

LTO based modular battery system with thermal management for fast charging application in electric buses

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Summary

Results from development, tests and application of LTO based battery modules with thermal management has been presented in this paper. LTO cells offer very high discharge and charge rates but to preserve its long lifetime and number of cycles, a dedicated thermal management systems has to be developed. Additionally for electric bus applications, system has to be modular and mechanically very flexible in order to fit large capacity in the electric bus body.

1 Introduction

Fast charging approach of electric buses becomes more and more popular for the cities. Ability of recharge the bus in several minutes at the end stop will allow to use pure electric buses to operate whole day. Additionally LTO pack can be smaller and lighter than e-bus standard battery packs resulting in more passengers allowance inside the bus. Modern LTO cells allows practically fulfilling the dream of electric bus working 24 hours a day (day and night shifts) with sustainable performance, fast charging at bus stops or end line stops and very attractive life cycle cost level during 10-12 years of operation.

So far the only big advantage of electric buses was reduction of the pollution and the noise level in the city. Due to long charging time and very heavy battery (typically 200kWh corresponds to ca 2,5t) the operation of pure electric buses was heavily limited and not always justified. Application of much smaller LTO packs with ultra-fast charging ability and very large number of full cycles (typically 12000-15000) will redefine the electric bus as a real replacement of standard diesel bus used widely today.

LTO battery pack has also its limitations mostly related to thermal management of lithium-titanate cells. Lifetime and performance of LTO cells is heavily affected by elevated temperature. High charge currents (fast charger can have 400kW) producing a lot of heat during charging. Proper cooling systems are essential to manage the pack toward 10+ years lifetime.

2 LTO cells

LTO – Lithium titanate battery is a modified lithium-ion battery that uses lithium-titanate nanocrystals on the surface of its anode instead of carbon. This give the anode a surface more than 30 times bigger than in standard Li-ion cells. The leading manufacturer of LTO cells is Toshiba with 20Ah and 23Ah models. The nominal voltage of LTO cells is little lower than standard NCM and LFP cells so the energy density also is a bit lower. Its great advantage is related to:

- a) High charge currents – typically 5C continuous
- b) High discharge currents – practically the same as in charging
- c) Large number of cycles – more than 12000 full cycles – to certain lifetime, cycles are not affecting ageing of the cell
- d) Very good performance (both charging and discharging) in subzero temperatures up to -30C

- e) High current is also not affecting lifetime of the cell

The LTO cell has also two big disadvantages:

- a) Very low specific energy – at a level of 90Wh/kg today
- b) High influence of elevated temperature on lifetime and performance (Fig. 1)

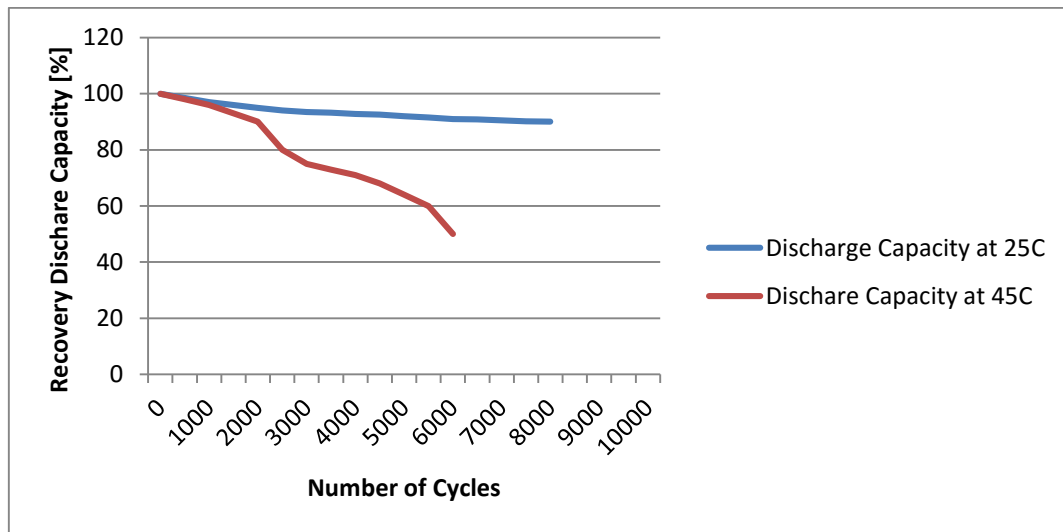


Figure1: Recovery discharge capacity at two different temperatures with 3C/3C charge/discharge profile for LTO cell

Automotive LTO cells are also designed to be assembled using very special laser welding process, which will secure the reliability of the joints toward minimizing thermal losses during high current operation.

All those features leads to fact, that to design a proper pack for electric bus, a lot of new factors has to be considered.

3 Modularity approach

There are still no either mechanical nor electric standard in e-bus battery packs specification. Each bus manufacturer has its own vision where to mount battery packs and how to integrate them with the electric drivetrain. In order to fulfil their requirements, sometime very different from one bus model to another, a modularity approach has been developed. Battery pack consist of small LTO module having 24 cells which are independently managed and cooled. Cells can be connected inside module in three different ways creating 24S1P, 12S2P and 6S4P configuration. Modules are connected in series to create full system voltage. To make bigger capacities, several strings should be connected in parallel.



Figure2: Basic ICPT LTO module with 12S2P configuration

Modular approach allows to design various shapes of the packs with very high maintainability level. Single module is relatively small and light (around 15kg) so it is easy to replace it in the pack during service. Due to thermal requirement, the individual cooling is applied to each module.



Figure3: Example of flat ICPT LTO battery pack roof mounted

4 Pack design considerations

In order to fulfil mechanical constraints of various bus assemblies and for match strict mechanical, electrical and safety standards, ICPT LTO modules are placed in modular packs having full system voltage, which can be later connected in parallel to create larger systems. Example of system configuration is presented on Figure 3.

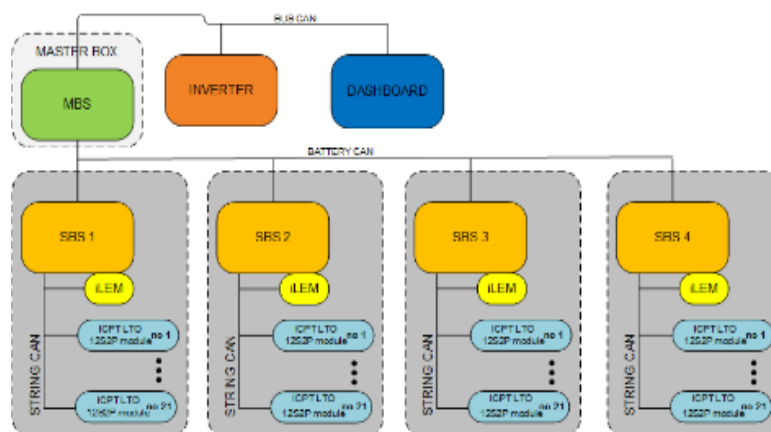


Figure4: Typical configuration for complete LTO Battery Pack for Electric Bus with 4 packs, each having 25KWh

5 Thermal management

LTO cells are very sensitive on elevated temperatures. Operation of LTO cells above 30°C can shorten dramatically the lifetime of the battery pack as well as number of cycles. For e-bus application, water cooled system has been developed to keep the cells in most favourable conditions. Basic ICPT LTO module has three different configuration of water cooling circuit depending on the duty cycle and environment conditions of the application.

Water cooling system for LTO batteries adds a lot of additional weight to the pack. For electric bus, weight is essential to bring more passengers to the vehicle. Additionally with modular and highly customized

approach to pack design, not every LTO system has to work permanently in high 5+ C charge/discharge rates at hot climate location.

ICPT developed three families of LTO modules with variable options of individual cooling methodology. Most sophisticated design for applications with C rates much higher than 5C include placing of water radiators directly to both sides of each LTO cell. It allows to very precise control and manage the temperature of LTO module.

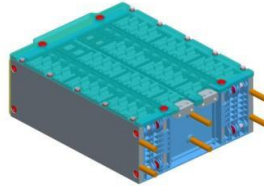


Figure5: Cooling option of LTO module via internal water radiators directly attached to the cells

Second family utilizes the design with additional aluminium radiators located between cells, cumulating heat from the cells and providing very good heat transfer to the cooling plate. This design is destined to applications located in elevated temperature,

Third, most cost effective and lightest design is based on sophisticated aluminium structure providing direct heat transfer to the bottom cooling plate still keeping 5C charging and discharging rate.

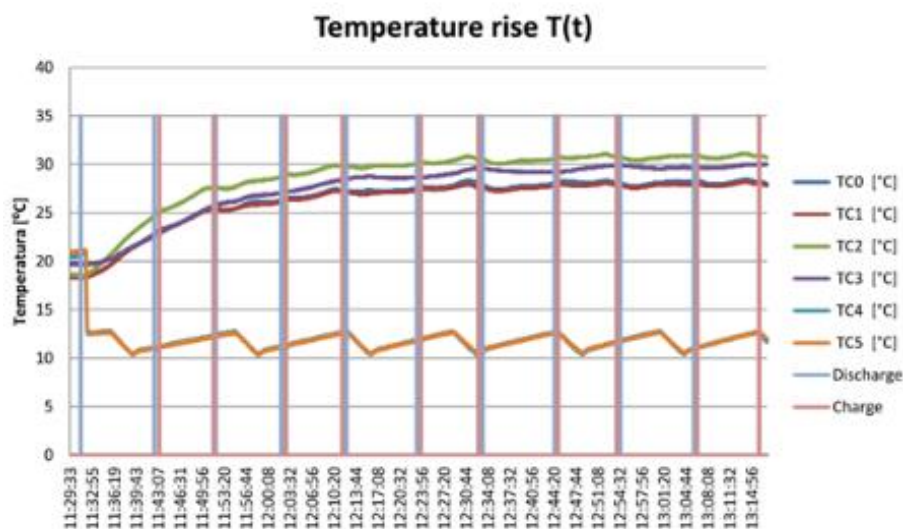


Figure 6: Example of thermal test scenario for ICPT LTO light module with 5C discharge and 4C charge cyclic operation

6 Achievement

Thermal management and design of ICPT LTO battery packs for electric buses developed by Impact Clean Power Technology allows to wider use of fast charging system in various configuration and specification independent on bus manufacturer individual demands and application constrains. LTO buses have a chance to widely penetrate the cites as they offer not only pollution and noise free operation but also can operate whole day without long stops for recharging. Additionally their lifetime and life cycle costs will soon become better than diesel buses.

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