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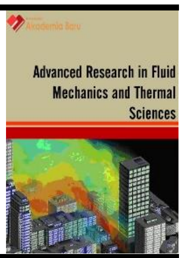

Evaluation of Charging Profile and Thermal Behaviour of Lead Acid Battery

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ABSTRACT

This paper discusses about the impact of battery charging rate towards lead acid battery. Selecting wrong battery charger may result in premature failure of the batteries. This experiment provides a technical analysis which helps the user to determine suitable charger for their respective application. Two different charger was with similar algorithm and different charging rate were tested on 48V series 12 V cells lead acid battery. The charging current, voltage and temperature were logged and analysed. The measurement design of experiment is presented in detail as well. The experiment was repeated for 4 times. The data taken from the higher charging rate and lower charging rate were compared. Fast charging of lead acid battery demonstrate in this paper shows it can reduce the charging time between 30 minutes to 1 hour. However, its capacity only reach 97.3% of the full battery capacity compares to the slower charger while the thermal behaviour for both charger were comparable during the charging process.

Keywords:
Multistage charging techniques, charging profile, battery reliability and lead acid battery

1. Introduction

Lead acid battery may not be a popular choice as a portable energy source but it still plays an important role in our daily life. The most common reason it is still widely used are it is inexpensive, reliable and well-understood technology, lowest self-discharge rate and capable of high discharge rates. It is important to note that the disadvantages are something we shouldn't ignore. Poor weight-to-energy ratio, cannot be stored without the need to maintain its voltage level, limited number of full discharge cycles, less environmentally friendly and can improperly charge would result in thermal runaway. The objective of this research was to evaluate two chargers with different charging rate and make recommendation to the user in terms of its advantages and disadvantages. If wrong charger parameters were chosen for an application such as wheelchair [1], it may result in battery

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reliability failure before its expected life cycle. If this battery is charged properly, it could help to eliminate the problem of thermal runaway and increase the life cycle which would result in less battery waste to manage hence reducing impact to the environment. In this paper, two charging method will be analyzed and evaluated. The objective of this experiment was to determine how can charging method effects the reliability or life cycle of a lead acid battery.

Battery charging technology evolves rapidly since the integrated circuit (IC) reinvent the battery charging design. IC minimize the use of individual components to create a battery charger with specific algorithm as application desires. Multistage charging method was one of the methods which uses IC capability to perform complex charging algorithm to enhance either the charging rate or increase the life of a battery.

Even batteries of the same chemistry, not all batteries are created equal. Batteries can be either superior in energy or power, but it cannot exhibit both quality. Manufacturer usually will classify batteries using these qualities. For this reason, this kind of study is only performed by the battery manufacturer and its stakeholder that is not shared in research community. Besides that, it is also classified as longer battery life with the power and energy as trade-off. This classification is associated with the level of State of Charge (SOC) which determine the change in battery capacity over time and Depth of Discharge (DOD) which implies the percentage of battery capacity that has been discharged expressed as a percentage of maximum capacity [2]. Both parameters are expressed in Eq. (1) and (2).

$$SOC = SOC\ (t_o) + \frac{1}{C_{rated}} \int_{t}^{t_o+\tau} (I_b - I_{loss})\, dt \tag{1}$$

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

$$DOD = \frac{C_{discharged}}{C_{rated}}\ x\ 100\% \tag{2}$$

One of the most important rules for charging any type of batteries are the voltage accuracy. Lower voltage level increases the cycle life of the battery while higher voltage level cuts the life of the battery prematurely [3]. Nevertheless, this data in [3] may be argued as 4.25 voltage level shows it can improve cycle life compares to 4.2 voltage level. This behavior shows that the voltage level should be lower and near to the rated voltage with a very minimum margin of error.

Charging current also contributes to the battery cycle life. In recent studies, where different charging rate being applied to a 900 mAh battery, as the charging current increases, the cell capacity reduced dramatically when charged for at least 500 cycle [4]. Equation 3 shows the equation to find the amount of charging current based on charging rate.

$$I_{charge} = I_{rated}\ (c) \tag{3}$$

where, I charge is the charging current, I rated is the rated current of the battery in Ah unit and c is the rate of charging. The voltage level and charging rate in both cases were used to select the charging method and parameter appropriate to achieve the required objective.

2. Methodology

2.1 Lead Acid Charging Method Selection

There are four methods for charging lead-acid batteries frequently used that is constant-current charging method (C-C), constant-voltage (C-V) charging method float charging method (FL) and trickle charging method (TR). In the C-C method, a fixed current is applied for a certain time to the battery to recharge it. In the C-V charging method, a fixed-voltage is applied. In the FL charging method, a constant voltage, set to a value just sufficient to maintain the full charge is applied to the battery. In the TL charging method, a low-value constant current about 1% of rated battery is applied to the battery [5-7]. Usually all these methods are combined together by using its behavioral against the battery at specific charging period. An example of charging profiles that combine two charging method are shown in Figure 3.

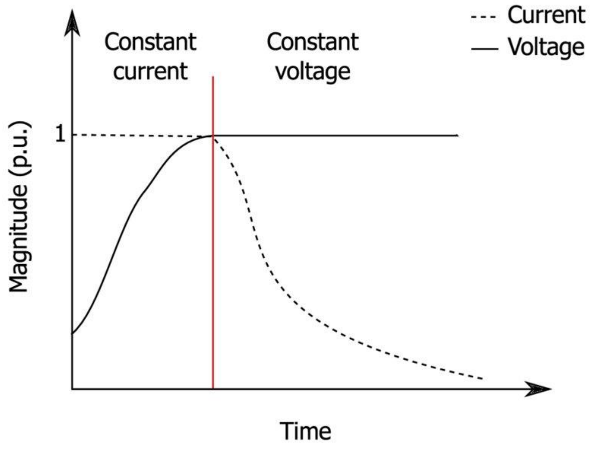


Fig. 3. Constant Current + Constant -Voltage battery charging profile [8]

Multistage charger in this experiment is a combination of C-C, C-V and TR where the maximum charging rate is 0.133 and 0.166 correspond to 1.6 amperes and 2.0 amperes. The battery charger is not design in this experiment, instead two different chargers with the characteristic described earlier were chosen and tested. The reason for choosing this charging rate was that the battery sets and charger were contribute by the distributor and used in their electrical scooter product.

2.2 Design of Experiment for Data Logger

The objective of this experiment is to collect and analyse the voltage, current and temperature of a 60V battery used in electrical scooter. A 12V lead acid battery cell were connected in series to achieve the 60V potential across charging terminal shown in Figure 4. The block diagram for this experiment is shown in Figure 5. Figure 6 shows the data logger in graphical view [9].

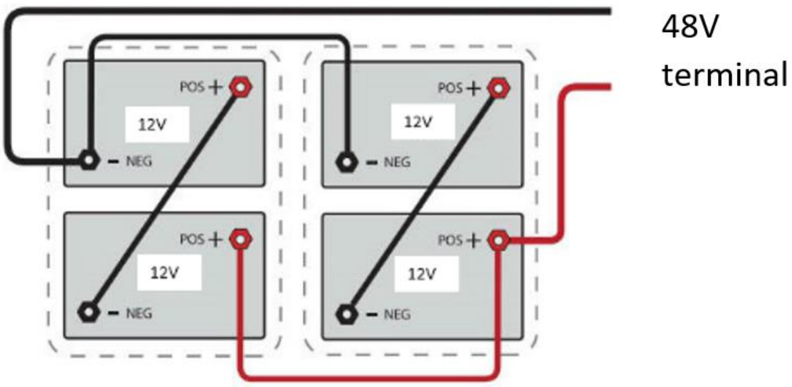


Fig. 4. Battery configuration [9]

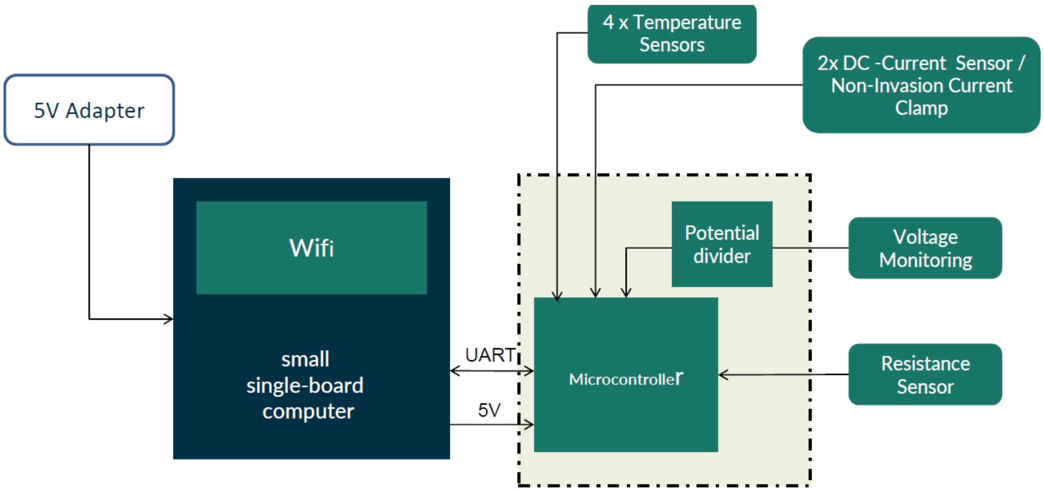


Fig. 5. Data Logger block diagram

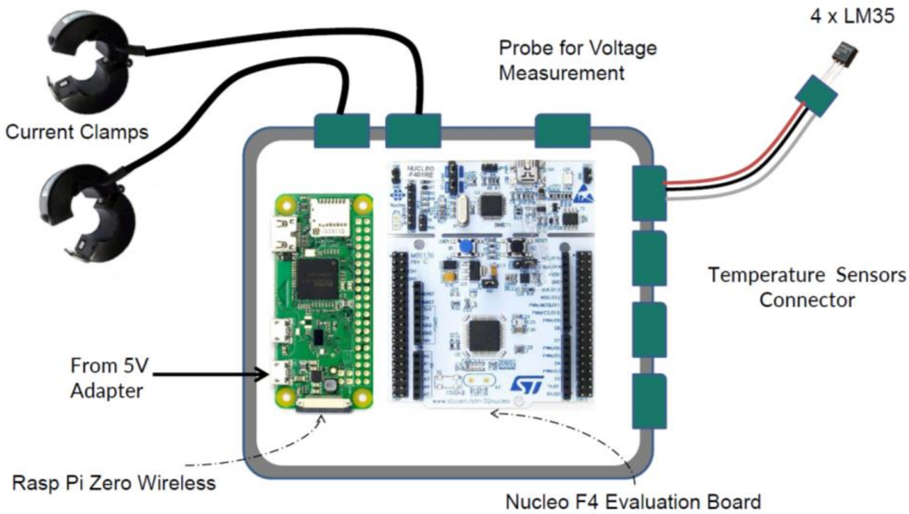


Fig. 6. Graphical view of the block diagram for measurement and data log

All sensors were connected separately from existing scooter system. Power supply source of the evaluation board and small single board computers came from external 5V power adapter during this experiment. Temperature or thermocouple sensors is mounted and patched on the ‘surface’ of each lead acid battery cell. Current sensors are clamped between each battery. The data logging capability is handled by Rasp Pi and saved in the SD card every 2 seconds. In order to charge the batteries, it has to undergo discharge cycle until it reaches near unusable voltage level of 42.5V. This voltage level was taken from the battery manufacturer datasheet. The load used for draining the battery was a 48V brushless DC motor [10,11].

3. Result

3.1 Charger Rate 0.133 (1.6 A)

Figure 7 and Figure 8 shows the charging profile of the 1.6 amperes charging rate and batteries temperature during charging process. The data logging was repeated for at least four times to eliminate noise and outlier present during the experiment. Two sets of 60 V batteries were tested. According to Figure 7, during the first 30 minutes, the charger was in bulk charging mode which supplies constant current of 1.5 amperes. As it reaches 45.9 V, it enters into absorption mode of C-V where the amount of current is slowly decreasing to reach the capacity of 59 V. At this point, the current is further decrease to maintain the full voltage level. In Figure 8, the temperature of all four batteries were between 24.9^{O}C to 33.52^{O}C.

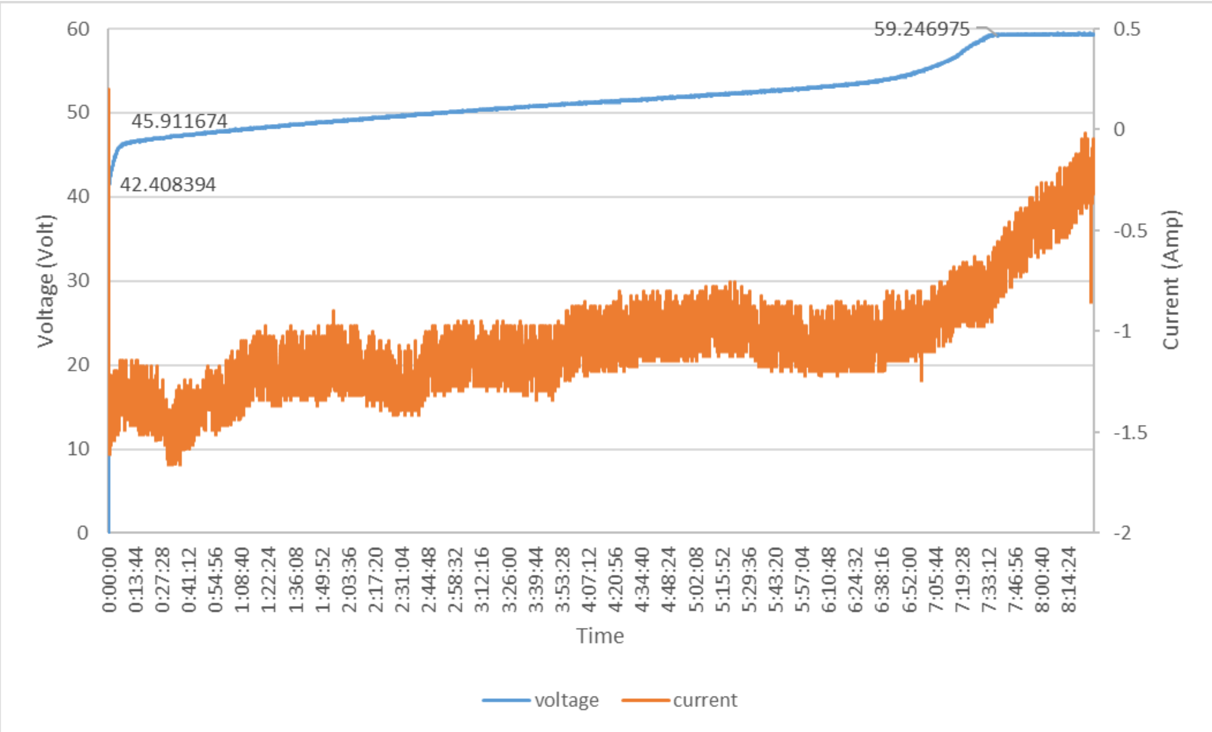


Fig. 7. Charging Profile of 0.133 (1.6 A) charging rate

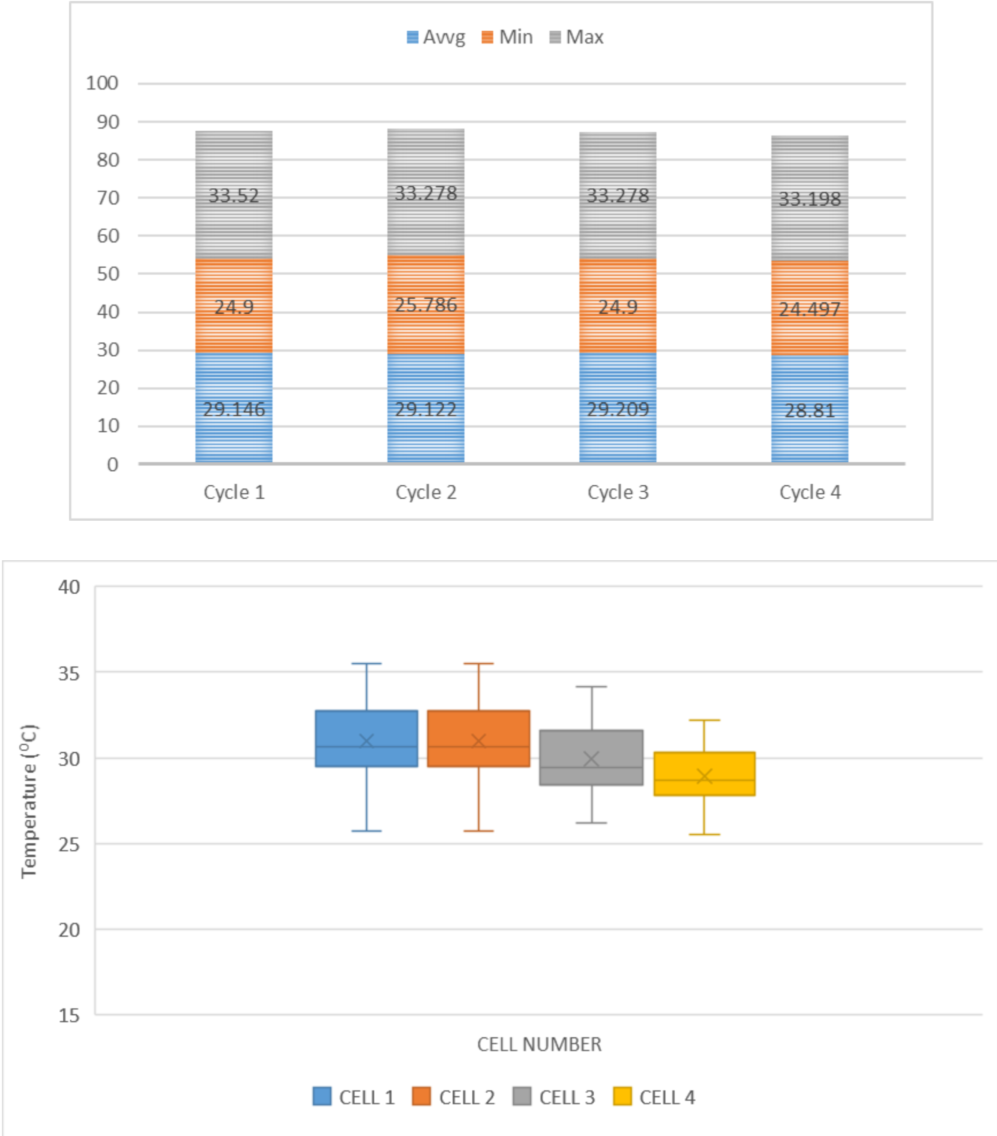


Fig. 8. Battery temperature during charging process of 0.133 (1.6 A) charging rate

3.2 Charger Rate 0.166 (2.0 A)

Figure 9 and Figure 10 shows the charging profile of the 2.0 amperes charging rate and batteries temperature during charging process. According to Figure 7, during the first 7 hours, the charger was in bulk charging mode which supplies constant current of 2.0 amperes. As it reaches 57.23 V, it enters into floating mode of C-V where the amount of current is slowly decreasing to maintain the full voltage level. In Figure 8, the temperature of all four batteries were between 24.9^{O}C to 35.53^{O}C. We can differentiate these two charger based on its charging profile. The slower charging rate apply 3 stages of charging method while the faster charging rate apply only 2 stages of charging method. This does not mean that the manufacturer only design 2 stage. The first stage which is the trickle charge stage may be invisible for charging this type of battery because the voltage differential to enable trickle bias was set probably lower than 41 V. In terms of battery capacity, slower charger reach 0.98% of full capacity while faster charger reach 0.95% of full battery capacity. Further investigation on the battery datasheet, the original full capacity was actually 58.8 V [12]. Hence the slow charger reach 102% while faster charger reach 97.3%. The fast charger reach 57 V 30 minutes faster than the slower charger. The capacity retention after both chargers completed its charging after 30 minutes was measured manually and showed an average of 54 V remaining. If we consider this retention value as our targeted full voltage, the charging time for the fast charger is 2.2 volt/hour while the slow charger is 2.0 volt/hour. Theoretically the charging time for 0.133 rate and 0.166 rate charger according to equation (3) are 6 hours and 7.5 hours respectively which validates our data. The temperature reading for both chargers are acceptable. According to the battery datasheet, the temperature of the battery may rise up to 50^{O}C as the capacity reached 105%. Hence for these data, no abnormalities were observed [13,14]. Since the data were taken for 4 cycles only, the prediction of SOC discussed in [15], cannot be applied here.

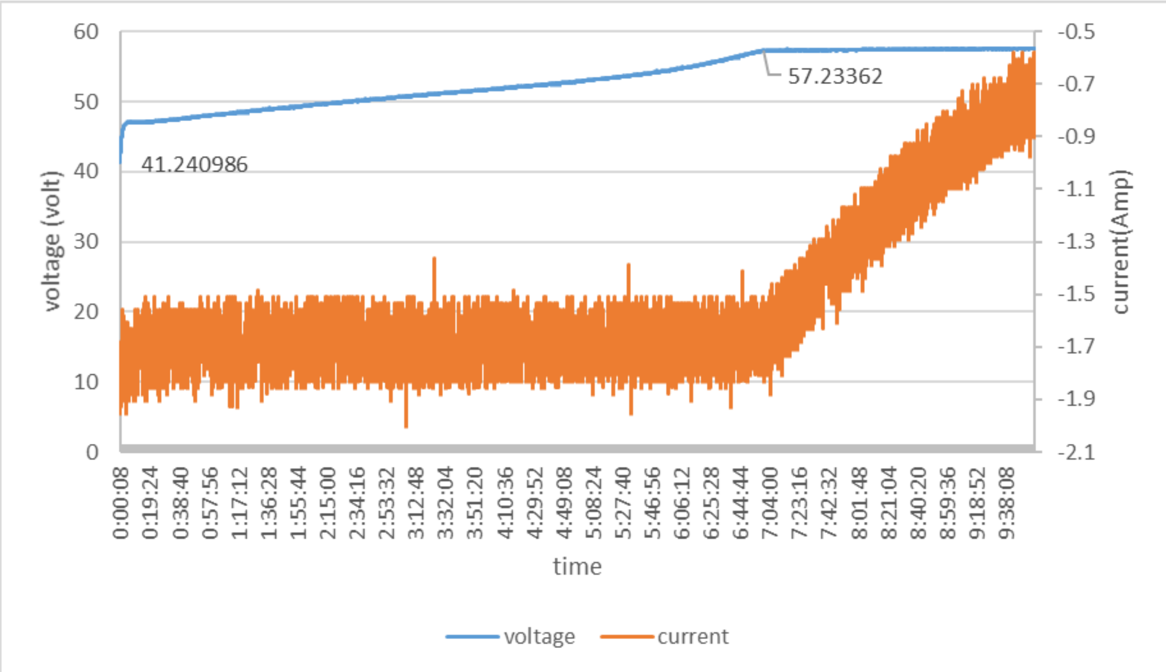
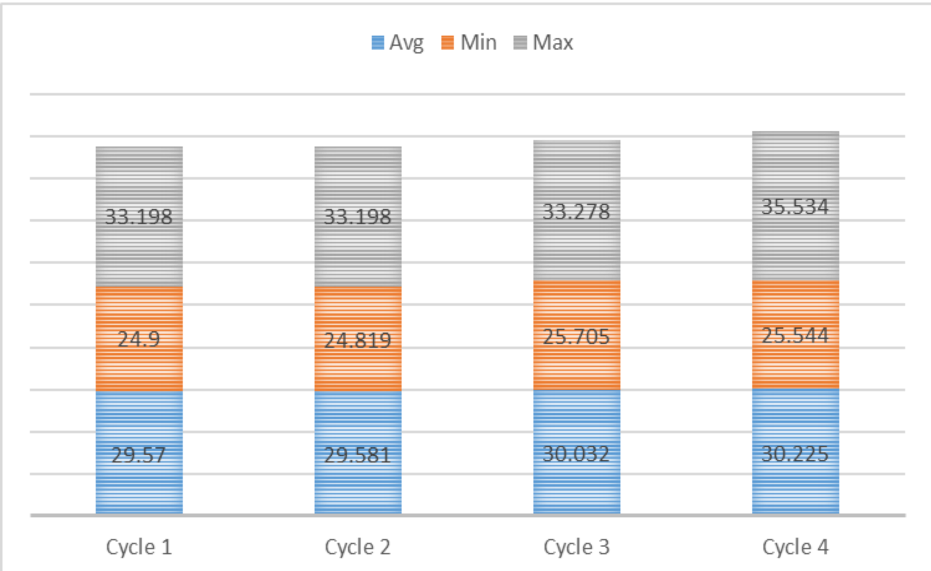


Fig. 9. Charging Profile of 0.166 (2.0 A) charging rate



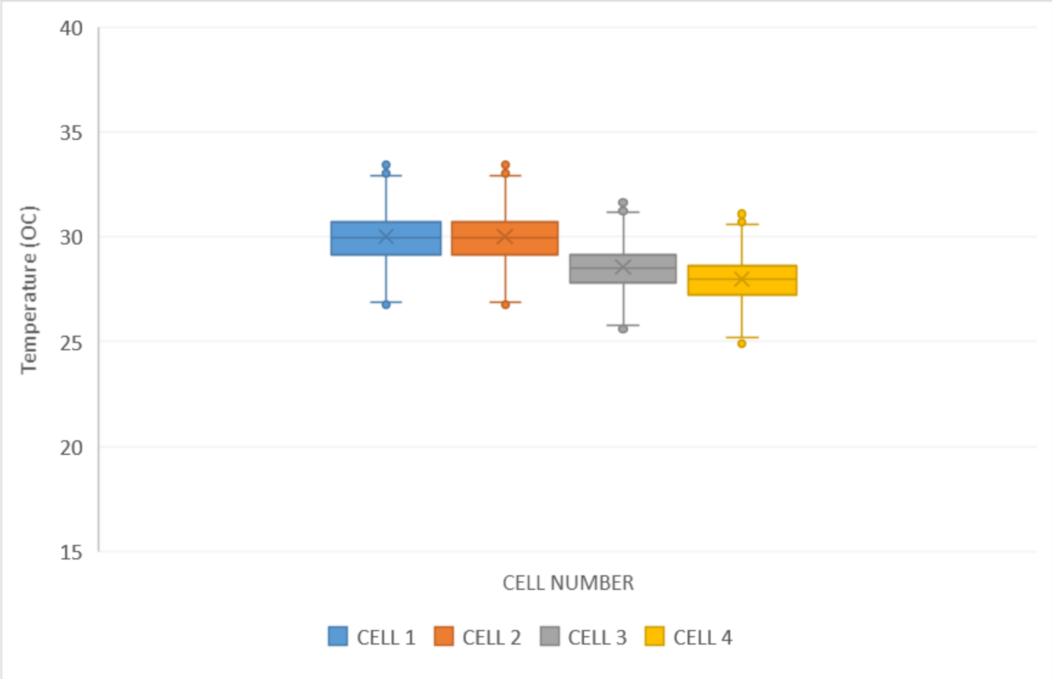


Fig. 10. Battery temperature during charging process of 0.166 (2.0 A) charging rate

4. Conclusions

This experiment provides a technical analysis which helps the user to determine suitable charger for their respective application. Fast charging of lead acid battery demonstrate in this paper shows it can reduce the charging time between 30 minutes to 1 hour but it only reach 97.3% of the full battery capacity compares to the slower charger. Based on the battery technical specification, the capacity retention will become difficult as temperature increase, and fast charger shows higher temperature reading in one of the cycle. The charging rate 0.133 to 0.166 are above the typical charging rate recommended by most manufacturer, 0.1 or 10% of the capacity. On the future experiment, charging rate of 0.2 and above will be selected. Temperature changes in the lead-acid battery cell are affected mostly by ohmic and polarization loses. At the end of the discharge the temperature rises due to the increase in inner resistance, at the end of charging due to the increase in polarization of the cell. According to the electrical scooter distributor, customer return had increase slightly after they adopt the fast charger replacing the slower charger recently. This may be due to the higher charging rate that impact the cycle life of the battery. Further experiment is required to understand the defect or degradation of the battery.

To provide better understanding of the charging behaviour, the sample size and repetition of charging and discharging cycle has to increase unfortunately due to higher cost of equipment, we can only extend this experiment at charging and discharging repetition. As for the conclusion, charging profile help the user to understand the pros and cons of a battery charger. By having this data, we can recommend to the user not to charge the lead acid battery more than 54V because the charge retention issue or the battery cannot hold the charge above the value. In certain condition, the battery only need to be at 50% of full capacity enough to demonstrate the load or application functionality.

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References
[1] R. Suntharamurthy, A. Anuar and F. Mahamud, "The Design of a Compact and Lightweight Wheelchair for Disabled Children." *Journal of Advanced Research Design* 9, no.1 (2015): 26-33.
[2] Murnane, Martin, and Adel Ghazel. "A closer look at state of charge (SOC) and state of health (SOH) estimation techniques for batteries." *Internet: http://www. analog. co m/media/en/technical-documentation/technical-articles/A-Closer-Look-at-State-Of-Charge-and-State-Health-Estimation-Techniques-.... pdf* (2017).
[3] Buchmann, Isidor. "BU-903: How to Measure State-of-charge." *Battery university* (2017).
[4] Maria Cortez and Upal Sengupta, "Introduction to Battery Management Part 1: Battery Technology Overview." training.ti.com, Texas Instrument Course Series, https://training.ti.com/zh-tw/introduction-battery-management (accessed December 12, 2018)
[5] K.V. Muralidhar Sharma, Veerendra. G.P, Manoj Kulkarni.G.P. "Some Innovative Concepts of Quick Charging." *International Journal of Innovative Research in Science, Engineering and Technology* 5, no. 4, (2016): 6446-6451.
[6] Horkos, Pamela G., Emile Yammine, and Nabil Karami. "Review on different charging techniques of lead-acid batteries." In *2015 Third International Conference on Technological Advances in Electrical, Electronics and Computer Engineering (TAEECE)*, pp. 27-32. IEEE, 2015.
[7] Baroody, Ronald. "Evaluation of rapid electric battery charging techniques." (2009).
[8] Mahmoud Sheperoa ,Joakim Munkhammara, Joakim Wid´en Justin D. K. Bishop and Tobias Bostrom. "Modeling of photovoltaic production and electric vehicles charging on city scale: A review." *Renewable and Sustainable Energy Reviews* 89(C), (2016): 61-71.
[9] Darren Somerville, "Batteries Online" https://www.impactbattery.com/blog/2017/06/3-ways-to-connect-lead-acid-batteries (accessed December 10, 2018)
[10] Diniş, C. M., G. N. Popa, and A. Iagăr. "Study on sources of charging lead acid batteries." In *IOP Conference Series: Materials Science and Engineering*, vol. 85, no. 1, p. 012011. IOP Publishing, 2015.
[11] Leccese, Fabio, Marco Cagnetti, Stefano Di Pasquale, Sabino Giarnetti, and Maurizio Caciotta. "A new power quality instrument based on raspberry-pi." *Electronics* 5, no. 4 (2016): 64.
[12] Chilwee, "6-DZM-12 DZM Series VRLA Gel Battery Data Sheet." 2014.
[13] Bandhauer, Todd M., Srinivas Garimella, and Thomas F. Fuller. "A critical review of thermal issues in lithium-ion batteries." *Journal of the Electrochemical Society* 158, no. 3 (2011): R1-R25.
[14] MEV Team. "A guide to understanding battery specifications." (2008).
[15] Omairi, Amzar, and Z. H. Ismail. "Modeling battery state of charge in wireless sensor networks based on structured multi-layer perceptron." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 5 (2016): 36-45.