FEASIBILITY STUDY OF MIXING PARALLEL STRINGS OF LITHIUM-ION BATTERIES AND LEAD ACID BATTERIES FOR TELECOMMUNICATIONS APPLICATIONS

Patrick K. Ng
Tyco/Electronics Power Systems
3000 Skyline Dr
Mesquite, TX 75149

INTRODUCTION

In the telecommunications industry, batteries have been a critical element of the backup power system for providing power during an AC outage. The rechargeable lead acid batteries, the flooded type in particular, have been used extensively in indoor central offices [1]. They are reliable and have a long life for the application. However, they are heavy and take up a lot of space. For the last 15 years, valve-regulated lead acid (VRLA) batteries have gained in popularity due to their compact foot print and higher energy density. They have been deployed extensively in outdoor cabinets, controlled environment vaults, and huts.

Despite the success of lead acid batteries in the backup power plants, they have several drawbacks. Lead acid batteries have been known to have low energy density, both in terms of weight and volume. Reinforced floors and spacious rooms are required. In normal float charge conditions, they evolve hydrogen gas and can be hazardous if not sufficiently ventilated. When using VRLA batteries in uncontrolled hot environment, they exhibit premature capacity failure and sometimes thermal runaway [2]. For flooded lead acid batteries used in central offices, the initial drop in bus voltage (Coup de Fouet region) during discharge may open the low voltage disconnect contactor and cause premature system failure, particularly at high discharge rates.

Efforts have been made to search for other energy reserve systems that can reduce or eliminate the drawbacks of lead acid batteries. Systems such as flywheels and microturbines have been evaluated but they still require further technical development. Nickel cadmium batteries [3] have been deployed with limited success due to their environmental concerns and marginal improvement in energy density. In recent years, lithium based batteries [4,5] have been gaining attention due to their success in laptop computers, cell phones, and other applications. They have energy density that is 2-3 times that of lead acid and no emission of hazardous gas. Improved protection features have been developed for safe operation of the batteries. The manufacturing process has also matured to the point that the cost is within reach for applications as the backup energy in telecommunication applications.

In this work, experiments were conducted to study the performance of a lithium based battery as the backup energy source in central office applications. Its compatibility with parallel strings of flooded batteries was studied. For central offices, space limitation and regulation codes can make it difficult to install more flooded batteries. For expansion, lower capacity battery strings have to be removed and replaced with higher capacity strings. This can lead to floor reinforcement and huge amounts of installation costs. A high density, lithium based battery can be a viable alternative if it performs in the mixed string situation.

EXPERIMENTAL

Figure 1 is a schematic of the experimental setup of the test. Parallel strings of flooded batteries and lithium based batteries were connected to a bank of rectifiers for charging and a load for discharge. The flooded battery is the round cell type with 1680 AH capacity. In this study, the 48-V lithium based battery is a 23" wide, rack mounted type battery with a capacity in the range of 45 to 50 AH. Its protection features include a contactor for high temperature and high/low voltage control, and a fuse for overcurrent control. It is available in versions that can work with both flooded (52-V) and valve-regulated (54-V) lead acid batteries.

In this study, different numbers of strings of flooded and lithium based batteries were tested at different recharge and discharge currents. Table 1 summarizes the tests conducted. A shunt was connected to each string to monitor the current. A data logger was used to collect current and voltage measurements. All tests were conducted at room temperature of 22-25 ^{o}C and a charge voltage of 52.8 volts.

RESULTS AND DISCUSSION

1. Comparison of discharge curves of flooded lead acid and lithium based batteries

The discharge behavior of the flooded lead acid and lithium based batteries can greatly affect their compatibility. Figure 2 shows their discharge curves at their 8-hr discharge rate. The lithium based battery is a 54-V version. Both flooded and valve-regulated types of lead acid batteries were shown for comparison. It can be seen that, after the initial drop, the voltage of the lithium based battery stayed high, about 52 volts, for most of the discharge period. It dropped sharply at the end of discharge. From 45V to 42V, the extra reserve time gained was only about 3 minutes. Most of the battery capacity was discharged at the relatively high voltage. For the lead acid battery, its voltage went through the unique Coup de Fouet region, in which the voltage took a precipitous drop and recovered to form a peak before the gradually sloping decay. The battery voltage also was lower than that of the lithium based battery. Figure 3 shows the two versions (52-V and 54-V) of the lithium based battery at the high discharge rate of ½-hr. The voltage still maintains a flat profile and a high value. The voltage difference between the two versions is about 2-3 volts.

The Coup de Fouet voltage drop of the lead acid battery is more pronounced at high discharge rates. Figure 4 shows the curve that relates the Coup de Fouet voltage drop to the discharge current of the flooded round cell. Backup power plants in central offices are traditionally sized for 8 hours of reserve. A more recent trend is to switch toward 4 hours of reserve without adding more batteries. The consequences of this change are a deeper drop of the initial bus voltage during power outage and the increased likelihood of system failure if this drop is below the low voltage disconnect threshold.

2. Discharge/charge behavior of mixed strings of flooded lead acid and lithium based batteries

Figure 5a shows the discharge curves of a test in which one string of flooded batteries was connected in parallel with two strings of lithium based batteries. The total discharge current was 400 A. Several factors influence the current distributed between the two types of batteries. As the discharge is initiated, the current drain from each battery type depends on its internal resistance. In this study, the internal resistance of each 2-V flooded battery is 0.00019 ohms, resulting in an internal resistance of 0.00456 ohms for the 48-V string. The 48-V lithium based battery has a nominal internal resistance of 0.032 ohms, about 8 times more resistive than the flooded battery. It is expected that the flooded lead acid battery will carry a higher initial discharge current, as indicated in figure 5a. Once the discharge begins, the discharge behavior of each type of battery, as shown in figure 2, starts to impact the current distribution. The lithium based battery has a higher discharge voltage than the flooded lead acid, and its discharge current will increase to keep that high voltage. The current of the flooded lead acid battery will decrease to a rate that matches its performance at the high voltage. As a result, the current from the lithium based battery will increase while that of the flooded lead acid battery will decrease, as shown in Fig. 5a. After the capacity of the lithium based battery was consumed, the flooded lead acid battery started to support the load.

During the recharge of the batteries, as shown in Figure 5b, the flooded lead acid battery took most of the initial recharge current (550 A) due to its lower internal resistance. Each of the lithium based batteries received only about 100 A initial recharge current. If not for the flooded lead acid battery, the initial inrush current to the lithium based battery can be so high that the internal protective device may be damaged.

3. Effect of the lithium based battery on the voltage drop in the Coup de Fouet region

One advantage of mixing the lithium based battery with the flooded lead acid battery is the reduction of the initial Coup de Fouet voltage drop of the system. In the 400 A discharge test in Figure 5a, the voltage dropped to about 46.5 volts in the beginning of the test. If only flooded lead acid batteries are used, the voltage can drop to 45.2 volts, as indicated in Figure 4. The improvement of this initial voltage drop can avoid the opening of the low voltage disconnect contactor, if available, and eliminate the possibility of system failure.

Figure 6 show similar results in mixing one string of flooded lead acid batteries with four lithium based batteries, discharged at 320 A. The four lithium based batteries maintained a higher bus voltage and dutifully discharged all their capacity in the early stage of the test. With more lithium based batteries, the improvement of the Coup de Fouet voltage drop of the system was even more evident (47.3 V vs 45.7 V).

4. Recharge behavior after a short power outage

Figures 7a and 7b shows the results of a practical situation in which the power outage is of short duration. During a short discharge, the flooded lead acid battery may not experience significant capacity loss while the lithium based battery can be fully discharged. As the power comes back on, more recharge current may be directed to the lithium based battery and may cause damage. The test conducted involved one string of flooded batteries and one of lithium based batteries. They were discharged at 320 A for about 30 minutes, followed with a recharge at a total current of 675 A. Figure 7a shows the discharge curves of the batteries. After 30 minutes, about 150 AH capacity was taken out of the flooded battery, less that 10% of its rated capacity. For the lithium based battery, more than 50% of its capacity was discharged. On recharge, the flooded battery took a majority of the current (500 A), as shown in Figure 7b. The lithium based battery received about 100 amperes recharge current and no damage was observed. With its higher conductance, the flooded lead acid battery shielded the lithium based battery from a high inrush current during recharge.

CONCLUSIONS

Lithium based batteries can be compatibly mixed with flooded lead acid batteries when they possess similar float charge voltage. In discharge, the lithium based battery maintains a high bus voltage and discharges all its capacity at the early stage of a power outage. It helps reduce the Coup de Fouet voltage drop that occurs during the discharge of the flooded lead acid battery. The possibility of system failure due to the opening of the low voltage disconnect contactor is greatly reduced. In recharge, the lithium base battery is protected from high recharge current by the flooded lead acid battery. The damage of any protective device in the lithium based battery is avoided. The two types of batteries are complementing each other in supporting the power plant, enhancing each other’s performance during the charge and discharge process.

REFERENCES

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Table 1: Summary of test conditions

Strings of flooded battery	Strings of lithium based battery	Total discharge current, A	Total recharge current, A
1	1	320	675
1	2	180	225
1	2	310	No recharge
1	2	400	750
1	2	500	225
1	2	600	225
1	4	200	1500
1	4	320	675
2	2	300	450

Figure 1. Experimental setup

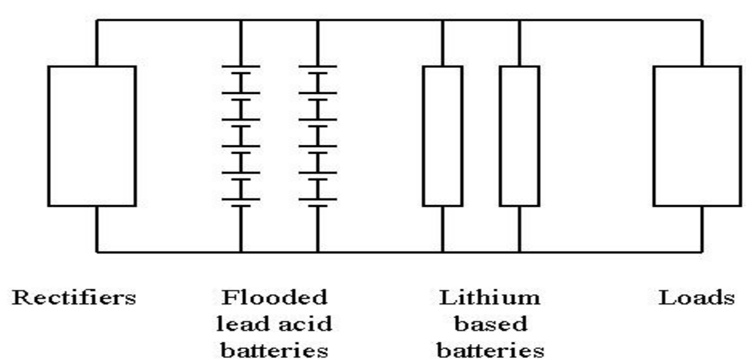


Figure 2. Comparison of discharge curves at 8-hr discharge rate

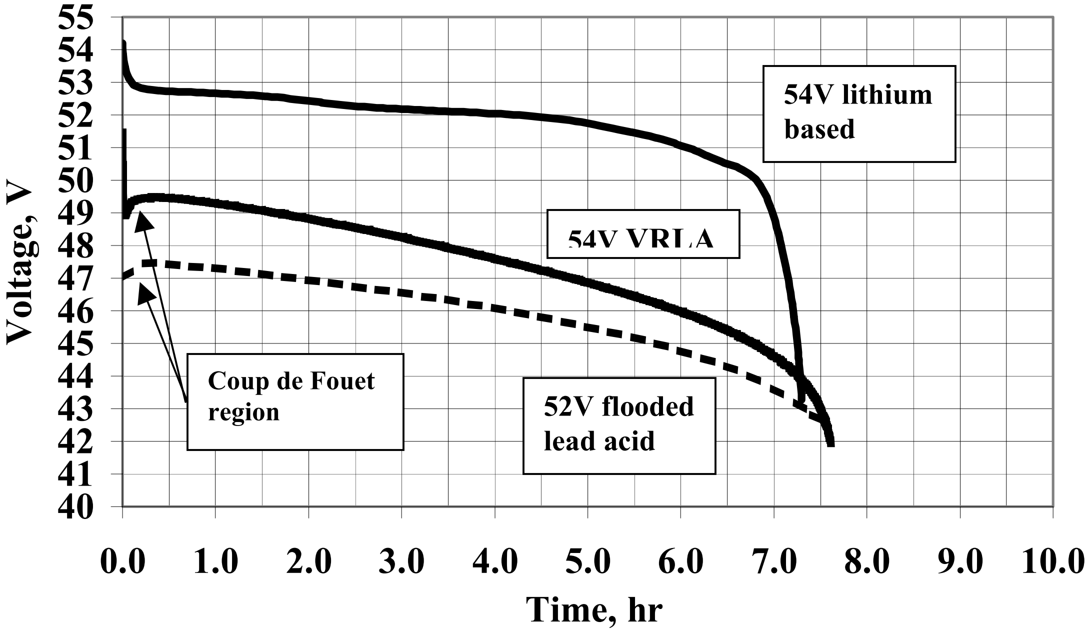


Figure 3. Discharge curves of lithium based batteries at high rate (1/2-hr)

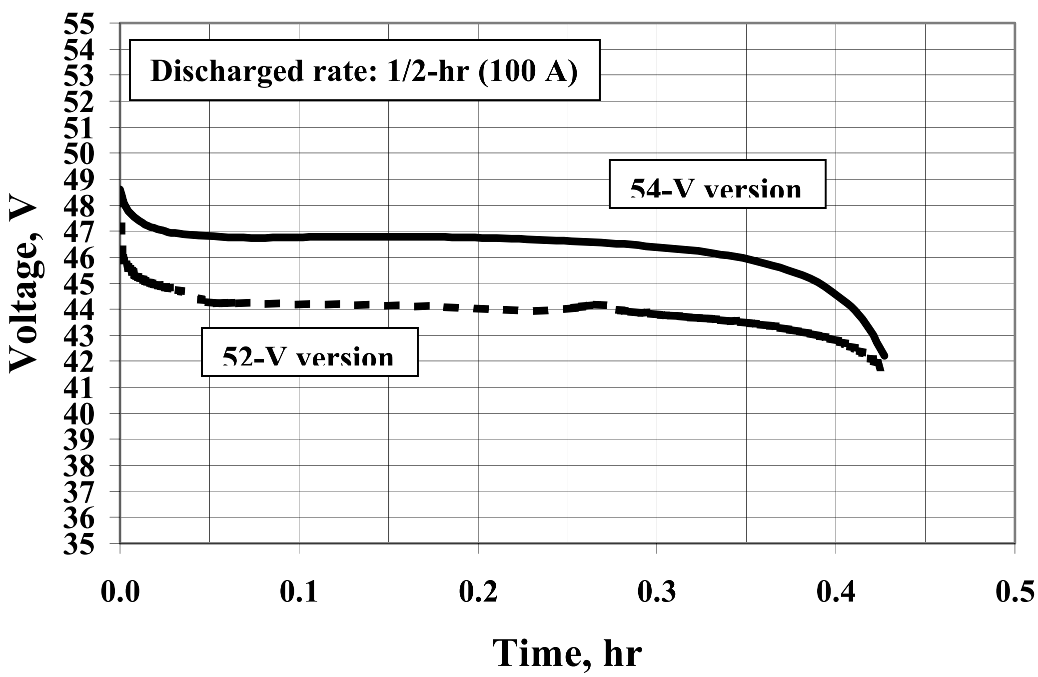


Figure 4. Coup de Fouet voltage drop of flooded round cell string

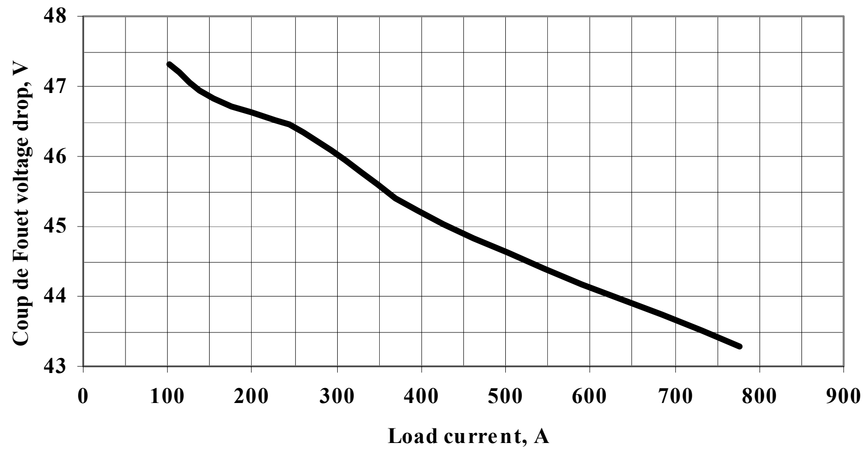
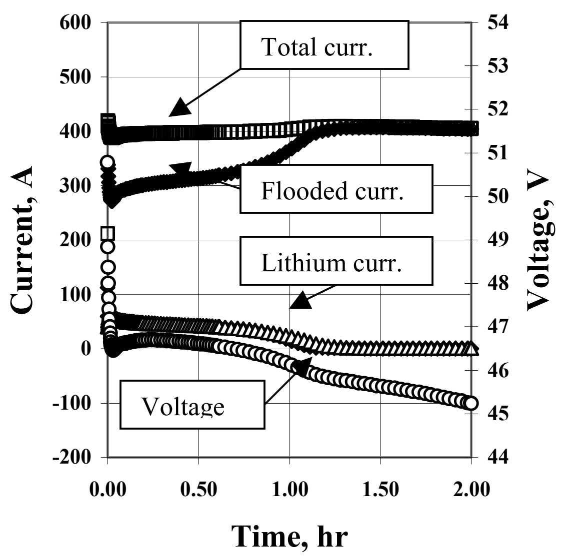


Figure 5a & 5b. Discharge/charge curves of 1 string of flooded battery and 2 strings of lithium based batteries

5a. Discharge at 400 A



5b. Charge at 750 A

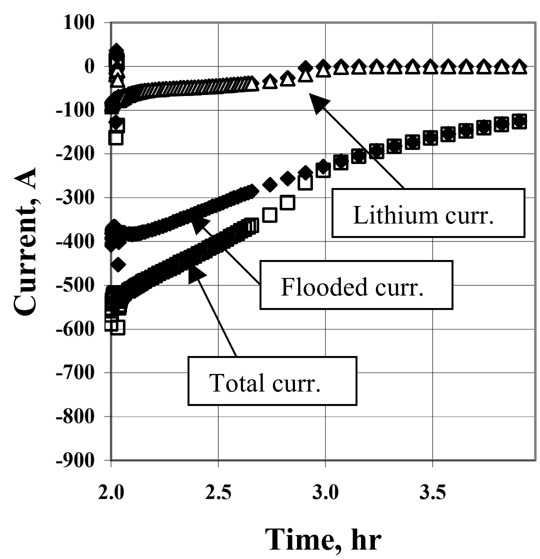


Figure 6. Discharge curves of 1 string of flooded battery and 4 strings of lithium based batteries at 320 A discharge current

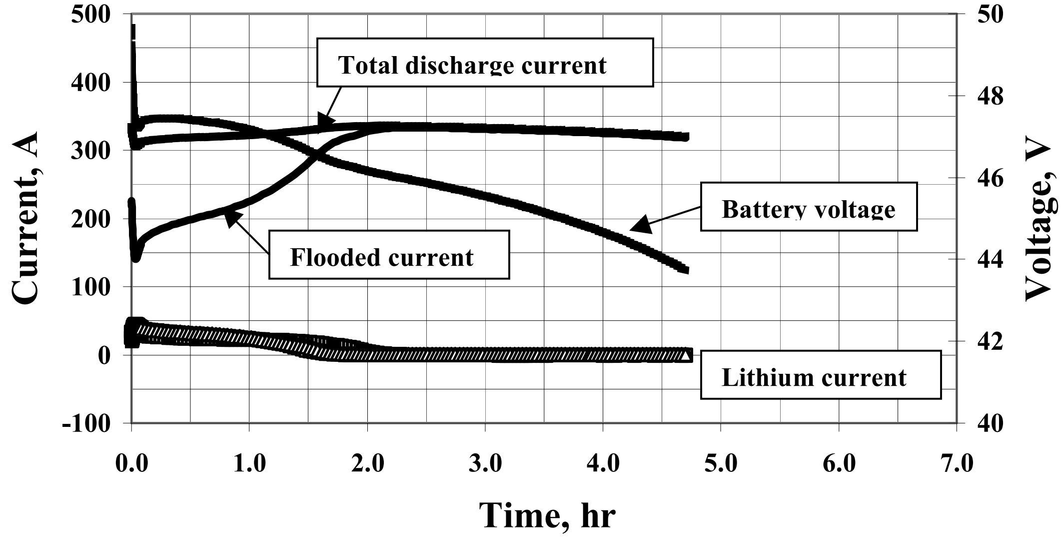
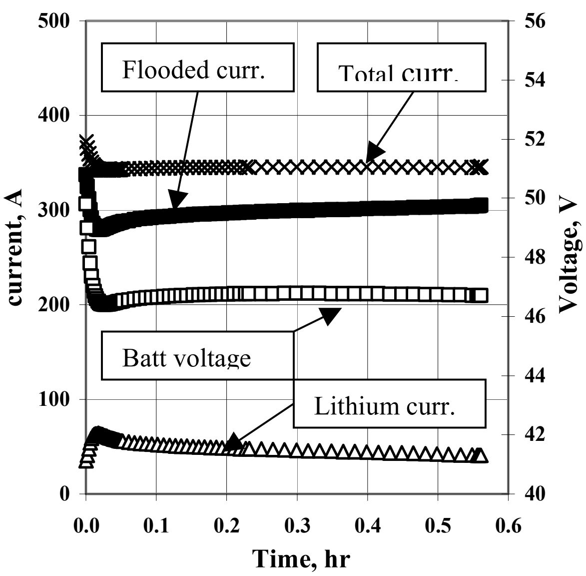


Figure 7a & 7b. Discharge/charge curves of 1 string of flooded battery and 1 strings of lithium based batteries

7a. Discharge at 320 A for 0.5 hours



7b. Recharge at 675 A