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A Survey of Wireless Charging Methods and Optimization Techniques of Electric Vehicles

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Abstract. Since the 1990s, electric vehicles have been extensively utilized, with a focus on extending the life of storage systems, lowering costs, and providing flexible grid connectivity—a feature that is currently being studied. The substitution of alternative energy sources for conventional fuels has resulted in significant advancements in energy conservation and greenhouse gas emission reduction. Electric vehicle power sources are discovered in power plants. Traditionally, the power grid supplies the power plant with its electricity. A power plant that uses a hybrid solar-wind system can save more energy and reduce greenhouse gas emissions more significantly. An overview of the latest wireless charging methods and optimization techniques is given in this article. Firstly, the essential characteristics of an electric car (EV), wireless charging techniques, and the type of charging system that is dependent on the location of the vehicle charging have been provided in detailed descriptions. After that, a few of the most common optimization techniques to determine the location and size of EV charging stations are presented. With a focus on its explicit application in electric vehicles, the paper provided researchers and scholars with an in-depth knowledge of the fundamentals of WPT and its mechanism of operation.

1 Introduction

Five major global trends are driving the rapid development of electric vehicles (EVs):

- Depletion of fossil fuels and the ensuing rise in fuel prices.
- rising public commitment to addressing climate change and awareness of it.
- technological developments and the viability of renewable energy technologies from a business standpoint.
- The development of electronic control systems and electric motors that directly regulate EV propulsion.
- Developments in EV-supporting technologies like Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V).

Due to the global demand for fossil fuels, the majority of nations are shifting to more environmentally friendly, dependable, efficient, and affordable energy sources. EVs are less sensitive to rising oil prices or do not directly emit CO2 [1]. Because they are a major source of CO2 emissions, fossil fuels pose one of the biggest threats to the environment on Earth. According to the International Energy Agency [1] - [5], Figure (1) illustrates the percentage overall of CO2 emissions by the following sectors: (i) electricity and heat, (ii) transportation, (iii) industry, (iv) residential sector, and (v) other areas.

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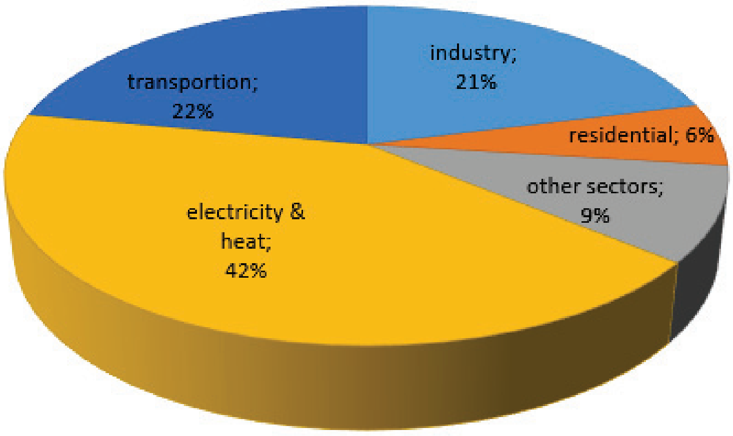

Fig. 1. Emission of CO2 by different sectors [1]

The majority of the electric utility sector should switch to renewable energy sources like solar, wind, and wave/tidal power to address the issue of global emissions. The transportation and energy sectors have benefited more socially and economically from the development of EV technology. Despite these advantages, the main obstacles to the widespread adoption of EVs remain the limitations of battery technology, including weight, lifespan, and storage capacity, as well as high battery cost [6] – [7]. Nonetheless, a large number of nations, organizations, and the automobile industry are funding the advancement of EV battery technologies.

A variety of technological devices are used in our daily lives that have facilitated speed and ease in various ways. These modifications have aided in our progress toward a comfortable future. The transition from a basic bullock cart to the newest electric vehicle was made possible by technological advancements, albeit it took years. These electric vehicles (EV) are showing to be a more preferable option than gas or gasoline-powered cars due to their advantages and comfort. Additionally, plug-in charging has given way to fully wireless charging in terms of the technologies used to charge these kinds of cars [8] – [9].

Because gas and petroleum-powered vehicles are primarily bad for the environment, wireless charging may be a major factor in the decision to phase out these types of vehicles. Even though it took years for various wireless power transfer (WPT) technologies to transfer power efficiently, the basic operating principle of these methods, which mostly rely on the concept of electromagnetic induction is fairly straightforward [10] – [12]. A basic structure of a wireless charging system is displayed in Figure (2).

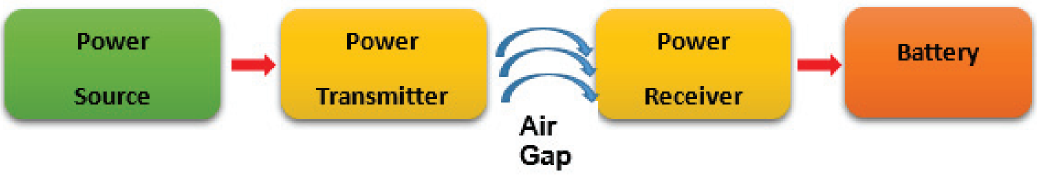

Fig. 2. Basic Structure of Wireless Charging System

2 EV Charging Methods

The three primary methods of charging are battery exchange, wireless charging, and conductive charging. Figure (3) illustrates the further division of Wireless Power Transfer (WPT) into three categories: Static Wireless Power Transfer Charging Technology, Dynamic Wireless Power Charging Technology, and Quasi Dynamic Wireless Power Charging Technology [13] – [14].

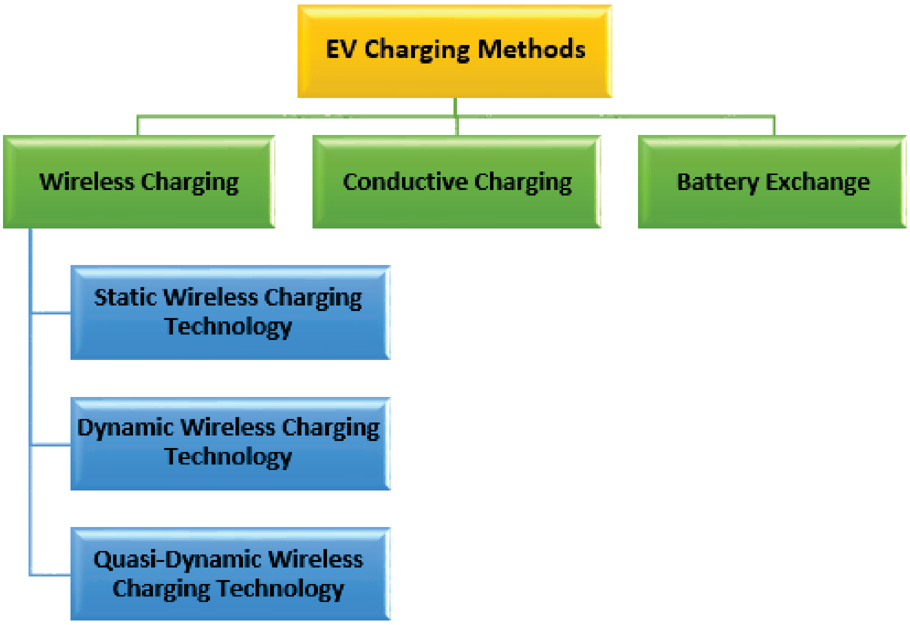

Fig. 3. EVs Charging Methods

3 Wireless Power Transfer (WPT)

"Wireless power transfer" (WPT), as the name indicates, is the process of transmitting power or energy without the need of physical cables or cords to connect the power source to the operating device. The idea of wireless power transfer was first put forth in 1899 by Serbian scientist Nikola Tesla [15] – [16]. He proposed Tesla coils to show how WPT roles. As per the experts' assessment, WPT was Tesla's greatest concept to date. Without the need for cables, he envisioned an international network of towers that could efficiently electrify the entire planet [17] – [19].

Following the concept's introduction, researchers became very interested in the topic. But scientists and researchers are still unable to come up with a workable answer to the issue that Tesla was attempting to solve [20] – [21]. Even though WPT is now feasible, more work needs to be done to increase how far the technology can transfer power in an easy and effective manner. There is no denying that WPT is superior to wired power transfer systems in a number of ways. Chief among them is that WPT boosts efficiency because it does away with the actual connecting wires that are required in wired power transfer systems [16], [22] – [24]. WPT also has the benefits of being easy to design, affordable, and able to function at low frequencies [25] – [28]. Benefits do not come without limitations, though, such as increased power loss, non-directionality, and the inability to operate over greater distances. WPT technology is utilized in newer technological applications like electric vehicles (EV), as well as charging devices like cell phones and light emitting diode (LED) headlights.

A microwave generator, a transmitting system, and a receiving system combine to create a basic WPT system. The WPT system uses a variety of techniques to accomplish its goals. The inductive coupling method [17], magnetic resonance coupling method [17], microwave power [17], and laser/light power [17] are a few of the fundamental techniques for power transfer in WPT systems.

Power transfer distances are referred to as near-field and far-field in systems. Additionally, the near-field operation techniques rely on the principles of resonance and electromagnetic induction [19]. Regarding the far-field operation, the techniques used to attain a greater power transfer in terms of distance rely on the electromagnetic radiation principle. Electric vehicles (EVs) charging is typically done using these WPT techniques as well. An electric vehicle can be charged in three different ways: dynamic, quasi-dynamic, and static. As implied by their name, static charging is the recommended method when the car is at rest or in a stationary position.

There are two types of electric vehicle charging technologies: conductive and inductive. The most widely used technique at the moment is conducting charging, which allows the battery to be recharged anyplace there is a standard charging outlet available. They are also known as plug-in charging systems because all that is required to charge the battery is to plug in the wire [29]–[31]. Inductive charging, or just wireless charging, is the alternative method of charging. The car and the charger do not make any physical contact during the power transfer process using this method. This kind of charging is gaining popularity quickly and may soon be a suitable replacement for wired charging systems. Furthermore, these systems are entirely user-friendly, robust, easy to use, and simple [15].

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3.1 Static Wireless Power Transfer Charging Technology

The most basic type of wireless charging for electric cars is a static WPT. Figure (4a) depicts a basic block diagram for the same. As the name implies, this technique is utilized to charge the car while it is parked. The receiver coil is located inside the car that needs to be charged, and the transmitter coil is located in the wireless charging pads [33]. The high-frequency AC provided by the grid enables power transfer via the wireless charging pads to the vehicle's receiver system. The power is applied to the receiving coil, which transforms HF AC into a steady DC supply that powers the car's batteries [34]– [35]. In both transmitter and receiver systems, components like magnetic planar ferrite plates are employed to enhance magnetic flux distribution.

3.2 Dynamic Wireless Power Charging Technology

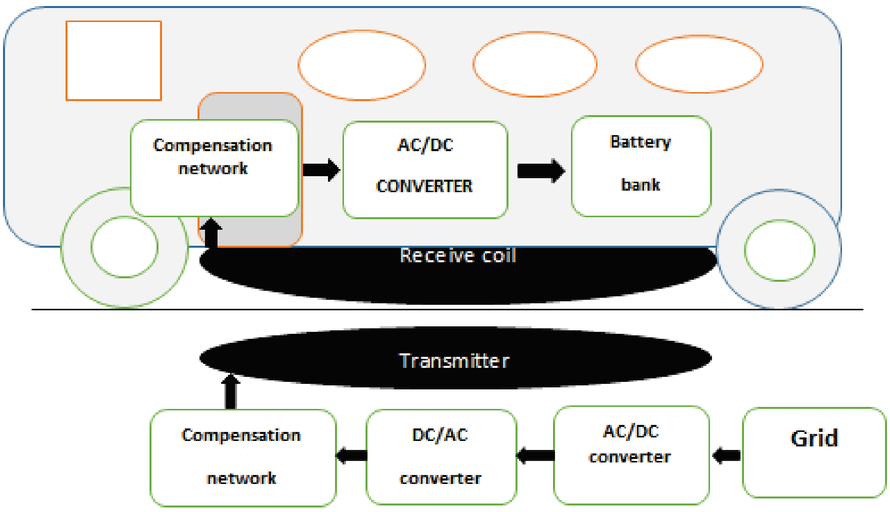
The second method of electromagnetic induction charging for electric vehicles is a dynamic WPT system, which allows charging to occur while the vehicle is moving. While the energy transfer occurs via the Magnetic Resonant Coupling (MRCWPT) method, it is comparable to static charging [17], [32]. High-frequency magnetic fields are produced by the transmitter coils, and the vehicle's receiver coil is coupled with these fluctuating magnetic fields. Consequently, battery charges and magnetic coupling are used to transfer power.

In order to accomplish dynamic charging, entire roads are built as one big transmitter system, and any vehicle traveling on the road, acting as a receiver system, receives a charge as it passes through the system. Because the battery can be charged on demand, dynamic charging offers the advantages of shorter stand-in charge times and a lower depth of discharge, which extend battery life. The battery is also smaller [35]– [38]. This approach to charging electric cars reduces range anxiety and is incredibly dependable and efficient. However, a few things could lower the system's effectiveness: foreign objects on the road; abrasions on the road surface; and modifications to the transmitting coil's coil structure. Dynamic charging is currently only in the experimental stage due to a few unresolved issues. These include flux leakage limitation, applicability of various coil types, selection of universal coil types, and real-time coil misalignment estimation. [32], [39] –[40]. Dynamic charging pads are installed in the roads, and as the car passes over the pads, it begins to charge. Dynamic charging pads are integrated into the road, as shown in Figure (4b), and the vehicle begins to receive charging as soon as it passes over the pods.

3.3 Quasi-Dynamic Wireless Power Charging Technology

The third kind of WPT for EVs is the quasi-dynamic WPT system. This kind of charging occurs when the car is traveling slowly or is stationary for a brief period of time, like when it stops at a traffic light. In terms of operation, this technology is comparable to the static type; that is, the battery is charged via the electromagnetic induction principle [41]–[42].

The receiver is mounted at the bottom of the vehicle, and the transmitter coils are placed where the vehicle stops, like at a traffic signal. The battery receives a brief charge with each brief stop over the charging pad during the brief power transfer. This extends the vehicle's range on a single charge and helps decrease the size of the battery. Figure (4c) displays a systematic diagram of quasi-dynamics.



(a)static wireless charging system for EVs.

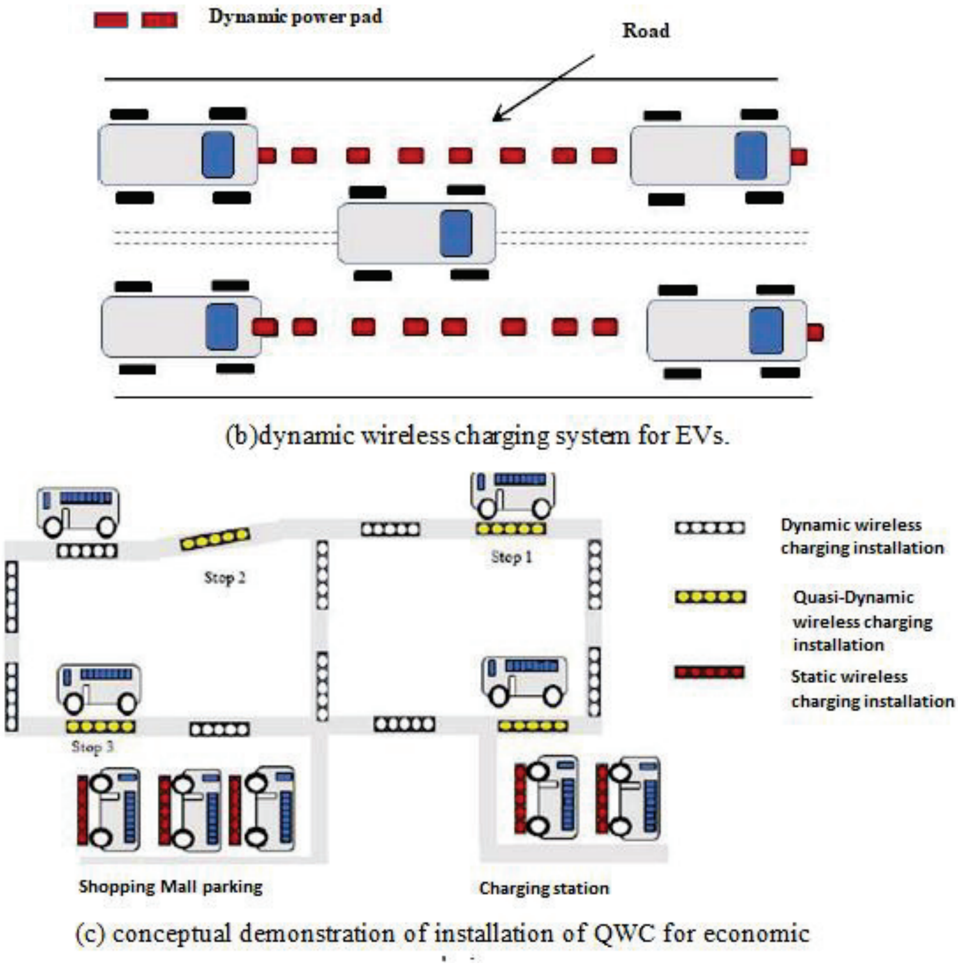


Fig. 4. Types of Wireless Power Transfer of EVs Technology

4 Optimization Techniques

Optimization is the process of precisely determining the value of the solution that minimizes or maximizes the objective function while satisfying the constraint. It is a task that involves searching for a set of decision variables that would minimize or maximize an object function subject to satisfying constraints in others. The widespread use of the smart grid is faced with several challenges due to the adoption of EVs. Thus, optimization is applied to resolve these problems. According to [43] – [45], energy loss could rise by 40% if 60% of all EVs are charged during off-peak hours. This depends on the charging strategies used.

Not only does the EV charging station solve the problem, but it also makes more money when it operates properly. Numerous optimization techniques for electric vehicle charging are documented in the literature. The innovative optimization methods employed in EV charging stations are as follows:

- Practical Swarm Optimization “PSO”
- Genetic Algorithm “GA”
- Simulated Annealing “SA”

These optimization techniques are used to accomplish a range of objectives, such as outage management, mismatch problems between the energy consumption and electricity generation of DG units, power swapping between downstream and upstream, selling power to PEVs to maximize annual profit, designing and placing fast-charging stations, voltage deviation, and parking lot ownership that maximizes profits by meeting specific requirements. The following cutting-edge optimization methods were applied to the distribution of energy resources:

- Mixed Integrated Programming (MIP)
- Mixed Integrated Linear Programming (MILP)
- Second Order Conic Programming (SCOP)
- Maekov Chain Monte Carlo Simulation (MCMCS)
- PSO and Voronoi diagram

- Simulated Annealing Approach (SA)
- Quadratic Programming (QP)

The authors in [46] presented an SA method for intelligent energy resource management from the aggregator point of view using the V2G facility. They then compared the simulation results with those from GAMS and GAMS_N. The aim is to reduce the aggregator operation cost, and the problem is referred to as MILP. Using an IEEE-33 bus test system with 66 distributed generator units (eight fuel cells, four wind farms, two small hydro stations, one waste-to-energy unit, three biomass units, and fifteen cogeneration units), 32 loads, and one thousand grid-able vehicles, the suggested method is validated. While the other approaches require more than five hours, the suggested SA method offers the solution in less than a second. Network simulation does, however, come at a 3% higher total cost than GAMS and GAMS_N.

The authors in [47] suggested utilizing ESS in a rapid charging station to lessen the adverse effect on the power grid during peak hours to keep the operational costs of a fast-charging station low. The optimal capacity of BESS is obtained by treating the suggested design as a mixed-integer linear programming problem (CESS). During off-peak hours, the BESS stores energy from the network and uses it to recharge EVs. Determining the ideal BESS size for a fast-charging station to reduce the station energy cost (SEC) and storage cost is the goal function of the suggested approach.

As EVs gain popularity and are increasingly charged from regular outlets in homes or parking lots, the distribution system will experience increased power loss and voltage deviation due to the uncoordinated charging of these additional electrical loads. To reduce power loss and increase load factor, coordinated charging is therefore suggested [48] – [49]. Using the quadratic programming technique and analysis on the IEEE-34-node test system, the ideal charging profile is found. Nevertheless, by using the Plug-in Hybrid Electric Vehicle “PHEV” reactive power control, this method can extend grid balancing and voltage control. Only loss minimization and load factor maximization can be achieved with the suggested approach.

The authors of [50] employed EVs' storage capacity to lower grid operating costs and wind power generation's erratic nature. Using the proposed stochastic security constraints unit commitment model (SCUC), the hourly coordination of wind power generation and EV operation minimizes the cost of grid operation. Owing to the mobility and grid complexity of V2G, mixed integer programming (MIP) was handled. The IEEE-6 bus and an altered IEEE-118 bus test system are used to evaluate the suggested methodology. But rather than using the BESS as a storage device, the authors only made use of the vehicle's storage capacity. Furthermore, the longevity of the car battery is shortened by frequent charging and discharging.

A three-level Energy Management System (EMS) with primary, secondary, and tertiary levels was proposed by the authors in [51] – [52] in order to reduce the financial costs associated with energy exchange between gird and micro-grid. When a vehicle plugs in, the EMS runs every three hours, minimizing the economic cost of microgrid operation. This is done by forecasting load, weather, and vehicle mobility profiles for the following day. For the next fifteen minutes, the secondary level reduces the forecast deviation between the real and forecast values. There are EMS runs every 30 minutes. To protect against any unforeseen load or fault, the primary level runs every three seconds. It does this by balancing generation and demand. These three management levels allow for the effective management of critical, adjustable, and shiftable loads. When shiftable loads are scheduled for off-peak times, profits are maximized and the economic cost of energy exchange between the grid and micro-grid is reduced. On the other hand, adding BESS to the suggested EMS can increase revenue and effectively handle them as shiftable, adjustable, and critical loads.

One of the biggest obstacles to the adoption of renewable energy systems “RESs” is wind power generation, as was previously mentioned to the intermittent nature of Photovoltaic PV. Because of this, the authors of [53] – [54] suggested a unique optimization strategy to manage the RESs' erratic performance and reduce the grid's power imbalance by coordinating the charging and discharging of EV batteries. The authors employed standard linear programming with a root-mean-square objective function and linear constraints, utilizing energy resources like wind, photovoltaic, and generators. Standard optimization software can compute the problem quickly and efficiently. The optimization is repeatedly computed to revise the V2G/G2V facilities to deal with the prediction error. However, the longevity of an EV's battery is shortened by frequent charging and discharging. The storage system can be integrated into the microgrid to address this power imbalance problem more effectively. Moreover, the ancillary service that produces the CO2 emissions is provided by the diesel generator.

5 Conclusion

Recently, there has been an improvement in the performance and range of electric vehicles (EVs). There are currently a number of commercial models available, and the quantity of EVs on the road is continuously increasing. While most electric vehicles are now charged through electric cables, automakers such as BMW, Tesla, and Mercedes Benz have begun to develop and produce electric vehicles that can be charged wirelessly, eliminating the need for unsightly wires. Dynamic charging, which includes charging while driving, is further expanded by wireless charging. Once this is found, there won't be any limits on the electric driving range of EVs, and the amount of battery capacity needed will be significantly decreased. Aside from that, the health and safety hazards connected to wireless charging are discussed, along with the regulations governing them. This paper went into detail on a modern analysis of EV charging techniques, with a focus on WPT systems. The benefits and drawbacks of current WPT techniques have been explored, as well as WPT methods for wireless charging of applications, particularly in transportation. A brief review of the various wireless charging techniques for EV charging was also included in the paper, with a focus on the techniques' transmission efficiency, power level, range, and energy-carrying medium. After that, a detailed analysis of the significance and impact of the magnetic coupler design for EV wireless charging was conducted. The design of the magnetic coupler, whether it be in track or pad form, is crucial because it determines the power transfer's depth and distance as well as its transmission efficiency.

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