

Integration of Electric Vehicles into Smart Grids and Urban Traffic Management Systems: A Review of Technologies, International Standards, Market Size, Challenges and Future

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Electric vehicles (EVs) have emerged as a transformative solution to address the pressing challenges associated with conventional diesel-based transportation systems, including greenhouse gas emissions, urban air pollution, and the reliance on finite fossil fuel resources. This review presents a comprehensive synthesis of recent advancements in EV technologies, evolving market dynamics, and the critical infrastructure required for widespread deployment. Particular emphasis is placed on the integration of EVs into smart grids and intelligent urban traffic systems, which has demonstrated quantifiable benefits such as up to 15% reduction in peak electricity demand, 20% savings in energy costs through smart charging strategies, and 25–30% decrease in urban CO₂ emissions. Moreover, bidirectional energy exchange via Vehicle-to-Grid (V2G) models is shown to enhance grid stability and flexibility, particularly during peak load periods. The review also identifies significant regional disparities in policy effectiveness, with China and the European Union leading adoption efforts due to structured incentives and coordinated charging infrastructure. This study aims to inform policymakers, urban planners, industry stakeholders, and researchers by providing strategic, data-driven insights into the transition toward intelligent, low-carbon transportation systems.

Keywords: Electric vehicles; Vehicle-to-Grid; Traffic management; Smart grids; Air pollutions

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1. Introduction

Due to the use of diesel-based vehicles, carbon is released into the environment, which poses a serious threat to the world's climate and environment [1, 2]. The carbon produced by these vehicles can cause global warming, climate change, air and water pollution, reduction of air quality, and human and animal health [3]. For this reason, reducing diesel vehicles and using cleaner transportation methods is essential [4]. With the advent of EVs, the problems caused by using diesel vehicles can be easily avoided. EVs do not release any pollutants into the environment and do not threaten the world's climate and environment [5]. In addition, EVs cost less than diesel cars because they do not use fossil fuels and are, therefore, more economical [6]. Due to these advantages, the emergence of EVs can be essential to protecting the environment [7]. EVs can be used in distribution networks as a flexible energy storage system [8]. Also, they play an active and essential role in the electricity market and ancillary services. Figure.1, illustrates the opportunities created by electrification of the transportation system.

Figure 2, shows the types of EVs. The proper operation and

control of battery energy storage are essential to EV effectiveness. However, the battery energy storage of EVs produces a significant voltage drop and an unreliable, uncontrolled power supply [10]. The power electronics sector has also progressed with the advent of EVs. These improvements help preserve the environment and make EVs more economical and efficient [11]. With the development of EVs, related technologies are also expanding. EVs can exchange their battery energy differently, but the most important types are vehicles-to-grid (V2G) and grid-to-vehicles (G2V) [6, 12]. The G2V method uses the flexibility of EV batteries to provide ancillary services to the grid, such as frequency regulation, peak shaving, and voltage support. EVs can absorb or generate energy to help balance the grid and stabilize its operation. In contrast, the V2G method enables two-way energy flow between EVs and the grid, allowing EVs to feed electricity back into the grid during periods of high demand or low renewable energy generation [13]. This can be particularly valuable for integrating renewable energy sources into the grid. Integration of EVs into smart grids and intelligent urban traffic systems has demonstrated notable quantitative benefits. Studies indicate that V2G integration can reduce peak electricity demand by up to 15%, while smart charging strategies may lead to energy cost savings exceeding 20% for urban operators.

Furthermore, the adoption of intelligent traffic management systems in conjunction with EV deployment has shown a potential to reduce average commute times by 10–18% and urban CO₂ emissions by approximately 25–30%. These figures highlight the dual role of EVs in enhancing both energy system efficiency and urban mobility.

To ensure the quality, diversity, and comprehensiveness of this review, a structured methodology was adopted. The research was conducted in four main phases:

Academic databases including IEEE Xplore, ScienceDirect, SpringerLink, MDPI, and Elsevier were used to retrieve peer-reviewed articles, technical reports, and institutional white papers. The search keywords included: EVs, EV technologies, V2G, G2V, converter topologies, charging infrastructure, grid integration, policy adoption, and traffic management. Only English-language articles from 2017–2024 were considered to maintain relevance and recentness. Articles were included based on their relevance to EV technology developments, charging architectures, smart grid integration, traffic management impacts, and regional policy case studies. Duplicates, commercial product advertisements, and opinion editorials were excluded. The selected literature was thematically clustered into five key dimensions: (i) EV market trends and policies, (ii) charging standards and coordination, (iii) converter technologies, (iv) motor systems and inverters, and (v) urban and smart-grid impacts. A bibliometric approach was also employed to identify high-citation clusters and research gaps. Following thematic classification, each cluster was analyzed based on its technological principles, regional deployment success, grid interaction strategy (e.g., V2G/G2V), and socio-economic implications. The study also critically compared findings across global regions to extract cross-country lessons and technology-to-policy translation mechanisms.



Fig.1. Illustration of the multifaceted benefits enabled by transportation electrification, including emission reduction, grid support, and improved energy efficiency across urban systems [9].

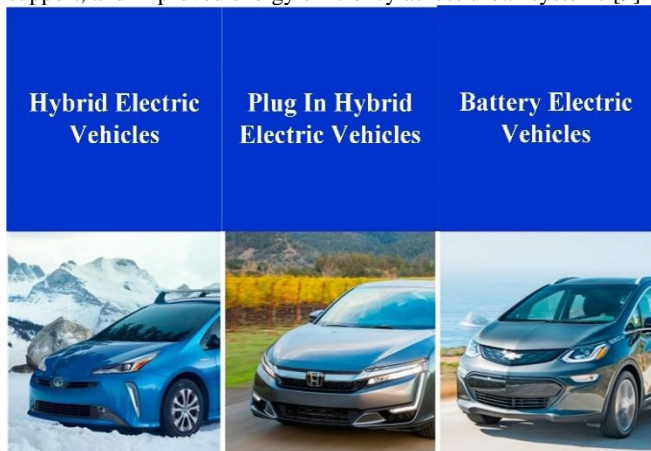


Fig. 2. Types of EVs.

Fuel-cell EVs are a promising technology with the potential to revolutionize the transportation sector. In study [14], the authors analyze the role of V2X technology in strengthening energy systems through bidirectional energy transfer from EVs by reviewing 75 articles published between 2018 and 2023. The main focus is on the involvement of local actors, such as regional governments and distribution network operators, in developing related infrastructure. The paper also highlights technological advancements, the need for policy interventions, and the potential of V2X to reduce grid expansion costs and enhance the use of local renewable resources. Finally, the authors identify policy-related barriers and offer suggestions for future research and decision-makers. In [15], the authors comprehensively review Fuel-cell EVs. Control strategies for charging and discharging EVs in vehicle-grid interaction modes have been studied in [16]. In [17], the process of transitioning from conventional fuel-based vehicles to EVs is analyzed, focusing on market trends, traction motor types, and drive train controller technologies. The study also highlights future developments in the EV sector driven by the demand for cleaner and more sustainable transportation solutions. Reference [18], compares EVs with batteries and Fuel-cell EVs. In [19], the process of developing a PV-based charging system for EVs is presented, featuring an Improved Trans Quasi-Z Source Boost Converter with coupled inductor and a Modified Hermit Crab Optimized Recurrent Neural Network MPPT algorithm. The study aims to enhance energy transfer efficiency to both EV batteries and the grid, achieving high tracking accuracy and reduced power losses, thereby contributing to sustainable and efficient EV charging solutions. In [20], the process of reviewing EV charging technologies is presented, focusing on converter topologies, control strategies, international standards, and charging station architectures. The study emphasizes the role of EV charging systems in supporting grid integration, enhancing charging efficiency, and addressing technical challenges arising from large-scale EV deployment. Future trends and integration with renewable energy sources are also discussed. In Work [21], the authors examine the challenges posed by the unregulated and stochastic charging loads of EVs on power generation, transmission, and distribution. The paper provides a comprehensive review of EV grid integration (EVGI) and related technological advancements. It begins by introducing EV technologies, charging standards, and their impacts on the grid. The authors explore two potential EVGI frameworks and analyze market mechanisms for procuring EV charging flexibility. Additionally, grid services provided by EVs and mathematical models for optimal charging strategies in a market environment are discussed. The conclusion outlines key issues and future research trends in EVGI deployment. Reference [22], introduce a new energy storage system to improve the efficiency of fuel cell EVs based on a new high-step DC-DC converter. The writers of [23] concentrated on the performance patterns of various kinds of EV s. Reference references examine EV control strategies and charging standards [24, 25]. The present state and anticipated developments in EV technologies are examined in [26]. Another research on EV technology has examined the smart energy management system for EVs and the commercial aspects of EVs [27]. In Work [28], the authors explore the impact of the growing EV demand on the energy sector, particularly in terms of integrating EVs into power system expansion planning. This systematic literature review categorizes articles based on research themes such as planning, smart charging, renewable sources, and techno-economic aspects. A detailed analysis is provided on the challenges addressed, overlooked topics, and key data like publication year and keywords. The study identifies research gaps, including the need to consider the costs of adapting charging systems to be smart and the effects of V2G schemes on battery lifespan. The authors in [29], focused on DC-DC converter topologies for EVs, plug-in hybrid EV s, and future trends. In [30], the authors investigate the topologies of multi-input DC-DC converters related to hybrid EV s and renewable energy systems. In another study, the authors investigate and compare the dc-dc converters used in EV applications[31]. The EV charging mechanisms have been outfitted

and examined in [32]. The authors of [33] talk about the current difficulties and how EV converters are configured. The cyber security and energy trading of EVs are investigated in [34]. In [35], a comprehensive review of the energy efficiency of series hybrid EVs with a DC-DC converter with double phase change has been done. Reference [36], carries out research on EV charging stations and battery management systems. Researchers have studied fuel-cell EVs in great detail in [37]. A thorough analysis of EV behavior modeling has been conducted by the authors in reference [38]. In Work [39], the authors present a bibliometric review of V2G integration, analyzing 16,457 articles published from 1970 to 2023. The review highlights a significant increase in V2G research post-2000, with the United States and China leading in publications. It shows a shift in research focus from "secondary batteries" to topics like "smart grid" and "greenhouse gases." The study maps global collaborations and provides recommendations for future V2G research, offering valuable insights for researchers, policymakers, and industry stakeholders. The authors in [40], have done a comprehensive review on battery charge balancing methods based on dc-dc converter in EVs.

Novelty and Contribution of This Review: In light of the extensive body of literature on EVs, this review advances the field through a comprehensive and interdisciplinary synthesis that goes beyond the scope of prior surveys. While many previous studies tend to address EV technologies, policy frameworks, or grid integration in isolation, this work presents a unified analytical framework that systematically interlinks five critical dimensions: (1) advancements in power electronic converters and their topological trade-offs, (2) the evolution of EV charging standards and their smart coordination with distribution networks, (3) comparative assessments of V2G/G2V models across geographical and regulatory contexts, (4) the impact of large-scale EV integration on urban traffic systems, and (5) regional policy-market dynamics and their correlation with EV adoption trajectories. Furthermore, this study offers a value-added perspective by bridging technical insights with real-world deployment considerations, an approach largely absent in earlier reviews. Through this multidimensional analysis, the review not only identifies underexplored subtopics but also provides actionable guidance for stakeholders including researchers, utility operators, urban planners, and policymakers. These elements collectively distinguish this review as both forward-looking and uniquely integrative within the EV research landscape.

Organization of this paper as follow:

Section 2, this article discusses the EV market. Section 3 examines the standards and the charging range of EVs. Also, in section 4, the authors examine the types of converters for EVs. Section 6 analyzes the high voltage (HV) inverter in EVs. In section 7, they review the types of engines used in EVs. Finally, section 8, is devoted to conclusions

2. EV market

The EV market is experiencing a remarkable surge in popularity, driven by a confluence of factors, including growing environmental concerns, government incentives, and technological advancements [1]. In developing countries, government incentives play a pivotal role in EV market activation due to high upfront costs, infrastructure gaps, and weaker consumer purchasing power. For example, India's FAME II policy (Faster Adoption and Manufacturing of Hybrid and EV offers direct subsidies for both consumers and fleet operators, leading to a fivefold increase in EV registrations between 2019 and 2023. Brazil offers import duty exemptions on electric drivetrains and mandates minimum EV production quotas for automakers. Similarly, South Africa's Green Transport Strategy has catalyzed early pilot projects for electric buses and taxis through public-private partnerships. These policy frameworks not only reduce cost barriers but also encourage local EV manufacturing, battery assembly, and

R&D investments. However, challenges remain in terms of policy continuity, inadequate charging infrastructure in rural areas, and lack of unified standards. Subsidy phasing and reliance on short-term incentives may result in market slowdowns without parallel investments in grid upgrades and public awareness campaigns. Effective policy in developing markets must therefore adopt a longitudinal, multi-sectoral approach, combining financial support with regulatory mandates, infrastructure planning, and localized innovation ecosystems.

This burgeoning industry is poised to transform the transportation sector and revolutionize how we move. With the development of the EV market and technology, some policymakers are starting to reduce the level of support. The question arises of when EV subsidy programs should be implemented and when the EV market can support itself [41]. The timing of EV subsidy programs and the point at which the EV market can support itself are complex questions that depend on a variety of factors, including the specific market, government policies, and technological advancements. Factors influencing the timing of EV subsidy programs:

- ✓ **Market maturity:** At the early stages of EV development, subsidies are crucial to incentivize consumer adoption and stimulate the market. As the EV market matures and EV technology improves, subsidies can be gradually phased out to allow the market to become self-sufficient.
- ✓ **EV cost:** A major factor driving EV adoption is the upfront cost of purchase. Subsidies can help to offset this cost, making EVs more affordable and enticing to buyers. As battery technology improves and EV production costs decrease, subsidies can potentially be reduced or eliminated.
- ✓ **Government policies:** Government policies, such as tax breaks, emissions standards, and regulations, can significantly influence EV adoption and market growth. Strong government support can accelerate EV adoption, justifying the continuation of subsidy programs.

Figure.3, shows the key factors driving the growth of EVs.

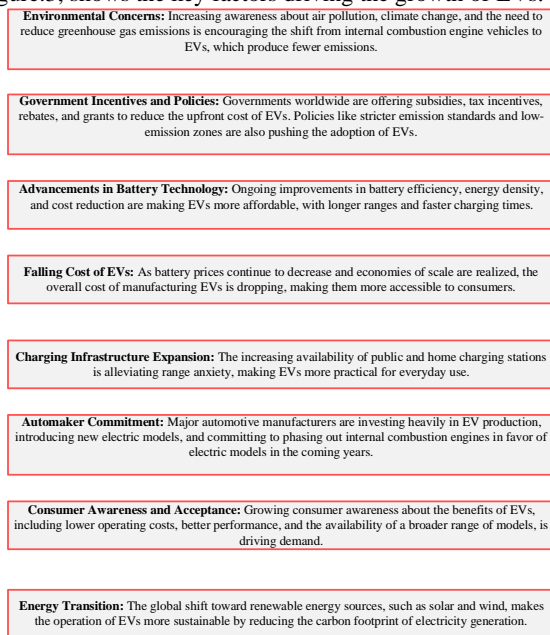


Fig.3. Key factors driving the growth of EV.

Figure.4, shows the sales of EVs by region, 2022-2030. Below is a specialized analysis based on the information in this figure:

China: Market Leader with Exponential Growth:

In 2022, China solidified its position as the world's largest EV market with 6.2 million units sold. Projections indicate this figure will

rise to 16.1 million units by 2030 (Scenario 1) or 14 million units (Scenario 2).

Key Drivers: Government incentives (e.g., subsidies), rapid expansion of charging infrastructure, and strong domestic manufacturers like BYD and NIO.

Europe: Steady Growth Fueled by Sustainability Policies:

Sales are expected to grow from 2.8 million units in 2022 to 10.6–11.6 million units by 2030.

Key Drivers: Stringent EU emissions regulations, the 2035 ban on internal combustion engines (ICEs), and consumer demand for premium EVs (e.g., BMW, Volvo).

United States: Accelerating After Initial Delays:

Sales will surge from 1 million units in 2022 to 8.3–8.4 million units by 2030, driven by federal policies (e.g., Inflation Reduction Act) and investments from Tesla and General Motors.

Japan and India: Emerging Markets with High Potential:

Japan: Sales are projected to rise from 0.1 million units (2022) to 0.9–1.4 million units (2030), though growth is tempered by reliance on hybrid technology.

India: Sales will climb from 0.1 million units to 1.1–2.2 million units, supported by initiatives like "Make in India" and affordable models (e.g., Tata Nexon EV).

Other Regions and Global Trends:

"Other Regions" will grow from 0.5 million units (2022) to 3.7–7.3 million units (2030), reflecting EV adoption in developing economies.

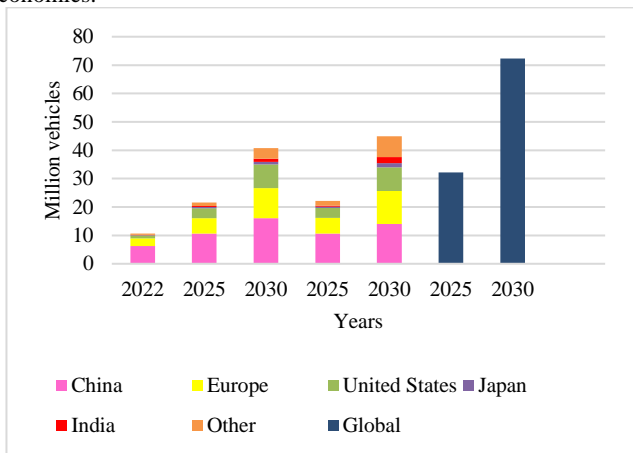


Fig.4. Forecasted EV sales from 2022 to 2030 across major global regions, based on policy-driven and market-driven scenarios. The data reflect governmental support levels, charging infrastructure readiness, and consumer adoption rates.

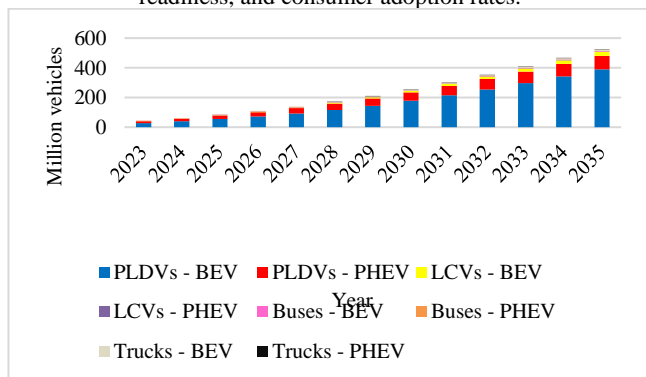


Fig.5. EV stock by mode in the Stated Policies Scenario, 2023–2035 [42].

In the context of analyzing future transportation trends, one of the key factors in determining future transportation policies is forecasting the number of EVs under different scenarios. In this regard, the Stated Policies Scenario is used as one of the predictive models for the future evolution of the industry. This scenario is based on current policies and decisions made by governments and regulatory bodies globally and predicts the growth and market share of EVs for the upcoming years. The adoption of EVs is influenced by factors such as environmental policies, technological advancements, and government support in terms of infrastructure and production costs. Additionally, the share of EVs in different modes of transportation, including private cars, public transit, and commercial vehicles, will directly impact long-term goals for reducing greenhouse gas emissions and improving urban air quality. The Figure.5. specifically shows the number of EVs in the Stated Policies Scenario for the period 2023 to 2035, categorized by different modes of transportation (private, public, and commercial), highlighting the progress and developments of the industry in the future.

2.1 Regional Adoption Insights and Future Research Directions

EV adoption varies significantly across regions, driven by differences in infrastructure maturity, government policies, income levels, electricity grid reliability, and consumer awareness. While regions such as China, Europe, and the United States show rapid uptake due to structured subsidies and robust infrastructure, other regions remain at nascent stages. For example, Latin America and Africa are witnessing slower adoption due to high upfront costs, unreliable grid access, and limited charging networks. These markets require targeted interventions, such as low-cost models, microgrid-based charging, and policy alignment with local energy security goals. Additionally, intra-regional disparities, such as between rural and urban areas in India or the U.S., reveal gaps in equitable access to EV infrastructure. These differences have implications for EV deployment strategies, especially in relation to long-range driving, commercial fleets, and public transit electrification. Future studies could explore comparative policy effectiveness across underrepresented regions, such as Southeast Asia, South America, and Sub-Saharan Africa, with attention to cost-effective charging models, hybrid vehicle transition plans, and local manufacturing policies. Regional behavioral studies on EV acceptance, resale market dynamics, and second-life battery policies are also underexplored and critical for long-term adoption.

3. EVs charging standards & Coordination plans

EVs charging standards are technical specifications that define the physical and electrical characteristics of EVs chargers and connectors. There are three main types of EVs charging standards, which are mentioned below. Table 1 provides more detailed information about the charging levels of EVs.

Level 1: These chargers use standard household 120V outlets and can provide a charging rate of up to 3.3 kilowatts (kW). They are typically used for overnight charging at home.

Level 2: These chargers use 240V outlets and can provide a charging rate of up to 22 kW. They are typically used for charging at home or work.

Level 3: These chargers use high-voltage direct current (DC) power and can provide a charging rate of up to 350 kW. They are typically used for rapid charging at public locations, such as highways, shopping malls, and parking garages.

Table.1. Characteristics of three charging levels of EVs

Characteristic	Level1	Level2	Level3
Type of current	AC	AC	DC
Connector type	J1772	J1772	CCS1
Average charge time	11-20h	3-8h	30-60min
Average miles per	5	12-80	75-1200
Slow or fast	Slow	Fast	Faster

Charging efficiency and compatibility with Levels 1–3 vary significantly across EV models due to differences in onboard charger capacity, battery size, thermal management systems, and communication protocols. For instance, Tesla models equipped with proprietary high-capacity onboard chargers can achieve up to 11 kW AC charging on Level 2 and utilize Level 3 DC fast charging (up to 250 kW) via Superchargers or CCS2 adaptors. In contrast, models like the Nissan Leaf rely on CHAdeMO DC fast charging, typically capped at ~50 kW, and support lower AC charging rates (~6.6 kW). BYD and Hyundai models, which adhere to CCS2 and ISO 15118 standards, often support bi-directional charging and higher efficiency under Level 3 charging. In terms of efficiency, Level 3 DC fast charging can introduce more heat loss and battery stress, reducing charging efficiency slightly (typically 90–92%) compared to Level 2 AC charging (92–96%). Advanced thermal management systems in premium EVs mitigate these losses, while older or entry-level models may experience performance degradation during high-power charging. Compatibility also depends on connector type and regional standards, making universal interoperability a persistent challenge, especially in mixed-market infrastructure.

AC charging is the most common method for charging EVs at home and at public charging stations. The electricity from the grid is AC, and the onboard charger in the EVs converts it to DC, which is the form of electricity that the EVs battery can store. AC charging is relatively slow, typically taking several hours to fully charge an EVs battery. In contrast, DC charging is much faster than AC charging. DC chargers convert AC electricity into DC electricity inside the charger itself, so there is no need for an internal charger. This allows DC chargers to transfer power directly to the EVs battery, which can significantly reduce charging times. DC chargers are commonly found at public fast charging stations. Figure.6, shows charging modes at different levels [43].

This section examines EV coordination strategies using the established classification. There are two main categories of EV coordination schemes:

- direct control
- indirect control

Three subcategories of indirect control can be distinguished:

- bilateral coordination
- implicit coordination
- mediated coordination

It is possible to categorize these groups into cooperative and competitive games. Figure.7, displays a hierarchy diagram that classifies various coordination schemes [44].

The effectiveness of the coordination strategies shown in Figure 7 has been supported by both simulation studies and pilot implementations worldwide. For example, direct control schemes have been successfully implemented in smart charging stations in California, where utilities directly throttle EV charging to reduce peak loads, demonstrating load reductions of up to 20% during demand-response events. Bilateral coordination models, like those tested in the Netherlands’ Jedlix platform, use price signals negotiated with aggregators and have shown to improve charging flexibility while preserving user preferences. Implicit coordination strategies, e.g., using real-time price feedback without centralized control, have been adopted in Tokyo’s metropolitan grid, enabling better alignment of EV charging with rooftop PV generation. However, their effectiveness depends on consumer responsiveness and behavioral incentives. Mediated coordination, often enabled via V2G aggregators and smart contracts, is under development in pilot projects across Germany and the UK, and shows potential for providing frequency regulation and voltage support services, albeit with moderate battery degradation trade-offs. Across these models,

studies confirm that hybrid schemes (e.g., indirect-mediated with price incentives and minimal override control) achieve the best balance between grid stability and user autonomy. Future research should focus on multi-agent systems that dynamically switch between coordination modes based on grid state, vehicle availability, and market prices.

With the rapid global expansion of EVs, the development, production, and deployment of these vehicles are governed by a comprehensive set of international and national standards. These standards ensure the safety [45], interoperability, performance, and communication between EVs, charging infrastructure, and the broader power grid. Given the fast pace of technological advancement and the diversity of stakeholders—from automakers and battery manufacturers to energy providers and policy-makers a clear understanding of these standards is essential. This document provides a structured overview of the most important standards related to EVs, categorized into key thematic areas. Table.2, presents the foundational standards governing various components of EVs, including electrical safety, battery regulations, charging systems, performance testing, and national regulations. It also introduces the responsible organizations behind these standards and provides a brief explanation of each one.

Table.3, compares the types of connectors used in different regions around the world in terms of voltage, power capacity, type of charging (AC or DC), and other notable features. Understanding these differences is vital for infrastructure development and the deployment of EVs across different regions.

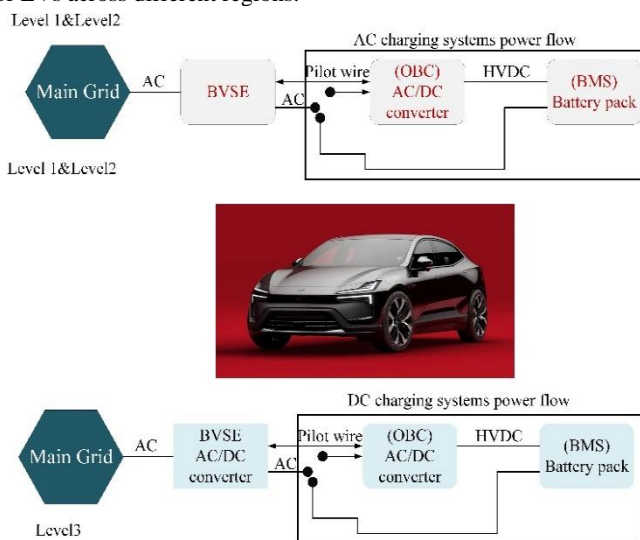


Fig.6. Charging modes at different levels.

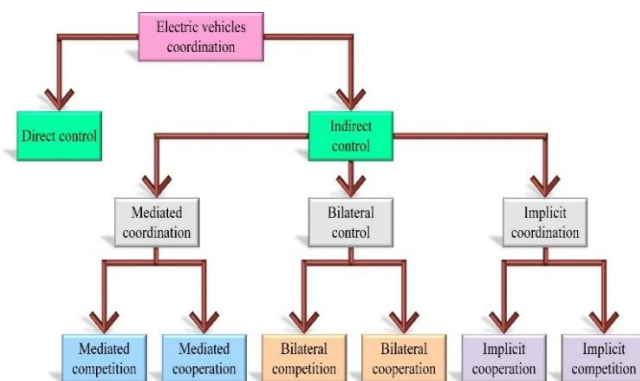


Fig.7. Hierarchical classification of EV coordination strategies, divided into direct and indirect control schemes. The figure outlines game-theoretic frameworks (e.g., cooperative vs. competitive coordination), enabling intelligent energy exchange and load balancing.

Table.2. General EV standards overview

Standard area	Standard Title	Code	Organization	Description
Electrical Safety	Functional safety against electric shock in EVs	ISO 6469-3	ISO	Safety requirements for high-voltage systems, insulation, direct and indirect contact protection
Battery	Safety requirements for lithium-ion batteries	ISO 12405 / UN38.3	ISO / UN	Thermal, vibration, shock, overcharge tests; required for international transport
AC Charging	AC charging system up to 43kW	IEC 61851-1	IEC	Framework for Level 1 and 2 AC charging station design
DC Fast Charging	DC fast charging system	IEC 61851-23 / CHAdeMO / CCS	IEC / Industry	Supports fast charging up to 400kW; includes CCS and CHAdeMO standards
Charger-Vehicle Connection	EV connector types	IEC 62196-1/2/3	IEC	Type 1 (US), Type 2 (EU), GB/T (China), Combo 1/2, CHAdeMO
Smart Charging Communication	EV to charger communication protocol	ISO 15118	ISO	Supports smart charging, Plug & Charge, V2G (vehicle-to-grid)
Driving Performance	Performance requirements for EVs	SAE J1634	SAE	Range tests, energy consumption, road testing
Certification & Testing	Environmental & durability tests for EVs	ECE R100 / GB/T 31467	UNECE / SAC	Safety and EMC requirements in EU and China
Battery Management System	Battery management system performance	ISO 26262	ISO	Focuses on software and hardware safety for BMS
National Standards	China EV standards	GB/T 20234, GB/T 18487	SAC (China)	Includes native connectors, charging protocols and communication

Table.4, focuses on communication protocols that enable smart charging, vehicle-to-grid (V2G) capabilities, and backend communication with support systems. Notable examples of these protocols include ISO 15118 and OCPP.

In addition, Table.5, summarizes key standards related to battery safety and performance testing. These include transport regulations, durability assessments, and environmental testing procedures developed to ensure the safe deployment of EV batteries across various markets.

3.1 V2G Models for Large-Scale Renewable Integration

V2G systems offer bidirectional energy exchange between EVs

and the grid, enabling EVs to serve as distributed energy storage units. This is particularly valuable in regions with high shares of intermittent renewables such as wind and solar, where supply fluctuations require fast-response flexibility.

Table.3. EV connector Types comparison (IEC 62196).

Connector Type	Region	Current	Voltage (V)	Max Power (kW)	Charging Type	Notes
Type 1 (SAE J1772)	North America, Japan	Single-phase	Up to 240V	Up to 7.4 kW	AC	Simple design, common in US and Japanese EVs
Type 2 (Mennekes)	Europe	Single/Three-phase	Up to 400V	Up to 43 kW	AC	EU standard, most common in Europe
Combo 1 (CCS1)	North America	DC + Type 1	Up to 1000V	Up to 350 kW	DC Fast	Combines DC fast charging with Type 1
Combo 2 (CCS2)	Europe	DC + Type 2	Up to 1000V	Up to 350 kW	DC Fast	Supports ultra-fast charging
CHAdeMO	Japan, Global	DC	Up to 500V	Up to 100 kW	DC Fast	First fast charging standard; V2G supported
GB/T	China	AC/DC	Up to 750V	Up to 237.5 kW	AC and DC	National standard in China

Table.4. EV communication protocols.

Protocol	Organization	Features	V2G Support	Description
ISO 15118	ISO	Plug & Charge, data communication, power management	Yes	New generation smart charging, becoming widely adopted
DIN 70121	DIN (Germany)	Initial DC charging communication	No	Basic version before ISO 15118
OCPP	Open Charge Alliance	Charger to central server communication	Indirect	Popular for charger backend management (v1.6 & 2.0.1)
GB/T 27930	SAC (China)	National charging communication protocol	Yes (in development)	For Chinese EVs and charging infrastructure

Table.5. EV Battery Testing Standards

Standard Code	Purpose	Test Types	Organization
UN38.3	Transport safety	Thermal, vibration, pressure, drop	United Nations (UN)
ISO 12405	Performance and safety	Charge/discharge cycles, thermal, short circuit	ISO
IEC 62660	Battery cells in EVs	Capacity, power, durability	IEC
GB/T 31467	EV battery safety	Impact, thermal, penetration	SAC (China)

Three key V2G models have been proposed and tested globally:

- **Aggregator-Based Model:** In this model, EVs are managed by an aggregator that bids their collective flexibility into

electricity markets. It is highly scalable and allows the provision of ancillary services like frequency regulation and spinning reserves. Countries such as Denmark and the Netherlands have piloted this model in coordination with high wind penetration.

- **Time-of-Use Price-Driven Model:** Here, EV charging and discharging are guided by dynamic pricing signals. While simple to implement, its effectiveness depends on user participation and real-time responsiveness. This model is increasingly explored in California and parts of Australia where rooftop solar leads to midday oversupply.
- **Grid-Integrated Smart Charging with V2G:** This approach involves integration of ISO 15118-compliant V2G infrastructure with grid dispatch systems. The system autonomously coordinates charging, discharging, and renewable generation forecasts. Japan’s TEPCO and Germany’s Next Kraftwerke are experimenting with this model to stabilize PV-heavy grids.

3.1.1. Key Enablers for Large-Scale Deployment Include:

High V2G-compatible penetration:

- Widespread use of ISO 15118-capable EVs and chargers
- Aggregator business models and market access
- Smart inverter and bidirectional charger availability

Despite promising pilot projects, challenges remain in battery degradation concerns, tariff design, and standardization. However, when coordinated with distributed renewables, V2G can reduce curtailment and improve grid inertia, offering a synergistic solution for future power systems.

4. EVs Converter Types and Configurations

EVs are revolutionizing transportation, offering a cleaner and more sustainable alternative to traditional gasoline-powered vehicles. However, the complex electrical systems of EVs require specialized power converters to distribute and manage the high-voltage energy stored in their batteries efficiently. These converters play a crucial role in ensuring EVs’ smooth operation and optimal performance. Figure.8, shows the entire classification of EV converters, including topology, control, modulation, and optimization [33]. Non-isolated converters are generally considered appropriate for medium- and high-power operation in EVs [46]. This is because they offer several advantages over isolated converters, including:

- **Lower cost:** Non-isolated converters do not require additional components for galvanic isolation, such as isolation transformers or optocouplers, which can significantly reduce the overall cost of the converter.
- **Higher efficiency:** Non-isolated converters can achieve higher efficiencies than isolated converters, especially at higher power levels. This is because they do not have the additional losses associated with the isolation barrier.
- **Smaller size and lighter weight:** Non-isolated converters are typically smaller and lighter than isolated converters, which can be a major advantage for EVs where weight and space are limited.

whereas isolated DC-DC converters are appropriate for low- and medium-power applications in

EVs [47, 48]. However, there are also some potential drawbacks to using non-isolated converters in EVs, such as:

- ✓ **Potential for emit electromagnetic interference and radio frequency interference:** Non-isolated converters can emit electromagnetic interference and radio frequency interference,

which can interfere with other electronic components in the EV.

- ✓ **Potential for grounding issues:** Non-isolated converters can also introduce grounding issues, which can cause problems with the vehicle’s electrical system.
- ✓ **For these reasons, non-isolated converters are typically only used in EVs when the potential drawbacks can be mitigated.** This is often the case for medium- and high-power applications, where the cost, efficiency, and size advantages of non-isolated converters outweigh the potential drawbacks.

Table. 6 summarizes the specifications of non-isolated and isolated converters for EVs applications:

Table.6. specifications of non-isolated and isolated converters.

Specifications	Non-isolated converters	Isolated converters
Topology	Buck; boost; cuk, buck-boost	Full-bridge; half-bridge, flyback
Voltage range	Can handle wide input and output voltage ranges, but limited by switching frequency	Offers more flexibility in stepping up/down voltage levels
Cost	Lower	Higher
Efficiency	Higher	Lower
Size	Smaller	Larger
Weight	Lighter	Heavier
EMI/RFI	More prone	Less prone
Grounding issues	More prone	Less prone

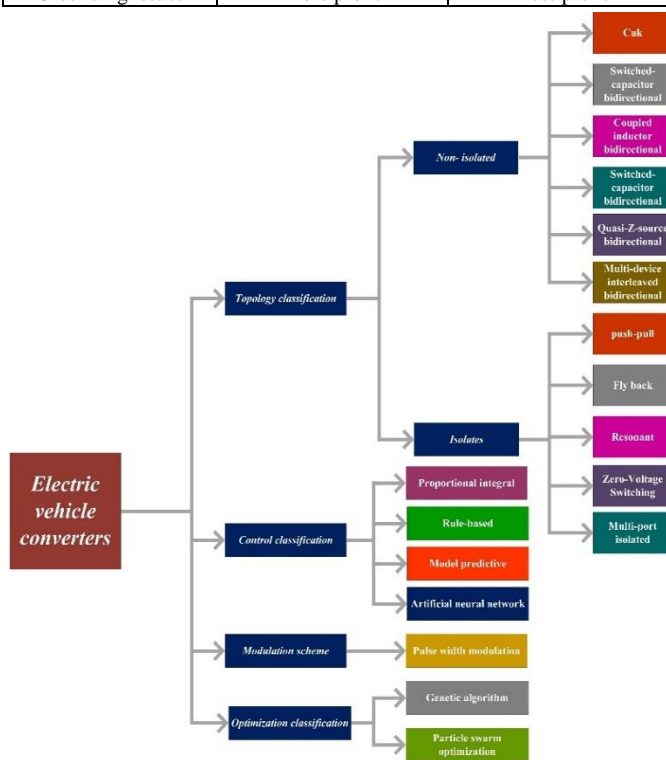


Fig.8. Entire classification of EV converters.

4.1. Non isolated converters

4.1. 1.Cuk converters

Cuk converters are a type of DC-DC converter that can efficiently step up or step down the voltage of an input DC power source [49]. This makes them well-suited for a variety of applications in EVs, including:

- ✓ **Battery charging:** Cuk converters can be used to step up the low voltage from the battery pack to the higher voltage required by the electric motor. This is essential for ensuring that the motor has the power it needs to operate efficiently.

- ✓ Regenerative braking: Cuk converters can also be used to step down the high voltage from the motor during regenerative braking. This allows the kinetic energy of the vehicle to be recovered and stored in the battery pack, improving the overall efficiency of the EV.
- ✓ Power-factor correction: Cuk converters can be used to improve the power factor of the EV's electrical system. This is important for reducing harmonic distortion and improving overall power quality [50, 51].
- ✓ Power management: Cuk converters can be used to manage the power flow between various components in the EV, such as the battery pack, the motor, and the auxiliary loads. This can help to optimize the performance and efficiency of the EV.

The advantages of using cuk converters in EVs are summarized in Figure.9. Also, the cuk converter schematic is shown in Figure.10.

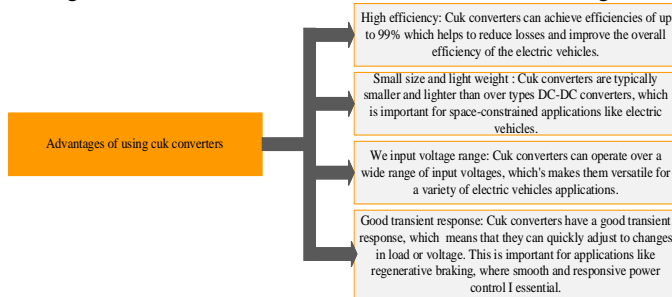


Figure.9. The advantages of using cuk converters in EV.

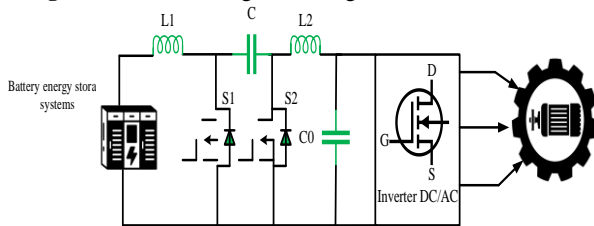


Fig.10. Cuk converter.

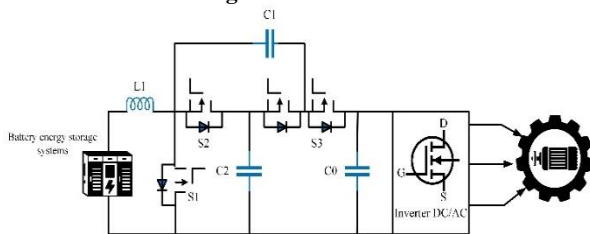


Fig.11. switched-capacitor bidirectional converter.

4.1.2. Switched-capacitor bidirectional Converter

Synchronous rectification is used by the switched-capacitor bidirectional converter in EVs to carry out the turn-on and turn-off functions [52]. By using power switches appropriately, the switched-capacitor bidirectional converter improves power conversion efficiency without the need for additional components [53, 54].

Synchronous rectification utilizes power switches instead of diodes. These switches can be controlled actively, allowing for precise control of the current flow during the rectification process. This results in several advantages:

- ✓ Continuous current flow: Synchronous rectification ensures continuous current flow, eliminating the voltage spikes associated with passive rectification.
- ✓ Higher efficiency: By eliminating the voltage spikes and reducing power losses, synchronous rectification significantly improves the efficiency of the conversion process.

- ✓ Faster switching: Power switches can switch much faster than diodes, enabling faster response times and improved dynamic performance.

Also, switched-capacitor bidirectional converter schematic is shown in Figure.11.

4.1.3. Coupled inductor bidirectional converter

A coupled inductor bidirectional converter is a type of DC-DC converter that can efficiently convert power between two DC voltage levels. It is a non-isolated converter, meaning that it does not require a galvanic isolation barrier between the input and output circuits. This makes it a compact and cost-effective solution for a variety of applications, including EVs.

Key features of a coupled inductor bidirectional converter:

- ✓ High efficiency: Coupled inductor bidirectional converters can achieve high efficiencies of up to 95%, making them energy-efficient and reducing heat generation.
- ✓ Wide voltage conversion ratio: Coupled inductor bidirectional converters can achieve a wide voltage conversion ratio, meaning they can step up or step-down voltages over a broad range. This makes them versatile for various applications.
- ✓ Compact and lightweight: Coupled inductor bidirectional converters are typically smaller and lighter than other types of bidirectional converters, making them suitable for space-constrained applications like EVs.
- ✓ Low input current ripple: Coupled inductor bidirectional converters exhibit low input current ripple, which helps to reduce noise and interference.
- ✓ High switching frequency: Coupled inductor bidirectional converters can operate at high switching frequencies, which can reduce the size of the inductors and capacitors required.

Applications of coupled inductor bidirectional converters in EVs:

- ✓ Battery charging: Coupled inductor bidirectional converters can be used to charge the EVs battery pack from a variety of sources, such as AC mains, DC chargers, and regenerative braking energy.
- ✓ Regenerative braking: Coupled inductor bidirectional converters can efficiently convert the kinetic energy of the vehicle during braking into electrical energy, which can be stored in the battery pack and reused for driving.
- ✓ Power distribution: Coupled inductor bidirectional converters can be used to distribute power between various components in the EV, such as the battery pack, motor, and auxiliary loads.
- ✓ Power conversion: Coupled inductor bidirectional converters can be used to convert power between different voltage rails in the EVs power system.

Figure.12, summarizes the of coupled inductor bidirectional converters. Also, coupled inductor bidirectional converter schematic is shown in Figure.13.

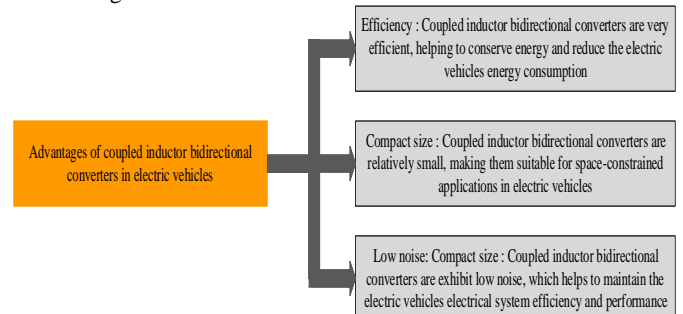


Figure.12. Advantages of the coupled inductor bidirectional converters.

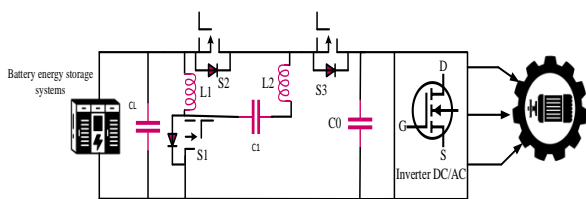


Fig.13. Circuit schematic of a coupled inductor bidirectional converter, used in EVs for both charging and regenerative braking. The design supports high-efficiency, bidirectional power conversion in constrained vehicular environments.

4.1.4. Quasi-Z-source bidirectional converter

The quasi-Z-source bidirectional converter is utilized in EVs because of its many benefits, such as its straightforward topology, shared ground, and broad voltage gain. A typical two-level is quasi-Z-source bidirectional converter made to operate on electricity. Additionally, this converter provides acceptable static and dynamic performance at low voltage stress [55-57]. Advantages and disadvantages of quasi-Z-source bidirectional converter shown in Figure.14.

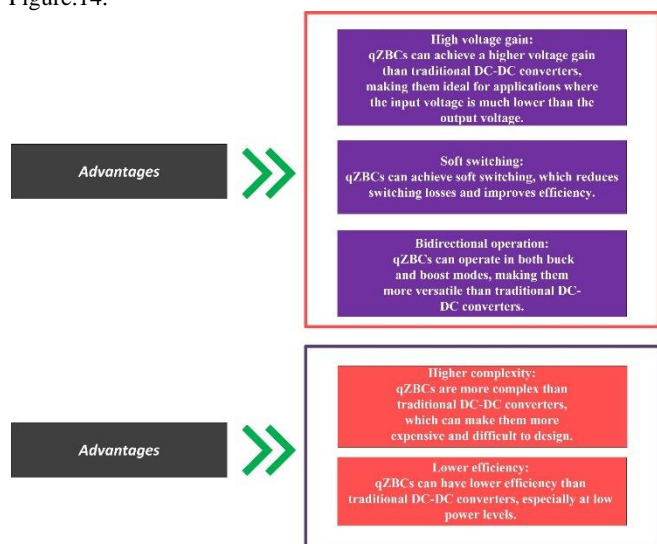


Fig.14. Advantages and disadvantages of quasi-Z-source bidirectional converter.

4.1.5. Multi-device interleaved bidirectional Converter

The MDIBC is a promising technology for EV power conversion due to its numerous advantages [58]. As research and development in this area continue, we can expect to see even more efficient and cost-effective MDIBCs powering future EVs. By interleaving multiple converter phases, the MDIBC can operate at higher frequencies, allowing for the use of smaller transformers and inductors. This translates to a more compact and lightweight converter, crucial for space-constrained EV applications. Also, the modular design of the MDIBC makes it easier to manufacture and maintain. Additionally, the use of multiple, lower-power devices instead of a single high-power device reduces component costs. Figure.15, shows the schematic of MDIBC. Figure.16, also shows some of the benefits of MDIBC.

4.2. Isolated converters

4.2.1. push-pull converter

The DC-DC push-pull converter in EVs utilizes a transformer to transfer power between the primary and secondary sides of the circuit, offering several advantages in EV applications [59].

Transformer-Based Power Transfer:

The push-pull converter employs a center-tapped transformer as a key component. Power is transferred through magnetic coupling between the transformer's windings, providing galvanic isolation between the input and output, enhancing safety. This isolation helps prevent high-voltage battery faults from affecting the low-voltage auxiliary systems in EVs.

Switching Mechanism:

Two active switches (usually transistors) are alternately switched on and off, creating a square wave voltage across the primary winding. This alternating voltage induces a current in the secondary winding, producing a regulated DC output voltage.

Also, these types of converters can be used as auxiliary power sources and traction drive systems. It is one of the oldest and most versatile converter topologies, which has several important advantages. They have high efficiency, can achieve efficiency of more than 90%, and are suitable for applications where energy saving is very important. Also, their power transmission capability is high, and they can withstand a wide range of power levels, from several watts to several kilowatts.

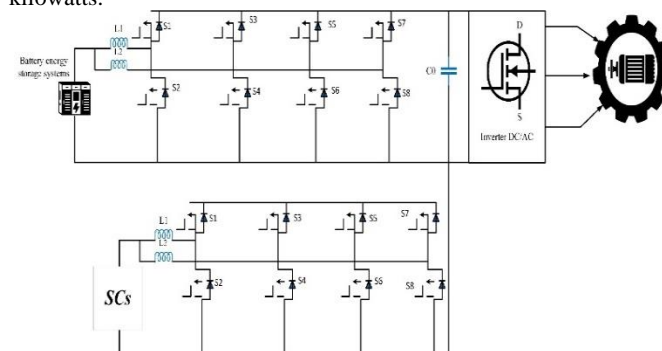


Figure.15. MDIBC schematic showing bidirectional power flow between battery, supercapacitors, and motor via a shared DC/AC inverter.

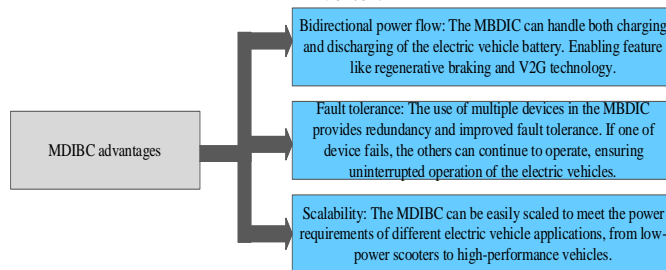


Fig.16. Some of the benefits of MDIBC.

4.2.2. Fly back Converter

The fly back converter is a non-isolated DC-DC converter topology offering several advantages in power conversion, particularly for low-to-medium power applications like laptop chargers, portable devices, and auxiliary power supplies in EVs. They consist of a buck-boost converter consisting of a divided inductor in the form of a transformer [60]. Figure.17, shows the considerations of the Flyback Converter.

4.2.3. Resonant Converter

Resonant converters are a unique class of DC-DC converters that leverage resonant circuits (combinations of inductors and capacitors) to achieve highly efficient power transfer. They operate by tuning the switching frequency to the resonant frequency of the circuit, enabling a smoother and more efficient energy transfer than traditional hard-switching converters. Figure.18, shows some of the advantages of this converter:

- ✓ Series resonant converters (SRC)
- ✓ Parallel resonant converters (PRC)
- ✓ LLC resonant converters
- ✓ Cuk resonant converters
- ✓ ZVS (Zero Voltage Switching) resonant converters
- ✓ ZCS (Zero Current Switching) resonant converters

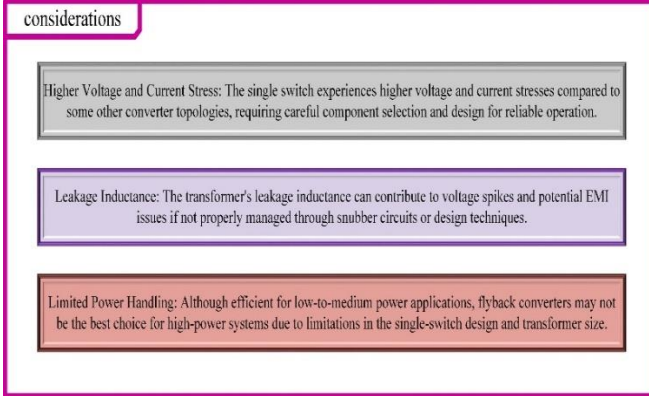


Fig.17. Considerations related to Fly Back Converter.

- High efficiency : soft switching significantly reduces switching losses, leading to high overall efficiency
- Reduced electromagnetic influences: Resonant converter generate less electromagnetic influence compared to hard switching converters
- Wider operating range: They can operate over a wider range of input and output voltages compared to some traditional converters

Fig.18. Some of the advantages of multi-port isolated converters.

4.2.4. Zero-Voltage Switching Converter

Zero-voltage switching (ZVS) converters are a specific type of resonant converter that prioritizes achieving zero voltage across the switching transistors before they turn on. This soft-switching technique significantly reduces switching losses and improves efficiency, especially in high-frequency applications. There are 2 basic challenges for these converters:

- ✓ Design Complexity: Designing ZVS converters requires careful consideration of the resonant tank, control circuitry, and component selection.
- ✓ Operating Range: Achieving ZVS consistently across a wide range of operating conditions can be challenging, necessitating advanced control techniques.

These types of converters are able to significantly reduce switching losses, which leads to improved overall efficiency, especially at higher switching frequencies, and this is their most important advantage.

4.2.5. Multi-port isolated converters

Multi-port isolated converters are a class of power converters that provide multiple isolated DC outputs from a single power source, combining isolation and multi-output capabilities. They are increasingly valuable for various applications, including EVs, renewable energy systems, and power distribution systems. There are 2 basic challenges for these converters:

- ✓ Design Complexity: Designing multi-port converters with high efficiency, compact size, and reliable isolation requires

careful design and control techniques.

- ✓ Control Complexity: Coordinating multiple isolated outputs and managing power flow can pose control challenges, especially in bidirectional systems.

5. A high-voltage (HV) inverter in EVs

A high-voltage inverter is a critical component in EVs, especially battery EVs and plug-in hybrid vehicles. It acts as the brain behind the electric drivetrain, managing the flow of electricity between the high-voltage battery pack and the electric traction motor. The HV battery stores electricity in DC form. The electric motor, however, needs AC to function. The HV inverter takes the high-voltage DC electricity from the battery and converts it into AC electricity with the appropriate voltage and frequency to drive the motor. The HV inverter doesn't just convert DC to AC; it also controls the AC output to regulate the speed and torque of the electric motor. This precise control is achieved by rapidly switching the inverter's power electronics on and off thousands of times per second. It is worth mentioning, during regenerative braking, the electric motor acts as a generator, converting the vehicle's kinetic energy back into electricity. The HV inverter facilitates this process by converting the AC electricity generated by the motor back into DC electricity to recharge the battery. Figure.19, shows HV inverters for EV.

Here are some key characteristics of HV inverters for EVs:

- ✓ High Efficiency: Minimizing energy loss during power conversion is crucial for maximizing an EV's driving range. Modern HV inverters can achieve efficiency levels exceeding 95%.
- ✓ Power Handling Capability: The inverter needs to handle the high voltage and current coming from the battery pack and deliver the necessary power to the electric motor. Power ratings can range from tens of kilowatts (kW) to hundreds of kW, depending on the vehicle's power requirements.
- ✓ Compact Size and Lightweight Design: Space is a premium in EVs, so HV inverters are designed to be compact and lightweight for optimal packaging within the vehicle's chassis.
- ✓ Thermal Management: The high-power conversion process generates heat, so efficient thermal management systems are essential to maintain optimal operating temperatures for the inverter's electronics.
- ✓ Safety and Reliability: HV inverters operate with high voltage electricity, so safety and reliability are paramount. They are designed and manufactured with rigorous safety standards and must comply with relevant automotive regulations.

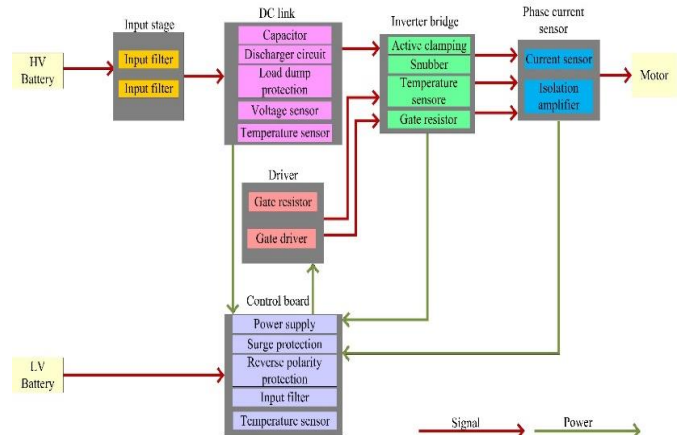


Fig.19. Block diagram of a motor drive system with dual power sources (HV and LV batteries), highlighting key components such as input filters, DC link, inverter bridge, phase current sensor, and control board with protection and sensing features.

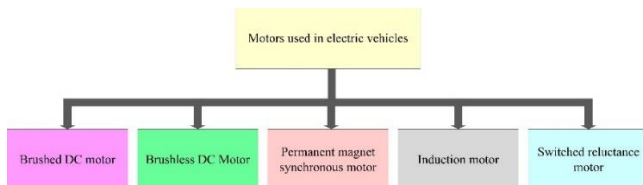


Figure.20. Overview of electric motor types used in EV propulsion systems, including Brushed DC, Brushless DC, PMSM, Induction Motor, and switched reluctance motor. Comparative analysis highlights their efficiency, torque, and cost attributes.

6. Types of motors in EVs

EVs rely on electric motors for propulsion instead of internal combustion engines found in traditional gasoline-powered cars. There are several different types of electric motors used in EVs, each with its own advantages and disadvantages. Figure.20, shows the most common types separately.

6.1. Brushed DC Motor

This is the simplest and least expensive type of electric motor. It uses brushes to make contact with a commutator, which reverses the current flow in the rotor to create continuous rotation. Brushed DC motors are efficient at low speeds but can generate sparks from the brushes, which can cause wear and tear. They are not commonly used in modern EVs due to their limitations [61].

6.2. Brushless DC motor

An improvement over the brushed DC motor, brushless DC motors use electronic controls to switch the current in the stator windings to create a rotating magnetic field. This eliminates the need for brushes, resulting in less maintenance and higher efficiency. Brushless DC motors are more complex to manufacture than brushed DC motors but offer better performance and are widely used in EVs for low-power applications like auxiliary systems [62].

6.3. Permanent magnet synchronous motor

The most common type of electric motor used in EVs today, Permanent magnet synchronous use permanent magnets mounted on the rotor and a stator with windings that generate a rotating magnetic field. They offer high efficiency, good power density, and excellent torque output, making them ideal for powering EVs [63]. However, Permanent magnet synchronous can be expensive due to the use of rare earth elements in the permanent magnets.

6.4. Induction motor

A mature and reliable technology, induction motors use a rotating magnetic field in the stator to induce current in the rotor windings [64]. They are relatively simple in design, robust, and less expensive than PMSMs. However, induction motors are generally less efficient than permanent magnet synchronous motor and may not offer the same level of performance.

6.5. Switched reluctance motor

Switched reluctance motors are a relatively new type of electric motor that uses the principle of magnetic attraction to generate torque [65]. They have a simpler design with no permanent magnets or windings on the rotor, making them potentially more reliable and lower cost. However, switched reluctance motors can be noisy and generate vibrations, and they are not yet widely used in EVs.

7. The Effects of EVs in Urban Traffic Management

The integration of EVs into urban transportation systems has brought significant opportunities and challenges for traffic management. As cities strive to reduce carbon emissions, enhance

air quality, and improve overall transportation efficiency, EV adoption has become a cornerstone of sustainable urban mobility strategies.

Traffic Flow and Infrastructure Adaptation:

The increasing number of EVs necessitates modifications to existing urban infrastructure. Dedicated charging stations must be strategically placed to minimize traffic congestion caused by vehicles queuing for charging. Additionally, traffic management systems need to account for the spatial distribution of charging facilities to avoid bottlenecks in high-demand areas [13].

Smart Traffic Management Systems:

Advanced Intelligent Transportation Systems (ITS) have become essential in managing EV traffic. Real-time data collection and AI-driven traffic optimization algorithms can monitor EV usage patterns, predict charging station congestion, and reroute traffic dynamically. Integration with Vehicle-to-Everything (V2X) communication allows EVs to interact with traffic signals and urban infrastructure, further improving traffic flow and reducing idle times.

Impact on Traffic Patterns and Peak Hours:

EV charging patterns often align with non-peak hours due to lower electricity costs during off-peak periods. However, sudden increases in demand for charging infrastructure during emergencies or peak travel hours can create localized congestion. Urban traffic models must account for these variations and develop adaptive charging schedules.

Noise and Environmental Benefits in Traffic Zones:

EVs contribute significantly to reducing noise pollution in urban environments, especially in heavily trafficked areas. Lower noise levels improve the quality of life for urban residents and may allow for innovative traffic management strategies, such as introducing Low-Emission Zones (LEZs) and pedestrian-friendly areas.

Policy and Regulatory Considerations:

Urban traffic management strategies for EVs must be supported by robust policies, including incentives for EV adoption, optimized charging tariffs, and regulations for equitable access to charging infrastructure. Additionally, governments must ensure that traffic management plans align with broader sustainable urban development goals.

The proliferation of EVs represents both a challenge and an opportunity for urban traffic management systems. Effective integration requires a multi-disciplinary approach, combining infrastructure development, smart technology adoption, policy support, and continuous research. Addressing the identified research gaps will be crucial for developing sustainable, efficient, and resilient urban mobility systems in the era of electric transportation.

7.1. Advantages and Disadvantages of EVs in Urban Traffic Management

Advantages:

Reduction in Air Pollution:

EVs help improve air quality in urban areas by eliminating emissions from internal combustion engines, contributing to cleaner and healthier cities.

Reduction in Noise Pollution:

EVs produce significantly less noise compared to conventional vehicles, leading to a reduction in noise pollution, particularly in busy urban zones. This improvement enhances the overall quality of life for city residents.

Increased Energy Efficiency:

EVs are more energy-efficient than traditional gasoline or diesel vehicles, with lower energy losses and better utilization of the energy stored in the battery.

Integration with Intelligent Transportation Systems (ITS):

EVs can be integrated with smart traffic management systems and technologies such as Vehicle-to-Everything (V2X), optimizing traffic flow, reducing wait times at intersections, and enhancing overall traffic management.

Alignment with Sustainable Development Goals:

The use of EVs is a key step toward achieving sustainable urban mobility goals, including reducing carbon emissions and improving urban transport infrastructure.

Better Management of Peak Demand Hours:

EVs can charge during off-peak hours, reducing pressure on the electricity grid during peak times and contributing to a more balanced demand for electricity.

Disadvantages:

Dependency on Charging Infrastructure:

The lack of widespread public charging stations and congestion at existing ones can lead to local traffic jams and increased waiting times, especially in high-demand areas.

Long Charging Time:

While fast chargers are available, the overall charging process still takes longer than refueling conventional vehicles, potentially causing traffic congestion at charging stations.

High Infrastructure Costs:

Developing fast-charging stations and upgrading urban electrical grids to accommodate EVs requires substantial investment, which can be a barrier to widespread adoption.

Impact on Traffic Patterns:

The concentration of charging stations in certain areas may create localized traffic congestion, particularly during peak demand hours, requiring effective traffic management strategies.

Limited Range:

Despite advancements in battery technology, EVs still have a more limited driving range compared to traditional gasoline-powered vehicles. This limitation can lead to more frequent recharging, which may impact traffic flow.

Dependency on a Stable Power Grid:

An increased number of EVs may place additional strain on the electricity grid, especially during periods when renewable energy sources are less available, requiring more reliable and resilient power infrastructure.

8. Conclusion

This study underscores the pivotal role of EVs in driving sustainable urban mobility and combating climate change. By integrating advanced power electronics, efficient charging infrastructure, and intelligent traffic management systems, EVs can address environmental and energy challenges while revolutionizing urban transportation. Their adaptability through V2G and G2V technologies enables dynamic energy exchange, enhancing grid reliability and renewable energy utilization. However, realizing their full potential requires addressing the challenges in charging infrastructure, battery technology, and market self-sufficiency. With ongoing innovations, EVs are poised to redefine the transportation landscape, promoting cleaner and smarter urban environments.

Limitations:

1. **Charging Infrastructure Challenges:** Limited access to fast-charging stations and potential congestion at existing facilities hinder EV adoption.

2. **Battery Limitations:** Current battery technologies restrict EV

range, lifespan, and cost-effectiveness.

3. **High Initial Costs:** Despite long-term savings, EVs remain expensive for many consumers due to battery and technology costs.

4. **Grid Dependency:** EV proliferation increases reliance on stable and resilient electrical grids, which may face challenges in regions with limited infrastructure.

5. **Traffic Congestion:** Inefficient placement of charging stations can lead to localized traffic issues.

Suggestions for Future Work:

1. **Battery Innovation:** Explore advanced battery chemistries like solid-state batteries to improve range, efficiency, and cost.

2. **Decentralized Charging Solutions:** Develop wireless and distributed charging technologies to ease infrastructure stress.

3. **Grid Integration Studies:** Analyze the long-term impacts of large-scale V2G integration on energy markets and grid stability.

4. **Sustainability Assessments:** Investigate the lifecycle environmental impacts of EVs, including raw material extraction and battery recycling.

5. **Policy Development:** Formulate policies to phase out subsidies while ensuring equitable access to EV technology and infrastructure.

6. **Enhanced ITS Integration:** Use AI-driven traffic optimization systems to manage EV traffic patterns and improve urban mobility.

Statement:

During the preparation of this work, the author(s) used ChatGPT to enhance the clarity and flow of the writing. After utilizing this tool, the author(s) thoroughly reviewed, revised, and edited the content to ensure accuracy and originality, taking full responsibility for the final manuscript.

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