LITHIUM ION BATTERY FOR TELECOMMUNICATIONS APPLICATIONS

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INTRODUCTION

For many years, lead acid battery has been the backup power source in the telecommunications industry. It provides reliable backup energy during power outage. In the central office (CO) environment, the flooded lead acid battery has been the battery of choice because of its long life and reliability. It, however, requires regular maintenance and occupies a sizable floor space. In the last decade, distributed power architecture and distributed telecom equipment architecture have led to smaller power plants and to outdoor installations. For outdoor sites, real estate and maintenance are important factors. As a result, the valve regulated lead acid (VRLA) battery has become the popular choice due to its smaller footprint and its perceived reduced maintenance. Many of these outdoor sites are in high temperature climate and the batteries are usually located in an uncontrolled environment inside a cabinet. In this environment, the VRLA battery suffers premature capacity loss and sometimes thermal runaway [1] which can lead to explosion caused by accumulated hydrogen gas. The life of the battery is generally less than 5 years in such high temperature sites.

For many years, the telecommunications industry has been looking for an alternative to VRLA that can provide better high temperature performance and higher energy density. Other available mature battery technologies under consideration are the nickel-cadmium and the lithium systems; both of which are more expensive alternatives. Nickel cadmium batteries [2] are known to have better high temperature performance. They require certain regular maintenance such as watering, and have the same likelihood of hydrogen emission. The slightly better performance may not justify the higher cost.

Lithium Ion (Li-Ion) batteries using $LiCoO_2$ as cathode have been widely used in powering small electronic equipment such as cell phones, digital cameras, and laptop computers. The protection circuitry built into the pack has mostly addressed the safety concern of the battery. The manufacturing process has been greatly improved that the cost of the battery has reached the point to be considered for backup applications in the telecommunications industry. On the other hand, the performance and safety of a large Li-ion battery needs to be evaluated and tested before final deployment.

One important feature of the Li-Ion batteries is its high energy density, both in terms of weight and volume. A properly designed Li-Ion battery can have 2-3 times the energy density over that of a VRLA battery. As a result, more space can be dedicated to equipment that is needed for generating revenue. Installation can also be made a lot easier. The steady state float current of Li-Ion batteries is usually small and independent of battery temperature, and the chance of thermal runaway at high ambient temperature is greatly reduced. Unlike the lead acid battery, the discharge profile of Li-ion battery does not exhibit the Coup-de-Fouet voltage drop and the concern of service shut down is eliminated for sites with the LVBD (low voltage battery disconnect) contactor. Lithium ion battery also does not emit explosive gas such as hydrogen during normal operation.

In this paper, the preliminary testing results of a high temperature Li-ion cell are presented. It is a rectangular cell with a capacity of 60AH at the 8-hr discharge rate. Its application as back-up energy reserve in telecom will also be discussed.

ENERGY DENSITY OF LI-ION BATTERY

Li-Ion battery, or lithium battery in general, has the distinct advantage of being light and small. The following Table 1 shows the comparison of energy density between typical VRLA batteries and lithium batteries.

Table 1. Energy density comparison between VRLA and Li batteries

Property	VRLA-1	VRLA-2	VRLA-3	VRLA-4	VRLA-5	Lithium-1	Lithium-2	48V60 Li-ion
Voltage, V	12	12	12	12	12	48	48	48
Capacity @C8, AH	145	60.6	71.7	88	71	70	55	60
Energy, @ C8, WH	1740	727	860	1056	852	3360	2640	2880
Volume, L	19.4	8.1	9.6	11	10.1	21.5	14.1	17.5
Weight, Kg	45.5	20.6	26.7	28	31.3	28.5	27.2	27.3
Energy density, WH/L	**89.7**	**89.8**	**89.6**	**96**	**84.4**	**156.3**	**187.2**	**164.6**
Energy density, WH/Kg	**38.2**	**35.3**	**32.2**	**37.7**	**27.2**	**117.9**	**97.1**	**105.5**

In this table, 5 VRLA batteries by different manufacturers were compared with 3 lithium batteries. The 48V60 Li-ion battery presented in this work is made of rectangular individual cells with a capacity of 60AH at the 8-hr rate. Some of the VRLA batteries are of thin plate design, and they have better energy density than the thick plate design.

Lithium batteries, due to the lightweight of the lithium element, have the highest energy density among batteries. They have 2-3 times more energy per weight and volume than the VRLA batteries. These are important considerations in applications where floor space and floor loading are critical. A smaller volume means more space can be devoted to revenue generating equipment. A lighter weight means ease of installation and maintenance, and easier compliance with the floor loading and earthquake requirements.

All lithium batteries discussed in this work are 48-V modules and one battery is a 48-V string by itself. No inter-cell connectors are needed in installation. At this point, no 24-V lithium battery module is available.

PERFORMANCE OF THE 48V60 Li-ION BATTERY

The 48V60 Li-Ion battery consists of prismatic cells (50 x 110 x 160 mm). Preliminary testing was done on the cell level and the results are expected to apply to the final battery.

Discharge Performance

The discharge performance of the cells was evaluated by conducting discharge test at different discharge rates. Figure 1 shows the discharge curves at 25^{o}C after fully recharging the cells for 24 hours to 4.1V with current limited to 2.5 A. For comparison, Fig. 2 shows typical discharge curves of both flooded and valve-regulated lead acid batteries. Several differences exist between the discharge curves of the two types of batteries. The discharge of lead acid battery has the well-known Coup de Fouet region in which the voltage drops precipitously, followed with a recovery before the gradual decrease. This drop in voltage is dependent on the discharge rate and the age of the battery. In sites with the low voltage battery disconnect (LVBD) contactor, the batteries can be disconnected from the load if the battery voltage drops below the set point during a discharge caused by a power outage. To avoid the problem, either the load size has to be reduced or more battery strings have to be added. Lithium batteries do not have this voltage drop and will not be prematurely disconnected from the load it is supporting.

Fig. 1. Discharge curves of prismatic Li-Ion cells at 25°C

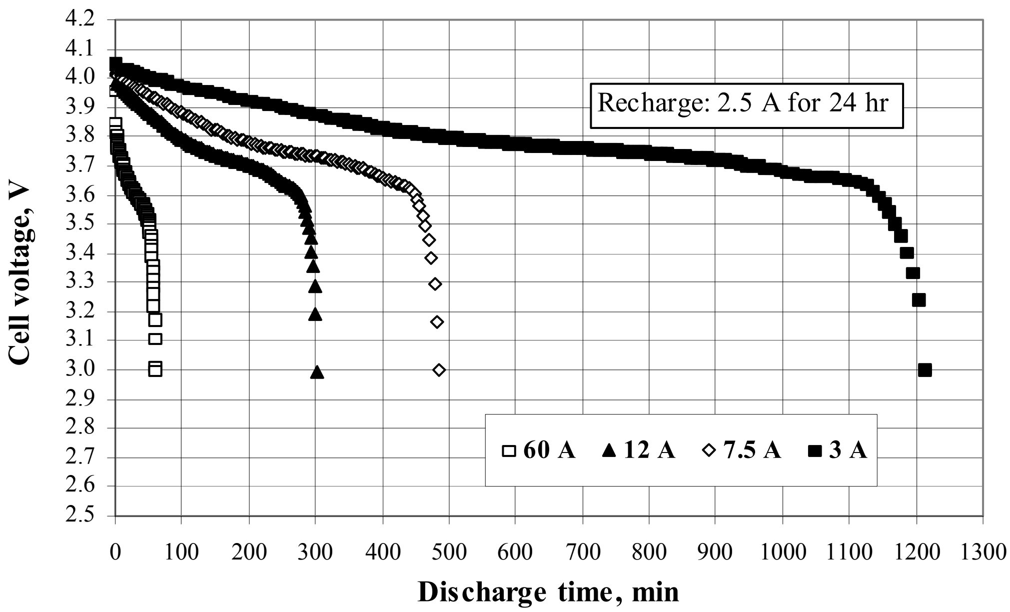
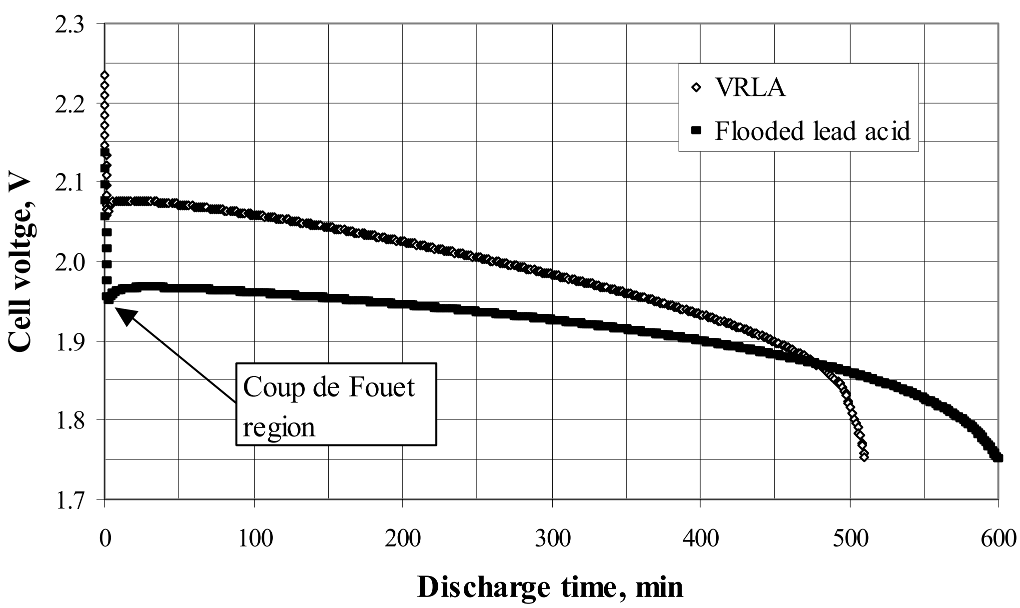


Fig. 2. Discharge curves of lead acid batteries



The profile of the voltage drop during discharge also is different in the two types of batteries. For lead acid, the voltage has a continuously sloping down profile with the dropping rate increasing throughout the discharge. For the lithium battery in this work, the voltage profile tends to have two segments of constant dropping rate and the final drop at the end of discharge is more pronounced. These characteristics are helpful in monitoring and predicting the capacity and life of Li-Ion batteries.

For lead acid battery, the float current after fully charging the battery generally increases with battery temperature and charge voltage. Valve-regulated lead acid batteries used in high ambient environment can have an elevated float current that can lead to thermal runaway of the battery. For Li-Ion batteries, the float current is very low. For example, the float current of the rectangular cell studied in this work has a float current of about 17 mA and is independent of battery temperature. The possibility of self-heating is greatly reduced, even at high ambient temperatures.

Capacity

Table 2 summarizes the measured capacity at different discharge rates of the Li-Ion cell in the 48V60 battery. The data of a typical VRLA battery were also included. Unlike the VRLA battery, the capacity of a lithium battery varies little with the discharge rate. The percentage capacity difference between high discharge rate (1C) and low discharge rate (C/8 or C/20) of a Li-Ion battery is about 5%. It makes sizing the required energy more straightforward and is not necessary to de-rate the battery for shorter reserve time applications.

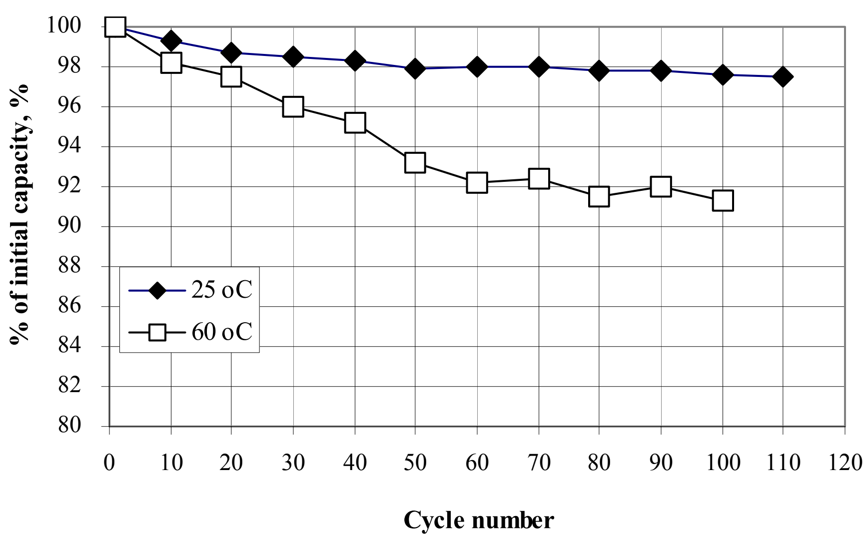
Table 2. Capacity variation of lithium battery at different discharge rates

C rate, hr	Capacity of 48V60 Li-ion battery, AH	Capacity of VRLA-2
1	57	46.2
5	60	57.8
8	60	60.6
20	60	66.1

Cycle Life

The cycle life testing is still in progress. Figure 3 shows the most recent data at 25 and 60^{o}C. All cells continue to maintain a high capacity after 100 cycles.

Fig. 3. Cycle life test of the 48V60 Li-ion cell



Recharge and Protection Circuit

With lithium being the most active metal, lithium batteries possess one of the highest energy density among batteries. At the same time, the high activity of lithium also poses a challenge in making the lithium battery safe. Pure lithium metal is very much avoided as the anode material, except at some high temperature polymeric type batteries [3]. For cathode material, lithium cobalt oxide has been the most extensively studied and used material due to its high energy density and simple manufacturing process. Other cathode materials with better safety performance have also been experimented, but are not in volume production as is the cobalt oxide material.

One key step to have a safe Li-Ion battery is to have a good control of the charging process. It is critical to avoid overcharging the battery and to maintain good cell balance in a battery. A Li-Ion battery with an effective protection circuit and an efficient thermal design can be operated safely, regardless of the type of electrode material used.

For the 48V60 battery, the float charge voltage is set to 4.1 V for safer operation and longer life without significant compromise of the capacity. A proprietary electrolyte enables the battery to be used in high temperature applications. Three levels of voltage control in the protection circuit ensure safe recharging of the battery. When an abnormal condition is detected, an alarm signal is sent to the controller of the power plant for corrective action. The recharge circuitry allows for a wide range of rectifier voltage commonly used for float charging VRLA batteries, providing drop-in compatibility with most VRLA batteries.

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