Design and Implementation of Battery Management System for Portable Solar Panel with Coulomb Counting Method

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Abstract. Secondary batteries are commonly used as the storage of energy produced by solar panels. However, the utilization of a battery without proper management can cause damage due to overcharging and over-discharging. This study aims to design a battery management system (BMS) on a Valve Regulated Lead-Acid (VRLA) battery. The method used was the battery State of Charge (SOC) estimation using Coulomb Counting (CC) method. The results showed that the BMS was successfully designed and implemented to automatically cut-off the current when the SOC value is 100% (charging limit) and 20% (discharging limit).

1. Introduction
The energy production of a solar panel can be optimized using an energy storage system such as a battery [1, 2]. A battery itself can be classified into two different types, i.e. primary and secondary. An example of a secondary battery that is commonly used is the Valve-Regulated Lead-Acid (VRLA) type. However, this type of battery has several drawbacks such as overcharging and over-discharging. In a long time of usage, these drawbacks could lead to the degradation of the battery lifetime and working quality.

A Battery Management System (BMS) is required to avoid battery damage due to battery incorrect usage. Several methods of BMS are available, one of them is by estimating the value of battery State of Charge (SOC). In this study, the Coulomb Counting (CC) method was used as the SOC estimation method. The basic principle of the CC method is to accumulate the electrical charge that is going in and out of the battery [3, 4]. The temperature and electric current could also affect the accuracy of the SOC [5, 6].

According to the problem stated above, this study aims to design a battery management system on Valve Regulated Lead-Acid (VRLA) battery using State of Charge (SOC) estimation with Coulomb Counting (CC) method. Several indicators were displayed on the battery monitoring system, i.e. the battery voltage, current and the percentage of SOC value. The CC method was selected due to its accuracy in determining the SOC. The accurate SOC is a crucial parameter required in battery monitoring and management system [7-9].

2. System Design
2.1. Hardware Design
In this study, a BMS for the portable solar panel by estimating the value of battery SOC using the CC method was designed. This system monitored the battery condition by displaying the percentage of SOC value calculated from the data obtained from the measurement. The measurement was divided into two-phase: charging and discharging. A 340 W solar panel was used as the power supply in the charging phase and a 5 W AC lamp and an inverter were used as the load in the discharging phase. The circuit model of the BMS for charging and discharging phase are respectively shown in Figure 1 and 2.
2.2. Coulomb Counting

Coulomb counting (CC) was the method used to estimate the SOC in this study. The basic principle of the CC method is to accumulate the electrical charge that are going in and out of the battery. The formula to calculate the operating charge, $Q_{out}$ of a battery is

$$Q_{out} = I \times t $$  \hspace{1cm} (1)

where:

$Q_{out}$ = operating charge

I = operating current

$ t$ = measurement time
Eq 1 was used to calculate the amount of charge at a certain condition. However, to estimate the battery SOC, the value of the total charge, $Q_{\text{total}}$ is required. The formula is

$$Q_{\text{total}} = Q_{\text{max}} - Q_{\text{min}}$$

(2)

Hence, the estimation of SOC can be calculated as

$$SOC(t) = SoC(t_0) - \left(\frac{Q_{\text{out}}}{Q_{\text{max}}}\right) \times 100\%$$

(3)

Where:

- $SoC(t_0) = \text{initial SOC before charging/discharging phase}
- Q_{\text{out}} = \text{operating charge of the battery}
- Q_{\text{max}} = \text{maximum charge of the battery}$

2.3. Software Design

Software design was required to integrate the system with the hardware. Arduino Uno was used as the microcontroller or the brain of the system. Similar to the hardware, the software also divided into two-phase, i.e. charging and discharging. The flowchart of the charging and discharging phase are shown in Figure 3 and 4, respectively.

![Figure 3. Flow Chart Charging System](image1)

![Figure 4. Flow Chart Discharging System](image2)
3. Results and Discussions

3.1. Current sensor calibration

Figure 5 shows the calibration result of ACS current sensor. The calibration was carried out using a current of 1 – 5 Ampere, with 30 repetitions for each current. The maximum current of 5 Ampere was used due to the maximum output current of the power supply. Based on these results, it can be concluded that the current sensor is accurate and in good condition.

3.2. Voltage sensor calibration

The calibration of the voltage sensor was carried out using 5 different voltages with 30 repetitions for each voltage. The calibration obtained a value of $R^2 = 0.9969$ as shown in Figure 6. It means that the voltage reading from the sensor matched the voltage reading from the standard instrument (multimeter) with an accuracy of 99.6%. It can be concluded that the voltage sensor is accurate and well function.
3.3. Battery Charging Phase

The solar panel of 340 W was used as the power supply in the battery charging phase. The time required to fully charge the battery was 1.07 hours with the initial SOC value 20% and maximum SOC value 100% (when the battery is fully charged).

![Graphical representation of battery charging capacity versus SOC](image)

**Figure 7.** The graphical representation of battery charging capacity versus SOC

Figure 7 illustrates the results of battery charging phase when the value of the initial SOC is 20% and progressively increases with the increase in battery capacity. In the battery charging phase, the battery is fully charged when the SOC value reached 100%.

![Graphical representation of current versus time during charging](image)

**Figure 8.** The graphical representation of current versus time during charging

In this system, the Maximum Power Point Tracking (MPPT) charge controller was utilized to extract the maximum available power (output current and voltage) from the solar panel [5]. In the charging phase, output current value decreased with time as shown in Figure 8. It occurred due to the reduction of charging current by MPPT when the battery is fully charged. This condition is required to minimize overcurrent during battery charging. Hence in this system, the charging current was automatically cut-off when the battery is fully charged or the value of SOC reached 100% [6].
Figure 9. The graphical representation of battery charging capacity versus time

Figure 9 illustrates the battery capacity that was increased with time during charging. The rate of battery charging capacity is directly proportional with the current. The higher light intensity gave greater current [10] resulted in a faster rate of battery charging capacity. The maximum capacity of 9,6 Ah was charged in the charging phase as the output of 9,6 Ah was used during the discharging phase.

3.4. Battery Discharging Phase

A 5 W AC lamp and an inverter was used as a load during the battery discharging phase. The graphical representation of battery discharging capacity versus SOC is shown in Figure 10.

Figure 10. The graphical representation of battery discharging capacity versus SOC

Figure 10 shows that the SOC value was decreased with the reduction of battery capacity. The current was cut-off when the SOC value reached 20% or the amount of discharged battery capacity was 9,6 Ah.
The reading of discharging current was constant at 1.04 A. The selection of load is important in the BMS design since it will affect the duration of discharging. The greater load gave a faster rate of battery discharging capacity, resulted in a shorter duration of discharging.

The battery capacity decreased with time when connected to a load as shown in Figure 12. The time required to discharged 9.6 Ah of battery capacity was 17.712 seconds or 4.92 hours.
Using an operating current of 0.89 A during the discharging phase, SOC reading using CC method obtained quite significant value of error i.e. 23.5% at the first reading. To minimize this error and to increase the accuracy of SOC, the CC method can be combined with the I-observer method. The value of error using the combination of these two methods can be reduced to <3% [1].

4. Conclusions

A maximum battery capacity of 9.6 Ah was reached during charging phase with the required time of 1.07 hours using 340 W solar panel as the power supply. A battery capacity of 9.6 Ah was used during the discharging phase with the required time of 4.92 hours using 5 W AC lamp and an inverter as the load. The minimum and the maximum error of 7.8% and 24% respectively were obtained during discharging with an operating current of 0.89 A using CC method. The battery management system in this study was successfully designed and implemented to automatically cut-off the current when the SOC value is 100% (charging limit) and 20% (discharging limit).

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