A Review: Issues and Challenges of Electric Vehicle Energy Storage Systems

Dr. Kumar K
Sri Venkateswara College of Engineerring
Dept. of EEE
Tirupati, A.P, India
kumar3kk@gmail.com

Dr. V Lakshmi Devi
Sri Venkateswara College of Engineerring
Dept. of EEE
Tirupati, A.P, India
vldevi.eee@gmail.com

ABSTRACT

Electric vehicles (EV) are the most promising technology in order to reduce the carbon emissions caused by to transportation sector. The concept of EVs is to use the maximum of renewable energy resources and minimize the dependency on fossil fuels. There is tremendous growth in EVs in terms of efficiency, acceleration capability, and endurance. However, EVs still face a challenge in energy storage systems (ESS). There are different types of ESS available with a combination of different power electronics converters which can be chosen based on the requirement and location. The ESS is a very important and central component of EV. The ESS should be cost-effective, efficient, reliable, safe, and compact which should withstand for a longer time. This chapter gives a better insight into existing ESS technology, its classification, conversion, and its merits for EV application. Moreover, this chapter also gives various classifications of ESS technology in accordance with its material used, power delivery techniques, and energy formulation. This chapter is intended to choose an appropriate ESS technology for an EV system and also highlights many factors affecting the life of storage systems.

Keywords— Electric Vehicle; Storage System; Power electronics Interface; Power conversion

I. INTRODUCTION

The transportation sector stands as the predominant contributor to greenhouse gas emissions and CO2 levels in the atmosphere, necessitating a focused effort on decarbonization to mitigate its environmental impact. While advancements in internal combustion engines for conventional fossil fuel vehicles have been made, they are yet to achieve the ambitious CO2 emission reduction targets set. Therefore, the integration of advanced technologies becomes imperative for the attainment of long-term and more rigorous emission reduction goals [1].

The global concern over the escalating levels of CO2 and other greenhouse gas emissions has prompted countries and researchers alike to seek effective solutions. Amidst various alternatives, electric-driven vehicles have emerged as a compelling prospect due to their inherent capacity for significantly lower emissions and efficient CO2 reduction. The electric vehicle (EV) system offers superior engine efficiency, distinguishing itself by circumventing traditional sources of pollution like tailpipe emissions, fuel evaporation, and refining byproducts. Consequently, the EV has garnered the moniker of a "zero-emission vehicle," making it a promising avenue for combating environmental degradation.

Central to the functionality of EVs is the use of electricity stored in diverse energy storage systems such as batteries, fuel cells (FCs), and ultracapacitors (UCs). These energy sources draw from an array of generation plants and renewable resources, necessitating plug-in charging infrastructure. Depending on the power source, EVs come in various forms including hybrid electric vehicles (HEVs), battery-powered electric vehicles (BEVs), plug-in hybrids, photovoltaic EVs, and fuel cell EVs. The effectiveness of these EV variants is inherently linked to advancements in energy storage technologies, such as the development of improved battery cells, FCs, and UCs, all of which are integral for power delivery and vehicle performance.

However, the successful integration of EVs into the transportation landscape brings about new challenges, prominently the increased strain they place on existing power grids. As the demand for electricity surges with the widespread adoption of EVs, many countries are redirecting their investments toward renewable energy sources, such as solar and wind power. These renewable resources offer a dual benefit, augmenting the power grid's capacity while also contributing significantly during peak demand periods.

The dynamic relationship between renewable and stored energy in EVs materializes through the concept of vehicle-to-grid (V2G) systems. These systems enable EVs to transfer excess stored energy back to the utility power grid during peak hours, effectively balancing demand and supply. The energy accumulated within the vehicle's battery and other storage systems is harnessed not only to power the electric motor and auxiliary systems but also to maintain the vehicle's core functions. The success of this arrangement hinges on striking the right balance between energy and power density to ensure optimal driving range and performance without exceeding technical specifications.

This chapter aims to provide an encompassing overview of Energy Storage Systems (ESSs), examining their current status, evolving features, assessments, prevailing challenges, and future prospects. Furthermore, the exploration extends to hybridization technologies within the realm of ESSs as applied to EVs. By delving into these aspects, a comprehensive understanding of the role ESSs play in shaping the landscape of electric mobility is attained. As the world strives to transition toward more sustainable transportation solutions, the significance of energy storage systems in enabling the effective integration of EVs cannot be overstated. The amalgamation of renewable energy sources, advanced storage technologies, and innovative vehicle-to-grid systems will undoubtedly form the cornerstone of a cleaner and greener transportation future.

II. Essential Energy Storage System for Electric Vehicles

Energy Storage Systems (ESSs) are pivotal for the seamless integration of electric vehicles (EVs) into modern transportation networks. These systems play a multifaceted role in enhancing the overall efficiency and usability of EVs. One of the core benefits of ESSs lies in their ability to optimize the performance and driving range of EVs. By efficiently managing the distribution of stored energy, ESSs ensure that the EV's electric motor and auxiliary systems receive a consistent supply of power, thereby extending the vehicle's range and eliminating concerns about "range anxiety" among potential buyers.

Furthermore, ESSs enable regenerative braking systems, a technology that recovers and stores kinetic energy during braking or deceleration. This energy can then be redeployed to power the vehicle, thus increasing overall efficiency and conserving valuable energy resources.

Fast charging, a crucial aspect of EV adoption, is also facilitated by ESSs. These systems boast high power density, allowing them to quickly accommodate the substantial energy demands of fast charging stations. This capability expedites the recharging process and enhances the practicality of EVs for daily use.

Another key feature is the incorporation of Vehicle-to-Grid (V2G) technology, which transforms EVs into dynamic energy resources. During peak demand periods, ESSs within EVs can release stored energy back to the power grid, contributing to grid stability and reducing strain on conventional energy sources. This bidirectional flow of energy not only benefits the grid but also leverages the potential of renewable energy sources, minimizing the environmental footprint of EVs.

The development of ESSs is a driving force behind innovation across scientific and engineering disciplines. Researchers continually explore novel materials, technologies, and designs to enhance energy storage efficiency, density, and safety. These advancements not only empower EVs but also stimulate broader progress in sustainable energy solutions.

In essence, Energy Storage Systems are at the heart of the EV revolution, enhancing their performance, addressing key challenges, and fostering a sustainable energy future. As EV adoption continues to expand, the evolution of ESSs remains critical to ensuring their competitiveness, efficiency, and positive impact on the environment.

Electrochemical batteries constitute the paramount energy storage systems employed in contemporary electric vehicles (EVs). Currently, the most widely employed types, alongside those in experimental phases, encompass Lead-acid, Ni-MH, Li-ion, Na-NiCl (ZEBRA), and Zn-O2 (as developed by "Electric Fuel"). Notably, the latter employs mechanical charging as an alternative to conventional electric charging methods. This array of electrochemical batteries will be subjected to a comparative analysis encompassing specific energy, specific power, cycle life, and cost as presented in Table 1.

Table 1: Shows a comparison of different energy storage systems

Energy Source	Lead-acid	Ni-MH	Li-ion	ZEBRA	Zn-O2	flywheels	Ultra capacitor
Wh/kg	35	70	130	110	200	40	5
W/kg	150	220	350	150	100	3000	2000
Cycle life	700	1500	1000	1500	1	5000	500000
Cost	150	1500	2000	700	5000	20000	25000

A. Lead acid

The lead-acid battery stands as the most ancient and prevalent form of energy storage due to its affordability and user-friendly nature. Nonetheless, it has encountered limitations in terms of specific energy, rendering it unsuitable for long-range electric vehicles (EVs). Additionally, its cycle life remains relatively short, necessitating battery pack replacement every two to three years. Effective charging behavior is also pivotal; there's a preference for swift recharging within minutes. However, high-current charging is discouraged due to the substantial reduction in cycle life, as observed from past experiences with lead-acid batteries. Despite these shortcomings, the utilization of lead-acid batteries is poised to persist due to their significantly lower cost compared to alternative energy storage options. Generally, lead-acid batteries exhibit a cycle life of approximately 700 cycles, a specific energy of around 35 Wh/kg, and a specific power of about 150 W/kg. A representative lead-acid battery is depicted in Figure 1.

Figure 1: Typical lead-acid battery

B. Ni-HM

Because of its impressive performance in terms of both specific energy and cycle life, this battery has demonstrated that it is an excellent option for use in electric cars (EVs). The Ni-MH battery is built using recyclable and non-hazardous materials, so it adheres to ecologically friendly principles and does not need any upkeep. The creation of this type of battery, which is distinguished by its use of nickel hydroxide for the positive electrodes and hydrogen-absorbing alloys for the negative electrodes, can be traced back to the 1970s, when Philips made significant strides in improving the hydrogen-absorbing capabilities of $LaNi_5$. Significant capacity increases have been made possible in recent years as a result of developments using innovative hydrogen-absorbing alloys that utilise combinations of elements such as aluminum, manganese, cobalt, zirconium, and vanadium. Ni-MH batteries, in general, have a cycle life of roughly 1,500 cycles, have a specific energy of approximately 70 Wh/kg, and have a specific power that is greater than 200 W/kg [2]. The cost of this battery is considerably more than that of a lead-acid battery; in fact, it is nearly ten times higher. This is a key disadvantage of the battery. Figure 2 presents a representation of a configuration that is characteristic of Ni-MH batteries.

Figure 2: Typical Ni-MH battery

C. Li-Ion

Li-Ion batteries exhibit notably high specific energy levels. Currently, a significant degree of inherent safety can be achieved at the cell level. Modern cathode materials like lithium-cobalt-nickel-manganese oxide or lithium-iron-phosphate demonstrate reduced exothermic reactions under misuse, in contrast to the conventionally employed lithium-cobalt oxide in consumer cells. The adoption of these cathode materials, coupled with enhanced separators featuring ceramic components and high-boiling electrolytes, substantially enhances safety at the cell level. The flexibility of Li-Ion cells enables the exploration of diverse electrode materials and electrolytes, allowing for advancements in safety alongside attractive energy and power densities. System-level safety measures, including monitoring sub-optimal conditions, their management, and efficient cooling, maintain the battery in a secure operational state, ensuring a high level of safety.

Lithium is stored and released within a solid lattice in Li-Ion cells by intercalation, which preserves the lattice structure while greatly increasing charge-discharge cycle counts. While lead-acid systems have achieved the pinnacle of development, the potential of lithium-ion battery systems is still being realized. The significantly higher specific energy of lithium-ion batteries allows electric vehicles to enter high-volume markets. Currently, certain lithium-ion batteries can sustain average charging currents of around 5 C (five times the charging current of the nominal capacity) while maintaining outstanding cycle endurance. This proves that rapid battery recharging is no longer a problem. However, the battery capacities of electric vehicles typically range between 15 and 20 kWh, resulting in high charging power requirements of 60 kW.

Consequently, the limitation for fast recharging in Li-Ion technology resides with charging stations and chargers. Standard household sockets (220V/16A ≈ 3.3 kW) cannot support this recharging power, necessitating the development of charging station infrastructure. As high-power charging stations become increasingly available and the concept of regularly "fueling" an electric vehicle gains acceptance, the need for an onboard charger might become obsolete [3]. Figure 3 depicts a representative Li-ion battery configuration.

Figure 3: Li-ion battery

D. ZEBRA

The Na-NiCl battery, also known as ZEBRA [4], operates at high temperatures (270°C) and necessitates a specialized enclosure to maintain warmth internally while remaining cool externally. Despite this limitation, the battery proves to be a favorable option for electric vehicles due to its safety, cost-effectiveness, and ability to endure 1,500 cycles with minimal degradation. Moreover, it can be discharged almost entirely without significantly impacting its cycle life. Its specific energy (Wh/kg) is comparable to high-quality batteries like Li-ion (120 Wh/kg). Another significant feature of this battery is that it can be kept cold forever without being damaged.

However, when it comes to specific power (W/kg), ZEBRA falls short of other batteries, as shown in Table 1. For example, Li-ion batteries have about three times the specific power of ZEBRA (approaching 400 W/kg), but they are roughly three times more expensive in terms of dollars per kWh (US$/kWh).It is currently difficult to find a low-cost Li-ion battery. The tiny 18650 cells (3.6 V, 2.4 Ah) are the least priced Li-ion batteries on the market today. It is conceivable to implement a battery for a car utilizing around 4,000 of these cells [5]. When acquiring more than 1,000 cells, the lowest market price per unit is $4.75, equivalent to $19,000 for 4,000 units.

This estimate excludes the significant number of electrical circuits required for voltage balancing, temperature management, and current balancing, which might raise the overall cost to more than $40,000. The cost of incorporating such a battery, combined with the container, reinforcements, mechanical safeguards, and the time and effort required for assembly and calibration, exceeds $50,000. The container, which houses 4,000 cells and stores around 25 kWh of energy, results in a battery cost per kWh that exceeds $2,000/kWh.A 30 kWh ZEBRA battery, on the other hand, costs around $20,000 [6] (actual cost as of March 2009), including auxiliary control circuits. As a result, ZEBRA's cost per kWh is less than $700/kWh, making it three times more cost-effective than Li-ion batteries. Figure 4 depicts a representative ZEBRA battery.

Figure 4: ZEBRA battery (MES-DEA)

E. Zinc Air

The zinc-air battery developed by "Electric Fuel" exhibits a notably limited cycle life, rendering electrical recharging impractical. Instead, it undergoes a sequence of mechanical and electrochemical stages for "charging," a process necessitating specialized infrastructure. This is why Table 1 only depicts a single charge-discharge cycle for this battery. Comprising a battery pack with detachable zinc-anode cassettes [7], the Electric Fuel zinc-air battery presently achieves a specific energy of approximately 200 Wh/kg and a specific power of 100 W/kg. An automated battery exchange system, situated at specific locations or refueling stations, facilitates swift vehicle turnaround. A refueling apparatus is utilized to swap out depleted anode cassettes with recycled and recharged counterparts. In the regeneration procedure, the discharged zinc oxide undergoes electrolytic dissolution, forming charged zinc particles that are subsequently fashioned into new anode cassettes.

Given its limitations in specific power and limited charging capability, vehicles equipped with this battery cannot utilize regenerative braking. Moreover, costs escalate due to the need to account for the intricate charging process involving a specialized electrochemical facility for zinc anode recovery. Notably, this battery offers advantages such as its impressive single-charge travel distance and rapid charging period (approximately five minutes for anode replacement). Furthermore, the battery's longevity is potentially indefinite as the anodes are perpetually renewed. A representation of a Zn-air battery can be observed in Figure 5.

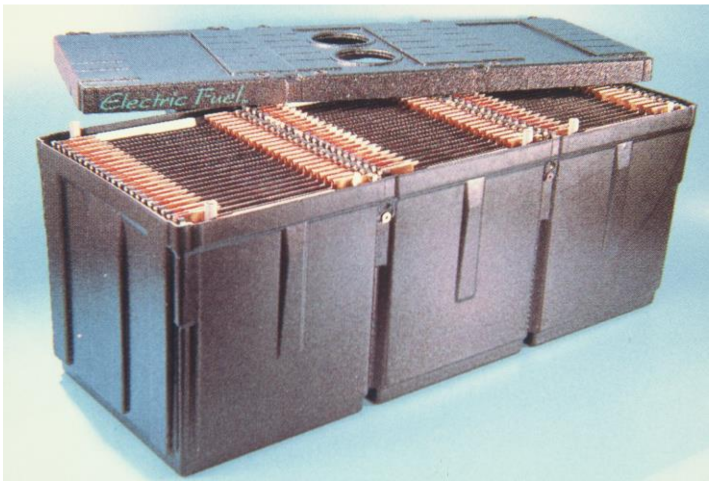

Figure 5: Zinc-Air battery

F. Ultra Capacitors

Ultracapacitors (Ucaps) represent a novel energy storage technology, distinguished by their noteworthy attributes of "fast charge" (high specific power) and extended cycle life. Their main limitation at present is their relatively modest specific energy (Wh/kg), preventing them from directly replacing conventional battery systems in electric vehicles [8].

The capacity of Ucaps is quantified in Farads rather than microfarads, with available components reaching over 1,000 F. In contrast, a typical conventional capacitor, featuring plates of 1 m² size separated by a mere one-tenth of a millimeter, yields just 0.09 µF. This outcome makes it challenging to envision a compact capacitor with a capacity exceeding 1,000 Farads. The substantial capacity of Ucaps relies on the utilization of highly porous carbon electrodes with extensive surface areas, separated by minuscule distances. Figure 6 illustrates an array of Ucaps, while Figure 7 provides an insight into the internal structure of an ultracapacitor.

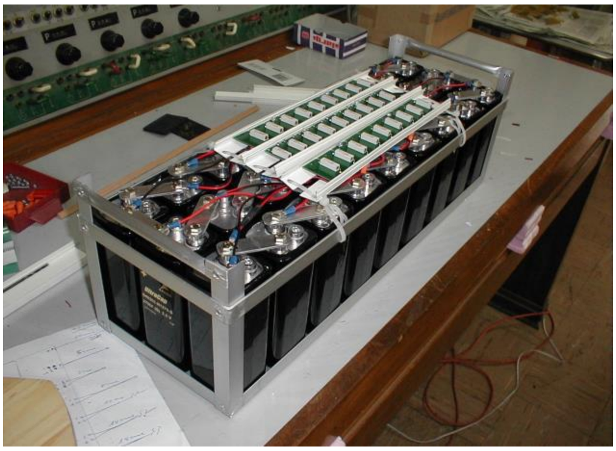

Figure 6: Ultracapacitor bank

III. Classification of Energy Storage System

Energy Storage Systems (ESSs) exhibit a diverse landscape defined by multiple parameters. Classification is established based on technology, encompassing mechanical, electrochemical, thermal, and electromagnetic approaches. Mechanical solutions involve mechanisms like flywheels, while electrochemical options span batteries and fuel cells, and thermal alternatives encompass heat storage methods as shown in Figure 8.

Another dimension of classification is application, dividing ESSs into stationary and mobile categories. Stationary applications encompass grid stabilization and backup power supply for industries, commercial facilities, and homes. Mobile applications, on the other hand, are primarily concerned with powering electric vehicles (EVs) and ensuring their efficient operation [9-11].

Operational traits further refine the classification. Long-duration ESSs cater to the needs of grid integration and large-scale energy storage, addressing the challenges posed by renewable energy sources' intermittent nature. These systems play a crucial role in ensuring a reliable and stable supply of electricity. Short-duration systems, on the other hand, specialize in swiftly responding to fluctuations in grid frequency, maintaining the grid's stability in real-time.

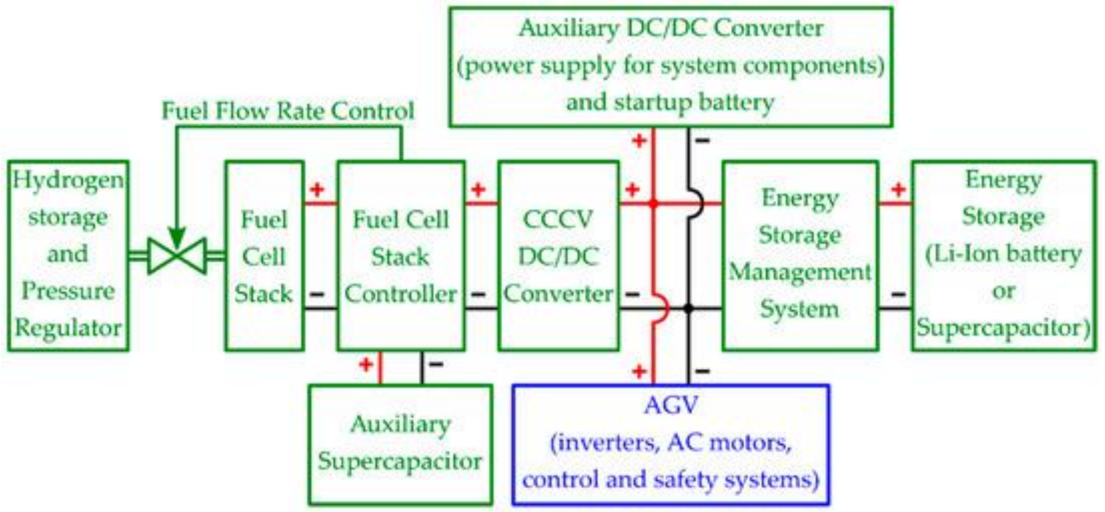

Figure 7: Energy Storage System for Electric Vehicles

A significant categorization also revolves around environmental impact. ESSs are distinguished by their eco-friendliness, with various technologies falling under green and redox flow battery categories, as well as hydrogen storage solutions. Lithium-ion batteries, commonly used in various applications including EVs, represent a prominent green option. Redox flow batteries offer scalable and flexible solutions for grid-scale storage. Hydrogen storage, utilizing hydrogen gas for energy storage and conversion, holds potential as a sustainable alternative for long-duration storage and clean energy generation [12-14].

In summary, the classification of ESSs encompasses a spectrum of technologies, applications, operational characteristics, and environmental impacts. This intricate framework serves as a guide for understanding the intricacies of energy storage and helps navigate the array of choices available to cater to diverse energy needs while striving for sustainability and efficiency.

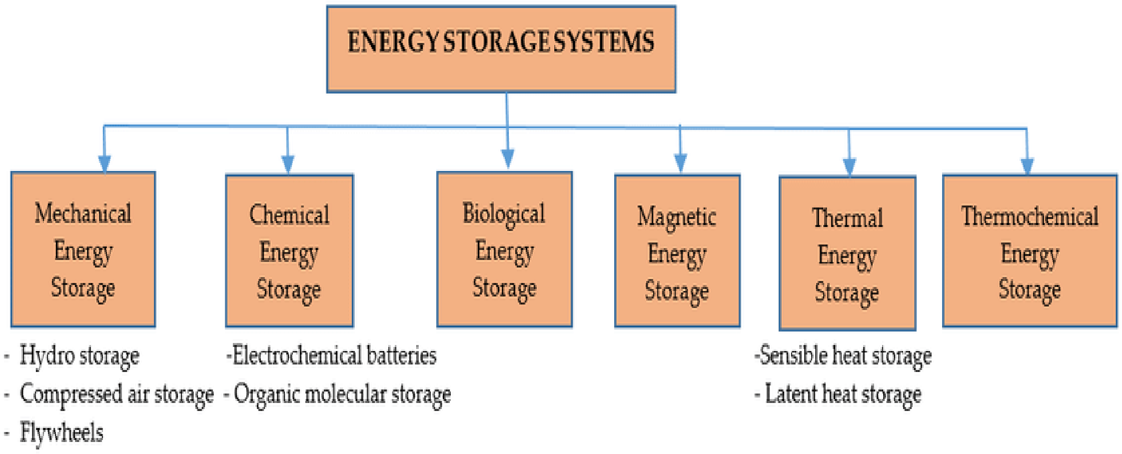

Figure 8: Classification of energy storage systems

IV. Issues and Challenges

The transition to electric vehicles (EVs) marks a crucial step towards sustainable transportation, yet its realization hinges on effectively navigating the multifaceted challenges within the realm of Energy Storage Systems (ESS). These challenges, central to the performance, viability, and widespread adoption of EVs, underscore the intricate interplay between technological innovation, environmental responsibility, and economic feasibility [15].

The challenges encompassing EV energy storage systems are not merely technical hurdles; they epitomize the intricate balance required to achieve a seamless and sustainable transportation revolution. Their successful resolution stands as the linchpin for realizing the environmental benefits, energy independence, and operational efficiency promised by EV technology. By conquering these challenges, we can catalyze a paradigm shift towards greener transportation and alleviate the detrimental impacts of fossil fuel-based vehicles on climate change and air quality.

A. Size and Weight*:*

Overcoming the size and weight constraints of energy storage systems is pivotal for EV design and efficiency. Advanced materials such as solid-state electrolytes and nanocomposites are being researched to reduce bulk while maintaining energy density.

B. Cost and Performance:

Striking a balance between cost and performance is pivotal to EV affordability and competitiveness. Battery technology advancements, scalable manufacturing processes, and shared research consortiums are driving down costs while improving performance metrics like energy density and cycle life.

C. Proper Disposal:

The sustainable lifecycle of EV batteries demands proper end-of-life strategies. Circular economy principles, such as battery recycling and repurposing, are being pursued to minimize environmental impact and resource depletion.

D. Energy Management:

Optimizing energy consumption through intelligent energy management systems is crucial. Smart algorithms, coupled with real-time data analytics, enable efficient energy distribution, extending driving range and reducing wastage.

E. Operational and Maintenance:

To make in-vehicle battery system, an advanced chemical battery is designed to meet in-vehicle requirements like small in size and high rating. The manufacturer provides the reliability index on the battery is of 8y to 10y at normal driving cycle with normal temperature. But in practical, EV undergoes different operating temperature and abnormal driving cycles. To meet this real time demand, battery size should be in bulk in size. [Energy storage system technology]

F. Power Electronic Interface:

Power electronic converters (PEC) are required to interface the vehicle with the battery to improve the performance, durability, and efficiency of the system. Several advanced PECs are available for interfacing, which itself handles the power conditioning, converting, controlling, and power flow control between ESS to the motor. Different converter configurations have their own pros and cons, including size, efficiency, current ripple, voltage stress, flexibility, and cost. To overcome these new converter configurations are required to develop.

G. Environment impact:

To overcome the drawbacks in conventional transportation systems, EVs are coming into the picture, but EVs are facing a minimal amount of problems in energy storage systems, especially in the manufacturing stage, disposal, and recycling stages. In the manufacturing unit by using special tools and handling equipment special skilled persons are required and they need to follow the safety measures.

H. Temperature:

In the battery system, the temperature will generate due to the chemical reaction in the battery in general, batteries are made up to operate in both charging and discharging modes in EVs at standard temperature conditions, but the chemical reaction taking place in the battery may cause high temperature and low temperatures, it affects the chemical properties of materials used in battery, battery lifetime and operating conditions. The low temperature in the battery affects the current and power handling capabilities during the charging and discharging periods and if the battery temperature increases gradually it may cause changes in the chemical reaction and sometimes it may lead to the explosion of the battery.

In EV, the operating cycle is not constant in all the conditions, based on road conditions it may vary, so special care should be taken in the selection of chemicals and materials used in the battery, usually, it is preferable to change high-temperature handling materials of larger in size.

I. Safety:

Battery safety operation is much more concern for the manufacturers and users, during charging and discharging special care should be taken by continuously monitoring battery parameters for continuous smooth operations and to overcome the faults occurring by the overcharging and overcharging of battery. The state of charge (SOC) will provide control over charging and discharging. Usually by maintaining SOC level of 10% to 90%.

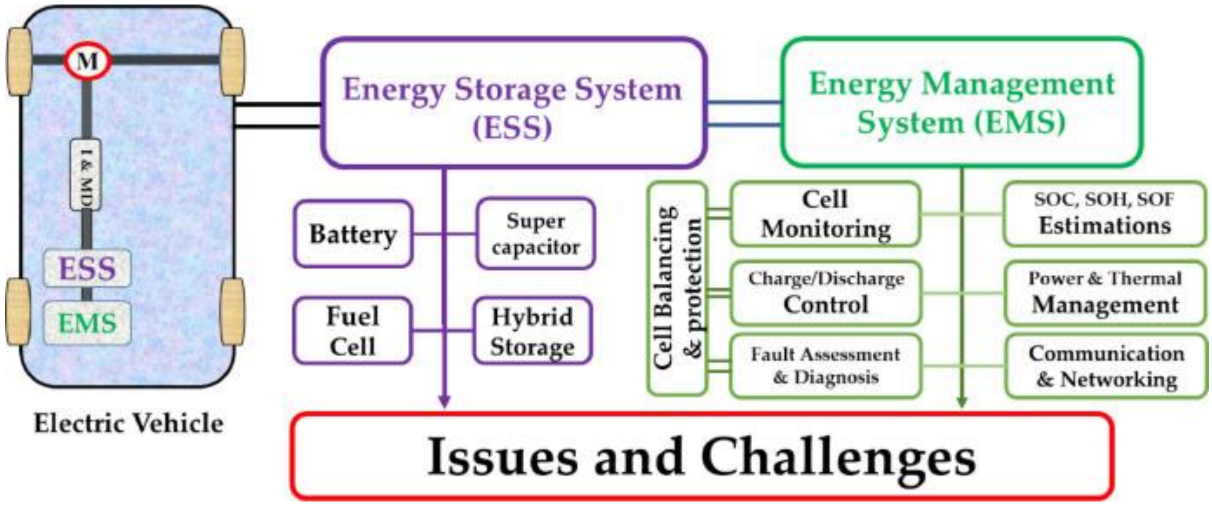

Figure 9: Issues and challenges of Energy storage system in Electric vehicles

CONCLUSION

The advent of electric vehicles (EVs) holds the potential to significantly cut carbon emissions from the transportation sector. Energy Storage Systems (ESS) are a challenge, despite the fact that electric vehicles (EVs) are getting more efficient and lasting longer. There is a wide variety of ESS alternatives, and the integration of electric vehicles requires cost-effectiveness, efficiency, and safety. This chapter provides information on the technology, classifications, and applications of ESS for electric vehicles (EVs). It provides direction for ESS selection and brings to light aspects that affect longevity. This chapter makes a contribution to a more environmentally friendly future by coordinating EVs and ESS for the purpose of achieving sustainable mobility.

Acknowledgement

This work was supported by the TiHAN-IITH under grant Ref. No. TiHAN-IITH/03/2023-24/369.

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