Wireless Charging for Electric Vehicles: A Review

Tushar Mehndiratta and Rakesh Kumar

Abstract In terms of performance and range, electric vehicles (EVs) have lately improved. Several commercial models are now on the market, and the number of EVs on the road is constantly rising. Although the majority of electric vehicles are currently charged via electric cables, the companies like Tesla, BMW, and Mercedes Benz have started to design and manufacture electric vehicles that are charged wirelessly and that do not necessitate the use of inconvenient wires. Wireless charging further broadens the scope of dynamic charging, which includes charging when driving. When this is discovered, EVs' electric driving range will be unrestricted, and battery capability requirements will be drastically reduced. This has been emphasized and endorsed around the world, with the United Kingdom, Germany, and South Korea leading the way. This study provides a comprehensive analysis of the literature on electric vehicle wireless charging. Wireless charging's key technological components are summed up and equated, including compensation configurations, coil styling, and connectivity. To boost the charging power, a novel way to using superconductivity materials in coil designs is examined, as well as their possible effects on wireless charging. Besides that, the health and safety risks associated with wireless charging, and the rules that regulate them, are addressed. From an economic aspect, the costs of various wireless charging technologies have also been summed up and analyzed.

Keywords Wireless Charging · Electric Vehicle · Wireless Power Transfer · Coupled Magnetic Resonance · Infrastructure Allocation · Charging Station

1 Introduction

Transportation is a major cause of climate change and carbon dioxide emissions. In 2017, transportation accounted for about 60% of global oil usage, necessitating the development of a clean alternative. Electric vehicles (EVs) are a critical component

T. Mehndiratta · R. Kumar (✉)
Automobile Engineering Department, Manipal University Jaipur, Jaipur 303007, India
e-mail: rakesh.kumar@jaipur.manipal.edu

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in the transformation to a green power society [1]. In terms of reliability and range, electric vehicles have come a long way recently. Several models are currently available for purchase on the car market. With the growing number of electric vehicles on the road, figuring out how to power them rapidly and easily remains a difficulty, putting a strain on electric networks. Electric cables are used to charge almost all current electric vehicles. For charging, whether at home or on the road, cables must be physically attached to the EVs [2–4].

The very first wireless device, a wireless lightning lamp, was invented by Nicola Tesla in the late 1800s. Tesla used alternating current (AC) potentials among two metal plates that were near but not touching to power the bulb. This innovation helped pave the way for new wireless charging options. Unresolved technological issues, such as low powered density and low transfer efficiency as distances rise, have hampered the development of this WPT technology [5].

Two advancements in Wireless power transfer technology have enabled wireless charging over ranges greater than 2 m using strongly linked coils after two decades. Inductive and capacitive power transfer are the two most common WPT technologies. Power can be transferred without the use of sturdy links using WPT, which consists of conductive power transfer and inductively power transfer [5, 6].

Several types of wireless charging systems for electric vehicles are static, semi-dynamic, and the dynamic systems of charging. Static charging technologies are equivalent to existing plug-in chargers, but they have several perks, such as the ability to "park and charge" [7]. The conductive charging method is replaced by an on-board acquiring device and a peripheral charging device in the asphalt. While vehicles are in motion, Dynamic WPT systems charge them. According to sources, the necessary capacity of the battery can be lowered by up to 25%, decreasing the upfront cost of a new electric vehicle. As a result, WPT appeals to EVs and has the potential to boost EV adoption [7–9].

Wireless charging system (WCS) can provide additional benefits in terms of simplicity, dependability, and accessibility when compared to plug-in charging solutions. Wireless charging systems have the drawback of being able to be used only when the automobile is stopped or in a static mode, for instance, in parking lots, car ports, or at red lights [10]. Furthermore, stationary Wireless charging system must contend with issues like electromagnetic compatibility (EMC), low power transfer, hefty constructions, shorter range, and higher efficiency. The WCS for EV's interactive method of functioning has been investigated so as to boost the two aspects of range and battery storage capacity. This technology allows for the charging of battery memory modules when the vehicle is moving. The car has a larger range of transportation and requires less expensive battery storage volume [11, 12].

This study focuses on apparently-dynamic and dynamic wireless charging, as previously indicated. While there are a couple of effective electric vehicle systems with wireless charging in the market, like the "KAIST On-Line Electric Vehicle", which are designed specifically for adaptable wireless charging, the bulk of apparent- and dynamic Electric vehicle systems that are charged wirelessly have been converted from fixed wireless charging apparatus or are based on static advances. As a result, for some prototypes and simulation designs, distinguishing the type of wireless charging is difficult. This section discusses some of the treatments that were created for static charging but are now frequently addressed in wireless charging research.

2 State of Art in Research

A variety of obstacles are preventing EV development and adoption. The battery is simultaneously the most vital and the most dangerous component of an electric car. Current electric vehicle batteries are expensive, have a short life duration, have a restricted driving range, and take a long time to charge as compared to ICEV batteries [13]. Additionally, batteries are still frequently large and underutilized, resulting in additional weight, volume, and inventory costs. Battery technology could help enhance battery longevity, power efficiency, and cost-effectiveness [5, 14].

The transfer of energy between an electrical outlet and an electric vehicle during wireless charging is accomplished using an electromagnetic field. There is no direct interaction between the electric vehicle and the source of power when using this charging methodology [15]. The leading disadvantage of this method is that it is less efficient than conductive charging and is more expensive. Wireless charging innovation, on the other hand, has been depicted to be approx. 85% efficient in charging points [15–18]. The main requirement for charging electric vehicles remains the distance it can transmit the charge. Inductive charging, Coupled Magnetic Resonance (CMR), laser, and radio wave are just a few of the charging innovations that have already been established for electric vehicle's batteries. [19].

To charge an electric vehicle wirelessly, the magnetic induction coupling employs the principle of electromagnetic induction. Its configuration consists of two coils. The acquiring coil sends a current to the transmitter coil, which stimulates a current in the transmitting coil, which can be used in charging of the electric vehicle. The transmitting and receiving coils must be close to one other and well linked to increase inductive coupling efficiency [20–22].

Environmental conditions have no effect on IPT systems, making them perfect in any situation and removing the need for maintenance. Due to core failures, the IPT requires ferrites for thermal assistance, requiring this to perform at lower frequency and resulting in a smaller size [23, 24]. Besides that, magnetic induction technology wirelessly transmits power from a stationary transmitter to a large number of relocating secondary receivers [25]. The magnetic coupling effect between the coils varies due to the huge air separation between the transmitter and reception coils. This leads to a loss in system stability due to the changing charging loops of the electrical characteristics. Because of the power requirements, it can hardly be a one-phase or three-phase supply. A wireless power transfer mechanism normally includes the following components: battery, transmitting coil, receiving coil, electrical grid, microcontrollers, sensors system, and related circuit. IPT modules are disseminated or endured based on the magnetic configuration of the coil [25, 26].

The current state of research is examined from a variety of angles:

- Infrastructure allocation for charging.
- Analytical and evaluation techniques for wireless charging technology for extending the driving range.
- A cost–benefit survey of wireless charging for electric vehicles versus alternative modes of transportation.

3 Charging Infrastructure Allocation

In traditional EV systems and operations research, the subject of charging infrastructure distribution or allocation is one of the most effectively addressed subjects. This also applies to electric vehicles that can be charged wirelessly [27]. The allocation problem poses a challenge in providing logistical perspectives to produce reports aimed at ideal charging framework distribution. The allocation issue is divided into two categories: microscopic allocation models and macroscopic allocation models, depending on the extent of the modeling. The microscopic allocation model, also known as micro-allocation, aims to locate the best charging infrastructure position on a vehicle's route or path. The design contemplates scenarios in which electric vehicles (EVs) with wireless charging only move along a defined route or path. The prototype is exemplified with a passenger bus (Fig. 1) [28]. More detailed modeling can be constructed on the basis of this micro-allocation. When determining critical areas for wireless charging routes or power outlets throughout the design stage of a wireless charging transport vehicle, micro-allocation techniques are very effective [29]. The model's goal is to provide a technical tool to help with mechanism findings for the wireless charging-based transport station. The macro-allocation version, often known as macro-allocation, looks at things at a higher level. The main objective of this form of modeling is to deliver scientific glimpse into the wireless charging electric vehicle as a whole, as well as to examine how the integration of EVs into larger transit networks impacts overall traffic behavior [30, 32]. Arithmetical optimization is frequently applied to solve allocation issues, whether they are macroscopic or microscopic. This methodology approach is used to either instantly find charging infrastructure sites or to provide alternative stages of the project of identifying the appropriate allotment. The use of an optimization technique to assess the user equilibrium assignment is an example of the latter circumstance [33, 34]. Despite the fact that Wireless Power Transfer has a variety of technical implementations, their conceptual setups are slightly different from the one shown in the figure, which can be used for both dynamic and quasi-dynamic wireless charging Electric vehicles. The following provides an explanation of the standard configuration's definitions and purposes:

Power Transmitting Unit The charging unit that transmits power to the vehicle via electromagnetic field or magnetic coupling from the grid is referred to as a power transmitting system. It is composed of a transmitting unit—the long track used to transmit power that is typically installed beneath the road—and a power supply unit that transfers grid power to the power track.

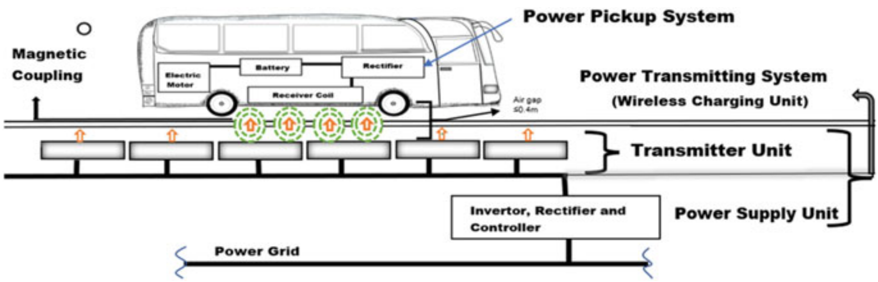

Fig. 1 Configuration of wireless power transfer in EV [20]

Table 1 The distance covered and time needed to fully charge the EV [31]

Scenario speed (km/h)	One coil receiver		Two coils receivers	
	Needed distance (km)	Needed time (h)	Needed distance (km)	Needed time (h)
10	166	40	833	20
100	400	83	2000	41

Power Pickup System The part that acquires power from the power transmitting unit is referred to as the power pickup system. It consists of a receiving coil or the pickup unit that is attached to the underside of the vehicle to obtain power and additional units like rectifiers and regulators that transfer power from the pickup to the traction motor and battery.

According to Table 1, if the lower speed is chosen and two receivers will be used, it will take 20 h to fully charge the vehicle. However, if only one receiver is used, 40 h would be required, assuming that the path is 1666 km long, has a WPT system, and that there is a 1.5 m space between each pair of transmitters. If two receivers are used, the vehicle can only be fully charged on a road that is 833 km long and has a WPT system with the same spacing between the transmitter coils that is 1.5 m. Based on these statistics, the suggested solution can assist in lowering the cost of Wireless power transfer pavement infrastructure and aid in proficiently charging the electric vehicles [31].

4 Driving Range Extension Analyses

This study makes use of a basic driving cycle, which is defined as an acceleration characteristics of a particular type of automobile offered by a government or organization that reflects driving styles. This article provides experiments in which the cost of charging infrastructure is calculated using a generalized driving cycle with the acceptance that the charging infrastructure is ideally assigned [35]. The goal of boosting is to shorten the charging lane's overall length while increasing the life of battery. The model predicts that the amount of protection necessary for power tracks changes dramatically depending on the driving conditions of the vehicles. A car equipped with 8 KWH batter requires only 0.47% reporting under the typical driving cycle condition, however, a heavily loaded vehicle in a mountain terrain needs up to 64.5% of the coverage [35, 36]. Despite the fact that the research does not look at financial expenses, it does analyses the notion of the power track availability in aspects of the reportage of road to obtain a desired range of driving. A case study is conducted out to ascertain the preliminary expenditure of a running of wireless charging electric buses with a driving range of 400 km. The study proposes a sound cost model for investment projects. Simulations and regression are used to determine the expenditure of the power track. Standard driving cycles are first simulated with varied parameters. Regression analysis is then used to analyze the connection between the proportion of charging station coverage over the mandatory road and the status of the battery at the end of the ride using the simulated results. Several scenarios are assessed using various characteristics, including charging facility road coverage, battery capacity, halting periods, and charging power level a 500-kilowatt-hour battery is suggested in the analysis [37]. A dynamic Electric vehicle with wireless charging with a 24 kWh battery is put to the test on three different traffic road contexts, each with its own traffic flow that is intensity speed and length. According to the analysis, the energy delivered to the EV in the city is roughly 0.6 kWh/km on average, but 0.25 kWh/km on the highway [37, 38].

5 Evaluation of Battery Stand by Time

As smaller batteries can be used by the wireless charging electric vehicles, so their adoption may not guarantee the system's long-term economic efficiency [39]. According to studies, the batteries which are too tiny have an adverse impact on battery performance as a whole because they are more susceptible to more-discharging cycles, which accelerate the depletion of battery, and batteries that have short life will need to be replaced more frequently, resulting in higher overall battery costs. As a result, larger batteries could save money in the long term. This little example emphasizes how important it is to consider battery life while constructing wireless charging EV systems. The capacity of a battery diminishes dramatically with time, according to independent studies. As a result, unlike when modeling wireless charging devices in the past, studies no longer consider battery capability as a parameter. Battery capability, on the other hand, must be viewed as a dynamic metric that declines over time [39, 40].

The issue of battery drain was first investigated, but few follow-up studies have been published, owing to the fact that Incorporating battery life into the model results in a strong nonlinear property, rendering the review mathematically irreconcilable and making the development of standard costing and optimal allocation models particularly difficult. Incorporating battery life into the study also demands specialist knowledge of different battery kinds and capabilities. This necessitates increased coordination between battery experts, activities, and systems investigators [41].

6 Conclusion

This report offers the first comprehensive overview of the current status in wireless charging EV operations and systems research. Investigations of present research efforts are crucial since technology and operations and systems-related research are still in their early stages. This surveying has a wide range of applications for researchers, industry, regulatory authorities, and policy experts. This section also goes over the notations, terms, and definitions used in the existing publications before delving deeper into the components of the wireless charging Electric vehicle. Because these ideas and classifications are not yet standardized, technology surveys at this level require precise design. It also demonstrates how variable terms and concepts are utilized in other polls.

The study's primary section reviewed existing journal articles from five distinct points of view: charging infrastructure appropriation, enhancement of the range of driving, evaluations of cost and benefits, existing parameters, and various viewpoints. A single article can be evaluated from multiple perspectives using the perspective-based review method. The most advanced research topic is charging allocation evaluations, which suggest methodologies for ideal charging infrastructure distribution.

Almost all of the journals studied saw dynamic wireless charging as a feasible choice for future electric vehicles. Rapid charging has the potential to reduce the cost of wireless charging infrastructure by simply increasing the charging amount per distance of wireless charging road, allowing as much power to be transmitted with a shorter recharging road. Another crucial topic is the impact of rapid charging on the economics of wireless charging electric vehicles. To summarize, wireless power transfer used to electric cars poses several risks and opportunities. Investigating these difficulties with analytical rigor will be a challenge for the future.

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