

Lithium Ion Battery for Hybrid and Electric Mobility under Indian Ambient Conditions - A Perspective

Kannan Subramanian, Ganeshkumar Ramakrishnan and Palanivelu Prabakaran
Mahindra & Mahindra Ltd.

ABSTRACT

Hybrid Electric Vehicles (HEVs), Plug-in Hybrid Electric Vehicles (PHEVs), Extended Range Electric Vehicles (EREVs), Battery Electric Vehicles' (BEVs) development is gaining traction across all geographies to help meet ever increasing fuel economy regulations and as a pathway to offset concerns due to climate change and improve the overall green quotient of automobiles. These technologies have primarily shifted towards Li-ion batteries for Energy Storage (due to energy density and mass). In order to make actual business sense of these technologies, of which, battery is a major cost driver, it is necessary for these batteries to provide similar performance and life expectancy across the operating and soak (storage) range of the vehicles, as well as provide the requirements at a competitive cost. In other words, the Li-ion batteries have to sustain the normal life cycle requirements and withstand wide span of storage temperatures that the conventional vehicles have been good at and still ensure good life.

HEVs and EVs have so far been a nascent market for South-East Asian regions and India in particular. The Indian ambient conditions range from less than -5°C to greater than 50°C with relative humidity up to 100% in most of the coastal areas where there is very high vehicular density. Hence it is reasonable to state that the batteries have to consistently withstand high temperatures with high humidity and still satisfy their calendar life requirements. It is very realistic that the vehicles would be subject to a parking soak of temperatures exceeding 45°C during the summer months. This leads to a challenging task of thermal and battery management to maintain battery life under these soaking conditions. The options of passive (when vehicle off) thermal management system and storage strategy is critical to ensure adequate battery life. Passive thermal management strategy calls for innovative solutions especially in the realm of air cooled systems (low cost solution). This paper studies this challenge pertaining to Indian ambient conditions. This includes understanding the actual ambient environment including variations in Relative Humidity, potential impact of this on High Voltage Battery pack calendar life, potential challenges of integrating such a pack with cost effective thermal management to ensure good life and uncompromised performance of the battery pack and the vehicle.

CITATION: Subramanian, K., Ramakrishnan, G. and Prabakaran, P., "Lithium Ion Battery for Hybrid and Electric Mobility under Indian Ambient Conditions - A Perspective," *SAE Int. J. Fuels Lubr.* 5(3):2012, doi:10.4271/2012-01-1611.

INTRODUCTION

Electrification of the automobiles has thrown open developmental activities across lots of domains like battery (system, materials), power electronics, e-motor etc. across every OEM and supplier base in order to meet vehicle requirements without compromise on quality. This development has been catalyzed by government policy across continents in order to mitigate and minimize the environmental impact of automobiles. As the developing nations gain more purchasing power, this push is going to be even more relevant to improving the green image of automobiles.

The level of electrification of the automobiles can range from Hybridisation (Mild, Full and Plug-in) to pure Electric

Vehicles (EVs, Fuel Cells) to Extended Range Electric Vehicles (EREVs). Each of these technologies incorporate an onboard Energy Storage System (ESS) which solely powers the vehicle in the case of EVs or supplements the Internal Combustion Engine (ICE) during hybridization. The Energy Storage System could either be a Battery (High Voltage) or a Fuel cell (not scope of this paper).

Lithium-ion Batteries have gained traction as a low mass, high energy (and power density) alternative to Nickel-Metal Hydrides [Fig 1] and is undergoing extensive development from the battery industry to reduce and optimize its cost. The developmental growth gap is also seen to be increasing between these two battery types. Being the primary energy source for Hybrid functionality and pure energy source for

EVs, they need to be extremely reliable and robust across the existing vehicle vibrational, environmental and safety domains.

The existing Lithium-ion Battery chemistries prove to be a challenge at high temperatures and need careful managing to get the optimum life out of it. It is also highly imperative to ensure good life as Batteries are currently the most expensive component of a hybrid propulsion system [Fig 2]. It is difficult to get a business case for batteries which don't come closer to meeting actual vehicle life targets while being expensive.

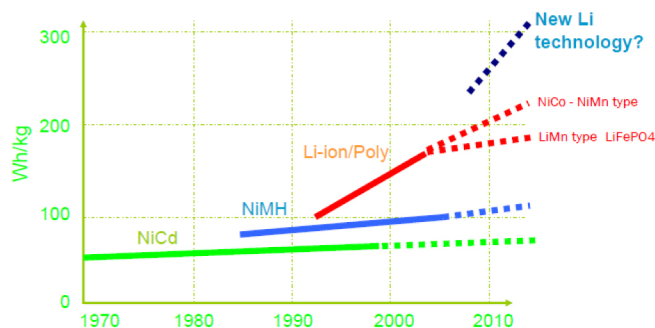


Figure 1. Battery types and their specific energy (Source: Avicenne analysis; reprinted with permission)

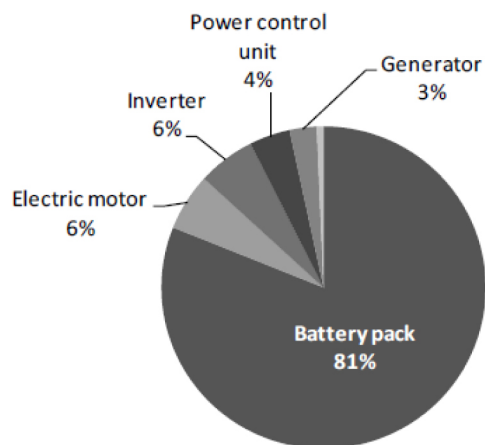


Figure 2. Breakdown of PHEV system cost by component (Source: MIT Energy Consortium; reprinted with permission)

Hybrid vehicles are yet to gain widespread visibility and acceptance in South East Asian countries, primarily because of frugal mindset of customers as well as engineering challenges pertaining to varied ambient conditions which has a potential effect on Lithium ion Battery life. Hence, it is important to understand the challenges of integrating such an Energy Storage System with as much minimal cost impact to the customer.

This paper briefly touches on the existing alternate propulsion product offerings on a mass market scale and the challenges facing their battery pack. The paper provides an

overview of actual driving usage over life in India, the existing cooling concepts, thermal profiles across the regions in India, impact of solar load on vehicle and other challenges which needs to be overcome in order to be a viable offering for Indian customer base. Thermal Management Strategies are outside the scope of this paper and it is assumed that actual cycle life will be maintained by cooling strategies during vehicle operation.

APPROACH

EXISTING MASS MARKET HYBRIDS AND EVs

Hybrids have been existent since the end of the last millennium with Toyota Prius being the most successful. The Battery pack of the Prius is of Nickel Metal Hydride (Ni MH) type chemistry and hence is outside the scope of this paper. All the recent activity in Hybrid and EV domain like Mercedes S 400, Nissan Leaf, Chevrolet Volt to name a few all use Lithium ion battery packs with active battery management and proprietary thermal management.

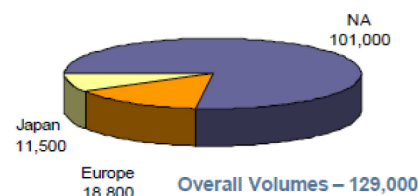


Figure 3. PHEV's projected volume (conservative) by geography-2015 -(Source: Frost and Sullivan; reprinted with permission)

The product offerings, especially Plug-ins have been primarily forecasted to the Japanese market (Prius) and the Western European and North American markets [Fig 3]. This calls for a strategy focused more on value than cost in these pristine offerings. The market roll out strategy and Battery pack warranty is in line with the expected challenges of these geographies. For example, the Nissan Leaf 2011 is equipped with a Lithium polymer pack which is passive air cooled [1] and the optimum thermal management would distribute the battery heat and bring the battery to the environmental temperature at its best. This challenges the battery pack life at high temperatures. Nissan encourages customers to lease the vehicle under these conditions. On the other hand, Chevrolet Volt from General Motors stable has a Lithium ion Battery pack which is actively managed thermally. This means, the Volt can actively cool and heat using 50-50 glycol/water mix and AC refrigerant [2] by using them intelligently. Though this approach ensures life of the Battery pack, it adds system cost and complexity. Mercedes hybrid [3] uses refrigerant and cabin cooling in tandem to ensure Battery pack life. Currently, only passive warming up strategy is available in certain EVs to keep the battery pack above a certain threshold to ensure that power is readily available after start. There is

Table 1. Vehicle usage over life over a range of drive patterns under Indian conditions

Total driven kilometers (km)/year	Overall vehicle lifetime assumed (years)	Average vehicle velocity (km/hr)	Overall usage over life time (years)
15000	12	30	0.68
20000	12	30	0.91
25000	12	30	1.14
30000	12	30	1.37

Table 2. Battery pack life influences

	Operational mode	Storage
Pack Load Profile influence	YES	NO
Environmental Temperature impact on Battery Life	NO	YES

no passive cooling down strategy defined in accordance with the ambient variations of the vehicle roll out areas.

While all the product offerings in the Hybrid and EV domain have been very innovative in terms of technology, safety and life management for the batteries, they are not clearly designed for Indian weather conditions and/or consumer preferences. This means that the solutions to improve battery life and management might add incremental cost(s) which work against the general frugal mentality of Indian consumers even if it comes with advanced technology. Or the product offerings do come with an inherent disadvantage of operation at certain extreme environmental conditions wherein life of the battery is compromised but these extremes are far and few in the launch markets and geographies mentioned above. Indian ambient is totally different. This challenges us to understand the Indian ambient conditions better and how it affects the battery life and performance and at the same time think about innovative and low-cost solutions to enhance battery life and gain customer acceptance by keeping frugal engineering in mind.

VEHICLE USAGE PATTERN AND IMPACT ON BATTERY PACK

The number of kilometers driven per year varies with customer, age group, vehicle type and an overall average is important to understand the actual duration a vehicle would typically be parked. The number of kilometers driven by a passenger car is typically less than that driven by a light truck. It is normal to average out the usage over these age groups and vehicle usage types. The table below summarizes typical overall usage profile for a 12 year life of a vehicle assuming a range of annual drive patterns.

It can be seen from [Table 1](#) that even with a frequent drive pattern profile, the overall vehicle usage duration is around 1.37 years out of a possible 12 year life time. In normal passenger car conditions, it is less than 1 year. This makes storage (soak) duration of the vehicle very significant.

In other words, the environmental conditions can have a significant impact on battery pack life time.

The battery pack life time can be defined based on its state of operation and storage. The operational state is dependent on the actual operating load profile. The battery pack life is heavily influenced by environmental storage conditions. The environmental changes don't have so much of an impact while the battery is in operation as the dynamic change has very less effect on individual cells which get heated due to cycling and also the thermal mass can aid to the extent of helping the battery pack. This is summarized in [Table 2](#) below.

THERMAL IMPACT ON LITHIUM ION BATTERIES

Lithium ion Batteries have been a preferred alternative to Ni-MH because of its lower mass and high energy density. However, life, safety and performance are its primary drivers for future commercial development. Each of these parameters are affected significantly by its storage and operating temperature. We will focus more on the storage temperature effects in this paper here and going forward. While lots of research work is being done in academia and industry worldwide on Li-ion chemistries to understand the mechanisms of life, performance and safety, it is clear that temperature has an influence on performance loss and energy loss on every chemistry of the battery being explored [4]. [Table 3](#) below summarizes the effect on performance and life (power and capacity loss) for a few battery chemistries with respect to soaking temperature and SOC.

It can be observed that the power fade is a strong function of storage temperature for a given storage time. It can also be seen that higher SOC and temperature accelerates power and capacity loss over time. Higher SOC levels at high temperature accelerate power loss and capacity loss further over time. Also, for a given SOC, increased concentrations of solvent also reduce loss of capacity. These clearly portray that SOC and temperature are critical parameters contributing