Research Article

Identification of Flowing Electrolyte Lead Acid Battery Operating Voltage

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Abstract.
Identification of the operating voltage of a lead acid battery with 30% sulfuric acid electrolyte flow has been carried out. The battery consists of six cells with Pb and PbO as electrodes. The battery is equipped with a 1200 ml reservoir system to collect electrolyte and supply electrolyte to each cell. Each cell has electrolyte inlets and outlets at the top and bottom that circulate through each cell using a peristaltic pump. The battery prototype built was tested for five charge-discharge cycles with a constant current of 2 A for the charging process and 0.5 A for the discharging process using Turnigy Accucell. During the charge-discharge cycle test, monitoring and recording of voltage data is carried out using a Laptop PC. Data processing uses WebplotDigitizer and Microsoft Excel for data graphing. The results are analyzed and used to identify the operating voltage of the battery by taking the average voltage over five charge-discharge cycles. The average voltage is 13.98 V for the charging process and 12.11 V for the discharging process. Six-cell battery with full capacity works at a voltage range of 12.11-13.98 V. In the process of charging with a constant current of 2 A, the battery takes an average of 7.49 hours. So, the charging capacity can be estimated at 14,980 mAh. Whereas the battery discharge process takes an average of 11 hours with a constant current of 0.5 A to a voltage drop of 10.81 V. The resulting capacity of the discharged battery is 5500 mAh.

Keywords: flowing electrolyte, lead acid battery, operating voltage

1. INTRODUCTION

Electrical storage system is a vital technology for the renewable energy plant. One of main applications of this technology is providing stability of voltage to ensure reliable energy supply and increase the share of renewable energy in the energy production. Electrical storage systems that are commonly used nowadays are supercapacitors and the battery technology [1]. Battery is the easiest to build electrical storage system and it is promising in terms of installation, convenience and stability of the energy supplied. Various studies of batteries as electrical storage system focused on the development of any potential aspects integrated to solar power plant. Some of them discuss the battery storage system integrated to wind power plant [2].

Basically, the idea of energy storage technology tends to focus on how to store electrical energy produced from renewable energy whose output is unstable depending on the weather. This is a weakness that must be resolved through the creation of an electrical energy storage system that is stable and available at any time. The basic idea concentrates on the application of batteries as energy storage systems on a large scale. Many articles have discussed in depth the application of various types and models of batteries according to their function in large-scale energy storage [3]. The discussion of redox flow batteries as large-scale energy storage systems has been studied periodically. Flow battery is a battery technology designed to store energy in its electrolyte. In contrast to conventional batteries where the energy storage role is held by the electrodes. The redox flow battery arrangement is unique in that it has the additional electrolyte stored in an external chamber separate from the battery cells. A stream of electrolyte is pumped from the reservoir through the unit cell to produce a redox reaction. This type of battery can be designed to have one unit cell with two different electrolyte tanks. As for the previous research, the design of one unit cell with one electrolyte tank is known as a single electrolyte redox flow battery [4].

Operational mode of this battery technology depends on the reduction and oxidation reactions from the electrolyte. In a charging process, one electrolyte undergoes a reduction reaction on the positive electrode and another electrolyte undergoes oxidation reaction on the negative electrode. Through this reaction, electrical energy is converted into chemical potential energy during the charging process, and vice versa, the chemical potential energy is converted into electrical energy during the discharging process. This process is reversible so the battery can be recharged (rechargeable). The capacity and energy density of this battery can be independently managed. Energy density depends on the amount of electrolyte stored in the external tank. While the capacity depends on the area of active materials on the electrodes. The flow battery technology has a great potential in storing large scales of energy and providing electrical energy continuously up to 10 hours [5].

The advantages of flow battery technology have prompted many authors to study redox flow, emphasizing the energy density characteristics, electrolyte type characteristics, comparison of static and dynamic electrolyte batteries based on energy efficiency, electrolyte flow rate characteristics, electrolyte type characteristics (single or multiple electrolytes), the physical shape of the electrode , capacity and charge-discharge current based on battery performance [6]. However, there are several obstacles faced by researchers, practitioners and industry in developing batteries as energy storage systems for renewable power plants. Some of these obstacles stem from the stability of the energy supplied over a long period of time, such as the stability of the quality of the output power produced which includes frequency, distortion, control system and battery working voltage. Challenges related to the stability of energy supply have prompted research to identify the operating voltage of a single-flow battery through modification of the type of electrode, electrolyte and battery cell. This study refers to the configuration of the Soluble Lead Flow Battery (SLFB) standard model used in M. Khrisna's research [7].

M. Khrisna's research configuration considered the cell dividing membrane into SLFB. The three configurations include undivided, half divided and fully divided systems. Undivided system is a traditional flow battery system or single flow battery system. This separatorless system is a very simple and low cost single flow battery system but its performance is limited by the effect of abnormal deposit growth which can cause electrical contact [8]. M. Khrisna has explained well the effect of precipitate growth on microporous separator membranes at positive and negative electrodes. However, this issue is not supported by battery performance voltage identification. So this study aims to identify battery performance voltages that focus on designing undivided battery systems or single-flow battery systems.

2. RESEARCH METHOD

2.1. Experimental Procedure

The research method was carried out experimentally on a laboratory scale, which consisted of twelve stages, namely: 1. Preparation stage, 2. Cell system construction, 3.

Electrolyte solution preparation, 4. Electrolyte reservoir construction, 5. Battery assembly, 6. Battery voltage monitoring system assembly, 7. Battery initial discharge test, 8. Data recording, 9. Charge-discharge test for 5 cycles, 10. Data recording for the 5 charge-discharge cycles, 11. Data processing with Web plot Digitizer and 12. Analysis and identification of battery operating voltage. The twelve phases of the research are described using a research flow chart as shown in Figure 1. In Phase 1, preparations were made to prepare tools and materials for this study, which includes PC laptops, Turnigy Accucell-6 80W as a monitoring device for voltage data real-time recording, DC power supply, peristaltic pump, digital multimeter, clamp wire, socket, solder, lead wire, glue gun, cutter, H_2SO_4 electrolyte solution, an accumulator consisting of six cells with Pb as the negative electrode and PbO electrode as the positive electrode [9].

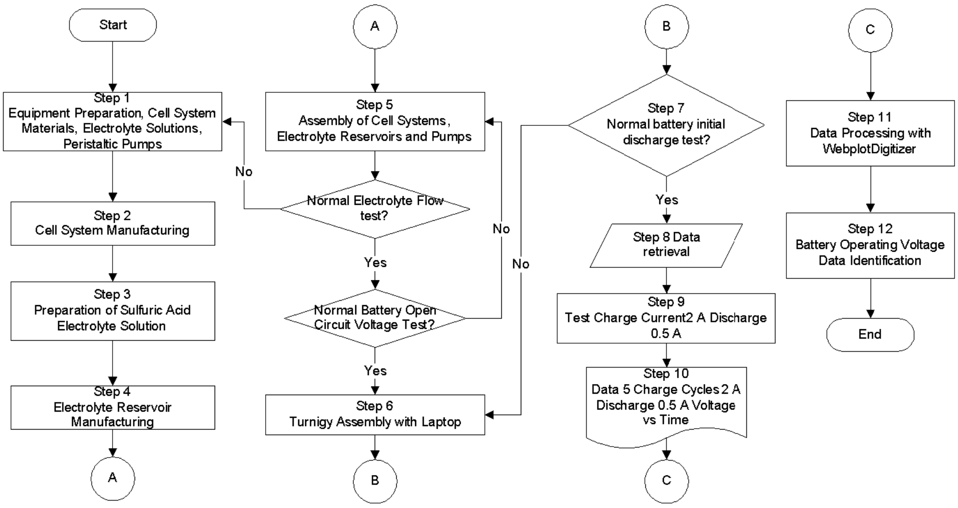

Figure 1: Flow chart of the experimental procedure of operating voltage.

2.2. Battery System

Battery is designed to resemble an accumulator consisting of 6 unit cells, but the electrolyte is modified to be circulated. Each cell produces an open circuit voltage of +10.8 volts. Battery made is a modification of an accumulator with Pb and PbO electrodes and electrolyte 35% H_2SO_4. Each cell has an electrolyte inlet at the top and an outlet at the bottom for electrolyte circulation through each cell [10]. Transparent tubes are installed at each inlet and outlet of the unit cell to facilitate monitoring of electrolyte flow from a 1200 ml capacity reservoir. The cell outlet is connected to the electrolyte reservoir inlet so a complete arrangement is made for the electrolyte circulation. The pump used to circulate the electrolyte is low power consumption peristaltic pump [11]. The electrolyte flow is kept at a relatively constant rate during the battery test. The

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battery test is carried out with a constant current method for 5 charge-discharge cycles, 2 A for the charging process and 0.5 A for the discharging process.

2.3. Data Recording

After stages 1 to 5 are carried out, the battery system is connected to Turnigy Accucell-6 which is a management system for the charge-discharge test (stage 6). The Turnigy Accucell-6 is also connected to a laptop with Chargemaster 2.02 software installed for monitoring and recording battery voltage data [12]. The battery must be empty before the 5 cycle test (initial discharge) as an indication that the battery is able to discharge and work normally which can be indicated by the initial battery voltage and discharge duration time. If the battery exhibits normal behavior during initial discharge, the modified battery has not failed in the electrolytic tubing or installation. The initial discharge of the battery was carried out using the 2 A constant current method, the trend in battery voltage was observed and recorded until the discharge stopped when the voltage dropped to 10.8 volts. Cyclic tests and data recording are continued for 5 simultaneous charge-discharge cycles to identify the resulting voltage trend for battery operating voltage range identification. The 5-cycle test is carried out using a constant charging current of 2 A and a constant discharging current of 0.5 A. The 5 cycle test takes 96 hours or 4 days to complete.

3. RESULTS AND DISCUSSION

The results of cyclic test measurements show a trend of charging and discharging voltages five times in a row. These results are used to identify the battery charging operating voltage range as shown in Figure 2 and the battery discharge operating voltage range as shown in Figure 3.

Based on Figure 2, the voltage chart for testing 5 charging cycles has the same characteristics. The charge voltage rises steadily from 11.3 volts to 14.4 volts for 1.5-2 hours where 14.4 volts is the charging saturation voltage. In this saturated state, the battery is assumed to be fully charged which is shown to have reached its maximum voltage [13]. Saturation time reaches 5 hours and charging takes around 7 hours. Detailed battery operating voltage data for the charging process is shown in Table 1.

Table 1 presents data for initial voltage (V_0), final voltage (V_f), average voltage (V_{mean}) and duration for each charge cycle. The result shows that all charge cycles have

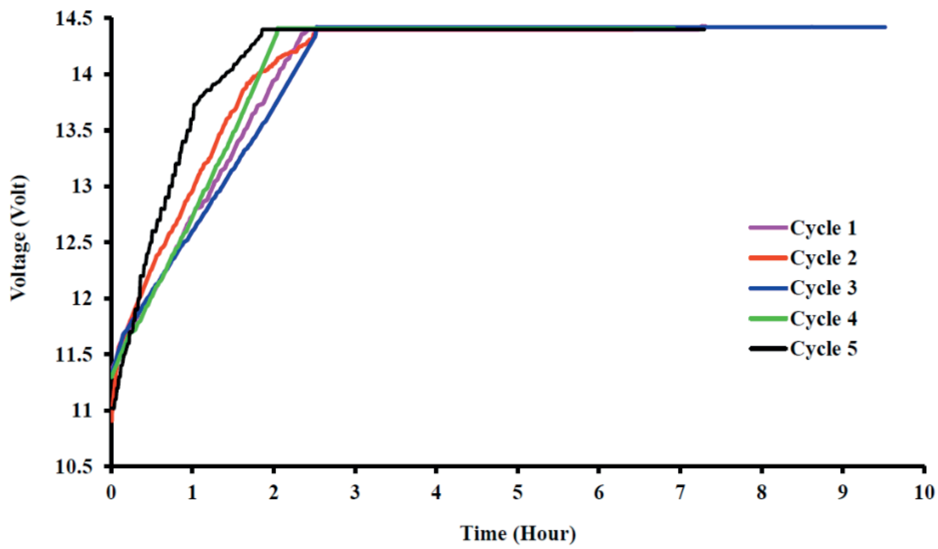

Figure 2: Voltage trend of 5 charge cycles with a constant discharge current of 2 A.

Table 1: Data for charge operating voltage identification.

Number of Charge Cycle	V_0 Charge (Volt)	V_f Charge (Volt)	V_{mean} Charge (Volt)	Charge Time (Hour)
1	11.36	14.43	13.98	7.30
2	10.91	14.4	13.84	6.41
3	11.32	14.42	14	9.52
4	11.3	14.41	13.98	6.92
5	11.02	14.4	14.13	7.29

relatively equal values of V_0, V_f and V_{mean}. Initial voltage has an average value of 11.81 volt, final voltage average value is 14.41 volt and average charge duration is 7.49 hours. The end of the charging process is indicated by a data recording which is automatically terminated by the Turnigy Accucell-6. Based on the charging duration of the five times test obtained at an average of 7.49 hours at a constant charging current of 2 A, it can be assumed the charging capacity of this battery is around 14980 mAh. Average charge voltage value during the charging process is 13.98 volts and this value is operating voltage battery charging.

Discharge cycle test with a constant current of 0.5 A is done after each charge cycle test is conducted. Figure 3 shows discharge voltage trend, showing a sharp drop from initial voltage of 13.35 volt to 12.65 volt over the first 10 minutes. In the first 10 minutes, the battery charge is not fully stored which is assumed during this period to be the open circuit voltage range. After the first 10 minutes, the voltage gradually decreased for 11 hours until it dropped sharply to a cut-off voltage of 10.81 volts. This cut off voltage

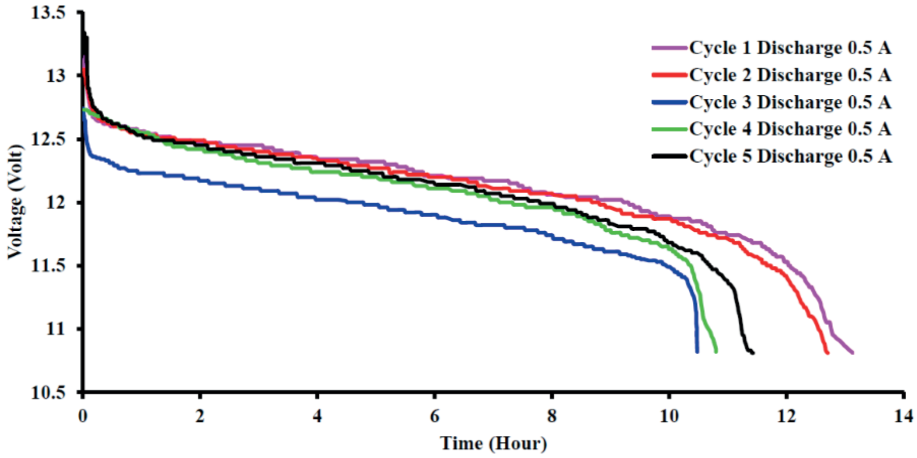

Figure 3: Voltage trend of 5 discharge cycles with a constant discharge current of 0.5 A.

assumes that the battery is running out of energy [14]. Detailed operational voltage identification data for the discharge process are shown in Table 2.

TABLE 2: Data for discharge operating voltage identification.

Number of Discharge Cycle	V_0 Discharge (Volt)	V_f Discharge (Volt)	V_{mean} Discharge (Volt)	Discharge Time (Hour)
1	13.07	10.81	12.15	12.71
2	13.05	10.81	12.14	10.48
3	12.74	10.82	11.95	10.48
4	12.73	10.82	12.12	10.79
5	13.35	10.81	12.19	11.43

Tests for 5 cycles of discharge process have been carried out using 0.5 A constant current method. Identification of discharge operational voltage includes initial voltage (V_0), final voltage (V_f) and average voltage (V_{mean}) of each discharge cycle as shown in table 2. The results show that all charging cycles have relatively the same values of V_0, V_f and V_{mean} are 12.98 V, 10.81 V and 12.11 V respectively. This means that each cell has an average voltage ±2 V. Average voltage (V_{mean}) is the sum of initial discharge voltage values up to 10.81 V cut off divided by total voltage data recorded during the discharge process. Duration of each discharge cycle is approximately 11 hours. The discharge process is terminated automatically by Turnigy Accucell-6 when the battery voltage drops to a cut-off value of 10.81 V. Average V_{mean} value is 12.11 V being the operating voltage of battery discharging. Average discharge time is up to 11 hours using the 0.5 A constant current method, it can be assumed that the discharge capacity of this battery is around 5500 mAh.

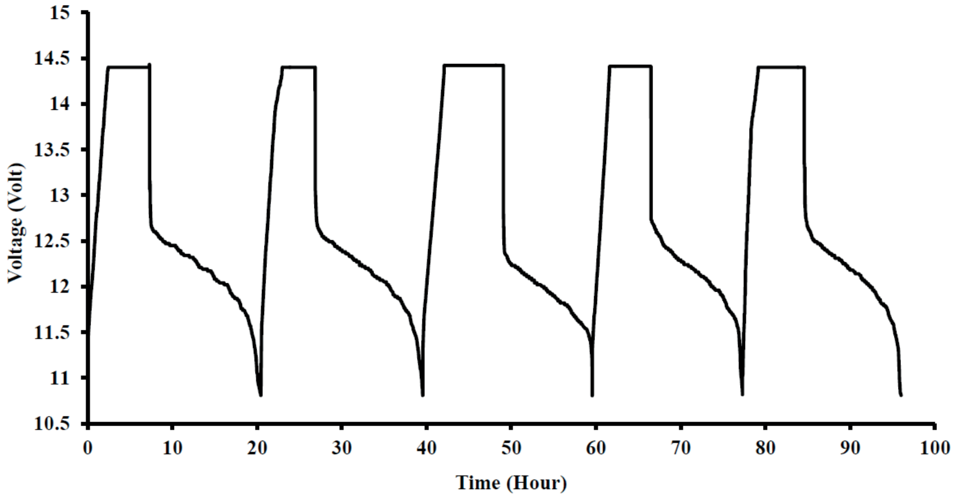

Figure 4: Voltage trend for five charge-discharge cycles with a constant charge current of 2 A and constant discharge current of 0.5 A.

Figure 4, graph of the combined voltage of 5 charge-discharge cycles shows that the third cycle has a longer charging duration of 2 hours compared to the first and second cycles, this is indicated by a wider curve in the third cycle. This is because the discharge of the first and second cycles takes longer so that the electric charge has to be completely discharged, the impact of the third cycle charging process takes 2 hours longer. The graph in Figure 4 shows identical trends for all 5 charge-discharge cycles indicating a stable battery performance over 5 cycles. It is also confirmed in Table 1 and Table 2 that the voltage value shows good performance without any indication of performance degradation for 5 cycles [15].

4. CONCLUSION

Operating voltage of a 6-cell lead acid redox flow battery in a constant current charging process of 2 A and a constant current discharge process of 0.5 A is 13.98 V and 12.11 V, respectively. The result is that the battery has an operating voltage range of 12.11 V - 13.98 V. The average charging duration is 7.49 hours and average battery charging capacity is 14980 mAh. Meanwhile, average discharge duration is 11.48 hours and average battery discharge capacity is 5500 mAh. Anomaly occurs in the third cycle which takes 2 hours longer than the other charging cycles. It is assumed that the electric charge of the battery is forced out more in the first and second cycles of discharge, so it takes longer for the third cycle to charge. It is recommended for further research to carry out a test of 10 charge-discharge cycles in order to examine other anomalous patterns.

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