Abstract

Long battery charge times and low battery charge-discharge cycle life are the two major limitations holding back the commercialization of electric vehicles. In order to resolve these problems, a robust battery system was developed by Microvast Inc. The batteries can be charged in less than 10 minutes and rapidly charged and discharged up to 20,000 times, while still maintaining more than 80% of the original capacity. 6 City Buses utilizing the Microvast battery systems have been tested in commercial operation in Chong Qing, China for more than one year. The batteries are still in good condition. The improved Li$_4$Ti$_5$O$_{12}$ negative electrode material gives the Microvast battery system its excellent properties.

Keywords: ultrafast charging, LTO technology, electric bus

1. LpTO Technology

As a negative electrode material, Li$_4$Ti$_5$O$_{12}$ (LTO) has been well documented with good stability and high charge-discharge rates. However, the gas generation in the charge-discharge cycles of LTO batteries has been a fatal drawback of the batteries, leading to the degradation of the batteries and limited use of such batteries in the market.

The investigation found that, in most cases, the gas generation in the batteries occurs because of the chemical reactions started on the surface of Li$_4$Ti$_5$O$_{12}$ material. In the charge-discharge process, the electrolyte solvent reacts with the Li$_4$Ti$_5$O$_{12}$ generating reductive lithium alcoholate, which can be oxidized on the positive electrode in the charged state to form H$_2$O, CO, CO$_2$, C$_2$H$_4$, and C$_3$H$_6$, which lead to much faster battery degradation. In order to resolve the problem, scientists at Microvast developed a new technology to enrich a layer of inert material...
on the surface of Li$_4$Ti$_5$O$_{12}$ and retard the reaction between the Li$_4$Ti$_5$O$_{12}$ and the electrolyte solution. The newly developed Li$_4$Ti$_5$O$_{12}$ material is called LpTO material (Fig. 1&2). Batteries using LpTO as the negative electrode material have long cycling life.

A battery with LpTO negative electrode material and NiCoMnO$_x$ positive electrode material has been tested for up to 18 months. The results, shown in Figure 3, reveal that, after 25,000 cycles, the capacity retention is still about 75%.

![Coating structure of LpTO material](image)

**Figure 2. Coating structure of LpTO material**

![NCM-LpTO battery cycle test](image)

**Figure 3. NCM-LpTO battery cycle test**

2. **Application of LpTO**

Li-ion batteries are beginning to appear in both the electric vehicle and smart grid energy storage markets. Although they are now entering markets, they still face high lifetime total-cost-of-ownership challenges, blocking true mass market development. The LpTO battery, with its long cycle life, brings an alternative solution, which is much more cost effective.

Combining the ultrafast charging solutions now available with the long cycle life LpTO technology can transform the electric vehicle industry. Two particularly attractive applications are the Shuttle Bus and the City Bus, which are typically operated on high use and fixed loop routes every day. With LpTO battery technology, the bus or shuttle can be ultrafast charged every loop, taking less than 10 minutes per charge. Because the battery is charged in each loop, a very small battery pack can be used, meeting a single loop energy requirement as opposed to a whole day energy requirement that would require a much larger battery pack.
The advantage can be found in the following example: Compare a 30 unit small bus fleet equipped with LTO battery technology with that of one equipped with LFP battery technology.

We find that a small bus equipped with an LTO battery that can be ultrafast charged, has the following advantages: 1) a smaller pack is less expensive, 2) a smaller pack weighs less reducing strain on the bus chassis and freeing up space, 3) reduced weight increases vehicle efficiency, and 4) reduced charging infrastructure investment is required due to higher charging port efficiency.

| Table 1. LFP / LTO Battery Comparison for Bus or Shuttle Use |
|-----------------------------------------------------------|
| Miles per loop                                           |
| LFP battery: 15                                          |
| LTO battery: 15                                          |
| Cycles per day                                           |
| LFP battery: 10                                          |
| LTO battery: 10                                          |
| Miles per day                                           |
| LFP battery: 150                                         |
| LTO battery: 150                                         |
| Energy consumption, kWh/mile                             |
| LFP battery: 1.2*                                        |
| LTO battery: 1.2                                         |
| Energy needed for one loop, kWh                          |
| LFP battery: 18                                          |
| LTO battery: 18                                          |
| Energy needed for one day, kWh                           |
| LFP battery: 180                                         |
| LTO battery: 180                                         |
| Charging time of battery                                 |
| LFP battery: 5 hours, at night                           |
| LTO battery: 10 minutes, every loop                      |
| Cycles per year                                          |
| LFP battery: 365                                         |
| LTO battery: 3650                                        |
| SOC intervals for operation                              |
| LFP battery: 20%-100%                                    |
| LTO battery: 20%-100%                                    |
| Capacity loss at EOL                                     |
| LFP battery: 20%                                         |
| LTO battery: 20%                                         |
| Battery capacity installed, kWh/bus                     |
| LFP battery: 281.25                                      |
| LTO battery: 28.13                                       |
| Weigh of battery pack                                    |
| LFP battery: 3 tons                                      |
| LTO battery: 0.8 tons                                    |
| Charging ports,                                          |
| LFP battery: 30                                          |
| LTO battery: 4                                           |
| Power of each charging ports, kW                         |
| LFP battery: 60                                          |
| LTO battery: 200                                         |
| Overall power of charging station, kW                    |
| LFP battery: 1800                                        |
| LTO battery: 800                                         |

*Assume same energy consumption for bus with different weight

3. City Bus Operation Data

Microvast Inc., through its majority owned joint venture company, HT eBus Power Systems Co. Ltd., fielded six, LpTO battery electric city buses in Chongqing, China in March, 2011. These six buses continue to run on their route in Chongqing and data is collected daily on each of the six buses. The buses operated on Line 609 in Chongqing, carry fare paying passengers each day.

The buses were put into service on March 18, 2011; the data contained in this paper reflects the data collected from one bus (bus number 62051) over the 12 month period from March
18, 2011 to March 31, 2012. During this period, bus number 62051 traveled 40,000km (24,000 miles) or approximately 100 km/day (65 miles/day).

The same circular route is run by each of the buses each day. The route is approximately 20 km (14 miles) long with an average 5 or 6 trips taken each day. Fast charging between routes takes place at a central location; fast charging times average about 10 minutes at charge power levels of approximately 400 kW.

The LpTO battery used (Fig. 4) in the buses is an air cooled, 560V, 110Ah (60kWh) battery pack utilizing 11Ah pouch cells (Fig. 5) connected in a 10 parallel, 254 series configuration.

Over the approximately 380 days run, the 62051 bus was charged approximately 1930 times. Over this time, battery capacity has decreased only slightly and we estimate a pack life of at least 15,000 cycles allowing for a 70% end of life capacity retention.

The following information reflects data captured from bus 62051 during its operation between March 18, 2011 and March 31, 2012.

1) Current during Operation (Fig. 6)
While driving, the current from the battery pack was recorded. Negative data indicates energy regeneration during braking or downhill driving. A maximum 380A or about 3.5 C discharge was observed.

2) Number of Charges (Fig. 7)
The number of charges was about 2,000 with the average energy added per charge of 20 - 40kWh. The average duration of each charge was less than 10 minutes, with the minimum charge duration being approximately 3 minutes, and the maximum charge duration being approximately 14 minutes. Charge power was, on average, approximately 400kW.
Figure 6. Discharging/regeneration current of battery pack during operation

Figure 7. Number of Charges
3) Battery Temperature

Battery temperatures were recorded (Fig. 8) at the cell surface during operation and charging. Air cooling was used for the battery pack; at no time was the recorded maximum temperature (T_max) above 55°C. Charging station ambient temperature ranged from a low of about 5°C to a high of more than 42°C. It should be noted that during the months of June, July, and August, 2011, the City of Chongqing experienced hot weather with daily high temperatures often reaching 42°C. During the months of September and October, the temperature dropped significantly.

4. Analysis of Battery Modules

In April, 2012, modules were removed from the buses and analyzed for capacity retention, increased impedance, and constant current capacity. These test results are shown below in Figure 9, 10, and 11.

1) Capacity Retention

In order to evaluate capacity retention, 5 cells were removed from the module and evaluated. The nominal 1 C capacity of the 5 cells was tested at 1 C and compared with original delivery capacity data:

Averaging these 5 cells, we observed about a 0.7% capacity loss, with a maximum capacity loss of 2.7%.
In order to test for impedance gain, initial impedance data was compared with that of the 5 removed cells. The impedance rose from 0.662 mOhm initially to 0.676 mOhm. An increase of about 2% was observed.

3) Constant Current Capacity

When testing for constant current capacity loss, the ratio of initial capacity of 5C constant current charging was compared with that of the removed cells. Nominal constant current capacity decreased from 90.2% to 88.6%.

Based on the results of the tested cells and modules, the data shows very good results after 2,000 ultrafast charging cycles.

Conclusion

Beginning with research and development on LpTO anode material, Micr ovast has introduced a battery that appears to offer long cycle life even during ultrafast charge events. Tests of buses utilizing the LpTO chemistry and ultrafast charge appear to validate the long cycle life of the Microvast cells. Further analyses on removed battery modules supports the bus test data.
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