

Future of Dynamic Electric Vehicle Challenges and Solutions

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Abstract

Dynamic Electric Vehicles are an advanced, sustainable, alternative to traditional Electric Vehicle technology that reduces the major issues associated with traditional EV technology (i.e. range anxiety, long recharging times and the requirement of high-capacity batteries). The application of Dynamic Wireless Charging (DWC) systems and new smart energy systems will improve the performance and accelerate the adoption of EVs. The methodology for this study performs a longitudinal review of the literature addressing DWC systems and included a number of case study examples from the various previous works. DWC systems based on either inductive or resonant power transfer, V2I (vehicle-to-infrastructure) communication, integration with smart grid, improved battery technology and dynamic load management systems were evaluated. The results indicate that dynamic charging systems are technologically capable and will provide improved performance compared to traditional EVs based on the case studies that used from Europe, North America and China. The results of this research show that charging EVs will decrease the time that EVs spend while they are in movement. It will remove the range anxiety and reduce the amount of battery power that EVs require.

Keywords: Electric Vehicle, Wireless Charging, Battery Technology, Renewable Energy Integration, Intelligent Transportation Systems, Smart Grid.

1. Introduction

Electric Vehicles (EV's) are a leading solution to achieve sustainable transport by providing more environmental friendly than Internal Combustion Engine Vehicles. As more people aware of the reduced supply of fossil fuels, increased levels of air pollution and the effects of climate change makes the huge demand for electric vehicles in the Global Economy. However, traditional or conventional electric vehicles have some disadvantages like time consumption while charging, relatively limited battery range, high cost battery and a need for extensive charging infrastructure.

The Dynamic Electric Vehicle (Dynamic EV) is achieved solution for the challenges that mentioned above using the development of next-generation technology. Dynamic EV's use an inductive/resonant magnetic coupling to charge from roadways while driving that enabled by Dynamic Wireless Charging (DWC) technology. This process decreases the time spent on recharging and provides high smaller/lighter battery cells by increasing vehicle efficiency and lowering costs.

1.1 Dynamic Electric Vehicles

Dynamic Electric Vehicles (Dynamic EVs) is a new way for users to use an electric vehicle to designated location (e.g., charging station) that stops the vehicle to initiate recharge. Dynamic EVs utilize a new advanced method of generating power while the vehicle is on the road. An advanced infrastructure designed specifically for the purpose to provide mechanism through the use of electrical components integrated into the existing roadways. The implementation of this technology will provide solutions to several challenges that faced by the electric vehicle industry such as range anxiety, charging interruptions and reliance upon large battery systems.

Dynamic Wireless Charging (DWC) is the primary technology operates the Dynamic EV system using Inductive Power Transfer (IPT) or Resonant Magnetic Coupling. The transmission coils are placed in the roadway below the surface while the receiving coils are connected within the electric vehicle (EV). Electrical energy is transferred to EV vehicles drives along the path where the transmission coils are placed without a physical connection between the coils and the vehicle.

The introduction of vehicle-to-infrastructure (V2I) communications system provides a real-time vehicle connection to transmit data with charging infrastructure. With the use of V2I communications, The EV charging occurs when there is a demand to maximize the available use of electrical capacity for high energy efficiency using V2I communications. The integration of the electric utility's smart grid provides the ability to manage loads as a part of all utilities, to optimizing the distribution of power to the level of EV demand, access to renewable energy sources and level of traffic congestion in urban areas on highways or in case of bus transport with improved traffic control will allow for continuous use of road transportation services. This combination of technologies provides a simple and efficient way to charge electric vehicles, to ensure consistent service for urban centres, highways and public transportation.

1.2 Implementation of Dynamic Electric Vehicles

Dynamic Electric Vehicles (Dynamic EVs) are based on a combination of hardware, software and infrastructure components uses a multi-level approach for implementation. Fig 1 focused on using Dynamic Wireless Charging (DWC) integrates vehicles with road systems particularly designed relevant to the vehicles.

1.2.1 Road Infrastructure Setup

Dynamic wireless charging begins with attached transmitter coils below the road surface. These coils are based on electric grid and activated only when a vehicle approaches. Roads must be designed to support these systems safely, providing waterproof, heat resistance and electromagnetic shielding.

1.2.2 Vehicle Modification

Vehicles are connected with receiver coils that installed under the vehicle aligned to capture energy from road transmitters. [1] These receivers are connected to the vehicle's battery and charging controller allows energy to be transferred and stored during motion.

1.2.3 Inductive Power Transfer (IPT) Mechanism

The energy transfer depends on IPT to alter magnetic field from the road's coil induces current in the vehicle's receiver coil. System uses resonant coupling allows energy to transmit even with slight misalignment between road and vehicle to increase efficiency.

1.2.4 Vehicle-to-Infrastructure (V2I) Communication

For optimal performance, Dynamic EVs use V2I communication to detect future charging lanes, authenticate vehicles and regulate power transfer. This ensures secure, focused and efficient energy delivery to reduce waste.

1.2.5 Power Supply and Smart Grid Integration

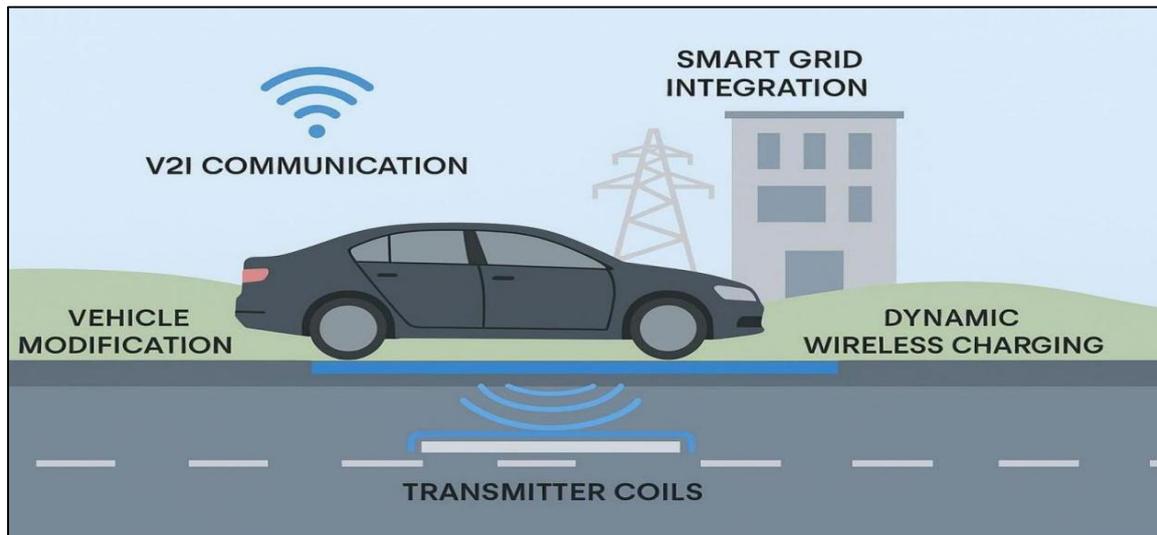


Figure 1. Implementation of Dynamic Electrical Vehicle

The entire system is supported by a smart grid manages real-time energy demand modifies power output based on vehicle traffic and integrates renewable energy sources when available [2]. Load balancing and grid communication is essential for scalability and energy efficiency.

2. Literature Survey

J. Du and D. Ouyang.[1] explained electric and hybrid cars removes the CO₂ emissions in the EU. Their study says that if EVs could charge while moving without need of huge batteries. This would be better for the environment. The research shows that using these charging systems could be better for economy. They also suggest some rules help to invest in the needed infrastructure and promote the use of renewable energy to power charging stations is important to achieve the most environmental benefits.

C. Lin et al. [2] explains the electric cars is designed based on wireless charging. They deliver the major EV problem is to wait for vehicle charging. This study finds problems like

using of same battery for all car brands. It also explains the need for smart grids that can handle the power flow for cars charging when they drive.

Y. Gao et al. [3] provided a comprehensive overview of the developments in electric machine technology for EVs. According to their research, improved motor power and efficiency are critical to the operation of dynamic charging systems in electric vehicles. They also discuss the innovations that can reduce the weight and gas consumption of automobiles. The study focuses on motor design and charging configuration work effectively to make the most out of electric vehicles.

M. Yilmaz.[4] explains the plug-in electric cars to use electricity. It also shows that charging while driving can save energy and more efficient, particularly when there's a lot of traffic signals in cities. Their work shows that charging while driving can reduce the effects of speeding up and slowing down in the car battery. It also suggests some charging techniques that change based on traffic to obtain the better mileage. This research explains the dynamic charging is better option for city planning and public transportation.

M. Koengkan [5] illustrates the fast electric cars became a large demand in China, particularly the cost they spent for chargers for work while driving. They also figured that using wireless and super-fast charging stations on a large scale is important. It helps the more users to buy electric cars. Their research also discusses when the government provided funding and regulations to enable the development of additional charges. According to the report, China must continue developing new charging technologies and charging locations to maintain its position in the field of electric cars.

S. K. Rastogi [6] explains a concept that powers transportation that has existed in the designs of manufacturers, customers and inventors for a long time. While engine technology has been dependent on fossil fuels for the past few centuries, alternative technologies like biomass and hydrogen fuel cells are still in the works. Internal combustion engines have been used for decades are at serious risk due to the rapid development of battery technology and inconsistent economic factors. This article discusses different factors of charging (battery-electric vehicles (BEVs)) because it is expected that electric cars (EVs) would have an important role in transportation.

Agamloh, A. [7] summarizes the developments and potential paths forward for II. High Specific Power Density Engines used in traction drives. This article will discuss existing and

excepted regions focused on innovation in high specific power requirements in this industry. The report includes electric motors employed in hybrid electric and battery electric vehicles but does not include the related power electronics used to drive these motors.

Aliprantis C. [8] explains the energy consumption in electric vehicle power stations (EVPS) through different methods. This paper used existing data provided in the United States to estimate energy consumption and electric demand through two methods for both EVPS situations. Uncontrolled charge method will allow private and commercial companies to choose the EFT practices based on inexpensive EVPSs in the US as determined from a National Household Travel Survey conducted in 2009.

P.B. Reddy [9] illustrates ferrite magnets made with Fe-Oxide remain cost-efficient Permanent Magnets (PM) in PM Motors due to the Rare Earth PM Magnets. Ferrite PM Motors have been considered as a disadvantage due to their low magnetic density and Coercivity (I). But a number of research on this topic suggest that Ferrite PM Motors could be an alternative to expensive PM Motors in the future.

The most recent technology from the Ferrite PM Motor is discussed in more detail by K. M. Rahman [10], describing a gear-based wheel propulsion system for electric and hybrid cars was developed mainly for use in fuel cell electric vehicles. The propulsion device makes use of an axial (liquid cooled) flux magnet machine to satisfy the drive requirements. The device's design includes technologies that can control the machine's speed and expand the continuous power range provides for the purpose to enable high-speed energy generation.

3. Research Gaps in Dynamic EV Charging

Table 1. Identifiers Research Gaps of Dynamic (EV)

Challenges	Research Gaps	Potential Solutions
System Performance [3]	Efficiency drops due to misalignment, air gaps, and magnetic leakage. Limited studies on high-speed scenarios.	Optimized coil geometry, adaptive alignment control, high efficiency power electronics.

Electromagnetic Safety [5]	Insufficient long-term EMF impact studies; safety compliance not fully established.	Advanced shielding, real time EMF monitoring, adherence to ICNIRP standards.
Infrastructure Cost [7]	High capital cost, road modification, and maintenance challenges.	Modular coil designs, standardized roadside converters, cost-benefit modelling.
Grid Integration of Vehicles [9]	Limited research on real-time load management, billing, and energy routing.	Smart grid integration, predictive energy management, vehicle-to-infrastructure communication.
Electrochemical Impact on Batteries [2]	Effect on battery degradation under frequent partial charging not fully quantified.	Simulation and experimental studies on shallow cycling and battery life extension.

The table 1 provides a summary of the major research gaps regarding the use of dynamic (in-motion) EV charging. It includes data related to technical, operational and infrastructure limitations and mentioned the issues based on energy transfer performance, Electromagnetic Field (EMF) exposure, infrastructure costs, standardization, Vehicle-to-Grid (V2G) integration, battery impact and scalability. It also provides data about the current limitations for these categories and identifies possible research directions or solutions that assist with the continued development and implementation of dynamic EV charging systems at scale.

4. Evaluation of Electrical Vehicle

As a result of this worldwide problem, countries have collaborated to create a number of vigorous initiatives to help manufacturers and customers achieve the transition to electric cars (EVs). The adoption rates of electric vehicles vary widely depending on the market sector and geographic area. The possible market value of EVs remains limited to prevent consumers and fleet owners from selecting EVs that refers in fig 2.

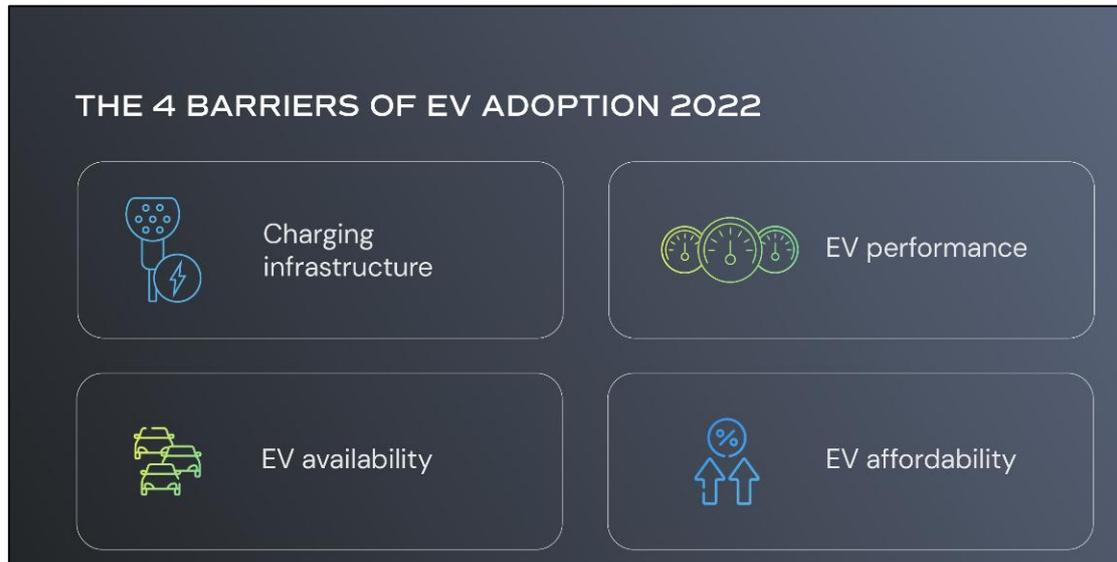


Figure 2. Barriers of Ev Adoption [12]

4.1 Charging Infrastructure

Batteries for electric vehicles (EVs) are supplied by AC energy found in homes. EV batteries have been designed to receive DC packets when being charged. Therefore, the EV's inbuilt AC to DC converter converted into DC packets for use at home. Since the EV may be charged using AC packets due to the inbuilt converter, there are different kinds of DC chargers available worldwide along with the standard home-based DC charger. As shown in Figure 2, these two kinds of charger exist within the broad categories of "Level 1" (slow) and "Level 2" (moderate) charging [4].

4.2 Electrical Vehicle Performance

EVs and gasoline-driven vehicles perform similar functions such as transferring people and goods when they use various forms of energy to operate. The majority of motor vehicles are operated by an internal combustion engine (ICE) and gasoline. However, the electric power supplied by the EV's batteries provides the energy required to start and operate the vehicle. [5] Additionally, an EV's electric power system enables speed modifications based on the surface or weather that the vehicle must travel around. Electric motors are not only the source of electricity for other vehicle systems and components, but also play an essential part in determining effectively an EV operates based on the features of the motor design and the capacity of the car's batteries (i.e., size, weight, number of voltages).

The mechanical power of an electric motor is calculated using its speed and multiplying it by its torque. The speed of a motor is measured in revolutions per minute (RPM) and represents by speed of the motor rotates. The torque signifies the amount of force generated by the motor and is expressed in Newton-Meters (Nm). The two attributes of the motor operate inversely when the power generated by the motor will limit both the speed and the torque generated. The challenge of integrating both the torque and speed of the motor creates a number of decisions that must be made to develop a cost-effective solution to achieve the performance needs of the users. This performance limitation has contributed to slow the development of commercial electric vehicle adoption except specific markets.

Electric vehicles are sold in a range of battery capacities including 17.6 kWh (for a range of about 58 miles on) in the Smart EQ for two to 100 kWh on a Tesla Model S (with a range of about 351 miles). Battery and electric motor size are the contributors to the electric vehicle's overall performance. However, power electronics and software advancements are also key performance factors. The performance of an electronic vehicle can be improved by using smart control techniques in the battery and electric motor that use the same battery and motor formats for a particular application (such as the Smart EQ for Two with 17.6 kWh batteries and the Tesla Model S with 100 kWh batteries). EVs are helped in their operation by lower operating expenses along with to their enhanced performance and efficiency.

4.3 Electrical Vehicle Availability

The widespread use of electric vehicles will continue to be delayed through existing OEMs, early EV innovators and new innovations to the market expand their range of products in all categories from micro mobility to massive industrial due to the lack of diverse and easily accessible EV models.

The process of gasoline-based cars may be referred to as "an ICE Ban" or "an Internal Combustion Engine Ban" [6]. Many governments have passed legislation that limit the sale of diesel cars for new registrations and the majority of countries have set rules for turning out diesel automobiles. The Zero-emission Vehicle Act of 2020 was introduced by the U.S. Senate on October 6, 2020, proposes that all new passenger cars sold in the country be 50% electric by 2025. After that, the percentage would rise by 5% annually until 2035, at when all cars sold in the country would be entirely electric. [7].

5. Implementation of Dynamic EV Charging

Dynamic electric vehicle (EV) charging systems is a new technology that allows the charging of EVs while the vehicle is in motion using a wireless power transfer (WPT) system embedded in the road. This technology has several advantages such as reduction of battery size and time spent on charging, but it also presents several challenges when implemented explained in Table 2.

1. **Cost of Performance:** Effective deployment of dynamic electric vehicle (EV) charging requires significant investment costs for the installation of embedded coils and related components such as roadway conversions, power electronic devices and equipment and a real-time communication system to determine the vehicle's location and the actual charge rate to that location. Therefore, widespread implementation will not be sustainable due to the installation and continuous maintenance expenses, particularly in metropolitan areas or on roads with multiple lanes as the current road infrastructure are not suitable for such large installations.
2. **Scalability of vehicle:** The complexity of the infrastructure needs to modify the road and the possible involvement of energy systems in their implementation to make dynamic EV charging within a highway or urban highway network. The required level of expenditure satisfies the expected demand on that path to ensure that an integrated deployment scheme is required for the implementation of dynamic EV charging within heavy traffic utilization.
3. **Failure Modes:** Dynamic EV charging will have technical problems such as misplaced coils, power electronics, communication problems between the vehicle and the charging station and electromagnetic interference between the charging devices. Technical issues will lead to less effective charging, a negative impact on the battery's capacity to maintain a charge and an imbalance in the stability of the grid. Table 2 represents the components, challenges and reduction methods of dynamic EV.

5.1 Table: Dynamic EV Charging Components, Challenges, and Reduction Strategies

Table 2. Components, Challenges, and Reduction Strategies of Dynamic

Component	Technical Challenge / Failure Mode	Mitigation Strategy
Road-Embedded Coils	Misalignment due to vehicle lateral movement; mechanical damage; wear over time	Adaptive coil design, protective casing, regular maintenance inspections
Power Electronics	Converter or inverter faults, overheating, voltage fluctuations	Redundant systems, thermal management, real-time monitoring, predictive fault detection
Communication System	Loss of vehicle–infrastructure communication, latency issues	Low-latency protocols, error correction, backup communication channels
Magnetic Field / EMF	Electromagnetic interference, human exposure limits, stray flux	Shielding, EMF monitoring, coil optimization, compliance with safety standards
Grid Interface	Localized peak loads, voltage instability, limited grid capacity	Load balancing, smart grid integration, energy buffering, predictive demand management
Vehicle Receiver	Alignment issues, reduced coupling efficiency, hardware failure	Real-time adaptive positioning, feedback control, robust receiver design
Maintenance & Operations	High maintenance cost, road closures for repair, accessibility	Modular and replaceable components, predictive maintenance scheduling, remote diagnostics

6. System Efficiency Losses in Dynamic EV Charging

Additionally providing a new and specific efficiency loss and electromagnetic limitation types when compared to conventional static charging systems. The electric vehicle

(EV) charging system with multiple dynamic wireless charging (DWC) features provide significantly different rates of loss when compared to the current conventional EV charging systems. These factors are important as they have significant effects on five systems' performance, safety, scalability and accessibility.

6.1 Wireless Power Transfer (WPT) Losses

Dynamic Electric Vehicle (EV) Charging depends on induction power transfer (IPT) or Resonant Magnetic Coupling (RMC). Since dynamic EV systems do not provide a direct conductive contact between the EV and the power source (as stationary wireless chargers do), there are various inefficiencies with this technology [figure 3]. These include:

1. **Inefficiency of the Magnetic Coupling:** The receiver coil on the EV will only be magnetically connected with a part of the magnetic flux produced by the transmitter coils attached to the road. This is because some of the magnetic flux penetrates into the ground and surrounding air.
2. **Air Gap Losses:** An air gap between the transmitter coil and the receiver coil of 150-300 mm will have a significant effect on coupling efficiency compared to stationary wireless chargers.
3. **High Frequency Losses:** Large quantities of power can be lost at these frequencies because the skin effect and proximity effect are capable of producing resistive losses within the coils and power electronics.

Thus, as dynamic EV charging systems interact with a vehicle for shorter periods of time, the overall efficiency of the system will be lower when the vehicle is moving at high speeds.

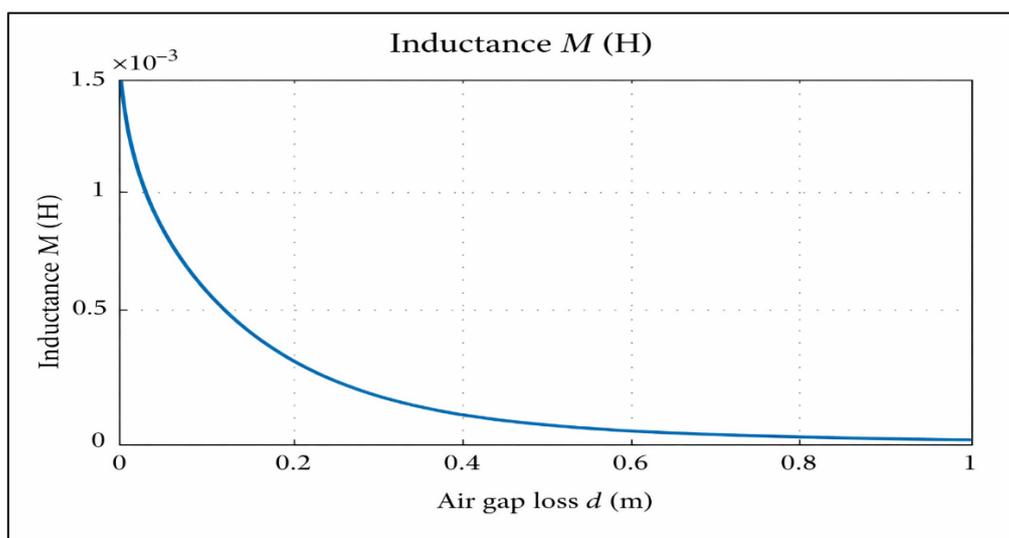


Figure 3. Inductance M (H) vs. Air Gap Loss d (m)

6.2 Misalignment and Dynamic Motion Effects

The misalignment of the transmitter coils buried in the road and the receiver coils installed on the vehicle can cause dynamic electric vehicle (EV) charging systems to lose efficiency. Dynamic charging differs from static charging in the vehicle's location compared to the road transmitter must constantly vary as it drives since dynamic charging does not have a set position.

- **Lateral Misalignment:** Normal operations such as lane based errors, repairs during driving, overtaking and lane changes can cause the coils to move sideways. Even a small side misalignment will significantly reduce the coils' capacity to transmit energy, lowering power transmission efficiency and raising the system's reactive power circulation and potential transient losses.
- **Longitudinal Misalignment:** It happens as a result of the vehicle's speed. The length of time a vehicle interacts with each piece of the road coil depends on the speed that it moves across the road since the coils are divided and each section is switched on at a separate time. While lower speeds may increase connection with the road, higher speeds will reduce the vehicle's time on the coils and its capacity to contribute energy.
- **Vertical Misalignment:** It can be caused by the vehicle's weight (tire wear), vehicle dynamics or poor road conditions (uneven roads). One of the primary

impacts on the amount of energy may be communicated via inductive coupling is the change in level of the ground modifies the distance between the transmitter and receiving coils.

6.3 Power Electronics and Conversion Losses

Power electronics are critical components in the dynamic EV charging systems as they enable the conversion, control and regulation of electrical energy that flows from the utility grid, through the embedded charging infrastructure in the roadway to the vehicle systems. The multiple stages of energy power conversions create an amount of efficiency loss due to the basic dynamic operation. In the infrastructure, grid provides alternating current (AC) must be converted to direct current (DC) and then inverted back to high-frequency AC to supply energy to road-embedded transmitter coils. Each of these conversions results in conduction and switch losses in the IGBT and MOSFET semiconductor devices. The losses are magnified when the devices are switched at higher frequency, because it is more efficient to achieve inductive or resonant coupling at this switching frequency.

The DC/DC converters convert the alternating current (AC) generated in the high-frequency supply to direct current (DC) to provide a charging profile that satisfies the car battery. Diode/synchronous rectifier conduction losses, high-frequency transformer losses and control overhead are the causes of the losses produced in this stage. In the normal working ranges, the dynamic charging pattern have lower operational efficiency because of the lower power levels (compared to a constant rated power supply). Coil activation and deactivation is a continuous process, leading to frequent switching which increases the amount of switching losses at high frequency.

6.4 Grid and System-Level Losses

The electrical grid and the electrical systems that facilitate dynamic EV charging are important to the use of EVs, but they are frequently removed because numerous users fail to consider the long-term effect of the energy efficiency on the entire electrical grid. Static and dynamic EV charging systems differ from the former installed in particular locations and depend on constant power loads, mobile and continuously changing electricity loads to numerous vehicles over a wide geographic area.

Dynamic EV charging creates higher levels of distribution grid losses than static charging because it allows for continuous energizing of several roadside EV charging sections at once. This creates a significant amount of resistive (I^2R) loss and decreases transformer efficiencies in areas with high levels of traffic such as in urban roadways because vehicle movements create rapid load fluctuations as they connect and disconnect from dynamic charging sections.

Additionally, the power electronics are located along roadsides causes large-scale losses throughout the electricity system. Since multiple electric vehicle (EV) charging systems require various power conversion, control and protection components. The total loss experienced in a particular charging system scheduled either electrical power or the total losses for various sections over an extended section of road. As a result of the combined losses across the entire length of roadway used for EV charging, the efficiency of energy transfer from the electric grid through the electronic power devices to the vehicle battery can be substantially reduced.

Load variability caused by traffic density, changes in speeds of vehicles and lane utilization is a key factor of challenges for optimal grid operation. Peak traffic times can produce rises in localized demand where the multiple EVs simultaneously connect to a charging system, creating localized low voltages, increasing the number of reactive losses in the electricity grid.

6.5 Electromagnetic Constraints in Dynamic EV Systems

Electric vehicle (EV) charging methods are used for EM (Electromagnetic) power generation through the production of high power and variable magnetic fields for the purpose to provide wireless energy transfer. Inductive and resonant charging allow immediate energy transmission before these techniques can be used consistently in a public area, additional safety, compatibility and regulatory issues need to be addressed.

6.5.1 Electromagnetic Field (EMF) Exposure and Safety

Dynamic electric vehicle (EV) charging creates electromagnetic fields that vary in intensity over time and space to generate average frequency of magnetic fields (typically being 20 Hz - 100 kHz). Such electric field emissions can reveal the users' vehicles and pedestrians, cyclists, road traffic personnel to electromagnetic radiation. Current research has shown that

these emissions can be limited to values less than the targeted limits that established by international safety guidelines. However, further studies need to be complete the potential additional and long-term exposure effects. It is important that proper approach to ICNIRP standards will be maintained and design limits are required.

6.5.2 Electromagnetic Interference (EMI)

Wireless systems for high power charging have the ability to introduce Electro-Magnetic Interference (EMI) into Electronic Systems.

The following are potential EMI sources in an EV Dynamic environment:

- In-vehicle electronics (Battery Management System, Sensors, Advanced Driver Assistance System (ADAS) Modules).
- Communication links between vehicles and infrastructure (V2I) then vehicles and the Electrical Grid (V2G).
- Communication and signalling devices are near to the roadways. Any interference caused to these systems by uncontrolled EMI can create data corruption, delayed communications or malfunctioning of safety critical systems, especially in high traffic crowded urban environments.

6.5.3 Stray Magnetic Flux and Shielding Requirements

Some of the magnetic field produced by coils that transmitting machine not connected with a receiving machine in a vehicle. It becomes 'stray' magnetic field. Stray magnetic fields have a few disadvantages:

- It decreases the amount of power transferred between two points.
- It increases the level of interaction with electromagnetic fields in next locations.
- It induces electric currents to create heat when there is conductive material nearby (e.g., metal rods used for reinforcing roads, bodies of cars).

As a way to avoid these problems, advanced dynamic electric vehicle systems use advanced shielding techniques with ferrite materials, optimized coil shapes and magnetic field

control. However, these methods increase system complexity, increase cost and additional work for installation.

7. Advanced Battery Technologies

In future, significant and accelerating developments in electric vehicle (EV) battery technology are expected [8]. Research and development activities in improved battery systems have increased due to increasing demand for electric vehicles and sustainable energy solutions. The improvement of EV batteries' energy density, charging efficiency and lifespan durability received an important part as a result of this demand. An essential technical shift is expected to improve overall system efficiency and promote the integration of renewable energy sources into transportation networks is the development of next-generation battery technology. Figure 4 increases the battery capacity into longer travelling ranges for EVs. This improves vehicle usability, lowers range anxiety and supports transportation efficiency with wider impact on society.

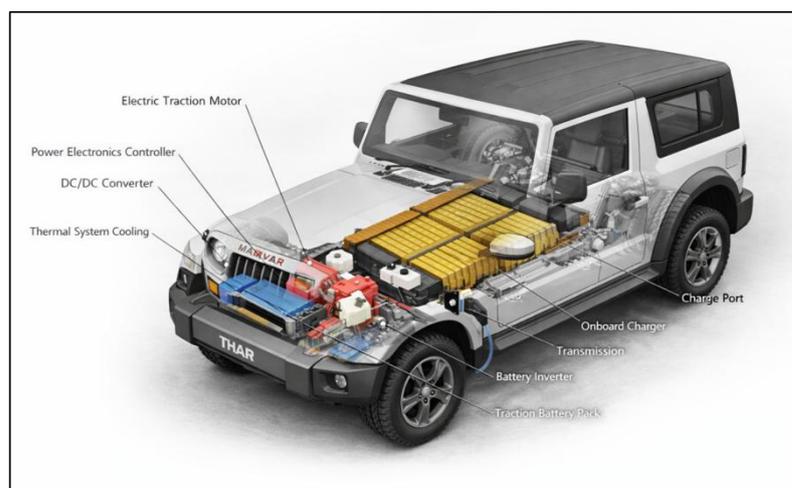


Figure 4. Battery Module's

The technological future of electric vehicle batteries has the potential to make an essential transformation. Developing battery technology has huge opportunities based on the demand for eco-friendly energy and the rate of growth in electric vehicles.

- **Solid State Batteries:** A solid-state battery represents a new generation of energy storage devices and can possibly substitute to the traditional lithium-ion batteries. Both batteries work under the same basic principle as lithium-ion batteries. During the charging process, a solid-state battery will use a solid electrolyte instead of a

liquid. The solid form of an electrolyte has unique advantages over liquid forms such as improved safety standards, more energy density and better thermal stability compared to conventional lithium-ion batteries. However, maintaining stable electrode/electrolyte interfaces develop large quantities of batteries and achieving solid electrolyte conductivity remain major challenges to the development of financially feasible solid-state batteries.

- **Lithium Sulfur Batteries:** Lithium-Sulfur (Li-S) batteries have demonstrated as possible replacements for traditional Li-ion batteries. The low cost and better supply of sulfur will enable Li-S batteries to possess a higher energy density and lower production costs than the traditional Li-ion batteries. Additionally, the increased energy density has many challenges such as corrosion resistance, conductivity characteristics connected with the use of sulfur and battery life cycle of Li-S batteries. There are number of new technologies developed to overcome these challenges
- **Lithium-Ion Battery Technology:** Advances in the material composition of lithium-ion batteries will result in a large increase in their energy storage capacity, decrease in the amount of time required to charge and an extended lifespan are used more widely. The most recent high composition nickel cathodes and silicon anodes belong to the new materials under review for lithium-ion batteries with shorter charge times and higher energy density.

7.1 Reduced Battery Sizing from In-Motion Charging and Its Impact on Advanced Battery Degradation Cycles

The use of dynamic vehicle charging technology changes when EV batteries are used. EVs usually receive stored energy from the chemical source on the vehicle due to dynamically charged wireless energy is transmitted through the roadway. Dynamic charging EVs can receive a continuous supply of electrical energy while they are traveling. The EV can utilize a smaller battery cell without losing its range or utility while driving because of the simultaneous real-time power charging.

7.2 Reduction in Battery Capacity Requirements

Traditional EV battery cells are designed with a buffer for the worst-case situations to travel long distances where charging stations are very few that make the users difficult to find when there is running out of battery. Now-a-days, most of the modern electric vehicles are provided with battery cells with a capacity of 60 and 100 kWh to provide drivers with sufficient range based on their driving style. The concept of in-motion charging is used when an electric vehicle battery is able to serve as a temporary energy source in between dynamic charging station. Research and trial programs have shown that the dynamic charging lanes easily maintain an automated EV's energy with significantly smaller cells in the range of approximately 20 to 40 kWh. A low energy vehicle will result from a lower mass of heavier batteries reduces the manufacturing costs, embedded carbon and the need for essential elements like lithium, nickel and cobalt to make battery cells.

7.3 Altered Charge–Discharge Cycle Characteristics

Degradation of batteries is mainly dependent on cycle depth, charge rate, temperature and cycle frequency. During regular daily use, bigger cells depend on a deep cycle schedules usually reach a state of charge (SOC) that ranges between 60% and 80% of the overall capacity. Deep cycling increases the capacity limitation because of higher solid electrolyte interphase, increased lithium-plating and increased thermal stress. However, vehicles use dynamic charging have both lower and more frequent charge cycles result in SOC with few variations from the optimal range (often 40 to 60%). The result of a shallow cycling method has been indicated to improve cycle life between 2-4 times greater than performing deep cycles within many lithium-ion batteries and lower peak discharge loads can reduce internal resistance losses and thermal gradients in each cell that increased the service life of the battery.

7.4 Implications for Advanced Battery Technologies

The transition to shallow and buffered cycling supports new battery cells are recognized for their long cycle life and fast charge speed.

- Lithium Iron Phosphate (LFP) is suitable for shallow cycling because of its stable cycle life and thermal resistance.

- Lithium-Titanate (LTO) is simple to use and create an ultra-fast-charging and high-cycle-life battery system, even having lower volume than traditional batteries since smaller devices can be charged while the user is moving.
- Solid-State Batteries (SSB) will significantly help the thermal and mechanical stress reduction at the electrode/electrolyte interface.
- Sodium-Ion and Lithium-Sulfur battery systems can be able to initiate production earlier than expected using shallow and buffered cycling than traditional lithium-ion batteries because of their lower energy density.

8. (DLM) Dynamic Load Management of EV

Dynamic Load Management (DLM) is a form of Dynamic Load Balancing. It is a system for dynamically managing the energy supplied to an individual electrical vehicle via EV charger and adjustable in real time. DLM (see DLM Fig. 5) manages the distribution of electrical energy throughout the EV station based on the type of connection for charging the electrical vehicles and allows the charging of electrical vehicles equally assigned for the time that the devices are connected to the charging station. This will provide benefits to the electric vehicle driver and to reduce the quantity of energy supplied to each electric vehicle and reduce the pressure on the EV Charging Point Operators (CPO) [9].

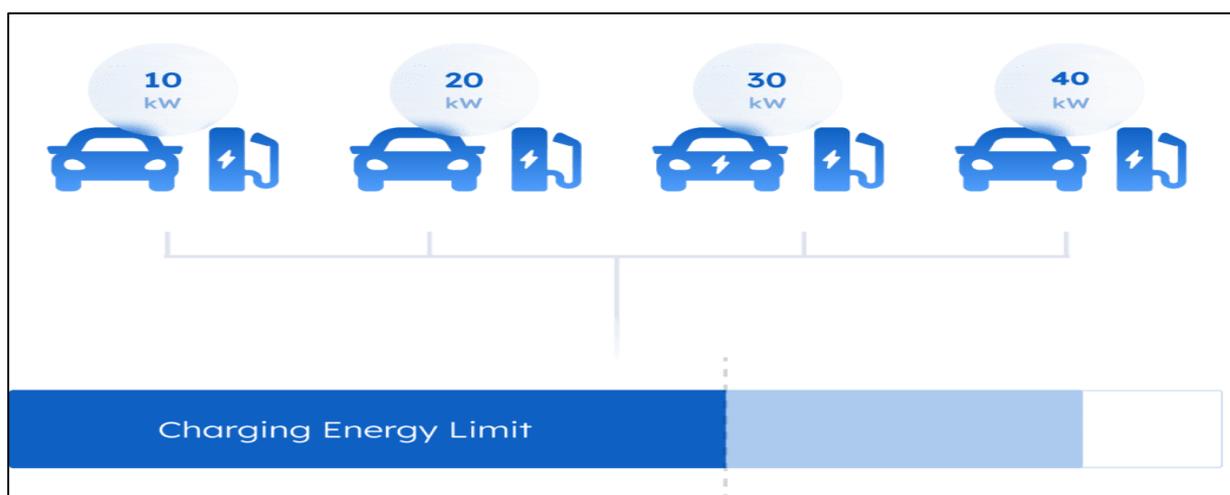


Figure 5. Process of (DLM) [13]

- 1. Latency Requirements:** A rapid data exchange between the vehicles, charging infrastructure and grid is essential for Dynamic Load Management (DLM). Low Latency (i.e., 10 - 100 millisecond) allows the DLM system to respond appropriately to change vehicle speed, lane changes and/or fluctuations in power. The alignment of inductive coils will misalign while charging if latency exceeds permitted limitations. As a result, power transfer and the voltage provided to reduce system performance when it is unstable.
- 2. Communication Protocols:** The reliability of Vehicle-to-Infrastructure (V2I) and Vehicle-to-Grid (V2G) communication is challenging. Some widely used automotive-to-grid methods/protocols are IEC 15118, ISO 15118-20 and OCPP (Open Charge Point Protocol). These protocols allow two-way communication between vehicles and infrastructure/scalable charger networks and various real-time modes of operation including secure logins, monitoring of charge status and control of charging power levels.
- 3. Grid Stability Implications:** Load management algorithms coordinate charging times for multiple EVs to share the load across the distribution system to prevent overload and utilizing renewable energy as possible. Smart grids, energy storage systems, predictive load scheduling and forecasting are used to maintain voltage and frequency consistency across the distribution network.

8.1 Prevention of Electric Grid Overload

Dynamic Load Management (DLM) will use the electrical supply to existing EV charging stations equally for each EV connected to the grid to prevent overloads on the electrical grid because a few EV charging stations will be consuming more energy at high-demand times. DLM will assist local energy providers and also EV charging stations by reducing the system's entire load during high demand.

8.2 Minimization of Utilization

A DLM provides EVs connected to an ECS with equal access that available for electrical resources. All EVs connected to a DLM-compatible ECS simultaneously charge while receiving the maximum quantity of electricity that available from that particular charging station. The number of charging stations in a geographical area indicates the lack of DLM leads to EVs can connect to a charging station. The user should wait for other EVs to finish charging until they can connect to a charging station for long time to acquire a full charge.

9. Case Studies and Practical Implementations in Dynamic Electric Vehicles

This model reviewed a variety of case studies to understand the difficulties and possible applications of dynamic electric vehicles (EVs) in real-life situations [10]. The following examples provide details on dynamic EVs are applied the decision were utilized to achieve the expected results, and these technologies continue to impact transportation and mobility in the future.

9.1 Case Study 1: Dynamic Wireless Charging Pilot in China

A wireless car power test was performed by China. It conducted wireless auto power testing for a high-speed dynamic wireless charging system that will enable electric vehicle (EV) charging as the EV is traveling over roads that contain coils. This will help to minimize the time that EV drivers need to take long breaks for EV charging. There are other issues that faces when implementing this technology and including the efficient transfer of energy at high speeds, minimizing infrastructure cost and expanding the use of this technology across the whole national highway network [5]. The test results show that when EVs use the magnetic resonance technique and smart power management techniques will able to charge with high efficiency allowing for long travel distances through the EV battery. Hence, this technology supports the use of EV in future obtained in Fig 5.

9.2 Case Study 2: Tesla's Supercharging Network and Battery Management

Tesla's electric vehicles have complex battery technologies and rapid charging methods facilitate longe-distances while reducing range anxiety [5]. The Tesla charging infrastructure allows extremely high charging rates for maximum protection of the battery and increased battery durability and performance. The advancements in charging speed, low degradation and reduced overall operating expenses address these main issues affecting the control of electric vehicle. Fig 6 shows the overall electric car sales in different regions during 2001-2024. Tesla provides a comprehensive solution for future implementation of electric vehicles using an integrated approach of expensive hardware and advanced software.

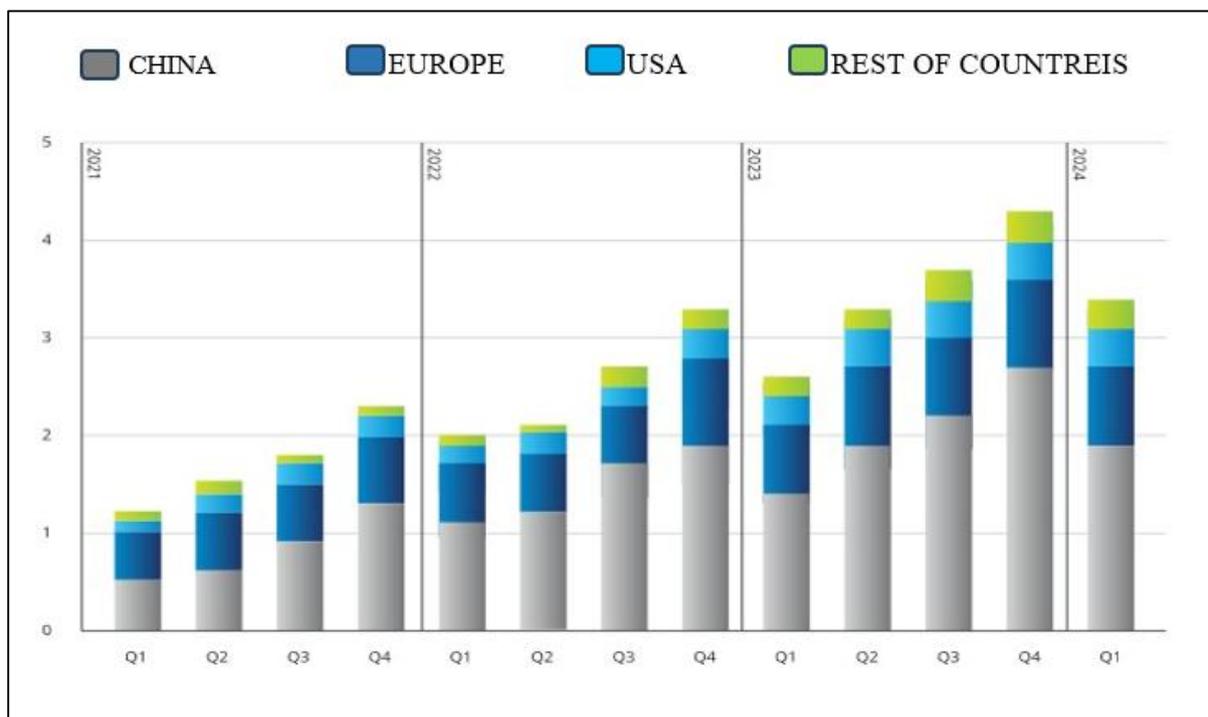


Figure 6. Electric Car Sales by Region (2021-2024)

9.3 Case Study 3: eHighway Project in Europe for Dynamic Charging of Trucks

In Europe, the eHighway project launched the first high voltage power line system in highways to provide hybrid vehicles with the ability to "plug in" to a power grid while driving on the highway network. The hybrid vehicle uses a pantograph to generate electricity from high wires when it is pulled. The open source allows the hybrid vehicle to operate on electricity alone and switch to use diesel when it is not travelling on an electrical highway.

10. Analysis of Static EV Charging vs Dynamic (In-Motion) EV Charging

When comparing static EV charging vs dynamic (in-motion) EV charging, the table 3 illustrates the differences between two technologies for their respective energy transfer mode(s), power transfer technologies, power delivery patterns, system infrastructure requirements, etc. The key difference of static charging is provided to the vehicle when it is parked (not moving) because it uses fixed charging stations then inbuilt conductive AC/DC charging systems. As a result, there is no delays in the installation or removal of static charging stations, but the power load is needed simultaneously creating breakdowns for the vehicle and concentrating a large power load at a single time.

Table 3. Static EV Charging vs Dynamic (In-Motion) EV Charging

Application	Static EV Charging	Dynamic (In-Motion) EV Charging
Energy Transfer Mode	Charging takes place only when the vehicle is parked. IT requires scheduled stops and unavoidable causes of delay when connected to charging.	Energy is transferred while the vehicle in movement that allows continuous operation with minimal change for charging.
Power Transfer Technology	It uses developed conductive AC/DC chargers and limited wireless systems with reliable interoperability standards.	It depends on inductive wireless power transfer embedded in road infrastructure with standards and interoperability under development.
Power Delivery Pattern	When high power arrives over short charging times, particularly while fast charging focused on demands are produced at particular location.	Moderate power continuously supplied on road areas. Over the road, the load distributes physically
System Infrastructure	It requires fixed charging stations with minimal structural modifications making installation and maintenance relatively simple.	It requires embedded coils, roadside converters and control units with installation demanding substantial roadwork and power system improvements.

Dynamic charging enables continuous Energy Transfer (Power Transfer) while the Vehicle is in movement through a combination of embedded Inductive Wireless Technology (ITT) built into roadways (as opposed to AC or DC) and continuous power (Supplied) along the Roadway. However, dynamic charging requires extensive infrastructure improvements and to achieve wide support for the use in initial stage.

11. Discussion

The future of EVs represents a technology that enables electric cars to recharge when they are in movement that provides huge benefits for range anxiety relief, battery size and increased efficiency. Some challenges include high cost in highways, variations in peak

demand for electricity and the lack of standard. The remaining factors used to build the road includes maintaining the road technology, inability to accept changes and environmental factors [12]. The solutions for these challenges include methodical approach involves a collaboration with the public sector, efficiencies improved by technological advancements in the coil technology and alignment, smart networking, global standardization, materials used to make the road reliable and environmental considerations used to constructing the road. The challenges will be solved with innovations that ensures the dynamic electric vehicles are a sustainable aspect of transportation in the future.

12. Conclusion

Dynamic electric vehicle (EV) technology represents an emerging approach for addressing key limitations associated with conventional EV charging paradigms. Dynamic charging systems contribute to reduce range anxiety, lower charging downtime and improved utilization of integrated energy storage by enabling energy transfer during vehicle operation. The significant technical, economic and infrastructural challenges remain, continued research and coordinated development of smart grid integration and control strategies could support the gradual implementation of dynamic EV systems and their role in advancing more efficient and sustainable transportation networks explained in this research work.

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