Rechargeable Electrical Energy Storage System Development for an Electrical vehicle Retro fitment kit

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***Abstract**: - Lithium ion battery has emerged as the most preferred electrical energy storage device not only in handheld gadgets & portable consumer appliances but also for electrical vehicles. The cost and performance of electrical vehicles are strongly affected due to rechargeable Electrical Energy Storage System, appropriate selection of cell chemistry, type of cells & their arrangement made inside the battery. This paper is an outcome of a battery related literature review undertaken by author under an electrical vehicle conversion project. The paper moves on through six sections starting with rationale/ introduction, followed by quoting requirement of ideal rechargeable electrical energy storage system (REESS) and then comparative study of prevailing battery technologies also. Further it elaborates lithium ion battery technology as the technology of choice for REESS & describes steps in its (REESS) development. Authors conclude the paper with a case study of REESS development for an e-bicyle conversion and a discussion/ conclusion.*

Key Words: REESS, Battery chemistry, Battery technology, cell configuration, BMS, BTMS, Indian Driving Cycle (IDC), Energy consumption, Form factor, Battery pack

1. INTRODUCTION

Rechargeable Energy Storage System (RESS) has been, is and will remain an indispensible part of any motor vehicle for its' plying on roads [5]. Not only this but also an act of proper selection of an energy storage system minimizes individual and societal issues associated with use of a motor vehicles. Any Conventional motor vehicle contains a fuel tank as a rechargeable energy storage system in which chemical energy in a fuel is stored and the fuel is recharged after it exhausts. As a fuel tank appears empty we recharge it with a fuel at a fuel refilling station conveniently and either petrol, or diesel, or CNG, or LPG, or biodiesel, or ethanol, or methanol is recharged in fuel tank. If anyone studies reasons for a conventional vehicle for becoming popular means of transportation since the beginning of last century till recent past s/he gets answer in a kind of energy storage it avails in terms of fuel tank and fuel stored in it. It is a mass motorization that the world witnessed for over more than 100 years along with issues of uncontrolled proportion like energy depletion, environmental pollution, climate change and traffic accidents [1] for want of proper energy storage for an Electrical vehicle (EV).

The concern about environment pollution, rapid increase in fuel cost, depletion in fossil fuel reserves has been main motivation behind switching from traditional transportation to electrical transport. In a recent past under Paris Convention majority of nations in the world have agreed to reduce greenhouse gas emission to an extent that will restrict rise in global temperature in this century to 2^0C by submitting a document related to Intent of Nationally Determined Contribution (INDC) [2]. Vehicular pollution has been contributing substantially in continual rise of gases with high Global Worming Potential (GWP) in the earth atmosphere. Therefore switching to electrical mobility is the solution. However such switching, that appeared as cause of concern in the beginning of 20^{th} century for want of proper battery, is demanding a lot of work in developing REESS [3] as convenient as that of conventional vehicles.

REESS requires a storage which gets recharged quickly and supply energy and power to an Energy Conversion System (ECS). The battery acts as a energy storage in this case and traditional batteries which are available to do so are with issues [3] of lower gravimetric and volumetric energy and power densities, more time they take for charging, less calendar life, more cost, memory effect etc. It is essential to deal with all these issues and develop REESS the way the energy storage system of conventional vehicle works. It will enable people to adopt electrical mobility wholeheartedly.

The following section explains requirement of ideal REESS which is guideline for achieving it.

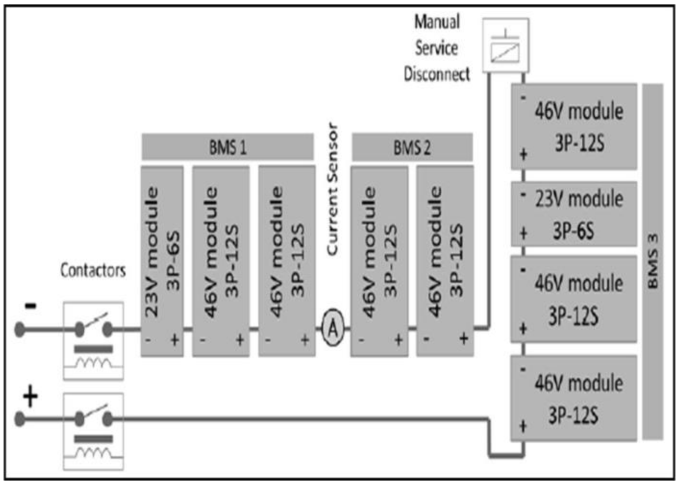

Fig.1 GM Chevrolet Volt Modular REESS - distributed BMS

Above fig 1 [4] shows the example of 368 V 288 cells 3P96S battery pack which contains 9 modules in which number cells are connected in series and parallel. Battery Management system used is distributed with a master and three slave BMS. There is one manual Service disconnect (MSD) and its output is given out through electromagnetic connectors.

2. REQUIREMENT OF AN IDEAL REESS FOR EVs

Electrical vehicles are zero emission vehicles (ZEV). They are quite in operation and by using them noise pollution of urban areas is also reduced. This is possible because of an electrical power train (EPT) that a part them. It is an electrical motor and a battery together which are subsystems of the EPT and are connected through a power controller. As no fuel burns in them and motor and battery are quite in operation hence both the pollutions are absent or are very small in EVs. These vehicles are known as battery electric vehicles (BEV) and a battery charging system (BCS) that connects a power grid with battery to charge it is equally important and a part of the EPT. REESS in a battery form is required to satisfy requirement explained below to be an ideal storage system [9]

2.1 Long life

In case of an electrical vehicle an Energy Storage System (ESS) is peculiar and different from a fuel tank as an energy storage system in ICE vehicles. Any storage system comprises of a container and energy stored in it. Here in the energy storage system for EVs a battery is a container and electrical energy is the energy to be stored while a fuel tank as an energy storage system has a fuel tank and petrol as a container and chemical energy in petrol as energy respectively. As we compare them we find that a capital expenditure (CAPEX) over a container part of REESS is more than that of RESS of ICE vehicles and an operation expenditure (OPEX) of REESS [17] is very small compared to that of filling petrol and adding chemical energy in the RESS of ICE vehicle. Therefore a battery as REESS, having cost almost 50% of EVs, should provide long life. It makes a battery vehicle affordable to people and helps in adoption EVs.

2.2 Less Cost

Making a motor vehicle affordable to a common person was found to be one of the important reasons for mass motorization of ICE vehicles. The same is valid today for EVs also and hence for achieving higher adoption. Even by offering [19] demand incentives on them Govt of India (GOI) is trying to increase adoption of EVs. Hence cost of REESS should be affordable to all.

2.3 High Energy and Power Density-

REESS should store more energy and power in small space and less mass. This enables us to keep its weight and volume small for given vehicle range and achieve better/ lower energy consumption in Wh/km.

2.4 High Voltage

A Power and Energy of any electrical storage increases with its voltage and current. So having high voltage makes every REESS powerful and energy rich at a given current capacity. Moreover more voltage is better for getting high torque in EVs

2.5 High Energy Efficiency

Energy efficiency is a measure of the extent of lost in a charging and discharging cycle. This loss should be least for REESS.

2.6 Good performance at extreme temperatures

REESS should work efficiently during wide temperature range as EVs are used not only at tropical zone but also in temperature zones and polar zones on either sides of the earth.

2.7 Minimum Self Discharge

There is a tendency in every battery to charge as and when it is kept for long time. REESS should have minimum self discharge for increasing its reliability

2.8 Good Safety

REESS experiences high charging & discharging cycles on the basis driving of a vehicle. Moreover they are high voltage systems. In case of discharging at higher rate a battery & a wire loom gets hot and some time start burning. REESS should be designed to take into account all these things.

2.8 Good Consistency

REESS should work consistently and supply current & power for proper, regular performance of a vehicle.

2.9 Easy to Assemble

Almost all batteries being used are getting assembled using cells to form a battery pack. It evolved many operations. An enclosure and lead are equally important.

2.10 Easy to Maintain

It should be easy to service & repair REESS to prevent breakdown and rectify faults. It should be serviceable a battery being costly item.

3. COMPARATIVE STUDY OF BATTERY CHEMISTRIES

As per Warner [2] batteries are either primary & Secondary based on whether are they chargeable or not. Primary batteries are not changeable but use once and throw type. Alkaline batteries used on house hold devices are of this type. However secondary batteries are rechargeable for number of times depending up on cycle life and they are important for use in REESS.

Depending upon chemistry of an anode and a cathode active material, electrolyte used and on the basis of popularity of Lithium batteries in all spheres of life, rechargeable batteries are classified into Non Lithium chemistry based and lithium chemistry based batteries. All these batteries are to be rated on the basis of the requirements stated in the section 2 for considering them in a REESS and rate/ grade batteries pack for a given automobile application. Table 1 shows comparison among various battery chemistries available till date

As per the details about each cell chemistry in a table 1[2]

3.1 Specific Energy & Energy Density

These properties convey about the extent of energy stored in mass and volume of a battery. As their value increases for given chemistry the battery size and mass for same energy capacity decreases than other having lower values. As per table the target values of PbA and NiMH are one third to half of the values of NMC and NMA. REESS need more energy to increase a range of EVs.

Hence it is not possible to build light weight and compact battery under Non lithium category of the battery due to their low specific energy and power and low energy and power densities. Better choice of battery chemistry to store more energy in a small volume and weight batteries are NMC and NMA

3.2 Specific Power and Power Density

These properties convey about the extent of power in Watt (W) stored in mass and volume of a battery. As their value increases for given chemistry the battery size and mass for same energy capacity decreases than other having lower values. As per table 1 their values for PbA and NiMH chemistries are very low compared to the values of LFP, NMC and NCA.

Hence it is not possible to build a light weight and compact battery using Non lithium category of the battery due to their low specific energy and power and low energy and power densities. Better choice of a battery chemistry the one which store more energy in a small volume and weight and therefore batteries of choice are LFP, NMC and NCA

Table 1: Comparative study Battery Chemistries [2]

Battery chemistry	Chemical Description	Specific Energy Wh/kg	Energy density Wh/L	Specific power W/Kg	Power Density W/L	Cell voltage in V	Cycle life	Self dis-charge %month	Operat-ing temp. Range
1.Non lithium	Lead Acid (PbA)	**30-40**	**60-70**	**60-180**	**100**	**2**	**300-800**	**3-5**	-20 to +60
	Nickel Metal Hydride (NiMH)	**30-80**	**140-300**	**250-1000**	**400**	**1.2**	**500-1000**	**30**	-20 to +60
	Sodium Nickel chloride (NaNiCl)	100-120	160-190	150	-	2.6	1000	0	300-400
2. Lithium	Lithium Cobalt oxide (LCO)	120-150	250-450	600	1200-3000	**3.6-3.8**	>700	1-5	-20 to +60
	Lithium Manganese oxide (LMO)	105-120	250-265	1000	2000	**3.8**	<500	5	-20 to +60
	Lithium ferrous Phosphate (LFP)	80-130	220-250	**1400-2400**	**4500**	3.2-3.3	1000-2000	**<1**	-20 to +60
	Lithium Nickel Manganese Cobalt (NMC)	**140-180**	325	**500-3000**	**6500**	3.6-3.7	**1000-4000**	1	**-20 to +55**
	Lithium Nickel Manganese Aluminum (NMA)	80-220	**210-600**	1500-1900	**4000-5000**	3.6	>1000	2-10	-20 to +60

3.3 Voltage per Cell

The range of cell voltage among Non Lithium Batteries is from 1.2 to 2.6 while the same for lithium batteries is from 3.2 to 3.8. Hence it is possible to build a pack of requisite voltage using less number of cells of lithium category of batteries than those of Non lithium category.

3.4 Cycle Life

It measures number of charge – discharge cycle for which a given battery last from Beginning of Life (BOL) state to End of Life (EoL). There is vast difference between life cycles among two categories. Batteries of Non Lithium Chemistry type have their life cycles some times 1/10th of those for certain Lithium chemistry batteries.

The lithium battery chemistry is with Max. Cycle life as per the table is NMC while battery with LTO anode chemistry, which is not a part of table, even has greater cycle life than NMC.

3.5 Self Discharge Percentage

It refers to tendency of battery to get discharged when it is stored on shelf or it is a part of a vehicle garaged for extended period of time. It creates inconvenience for Owner even some to replace battery i.e. REESS under such circumstance. To avoid it is better to choose for a chemistry having very less self discharge percentage.

Self discharge percentage in lithium batteries is lower than NLBs and in case of LFP is further low for making its choice in case a use of the vehicle of that kind

3.6 Operating Range of Temperature

As per Warner [3] for a given battery there are three temperature ranges viz. survival, operational and optimal. They are derived out of a field and a plant testing experience of manufacturers. The survival temperature range conveys that it is not possible for a battery to survive if it works beyond while optimal one ideal range of temperature for safe working a battery. Practical use of a battery is done within operating temperature range for getting more from battery and within safe zone.

3.7 Maintenance

We can compare battery chemistries on the basis of cost per kWh of battery over period of time. Non Lithium battery like a Lead acid battery evolved over last 100 years and finally we have it as a maintenance free battery.

Comparatively Lithium chemistry based batteries require more maintenance and more costly than those of non lithium based chemistries

4. LITHIUM ION BATTERY TECHNOLOGY FOR REESS

Lithium ion battery Pack technology means a technology of cells as well a technology of pack. It is two tier technology which supports development of REESS not only for motor vehicles but also for other mobility solutions like aircrafts, ferries, rails etc. The cells as shown in are building blocks of a battery pack and a pack requires to follow systematic procedure to develop it into strong, reliable, light weight, compact energy storage system suitable REESS for EVs. Let us study cell level lithium ion battery technology in the beginning

4.1 Lithium ion Battery Cell as a Technology

Lithium ion cells as shows in **Fig 2** are similar in size and shape to normally use and throw primary cells like AA, AAA, type used in domestic appliances and portable gadgets. The shapes of these cells are cylindrical, prismatic and pouch and they are available in different sizes and capacities. The outer casing of these cells is of either metallic or plastic material, where metals used are steel or aluminum. There are many companies in their production and due to their extensive use in wide spheres they are produced in millions with Giga capacity. Table below shows details about cells

Table 2: Details about Lithium Ion Cell used in REESS

Sr. No	Cell form factor	Sizes	Leading companies	Application
1	Cylindrical	18650, 21650, 32650, 37650	LG Chem, Samsung, A123, BYD,	All models of Tesla
2	Prismatic	18 x 36 x 65	LG Chem, Samsung, A123, BYD,	Toyota Prius, Ford
3	Pouch-polymer	Tailor made	LG Chem, Samsung, A123, BYD,	GM Volt, Nissan Leaf

The cells of different shapes have voltage (V) as per their battery chemistry only but current capacity (Ah) varies with size and chemistry of cells. We get cell catalogue/data sheet from every cell manufacturer from which we get different values related to the cells they produce.

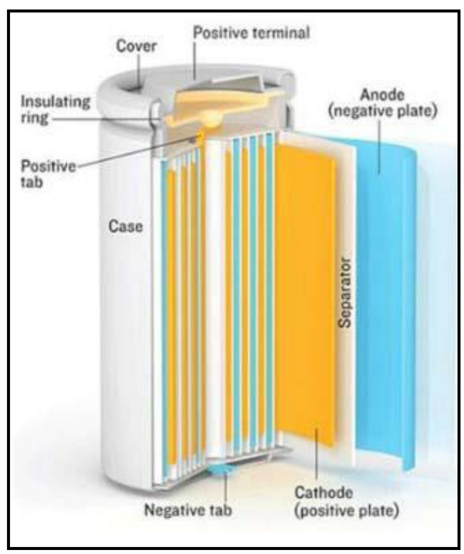

Fig. 2 Internal Structure of Cylindrical Li Ion Cell

Before we enter into discussion about pack technology let us get conversant with important key terms used in describing battery status. Following are some terms applicable for both cells and packs [3, 4]:-

4.1.1 Nominal/ peak Voltage – It is voltage of a cell in normal situation and when a cell is charged 100%

4.1.2 Nominal/ peak Capacity- It is measured in Ah or Wh and is a measure of amount of current/ energy in a cell/ a pack Nominal capacity is discharging at 1C rate

4.1.3 Energy- It is measured in watt hour (Wh) and is also called energy capacity of a battery which indicates an extent of power battery delivers over a period of time.

4.1.4 Power- It is measured in Watt and is nothing but rate of doing work

4.1.5 SOC- It is measure of the extent of energy and power left in battery at a given instant. As per battery use SOC changes from 90% to 10%. It is normally made available on dash board

4.1.6 SOH-It refers to current state of a cell with reference to state at the Beginning of Life (BOL) and how long it takes to reach End of Life (EOL) state

4.1.7 SOA-It is nothing but safe operating area or zone and it about extreme values of temperature, current and voltage within which a cell operates for a purpose and

4.1.8 DOD- It is a measure of discharge has occurred at the time of testing cell.SOC = 1-DOD

4.1.9 BOL- It refers to the battery energy, capacity, and power when it is first built or is at the beginning of its life

4.1.10 EOL-It is a state when battery energy and power reaches to 80% to that at BOL

4.1.11 C-rate- It conveys the way a cell or a pack discharges/ charges in a given situation. 1C rate means with that amount of current a battery charges or discharges battery takes 1 hour to get fully charged or fully discharged. Higher C-rate means fast charging/ discharging and lower C-rate means slow charging/ discharging

4.1.12 High Voltage (HV)- If a given system voltage is above certain value like 60 V then the system is termed as HV system and system voltages above that value are high voltages

4.1.13 Cycle- As a battery passes through a sequence of charging followed by discharging it completes a cycle

4.2 Lithium ion Battery Pack as a Technology

A battery pack is a system [3, 4] comprises interconnected subsystem. It is a cell assembly, a Battery Management System (BMS), a battery Thermal Management System (BTMS), a wiring loom with fuses, switches, circuit breakers and connectors and finally a casing that are put together to form a battery pack. Battery pack is nothing but a REESS that stores electrical energy in chemical form during charging and as it starts discharging the chemical energy stored is released back in the original form.

The pack as per S. Santhanagopalan et al [4] comprises of four systems viz. an electrochemical system, a Thermal system, a Mechanical system, and an Electronics and control system and hence there is a technology behind building every one of them. Let us start discussing them here:-

4.2.1 Electrochemical Technology

It is a technology of connecting cells together and finally connecting a whole cell cluster to a charger on one side to ECS on another. The battery pack is expected to provide energy and power to an EV and it should as per its (EV) requirements. In order to achieve this it is required to select a cell with proper chemistry and eventually of proper voltage and current capacity. Then the cells selected are to be arranged in series and parallel configuration/ topology as per the voltage and current capacity requirement of the pack.

By getting four things for a pack viz. voltage (Vp), energy (Ep) and cell voltage (Vc) and capacity (Ahc) it is possible to formulate the pack. Pack formulation is nothing but arrangement of cells in series and parallel called a pack configuration/ topology. Among them number of cells in series (nS) are calculated using nS = Vp/Vc relation and those in parallel (mP) are calculated following mP = Ahp/Ahc relation. Here Ahp is a current capacity of the pack for the calculating which we have a one more relation Ahp = Ep/Vp. There are two topologies viz. P before S and S before P topology, which are used usually. In this way a pack is formulated out of number cells and we get that number by multiplying mP by nS. The connections among cells in parallel and series are carried out by either of the joining process [15] viz. spot welding, laser welding, soldering etc. The figure explains the way the cells are connected

Fig. 3 Cylindrical Cell Configuration with cell Holders

We get two terminals namely +ve and -ve at the pack level as per fig and they need to connect to a target load and a battery charge. For which there is arrangement of a wiring loom containing wires, connectors, switches and circuit breakers. It is required to choose all of them based on voltage and current rating of a target pack. Moreover there is a Battery Control Module [5,6] called BMS which plays a role of cell balancing, switching on and off the supply during charging as well as discharging.

4.2.2 Thermal Technology

This is a nothing but cooling and heating system for a battery pack the role of which is to maintain pack temperature within operation temperature range of cells and further observe inter-cells variation in temperature within a predefined limit [11]. It is done to avoid degradation of cells, thermal runaway, explosion and fire. During fast charging and severe discharging during acceleration and ascending grade as large amount of heat is generated the provision of cooling is made. In cold weather working of an EV pack cells loose effectiveness as well degrade due to lithium plating and avoid that there is a provision of heating of the pack. Therefore this system is known as BTMS and further it takes care of thermal management of a power control and an ECS i.e. motor which are parts of electric power train

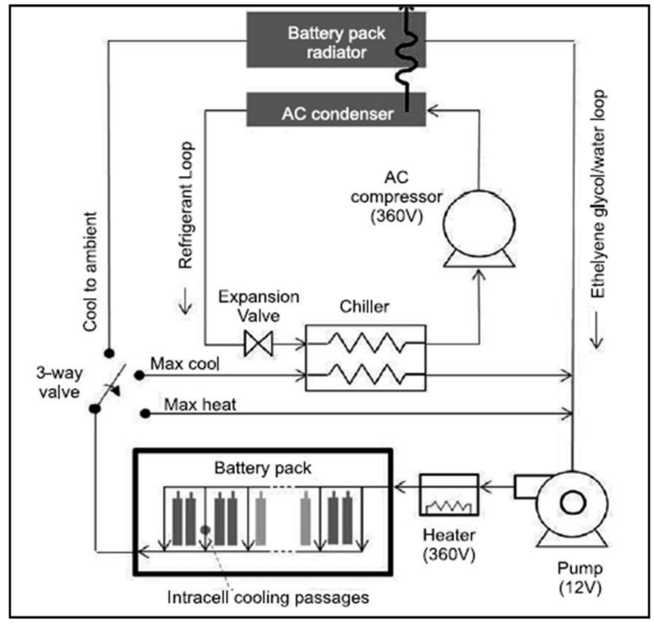

Fig 4 Active Battery Thermal management System

There are basically two thermal management systems (TMS), passive and active, that are used in EVs. Air, coolant, refrigerant and Phase Change Material (PCM) are used as per Fig to carry away or to bring heat from all entities either naturally or forcefully.

This system is vital for four wheeler and commercial vehicles that work in such a way that demand large amount of current in discharging and frequent super/ fast charging

4.2.3 Mechanical (PACKAGING) Technology

Provide a proper enclosure to a battery pack is equally important in mobility application in general and surface mobility in particular. While vehicle moves on road its each and every part is subjected to shock, vibrations and also crush and damage due an abusive conditions inside and outside and battery pack is equally prone to all of them. The casing also plays a role of providing channel to BTMS. Moreover it is required to avoid in grassing of dust, water etc inside to avoid short circuit and pre-mature failure of certain parts

Hence mechanical technology of case strength design, damping vibration etc used

4.2.4 Electronics and Control Technology

Any system in modern motor vehicles, being mechatronics based, never completes without sensing parameters, communicating them and plant control. As every battery pack needs to support achieving more range and battery life on one side and safety on the other and as they are conflicting conditions it is essential for it to operate in close loop. It is required to measure rate of charging and discharging current and voltage, temperature of cells, modules and packs, State of Charge/ health (Sox) and depth of discharge (DOD) at cell and battery pack levels, communicate them for a display and processing within battery or to vehicle control systems and energize and de-energize relays and switches via controller to control battery pack functioning. BMS with varied functionality plays important role in this system

This is a vital technology for battery pack.

5. DEVELOPMENT OF REESS FOR A TARGET VEHICLE

Development of a REESS, as per [4,7] that takes place following steps discussed below: -

5.1 Identification Energy and Power at BOL of REESS

In order to develop a REESS for a given vehicle it is essential to identify vehicle energy and power requirements. The range expectation from a target vehicle and its energy requirement for plying a kilometer distance are two things are needed to arrive at its energy requirement. To identify an energy the vehicle consumes during its 1 km travel we have to take in to account vehicle dynamics and driving cycle of that vehicle. There are driving cycles available for testing vehicles and same can be used in this activity. Under vehicle dynamics we calculate four forces viz. Aerodynamic drag, Rolling resistance, Gradient resistance/ climbing force and force for accelerating to which vehicle is subjected. The details are given below: -

Table 3: Formulae for Vehicle Dynamics

S. No	Force	Formula
1	Aero-dynamic Drag	$\frac{1}{2}*Cd*Af*\rho a*(Vv+Va)^2$ Cd– Co-eff. of drag Af- frontal area of vehicle ρa – air density Vv –Vehicle velocity Va- Air velocity
2	Rolling Resistance	$Cr*m*g*\cos\theta$ Cr– co-eff. of rolling resistance m- mass of vehicle g-gravity acceleration θ- Road gradient
3	Climbing Force	$m*g*\sin\theta$ Usual notation
4	Force for acceleration	M*a a vehicle acceleration

The values of all the vehicle parameter are used in a spreadsheet prepared on the basis of a driving cycle applicable to the target vehicle. In our country following driving cycles are used

i. Indian Driving Cycle – 2W and 3W
ii. Modified Indian Driving cycle 4W

In this exercise we get energy over a cycle with distance covered under different conditions of vehicle operation viz. moving on a leveled road, ascending or descending grade and accelerating at a given value. Considering appropriate condition we can calculate peak, average, and RMS value of energy required. Considering the discharge of battery to take place between 90% and 10% SOC and efficiency of drive train of vehicle as 95% we are required to arrive at Beginning of Life energy. This takes into account the extent of energy vehicle shall get at End of Life (EOL) stage.

5.2 Selection of Battery Cells and Cell Topology

The selection of a cell is done as per a nature of vehicle, its duty cycle, life of a battery expected, range etc. The vehicles are classified as follows: -

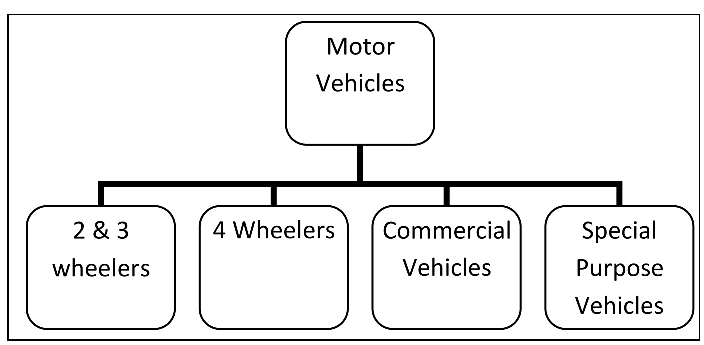

Fig. 5 Classification of Motor vehicles

Even we have to into account a kind of electrical vehicles [4] viz. Micro, p-assist, HEV, PHEV or BEV into which the vehicle is getting convert while deciding cell. We have also take in consideration cost, cycle life, operating temperature range, maintenance cost per kWh of a battery, etc in deciding whether to go for Spinel, olivine, or layered transition metal oxide cathode cell and graphite or lithium titanate as anode. This exercise is very important and one is expected to take more time.

Once chemistry of cell is selected we have to decide on the basis of energy, power, voltage and current requirement form of a cell which has bearing on all succeeding development activities. Then a cell manufacturer is decided based on availability of form and current capacity and also the need of the pack. The branded cells [3, 5] give consistent performance but are costly while many non standard cell manufacturers give cell with less cost but with less assurance of getting desired performance. One has to exercise trade off in this act. We get data of sheet along with the cell which is of great help in identification cell topology of a battery pack. Here we get nominal, peak, minimum values of cell parameters using which we can decide mPnS configuration.

Finally entire cell cluster is required to arrange in series and parallel topology using proper cell holders and the cells are to be connected to each other using bus bar, nickel strips, wires using joining technologies like spot welding, lacer welding, mechanical fasters, soldering etc.

5.3 Selection of BMS and BTMS

Battery Management System (BMS) is an indispensible for proper functioning of lithium ion battery pack. BMS is a brain behind entire functioning. So its selection is important. In case of small battery pack one can go for centralized topology of BMS while for large battery where more control at cell level is vital and is not possible in earlier topology one should go for distributed on with master and slave BMS

5.4 Selection of pack casing

There is no standardization in battery shape and batteries are developed on the basis of space availability in vehicle. The kind of battery decides shape of casing and they are made out of stamped steel sheets, aluminum, fiber glass, plastic, composite material. The sealing standards need to be considered

5.5 Selection of wiring loom along with its entire element

Loom of a battery comprise of a main contractor, a pre-charge contactor, a high-voltage interlock loop (HVIL), a Manual Service disconnect (MSD), fuses, bus bars, cell interconnect boards, and low- and high-voltage wiring harness. They should be selected based on the type of system, a system having voltage equal or above are High voltage and those having voltage less than 60V are low voltage system. This entire assembly is called as High Voltage front End (HVFE)

5.6 Fabrication of REESS.

Fabrication of REESS required following equipment and machines [8]

i. Spot welding machine for LIB pack
ii. Nickel strip cutter
iii. Solder gun
iv. Cell holders
v. Cell tester
vi. Heat Gun
vii. Multimeter
viii. General tools

Material required

i. Lithium ion battery cells
ii. Nickel strip
iii. BMS with wire plug
iv. Electrical wire of proper current capacity
v. Heat sink
vi. Solder and wax
vii. Hot glue
viii. Cleaning oil, cloth and cotton waste

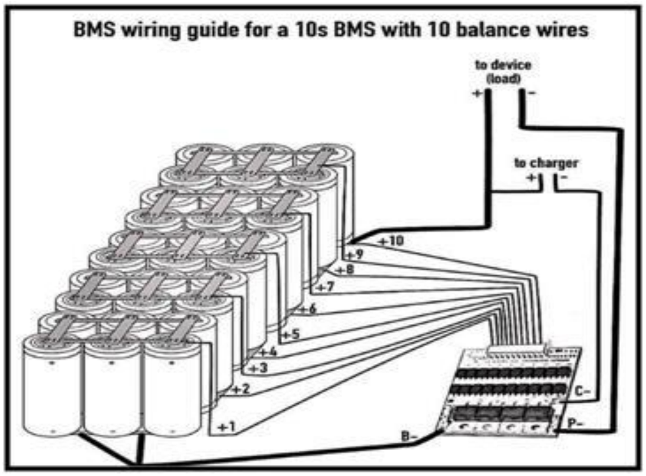

Fig.6 Electrochemical System of REESS

5.7 Procedure

i. Matching cells – for SOC using a cell tester and if required charging cell for reaching required voltage

ii. Cell alignment and containment- using Cell holder as shown in Fig. 3

iii. Connecting BMS –Connecting charge and discharge wires, Connecting the balance wires as shown in fig. 6

iv. Performing final quality and performance check- for getting voltage current and continuity along cell using multimeter

v. Sealing the battery- Heat shrink, hard case etc

6. A CASE – Development of REESS for E-BICYCLE CYCLE RETRO FITMENT KIT

Let me put before you a case of developing REESS for retro kit to convert normal bicycle into e-bicycle. A bicycle is a manually operated vehicle which is considered as a mother of all motor vehicles. As per Eckermann [2] G. Daimler and V. Maybach, pioneers of automobile industry converted wooden bicycle into their first motorcycle by mounting Grandfathers' clock engine. Many e-bicycle and retro fitment kit are available in market. This is an attempt to optimize a battery pack for a Bicycle.

6.1 Identification of Energy Requirement

Considering battery data as follows and using vehicle dynamics we can calculate energy requirement

Table 4 Details of Bicycle

Sr. No	Description	Value
1	Mass of Rider (Mr) in kg	68
2	Mass of bicycle (Mb) in Kg	7.5
3	Range to be achieved	50
4	Max. Bicycle Speed in Kmph	25
5	Average wind speed Kmph	05
6	Gradability in Θ	10
7	Air density in kg/m3	1.225
8	Coefficient drag (Cd)x Frontal area of Bicycle (Af)	0.321
9	Coefficient of Rolling resistance(Cr)	0.008

As per formulae given under values of forces acting on bicycle are as under

Table 5 Forces acting of Bicycle

Sr. No	force	Value
1	Aerodynamic drag (Ra) in N	13.6525
2	Rolling resistance (Rr)	5.925
3	Climbing Force (Rg)	128.613
4	Total Resistive force to be overcome by bicycle rider (Rt)	148.19 N
5	Power required (Rt) in W	1036.45

As a bicycle doesn't have any driving cycle the energy requirement of bicycle is calculated empirically considering energy consumption of bicycle as 15Wh/km. Hence energy requirement of battery is 50x15 = 750 Wh. By considering energy will be used from 90% to 10% of battery SOC for getting more cycle life and less degradation of REESS.

Calculated EBol = 0.9868 kWh = 1000kWh. Summary about bicycle is as follows

i.	Power requirement (W)	1036.45
ii.	Energy requirement (Wh)	1000.00
iii.	System Voltage (V)	36 V
iv.	Nominal Voltage of battery (V)	36 V
v.	Current Capacity of battery	27.78

6.2 Selection of Cells and Cell Topology

Among cell chemistries suitable for mobility viz. LFP, NMC and NCA Lithium ferrous Phosphate cell is selected based on considerations given below:-

i. Less cost
ii. More cycle life
iii. High specific power and power density
iv. Available in appropriate form factor
v. Supplier of Indian origin
vi. Energy efficiency
vii. With proper C-rate

Manufacturer of cell chosen is of Indian origin SCION Energy [18] with data sheet of cell as below: -

Table 6: Data sheet of a cylindrical Cell

Sr. No	Cell Details	Specification	Figures
1	Manufacturer	SCION Energy	
2	Cell Chemistry	LiFeO4	
3	Form factor	Cylindrical 326500	Φ32 mm L 65
4	Nominal Voltage	3.2 V	
5	Current Capacity	5000 mAh	5 Ah

Hence the pack topology that needs to satisfy energy and power requirements of battery pack can be calculated as

i. No of cells in parallel (m) (Ahp/Ahc) = 27.78/5 = 5.556 ~ 6

ii. No of cell in series (n) (Vp/Vc) = 36/3.2 = 11.25~ 12

iii. Need of Pack Configuration = 6P12S

iv. No of cells required = 72

6.3 BMS and BTMS Selection

Based on cell chemistry and the calculated pack configuration it requires LFP 12 S 35 Ah BMS from standard make. The details available of BMS manufactures are available on net. This BMS will have 13 balancing leads and it can support peak discharging current of 35Ah. It will take care of charging, discharging, and temperature rise in pack

As the bicycle system is low voltage (<60V) and chances of high heat generation are very rare passive Battery Thermal Management system is more than enough to this pack. The battery can dissipate heat in environment using convective mode of transfer.

6.4 Battery Pack Case

Heat shrink of proper quality is used to wrap the cells and BMS inside and then that pack will be inserted in plastic container of appropriate shape and size. The outer case is such that the same can be mounted on a down tube of a target bicycle and should be able to fix quickly.

7. CONCLUSION

A good REESS achieves many things in performance of any Electrical vehicle and also it is cause of concern in case not properly developed. It degrades and experiences thermal away, explosion and fire if it is abused due to high rate of discharge. Hence it is very important and sensitive system not only in producing a new EV but also in converting an ICE vehicle into an EV. It is a technology in itself and is new as compared to traditional battery technology used in PbA battery. Hence the effort to disseminate to information this paper is prepared

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