Performance of different Lithium-ion batteries for Electric/Hybrid Vehicles

Hari Shankar
Department of Electrical and Electronics Engineering, APJ Abdul Kalam Technological University

Abstract- **A lithium-ion battery or Li-ion battery is a type of rechargeable battery that are incredibly popular these days. Lithium-ion batteries with a modified recipe which has a higher charge absorption capability to facilitate efficient regenerative energy harnessing. There is potential for higher energy densities. However, the potential of Lithium-Ion batteries in this field has not been fully evaluated. We compare the dynamic charge acceptance capability at multiple partial state of charge points and different relaxation periods by simulating real-time conditions. Moreover, the ideal operation temperature will be experimentally evaluated for different chemistries with different temperatures.**

Index Terms- DCA(Dynamic Charge Acceptance); SOC (State of charge); PSOC (Partial state of charge); Lithium-Ion; Batteries; Electric Vehicles; Hybrid Vehicles.

I. INTRODUCTION

Electric and Hybrid vehicles require cells with high ‘dynamic charge acceptance’ which gives them the capability to accept instantaneous energy while charging. Lithium-ion cells have different cathode chemistries and present a wide range of combinations having dominant properties which are very useful for hybrid and electric vehicles. Here DCA is essential whilst there is a trade-off in a different attribute. They're generally much lighter than other types of rechargeable batteries of the same size. The electrodes of a lithium-ion battery are made of lightweight lithium and carbon. Lithium is also a highly reactive element, meaning that a lot of energy can be stored in its atomic bonds. This translates into a very high energy density for lithium-ion batteries.

Despite its overall advantages, lithium-ion has its drawbacks. It is fragile and requires a protection circuit to maintain safe operation. Built into each pack, the protection circuit limits the peak voltage of each cell during charge and prevents the cell voltage from dropping too low on discharge. In addition, the cell temperature is monitored to prevent temperature extremes. The maximum charge and discharge current on most packs are is limited to between 1C and 2C. With these precautions in place, the possibility of metallic lithium plating occurring due to overcharge is virtually eliminated.

The most economical lithium-ion battery in terms of cost-to-energy ratio is the cylindrical one. This cell is used for mobile computing and other applications that do not demand ultra-thin geometry. If a slim pack is required, the prismatic lithium-ion cell is the best cost in terms of stored energy.

II.EVALUATING DIFFERENT PARAMETERS

A) Analysing Indian battery scenarios.

A common observation that has been seen across all platforms in Indian Electric Vehicles is that the Battery packs are critically sized to reduce the overall cost and size of the vehicle. Another significant observation is that the maximum available energy and usable energy are almost same which points to the fact that the cells are operating under very fine margins of Safe operating area. The repercussions are drastic as each cell is subjected to larger electrical stress and they are operated at higher C rating causing an accelerated capacity degradation and faster approach to ‘end of life’ by reducing the number of cycles to a large extent.

These cells, when charged to a lower voltage i.e. less than 3.90V/cell, accelerated the formation of solid electrolyte interface at the anode.

On the other hand, if the cells are charged to a higher voltage particularly more than 4.10V/cell and are operated at higher temperature then it causes electrolyte oxidation at the cathode.

The above mentioned factors cause the cells to have gradually decreasing coulumbic efficiency. Since lithium-ion chemistry does not have a "memory", you do not harm the battery pack with a partial discharge. If the voltage of a lithium-ion cell drops below a certain level, it's ruined. Lithium-ion batteries age. They only last two to three years, even if they are sitting on a shelf unused.

B) Cell Selection and Boundary Conditions

Lithium-ion cells are commercially available in various formats and chemistries, but only certain samples are selected for the scope of research purpose. The samples are taken by carefully studying the different types of cells being used in the Indian Electric vehicles and Hybrid Electric vehicles till date and their battery configuration, the most common being LiFePO4 chemistry in prismatic format. LCO (Lithium Cobalt Oxide) chemistry in pouch and NMC(Lithium Nickel Cobalt Manganese Oxide) chemistry in 18650 cylindrical formats. However, samples from 3 different manufacturers were used and 3 samples were used per test to increase the reliability of the test results. The charge-discharge rates are calculated by finding nominal cell discharge current and nominal regenerative braking current over standard driving cycles The no-load loss of a single- phase transformer can be determined by the open circuit test and is proportional to the maximum flux density values.

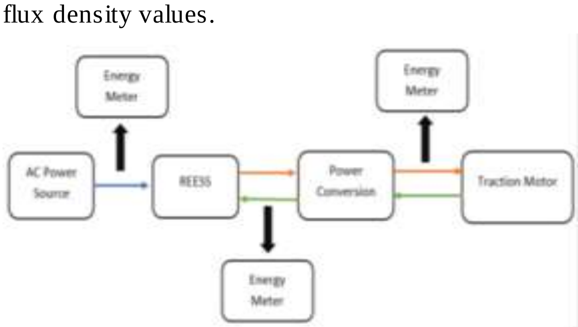


Fig.1. Energy measurement system for data acquisition

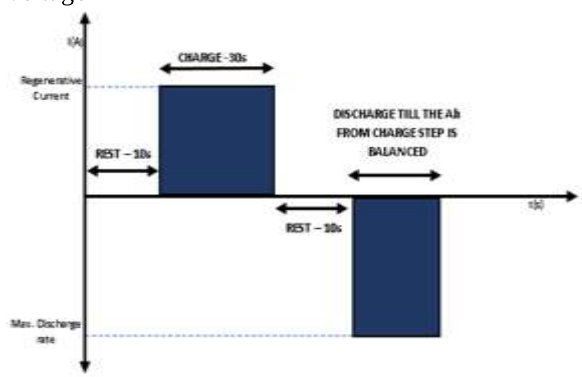
The data obtained from the above method was used to calculate cell test parameters which are given below.

	Prismatic			Pouch		Cylindrical		
	$LiFePO_4$	LMO	NMC	LCO	$LiFePO_4$	NMC	NCA	LiFeMgPO4
Max. Cell Potential	3.65	4.2	4.2	4.2	3.65	4.2	4.2	3.65
Min. Cell Potential	2.5	3.0	2.7	3.0	2.5	2.7	3.0	2.5
Avg. Discharge rate	0.7C	0.5C	0.3C	0.4C	0.3C	0.5C	0.3C	0.5C
Max. Discharge rate	2C	2C	1.8C	0.9C	0.6C	2C	1C	2C
Avg. Charge rate	0.45C	0.6C	0.8C	0.3C	0.2C	0.3C	0.5C	0.5C
Regenerative Current	1.2C	1C	1.5C	0.5C	0.5C	1.5C	0.7C	2.5C

DCA Test Cycle

Conventional method of finding dynamic charge acceptance was mainly limited to SOC range of the batteries. To find the real-time driving conditions for vehicles, a novel preconditioning and cycling method has been improvised. The tests are performed using dedicated multi-channel battery cycler. The cells are charged from a fully discharged state to fully charged state which are followed by 20 cycles of Dynamic Charge Acceptance Pulse power. The measurement is in high accuracy and in fast sampling rate mode and has mainly 3 different temperature points i.e. 25°C, 35°C and 45°C. Energy recuperated per cycle by the cell during DCApp is recorded.

Trends at every SOC level gives insight into the particular cell's behavior during regenerative braking. DCApp microcycle consists of energy balanced cycles where the cells are subjected to short duration charge and discharge pulses. The maximum amount of charge accepted is limited by the maximum cell voltage. The current tapers down as the charging voltage is clamped to the maximum cell voltage



- The average energy recuperated in the 20 cycles is expressed in the units of A×Ah-1 represented as Idca.

$$I_{dca} = \frac{\left(\sum_{n=1}^{20} Ah_{chg}(n)\right) \times 3600}{C_{ref} \times t_{step}}$$

And the average over the complete microcycle can be computed with the following equation

$$\eta_{cyle\ energy} = \frac{\left[\sum_{20}^{n=1} Wh_{acc}(n)\right] \times 3600}{Wh_n \times t_{total}}$$

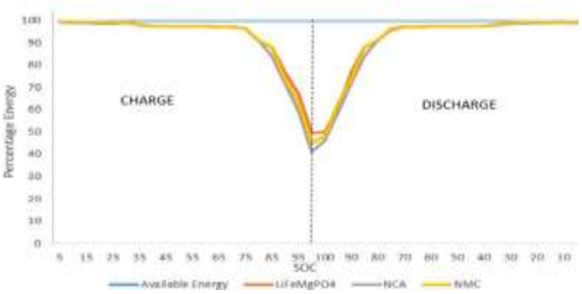
TEST SETUP

The test setup for cycling is shown in Figure 4 where dedicated cell cycler was used to test the cells. The ambient temperature was maintained using a thermal chamber and was continuously monitored by the cycler using K-Type thermocouples. The contact resistance was kept to minimum by proper terminal connection.

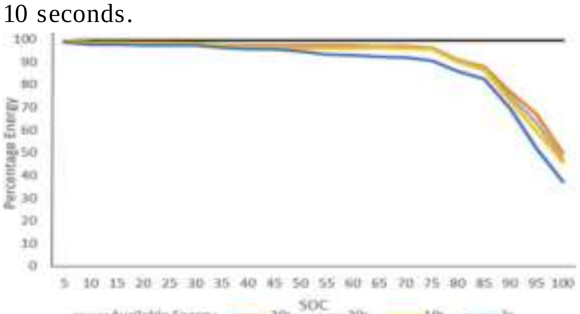
Fig.2. Testing pouch cells.

III. OBSERVATION AND RESULTS

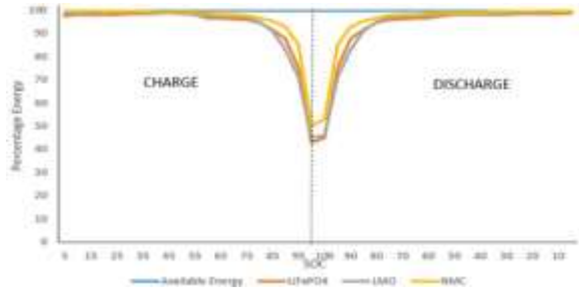
Cylindrical format cell of LiFePO4, NCA and, NMC chemistries were cycled with the DCA test procedure for 25 cycles. Average values of the energy recuperated per micro cycle over the multiple test cycles were calculated and plotted as shown in Figure 3.



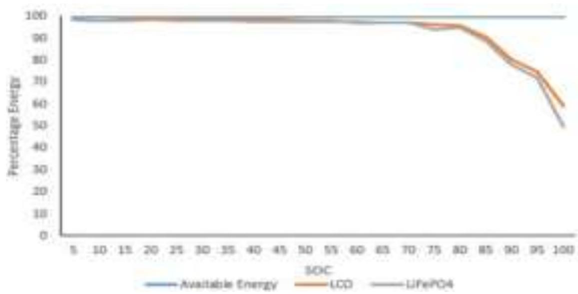
The effect of relaxation time during the microcycle was found out. A drastic drop in energy recuperation was observed as the relaxation period reduces below 10 seconds.



In Prismatic format LiFePO4, LMO and NMC chemistries were taken for evaluation. NMC cells showed excellent charge recuperation at both lower and higher SOC range with almost negligible hysteresis.



Pouch cells were subjected to relatively lesser electrical stress compared to pouch and prismatic counterparts. Their field of application is such that it subjects the cells to much lesser C rate during its operation. In the figure we can see the average charge recuperation over multiple cycles of LCO and LiFePO4 chemistry.



IV. CONCLUSION

We focused on dynamic charge acceptance and energy recuperation ability of lithium-ion cells of different formats and varying chemistries. From the results it is evident that the most reliable and consistent performance is of prismatic format. Both NMC and LiFePO4 had brilliant characteristics at elevated temperatures. NMC chemistry had superior repeatability and negligible hysteresis. Among the cylindrical cells LiFeMgPO4 had the best overall performance with respect to temperature, relaxation time and consistency. Finally, in pouch format both LCO and LiFePO4 performed reliably over the entire SOC range and there were no anomalies.

AKNOWLEDGEMENT

I would like to extend my warm gratitude to all the persons who helped me to complete my paper. I am highly grateful to my guide and other staffs for their constant support and guidance.

REFFERENCES

[1] M. J. Smith, D. T. Gladwin and D. A. Stone, "Experimental analysis of dynamic charge acceptance test conditions for lead acid batteries," 978-1-5090-3474-1/16/$31.00 ©2016 IEEE.

[2] Phil Weicker, A Systems Approach to Lithium-Ion Battery Management.

[3] Rami Abousleiman and Abdullah Al-Refai and Osamah Rawashdeh,"Charge Capacity Versus Charge Time in CC-CV and Pulse Charging of Li-Ion Batteries" SAE International 2013-01-1546 Published 04/08/2013.

[4] Yamato Utsunomiya and Yuki Nagai and Jun Kataoka and Hirobumi Awakawa, "Lithium-Ion Battery Pack for Stop and Start System" SAE International 2013-01-1538 Published 04/08/2013