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Silver-Ion Solid-State Battery Swapping System in Electric Vehicles

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Abstract: Electric vehicles (EVs) are one of the most efficient technologies for green and environmentally friendly transport systems. An energy storage system is the key element for the sustainable economic and ecological use of electric vehicles in the automotive industry. The battery is the key and core part of EVs with battery energy storage. Currently, EVs are based on lithium-ion batteries, which have a shorter life span than silver-ion batteries. As an alternative to recharging vehicles and spending time, this paper suggests the concept of battery swapping with silver-ion batteries for EVs. It is important to select batteries that ensure high power density, stable and high peak power output, high-energy efficiency, lightweight construction, long-lasting durability, safety, reliability, fast charging and environmental friendliness. Novel-based batteries and All Solid-State Batteries (ASSBs) can be the future generations of energy storage technology. Batteries and the battery management system are two vital elements controlling safety, reliability and proper functioning of energy storage systems. Cell balancing is an efficient way to increase energy efficiency, prolong battery life and support the goals of electrification. A smart battery management system promotes further development and makes a sustainable component of decentralised energy systems.

Keywords: *Electric Vehicles, Green Technology, Lithium-Ion Batteries, Silver-Ion Batteries, Solid State Batteries, Battery Swapping.*

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I. INTRODUCTION

The sudden escalation in fuel costs and heightened knowledge about the adverse effects of the use of fossil fuels on the environment have contributed to the movement towards the use of electric cars. Literature indicates that electric cars can be regarded as some of the best modes of transport that can reduce carbon footprint and dependence on fossil fuels.. Lithium-ion batteries are currently utilised by almost all electric vehicles. Although lithium-ion batteries have played an important role in making electric cars, some challenges are yet to be addressed when using such batteries for power supply in EVs. These include slow charging speed, overheating, decreased lifespan, and low range. To address these problems, this project introduces the idea of the Solid-State Silver-Ion Battery Swapping System for Electric Vehicles. Silver-ion batteries are a highly advanced form of battery in which silver ions (Ag^+) are transferred from the anode to the cathode by passing through a solid electrolyte rather than a liquid one. The principle of solid-state technology involves using solid matter for transferring, storing, and controlling electric current, thereby making the solid-state battery safe, efficient, and thermally stable in comparison to traditional lithium-ion batteries. These batteries are likely to offer a much greater driving distance along with an ultra-rapid charging capacity in 10-20 minutes. Yet, despite having rapid charging capability, EV drivers face downtime due to charging during long drives. To address this issue, the idea of using Battery Swapping Systems has been proposed. Rather than waiting for the battery to get charged, the discharged battery can be replaced with a charged battery, which takes only minutes. This technology not only cuts down on waiting time but also improves user convenience and makes electric vehicles more effective. The solution that we are proposing includes a combination of solid-state silver-ion batteries and a smart system of battery swapping [2], [7]. The Battery management system (BMS) would always monitor the battery's performance, temperature, charging percentage, etc. In this way, the status of the battery would be communicated to the driver through a display. Also, a Power management system (PMS) will be incorporated to manage energy distribution and maximise the lifespan of silver-ion batteries. This system of battery swapping can be utilised in many electric transportation devices like electric bikes, electric scooters, electric cars, buses, and electric auto rickshaws.

II. LITERATURE REVIEW

It is now considered that electric vehicles can be regarded as one of the most promising means for developing a sustainable and eco-friendly transportation system. Because of the increase in fuel costs and pollution caused by the transportation industry, battery improvements have become quite significant. Lithium-ion batteries have been identified as an important component for EVs due to high energy density and long-life battery cycles. However, despite its efficiency, the lithium-ion battery faces several challenges such as long charging times, thermal runaway, overheating, safety problems, inadequate driving ranges, and battery deterioration [3], [5], [6].

The invention of solid-state battery technology is among the most advanced battery technologies compared to conventional lithium-ion batteries. Instead of using liquid electrolyte batteries, in solid-state batteries, solid electrolytes play the role of allowing ion movement. It was observed that solid-state batteries provide high energy density, longer lifespan, mechanical stability, and prevent fire hazard. Moreover, researchers suggest that solid-state batteries will facilitate quick charging of EVs [1], [2]. Recent developments regarding the application of silver-ion conducting solid-state batteries have been reported in several research studies. Silver-ion batteries make use of silver ions (Ag^+) as charge carriers through solid electrolytes instead of liquid electrolytes [1]. The preliminary experiments on silver-ion conducting solid-state batteries revealed their high effectiveness with good ionic conductivity and chemical stability, as well as applicability for electrochemical devices.

Recent improvements in silver-based solid-state electrolytes are discussed in the literature. Stability of superionic conductors in silver-based solid-state electrolytes was examined electrochemically [1].

The study reported that silver-ion conductors have a significant potential for future solid-state batteries due to high ionic conductivity and superior electrochemical properties. Some recent papers have focused on the contribution of silver to the performance of all-solid-state batteries. Some researchers suggested silver-doped electrolytes and decorated silver electrodes to enhance metal plating, cycle life, and battery efficiency [1], [2]. It was found out that silver based interfaces could enhance ion transfer, reduce dendrite formation, and increase battery safety.

Besides battery chemistry, another area of interest is the charging downtime issue in EVs solved by using Battery Swapping Systems [7], [9]. In battery swapping systems, the discharged battery is replaced with a completely charged one in just a couple of minutes, thus reducing the considerable charging waiting time required for typical charging methods [9]. According to studies, battery swapping systems increase efficiency, reduce congestion in charging stations, and help operate EVs continuously [7]. Smart integration of BMS and PMS further enhances efficiency, monitoring, thermal management, cell balancing techniques, charging, and longevity of batteries [4], [8].

Current automotive industries and research organisations are actively researching solid-state batteries for commercial purposes in EVs [2]. Companies and research groups from around the world are making great efforts in the research and development of solid-state batteries, which provide much better fast-charging capability, better safety, and greater range than their lithium-ion counterpart batteries [2]. Latest findings show that EV batteries in the near future will have charging times of less than 20 minutes and better lifetime and safety than lithium-ion batteries [1], [2]. While remarkable progress has been achieved in the development of solid-state batteries, there are issues like high production costs, scalability, stability of the electrolyte interface, and commercialisation that need to be overcome [2], [6]. Thus, more research is needed to develop cost-effective, efficient, and environmentally friendly solid-state silver-ion battery systems to be used in the next generation of EVs. The suggested Solid-State Silver-Ion Battery Swapping System can become an innovative solution through integration of silver-ion solid-state batteries and smart battery swapping technology [7], [9].

III. METHODOLOGY

The proposed research presents a Solid-State Silver-Ion Battery Swapping System for Electric Vehicles (EVs) designed to reduce charging downtime, improve battery safety, and enhance the overall efficiency of electric transportation systems. The methodology of this project focuses on the integration of solid-state silver-ion battery technology with an intelligent battery swapping infrastructure supported by Battery Management Systems (BMS) and Power Management Systems (PMS).

➢ *Proposed System Design*

The proposed system consists of an electric vehicle powered by a solid-state silver-ion battery pack connected to a smart battery swapping station. Instead of charging the battery inside the vehicle for a long duration, the discharged battery is removed and replaced with a fully charged battery at the swapping station. The system is designed to minimise waiting time and improve the operational efficiency of EVs. The architecture of the proposed system includes:

- Solid-State Silver-Ion Battery Pack
- Battery Swapping Station Infrastructure
- Battery Management System (BMS)
- Power Management System (PMS)
- Charging and Intelligent Monitoring Unit
- Smart Driver Display Interface for Real-Time Battery Status

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➢ *Working of Solid-State Silver-Ion Battery*

The new type of battery employs silver ions (Ag+) as charge carriers through a solid electrolyte medium. In contrast to regular lithium-ion batteries, which use a liquid electrolyte, solid-state batteries have their electrolyte as a solid substance. Hence, they offer improved thermal stability and safety. Silver ions travel from the cathode to the anode in solid-state batteries and vice versa. This ensures that there is high efficiency in terms of energy and there are no problems such as leaks or overheating. Additionally, solid-state batteries have higher capacity than the common lithium-ion batteries.

➢ *Battery Swapping Process*

It should be noted that the battery swapping technology was developed to greatly minimise downtime in EV charging. The battery swapping takes place in the following order:

- The EV arrives at the automated or semi-automated battery swapping station.
- The Battery Management System performs an automated check on the battery health and charging percentage.
- The discharged silver-ion battery is mechanically unlocked and safely removed from the vehicle chassis.
- A fully charged silver-ion battery is selected from the station repository and installed in the EV.
- The internal diagnostics unit verifies battery compatibility, connection integrity, and safety parameters.
- The EV is cleared for departure and resumes operation within a few minutes.

This linear process significantly minimises user wait times compared to conventional plug-in charging methods.

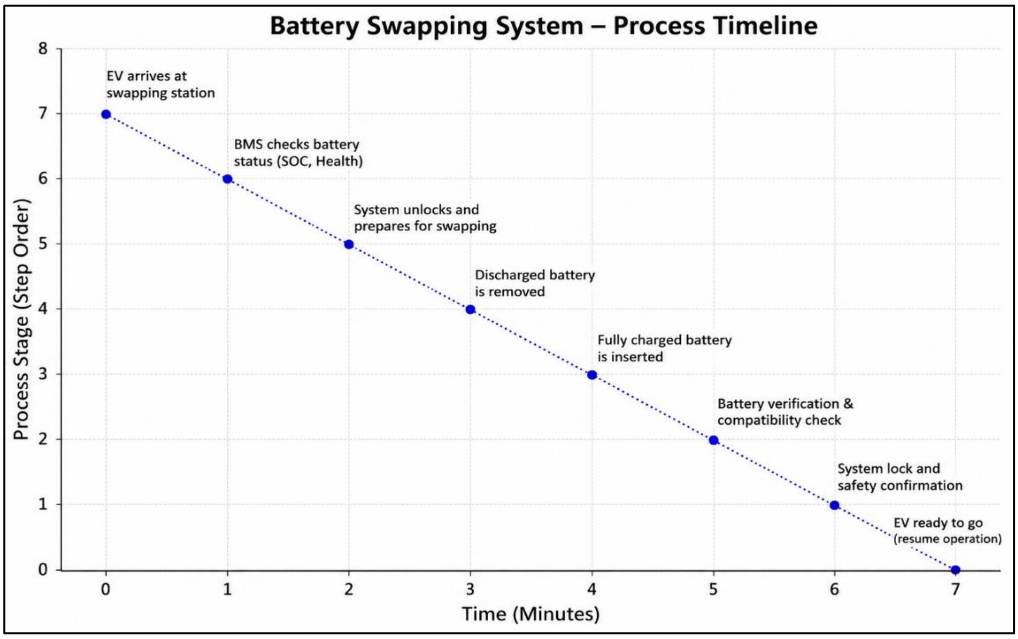

Fig 1 Swapping Timeline

➢ *Battery Management System (BMS)*

The Battery Management System is incorporated for monitoring and controlling the operation of the battery in real-time. Some of its important functions include:

- Monitoring battery cell temperature to prevent thermal runaway.
- Tracking individual cell charging and discharging cycles.
- Measuring real-time battery pack voltage and total current draw.
- Preventing overcharging and destructive deep discharge scenarios.
- Calculating accurate State of Charge (SoC) and displaying battery percentage to the driver.
- Executing intelligent cell-balancing strategies to maintain pack integrity.
- Detecting electrical faults, isolation issues, and operational abnormalities.

➢ *Power Management System (PMS)*

The Power Management System is utilised to optimise energy distribution and maximise battery system efficiency. The PMS actively controls the bidirectional power flow between the battery, vehicle traction motor, and auxiliary sub-systems. It functions to:

- Reduce parasitic energy losses during vehicle idle and running states.
- Maintain highly stable power output across varying load profiles.
- Coordinate with the swapping station grid under energy arbitrage models.

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- Enhance total charging and energy regeneration efficiency.
- Support adaptive power distribution algorithms to improve overall pack lifespan.

➢ *Charging and Monitoring Infrastructure*

There are a number of specific charging stations within the swapping station housing for safely recharging solid-state batteries that have been used up. There is smart monitoring for each battery in terms of its condition, amount of charge remaining, thermal changes, and general health at any point in time during charging.

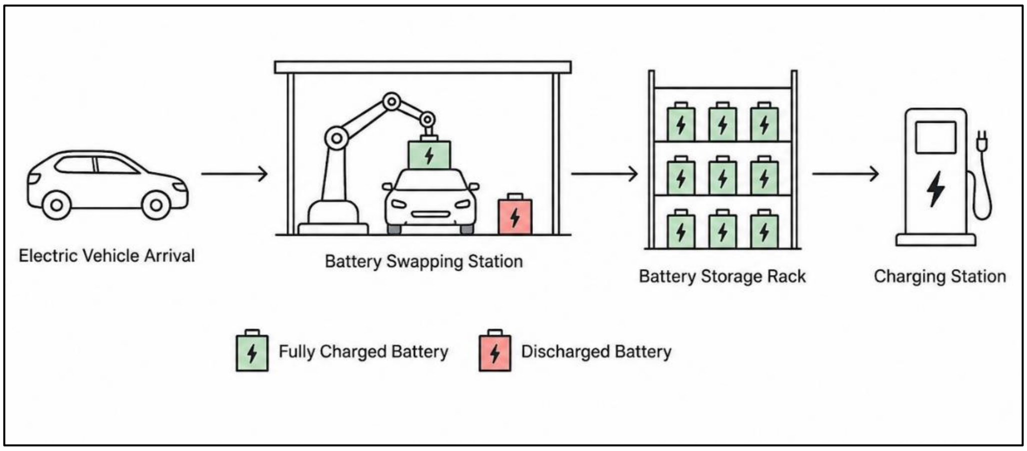

Fig 2 Swapping Process

➢ *Comparative Analysis*

The proposed solid-state silver-ion battery swapping architecture is evaluated against conventional fixed lithium-ion plug-in configurations. The comparative frameworks indicate that the silver-ion solid-state structure yields significantly improved thermal stability, eliminates liquid leakage hazards, and reduces charging downtime from hours to less than five minutes through the station network. Furthermore, the integration of dedicated smart BMS and PMS ensures that cell-balancing and degradation-aware control systems prolong the operational lifecycle of the assets well beyond standard metrics.

IV. FUTURE SCOPE

There is a wide range of potential applications for the suggested Silver-Ion Solid-State Battery Swapping System for Electric Vehicles for sustainable transport and intelligent energy management solutions. Even though the present study mainly addresses the design and integration of silver-ion solid-state batteries within the battery-swapping system, there are certain areas that can be improved upon and researched further. The development of effective silver-ion solid electrolyte materials with higher ionic conductivity, low internal resistance, and electrochemical stability can be addressed by researchers in the future. Nanotechnology and hybrid composite materials can be used to increase battery efficiency and minimise production losses. The study can also involve designing lighter battery casings for vehicles.

Another significant trend that is gaining momentum is the adoption of artificial intelligence and machine learning approaches to ensure intelligent monitoring of battery usage and conducting predictive maintenance operations. Intelligent algorithms will be able to analyse all the necessary information, including the condition of batteries, their charging cycle, variations in temperature, and energy consumption, to identify potential faults that will allow preventing failures. Battery swapping technology can also incorporate IoT and cloud computing tools, ensuring effective communication between automobiles, swapping stations, and central monitoring tools, which will facilitate automated allocation of battery packs, efficient routing, diagnosis, and operation of swapping stations. Finally, future research may involve the study of renewable energy sources used in battery swapping stations, where solar panels and wind power generation equipment can be connected to charging stations.

More study is also needed in the area of efficient robotic battery swap systems in order to further reduce time in replacing batteries, improve safety, and increase efficiency in swapping station operations in busy urban areas. Automation will also minimise human involvement in the process and increase service efficiency. The concept of the system can be extended to buses, logistics vehicles, commercial fleet vehicles, emergency transportation, and industrial use cases of electric mobility systems by implementing wide-range deployment of battery swapping networks, which will help in the swift transition to the electrified public transport sector and decrease vehicle emissions from traffic congestion in metropolitan cities. Production cost analysis, commercial viability analysis, battery recycling technologies, and other economic aspects could also be studied to evaluate costs and benefits related to battery swapping. In addition, recycling of silver-containing batteries could be an environmentally sustainable method for maintaining battery lifecycle and resource savings, and with ongoing advances in technology, the integration of solid-state silver-ion batteries along with an intelligent battery swapping system could become a viable energy source for next-generation high-performance electric vehicles.

V. CONCLUSION

Using of Solid State Silver-ion battery provides EVs with a long lifespan and a long battery backup. The driver doesn't need to worry about battery range because it offers greater range than a lithium-ion battery. Silver-ion batteries can be recycled easily, but recycling lithium-ion batteries is very difficult and can harm the environment.

Silver-ion batteries provide excellent conductivity because using Silver. It has a strong potential to be a future alternative to conventional EV batteries. It can be charged quickly in a short duration of time, so time can be saved.

REFERENCES

[1]. J. Pan, Y. Qiu, Y. Sun, and Z. Wang, "A study on $AgCuO_2$ as ultra-fast charging cathode material for alkaline secondary battery," Journal of Power Sources, vol. 482, p. 228912, 2021.
[2]. Ahuja, J., Dawson, L., and Lee, R., A circular economy for electric vehicle batteries: driving the change. Journal of Property, Planning and Environmental Law, 12(3), 235-250, 2020.
[3]. M. Almadani, O. E. Oni, and O. M. Long, "Comparison of Battery Chemistries for Electric Vehicle Applications," International Journal of Energy Research, vol. 2023, pp. 1–12, 2023.
[4]. A. Safari, H. Sorouri, A. Oshnoei, and F. Blaabjerg, "A State-of-the-Art Review on Battery Cell Balancing Strategies," IEEE Transactions on Power Electronics, vol. 36, no. 8, pp. 9112–9127, 2021.
[5]. M. Sarker, G. Ramasamy, Marranalqwaid, and M. S. M. Mohammedharam, "Performance Evaluation of Second-Life EV Batteries for Off-Grid Solar Energy Storage System," Sustainability, vol. 14, no. 3, p. 1234, 2022.
[6]. E. Hossain, D. Murtaugh, J. Mody, H. M. R. Faruque, M. S. H. Sunny, and N. Mohammad, "A comprehensive review on second-life batteries: Current state, manufacturing considerations, applications, impacts, barriers & potential solutions, business strategies, and policies," IEEE Access, vol. 7, pp. 13672–13692, 2019.
[7]. X. Chen, Y. Yang, J. Wang, J. Song, and G. He, "Battery Valuation and Management for Battery Swapping Station with an Intertemporal Framework," IEEE Transactions on Smart Grid, vol. 12, no. 4, pp. 3122–3133, 2021.
[8]. R. Li, Z. Chen, Z. Zhang, R. Guo, Z. Sun, J. Yao, and J. Ma, "Degradation-Aware Model Predictive Control for Battery Swapping Stations under Energy Arbitrage," IEEE Transactions on Transportation Electrification, vol. 9, no. 1, pp. 445–457, 2023.
[9]. G. S. Lakshmi, "Review on Electric Vehicles Battery Swapping Technology," International Journal of Electrical and Electronics Engineering, vol. 8, no. 2, pp. 15–22, 2020.