

Investigation of Lithium Iron Phosphate Battery Performance for Water Corporation Applications in WA Conditions

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Abstract

The Water Corporation operates numerous systems which utilize rechargeable batteries. Many of these sites are remotely located, without mains electricity and can reach temperatures above 40°C during summer. Lead acid batteries are invariably used in these systems as they are well-established and low in cost. Newer battery technologies such as Lithium Iron Phosphate (LFP) offer advantages including durability in elevated temperatures, greater efficiency and lower energy density. However, these benefits are mostly derived from manufacturers' claims. This project aims to investigate the performance of LFP's in WA conditions in comparison with manufacturers' claims and also lead acid batteries, with a particular focus on the effect of elevated temperature.

Two laboratory trials were conducted to discover the effect of high temperatures on the cycle-life and self-discharge characteristics of LFP and lead acid batteries. The results of the experiments show improved cycle-life and self-discharge of LFP batteries when compared to lead acid both at room temperature and 50°C. Field trials of LFP's within the Water Corporation were also instigated to assess the suitability and performance of these batteries in real applications. Continued monitoring of these sites is recommended to determine long term behaviour.

1. Introduction

Lead acid batteries are cheap and well-established, and as a result are widely used throughout the Water Corporation where rechargeable batteries are required. However, the potential and versatility of rechargeable batteries has driven an industry which is constantly developing new technologies. These newer technologies are the focus of current research, however in general most claims of improved performance are derived from manufacturers' testing. There is currently a lack of independent data, analysis and standards for newer technologies including the focus of this project, Lithium Iron Phosphate (LFP).

There are several key motivations for the project, all of which strategically align to the Water Corporation's values. The price of lithium-ion batteries is predicted to reduce by more than 60% by 2020 (AECOM 2015). In combination with longer cycle-life this could see the whole-of-life cost of LFP batteries become competitive with lead acid. Longer cycle-life is of particular interest in the North West region of the Water Corporation's operations where high

temperatures are hypothesised to be the predominant cause of reported short lifetime of the lead acid batteries currently in use.

Claimed advantages of LFP batteries include a higher upper limit of their operating temperature range, longer cycle-life and lower self-discharge rates (Anuphapparadorn et al. 2014). The project aims to investigate these claims, quantify the effect of temperature on cycle life and self-discharge, and consequently evaluate the viability of LFP batteries as an alternative to lead acid with the Water Corporation.

Other claimed benefits of LFP batteries include higher efficiencies which make them suitable for solar PV systems and also high energy density which translates to reduced weight in comparison to lead acid. This is particularly important for remote sites that are often difficult to access and so replacement of heavy lead acid batteries can pose an Occupational Health and Safety lifting hazard to site operators.

1.1 Effect of Temperature

The electrochemical nature of rechargeable batteries translates to an inherent dependence on temperature of both their useful and unwanted chemical reactions. The unwanted chemical reactions within rechargeable batteries are the cause of battery aging and the primary reason they have a finite cycle life. For lead acid batteries, this relationship between temperature and aging is well-documented. They operate optimally at 25°C and experience a decrease in life of 50% for every 8°C above 25°C (IEEE Standards 2007). Temperature is also known to increase the self-discharge of rechargeable batteries i.e. loss of capacity when in open circuit. For lead acid batteries, the monthly self-discharge rate of approximately 3% at 25°C will double for every 7°C increase in temperature (C&D Technologies 2012).

More generally, chemical reaction rates are commonly described by the Arrhenius equation, Equation 1 (Liaw et al. 2003).

$$A = A_0 \exp\left(\frac{-E_a}{RT}\right) \quad (1)$$

Where A is the temperature dependent reaction rate, A_0 a constant, E_a the activation energy, R is the universal gas constant and T the temperature in Kelvin.

2. Methodology

2.1 Accelerated cycle-life experiment

The trial seeks to determine the cycle-life of both Valve Regulated Lead Acid (VRLA) and LFP batteries at two temperatures: 25°C and 50°C. The elevated temperature of 50°C was chosen as it matches the maximum temperatures reached in the North West region of WA. The cycle-life was determined by the number of charge-discharge cycles completed by the battery pack before End of Life (EOL) is reached. The EOL for this experiment is defined as the point at which the achieved Depth of Discharge (DOD) falls below 80% of the target DOD. The experiment has been extended beyond the EOL in order to investigate degradation after that point. Figure 1 is a basic schematic diagram of the experimental setup (O'Brien, 2015).

The charging and discharging was controlled by the Battery Management System. The DOD for each cycle was set to 50% for the lead acid and 80% for the LFP's. These DOD's were achieved by voltage set points which were determined from manufacturer's specifications as well as the first few cycles of the tested batteries. Key parameters such as cell voltage, current and temperature are recorded at 2 minute intervals by the Battery Management Systems. The method of coulomb counting or current integration was employed to estimate DOD and capacity from this data.

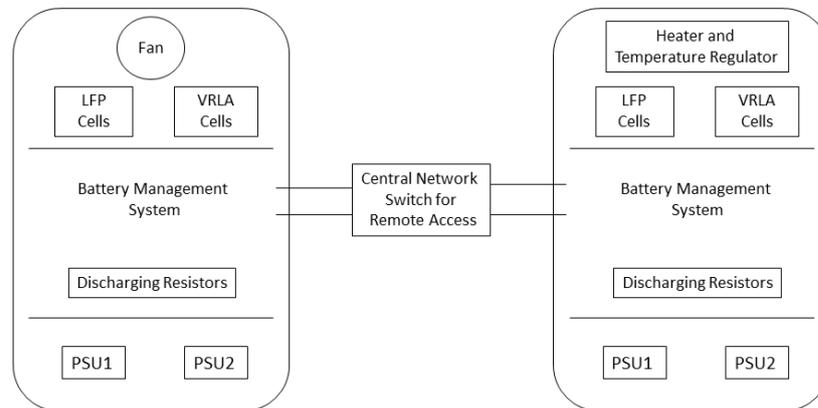


Figure 1 Schematic of accelerated cycle-life experiment setup

2.2 Self-discharge experiment

Further to the first laboratory trial, an experiment was run to determine the 30-day self-discharge of LFP and lead acid batteries with a focus on the effect of high temperature on these values. Figure 2 illustrates the basic procedure followed to determine the 30-day self-discharge of three different batteries: a 12V 24Ah sealed lead acid battery which is known to be used within the Water Corporation, a 3.2V 3.2Ah cylindrical LFP cell and a 3.2V 40Ah prismatic LFP cell. The experiment was replicated at both room temperature and 50°C.



Figure 2 Self-discharge experiment process flowchart

A laboratory DC power supply was employed for the battery charging with a Constant Current/Constant Voltage charging regime. The discharge of the batteries was conducted through resistors which were sized to achieve approximately 1.5-2 hour discharges. The battery voltage and discharge current were recorded throughout the discharge via a data logger. These parameters were used to calculate the capacity discharged by the coulomb counting method discussed in section 2.1.

2.3 Field Trials

Three of the four field trials involved replacing lead acid batteries on Water Corporation sites with LFP's and monitoring key parameters such as battery voltage, current and ambient temperature with data loggers. The data from these sites was gathered remotely via modems

or alternatively via USB transfer. Two of the field trials were remote systems run on solar PV power. The first being a radio repeater for Wungong dam and the second a RTU for a water tank in Karratha, the target region of the project. Another trial was implemented on Christmas Island where rechargeable batteries are used on rotation to power a tank level transmitter. Finally, a fourth trial assessed the health of LFP batteries in an Uninterruptable Power Supply (UPS) at a Chemical Dosing Plant which was commissioned in 2011.

3. Results and Discussion

Figure 3 depicts the results at the time of writing for the accelerated cycle-life experiment. From the graph it can be observed that all four batteries experienced approximately linear degradation of capacity over the trial. The dependent variable of energy throughput per initial energy discharged was chosen to account for the difference in nominal capacity of the batteries.

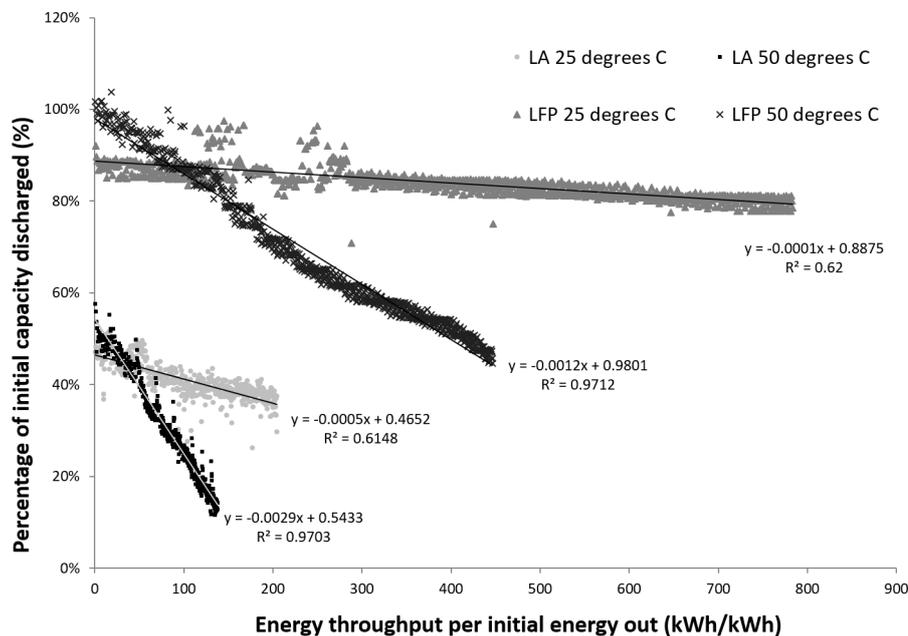


Figure 3 Capacity fade of batteries in the accelerated cycle-life experiment

The lead acid and LFP batteries in the 50°C rig both experienced a more rapid degradation than their room temperature counterparts. This is consistent with current literature (Wang et al. 2010) but contrary to manufacturer’s specifications for the maximum allowable operating temperature of the tested LFP cells. It can also be observed that both LFP cells experienced capacity fade over a larger energy throughput than the lead acid batteries. This highlights the advantage of the deeper allowable discharges for LFP’s.

Figure 4 shows the results from the self-discharge experiment. Increasing the storage temperature had the predicted effect of an increased self-discharge for each battery type. The self-discharge for the lead acid battery stored at 50°C was approximately 5.6 times the room temperature value. The self-discharge for both the LFP batteries met the manufacturers’ specifications at room temperature. Furthermore, the effect of storage at an elevated temperature was less significant than for the lead acid battery. Of interesting note is the difference in the results for the prismatic and cylindrical LFP cells with the elevated temperature having a considerably smaller effect on the cylindrical cell.

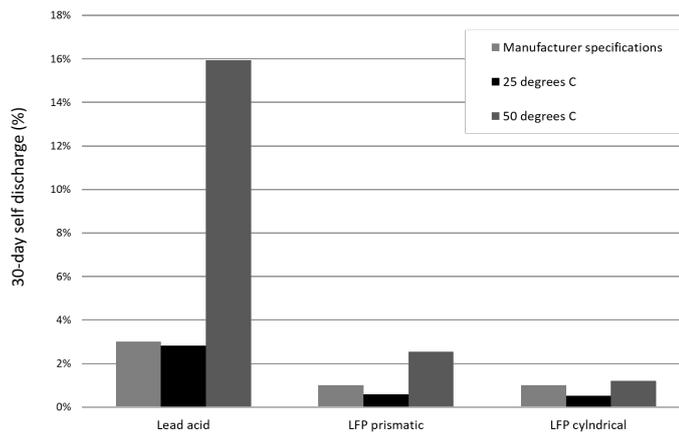


Figure 4 Results of Self-discharge experiment

Figure 5 illustrates the analysis of data collected from the Wungong trial up until the time of writing. It highlights the sensitivity of the batteries performance to the power output of the PV panels. Low battery voltage and State of Charge (SOC) were experienced on two occasions following several days of low solar radiation and overcast conditions. However, the batteries had recovered to reach 80% SOC within 5 days of these incidences occurring. The long term performance of the batteries in this application will only be known in several years' time.

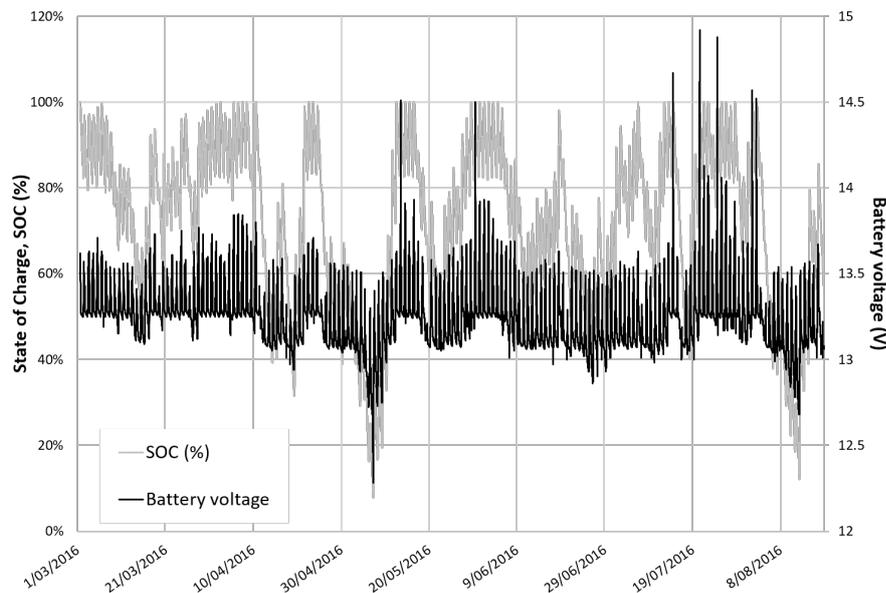


Figure 5 Field trial 1: Solar PV charged battery State of Charge and voltage over time

4. Conclusions and Future Work

The project has successfully determined the effect of elevated temperature on the cycle-life and self-discharge characteristics of both lead acid and LFP batteries. While LFP batteries met manufacturer's claims at room temperature, they demonstrated a more rapid degradation of capacity and an increased self-discharge at 50°C. However, the effect of temperature on both these characteristics for LFP's was less than the effect on lead acid batteries. Further

analysis of the temperature dependence of the cycle-life and self-discharge characteristics in relation to the Arrhenius equation is still to be completed as part of this project. These conclusions in combination with the continued analysis of data obtained from the field trials will better inform the future battery design, procurement and maintenance decisions of the Water Corporation.

A decision framework and financial analysis to evaluate and compare the Net Present Value of LFP and lead acid batteries is yet to be completed at the time of writing. The conclusions of the laboratory experiment and field trial data will assist in developing this framework and analysis.

5. Acknowledgements

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