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RESEARCH ARTICLE

BATTERY TECHNOLOGY AND FUTURE OF BATTERY SWAPPING SYSTEM FOR ELECTRIC VEHICLES – OPPORTUNITIES AND CHALLENGES

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Manuscript Info | **Abstract**

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Introduction:-

For a greener and cleaner environment, the whole world is trying for a paradigm shift from ICE vehicles to electric vehicles.

Electric vehicles need batteries to power it up. Its electric motor draws power from battery. In electric vehicle ICE & other accessories are replaced by motor, it's controller, battery, vehicle controller unit, DC/DC converter, thermal management (cooling) system, transmission. Battery is the heart of the electric vehicle's powertrain.

There are various battery technologies with their own advantages and disadvantages. Over a period of time efforts have been made to develop better battery technologies for optimum output.

In an electric vehicle the battery can be either a fixed one or a swappable one. The fixed battery is rechargeable and can be charged either by an onboard charger through 16A industrial socket at homes / industries or from Public Charging Station which has AC or/and DC chargers. Rechargeable swappable battery can be swapped when it gets discharged by a charged battery from Battery Swapping Station.

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Fig. 1:-

Source: yourstory.com.

Fig. 2:-

Source: INDUSTR.com

Battery Technology:

Battery Technology with regards to electric vehicles (EVs) is evolving at a fast pace. Battery chemistry continues to evolve and active research continues to improve energy and power densities of batteries.

Battery is a combination of number of cells assembled in series and in parallel to give the required capacity of the battery in AH and since in electric vehicles it is the energy consumed so we can address the battery's capacity in kWh too.

Each cell of a battery is electrochemical cell which has cathode, anode, separator and electrolyte so their chemical energy gets converted to electrical energy on completion of a circuit and powers the EVs.

The cells are primary or secondary depending on whether it can be recharged or not. The cell in which electric energy is derived from irreversible chemical reactions is a primary cell and a cell that converts chemical energy into electrical energy by reversible chemical reaction is a secondary cell which is chargeable.

Electric vehicle uses chargeable batteries for optimization. Electric vehicles can be energized in two ways either by large fixed rechargeable battery or by small swappable rechargeable battery.

Cells come in various chemistries to form a battery.

Below are some of the rechargeable battery technologies for electric vehicles,

Lead Acid –
It was the first rechargeable battery for commercial use. Lead acid is dependable and inexpensive on a cost-per-watt hr base. It has low self-discharge and capable for high discharge current but has poor weight to energy ratio. Takes 14-16 hours for full charge. It is heavy and less durable when deep cycled. Not environmentally friendly. It must be stored in charged condition to prevent sulfation. Adding carbon-based material to the negative electrode lowers sulfation, improves conductivity and increases charge acceptance – in other advanced lead acid systems.

Ni-based –
The nickel-cadmium battery offered several advantages over lead acid, then the only other rechargeable battery however, the materials for NiCd were expensive. In the late 1980s, the ultra-high capacity NiCd rocked the world with capacities that were up to 60 percent higher than the standard NiCd.Other attributes - rugged, high cycle count with proper maintenance, only battery that can be ultra-fast charged with little stress, good load performance, forgiving if abused, long shelf life, can be stored in a discharged state, needs priming before use, not subject to regulatory control, good low-temperature performance, economically priced; NiCd is the lowest in terms of cost per cycle, available in a wide range of sizes and performance options. Relatively has low specific energy compared with newer systems. Cadmium is a toxic metal. Cannot be disposed of in landfills. In the 1990s, nickel-metal-hydride (NiMH) took over the reign to solve the toxicity problem of the otherwise robust NiCd.

Li-ion –
First non-rechargeable Li-ion battery became commercial in 1970. Rechargeable one got commercialised in 1991.Lithium is the lightest of all metals, has the greatest electrochemical potential and provides the largest specific energy per weight. Li-ion uses graphite as anode and active materials in the cathode. The metal-lithium battery uses lithium as anode. Rechargeable batteries with lithium metal on the anode could provide extraordinarily high energy densities. Long cycle and extended shelf-life; High capacity, low internal resistance, good coulombic efficiency maintenance-free. Simple charge algorithm and reasonably short charge times. Requires protection circuit to prevent thermal runaway if stressed. Degrades at high temperature and when stored at high voltage. Li-ion is a low-maintenance battery, an advantage that most other chemistries cannot claim. The battery has no memory and does not need exercising (deliberate full discharge) to keep it in good shape. Self-discharge is less than half that of nickel-based systems and this helps the fuel gauge applications. It has high energy density though little costly but worth the money in longer run as it is maintenance free and has long life.

The most widely accepted and used batteries in electric vehicles now-a-days is Li-ion / Li-based batteries in different chemistries v.i.z. NMC, NCA, LFP.

Al-ion:
The University of Queensland Research, and UniQuest has commenced their scale-up research project on the Graphene Aluminium-Ion Battery.

The laboratory testing and experiments have shown so far that the Graphene Aluminium-Ion Battery energy storage technology has high energy densities and higher power densities compared to current leading marketplace Lithium-Ion Battery technology – which means it will give longer battery life and charge much faster.

In the Aluminium-Air battery, energy is released when Al. reacts with oxygen in ambient air to produce aluminium hydroxide. Due to light weight and high energy density this battery significantly increases the range of EVs.

Aditya Birla Group, Hindalco has partnered with Phinergy and IOP (IOC PhinergyPvt. Ltd.) to create aluminium air batteries for electric vehicles in July 2022 for R&D and pilot production of aluminium plates for Aluminium-Air batteries and recycling of aluminium, after usage in these batteries.

Solid state:
Solid-state batteries promise far higher energy density and quicker charging, along with lower fire risk. The big difference with a solid-state battery lies inside the electrolyte. While lithium-ion batteries use a liquid electrolyte, their solid-state part use a solid form.

But analysts predict it will be a long while before solid-state technology moves from battery labs to the real world. Some conductivity and instability issues are being looked at. Solid-state batteries employ a solid electrolyte consisting of glass, ceramics, solid polymers or sulfites, as opposed to the polymer gel or liquid electrolyte used in traditional lithium-ion batteries for electric vehicles (EVs). Solid-state batteries have much higher thermal stability, and they can store 50% more energy than lithium-ion batteries.

Nissan, Renault, and Mitsubishi have announced a combined investment of €23 billion in electric vehicles. In addition, the alliance intends to achieve widespread commercial manufacturing of all-solid-state batteries (SSB) by mid-2028.

Toyota, has been monitoring the solid-state battery industry for years and even holds the most patents for solid-state batteries. However, the largest automaker in the world upped the ante by declaring its commitment to invest more than $13.5 billion by 2030 in developing next-generation solid-state batteries.

Samsung introduced a high-performance and durable all-solid-state battery. The prototype battery can drive an electric vehicle up to 800 km on a single charge and has a lifespan of more than 1,000 charge cycles.

QuantScape has already developed a solid-state battery that can charge from 0 to 80 percent in less than 15 minutes, whereas a Lithium-ion battery takes 60 minutes to charge from 10 to 80 percent. The energy density of these batteries is 80% higher than Lithium-ion batteries. Commercialization of solid state batteries will take time.

Fuel Cell:
A fuel cell is an electrochemical device that combines hydrogen fuel with oxygen to produce electricity, heat and water. The fuel cell is similar to a battery in that an electrochemical reaction occurs as long as fuel is available. Hydrogen is stored in a pressurized container and oxygen is taken from the air. Fuel cell technology is twice as efficient as combustion in turning carbon fuel to energy. Hydrogen, the simplest chemical element (one proton and one electron), is plentiful and exceptionally clean as a fuel.

Fuel Cell Electric Vehicles use a propulsion system similar to that of electric vehicles, where energy stored as hydrogen is converted to electricity by the fuel cell. Unlike conventional internal combustion engine vehicles, these vehicles produce no harmful tailpipe emissions. FCEVs are equipped with other advanced technologies to increase efficiency, such as regenerative braking systems that capture the energy lost during braking and store it in a battery.

Fuel cell electric vehicles use fuel cell stacks to convert onboard gaseous hydrogen to electricity, which is then stored in a battery to power the vehicle's electric motor.

Supercapacitor:
The supercapacitor, also known as ultracapacitor or double-layer capacitor, differs from a regular capacitor in that it has very high capacitance. A capacitor stores energy by means of a static charge as opposed to an electrochemical reaction. Applying a voltage differential on the positive and negative plates charges the capacitor. The supercapacitor has evolved and crosses into battery technology by using special electrodes and electrolyte. While the basic Electrochemical Double Layer Capacitor (EDLC) depends on electrostatic action, the Asymmetric Electrochemical Double Layer Capacitor (AEDLC) uses battery-like electrodes to gain higher energy density, but this has a shorter cycle life and other burdens that are shared with the battery. Graphene electrodes promise

improvements to supercapacitors and batteries but such developments are about a decade away. The charge time of a supercapacitor is 1–10 seconds. The supercapacitor is not subject to overcharge and does not require full-charge detection; the current simply stops flowing when full. Supercapacitors have also made critical inroads into electric powertrains. The virtue of ultra-rapid charging during regenerative braking and delivery of high current on acceleration makes the supercapacitor ideal as a peak-load enhancer for hybrid vehicles as well as for fuel cell applications. Its broad temperature range and long life offers an advantage over the battery.

Sodium-ion:
Sodium-ion battery manufacturer in India is Faradion Limited which is bought by Reliance Industries.

A team of researchers from IIT Kharagpur has developed low-cost, fast-charging Sodium-ion batteries and have used nano-materials to develop Sodium-ion-based batteries and supercapacitors for next-generation energy storage technologies and their use in e-vehicles.

Looking at some more innovations in this line. The new cell manufacturing facility by Log9 Materials, Bangalore is going to be the largest cell manufacturing facility in South East Asia and will have a capacity of 50MWh within one year. With 16 patents around Graphene, Log9 Materials has developed aluminium fuel cells for both mobility and stationary energy applications.

It has been working on an unique cell chemistry for its RapidX battery packs powered by InstaCharge technology, which offers nine times faster charging, better performance, and battery life as compared to conventional lithium ion electric vehicle batteries.

Intelligence of a battery is the Battery Management System (BMS). Features of which are as below,
• State of charge calculations
• Voltage & current of battery pack and of individual cells monitoring
• Cell over-voltage and under-voltage protection
• Short circuit protection
• Intelligent cell balancing (passive/active) in battery pack
• Battery charger control
• Pack over temperature monitoring & protection (temperature sensors)
• Monitors health of battery pack
• Over current protection while charge/discharge
• Over temperature protection while charge/discharge
• Under temperature protection while charge/discharge
• Monitoring
• Polarity protection
• Current shunt
• Determination of cut-offs, algorithm

Cells are protected from over-voltage, under-voltage, over-current, over-temperature, and under temperature based on the programmed minimum and maximum values in the battery profile.

Pack triggers error trouble codes if either the pack or individual cells are in poor health.

There is a flash memory on BMS which stores all the battery data like current, voltage, temperature, SoC, SoH, charging and discharging profile with time stamp, speed of the vehicle.

So, some batteries like Li-ion batteries need BMS for protection and for monitoring data whereas some batteries have few protections in them.

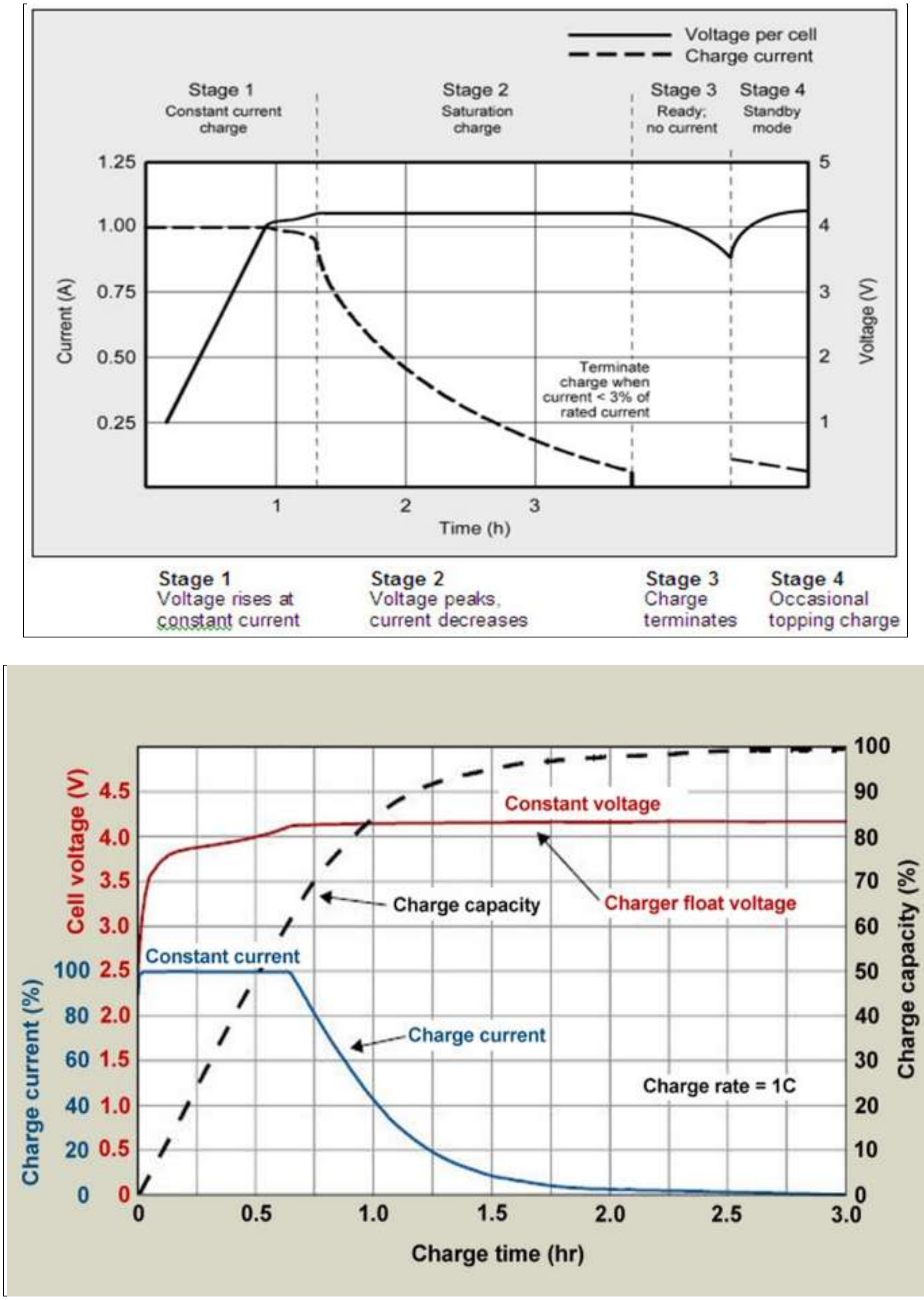

Fig.3:- Some graphs used to understand the charging profile of Li-ion battery.
Source: Battery University.

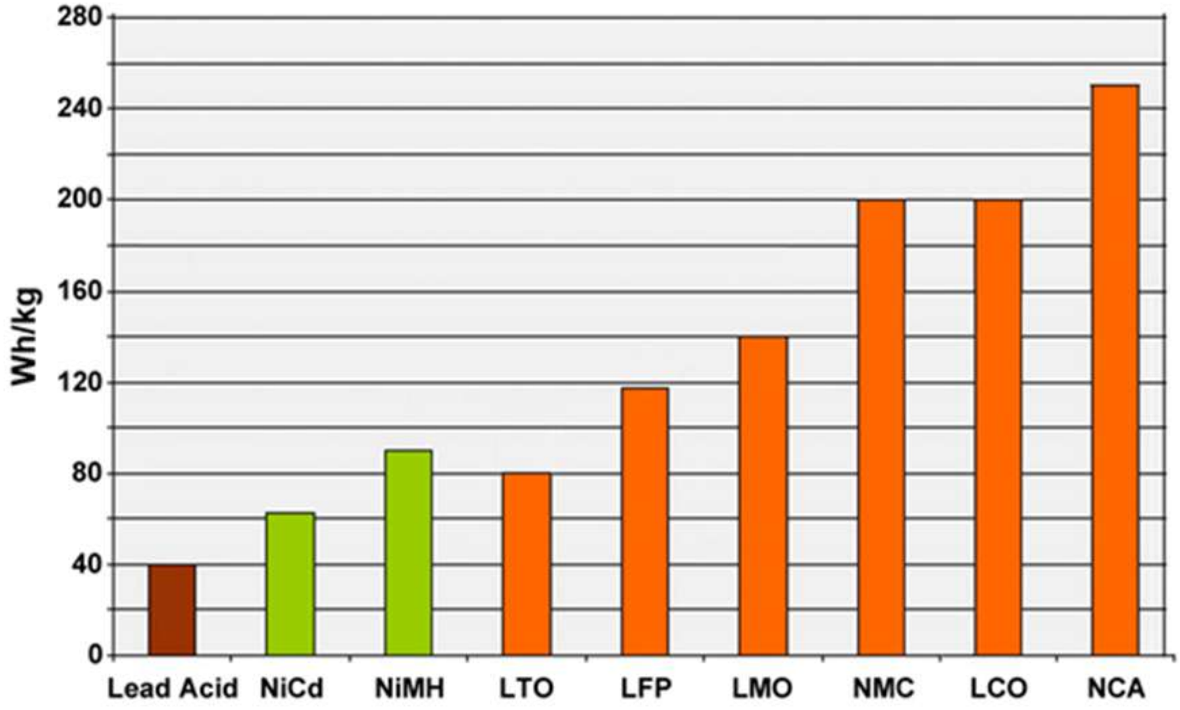

Fig. 4:- Chart showing - typical specific energy of lead-, nickel- and lithium-based batteries.

NCA enjoys the highest specific energy; however, manganese and phosphate are superior in terms of specific power and thermal stability. Li-titanate has the best life span.

Source: Battery University

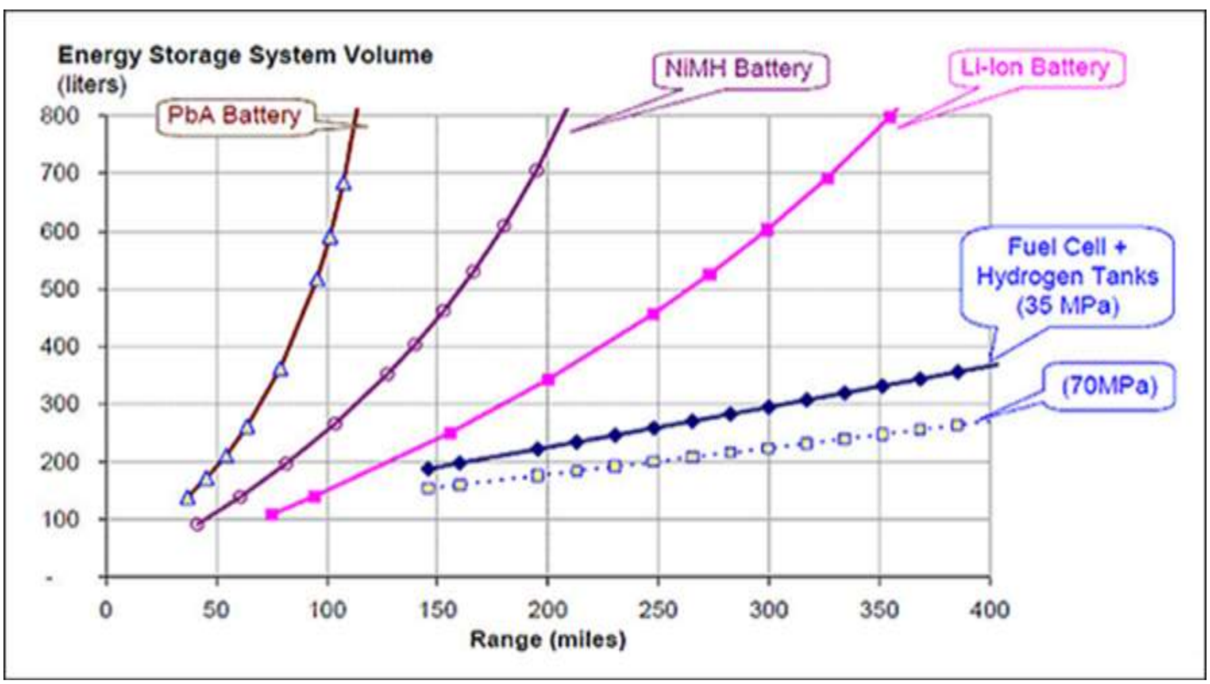

Fig. 5:- Graph to understand - driving range as a function of energy storage for different battery technologies. Source: Battery University.

Battery Swapping Concept

Battery swapping is exchanging the discharged or near-discharged batteries of electric vehicle with other fully charged batteries which is done within 3 minutes resulting in a very less turn-around time compared to filling fuel in ICE vehicles and to charging fixed batteries in in EV which takes 2-16 hours. Other advantages are swapping system is cost-effective and space efficient. These swappable batteries need not be big & heavy to give good mileage as these can be easily swapped at nearby swapping stations without range anxiety. Battery swapping concept is better for smaller electric vehicles. In this case vehicles are purchased without batteries which reduces the cost of vehicles by half approximately and becomes quite affordable. EVs are maintenance free compared to ICE vehicles. For 2 & 3 wheelers these small light-weight batteries are swapped manually with authentication & payment through mobile app at swapping stations. Swapping of bigger & heavier batteries of 4 wheelers - cars / trucks / buses may be done by battery swapping machine or robotic arms. Here the batteries are not owned by vehicle owners but by the energy operators of swapping centres or charge-cum-swap centres. The energy operator may run many centres like this in a locale. The energy-operator charges the discharged batteries for subsequent use in other vehicles. These batteries can be charged in a controlled environment at an appropriate charging rate and temperature. The controlled charging of batteries ensures longevity of the same.

Fig. 6:- Swappable Honda E-2W batteries.

Batteries are considered as a service (BaaS) for battery swapping technology. For energy operators or swapping station operators, batteries are the most important asset to generate revenue. EV owners without batteries pay a regular subscription fee (daily, weekly, monthly, etc.) to service providers for battery services throughout the vehicle lifetime. BaaS is applicable for both fixed and removeable batteries and is the channel to implement swapping solutions.

Their priorities are uninterruptible services to clients, safety of assets and ROI. Battery swapping technology helps to safeguard all these.

Batteries should be compatible (in shape and size) with the battery slots in all electric vehicles. Standardization of battery interface (connector) with vehicle powertrain is required. To prevent theft users' authentication who will swap battery packs are required which is done by mobile app along with the online payment procedure. Swappable batteries can also be assigned to different vehicles through mobile app. There is communication of battery pack with VCU (vehicle controller unit), motor controller, display unit, charger, mobile app. Measurement / reading of energy in battery pack is through blue tooth, mobile app, charger software. Cloud based AI and analytics platform is built for battery swapping technology.

Indian government has announced Battery Swapping Policy and interoperability standards, with the intent of building and improving the efficiency of the battery swapping ecosystem in recent past (Budget 2022-23 / June 2022) for faster adoption of EVs apart from previous incentives for EV Manufacturing and for Advanced Chemistry Cell Battery Storage to boost indigenous Battery Manufacturing capacity.

Battery swapping is still nascent in India but gaining ground especially for commercial and fleet operations. There are currently a limited number of battery swapping service providers that have been engaging with original equipment manufacturers (OEMs), individual / commercial users, and other relevant stakeholders, to develop ecosystems of swapping services with compatible components (batteries, vehicles, chargers, etc.) within each ecosystem.

The business models mainly differ in the extent to which different roles in the battery swapping ecosystem are integrated or kept separate. At one end, Battery Providers work with battery OEMs to develop smart, swappable batteries, provide them to the end user, and also operate charging facilities or BCS (Battery Charging Station) / BSS (Battery Swapping Station). Each of these roles can also be separated, whereby the batteries manufactured by an OEM are purchased by a Battery Provider, which then partners with relevant entities (such as retail / kirana stores) that deliver customer facing facilities such as BCSs/BSSs.

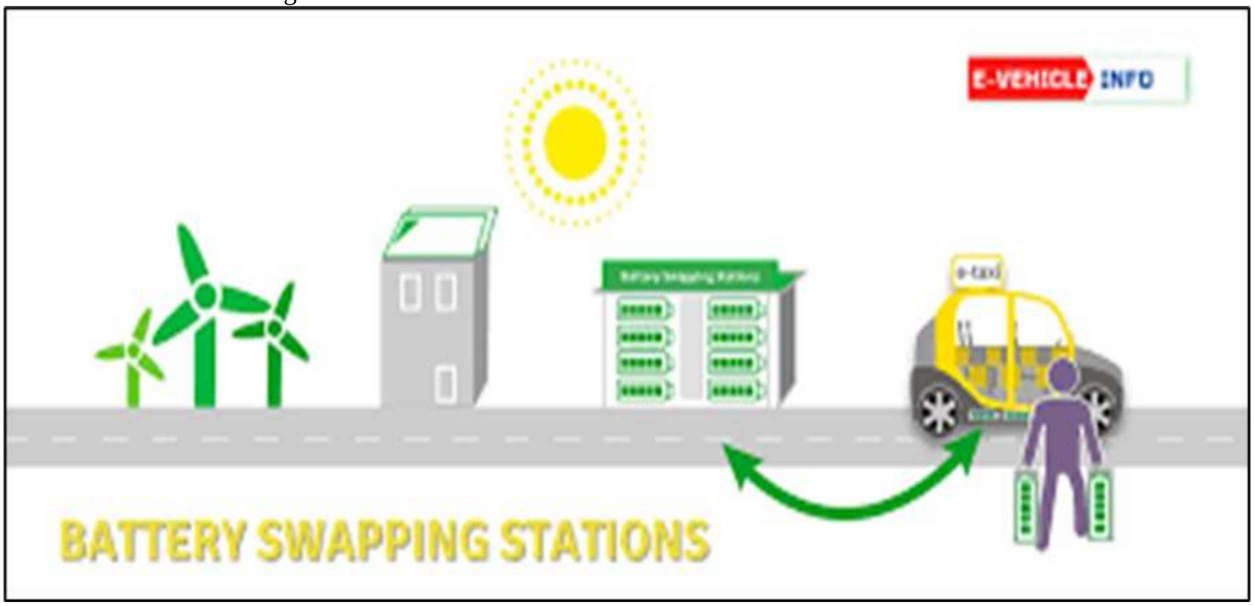

Fig. 7:- (Source: e-vehicle info).

Battery standards will be adopted or approved by the appropriate agencies to enable the safe operation of certified battery packs in different vehicles and for compatibility of BCS and BSS with different battery types. Battery manufacturer shall ensure that appropriate BMS is in place to protect the battery from conditions such as thermal runaway.

To ensure battery safety and security of assets, swappable batteries will be equipped with advanced features like IoT-based battery monitoring systems, remote monitoring & immobilization capabilities, and other required control features.
Additional standards and specifications for batteries regarding battery pack dimensions, charging connectors, etc. will be notified over time with adequate notice to, and consultation with, industry stakeholders, to support a phased transition to interoperability between ecosystems.

To implement unique traceability across the battery lifecycle, a Unique Identification Number

(UIN) shall be assigned at the manufacturing stage for tracking and monitoring EV batteries.

Various tracking and tracing solutions are used in different industry sectors, and an appropriate system may be applied for EV batteries which is tamper-proof and allows centralized monitoring. The standard or generic methodology and the detailed definition of the UIN system for EV batteries will be developed by the relevant authorities.

In this business CAPEX and OPEX of BSS is less compared to Public Charging Stations (fixed chargers) and ICE vehicles.

Required technical data of the battery will be mapped by the OEMs with UIN of battery pack at the manufacturing stage. Battery swapping operator must store the usage history and required performance data of battery with UIN during EV application, and data must be maintained to facilitate the traceability of EV batteries during the entire lifecycle.
Similarly, a UIN number will be assigned to each Battery Swapping Station.

Standards approved or defined by BIS shall be implemented for the electric vehicle, battery safety requirements, Degrees of Protection (IP-code) of electrical equipment against foreign objects, technical specification of cables and connectors, and traction battery safety requirements. To encourage "back-end" interoperability in the battery swapping ecosystem, an open standard communication protocol such as OCPP may be adopted, which must allow switching of networks.

To ensure safe and cost-effective infrastructure for charging and swapping of EV batteries, standards for BCS and BSS will be developed or approved by BIS/ Ministry of Power (MoP) or other competent authorities.

Policy recommends the following measures to support the development of such business models:

1. Encourage collaboration among stakeholders to form battery swapping ecosystems that are sustainable, scalable and leverage the strengths of each party to develop compatible solutions.
2. The Battery Provider would also be the potential point of contact representing the ecosystem for any coordination with external stakeholders including EV users, and government agencies.
3. Provide flexibility to end users (personal and business) to have different arrangements with Battery Providers with the option of switching operators in the future. For added flexibility, this Policy does not prevent Battery Providers from allowing EV users to detach swappable batteries from EVs to charge elsewhere (at home for instance), with appropriate measures to ensure safety and performance.
4. Support enabling technologies, which promote standardization, interoperability, safety and improve communication among stakeholders (including EV users where applicable). This would include providing access to real-time data on battery statistics like charge levels and range, discovery of nearest swapping stations as well as seamless options to book and pay for the services through multiple modes.

Subsidies and incentives are there from government for end users to purchase EVs without fixed batteries and for energy operators/battery providers.

Any individual or entity is free to set up a battery swapping station at any location, provided that the specified technical, safety and performance standards are adhered to.

Some real-world successful examples of Battery Swapping Technology in India are ACME- Nagpur, BPCL-Lucknow/Kochi, FORTUM-Gurgaon/Noida, Lithion Power-Delhi, Magenta Power-Mumbai, Sun Mobility-Gurgaon/Chandigarh/Punchkula/Mohali/Ahmedabad(e-buses), OLA Electric-Nagpur/Gurgaon, Amara Raja-Tirupati, Exicom-Delhi NCR, Exide-Gujarat, Ather-Chennai/Bangalore, Kinetic-Gurgaon/Nagpur, Okinawa Electric Scooter-Bhiwadi, Zypp-Rapido-many cities, Grofers, Bounce, etc.

Utilisation of renewable source of energy: A swapping establishment using renewable sources of energy can help BSOs reduce battery swapping cost and become more competitive. Old batteries with degraded capacity or batteries with EOL (end of life) in EVs can be utilised as power storage at renewable power generation plants and at energy grids.

Fig. 8:-
(Source: Bharti Solar)

Review of Literature:-

1. Looking at the battery technologies, it is clear that there is high scope of research and development in future battery technologies and hence business opportunities in electric vehicle battery manufacturing.
2. Battery Swapping System for small electric vehicles like 2 & 3 wheelers is viable and economical. The vehicle owner purchases EV without battery which cuts down the cost by about 40% and the owner just have to swap the discharged battery with charged ones at Battery Swapping Stations, which can be easily located using mobile app. It is interesting to note that the owner just pays, through mobile app or some other technology for only the battery energy consumed in the electric vehicle.

Objectives:-

Moving ahead in the report it will be clear, which battery technology is good for electric vehicles and how feasible is battery swapping system for EVs, so this becomes the basis or objective of this research.

Methodology:-

Both primary and secondary methods of data collection are being used. Primary methodology covers interviewing the public/customer. Source of secondary data are newspaper, magazines, journals, publications, bulletins, media.

Limitations / Challenges:

Lack of lucrative govt. policies though efforts from them are there, ever evolving battery technologies and cell chemistries, lack of standardization of swappable battery.

Authorities, scientists and committees are working on above challenges.

Conclusion:-

1. **Battery Technology** – technology to go for at the moment is Li-ion / Li-based. Below is the list of different types of Li-based battery technology to study and understand the difference between them.

Table1:- Summary of most common lithium-ion based batteries.

Chemistry	**Lithium Cobalt Oxide**	**Lithium Manganese Oxide**	**Lithium Nickel Manganese Oxide**	**Lithium Iron Phosphate**	**Lithium Nickel Cobalt Aluminum Oxide**	**Lithium Titanate Oxide**
Short form	Li-cobalt	Li-manganese	NMC	Li-phosphate	Li-aluminum	Li-titanate
Abbreviation	$LiCoO_2$ (LCO)	$LiMn_2O_4$ (LMO)	$LiNiMnCoO_2$ (NMC)	$LiFePO_4$ (LFP)	$LiNiCoAlO_2$ (NCA)	Li_2TiO_3 (common) (LTO)
Nominal voltage	3.60V	3.70V (3.80V)	3.60V (3.70V)	3.20, 3.30V	3.60V	2.40V
Full charge	4.20V	4.20V	4.20V (or higher)	3.65V	4.20V	2.85V
Full discharge	3.00V	3.00V	3.00V	2.50V	3.00V	1.80V
Minimal voltage	2.50V	2.50V	2.50V	2.00V	2.50V	1.50V (est.)
Specific Energy	150–200Wh/kg	100–150Wh/kg	150–220Wh/kg	90–120Wh/kg	200-260Wh/kg	70–80Wh/kg
Charge rate	0.7–1C (3h)	0.7–1C (3h)	0.7–1C (3h)	1C (3h)	1C	1C (5C max)
Discharge rate	1C (1h)	1C, 10C possible	1–2C	1C (25C pule)	1C	10C possible
Cycle life (ideal)	500–1000	300–700	1000–2000	1000–2000	500	3,000–7,000
Thermal runaway	150°C (higher when empty)	250°C (higher when empty)	210°C(higher when empty)	270°C (safe at full charge)	150°C (higher when empty)	One of safest Li-ion batteries
Maintenance	Keep cool; store partially charged; prevent full charge cycles, use moderate charge and discharge currents					
Packaging (typical)	18650, prismatic and pouch cell	Prismatic	18650, prismatic and pouch cell	26650, prismatic	18650	prismatic
History	1991 (Sony)	1996	2008	1996	1999	2008
Applications	Mobile phones, tablets, laptops, cameras	Power tools, medical devices, powertrains	E-bikes, medical devices, EVs, industrial	Stationary with high currents and endurance	Medical, industrial, EV (Tesla)	UPS, EV, solar street lighting
Comments	High energy, limited power. Market share has stabilized.	High power, less capacity; safer than Li-cobalt; often mixed with NMC to improve performanc	High capacity and high power. Market share is increasing. Also NCM, CMN, MNC, MCN	Flat discharge voltage, high power low capacity, very safe; elevated	Highest capacity with moderate power. Similar to Li-cobalt.	Long life, fast charge, wide temperature range and safe. Low capacity, expensive.

		e.		self-discharge.		

Source: Battery University

Can think of scaling up and commercialising the prototype sodium-ion battery developed by IIT Kharagpur through dialogues and engagement with them.

Future of Battery Technology: LFP, Sodium-ion, Solid state and batteries studied in introduction section. Iron and sodium are cheap and plentiful in nature. Besides lower costs, LFP offers a long life-cycle and high safety performance.

There are numerous battery technologies. R&D is going on various newer / future batteries and alternate batteries.

At present electric vehicles are using lead acid batteries (already in the phase-out process), Ni-based (Nickle cadmium, Nickle metal hydride), dominant Li-based batteries with different chemistries (NCA, NMC, etc.), LFP majorly.

Battery Swapping System:
To adopt BSS with renewable energy for pilot project / BCS - using renewable microgrid or renewable energy tied to grid.

India is the world's third largest renewable energy producer with 19.8 per cent of the installed energy capacity coming from renewable sources. This is set to increase 30% by 2030.Developing decentralized solar power plants at charging or swapping stations can make the use of EVs more eco-friendly.

Swappable batteries can be charged from the DC bus / storage battery of the renewable energy sources & controllers with some power electronic boards (DC/DC converter, filters, safety components, DC/AC converter, reverse polarity protection, etc.).

Fig. 9:- Use of renewable energy for charging swappable batteries at BCS
Source: The Economic Times (ETEnergyWorld)

Primary use of these batteries is to power EVs. Old batteries of EVs are utilised for secondary use as energy storage. After the secondary use, the batteries whose life is completely over can be sent to battery recycling plant through BSSs (battery swapping stations). Also, repair and maintenance check of batteries can happen in BSS.

In short BSS can become an excellent business model in electric vehicle ecosystem.

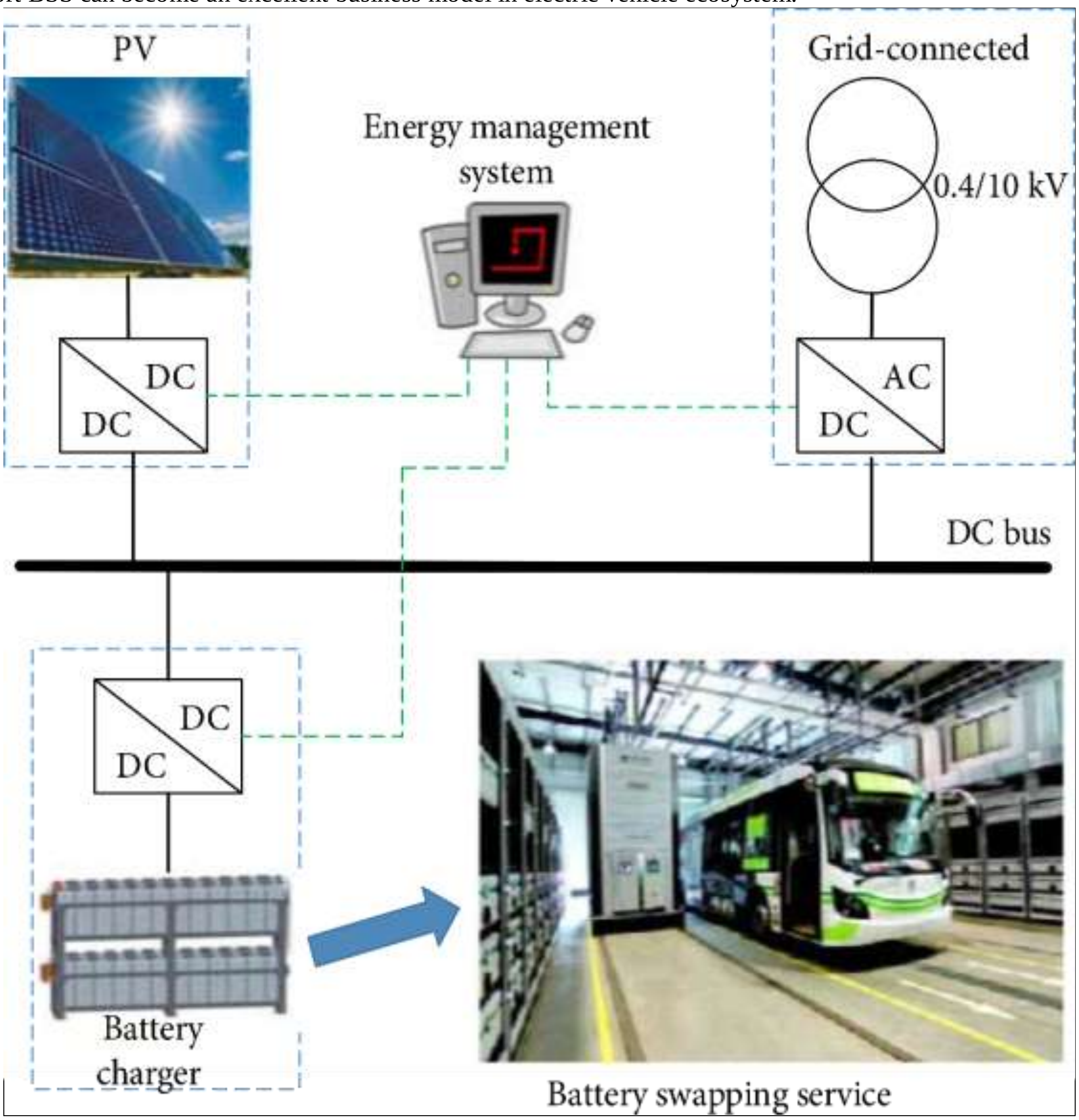

Fig. 10:- Structure of a PV based BSS.
Source: hindwai.com/journals

The PV system consists of PV modules and DC/DC converters. The PV modules directly convert solar energy into electric energy and deliver power to the DC bus through the DC/DC converter. The actual output power of the PV system is mainly affected by solar irradiation and environmental temperature. The battery charging system is comprised of DC chargers and batteries. The grid-connected system consists of a bidirectional AC/DC inverter and a distribution transformer. The grid-connected system balances power between the distribution grid and the DC bus and maintains a stable voltage in the DC bus. The energy management system monitors and controls the operation of each component in the PV-based BSS. The optimal charging strategy will run on the energy management system to achieve the operational objectives of the BSS. The battery is initially charged with a constant current until the state of charge (SOC) reaches a certain value, after which it is charged with a constant voltage. Recently, batteries have also been charged with a constant power.

Cost assumptions

Capital expenditure (CAPEX) and Operating expenditure (OPEX) in Battery Swapping System.

CAPEX	COST (INR)
Swap station with rectifiers (swap-cum charging station)	13,50,000 per unit with 15 battery slots
Battery	25,000 per kW
Electrical work / BSS	New electricity connection (as per EB) + transformer (if needed - as per kVA required –> 1-7 lakhs) + circuit breaker (5,000) + energy meter (2,500)
Civil work	150 / sq.ft.
BSS management software	50,000
CCTV set-up	12,000
Logistics (in case of centralised charging at different location)	2,00,000

OPEX	COST (INR)
Site maintenance staff	10,000 / person
Driver for logistic vehicle if any	10,000 / person
Fees of network service provider	25,000
Payment gateway fees	2.25% of the net margin on cost per swap
Operation & Maintenance	1% of capital cost
Electricity tariff	6 / unit
Land lease cost if any	200 / sq.ft.

Table 2:– BSS set-up estimate.

Revenue of BSS operator: Rs. 50 per transaction.

Topics for further research:

Further in-depth study and research can happen on alternate battery chemistries like Sodium-sulfur, Sodium-nickel-chloride (ZEBRA), Zinc-air (primary and secondary), Silver-zinc, Silver-oxide, Reusable Alkaline, Supercapacitor, Flow battery, Fuel cell and future batteries like Lithium-air, Lithium-metal, Solid-state Lithium, Lithium-sulfur and Sodium-ion.

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