A Study on Energy Storage System for Electric Vehicle and its Challenges

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ABSTRACT

The evolution of electric vehicle during the last decades and it advantages over the conventional IC engine-based vehicle in terms of various parameters viz. durability, endurance, efficiency has given of an edge in global scenario. In specific it’s several advantages over the fuel-based vehicle, it is lagging in terms of storage handling capability with high specific energy and high specific power which permit for rapid charging to reduce the charging duration. Challenges like cost reduction deployment and sizing of the batteries are again other related issues. In this paper different technology with solution to the challenges such as minimizing the charging time with fast charging solution, reuse of batteries for energy storage and solution to other issue are discussed briefly.

Keywords – EV, BESS, FESS, Optimal Sizing, V2G

I. INTRODUCTION

The global shift towards sustainable mobility has sparked an unprecedented interest in electric vehicles. This section sets the context by discussing the importance of energy storage systems in EVs and their significance in achieving a milestone in transportation sector.

In the ever-evolving world of electric vehicles (EVs), one critical aspect stands out as the cornerstone of their success: energy storage systems. As we race towards a sustainable and greener future, the demand for efficient and reliable EVs is at an all-time high, and the spotlight is firmly on energy storage technologies that can revolutionize the way we drive.

In an era where sustainable mobility is steering the course of innovation, the spotlight falls unequivocally on electric vehicles (EVs) as the vanguards of a cleaner and greener future. As the automotive landscape reshapes itself with electrifying fervour, the quest for an optimal energy storage. Different energy storage technologies such as battery energy storage system, flywheel storage system, ultracapacitors etc. cost reduction, battery sizing, deployment and the impact of grid capacity on battery performance on these parameters has come up as challenges to battery performance and efficiency.V2G technology is one of the latest technologies which has given an edge over the conventional IC engine-based vehicle so far as bi-directional power flow to grid is concerned.

Electric vehicles (EVs) are increasingly being adopted for several reason, those are environmental impact of conventional fossil -fuel- powered faces a major hurdle-energy storage is exploring innovative approaches like solid- state batteries and lithium - sulphur batteries. Energy efficiency storage system plays a major role in electric vehicle. To address these challenges, researchers aiming to enhance energy density and safety while reducing costs. Additionally, research on alternative materials, such as graphene and silicon anodes, promises to revolutionize EV battery capabilities.

II. ENERGY STORAGE SYSTEM

The automotive industry is undergoing a remarkable transformation with electric vehicles (EVs) emerging as a leading contender for the future transportation. One of the crucial factors determining the success of EVs is the performance, efficiency and reliability of their energy storage system. This paper depicts the latest advancements in the energy storage technologies for EVs, focusing in the development of the innovation solution to enhance performance, range, and overall performance.
Energy storage system can be categorized into

A. Mechanical Storage System

Certainly, let's delve into the theory behind mechanical energy storage systems (MESS) and explore how they function, particularly in the context of electric vehicles. Mechanical energy storage systems store energy in the form of kinetic or potential energy, which can be released and harnessed when needed. One of the most notable examples of MESS is the flywheel, which will be the primary focus in this discussion.

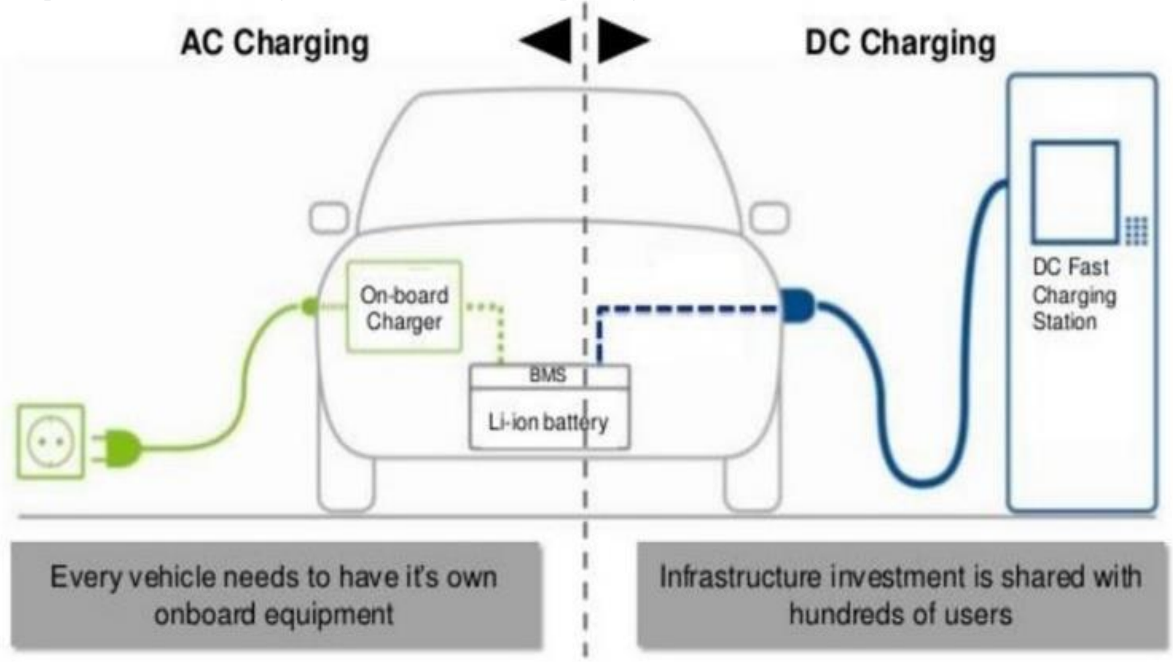

Fig-1, Charging station for EV

Fly Wheel Energy System

It is a mechanical device which storage the energy in the form of rotational kinetic energy. Flywheel energy storage (FES) is a fascinating technology that uses the principles of physics to store and release energy in a smart and effective way. This innovative approach holds promise in various applications, ranging from storing energy for the electricity grid to transportation systems, offering many advantages over regular energy storage methods. Its core, FES revolves around the idea of rotational energy. The system works by speeding up a flywheel a spinning wheel to a high speed, thus storing energy in its spinning motion. This stored energy can then be released when needed, causing the flywheel's speed to slow down while giving out the stored energy to the connected devices or systems. This process is based on the basic rule of saving energy, making sure that the energy put into the system is never lost but instead changed and used.

The main parts of FES are important. A typical FES system consists of a flywheel supported by bearings and connected to a motor-generator. The use of magnetic bearings instead of regular mechanical bearings helps reduce friction and energy loss, improving how well the system works. Also, the growth of FES technology has led to the making of advanced systems that use strong but light materials for the flywheel, making it even better at storing energy while keeping its weight low.

The special features of FES systems make them different from other energy storage methods. Especially, FES systems last a really long time, even decades, with very little need for repairs. The specific energy how much energy is stored in each kilogram of the system is impressively high, ranging from 100 to 130 watt-hours per kilogram (Who/kg). This high specific energy, along with the ability to give out a lot of power quickly, lets FES move energy around fast and react quickly when the amount of energy needed changes.

But FES also has some challenges and things we need to think about. The risk that flywheels might break and cause problems reminds us how important it is to be really careful with their design and upkeep. Making flywheels that can handle high speeds and manage possible problems is crucial to make sure people stay safe and the system stays working.

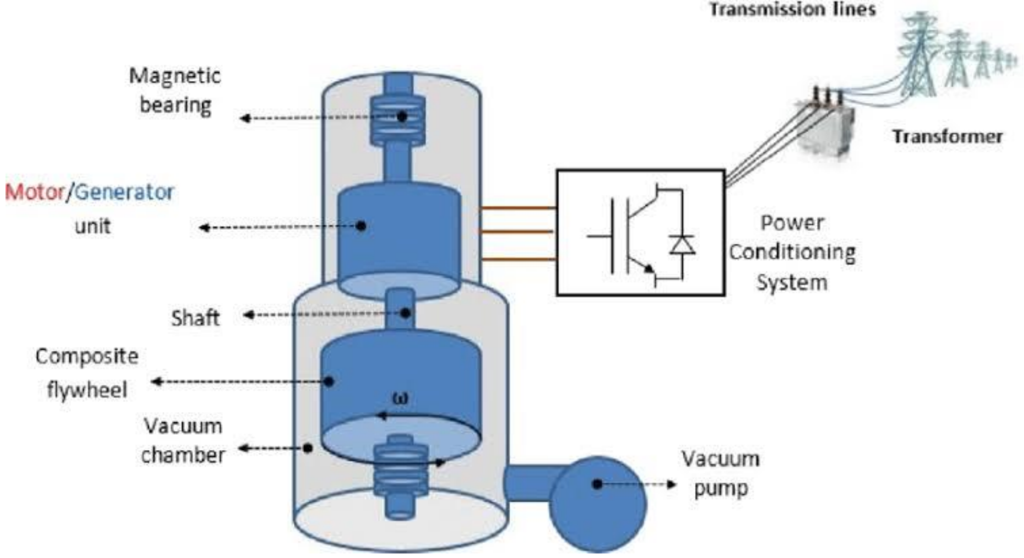

Fig-2, Flywheel storage system

To sum up, flywheel energy storage is a really interesting and useful technology that looks really promising for energy storage and management. Its different way of using spinning wheels to store and release energy has caught the attention of many areas, from transportation to storing energy for the electricity grid. With good things like using energy well, lasting a long time, and reacting quickly, FES gives us a nice option instead of the usual energy storage ways. As technology gets better and we learn more about safety, flywheel energy storage is all set to play a bigger and bigger part in making a better future with sustainable energy solutions.

B. Electro chemical storage system

An electrochemical storage system is a technology used to store electrical energy in chemical form. It is commonly found in devices like batteries and fuel cells. In this system, electricity is converted into chemical energy during charging and then reversed during discharge to produce electricity again. This process involves chemical reactions within the system, allowing it to store and release energy as needed. These systems are vital for storing renewable energy from sources like solar and wind, ensuring a consistent power supply even when the sun isn't shining or the wind isn't blowing. They also power portable devices like mobile phones and laptops, making them an integral part of modern life by providing efficient and reliable energy storage solutions.

Energy storage devices are becoming increasingly crucial for our tech-driven society's high energy demands. We need effective ways to store electricity for times of high demand and for portable devices like electric cars. Two main players in this field are batteries and supercapacitors. Lithium-ion batteries are particularly popular because they're light, affordable, and offer good energy capacity, long lifespan, and no memory effect. They consist of parts called cathodes and anodes held together by materials like PVDF, which has excellent stability and strength.

Another type, PVDF-Tref, has shown promise as a material to bind certain battery components. It was found that certain forms of PVDF can help lithium ions move more freely, enhancing battery performance. This can lead to safer and more durable batteries. Moreover, PVDF is used to create separators that allow ions to move between battery parts. Different forms of PVDF can make these separators even more effective. In summary, PVDF plays a crucial role in developing improved energy storage solutions.

Lead -Acid Battery

Usually lead acid battery comprises of a negative electrode made of porous lead and spongy in nature. The lead is porous to accommodate the formation and dissolution of lead. The positive electrode consists of lead oxide. Two electrodes are immersed in an electrolytic solution of sulfuric acid(H_2SO_4) and water. The reversible chemical reaction which takes places is given below.

$$PbO_2 + Pb + 2H_2SO_4 \underset{charge}{\overset{discharge}{\Longleftrightarrow}} 2PbSO_4 + 2H_2O$$

The charging and discharging reactions are

$$Pb + SO_4^{2-} \underset{charge}{\overset{discharge}{\Longleftrightarrow}} PbSO_4 + 2e^-$$

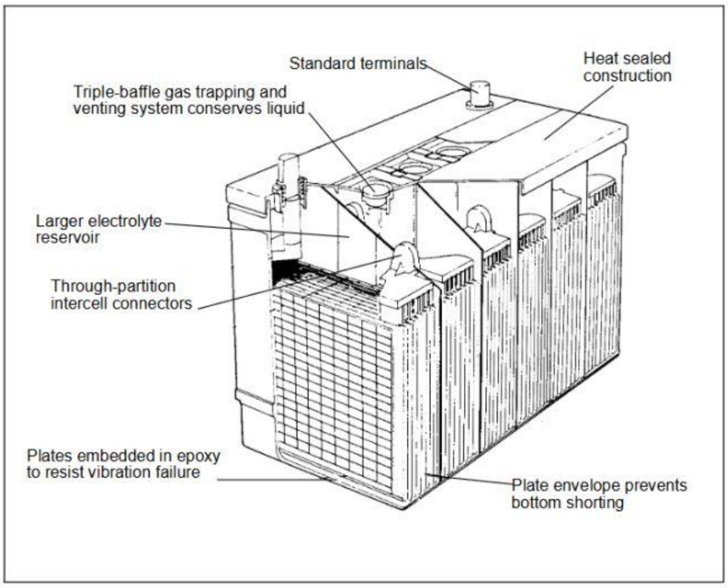

Fig-3, Lead-Acid Battery

C. Charging Infrastructure and EV Integration

EV Charging Infrastructure Expansion - In recent years, the EV charging infrastructure has experienced rapid expansion, encompassing various types of charging stations. Level 1 chargers offer standard AC charging through household outlets, while Level 2 chargers provide faster AC charging and are commonly found in public areas. High-speed DC fast chargers offer swift charging times and are strategically positioned along highways and urban centres for convenient long-distance travel.

Integration Challenges and Solutions

Integrating EV charging infrastructure presents challenges that span technical, economic, and regulatory aspects. Balancing energy demand during peak periods necessitates smart grid integration and load management to prevent strain on the power grid. Additionally, interoperability standards are crucial to ensure compatibility among different charging networks and EV models.

Policy incentives, tax credits, and private investments have driven the expansion of charging networks. Governments worldwide are supporting research and development for innovative solutions such as wireless charging and bi-directional charging, enabling EVs to discharge energy back into the grid during high demand.

Future Prospects

The future of EV charging infrastructure is promising, with advancements in battery technology, charging speed, and convenience. Integration with renewable energy sources like solar and wind power enhances the sustainability of EVs. The continued collaboration between governments, industries, and researchers will be pivotal in creating an integrated and user-friendly charging network, accelerating the global shift towards greener transportation.

III. CHALLENGES

One of the primary problems with EVs is their limited driving ranges compared crucial to extend the range of EVs, marking them more practical another problem is the availability of charging infrastructure. Although progress has been made, the lake of a widespread. Fast charging network can lead to range anxiety and to make it more difficult for somebody confidence in adopting EVs as their primary model of transportation the primary problem is centred around the limitation of current battery technologies, mainly lithium-ion batteries, which are widely used in EVs. Although lithium-ion battery has shown significant improvement in energy density and longevity they still face challenges related to cost, charging time and over all energy capacity.

A. Battery life

Battery life span and battery degradation over time is a concern, as it affects the long terms performance and resale value of electric vehicles. Improving battery life span implementing effective recycling and re-purposing strategies are essential to ensure the sustainability of EVs and minimize environmental impact.

Limited Energy Density - Current energy storage technologies, predominantly lithium-ion batteries, suffer from limited energy density. This constraint directly impacts the driving range of EVs and may lead to range anxiety among potential consumers. Developing higher energy density batteries is crucial to extend the driving range and boost consumer confidence in EVs.

Energy Density Predicaments - Contemporary energy storage technologies, typified by lithium-ion batteries, grapple with energy density constraints. These limitations translate into compromised driving ranges, which in turn fuel the apprehension of "range anxiety" among prospective EV buyers. Addressing these energy density issues emerges as a critical step in boosting consumer confidence in EVs.

Charging Conundrums - The intricate challenge of establishing a comprehensive and accessible charging infrastructure is a major hurdle to EV adoption. Scarce charging stations, especially in remote locales ordering lengthy trips, hamper the practicality of electric vehicles. Developing a network of well-placed, efficient charging stations is imperative to surmount this obstacle.

B. Cost Reduction

Cost Reduction in EV Energy Storage Systems This section discusses the main cost drivers in energy storage systems for electric vehicles. It analyses the cost components of battery technologies and explores recent advancements and research initiatives aimed at reducing the overall cost per kilowatt-hour (kWh) of stored energy. Strategies such as economies of scale, materials innovation, and production process optimization are examined to pave the way for cost-effective ESS solutions.

Innovations in Battery Manufacturing - Advancements in battery production techniques, such as continuous manufacturing and automated assembly, can drive down production costs. Additionally, research into low-cost and abundant materials will contribute to affordable and eco-friendly energy storage solutions.

Economies of Scale and Manufacturing Innovations - Achieving cost parity with traditional vehicles demands economies of scale in battery production. Innovations in manufacturing techniques, such as continuous improvement of assembly processes and advanced automation, can significantly lower production costs and enhance affordability.

Material Efficiency and Recycling - Enhancing the efficiency of materials used in battery manufacturing can reduce costs. Moreover, investing in battery recycling and second-life applications can recover valuable materials, reducing the need for raw resources and decreasing the overall cost of battery production.

Cost of EV Energy Storage Systems - The high cost of energy storage systems hinders EV adoption. Mass production is key to reducing costs. Governments and industries should promote the scale production of EVs and energy storage systems, leveraging economies of scale to lower manufacturing and material costs. Exploring new materials like lithium iron phosphate (LiFePO4) can reduce costs while improving battery lifespan.

Material Innovation to minimize the cost - Investment to develop cost-effective materials with similar or better performance characteristics than current battery materials may be an upcoming solution to minimize the cost. Materials like lithium iron phosphate (LiFePO4) are less expensive and have longer lifespans compared to traditional lithium-ion materials to overcome the challenges of greater price so far as cost is concerned.

Economies of Scale - Mass production of EVs and energy storage systems to achieve economies of scale, increased production volumes can lead to reduced costs for both manufacturing and materials.

C. Optimal Sizing

Sizing Optimization of Energy Storage Systems Optimal sizing of energy storage systems is crucial for maximizing performance while minimizing costs. This section explores the factors affecting the determination of the ideal ESS capacity for electric vehicles. It investigates methodologies for sizing ESS based on driving patterns, vehicle characteristics, and charging infrastructure. Furthermore, the benefits of advanced energy management algorithms and predictive control techniques for efficient sizing are explored.

Tailored Design for Specific EV Models: Different electric vehicle models have varying energy requirements based on factors such as size, weight, and intended use. Customizing energy storage systems for specific models allows for better integration and improves overall efficiency.

Balancing Energy Density and Weight: Energy density refers to how much energy can be stored in a given volume or weight. While higher energy density enables longer driving ranges, it often comes with increased weight. Striking the right balance between energy density and weight is essential for achieving optimal performance and safety in electric vehicles.

Weight Considerations: Striking a balance between energy density and weight is critical. Lightweight energy storage systems can extend driving range and improve overall vehicle efficiency.

Power converter capacity (in MW) is the primary sizing consideration for frequency regulation and black start Battery Energy Storage System (BESS) grid applications. These applications require fast response times and rapid changes in power output to stabilize the grid during fluctuations in supply and demand. Power converters play a crucial role in efficiently converting the DC power stored in batteries to AC power that can be injected into the grid.

Example:

$$BESS\ Capacity\ [MW] = Frequency\ gain\left[\frac{MW}{Hz}\right] \times Governor\ drop[\%] \times System\ frequency\ [Hz]$$

e.g., $41.667\,\frac{MW}{Hz} \times 4\% \times 60\ Hz = 100MW$

$$BESS\ Capacity\ [MWh] = \frac{power\ required\ [MW] \times duration\ required[h]}{depth\ of\ discharge\ [\%] \times battery\ efficiency[\%]}$$

e.g., $\frac{100\ MW \times 4h}{80\% \times 95\%} = 263MWh$

BESS = battery energy storage system, h = hours, Hz = hertz, MW = megawatt, MWh = megawatt-hour

Enhanced Battery Technology: Invest in research and development of new battery technologies that offer higher energy density, longer lifespan, and faster charging capabilities. Solid-state batteries, for example, have the potential to overcome the limitations of lithium-ion batteries and provide longer driving ranges.

Vehicle-to-Grid (V2G) Integration: Integration of V2G technology which allows EVs to feed excess energy back into the grid during peak demand is an upcoming solution. This not only provides an additional revenue stream for EV owners but also helps stabilize the grid. By implementing these solutions, the EV industry can address the challenges related to driving range, battery life, cost reduction, and optimal sizing of energy storage systems. These strategies will contribute to making EVs more practical, sustainable, and appealing to a wider range of consumers.

D. Deployment

The deployment of electric vehicle (EV) storage systems faces critical challenges, primarily cantered around scalability and grid integration. The rapid growth of the EV market strains the power grid's capacity, raising concerns about potential grid overload during peak demand periods. The integration of EV storage systems with the existing power grid presents grid instability risks. The fluctuating power injections from EVs can lead to voltage variations and undermine overall grid reliability.

Lack of standardization poses hurdles to the deployment of EV storage systems. Variability in charging connectors and protocols undermines user convenience and confidence in adopting EVs, hindering seamless grid interaction.

To address scalability challenges, innovative approaches such as smart charging strategies can offer solutions. Implementing advanced metering and load management techniques allows for optimized charging schedules, while integrating demand response mechanisms facilitates real-time adjustment of charging rates based on grid conditions. These strategies alleviate grid congestion during high-demand periods, ensuring a more equitable distribution of power load.

Standardization plays a crucial role in streamlining EV storage deployment. Advocating for a standardized framework for charging connectors and protocols enhances user experience and encourages widespread EV adoption. Furthermore, standardized infrastructure simplifies the integration of EV storage with the grid, promoting smoother and more efficient interaction between the EVs and the power grid.

CONCLUSION

The evolution of energy storage systems for electric vehicles holds tremendous promise for a sustainable and greener transportation future. By addressing cost reduction, optimal sizing, deployment challenges, and performance enhancement, we can overcome existing barriers and accelerate the adoption of electric mobility. Collaboration between governments, industry players, researchers, and consumers are imperative in fostering innovation and driving progress in the realm of energy storage systems for electric vehicles. Embracing electric mobility is not just an option; it is a collective responsibility to secure a cleaner and more resilient world for generations to come.

In conclusion, the successful integration of energy storage systems in electric vehicles is essential for building a sustainable and cleaner future. By optimizing sizing, addressing challenges, reducing costs, and enhancing performance, we can surmount current barriers and propel electric mobility forward. Governments, industries, researchers, and consumers must work together to create an enabling environment for the mass adoption of EVs, promoting sustainable transportation and curbing carbon emissions. Embracing electric mobility is not merely an option; it is an imperative step towards a greener and more resilient future for generations to come.

FUTURE SCOPE

Enhancement of efficiency of the battery during the experimental hours can be derived through safe operation of EV devices integrating battery management system (BMS), longer duty cycle, battery sizing and cyclic-life. The future of energy storage systems for electric vehicles holds immense potential for further advancements. Ongoing research and development in battery technology are expected to yield batteries with higher energy density, faster charging capabilities integrated to grid with V2G technology for bidirectional power flow with better load frequency control using optimization model, and longer lifespan and durability These advancements will address current challenges, such as range and charging times, making electric vehicles even more competitive with traditional vehicles.

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