Survey on Wireless Charging and Placement of Stations for Electric Vehicles

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***Abstract*—Electric vehicles(EVs) is a candidate to be the future of world transportation. The idea of changing fuel charged transportation services to electrically charged systems is a breakthrough for efficient energy harnessing, conservation, and smooth energy transformation. Also, it is an effort to reduce detrimental emissions which have corresponding ramifications on a global scale. This directly impacts the present weather conditions plummeting the effects of global warming. In the current age of advanced technologies, there are many organizations which host the manufacturing of these vehicles. However, charging is a well-known problem for EVs. Therefore, several methods have been proposed to charge EVs. One of the conventional way is to charge a vehicle at a stop or a "station." The significant limitations are the time required for charging EVs and shorter traveling distances. Therefore, wireless charging has been proposed. There are several factors which affect the wireless charging. This paper surveyed the works which have been introduced by researchers. Numerous techniques are developed where the EV is charged based on the electromagnetic induction or inductive power transfer. Even though the passive wireless charging is implemented, the main issue which arises is the placements of wireless charging pads as well as the placement of the charging stations. Therefore, the paper introduces implementations and simulations from several research papers that focus on placements of wireless charging sections. Also, the paper describes several challenges to implement these systems. The factors affecting the charging methods and placements of the charging pads and stations are listed in the form of the parameters. The discussion and literature reviews will help the researcher and the general audience to understand the deployment of wireless charging pads or providing eco-routing of electric vehicles.**

***Index Terms*—Inductive power transfer (IPT); Inductive Wireless Power Transfer (WPT); eco-routing; dynamic placements.**

I. Introduction

In continually growing mega-cities, there is an exponential demand for fuel for vehicles used for commuting [1]. Also, in such cases, the greenhouse gas from these vehicles remains one of the significant causes of weather degradation [2]. The emissions from these transporters are causing pessimistic effects on the global weather [2]. Electric Vehicles (EVs) are becoming popular by providing support in such times of crisis. EVs have zero level emissions, but emissions may be produced by the source of electrical power, such as a power plant [3].

On the other hand, to run EVs for long distances, they are required to be charged frequently [4]. Even though EVs are fully charged, they may run for a short or limited period and distance according to their battery capacities. Moreover, for a charging event, EVs need to be ceased at a certain point and charged for a duration, causing an overhead. Therefore, according to [4], owners of EVs mostly prefer to charge their vehicles at home. The researchers, therefore, focus on placements of charging stations which would be dynamic in according to the traffic historical data and develop a system where EVs would be dynamically charged without stopping. This solution for charging enables EVs to drive long distance in the urban areas. Therefore, in the next section, we summarizes some of the significant works in Wireless Charging.

II. Previous Works on Wireless Charging and Infrastructure

In this section, the review of the wireless charging and wireless charging sections/pads placements are provided.

A. Wireless Charging

A significant term noted in all the research papers is Wireless Power Transfer (WPT) or the Inductive Power Transfer (IPT); a simple method of charging the EV through electromagnetic flux where the current is induced through transmitter and receiver coils. The methodologies for implementations of the induction may be different, but the principal for charging the batteries of EV remains the same with air as the medium of transfer. [5], [6] and [7] provide the fundamentals about the IPT, the principle of electromagnetic charging and facets about power management. Along with [8], the technical standards required for sustaining the system and getting the expected results about dynamic placements of wireless chargers through studies of real-time vehicular networks are listed. [9], [10], and [11] describe the basics of wireless charging WPT as focus and methodologies to boost the dynamic outputs from primary coils. The wireless charging can be in two ways, WPT through magnetically induced coils or WPT through electronically induced plates.

[12] starts by specifying the necessity of wireless charging of an EV due to the limited distance the EV travels. It is similar to the concept stated in [13] where the researchers report important energy conserving strategies like installations of a specific number of pads based on the requirements or the demand for charging; and swapping full-charged and discharged batteries. It uses the technique where a truck carries a transmitter coil and travels behind an EV for charging the battery as the EV moves. [13] also introduces the need for dynamic wireless charging to promote more EVs by limiting

the CO_2 emissions (road transportation brings the second largest source of CO_2 after power generation).

[14] proposes a commercial system which focuses on the passive wireless charging of devices. The idea is to apply the same technique (the passive wireless charging) to charge an EV wirelessly. The implemented system is safe and reliable and meets the standards of Qi, PMA, and A4WP which are significant for inductive electrical power transfer or IPT in a range or radius of 4 cm. Devices are charged from a magnetic field induced from source coil. In addition to these standards, for expected IPT or WPT results, an investigation on standards for wireless dynamic charging are listed in [8].

B. Infrastructure

Another focus is on the infrastructure of the system. Three charging models are employed for charging of EVS. [15] provides the term, State of Charge (SOC) which gives the current status of the battery of the EV. If the SOC falls below a set of predefined threshold values, then the driver heads to the nearest charging station. The extended two models are based on the facet where the energy computations are done before reaching to the destination along with measurement of energy calculation to the nearest charging station. Through the models and viewpoints stated above, [15] concludes by stating the system should consider not only dynamic deployment of wireless charging stations but also demand or requirement to charge the batteries.

To overcome crisis like shortage in resources and climate degradation due to heavy road transport emissions, [16], [17], [18] and [19] provide a solution in the form of a deployment model for charging stations in two stages. Based on the maximum flow algorithm and a greedy model, like an algorithm stated in [20], optimal charging stations are identified which considers real-time traffic, then Flow Refueling Location Model outputs the location of the wireless charging pads to a particular map-based scenario.

[21] builds an environment for Electric buses. Dynamic charging is attained by installing the wireless transfer pads in a selected portion of roads as shown in Fig. 1. Through such installment, IPT occurs, charging the battery pack of buses as they commute. The size of the battery is majorly considered which acts as a variable for distinct buses. A similar concept is observed in [22] as well as in [23]. These both systems illustrate methods which try to optimize the battery efficiency based on the number of stops that the bus makes as well as the time for which bus waits at a specific stop. This leads to minimizing the time required to charge the battery to expected levels for a trip. Also, onboard checking is done for energy levels, and the corresponding decisions are made to state if the driver needs to make a trip to a charging station. Based on the frequency of stops, where the passengers board or debus, the charging stations are identified. Transmitters are visible to drivers, the point where buses stop for the longest time at the center of coils. An essential factor to consider is the time, for example; charging vehicles in garages at the mornings and after the service ends; charging vehicles at wireless charging sections/pads during servicing. Based on analysis of the frequency of the vehicle stops, the stations are identified for placing wireless charging pads. The motive is to provide services only when on demand rather than providing service all the time. A pivotal facet stated in [22] is that the installation costs are minimal if the battery size of an electric vehicle is large. [24] and [25] also possess similar research. In addition to bus systems, [26] explains the research works of several current commercial based applications. It scrutinizes and provides an evaluation of the systems, thereby also explaining details of WPT and IPT.

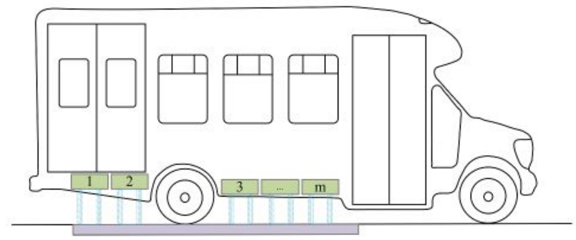

Fig. 1. Dynamic Wireless Charging (IPT) for an Electric Bus [23].

[27] and [28] show the research works on the data produced by four different dynamo meters. For experiment, based on IPT, a two coil wired system is installed on a road as shown in Fig. 2. The EV is passed on this road with different velocities, gradients, distances, and several other parameters. The researches provide a proof stating the dynamic wireless power transfer or WPT can be given in terms of average speed. This ultimately helps in re-sizing the number of coils and computation of current energy requirements for each trip the EV makes.

Fig. 2. The experimental of the passage of an EV through a two-coil track [27].

[29], [30], [31], and [32] focus on the selection of a candidate which is a wireless charging unit for an EV. The authors use integer programming and an approximate algorithm for computing these stations based on the status of vehicle, whether it is static or mobile. In [33], another similar algorithm is proposed for dynamic charging using both fuel and electric based-vehicles. Based on the traveling cost estimation and limit of the distance, different modes or " mixed" modes are used ensuring the EV's battery utilization is optimal. Specific to [31], the static wireless charging stations are replicated which defines the dynamic placements of transmitters for charging the batteries of EV.

[34] provides a system designed to reduce the adverse effects of emissions at airports, specifically experimented at the Stuttgart Airport, Germany. A grid powered coils are installed at the spots where specific areas are selected for simulation and experimental purposes [34]. The primary motive is to transform the fuel-powered devices to the electrically powered devices which has zero percent emissions thus also helping in improvising the quality of air as well as air transport services. Fig. 3 states the design of the system.

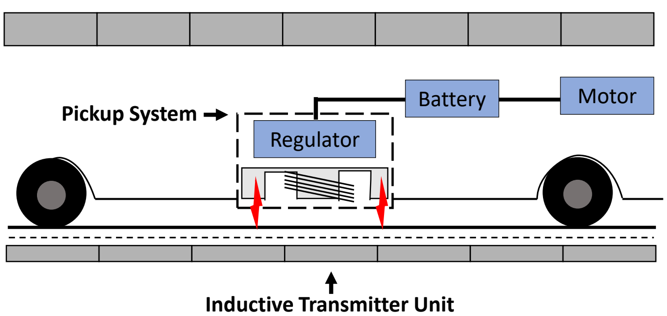

Fig. 3. The system components for dynamic charging [34]

[35] provides a different approach for dynamic charging. In this approach, it is considered there are a number of lanes through the vehicles commute. A distinct lane is reserved for EVs. The coils are installed below the pavement and EVs travel through these pavement areas while commuting. Simulations and graphical results are provided for this purpose which portray the dynamic charging results. This system is similar to [36], Qualcomm Halo where irrespective of speed and direction of vehicle, the batteries of EVs are charged accordingly.

[37] introduces the six necessary protocols of communication-based on WiFi Enabled Network where vehicular communication takes place. [37] also exhibits a complex infrastructure for two network models, ad-hoc interconnected network and inter-vehicular network. For the benefit of dynamic charging, such communication can be a bright side to check the availability of charging stations or provide charging stations on demand leading to the creation of an optimistic energy saving and harnessing system. [38] provides a similar kind of solution where vehicles are notified about available charging stations based on a communication model using genetic programming.

[17] and [39] address one of the most significant limitations of the system, the strain on the electric grid for generating extensive amounts of power for charging stations in a smart city. [17] and [39] satiate the demand by encouraging the use of renewable energy resources. The both studies have suggested the use of solar panels to harness solar energy and charge the wireless charging pads as per the requirements. An extension to the idea can be stated as communicating the vehicle and providing the nearest available solar panel grids for charging on the go.

In [40], an estimation of cost is discussed if a full-fledged system was to be implemented. Also, [41] and [42] describe the structure of the charging system which is made up of various components to contribute to wireless charging. They also provide a novel idea where the receiver coils are installed in the tire or wheels of the vehicle. This is advantageous as the coils will be in proximity to the transmitter coils promoting faster charging.

III. Significant Parameters for Wireless Charging

Research for the survey began from the basic concepts along with principles of electromagnetism [12], [24], [8]. Intelligible research works based on current commercial systems which advocated the technology of magnetically induced currents to charge batteries were utilized. As the researches reach advanced level, the theory of the IPT surfaced [10], [12]. Deep scrutiny of the working of the existing systems was followed where different charging methods were acknowledged. This ongoing research led to the foundation of the idea of the dynamic charging which listed several factors or parameters responsible for wireless charging of an EV. These parameters focus on the accuracy of the dynamic charging for the EVs. Also, these are indeed responsible for the expected system results. In the following subsections, the parameters which affect the wireless charging are explained.

A. Speed

The primary parameter observed is the "speed" [23]. The speed of the vehicle is a crucial and significant factor for charging the batteries [23]. With the help of advanced technologies, the effect of the vehicle speed, as a parameter is tried to be reduced, and some of them are successful [36]. But it is seldom limited to a few institutes or organizations. Qualcomm Halo which is implemented by Qualcomm [36] would be a good example. Qualcomm transmitters or an electromagnetic system are installed on a roadway. This system included BAN blocks, Power Distribution Backbone, and Power Supplies carrying current and capable of inducing charge resulting in charging of an EV battery for one hundred meters. The car could move forward or backward with 120 km/h speed by receiving 20kW. The limitation observed in the system is the cost required to build or install the system to be in operation.

B. Positioning

Charging of an EV while moving is also affected by positioning. The power can only be transferred to the EV effectively where an EV should be placed on a certain position on a charging pad while it is commuting. It should be positioned in such a way that the EV exploits the charging levels to its maximum extent. Hence, another significant parameter is the position of an EV on the charging pad [42]. An EV may experience an eighty percent of the charging capacity if it is positioned close to the accurate or expected placement of an EV. If this case is out of accuracy, the charging levels may be expected to be as low as thirty percent [42].

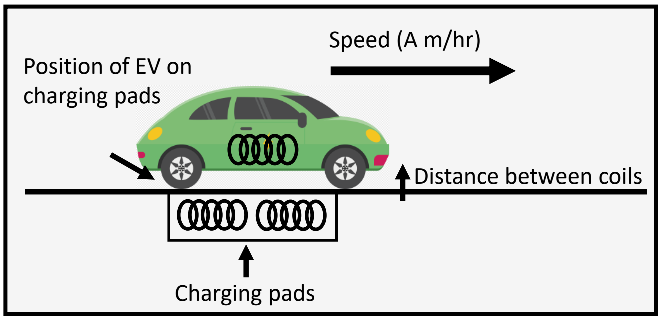

Fig. 4. Three Major Parameters of the System.

C. Distance between Coils

Distance is pivotal to the rate of charge per unit time. Hence, the third primary parameter is the distance between the transmitter and receiver coil. The transmitter coils are installed in the road or a distinct source of IPT-current, and the receiver coils are set up in the cars. The distance between these coils is of the utmost important parameter for deciding the intensity of charging an EV battery (shown in Fig. 4). This parameter determines the rate of charging EV. In addition, this is observed to be one of the crucial challenges [43] to get the coveted outputs.

The distance in an inductive charging is pivotal when coupled with the speed and position of an EV on a charging pad as explained in [16], [23]. The condition and types of the roads matter for the speed limit [21], [27] to be computed. Hence, there may be different speed limits based on different types of roads for better charging (different dynamo meters state distinct kind of roads). To provide an example, a speed limit can be 60-80 on Highways for efficient charging compared to speed limit like 40-50 on Streets and Avenues in the cities. Moreover, as the vehicle commutes through the roadways, the receiver coil should be at a minimal distance like 0.5 meters to the installed transmitter coils in the charging pads [21], [17]. This indeed again depends on the conditions of the roads. This distance varies according to the gradients and curves of the streets. Additionally, the EV should pass directly over of the charging pads while moving. If the EV charging management effectively arrange these three parameters which are explained and shown in Fig. 4, the energy lost would be limited.

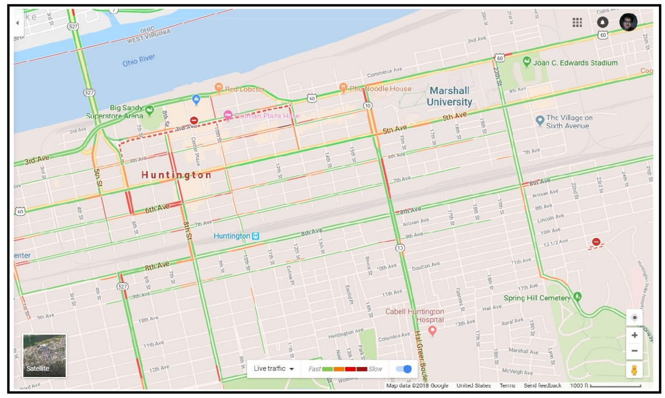

Fig. 5. Live Traffic in Huntington, West Virginia.

D. Traffic

An important note to cite would be the EV travels along with a number of other vehicles. Fig. 5 is an excerpt of the Google Maps showing live traffic in Huntington, West Virginia which was observed during a mid-day of a weekday. In the stated Google Map, some road segments has low, average or high traffic. If there are wireless charging sections on those roads and EVs travel through those areas, the charging levels of the batteries will be distinct because of traffic. This was also observed in [16], [23].

E. The Number of Stations and Coils

Identification of the number of stations in a city is another significant parameter. The placement of the charging pads is a quantifiable parameter and can be computed after completion of specific on-site research work. As seen in the Google Traffic Live Data Feed in Fig. 5, a higher number of charging pads can be placed in areas showing higher traffic [27], [29]. Places having less traffic can be placed with passive stations or lower number of charging pads. The primary motive of computing these pads is using the system's power efficiently and averting the power wastage.

The power transfer depends mainly on the coil, air as the medium of transfer, and there is an element of flux leakage [15]. To avoid power loss, the receiver coils are divided into n groups [23], [27], [34]. This analogy is like a coaxial cable carrying signals to transfer from one end to another. Suppose there is a transmitter coil of 20KW in transmitter coil, then there can be five coil groups, each capacity with 4KW. This exemplifies how the number of coils is significant to the system [5]. However, the number of coils notably varies where a gradient is observed on the road.

F. Road Gradient

A gradient on the road can also be used effectively to for coil pad placements as shown in Fig. 6. For a slope, more coils can be installed as the time taken by a car to pass over a charging pad. A small-time frame is generated compared to a road not having any gradients. The charging time can be minimized based on two pivotal data points: the distance

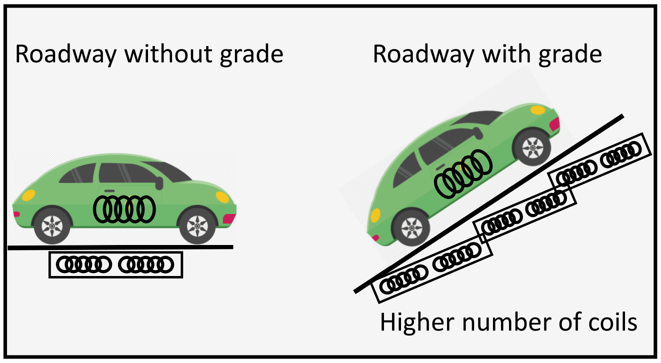

Fig. 6. Difference between Placements of Coils on a Roadway with and without a gradient.

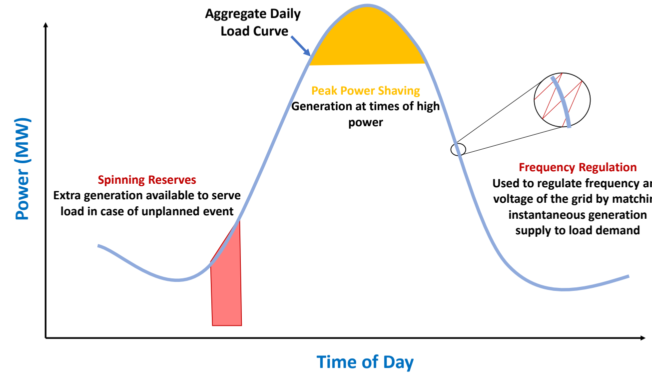

Fig. 7. Impact of the parameter time on dynamic charging of EVs [44].

between the coils and the condition of the roads [17]. For gradients or slopes , the number of coils can be increased or decreased as the fraction of time the EV passes can be more or less [27], [38]. Also, based on the frequency of vehicles [15], the number of coils in a particular slot may be increased or decreased to save energy. Stating these points, the distance between the coils and condition of the roads prove to be significant parameters indeed.

G. Battery Size and Coil Position

From an infrastructural point of view, different EVs have different charging capacities. This is due to varying sizes of the batteries [5]. Larger the battery is, longer is the traveling time, but also longer charging time [15]. The size of the battery becomes additional parameter in such a case where the charging time during commuting gets affected [30], [25]. Moreover, the position coils of an EV is of utmost importance as it achieve higher rates charging [23], [31]. If the EV is not properly placed on the desired area to be charged, the EV may take more time than expected to charge or even may not charge as it may be out of radius of charging [23], [31].

H. Day Time

Another essential parameter is the time (also directly depends on traffic) while the EV charges. This parameter was obtained from the research work acquired from the National Renewable Energy Laboratory (NREL) and Oak Ridge National Laboratory (ORNL) research [44]. Based on a scenario like daytime, the roads in the cities may experience more traffic [16], [28], [7]. In such case, such areas can be identified as the candidates for wireless charging pads [27], [24]. Similarly, in mornings or evenings, before and after services commences and ceases, electric buses can be subjected to charging in garages or service stations. As shown in Fig. 7, a load factor of power supply must be planned to provide enough power at different times of the day. Based on the time of the day, more optimistic decisions can be made which may help in building an efficient energy saving dynamic charging system for EVs.

Conclusion

Duration of Charging of Electric Vehicles is a limitation and does not allow Electric Vehicles to be widely adopted by public. Therefore, wireless charging is crucial for Electric Vehicles in order to overcome the charging duration problem. In this paper, we surveyed a number of research works and summarized the current state of the art in electric vehicle wireless charging and the parameters for charging section deployments. The most important parameters for electric vehicle wireless charging are speed, traffic, the distance between charging sections and coils, the number of coils, the position of the coils on EV, battery sizes, the road condition, and the time for charging. Our short survey study would help the new and interested researchers in the field of electric vehicles wireless charging to easily understand the current research works and the important parameters.

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