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A COMPREHENSIVE ANALYSIS OF ISOLATED AND NON-ISOLATED CONVERTER TOPOLOGIES AND FAST CHARGING TECHNOLOGIES FOR HYBRID ELECTRIC VEHICLES

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Abstract - Electric vehicles (EVs) are a promising solution for future transportation systems due to their significant role in reducing carbon emissions, making them a central focus of research and development efforts. One crucial aspect of EVs is rapid charging technology, which aims to deliver refuelling experiences comparable to traditional gasoline cars. This article delves into the current state of electric vehicle charging infrastructure, with a particular emphasis on the importance of rapid charging technology to meet the present and future refuelling demands of EVs. It presents a comparative analysis of different DC-DC converter topologies for both battery electric and plug-in hybrid vehicles, considering factors such as performance, output power, current and voltage ripples, conduction loss, recovery loss, switching frequency loss, reliability, durability, and cost. Additionally, the article explores the architecture, advantages, and disadvantages of AC-DC and DC-DC converter topologies for rapid charging stations. Moreover, the study addresses critical issues and challenges associated with direct current rapid charging in electric vehicles. Finally, the article offers valuable technical insights and contributions to the ongoing development of electric vehicle systems. In essence, this article highlights the environmental benefits of electric vehicles and their growing popularity, emphasizing the need for advanced rapid charging technology while providing a comprehensive analysis of related technologies and challenges.

Key Words: Power output, Current fluctuations, Voltage fluctuations, Voltage fluctuations, Conductive losses, Recovery inefficiencies, Switching frequency-related inefficiencies, Dependability, Longevity, Economic considerations, AC-DC converter configurations, DCDC converter designs.

1.INTRODUCTION

In recent decades, electric vehicles (EVs) have witnessed a surge in popularity due to their outstanding performance, efficiency, and environmental advantages. These EVs are primarily battery-powered and have the unique advantage of being chargeable through sustainable energy sources like solar and wind power. This sustainability aspect positions EVs as a greener and eco-friendly alternative to traditional gasoline-powered vehicles. EVs produce no tailpipe emissions, contributing significantly to curbing air pollution and mitigating greenhouse gas emissions. This is a crucial step in combating climate change and enhancing air quality. Operating EVs is far more economical compared to conventional vehicles, thanks to the efficiency of electricity as a fuel source. EV owners can potentially save hundreds or even thousands of dollars annually on fuel costs. EVs boast simpler mechanical components compared to their internal combustion engine counterparts, resulting in lower maintenance requirements and reduced chances of breakdowns, translating to cost and time savings. EVs offer instantaneous torque, delivering impressive acceleration. They also provide a quieter and smoother driving experience, setting them apart from their noisy, gas-powered counterparts.

A emerging green technology with significant promise for the future is biobatteries. These innovative batteries harness biological materials to generate electricity. While still in the early stages of development, biobatteries hold the potential to outshine current metal lithium batteries in terms of environmental sustainability. They can be crafted from renewable resources like sugarcane and corn and are recyclable or compostable at the end of their life cycle. Furthermore, the automotive industry's surging energy demand can no longer rely on traditional energy sources due to rising costs, pollution concerns, and resource limitations. To address this, renewable energy sources such as solar and wind power are viable options to meet this growing energy demand. However, the intermittent nature of these renewable sources poses a challenge as they may not always produce power when needed. Energy storage solutions become crucial in this context, allowing the storage of excess electricity generated by renewables for later use, including charging EVs. Electric vehicles are poised to be a transformative force in the realm of transportation, with their numerous benefits, including emissions reduction, cost efficiency, minimal maintenance, and stellar performance. As the world shifts towards a more sustainable future, electric vehicles are poised to play a pivotal role in redefining the way we travel. Additionally, your introduction underscores critical points such as the need to decarbonize transportation and improve air quality, the significance of accurate carbon dioxide emission measurement, the role of CO2MPAS methodology in this context, the driving forces behind EV adoption, and the influence of manufacturer subsidies in fostering EV adoption.

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2. LITERATURE REVIEW

In a recent publication by Dupont et al. (2023), the focus was on the most progressive advancements in the medical field over the past decade, particularly highlighting the innovative robotic equipment. A standout development in this realm is the Raven-II platform, designed for collaborative research in surgical robotics. This platform features dual 3-DOF spherical positioning systems that accommodate swappable four-DOF instruments. Notably, the Raven II software is based on open standards like Linux and ROS, streamlining software development for improved efficiency (Hannaford et al., 2019). The continued evolution of medical robotics holds the potential to transform healthcare delivery, with the Raven-II platform poised to expedite the creation of new surgical robots. Embracing open standards may also make medical robots more cost-effective and accessible [1]. Hybrid electric vehicles (HEVs) represent a fusion of internal combustion engines (ICE) and electric motors to propel the vehicle. The power converter assumes a pivotal role within the HEV powertrain, responsible for adapting voltage and current from the battery and ICE to match the electric motor's requirements and the vehicle's electrical system. Two primary categories of power converters are prevalent in HEVs: isolated and non-isolated converters (M. H. Rashid, Power electronics: circuits, devices, and applications, 2004) [2]. An in-depth exploration of these converters is available in "Isolated and non-isolated DC-DC converters for electric vehicle charging: A review" by J. R. Fernandes, A. C. Moreira, I. J. da Silva, and B. J. Cardoso, published in IEEE Transactions on Industrial Electronics (2019) [3].

Optimization techniques have been developed to enhance the efficiency and performance of EV charging systems. Some common strategies include dynamic pricing, vehicle-to-grid (V2G) technology, and smart charging algorithms. These techniques help reduce peak demand, balance the grid, and optimize charging based on factors such as renewable energy availability and electricity cost. The rapidly evolving EV technology landscape introduces new charging methods and standards that harmonize charging protocols for global accessibility [4]. Electric vehicles (EVs) are gaining popularity due to their multitude of advantages over traditional gasoline-powered vehicles. These benefits encompass zero emissions, cost savings, reduced maintenance, and superior performance. Notably, regenerative braking technology plays a crucial role in enhancing EV efficiency and range. It converts the vehicle's kinetic energy into electrical energy, which is then stored in the battery. Modified non-isolated bidirectional DC-DC converters are emerging as a promising solution for regenerative braking in EVs, offering high efficiency, power density, and cost-effectiveness, albeit with certain challenges such as noise and safety concerns [5].

3. METHODOLOGY:

Hybrid electric vehicles (HEVs) use a combination of an internal combustion engine (ICE) and an electric motor to power the vehicle. The power converter is a key component of the HEV powertrain, responsible for converting the voltage and current from the battery and the ICE to match the requirements of the electric motor and the vehicle's electrical system.

3.1 Isolated Converter Configuration:

Isolated converters use a transformer to isolate the battery and the ICE from each other. This can be done using a variety of transformer topologies, such as a two-winding transformer, a three-winding transformer, or a high-frequency transformer. The methodology for designing and implementing an isolated converter configuration in an HEV is as follows:

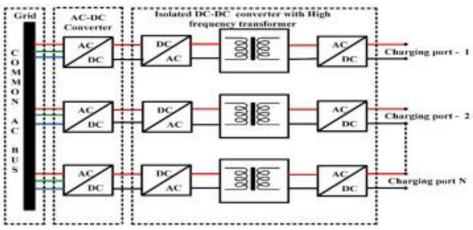

Fig:1 AC bus bar [1].

Select the appropriate transformer topology. The choice of transformer topology will depend on the specific requirements of the HEV, such as the voltage and current requirements, the operating frequency, and the cost and size constraints Design the transformer. The transformer design will involve calculating the core size, the number of turns on the primary and secondary windings, and the winding wire gauge.

3.2 Non-isolated Converter:

Non-isolated converters do not use a transformer to isolate the battery and the ICE from each other. This makes them simpler and less expensive to implement than isolated converters. However, it also means that they offer less safety and noise reduction benefits. The methodology for designing and implementing a non-isolated converter configuration in an HEV is as follows: Select the appropriate converter topology. There are a number of different non-isolated converter topologies that can be used in HEVs, such as the Buck converter, Boost converter, Buck-Boost converter, and Cuk converter [3]. Design the converter circuit. The converter circuit will include the switches, diodes, and capacitors required to implement the chosen converter topology the appropriate control scheme. The control scheme will be responsible for regulating the voltage and current output of the converter. Implement the converter circuit and control scheme. The converter circuit can be implemented using a variety of power electronics components, such as MOSFETs, IGBTs, and diodes. The control scheme can be implemented using a microcontroller or a dedicated IC.

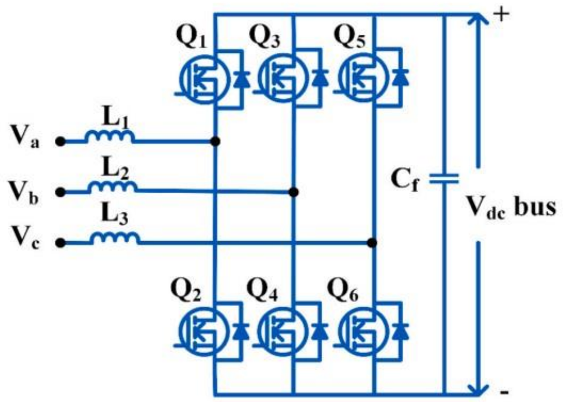

Fig:2 Three phase boost converter without a bridge [3].

3.3 Fast Charging Technology:

Fast charging technology can be applied to hybrid electric vehicles (HEVs) using either isolated or non-isolated converter configurations. A prevalent and effective form of fast charging technology employed in HEVs is the bi-directional DC-DC converter. This versatile device is capable of charging the vehicle's battery rapidly by converting the high voltage output from the internal combustion engine (ICE) into a lower voltage that aligns with the battery's requirements. Additionally, bi-directional DC-DC converters can discharge the battery to supply power to the vehicle's electrical system, especially when the ICE is inactive. The process of designing and implementing a bi-directional DC-DC converter for fast charging in an HEV typically involves the following methodology:

3.4 charging method:

Electric vehicles (EVs) rely on electric motors powered by batteries, offering a host of advantages over traditional gasoline-powered counterparts. EVs excel in environmental friendliness by eliminating tailpipe emissions, thereby contributing to improved air quality and reduced greenhouse gas emissions. Operating EVs proves highly cost-effective in comparison to gasoline-powered vehicles, thanks to the superior fuel efficiency of electricity. EVs stand out for their simplicity, boasting fewer moving parts than gasoline vehicles. This translates to reduced maintenance needs and enhanced reliability. With instant torque delivery, EVs offer impressive acceleration. Moreover, they provide a quieter and smoother driving experience, distinguishing them from their gasoline-powered counterparts. The slowest method employs a standard household outlet and may require up to 12 hours for a full EV battery charge. Utilizing dedicated charging stations, Level 2 charging significantly accelerates the process, typically completing an EV battery charge in 2-4 hours. The fastest option, DC fast charging, can fully charge an EV battery in 30 minutes or less. These stations are commonly available at public charging points and along highways.

4. CHARGING STANDARDS AND MODES:

There are a number of EV charging standards that have been developed around the world. The most common standards include: Charging standards define the types of connectors and electrical communication protocols that are used to charge electric vehicles (EVs). There are a number of different charging standards in use around the world, and the most common ones include:

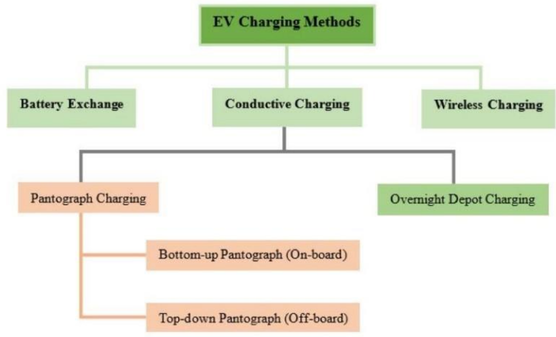

Fig:3 EV charging methods [3]

Combined Charging System (CCS): This is the most common standard in Europe, North America, and China. CCS supports both AC and DC charging, and it can charge an EV battery at a rate of up to 350 kW. CHAdeMO: This is a common standard in Japan and South Korea. CHAdeMO supports DC charging only, and it can charge an EV battery at a rate of up to 90 kW.GB/T: This is a common standard in China. GB/T supports both AC and DC charging, and it can charge an EV battery at a rate of up to 480 kW. Charging modes define the speed at which an EV can be charged. There are three main charging modes: Level 1 charging: This is the slowest type of charging, and it uses a standard household outlet. Level 1 charging can take up to 12 hours to fully charge an EV battery Level 2 charging:

4.1 charging modes:

A variety of charging modes have recently been introduced to address the basic needs of electric vehicles in various contexts. The charging modes defined by the SAE J1772, IEC 61851-1, and GB/T 18487-1 standards are commonly used around the world . The most popular AC slow loading mode is AC Level 1, which can be easily accomplished using the inboard power converter from a household socket. Normally, the Model 1 takes several hours to charge in this situation . A safety mechanism integrated into the cable connecting the EV to the connector is a possible solution to this issue when charging from a domestic socket outlet. When operated through this charging mode, known as Mode 2 (AC Level 2), can reach a power demand of up to 19.2 kW by using a 3Ø voltage AC source. AC quick charging is known as Mode 3. Special power units with control pilot function are needed as EVs are linked to the power grid to resolve changes in AC voltage and frequency values between regions and meet the need for increased charging capacity. With a power level of 400 kW, Mode 4, when used in conjunction with a DC offboard charging unit, is available option. Tesla also specifies the charging mode specifications. According to the most widely used guidelines, Table 2 lists conductive charging device modes.

4.2 Connector for charging:

Various charger plug types configurations are used depending on the charging conditions and modes of various countries. Men nekes connectors of types 1 and 2, which are based on SAE J1772 and IEC 62196-2, are frequently used for AC charging operations in the United States and Europe. Often level 1 and level 2 connectors are mostly used for chargers. Combined Charging System (CCS) connectors use both the Type 1 and Type 2 charging pins and two most electric vehicle users in the world use the GB/T234 socket. The CHAdeMO connector, made by Tepco, became the official Japanese DC charger standard. There are two main pins for sharing of power and one for touch. The communication protocols CAN is used for GB/T and CHAdeMO, while PLC is used by the others. In actuality, Tesla offers a proprietary cable which can support AC and DC in the charging stations of Tesla only. The proprietors will also obtain an adaptor for the Tesla charger that enables their cars use of category 1 connector charging points. Fig. 1 summarizes the key charging outlets for electric car connectors. The two objectives of energy consumption and battery loss are balanced in the cost function by a weighting factor that changes in real-time with the operating mode and current state of the vehicle.

4.3 Charging system:

EV charging systems typically have several power outlets, inverters/converters, and an internal battery. Fig. 2 depicts a conventional green energy-powered grid-connected charging device. Renewable technology can be used to charge EVs and excess power is sent converters/Inverters to grid. Combine various sources of energy to power electric vehicles with a common power source.

Fig:4 Charging systems of IEC DC [1]

The battery management system (BMS) controls battery resources and communicates with the battery. Then it shows commercially available of OFF-board EV battery charger and Table 4 shows specification of commercially available EV battery charger.

4.4 Converter topologies for fast charging:

➢ AC-DC converter for quick charging:

The AC bus architecture as shown in Fig. 3, the Fast-Charging Architectural design includes high-frequency transformers stages for AC-DC conversion and, while the dc bus design stage low-frequency transformer includes a specific AC-DC conversion stage. According to the SAEJ1772 standard, 600 v and 550 A of dc voltage in fast charging to charge the electric car in less than 10 min, the electric vehicle should be charged, and a quick charger should be put outside the vehicle

➢ Bridgeless 3Ø boost converter:

The 3Ø boost ac/dc full-bridge topology for the power conversion of higher power factor values is corrected in the converter. Any changes in load and phase resistances alter the sliding mode regulation for the optimal output voltage and any uncertainties, resulting in apower factor value close to unity. This topology explores the application of hysteresis regulation with frequency constant to a 3Ø boost converter. When converter output voltage exceeds the maximum phase neutral input voltage by three times, this technique is employed

5. HEV Charging Configurations and Standards:

The EV charging configurations such as on-board and off-board, charging standards including IEC and SAE, and the country-wise EV charging infrastructure and connectors are explained. an HEV is a vehicle that comprises a conventional fuel engine and an electric powertrain, wherein the electric motor assists the engine to extract more performance, and better fuel economy, depending on the type of the system the main objective of this chapter is to describe components and configurations of electric drive systems used for electric or plug- in hybrid electric vehicles. Components such as the battery and configurations the battery charger are also included. The aim is to describe different alternatives, possibilities and bottlenecks associated with such components and. We also outline some of the key factors that influence automobile design.

5.1 EV charging methods:

Higher-order implicit schemes, such as implicit Runge-Kutta methods of higher orders, aim to improve accuracy while maintaining stability for stiff equations. These methods employ higher-order approximations to minimize error accumulation over successive time steps. While computationally demanding, they offer superior accuracy and robustness compared to lower-order counterparts, particularly in capturing finer details of nonlinear dynamics.

5.3 EV Charging Configurations:

Electric vehicles (EVs) can be charged in two ways: On-board charging: The charger is built into the vehicle and converts AC power from the grid to DC power to charge the battery pack. Off-board charging: The charger is external to the vehicle and converts AC power from the grid to DC power before it is delivered to the vehicle.

5.4 Benefits of off board charging:

Off-board chargers can offer higher kW transfer, which means faster charging times. Off-board chargers remove weight from the vehicle, which can improve performance and range. Offboard chargers can be more efficient than on-board chargers, which can save money on

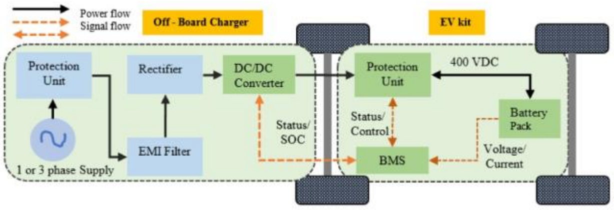

Fig:5 EV of off board charging [2].

Off-board charging is the preferred option for most EV drivers in the U.S. Off-board chargers offer faster charging times, improved performance and range,and better efficiency.

6. RESULTS AND DISCUSSION:

The use of isolated converters in HEVs has several advantages, including increased safety, reduced EMI, and increased flexibility. However, isolated converters are also larger and heavier than non-isolated converters. Fast charging technology is becoming increasingly important for HEVs. It allows drivers to charge their vehicles more quickly, which can reduce range anxiety and make HEVs more convenient to use [1]. Electric vehicles (EVs) are becoming increasingly popular due to their environmental benefits and reduced operating costs. EVs use a variety of technologies to convert electrical energy from the battery pack into mechanical energy to power the wheels. The most common EV technologies include: Battery electric vehicles (BEVs): BEVs use a battery pack as the sole source of energy. BEVs have the longest range and the smallest environmental impact of all EVs. Plug-in hybrid electric vehicles (PHEVs): PHEVs have a battery pack and an internal combustion engine (ICE). PHEVs can be plugged in to charge the battery pack, but they can also run on gasoline if the battery is depleted. Mild hybrid electric vehicles (MHEVs): MHEVs have a small battery pack and an ICE. The battery pack is used to assist the ICE, but it cannot be plugged in to charge.

Optimization Techniques: A variety of optimization techniques can be used to improve the efficiency and reliability of EV charging. Some common optimization techniques include: Demand response: Demand response programs allow EV owners to reduce their electricity costs by charging their vehicles during off-peak hours. Vehicle-to-grid (V2G): V2G technology allows EV owners to sell electricity back to the grid when it is needed. Smart charging: Smart charging algorithms can be used to optimize the charging of EVs based on factors such as the availability of renewable energy and the cost of electric.

EV technology is rapidly advancing, and charging methods, standards, and optimization techniques are constantly evolving. As EVs become more popular, it is important to stay informed about the latest developments in this field. One of the key challenges facing the EV industry is the development of a fast and reliable charging infrastructure. DC fast chargers are becoming more common, but they are still relatively expensive and not widely available. Another challenge is the need to harmonize EV charging standards. This would make it easier for EV owners to travel between different countries and regions. Optimization techniques have the potential to play a significant role in improving the efficiency and reliability of EV charging. For example, V2G technology could help to reduce the reliance on fossil fuels and improve the stability of the electrical grid. Overall, the future of EV technology is very promising. EVs are becoming more affordable and efficient, and the charging infrastructure is improving all the time. With continued investment and innovation, EVs are poised to play a major role in transportation in the years to come [2].

The modified non-isolated bidirectional DC–DC converter proposed in this paper has several advantages over conventional bidirectional DC–DC converters, including Higher voltage gain: The modified converter has a voltage gain of twice that of a conventional bidirectional DC– DC converter in the motoring mode. This makes it suitable for EV applications where a high voltage gain is required to drive the electric motor. Lower voltage stress on the switches: The modified converter has lower voltage stress on the switches than a conventional bidirectional DC–DC converter in both the motoring and braking modes. This reduces the risk of switch failure and improves the overall reliability of the converter. Lower component count: The modified converter has a lower component count than a conventional bidirectional DC–DC converter. This makes it smaller and lighter, which is important for EV applications.

The results of the simulation and experimental studies show that the modified converter has excellent performance in both the motoring and braking modes. The converter is able to achieve high efficiency and good voltage and current regulation. The modified converter is a promising candidate for EV applications involving regenerative braking. It offers several advantages over conventional bidirectional DC–DC converters, including higher voltage gain, lower voltage stress on the switches, and lower component count. One of the main challenges in designing bidirectional DC–DC converters for EV applications is the wide range of input and output voltages. The modified converter proposed in this paper is able to operate over a wide range of voltages, making it suitable for EV applications with different battery and motor voltages. Another challenge is the need for high efficiency and power density. The modified converter is able to achieve high efficiency and power density, which is important for EV applications where space and weight are limited.

7. CONCLUSION

EV technology is rapidly advancing, and charging methods, standards, and optimization techniques are constantly evolving. As EVs become more popular, it is important to stay informed about the latest developments in this field. Isolated and non-isolated converters both have their own advantages and disadvantages. The best choice for a particular HEV will depend on the specific requirements of the application. Fast charging technology is becoming increasingly important for HEVs. It allows drivers to charge their vehicles more quickly, which can reduce range anxiety and make HEVs more convenient to use. Off-board charging is the preferred option for most EV drivers in the U.S. Off-board chargers offer faster charging times, improved performance and range, and better efficiency. This review has focused on power electronic converters for electric vehicle drivetrains, providing detailed information and study on different advanced and possible dc-dc converter topologies.

Non-isolated converters, such as the buck, boost, and buck-boost variants, provide a diverse array of voltage gains. However, their power conversion efficiency is somewhat constrained by their cascaded structures. Switched capacitor bidirectional converters enhance conversion performance but are hampered by substantial ripple current. Compact and low-output current solutions can be found in coupled inductor bidirectional converters, yet they contend with leakage inductance issues. Quasi-Z source bidirectional converters often offer substantial voltage gain but place significant demands on capacitance. Multidevice interleaved bidirectional converters have emerged as the preferred choice in electric vehicle applications. They excel in minimizing ripple current and voltage, while also offering high levels of reliability, durability, and robust power-handling capabilities.

Isolated converters, like the flyback converter, offer the advantage of controlling multiple output voltages but tend to have higher electromagnetic interference (EMI) and ripple current ratings. Resonant converters exhibit superior performance and operation, although they come with the challenge of requiring a complex transformer design and having limited capacity for magnetizing current. Zerovoltage switching (ZVS) converters are known for their low switching losses and reduced EMI, although they can be intricate in terms of design and control. Selecting the most suitable converter topology for a specific electric vehicle application hinge on various factors, including the desired voltage gain, power rating, efficiency, size, weight, and cost. Future trends in power electronic converters for electric vehicles encompass the development of novel topologies with heightened efficiency, power density, and reliability. The utilization of wide bandgap semiconductor devices, such as silicon carbide (Sic) and gallium nitride (Gan), will enable higher switching frequencies and more compact, lightweight converters. The evolution of integrated converters featuring embedded control and protection circuits, along with the incorporation of artificial intelligence and machine learning, will contribute to the creation of more efficient and dependable control algorithms. These trends are anticipated to drive the emergence of innovative power electronic converters, playing a pivotal role in shaping the future of electric vehicles. Flywheels and modern flow batteries are the dominant energy storage technologies in this field, with lead-acid batteries and pumped hydro energy storage (PHES) playing a smaller role. While operating a single energy storage system is relatively inexpensive, using it for multiple purposes, such as load levelling, frequency regulation, and backup power, can be more challenging. Hybrid energy storage systems, which combine two or more different energy storage technologies, are becoming increasingly popular as they can address the limitations of single-type storage systems. Swappable battery charging stations are the most promising way to reduce EV charging time. However, for this technology to reach its full potential, manufacturers need to standardize energy storage and EV energy management systems. Batteries are still the most popular energy storage technology for EV charging stations, but they have environmental drawbacks. For example, the mining and processing of battery materials can be harmful to the environment, and the disposal of used batteries can be challenging. Two distinct distribution strategies are available for XFC stations: DC distribution and AC distribution. DC distribution offers lower costs and improved efficiency, while AC distribution is a more mature solution with readily available components and well-established standards. The SST-based DC fast charger is a promising new technology that offers rectification, voltage step-down, and isolation function in a single device. This makes SST-based DC fast chargers smaller and more efficient than state-of-the-art DC fast chargers, which require MV-to-LV line-frequency transformers. The European Union (EU) has established a comprehensive strategy and infrastructure plan to gradually expand electric vehicle charging points. However, the development of the charging infrastructure within the EU countries will progress at varying levels due to their significant economic diversity. It is imperative to prioritize placing fast charging points along the TEN-T network and highways.

Overall, the review highlights the following key points: Energy storage is essential for remote/standalone EV charging stations Hybrid energy storage systems are becoming increasingly popular as they can address the limitations of single-type storage systems. Swappable battery charging stations are the most promising way to reduce EV charging time, but standardization is needed. DC distribution offers lower costs and improved efficiency for XFC stations, but AC distribution is a more mature solution. SST-based DC fast chargers are a promising new technology that can make XFC stations smaller and more efficient. The EU has a comprehensive strategy to expand electric vehicle charging points, but the development of the charging infrastructure will vary across EU countries. Future research directions in this field include Developing new and more efficient energy storage technologies for EV charging stations. Developing standardized energy storage and EV energy management systems for swappable battery charging stations. Developing new and innovative DC distribution architectures for XFC stations. Further optimizing the design and performance of SST-based DC fast chargers. Developing cost-effective and efficient ways to integrate EV charging stations into the existing electricity grid.

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