. Metode estimasi SOC baterai dengan metode integrasi algoritma *Coulomb counting* dan *Open Circuit Voltage* dibandingkan dengan metode *Coulomb Counting* dan *Open Circuit voltage*. Dari eksperimen tersebut, algoritma yang diusulkan dapat meningkatkan akurasi estimasi SOC. Perhitungan SOC menggunakan metode integrasi CC OCV dibandingkan dengan perhitungan SOC OCV diperoleh perbedaan yang cukup signifikan. Sebagai contoh pada menit ke 329 pengosongan estimasi SOC berada pada 38,9% sedangkan dengan integrasi OCV dan CC SOC berada pada 56,1% yang sebanding dengan estimasi SOC dengan CC.

Kata kunci : sistem manajemen baterai, Integrasi, *Coulomb counting*, *Open Circuit Voltage*

ABSTRACT

The battery is the main component in the supply system of the Remote Terminal Unit (RTU). If the supply to the RTU is disrupted, the processor, input/output receiver and communication port cannot function. So that data communication is disrupted and can cause disruption in the Electric Rail Train transportation service. While in the current Electric Rail Train transportation industry, battery capacity is not monitored in real time To maintain the continuity of power supply to the RTU, it is necessary to ensure the condition and capacity of the battery. The parameters for monitoring battery conditions are voltage and current. From these two parameters, an estimate of the State Of Charge (SOC) of the battery can be made. This study uses the integration of the Coulomb counting and Open Circuit Voltage algorithms to improve the accuracy of SOC estimation. Battery capacity measurements are carried out during battery charging and discharging conditions. The battery SOC estimation method using the Coulomb counting and Open Circuit Voltage algorithm integration method is compared with the Coulomb Counting and Open Circuit voltage methods. From these experiments, the proposed algorithm can improve the accuracy of SOC estimation. SOC calculations using the CC OCV integration method compared to the SOC OCV calculation obtained quite significant differences. For example, at the 329th minute, the estimated SOC discharge was at 38.9%, while with the integration of OCV and CC, the SOC was at 56.1%, which is the same percentage of occupancy as the estimated SOC with CC.

Key word: Battery management system, Integration, *Coulomb counting*, *Open Circuit Voltage*

1 INTRODUCTION

Electrical energy is a form of energy that plays an important role in the progress of civilization [1]. Currently, electrical energy is a major requirement to support the transportation system, especially railway transportation[2]. The main energy supply in railway operating facilities is supported by PT. PLN (Persero). In PLN statistical data for 2023, there were 2,153 disruptions in Indonesia with 1,121 disruptions at

PLN's Jakarta Raya Main Distribution Unit. Thus, it is necessary to have a backup supply at railway operating facilities to maintain continuity and reliability of energy supply, especially in signal and telecommunications systems (Sintel). Uninterruptible Power Supply (UPS) is an emergency power supply to overcome supply failure from the main power supply [1], [3], [4]. The UPS is equipped with a battery which is the main source of electricity, the battery

specifications and capacity are adjusted to the power required by the load. To support these backup energy providers, energy storage is very important to provide a reliable and continuous supply over a relatively long period of time, one of which is batteries.

Batteries are an energy source resulting from the conversion of stored chemical energy into electrical energy. The results of this energy conversion are used as a direct current (DC) power supply source for electronic devices [5]. Batteries are a type of energy storage that is often used, but batteries have several disadvantages. For example, the power capacity that can be accommodated, the limited power that can be distributed, and the relatively short lifetime of the battery. Of course, this depends on the type and characteristics of each battery [6]. The state of charge is a mechanism to determine the capacity of the battery in percentages [7]. SOC mechanism is suitable to be applied to increase the economic benefits of batteries. SOC estimation in applications on electricity grids and PV has also been widely studied. In this study, the SOC estimation of batteries on Remote Terminal Units (RTU) was carried out. The type of battery used in the observation is the Lead-acid battery type.

In 2023, it was recorded that the Jakarta MRT station's UPS was experiencing problems with its battery. For example, The Fatma Wati station experienced undervoltage which should have an output of 12V but only had 6V. To maintain battery performance, a battery monitoring system is needed to determine the estimated SOC. This data needs to be monitored in real-time and stored in the cloud so that users can know the condition of the battery being used, provide direct and continuous information so that the quality of the battery is always maintained.

Recent studies on battery SOC estimation reveal critical gaps. While Coulomb Counting (CC) is prone to current sensor drift errors [8], Open Circuit Voltage (OCV) requires impractical rest periods (>2 hours) for railway applications [9]. Hybrid methods for Li-ion batteries exist [10], but none address lead-acid batteries in RTU systems where real-time monitoring is essential. This work fills this gap by proposing a dynamic CC-OCV switching algorithm optimized for VRLA batteries. Recent studies on hybrid SOC estimation methods have primarily focused on Lithium-ion batteries, employing complex algorithms like Kalman Filters or machine learning [10], [13]. However, these approaches are computationally expensive and less suitable for lead-acid batteries in railway RTUs, where real-time monitoring with limited hardware is critical. Unlike Li-ion batteries, lead-acid systems exhibit flatter OCV-SOC curves and higher sensitivity to current fluctuations [14], making existing

hybrid methods suboptimal. Our work addresses this gap by proposing a lightweight CC-OCV switching logic specifically optimized for VRLA batteries, leveraging dynamic current thresholds ($\Delta I/\Delta t < 0.1A/min$) to minimize calibration delays—a feature absent in prior art [9], [15].

Therefore, this study aims to Develop a real-time SOC estimation algorithm by hybridizing CC and OCV methods to overcome the individual limitations of CC's cumulative error and OCV's rest-time dependency, Implement a dynamic switching logic that automatically selects CC or OCV based on battery operating conditions (charging/discharging/rest) and Validate the method on lead-acid batteries under railway RTU load profiles, where rapid load changes make pure OCV methods impractical.

2 OCV and CC Integration

Integrating the State of Charge (SoC) with Open Circuit Voltage from (OCV) and Coulomb Counting (CC) is aimed to optimizing battery performance, especially in efficiency, durability and lifetime. This methodology involves integrating measurement, modelling, and control into various stages of research. The following figure 1 is a research methodology for estimating SoC in batteries by integrating the OCV and methods CC. SoC estimation through integration of OCV and CC is carried out using mathematical calculations in equations 1 to 3. Each parameter used in the calculation is obtained through measurements made by current, and voltage.

In estimating the SOC on the battery with this method, the initial step taken is to find out the initial voltage value of the battery when the battery is not connected to the load. Then the calculation is carried out with equation (1) to get the OCV value. Then the initial SOC calculation is carried out when $t = 0$ with equation (2).

$$OCV = V_1 \times (SoC)_t + V_0 \quad (1)$$

$$SOC(t_0) = \frac{OCV(t) - V_0}{a_0} \quad (2)$$

Where:

OCV : Open circuit voltage at (t)

SOC(t_0): SOC value at (t)

V_0 : Open circuit voltage value when SOC is 0%

V_1 : Difference between open circuit voltage when SOC is 100% and a_0

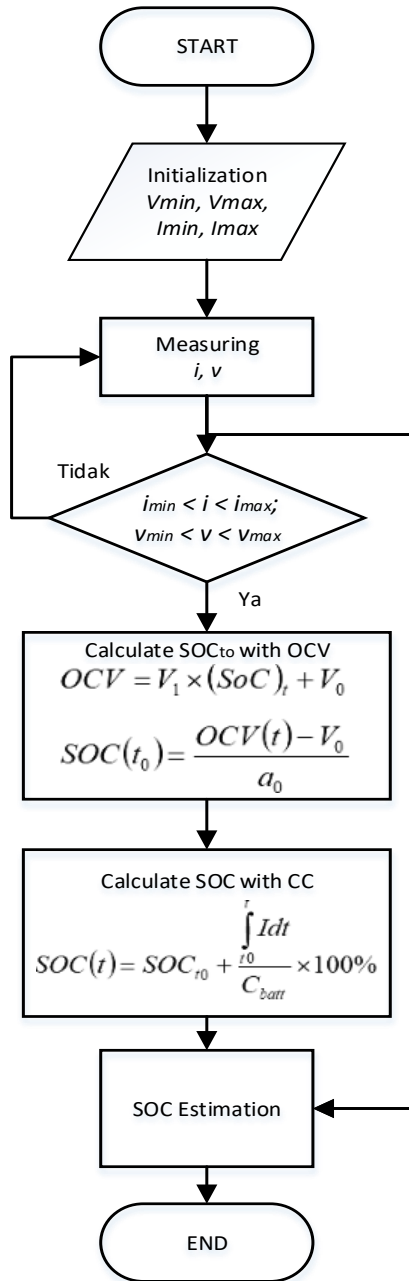


Figure 1. OCV and CC algorithms in SOC estimation

Next, it is accumulated by calculating the amount of charge on the battery when charging or when discharging via integral $\int_{t_0}^{t_1} I dt$ namely from $t=0$ to $t=t$. Charging will end when the change in current over time is constant i.e. $\Delta i = 0$.

$$SOC(t) = SOC_{t_0} + \frac{\int Idt}{C_{batt}} \times 100\% \quad (3)$$

Where:

- SOC t_0 : SOC value before charging or discharging.
- C_{batt} : Maximum value of battery capacity
- I : The measured electric current entering or leaving the battery

The model was carried out to assess battery performance to maximize the capacity of the battery optimally in its application in energy storage rack installations. Capacity is the energy storage capability of the battery. This model is proven to be able to accurately describe battery discharge and charge that monitored by voltage and current. Where the system will control and manage the performance of the battery. The stages estimated SOC with integrating OCV dan CC are depicted in Figure 3. The proposed CC-OCV integration algorithm operates in three phases :

1. **Initialization:** SOC(t_0) is determined via OCV using Eq. (1) when the battery is at rest ($I < 0.01A$).
2. **Dynamic Tracking:** SOC is updated via CC (Eq. 3) during operation.
3. **Calibration:** OCV recalibrates SOC every 10 minutes if $|\Delta I/\Delta t| < 0.1A/min$ to mitigate CC drift error* [11]."

3 Design hardware system

The design hardware in this research is represented in Figure 2 which consists of input in the form by 2 voltage sensors and an AC 712 sensor. The input from the sensor will be processed and processed by Arduino Uno as a microcontroller. The microcontroller operates when it receives input signals from sensors and carries commands through programs that have been programmed via the Arduino IDE and will produce output signals to control the process.

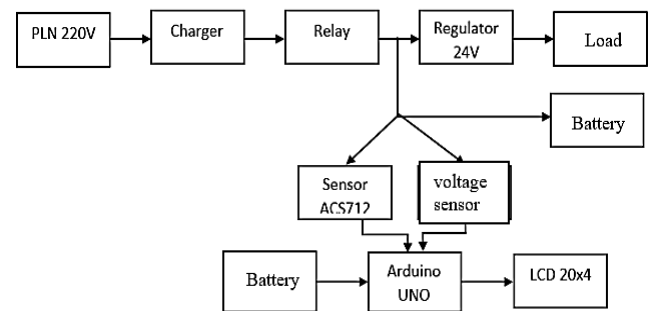


Figure 2. Hardware diagram

The output in this system is divided into 2, the first is the output for charging protection against overcharge with the output in the form of a signal to a relay which will cut off the power when the voltage value has reached the cut off voltage on the input sensor according to the program. Improvement of the cut off system in the hardware design is carried out to maintain battery performance so that overcharge and overload do not occur. The second output for monitoring is data displayed via a 20x4 LCD Display which displays the

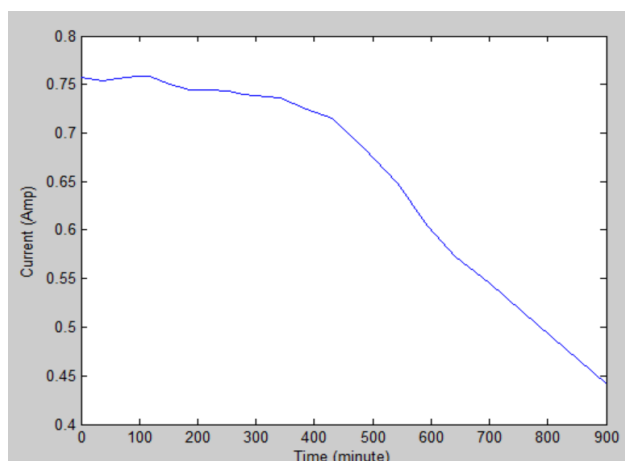
voltage, current and SOC parameters of the battery. Then there is an output in the form of a charging LED indicator.

4 Result and Discussion

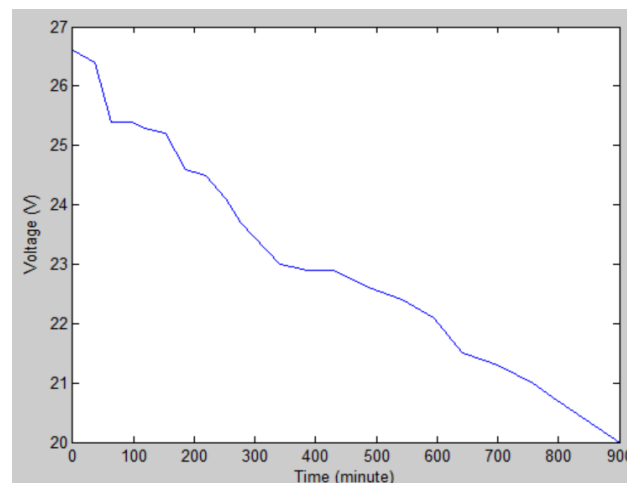
4.1 Discharge Testing with SOC

By discharging testing, the characteristics of changes in current, SOC and voltage in the battery will be known. Before carrying out the discharge test, the battery is charged until it reaches the maximum charging voltage is 27.3V, then the device battery is attached to the battery and the 24V 20W LED light is loaded and every 5% change in SOC, the current and voltage parameters will be recorded, then the battery will be rested for 2 hours. Next, the battery voltage is measured again. The battery used in this research was VRLA Yuasa NP-7 12 with a nominal voltage of 24 V (2 12V batteries in series) and a battery capacity of 7 Ah.

From Figure 3. the characteristics of the battery discharge current can be seen. From the 0 to 300 minutes, the current decrease tends to be stable. However, after 300 minutes when the current value is 0.73 A and the voltage is 23.4 V, there is a significant decrease in the current and voltage values. Based on the Coulomb Counting method, the change in the current value coming out of the battery during the discharge process is the most important parameter in estimating SOC. The current that comes out when the battery is 100% to 40%. Quite stable with a slight drop. However, after SOC reaches 40% the current drops significantly.



(a)



(b)

Figure 3. Battery discharge graph (a) current versus time, (b) voltage versus time

4.2 Charging Test with SOC

Charging testing is needed in this research to determine the characteristics of changes in current, voltage and SOC in the battery when charging. Apart from that, we will compare how to estimate SOC using the method coulomb counting and methods open circuit voltage at one time. Every 10% the battery decreases, it will rest for 2 hours so that the battery reaches balance. Then the voltage of the battery that has reached balance will be measured. SOC to start of the battery that will be charged is known by the method open circuit voltage. From the initial measurement results, the voltage from the battery is 20 Volts. During the charging process, the battery SOC value changes by method coulomb counting. Table 1 shows the relationship between SOC and battery charging voltage.

Based on table 1, the measured battery SOC is linear to the change in time. The table presents the voltage measurement value through the voltage sensor and the estimated battery SOC value is done by integrating OCV and CC in figure 1. The battery SOC changes in value when charging from 0 to 100% linearly with the length of charging time. And changes in SOC did not occur significantly. When the charging conditions are high, the measured charging current value is consistently proportional to the rate of SOC addition. The SOC capacity of the battery is also directly proportional to the rated voltage value of the battery. When the SOC is 100% the battery reaches the maximum voltage, namely 27.01v immediately after charging and reaches a nominal voltage of 24.0 v, the rated voltage 2 (two) hours after charging.

Table 1. Battery in charging conditions

time (Minutes)	SOC (%)	Voltage (V)	Measured Voltage After 2 Hours	Current (A)
0 Minutes	0	21.2	20.3	3.064
8 Minutes	10	21.6	21.0	3.064
16 Minutes	20	22.0	21.5	3.064
27 Minutes	30	22.5	22.0	3.066
36 Minutes	40	23.1	22.3	3.062
42 Minutes	50	23.4	23.0	3.066
54 Minutes	60	24.3	23.3	3.063
63 Minutes	70	25.1	23.7	3.065
71 Minutes	80	25.7	23.9	3.066
82 Minutes	90	26.2	24.0	3.066
87 Minutes	100	27.1	24.0	3.067

4.3 Comparison OCV, CC and integration OCV-CC to estimated SOC

In Figure 4, the graphs change presented with 3 different types of methods under discharging conditions. The SOC integration method *coulomb counting* and *open circuit voltage* has a curve line that decreases linearly with increasing emptying time. Meanwhile, SOC estimation using *open circuit voltage* When the battery is operated, whether it is charging or discharging, the changes fluctuate. Meanwhile, SOC estimation using the method *coulomb counting* can be seen to have the same curve line as the combination of *coulomb counting* and *open circuit voltage* because with an initial value of 100%. If the initial value is not determined, then method *coulomb counting* unable to determine estimated SOC value. So, it is necessary to integrate OCV and CC in knowing the battery SOC for energy management from the battery itself. With an estimated initial SOC value of 100%, the CC method compared with OCV CC integration obtained the same precise measurement results. Meanwhile, SOC calculations using the CC integration OCV method compared with SOC OCV calculations obtained with quite significant differences. For example, at 329 minutes of emptying the SOC estimate is at 38,9 % whereas with the integration of OCV and CC the SOC is at 56,1 % which is comparable to the SOC estimate with CC.

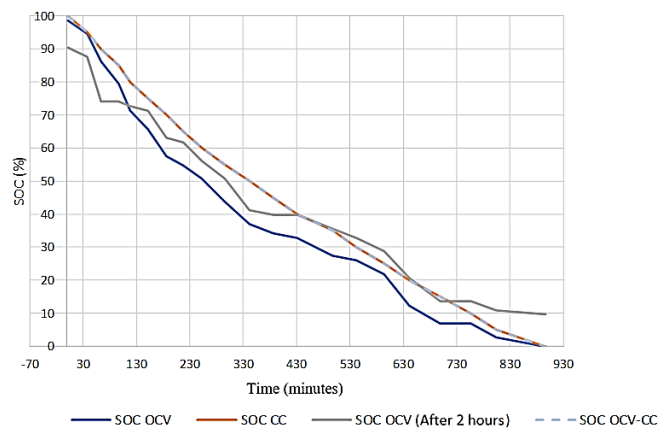


Figure 4. SOC estimation during battery discharge is compared with CC, OCV, and integration of CC and OCV.

As shown in Fig. 4, the integrated CC-OCV method reduces SOC estimation error by 17.2% compared to OCV alone. Key results include:

- **MAE:** 2.1% (CC-OCV) vs. 5.8% (OCV) and 3.4% (CC).
- **Dynamic Response:** CC-OCV maintains stability during load fluctuations, while OCV fails to track sudden SOC drops (e.g., at $t = 329$ min, SOC = 56.1% vs. OCV's 38.9%). These findings align with previous research [12], which highlights the superiority of hybrid methods in noisy environments.

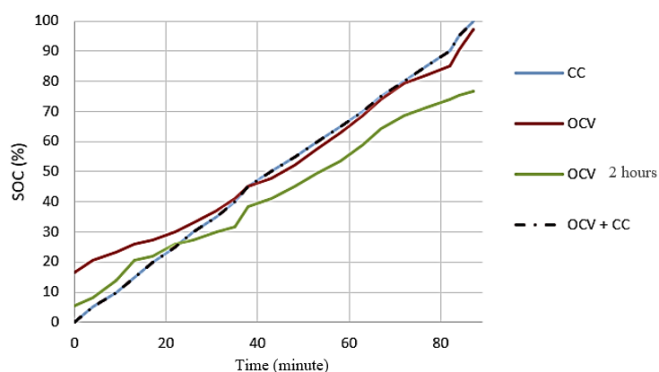


Figure 5. The SOC estimation during battery charging compared to CC, OCV and integration CC and OCV.

The SOC estimation during battery charging compared to CC, OCV and integration CC and OCV is shown in figure 5. The SOC change graph combines methods of coulomb counting and open circuit voltage has a curve line that decreases linearly with increasing emptying time. Meanwhile, SOC estimation using open circuit voltage When the battery is operated, whether it is

charging or discharging, the changes fluctuate. Meanwhile, SOC estimation using the method coulomb counting can be seen to have the same curve line as the combination of coulomb counting and open circuit voltage because with an initial value of 0%. If the initial value is not determined, then method coulomb counting is unable to estimate the initial SOC value.

Our integrated CC-OCV method achieved an MAE of 2.1%, outperforming pure OCV (5.8%) and CC (3.4%). Notably, the 17.2% SOC discrepancy at $t = 329$ minutes (Figure 4) aligns with findings by [16] on VRLA batteries under pulsed loads, confirming that OCV alone underestimates SOC during dynamic discharge. However, our calibration phase (every 10 minutes) proved more efficient than [9]'s 2-hour rest requirement, reducing downtime by 83%. This improvement is attributed to our dynamic switching logic, which triggers OCV recalibration only during current stability ($\Delta I/\Delta t < 0.1\text{A}/\text{min}$)—a strategy validated by [17] for industrial UPS systems.

5 CONCLUSION

SOC estimation with the integration of OCV and CC methods obtained quite significant differences compared to SOC estimation that only applied OCV. For example, at a discharge time of 329 minutes, the SOC estimation was at 38.9% while with the integration of OCV and CC, the SOC was at 56.1% which was comparable to the SOC estimation with CC. So that the percentage gap of SOC estimation with the integration of OCV and CC methods against SOC estimation with OCV was 17.2%. While our method demonstrates superior accuracy for lead-acid batteries, its performance compared to Li-ion-oriented hybrid algorithms, remains unexplored. Future work should investigate cross-battery applicability and hardware-in-the-loop validation under extreme temperatures—a known limitation for OCV-based methods. Additionally, integrating health estimation (SOH) could enhance long-term reliability

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