Evaluation of Charging Profile of Lead Acid Battery used in Electrical Scooter

M F Mohd Ab Halim 1, K A M Annuar 1, M H Harun 1, N F Anuar 1, M A ‘Azam Mohd Abid 2, M A Zainuddin 3

1Center for Robotics & Industrial Automation (CeRIA) Faculty of Electrical and Electronic Engineering Technology, Universiti Teknikal Malaysia Melaka (UTeM), Malaysia.
2Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka (UTeM), Malaysia
3Cervello Tress Sdn Bhd

Email: mohd.firdaus@utem.edu.my

Abstract. This paper discusses about the charging profile of a lead acid battery used in electrical scooter. Lead acid battery is a robust and widely used in small electric vehicle because of its price tag. It can be considered to be one of the mature battery in the market thus the charger too. Each lead acid battery from different manufacturer possess different characteristic hence not all charger is suitable for any lead acid battery. The experiment was conducted to determine the charging profile of a 12 V cells lead acid battery connected in series to make 48V battery source. The charging current and voltage were logged and analysed for 3 charge rate. The measurement design of experiment is presented in detail as well. The experiment was repeated for at least four times. As the charging rate increase, the time taken for the charging process to complete became shorter. Nevertheless, we saw that the full battery capacity reduced at faster rate for a higher charger rate. The charging profile of the battery are also validated by the single-cell 12V battery to prove the series and parallel charging significance.

Introduction
In recent years’ electrical vehicle technology has been rapidly developed. The demand for mobile energy storage were increase as it is the main component for electrical vehicle. Lithium based battery has become the first choice for many high end EV manufacture to power their vehicle versus lead acid battery due to its weight and its energy density. Nevertheless, lead acid battery is not phasing out soon because it is inexpensive, reliable and well-understood technology, lowest self-discharge rate and capable of high discharge rates. Even though we cannot improve the energy density of lead acid battery, we can definitely improve the charging rate and avoid infant mortality through improperly charge and bad maintenance. The objective of this research is to evaluate three chargers with different charging rate and make recommendation to the user in terms of its advantages and disadvantages. Table 1 gives broad summary of the installed cost, life and efficiency of various battery type [1]. State of Charge (SOC) and Depth of Discharge (DOD) parameters are expressed in equation (1) and (2).
Table 1. Comparison of key parameters for battery type

| Battery type         | Life, years | Cycles | Energy efficiency, % | Installed system cost, $/kWh |
|----------------------|------------|--------|----------------------|------------------------------|
| Lead-acid            | 15         | 2000   | 85                   | 400–600                      |
| Ni-Cd                | 20         | 2000   | 85                   | 1200–1500                    |
| Li-ion               | 15         | 2500   | 90                   | 1250–1500                    |
| Na-S                 | 10         | 4000   | 75                   | 600–800                      |
| Na-NiCl2             | 10         | 4000   | 75                   | 750–1000                     |
| Vanadium redox batteries | 15     | 10000  | 70                   | 750–850                      |
| Zn-Br2               | 7          | 3000   | 70                   | 600–800                      |

\[
SOC = SOC (t_0) + \frac{1}{C_{\text{rated}}} \int_{t_0}^{t} (I_b - I_{\text{loss}}) \, dt
\]  

(1)

where SOC \((t_0)\) is the initial SOC, \(I_b\) is the battery current, \(C_{\text{rated}}\) is the rated capacity of the battery and \(I_{\text{loss}}\) is the current consumed by the loss reactions.

\[
DOD = \frac{C_{\text{discharged}}}{C_{\text{rated}}} \times 100\%
\]  

(2)

In recent studies, where different charging rate being applied to a 900 mAh battery for 500 cycle, as the charging current increases, the cell capacity reduced dramatically [5]. Equation 3 shows the equation to find the amount of charging current based on charging rate.

\[
I_{\text{charge}} = I_{\text{rated}} \cdot c
\]  

(3)

where \(I_{\text{rated}}\) is the rated current, \(I_{\text{charge}}\) is the charging current of the battery in Ah unit and \(c\) is the rate of charging. The voltage level for charging and charging rate that enables faster charging process in both cases were considered for the selection of the charging method and parameter appropriate to achieve the required objective.

**Methodology**

1.1. Methods of Charging

A common lead acid battery was discussed recently in [6][7][8][9]. These methods were combined to form a multi-method or stage that utilize each method at different time-frame during charging process. Figure 1 shows the graph of voltage and current versus time of a multi-stage charger [10].
Figure 1. Voltage and current against Time during multistage charging

Multistage charger in this experiment is a combination of C-C, C-V and TR where the maximum charging rate is 0.133 to 0.25. The battery charger is not design in this experiment, instead three different chargers with the characteristic described earlier were chosen and tested. We chose this charging rate was the batteries and discharge load is available in our premise and were contributed by our research partner. For 3.0 amperes charger, the experiment is replaced with interpolation data.

1.2. Design of Experiment for Data Logger
In order to understand the behaviour of charging profile across three different charging rate, a data collection was performed. The parameters that were required were voltage, current and temperature for all three charging rate. The battery setup is shown in Figure 4 [11]. A 12V-14V lead acid battery cell were connected in series to achieve the 48V-56V potential across charging terminal. This setup was chosen to simulate the requirement of the application of electrical scooter. Figure 2 shows the block diagram to log voltage, current and temperature while Figure 3 shows the hardware setup for data logging during the charging process.

Figure 2. Data Logger block diagram to log voltage, current and temperature.
Figure 3. Data logging hardware and batteries.

The charging profile is validated with single-cell charging setup. In single-cell charging, the charging and discharging current are 1.2A (cycle 2&3), 2.5A (cycle 4&5), 3.6A (cycle 6) respectively. The starting capacity for charging is 11V while the stop capacity for charging is 14V.

Result

3.1 Battery capacity initial and final condition

Figure 4 shows the box plot of initial and final condition of battery charging process for 3 sets of batteries. This initial condition will be used as the starting point for battery to start the charging process and the final condition will be used to end the charging process. The highest remaining capacity 46V was chosen because this is the first level which the motor with no load stop running. The lowest reached capacity 58V was chose as the target level for full charged battery.

3.1 Charger Rate 0.133 (1.6 A)

Figure 5 shows the charging profile of the charger rated at 1.6 Amp.
Figure 5. Charging Profile of 0.133 (1.6 A) charging rate

3.2 Charger Rate 0.166 (2.0 A)
Figure 6 shows the charging profile of the 2.0 amperes charging rate and batteries temperature during charging process.

Figure 6. Charging Profile of 0.166 (2.0 A) charging rate

3.4 Single-cell charging profile
In a single-cell charging profile, a 12V battery 12 Ah is injected with a programmed current and voltage for 2.6 days charging and discharging cycle. In Figure 7, as the charging current increase, the capacity decrease. The complete charging and discharging cycle also decrease from 0.3 days to 0.1 days.
Figure 7. Single-cell charging profile for 1.2A, 2.5A and 3.6A for 12V 12Ah scooter battery

Conclusions

In this experiment, we prove that as the charger rate is increased, the time taken for the battery to be fully charge is decrease, and for this case between 30 minutes to 1 hour. Assuming that the full capacity is 58V, 2.0A charger can only reach 97.3% of the full battery capacity compares to 1.6A charger. The battery technical specification also highlights the capacity retention difficulty when higher charging current is used for the charging process. When the result in single-cell charging profile is compared with the charging profile of 1.6A and 2.0A, it validated the trade-off concept between faster charging time with the increase of degradation of battery capacity. Hence, for lead acid battery user who are planning to improve the charging time, it is worth to note this drawback.

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