Investigation of Lithium Iron Phosphate battery technology and performance in WA Conditions

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Abstract

The Water Corporation currently has a large number (over 500) of remote sites requiring back-up power, which is traditionally supplied by lead acid batteries. During summer these sites can reach temperatures well in excess of 40ºC, which is known to drastically reduce the life of lead acid batteries. The aim of this project is to investigate through experimentation the use of $LiFePO_4$ (LFP) batteries as an alternative energy storage method for remote, high temperature environments. It is also necessary to quantify the lifetime of lead acid batteries at high temperature in practice to ensure that existing maintenance plans are optimised. In order to achieve this two test rigs (one at elevated temperature) have been designed and constructed and are cycling the batteries in a UWA lab.

The potential benefits of LFP extend beyond longer life at high temperatures. They also have much greater power density, and can be charged/discharged more regularly and at faster rates than their lead acid counterparts. This opens up renewable energy options such as solar PV (Photovoltaic) panels and wind turbines that have intermittent power generation and therefore need high capacity energy storage. However higher initial costs have hindered the uptake. With the price of LFP falling in recent times it has become a more economically viable option. Therefore independent tests are essential to verify LFP battery manufacturer's performance claims. From these laboratory tests an accurate cost benefit analysis will be undertaken in order to meet Water Corporation's current and future energy storage needs. Initial results from these tests indicate consistent charge/discharge curves, however, it is too early to see the onset of any deterioration of the batteries due to their long expected life.

1. Introduction

The Water Corporation has in excess of 500 UPS (Uninterruptable Power Supply) systems deployed across Western Australia. These systems all require a method of energy storage to function. Traditionally this has been achieved through the use of lead acid batteries, however, due to their drastically reduced performance at higher temperatures alternative energy storage options must be considered. According to the Arrhenius equation the battery life of a lead acid battery is halved for every 10ºC above their rated temperature of 25ºC (Jones & Vanasse, 2006). Although this gives an estimate of battery life a more accurate, experimentally validated, estimate of modern battery lead acid technologies would greatly assist Water Corporation in determining an optimal maintenance plan. Due to its popularity the low maintenance Valve-Regulated Lead Acid (VRLA) type is the focus of this investigation alongside $LiFePO_4$ (LFP).

LFP batteries are an emerging battery chemistry that claim to operate at temperatures of up to 70ºC without a significant effect on performance. LFP batteries are also offer greater power density than their VRLA counterparts; for a 200Ah, 12V VRLA battery weighing 65kgs, the equivalent LFP battery weighs only 25kgs (Magellan Power, 2015). Finally LFP batteries don't suffer from thermal runaway that has hindered the uptake of Li-ion batteries in the past. Thermal runaway is initiated by the cells being exposed to a high temperature and then perpetuated when the rate of internal heat generation exceeds the rate at which the heat can be dissipated by the environment (C&D Technologies, 2012). It ultimately leads to damage to the battery and possibly surrounding equipment or even nearby personnel as the cell can be exposed to hundreds of degrees Celsius during the reaction. LFP has both a much lower energy release and a much higher activation temperature of over 300ºC (Linden & Reddy, 2002).

As Water Corporation shifts its focus towards renewable energy sources such as solar PV (Photovoltaic) panels and wind turbines, a more suitable energy storage method needs to be investigated to complement their intermittent power generation. High capacity, fast charging/discharging energy storage methods that are able to withstand a large number of charge/discharge cycles are therefore required. LFP batteries match all of these requirements where VRLA batteries are much less suitable. The overarching aim of this project is to quantify the lifetime and performance of both of these battery types and identify the most cost effective and reliable battery type in high temperature environments.

2. Process

In order to test the batteries impartially the Depth of Discharge (DOD), charge rate and discharge rate have been adjusted to allow for the way each chemistry behaves. The DOD of VRLA is set to 50% while the LFP batteries are set to discharge 80% of their total capacity. This is due to the drastic reduction in lifetime when a VRLA battery drops below 50% (Saengprajak, 2007) or if LFP batteries drop below 80% (CALB USA Inc., 2014). Due to the long rated lifespan of both battery types (>10 years) any lifespan tests need to be accelerated as if the tests were conducted at normal speeds the results would be redundant by the time they were collected. This is where the "C rate" is used to determine the maximum rate that the batteries can be charged and discharged at for each battery chemistry. The "C rate" is a measure of the rate at which the battery is charged relative to its maximum capacity (MIT, 2008). i.e. a 0.5C discharge rate means the battery will discharge the entire battery in 2 hours. For a 40Ah battery this results in a discharge current of 20 Amps.

Figure 1 below shows the effect of changing the C rate on the discharge curve and available capacity of LFP. LFP can withstand a much higher C charge and discharge rate than VRLA and thus the C rates have been set accordingly. The C rate of LFP was set to 1C charge and discharge and VRLA 0.6C discharge and 0.1C charge as specified by their respective manufacturers.

2.1 Testing Equipment

Two test rigs have been developed for this project to collect the data required. A schematic of the experimental set-up is shown in Figure 2 below:

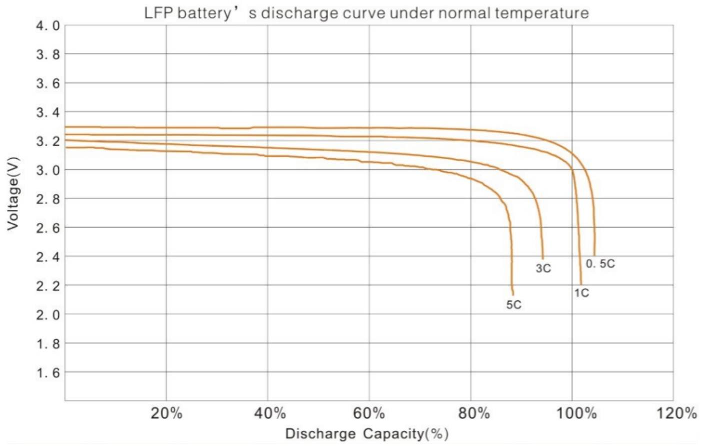

Figure 1 LFP discharge at normal temperature (PowerTech Systems, 2013)

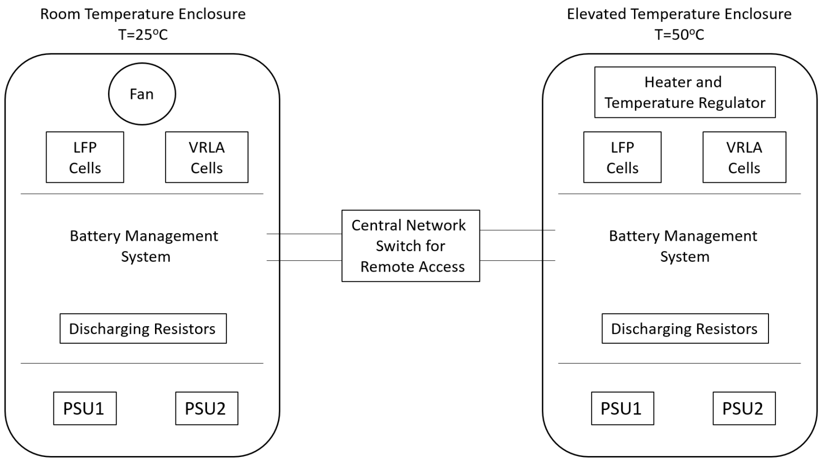

Figure 2 Battery test rig schematic

Each of the batteries are connected to a smart charger and management system which can charge and discharge the batteries automatically. Both batteries are charged and discharged continuously (24/7). The smart charger logs the voltage, current and internal temperature of each cell in 2 minute intervals. Each charger has a dedicated I.P address which enables remote access to the logs via an Ethernet cable from each charger to a central network connected switch. The Battery Management System (BMS) can then be accessed remotely via any PC with Access Facility installed and reprogrammed through a USB cable. A temperature logger logs the temperature inside each of the rigs every 5 minutes with the heated enclosure maintained at 50ºC via a heater and simple on-off controller.

Each of the batteries have their own BMS which actively balances the cells (required for Lithium) and restarts the charging process once the batteries reach their specified DOD. For this particular type of VRLA battery the 50% DOD voltage is 2.03Vpc or 24.36V for the room temperature enclosure and 2.105Vpc or 25.26V for the elevated temperature enclosure. These voltages are specified by the manufacturer with the elevated temperature enclosure temperature compensated by adding 3mV per degree above 25ºC. The LFP batteries are discharged to 3.1Vpc or 24.8V to reach a DOD of 80%. This is true for both enclosures as LFP batteries do not need to be temperature compensated i.e. their capacity remains the same at temperatures below 70ºC. The rated capacity of the VRLA batteries is 33Ah for each of the two 13.65V (nominal 12V) blocks while LFP cells are rated at 3.2Vpc with 8 cells at 40Ah capacity.

3. Results and Discussion

The test rigs have been running for 3 weeks as of writing and will need to run for another 2 months before noticeable deterioration begins to surface. This is due to the long expected life of the batteries even at elevated temperatures. However some preliminary analysis shows consistent charge/discharge curves with an average cycle length of 6.4 hours for LFP allowing for 4 charge/discharge cycles every 24 hours. This is shown in the 24 hour (approx.) excerpt of the data graphed in Figure 3 below:

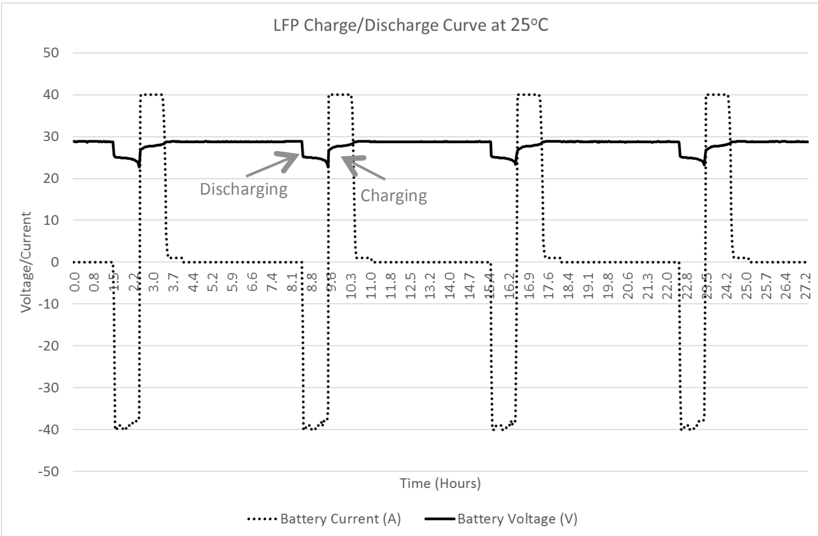

Figure 3 LFP battery charge/discharge curve at 25ºC over approx. 24 hours

The longer than expected cycle length is due to cell balancing by the BMS neccesary for optimal performance of the LFP cells. Regular analysis of the discharge curve will ensure that the onset of deterioration is detected and quantified. Expected deterioration in LFP manifests itself with an increased internal resistance (Takeno & Shirota, 2006) as well as a steeper and more linear voltage discharge curve than that shown in Figure 3.

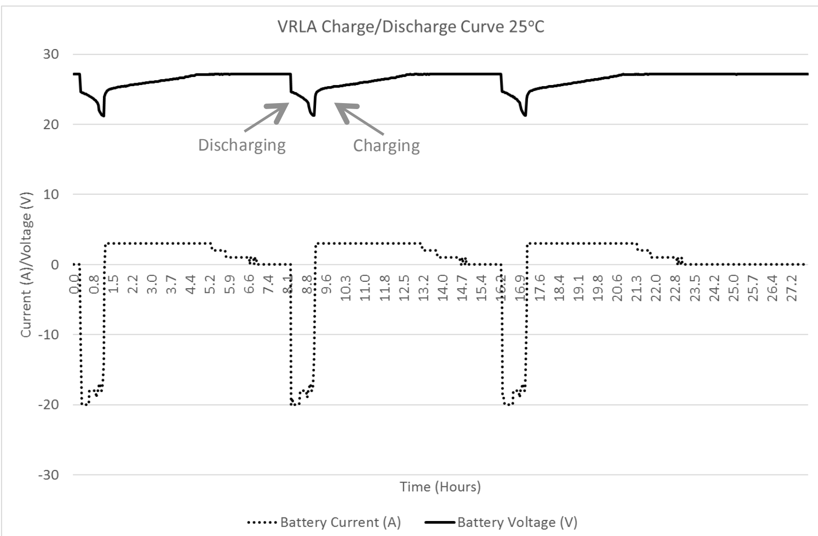

Figure 4 VRLA battery charge/discharge curve at 25ºC over approx. 24 hours

Analysis of the VRLA charge/discharge curves yields an average cycle length of 7.5 hours allowing for 3 charge/discharge cycles every 24 hours. This is observed in the 24 hour excerpt of the recorded data given in Figure 4 above. Deterioration of the VRLA battery can also be observed by a change in the discharge profile. A reduction to 80% of the original capacity of the battery is usually defined as the end of life as below this it rapidly deteriorates and is susceptable to sudden failure (Power-Thru, n.d.). For the VRLA batteries selected this is when it can only recharge to 2.07Vpc or 24.84V for the room temperature enclosure and 2.145 or 25.74V with temperature compensation.

LFP batteries are expected to withstand over 5 times the number of charge/discharge cycles compared to lead acid with LFP being rated to 2000 or more cycles compared to only 400 for VRLA (Nabavi, 2014). Therefore the deterioration of the VRLA cells should occur much earlier despite achieving less cycles per day.

4. Conclusions and Future Work

Thus far the groundwork has been laid for a reliable and accurate measurement of LFP and VRLA battery performance at elevated temperatures. Initial data shows consistent charge/discharge curves, however, the experimental phase is still at an early stage and so no signs of the onset of deterioration in the batteries has been detected. This was expected due to the long expected life of the batteries.

Further work is required in analysing the continued flow of data from the test rigs and detecting the onset and extent of any deterioration of the batteries. This manifests itself as increased internal resistance and a change in the profile of the voltage discharge curve. After an estimate of the lifetime of each battery type at elevated temperature has been determined the cost-benefit analysis can begin. This will consist of gathering quotes for equivalent VRLA and LFP systems as well as estimating maintenance costs over the predicted lifetime of the batteries in order to determine the energy storage method with the greatest NPV (Net Present Value).

A field test is also planned in order to take the batteries out of controlled conditions into a practical environment in order to measure how they perform in the real world. This would be at a site which is most suited to the LFP battery type (i.e. where it would most likely be used). This site would ideally have a high frequency of charge/discharge cycles at a high ambient temperature. An example of this would be an off-grid remote site in the North of WA powered by solar panels.

The results of this study will ensure Water Corporation is well informed when making future decisions on energy storage for the harsh Western Australian climate. Not only will it provide experimental data for the existing installed technology (VRLA) that will assist in creating less wasteful maintenance plans but it will also provide valuable independent testing of the newer LFP technology. This becomes more relevant as the uptake of renewable energy sources gains momentum and appropriate energy storage methods need to be employed to compensate for their intermittent power generation.

5. Acknowledgements

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