Internet-of-Things-based Monitoring and State of Charge Estimation for Battery Management Systems

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***Abstract*—this paper considers the battery management system with State of Charge estimation for estimate the battery capacity percentage and using Internet-of-Things-based monitoring system for a real time monitoring purpose. This paper using a Coulomb counting method and open circuit voltage method to estimate the State of Charge for 7.5AH 12V lead-acid batteries. The open circuit voltage method used for determine the initial State of Charge of the battery, so the estimation would be more precision, the BMS also send data through internet for monitoring purpose using internet-of-things system. Using AWS cloud computing server, the Battery Management System Internet-of-Things has 79.32 ms latency, and 94,868% availability.**

Keywords—State of Charge, Internet of Things, Coulomb Counting, Lead Acid Battery

I. Introduction

Rising costs of supplying electricity from local grids, decreasing photovoltaic technology (PV) costs and decreasing feed-in-tariff tariffs under the current German Renewable Energy Sources Act in the future will increase monetary incentives to increase PV's own energy consumption. This is especially attractive for commercial buildings because for the most part there is enough space to increase the high capacity photovoltaic panels on their own roofs. Furthermore the purchase price of electricity from the local community grid for commercial consumers is currently around 20 € ct/kW h, which is higher than the cost of generating electricity from solar panels (about 8-12 € ct/kW h). In addition, the load profile in commercial applications is high and solar energy is generated. Hence, there is a great opportunity to save the economy.

Self-Consumption is defined as the percentage of that PV electricity consumed locally vs. total electricity generated by it a particular PV generator. If there is an amount of solar energy that exceeds the electrical energy, it can be stored in the battery for use at a later time when the solar electricity does not cover the load requirements. Thus the battery can be a means to increase Self-Consumption [1].

The BMS consists of hardware and software for battery management including, among other things, algorithms that determine battery status. Continuous determination of battery status during operation is called battery monitoring. Methods for monitoring battery status from charge, capacity, impedance parameters, available power, health status, and remaining useful life are reviewed with a focus on elaborating their strengths and weaknesses for use online BMS applications [2].

The Life-Cycle of a battery indicates the number of possible charge and discharge cycles before it loses its ability to store a useful charge (usually when the available capacity drops below 80% of the initial capacity) [3].

II. Related Works

A. *Battery Management System*

In recent studies P. Ningrum et al [4] make Battery Management System development using the same method namely coulomb counting and open circuit voltage to estimate system development for 4 AH Li-Ion battery. The main contribution of our work to the problem are we also using the same method to develop battery management system for Lead Acid Battery using Coulomb Counting Method and Open Circuit Voltage.

B. *Internet-of-Things based Monitoring*

Kamaruidzaman et al [5] make a similar Internet-of-things architecture based monitoring system for monitoring water quantity and water quality using Arduino Uno as the microcontroller. Ida et al [6] also conducted study on energy consumption monitoring system using Internet-of-Things architecture.

C. *State of Charge Estimation*

Its big concern to estimate the SOC for battery management system. The estimation accuracy of SOC does not only give an information about the remaining useful capacity, but also indicates the charge and discharge strategies, which have a significant impact on the battery. Several methods for estimating SOC have been introduced in the literature. In this paper three main categories of SOC estimation methods are identified as presented in Table 1.

1) Model Based

The model based methods used various models and algorithms to calculate the State of Charge. Actually, they require an equivalent model used to simulate the battery behaviors [7]. These methods also require an adaptive algorithm generally based on state observers such as Kalman Filter, Extended Kalman Filter [8] and others. Accordingly, their accuracy depends on the efficiency of the battery model and the precision of its characterized parameters.

2) Data Oriented

The data oriented methods, essentially based on artificial intelligence algorithms like neural network [9] and fuzzy logic [10], estimate the SOC accurately for all kinds of batteries without the need for any information about the internal behaviors of batteries. These methods require a large number of training data. Therefore, they need powerful and costly processing and their effectiveness depends on the accuracy of the learning data that used to train models.

3) Book Keeping

The book keeping methods is also known as Coulomb Counting method, consist of a temporal integrating of the battery current during charge and discharge. The accuracy of these methods is strongly dependent on the precision of current sensors. These non-model-based methods may accumulate errors caused by measurements, possible embedded noise and an inaccurate initial SOC [11][12].

TABLE I. REVIEW OF SOC ESTIMATION METHODS

SOC Estimation Method	Characteristics
Model Based Kalman Filter, Extended Kalman Filter	- Good Precision - Not Easy to Implement - Accuracy Depends on the precision of battery model
Data-Oriented Neural Network Fuzzy Logic	- High Accuracy - Hard to Implement - Accuracy Depends on Training Data
Book-Keeping Coulomb-Counting	- Average Precision - Simple to Implement - Cumulative Errors - Accuracy Depends on Sensor Measurement

III. BATTERY MANAGEMENT SYSTEM DESIGN

A. Battery Management System

The battery management system that used in this research are consist of a microcontroller type ESP32 NodeMCU, PZEM-004t for the load current and voltage, and for the research purpose ACS712 current sensor, and for the actuator that controls the discharge or charging process Relay 5V single channel used.

The Battery Management System Diagram shown on Figure 1, the system itself designed with 5V DC power supply to supply used sensors, the parameters that used for State of Charge estimations are Battery Voltage (DC), Battery Discharging Current (AC) and Battery Temperature (C^0). All of the parameters that used for State of Charge estimations are sent into local web server using Internet-of-Things system with additional parameters such as Load Current (AC) and Load Voltage (AC) after inverter from the battery load.

Relay 5V Single channel functions will trigger when on discharging condition and Battery State of Charge less than 30%, the Relay will switch to charging condition, also when on charging condition and Battery State of Charge more than 85%, the Relay will switch back to discharging condition.

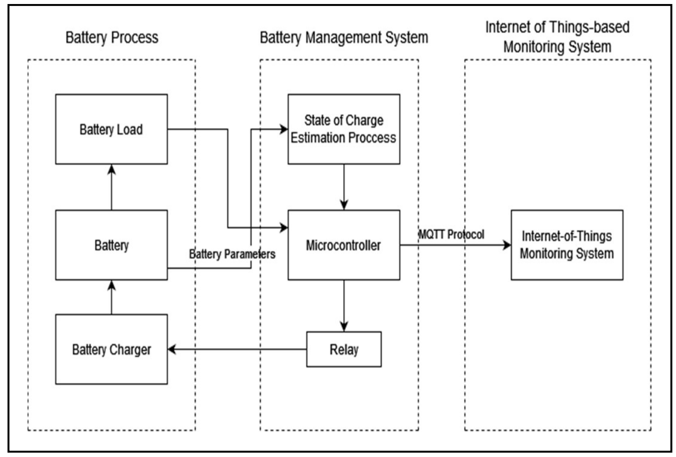

Fig. 1. Battery Management System Diagram.

B. State of Charge Estimation Method

There are a modified method used to estimate Battery State of Charge for battery management system (BMS) using coulomb counting method and open circuit voltage method would be implemented to this research. The method used here are briefly described.

1) Coulomb Counting Method

The Coulomb Counting method is a method that can be used to calculate the electric charge (coulomb) that enters or leaves the battery so that this method can determine the value of the capacity that is in the battery. Electric current is generated from several electric charges moving per unit time (seconds). The equation for calculating State of Charge (SOC) is shown by equations (1) and (2) where SOC_0 represents the initial SOC, I_{Bat} represents the current through the battery and Q_{rated} is the nominal capacity of the battery [13]. In general, the Coulomb Counting method is formulated as follows:

$$SOC = SOC_0 + \frac{\int_{t_0}^{t_0+t_n} I_{bat}\Delta t}{Q_{rated}} x\ 100 \quad (1)$$

$$SOC = SOC_0 - \frac{\int_{t_0}^{t_0+t_n} I_{bat}\Delta t}{Q_{rated}} x\ 100 \quad (2)$$

2) Open Circuit Voltage Method

The battery SOC estimation technique with Open Circuit Voltage (OCV) is one of the SOC estimation methods. Open circuit voltage is the voltage in an open circuit that is not connected to the load. Open circuit voltage represents the full source voltage because there is no voltage drop to the load or because the voltage is not shared with the load. OCV is a voltage condition when the voltage source is not connected to the circuit or the load.

The voltage at no load is the true voltage. Therefore, to get an accurate SOC estimation result, the battery must rest (rest time) to reach a state of cell balance before measuring the OCV of the battery or, it can be said that the battery state must be completely at no load. The output of the OCV method is a battery State of Charge (SOC) estimation value which can be used as a reference for measuring battery capacity [4].

C. Internet-of-Things Monitoring

The ESP32 NodeMCU to connect with website server or local website server using the protocol called MQTT, MQTT itself has low system requirements and high compatibility with internet-connected application, in this paper, author using local web server to do monitoring with the system and stored data via local database. Also using amazonaws.com as MQTT broker to test the latency and availability of the system.

IV. System Implementation

Variable reviewed in this research are the electric current and voltage from renewable energy, PLN electric current and voltage, battery charging/discharging current and voltage, battery temperature, actuator relay switch condition, and load current and voltage. After that, the developed State of Charge Estimation system and Monitoring with Internet-of-Things system is tested.

Internet-of-Things is a concept in which an electronic object has the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction [14]. Figure 2 shows the battery management system flowchart program and Figure 3 shows the Internet-of-Things website interface developed in this research.

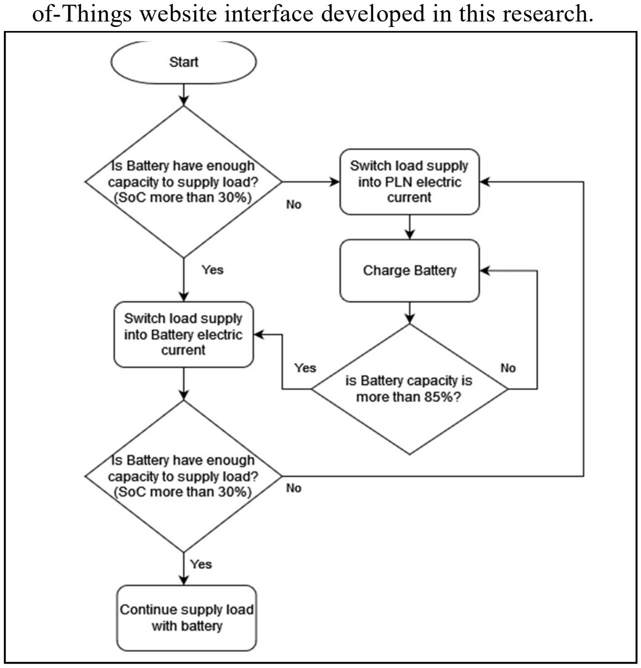

Fig. 2. Battery Management System Program Flowchart.

The Flowchart program that shows on Figure 2 programmed inside microcontroller ESP32 NodeMCU that will control the switching on battery charging or discharging status. The state of charge estimation method for battery management system is done by measuring the charge that is covered by the battery at its current state when charging or discharging. However, there are some inefficiencies when using this method, due to the conditions of the initial State of Charge reading [11]. An improved method used in this research using coulomb counting with open circuit voltage to determine the initial battery capacity to make estimation of initial battery State of Charge value.

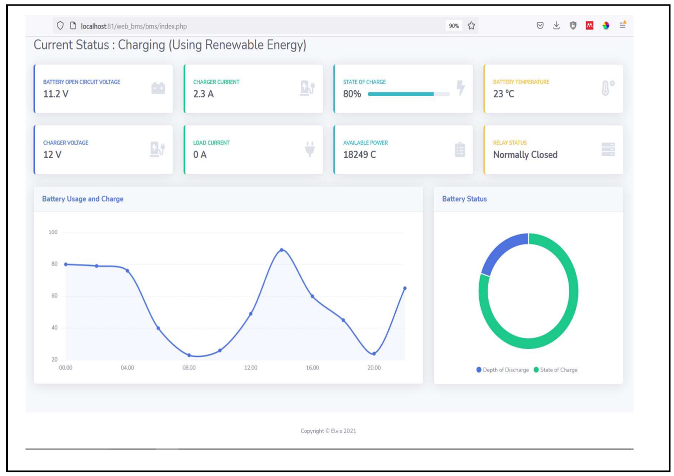

Fig. 3. Website Interface of Internet-of-Things System Design.

The interface information displayed on the Battery Management System website dashboard page as per Figure 3, including:

- Battery Usage and Charge, Line Chart that show event history of the battery state of charge over the last 24 hours.
- Battery Status, Pie Chart that shows currently battery state of charge.
- Battery Open Circuit Voltage, Charger Current, State of Charge, Battery Temperature, Charger Voltage, Load Current, Available Power, Relay Status.

V. Harware Implementation

A. Battery Parameter Planning

This paper uses a Lead Acid ($PbSO_4$) type battery with 12V and 7.5AH as an object in this research because of the cheap and easy rechargeable characteristic that Lead Acid Batteries have. On this implementation, this battery will be used on discharging condition. The battery characteristics shown in Table II below [15].

TABLE II. Battery Characteristics

Battery Type	Characteristic		
	Pros	Cons	Power Density
Lead Acid	Cheap, powerful, easy rechargeable, high power output capability	Very heavy	7 Wh/kg
Nickel Cadmium	Inexpensive, rugged, easy to recharge	Lower power density, contains toxic metal	60 Wh/kg
Nickel Metal Hydride	High power density	More expensive than Ni-Cad, self-discharge quickly	100 Wh/kg
Lithium Ion	Ultra-light, high power, high capability, high cell voltage	Expensive, delicate	126 Wh/kg
Alkaline	Popular, well known, safe	Non-rechargeable, low-capability	100 Wh/kg

B. State of Charge Estimation Test

The open circuit voltage test is used to obtain parameter data in the form of current, voltage, and time when the open circuit voltage is used to determine the OCV - SOC relationship on a lead acid battery.

From the test results, it is then used to determine the State of Charge estimation using the modified Coulomb counting method with open circuit voltage method.

C. Dummy Load

The dummy load used in this research are resistor as the load, and the specifications are as follows: R = 6Ω, W = 100W.

VI. Experimental Result

A. State of Charge Estimation

After testing and taking actual data, multiple constant current tests are obtained and the parameters of current, voltage, discharge time are obtained. From this parameter, the State of Charge can be estimated using the Coulomb counting method with open circuit voltage measurement.

The tests performed when testing the battery characteristics data in discharging condition, the first thing to do is charging the battery until its maximum battery voltage, and then discharge it with the dummy load. The discharge process is carried out from 100% state of charge to 0% state of charge.

TABLE III. Data State of Charge against Terminal Voltage

State of Charge (%)	*Terminal Voltage (V)*	*Total Discharged (As)*	*Total Available (As)*
100%	12.67	0	23478
95%	12.60	1173.9	22304.1
90%	12.51	2374.8	21130.2
85%	12.49	3548.7	19956.3
80%	12.47	4722.6	18782.4
75%	12.39	5896.5	17608.5
70%	12.33	7070.4	16434.6
65%	12.28	8244.3	15260.7
60%	12.20	9418.2	14086.8
55%	12.16	10592.1	12912.9
50%	12.14	11766	11739
45%	12.13	12939.9	10565.1
40%	12.05	14113.8	9391.2
35%	11.99	15287.7	8217.3
30%	11.90	16461.6	7043.4
25%	11.85	17635.5	5869.5
20%	11.75	18809.4	4695.6
15%	11.69	19983.3	3521.7
10%	11.62	21157.2	2347.8
5%	10.80	22331.1	1173.9
0%	10.51	23478	0

The number of coulombs remaining in the battery is obtained by experimenting with emptying (Discharge) the battery when it is 100% or full, calculated by the amount of current that comes out multiplied by the time it takes for the battery to be empty or 0%, it is found that the number of Coulombs (Ampere second) on the battery used in the experiment is about 23478 Coulomb, with an estimated time of about 12043 seconds or about 3 Hours 20 Minutes and 43 Seconds. The graph of State of Charge against Open Circuit Voltage shown on Figure 4.

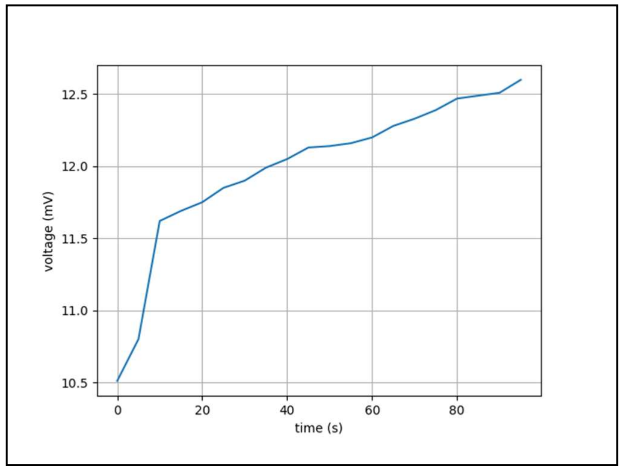

Fig. 4. State of Charge against Open Circuit Voltage measurement.

B. Performance Testing

In this research, the data transmissions are carried out 12043 times. And two analysis are used to test the Internet-of Things system performance, namely latency and availability (using amazonaws.com as MQTT broker). Latency or delay is the time needed to transfer data package from origin to destination in milliseconds (ms) [16]. Whereas availability is a metric to assess the percentage possibility that the system can operate and perform its functions at a certain time. Using AWS cloud computing server, the Battery Management System Internet-of-Things has 79.32 ms latency, and 94,868% availability.

VII. Conclusions

In this paper, a modified coulomb counting method used to get into objective of this work that was to estimate the state of charge of lead acid 12V 7.5AH battery using coulomb counting and open circuit voltage methods, battery management system that consist of microcontroller ESP32 NodeMCU used as processing hardware, ACS712 current sensor to measure the battery discharging current into dummy load that have 6 ohm resistance to discharge about ~2 amperes on the discharging current, using voltage sensor module to measure the open circuit voltage of battery, and lastly make the monitoring system using internet-of-things. The method was used to estimate the state of charge of battery was success, and the internet-of-things also succeeded to perform monitoring system that provide excellent data package transfer speed and delivery for 79.32 ms latency and 94,868% availability.

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