COMPARATIVE ANALYSIS OF LITHIUM-ION BATTERIES FOR EV/HEV APPLICATIONS

M.Sc. Velev B. PhD.,

Institute of Mechanics - BAS , Bulgaria

boris_velev81@abv.bg

Abstract: *For the serial production of electric cars, the development of Li-Ion cell technology to achieve high energy density of packaging batteries is critical and is subject to great research and development. This paper reviews the latest developments in cell technology and cathode chemistry for the production of traction lithium-ion batteries. Are made non-destructive testing and comparative analysis of the most important characteristics of the batteries with the known Li-Ion cell electrochemistry. The advantages and disadvantages of different types of Li-Ion cells are presented. Conclusions were made on the degree of applicability of the respective types of lithium-ion batteries in EV / HEV applications.*

Keywords: LI-ION - LITHIUM-ION BATTERY; EV/HEV- ELECTRIC AND HYBRID VEHICLES; BMS-BATTERY MANAGEMENT SYSTEM**.**

1. Introduction

Enhanced EV / HEV production depends on the development of lithium-ion batteries to store and manage energy. Although lithium-ion technology is relatively young, it has significant potential for both reducing costs and increasing energy density (specific Wh / kg energy) by rationalizing the manufacturing process. Specific energy is a key indicator in the production of Li-Ion cells for EV. The advantage of energy density lies in the fact that less electrolyte is required, which allows faster transfer of ions from the anode to the cathode which, when assembled, results in a lower cell weight and hence lower total weight of the battery pack for EV. In recent years, great progress has been made in the development of Li-Ion cell technology to achieve high energy density.

2. Purpose of the work

To review the cell characteristics and chemistry of cathode materials for the production of traction lithium-ion batteries. Perform battery tests with the most popular Li-Ion cell electrochemies, analyzing the advantages and disadvantages of different cell types. To draw conclusions on the degree of applicability of the respective types of lithium-ion batteries in EV / HEVapplications.

3. Characteristics of the most used battery cells for EV / HEV

Largest distribution in EV / HEV battery production has received the following types of Li-Ion cells: LFP, NCA and NMC [4,5]. The most common classical LCO cell with $LiCoO_2$ cathode material has a high specific energy (240Wh / kg) but is not suitable for EV / HEV applications because of its propensity for ignition and harmfulness. The main cell characteristics are as follows:

- Specific energy. This feature has recently proven to be the most important, due to the development of battery management systems, the BMS, which has helped remove major flaws in increased density (heating, ignition, etc.).

- Chemical composition of the cathode material. It depends on the specific energy of the cell, and hence the maximum EV range with one charge [4,5].

- Cell size. Until recently, prismatic design of cells was considered to be the most suitable for EV. However, it is only suitable for LFP cells that are fire-safe but have low energy density. The reason is that in this design there is a greater probability of microscopic "short-circuits" between the electrodes in the folding zones and causing the "fugitive heat" effect (spontaneous temperature rise and cell destruction) [6]. Therefore, most of the NCA and NMC for EV cells are cylindrical, where there are no sharp folds between the electrodes and the heat-fugitive effect is less likely. The most widespread in EV are the cells of size 18650 [11].

- Internal resistance (impedance). This is an important functional feature of the cell. It is necessary to know the impedance of the cell to calculate the generation of Jaw heat or the loss of power in the cell. With cell aging, its internal resistance increases. This reduces the ability to receive and hold charge, but the OCV will still display as normal and even higher, despite the reduced battery capacity. Periodic comparison of actual internal resistance with new battery resistance will show any deterioration in battery functionality [8].

- Charging / dilution characteristic curve. Another main functional characteristic is the charge / dilution curve. It depends mainly on the choice of anode and cathode materials. This is an important feature that determines cell behavior during charging / discharging and is fundamental in the development of algorithms and software for battery management and monitoring systems.

4. Subject of research, equipment and methodology

In order to determine the most promising cells for EV / HEV applications, non-destructive tests of the basic functional characteristics have been performed - internal impedance and charging / discharging characteristics of cells of different design and different cellular electrochemies of the most popular types of Li- Ion batteries for EV / HEV applications.

4.1. Object of the study

The object of the study is LFP, NCA and NMC type 18650 Li-Ion cylindrical cells, and a large LFP prismatic LFP cell line with $LiFeYPO_4$ cathode material. Cylinder cells are new, commercially purchased by different distributors [1,2,3]. From a used battery pack for EV, two large prismatic cells with the largest difference in nominal voltage at OCV were tested (Table 1). Cells are tested without protectors and control systems. Tests are subject to at least two cages of the species.

Table1: Commercial characteristics of the species Lithium - ion cells used for EV / HEV

Type	Format, mm	Commercial name	Nominal V
LFP	**Φ18x65**	LFP18650 Zelle	**3,2**
NCA	**Φ18x65**	NCR18650A	**3,6**
NMC	**Φ18x65**	INR18650-29E	**3,7**
LFP	**179x62x218**	LYP100AHA	**3,3**

4.2. Apparatus for research

For the experimental tests a modern safety device was developed, working together with the LabVIEW software package and LabJack U12 test card. It can work with different type and format Li-Ion cells [8]. Photographs of the unit in action are shown in Fig. In Fig. 1.a) shows a large prismatic cell test and Fig. 1.b) cylindrical cell test format 18650.

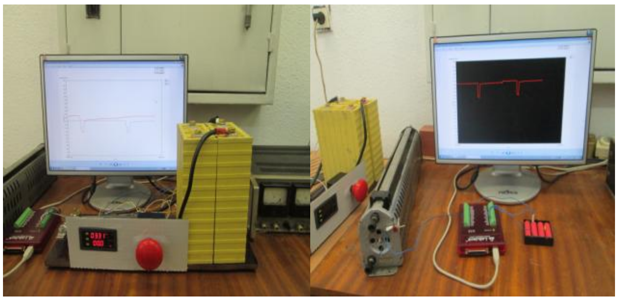
4.3. Experimental Research Methodology

1. Preliminary testing

The objectives of the preliminary test are:

- Determine the charge / dilution curve and assess to what extent the characteristics of the new cells meet the characteristics of the manufacturer;
- Make a comparative analysis of the charging / dilution curves of three types of the most common in the practice of EV applications lithium-ion cells with different electrochemistry to identify differences in their behavioral patterns during charging / dilution.

All cells must be fully charged to the allowable level before testing begins. The cell format 18650 is then diluted with a current of 0.25 C, with C being the battery capacity taken from the manufacturer's data. Dilute for 1 to 4 hours (up to 250 minutes) depending on the capacity of the cell types. The test is carried out with the apparatus shown in Figure 1 (b). The test results are shown in Figure 2.



a b

Fig.1 Images of the impedance measurement unit and the charging / dilution characteristics of lithium-ion cells. Fig. 1a) for large prismatic cells; FIG. 2.b) - For cylindrical cells format 18650.

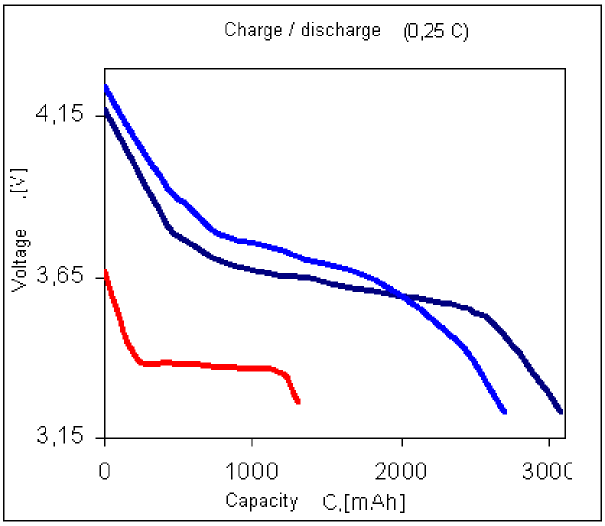


Fig.2. Load / discharge curves of cylindrical cell format 18650 with different cathode materials

2. Full cycle with 0.25C DC charging / discharging current.

Fig. 3. shows cell voltage during a pre-test cycle with a 25 A charge / discharge current of a large LFP cell and a 0.8 A charging / discharging current of a small NCA cell. The cell voltages are displayed as a function of the charge state (SOC). This allows direct comparison of voltage levels between charge and discharge in the same charge state of the two cell types. At the large prismatic cell, the charging and dilution time is halted for a short time for each 10% change in capacity to measure the voltage and analyze the relaxation at OCV [11]. In the NCA type cell, relaxation is not necessary because the charging curve matches the dilution curve, i.e., no special charging / dilution cycle is required as in the large cell.

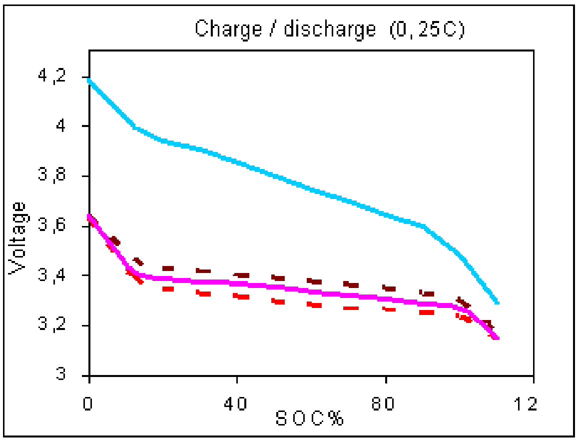


Fig. 3. Cellular voltage development in a 0.25C charge / discharge current with a large LFP cell break and a small NCA cell.

3. Determine the internal resistance

An electrical method [8] is used to determine the impedance. In order to determine the internal resistance, it is first necessary to measure the OCV of the cell. Then a load must be connected through the cell, which will cause a current to flow. This will reduce the cell voltage due to the drop in IR voltage across the cell, which corresponds to the cell's internal resistance. Then the cell voltage must be measured again when the current is running. The

Rin impedance is calculated according to the law of Om by the V cell between the two measurements and the $\Delta Vcell$ difference in voltage current I flowing through the cell according to formula (1).

$$Rin = \Delta Vcell/I \text{ , } m\Omega \qquad (1)$$

For the test, an impulse current of 1.5 ° C is applied for each individual cell for 2 seconds. Using a 2 second pulse time is sufficient to allow cell voltage to stabilize but has a negligible effect on SOC. The pulse current for the large LFP cells is 150A and the current for the small NSA is 4.5A.

5. Analysis of experimental results and discussions

The average values of the impedance test data and the specific energy of the cell types calculated from the charging / dilution curves are presented in Table 2. The analysis of the experimental results of Fig. indicates that the charging / dilution curves of different types of cylindrical cells differ.

Table2: Test results

Type	Cathode materials	Capac. *Ah*	Imp. *mΩ*	Energ *Wh/kg*
LFP	$LiFePO_4$	1,4	40	110
NCA	$Li(NiCoAl)O_2$	3,1	79	260
NMC	$Li(NiCoMn)O_2$	2,9	75	220
LFP	$LiFeYPO_4$	100	39	90

The nominal (working) area of the LFP cells is seen to be rectilinear with a very small slope, i. E. the voltage changes very little over the charge / discharge time. It is also seen that the characteristics of NCA and NMC cells resemble and differ only in capacity [4]. Therefore, the actual charging curve characteristics match the performance characteristics given by the manufacturer and the next tests can be performed.

In FIG. represents the cell voltage charge / discharge curve during testing at a 0.25C DC charge / discharge with large LFP cell breaks and no pause (continuous cycle) on a small NCA cell. The difference from the graph in Fig. 2 is that the voltage on this graph depends on the SOC and not on the time that the maximum capacity is reached. The upper cut-off curve of the LFP cell cycles represents a charge (brown), and the lower cut-off curve (red) represents the break with one-minute break when OCV is counted. Measurements of cell voltage during the test cycle indicate that the cell does not reach balance at the end of the pauses if the response step is paused for 1 minute which is very small. This makes the test more difficult and neglects because it extends the test cycle time to several days. It is necessary to accelerate the cycle time. This is done with a special algorithm where continuous averages (purple line) are interpolation between voltage levels at the end of 1 minute long pauses. This allows the test cycle to run in a very short time, with no great relaxation pauses [4,10]. Also from the analysis of the charge / dilution curves of the two cells, it is confirmed that the nominal area of the NCA cell curve has a non-linear character and the nominal curve region of the LFP cell has a linear characteristic. This means that the load state (SOC) assessment in NCA cells becomes much easier by measuring voltage only, whereas for LFP cells, due to the small slope of the dilution curve, the SOC measurement with voltage measurement only is imprecise . It is also necessary to measure the amount of electricity (Coulon count), which complicates the algorithm and the software of the respective management system (BMS).

Figure 1 (a) of the monitor graphically shows the impulses impulses of two large LFP (LiFeYPO4) cells, and in Figure 1 (b) the impulses of two small NCA cells. There is a slower relaxation of OCV in large cells than small cells. See also, the larger internal resistance of one LFP cell having a higher OCV. Therefore, bigger cells with higher voltages have a higher internal resistance or are not well balanced. Small NCA cells have exactly the same impedance and relax immediately, which means their high quality. From the data in tab. 2 shows the smaller impedance of LFP cells compared to other species. This means longer life and more charging / discharging cycles of this cell type.

6. Conclusions

- LFP cells are of great fire safety and security. Their functionality is very good, they have a large number of charge / discharge cycles and up to 1-2 years ago they were considered the most suitable for EV / HEV applications [8,10]. However, they have one major disadvantage - low specific energy, making this battery unpopular for modern EVs. Especially difficult to balance and require complex software to determine SOC, large prismatic LFP cells.
- NCA cells offer high energy density and are widely used in consumer electronics. They form the basis of Panasonic's battery packs in the current EV models of Tesla motors [11,12].
- NMC cells are also suitable for use in EV. NMC Chemistry is used by Renault and BMW for EV. According to Samsung, the current specific power of its NMC is 130Wh / kg (about half of Panasonic's NCA, but by 2019/2020 it would be 250-300 Wh / kg.) The cost of producing NMC cells for the time being is 12-19% higher than NCA [9,11,13].

In the near future, intelligent BMS developed by leading companies, specifically for NCA and NMC cells, will contribute to the formation of EW battery packs with power over 100KWh and specific energy over 350Wh / kg with high quality and high safety.

7. Literature

1.www.ev-power.eu/.../WB-LYP100AHA-LiFeYPO4-3-2V-100Ah.html.

2.https://batteryservice.bg/kategoria/baterii/li-ion-baterii/visokorazryadni-li-ion-baterii/.

3. https://www.liontecshop.com/shop/18650.

4. H.Popp, J.Attia, F. Delcorso, A.Trifonova, Lifetime analysis of four different lithium ion batteries for (plug–in) electric vehicle, Transport Research Arena (TRA) 5th Conference: Transport Solutions from Research to Deployment, Paris , France, 2014-4-14 to 2014-4-17(2014).

5.http://batteryuniversity.com/learn/article/types_of_lithium_io

6. https://electrotransport.ru/ussr/index.php?board=48.0

7. Meng Wang, Anh Le, Daniel J Noelle and other, Effects of electrode pattern on thermal runaway of lithium-ion battery, International Journal of Damage Mechanics 0(0) 1–8, DOI:10.1177/ 1056789516660176 (2016).

8. Zhu Wei, A Smart BMS for Large Format Lithium Ion Cells , utdr .utoledo. edu/cgi/ viewcontent .cgi? article...dissertations, (2011).

9. M. Brand, S. Glaser and other, Electrical safety of commercial Li-ion cells based on NMC and NCA technology compared to LFP technology/ World Electric Vehicle Symposium EVS27(2013).

10. Doerffel, Dennis (2007) Testing and characterisation of large high-energy lithium-ion batteries for electric and hybrid electric vehicles. University of Southampton, School of Engineering Sciences, Doctoral Thesis, (2007) .

11.G. Hawley, https://evannex.com /blogs/news/ understanding-teslas-lithium-ion-batteries (2017).

12.C.Arcus ,https://cleantechnica.com/2018/03/04/exciting-developments-nmc-811-lithium-battery-technology (2018).

13.https://cleantechnica.com/2016/07/16/bmwsamsung-batteries-vs-teslapanasonic-batteries-better (2016).