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Electrified Road for Charging Electric Vehicle Wirelessly

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Abstract: The recent development in simulation speed and capacity of magnetic field, and the power electronics, the field of wireless power transfer has been developed significantly. In the future transport area, electric vehicles are considered as replacement of oil-powered internal combustion engine driven vehicles, especially for the CO2 reduction and alternative energy perspective. However, electric vehicle requires several key issues resolved in view of the heavy weight, bulky volume, and limited driving distance. In this paper, the innovative on-road dynamic wireless charging technology for electric vehicle, called OLEV, is introduced. The electric vehicle charging technology can be classified as conductive or wireless, stationary or dynamic, and slow or fast. The fast charging in the range of 100 kW of power capacity and wireless dynamic charging concept are described. Also the design concept, system architecture and development process of optimizing the magnetic flux field for the higher power transfer efficiency are described in this paper. The dynamic charging technology is also compared with the stationary conductive charging for electric vehicles, in view of its development concept and status, and practical feasibility of the innovative technology. Energy is transferred from two tracks of rail in the road via a movable arm attached to the bottom of a vehicle. The design is not dissimilar to that of a Scalextric track, although should the vehicle overtake, the arm is automatically disconnected.

Keywords: Wireless charging, Wireless power transfer, EV charging infrastructure, demonstration; instrumentation, electric road, Electric Road System, Inductive Power Transfer

I. INTRODUCTION

Nowadays, the depletion of fossil fuels and the phenomena of global warming are key factors that push us to change our modes of transportation. Vehicle-based internal combustion engines are no longer desired, they contribute significantly to climate changes, and they are dependent to the petroleum product. The electric vehicle (EV) is an alternative choice, it can be considered as a suitable method for a sustainable transportation, it has the advantage of zero emissions and it is powered by electricity which can be considered as a renewable energy. However, the basic configuration of an EV contains a rechargeable battery pack which can be considered as its main drawback. The battery needs to be recharged frequently because of its low capacity, thus the charging operation takes several hours, which reduce the driving range of the EV and limit its success in the market. Several methods are used to recharge EV batteries. In the conductive charging, the power is transferred efficiently to the vehicle by cables, but the user must intervene in this operation which is dangerous in certain specific conditions such as snow and rain that can cause electric shocks. Powering an electric vehicle using the wireless method is much easier and safer for the user, thus, the absence of physical contact (no mechanical friction) can prolong the product life and reduce its maintenance. The wireless power transfer (WPT) can be in a stationary or dynamic way. In stationary mode, the vehicle is wirelessly charged while parked in a location (parking or garage) equipped with a specialized power utility. The dynamic charging which means that the vehicle can be recharged while moving is invented as an attempt to reduce the size of the battery (i.e. reduce long charging times and vehicle weight) and extend the vehicle driving range. In general, the electric field (EF) and the magnetic field (MF) are used in the wireless power transfer. In the inductively coupled power transfer (ICPT) method, the power is transferred wirelessly between separated coils via MF, while the capacitive power transfer (CPT) relies on the EF to transfer power between two pairs of metal plates. Recently, several automobile manufacturers are adopting the WPT charging method, especially the ICPT, one can quote Toyota, Nissan,Chevrolet, Audi, and BMW. The CPT has been widely used in applications where low powers (few watts) and short distances (few mm) are required but despite these limitations several recent researches are devoted to make it a suitable method for EV applications. Transportation is a necessity and facilitator for people to meet their needs in today's society. At the same time, side effects of the current, fossil-based transport system, such as emissions of carbon dioxide, particulate matters, nitrogen and sulfur oxides, undermine human health as well as eco-system quality. In the EU, the transportation sector accounts for one third of the total energy use and one fifth of all greenhouse gas (GHG) emissions. At the same time, living up to the Paris Agreement requires drastic emission reductions and Europe wants to be the leading region in the transition towards a sustainable society. Electrification of vehicles has been pointed out as a key factor for success, due to zero exhaust emissions in the use phase. However, there are still sustainability constraints in other life-cycle phases. So far, most attention has focused on electric vehicles (EVs) for passenger transport. Still, trucks accountfor25%ofGHGemissionsofEU'stransport sector and the number of heavy trucks, especially, is increasing more and more. Battery electric vehicles are often regarded as the main solution and several fully electric, battery-powered trucks have been presented to the public, for example the Tesla Semi and the

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Nikola One. Enabling a heavy truck to drive 800 km on one charge, however, requires large batteries. Batteries have a substantial sustainability impact during their life-cycle, at least with current designs. Also, the substitution of today's global truck fleet with battery-powered Also, the substitution of today's global truck fleet with battery-powered freight transport is limited by resource constraints, especially considering metals like cobalt and lithium. In addition, the batteries account for a major part of the vehicle cost, which is one of the largest barriers for the introduction of EVs. Electric Road Systems (ERS)—defined as roads that support dynamic power transfer from the road to vehicles while the vehicles are in motion—could be a supplement to overcoming some of the challenges of battery EVs. Still, it is important to reflect on the original aim of pursuing EV technology, namely making the transition towards a sustainable transport system, and to investigate if and how ERS can contribute to reaching this aim. Previous studies have so far investigated technical aspects of ERS or conducted environmental comparisons based on specific life-cycle stages, focusing on the potential for GHG emission reductions.

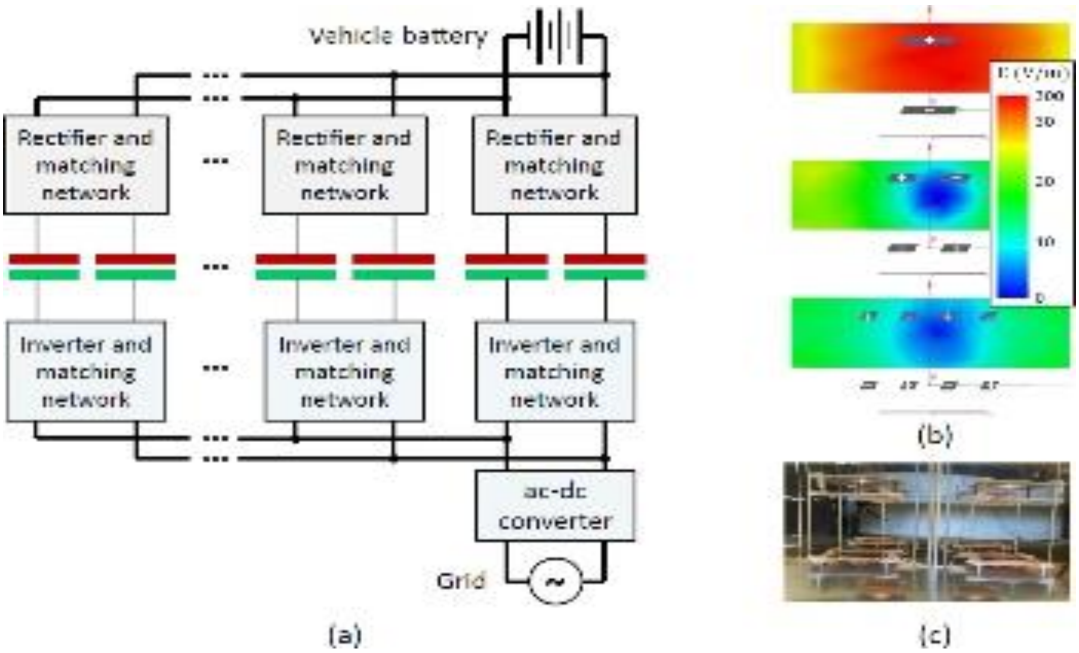

Fig- 1: Wireless Charging of Electric Vehicles

II. MECHANISM OF WIRELESS CHARGING FOR ELECTRIC VEHICLE

Near-field WPT systems are of two types: inductive, which use magnetic field coupling between conducting coils, and capacitive, which use electric field coupling between conducting plates to transfer energy. For medium-range applications (in which the distance between the transmitter and the receiver couplers is comparable to the size of the couplers, as in EV charging), inductive WPT systems have traditionally been preferred. Physical implementation (left) and block diagram representation (right) of two approaches to deliver energy wirelessly to electric vehicles from an electrified roadway: (a) inductive wireless power transfer (WPT) using coils (embedded in the roadway. Building on work done for material handling applications during the 1990s, the past decade has seen tremendous progress in inductive WPT technology for stationary charging of EV. Aftermarket stationary chargers are already available, and some EV manufacturers have announced plans to introduce built-in stationary inductive WPT systems as early as 2018. However, for magnetic flux guidance and shielding, inductive WPT systems require ferrite cores, making them expensive and bulky. Also, to limit losses in the ferrites, the operating frequencies of these systems are kept under 100 kHz, resulting in large coils and low power transfer densities. The high cost and low power transfer density are particularly problematic for dynamic WPT, as these systems need to have very high power capability to deliver sufficient energy to the vehicle during its very brief time passing over a charging coil. For these reasons dynamic inductive WPT is yet to become commercially viable, although a few experimental systems have been demonstrated. To achieve effective power transfer, WPT systems need to operate close to the resonant frequency of the resonant tank formed by the reactance (capacitive and inductive) of the coupler and compensating network. However, the coupler reactance depends on the vehicle's road clearance, and varies as the vehicle moves across the charger. The drift between resonant and operating frequency causes a reduction in power transfer and WPT system efficiency. In WPT systems that operate at frequencies below 100 kHz, where bandwidths are not restrictive, the traditional way to deal with variations in coupling is to change the operating

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frequency to track the resonant frequency. But in high-frequency WPT systems the operating frequency must stay within one of the designated, very restrictive industrial, scientific, and medical (ISM) bands. One solution, employed in low-power inductive WPT systems, is to use a bank of capacitors that can be switched in and out of the compensating network, to keep the resonant frequency roughly unchanged as the transmitter and receiver move relative to each other. But this is not an effective approach for higher-power WPT systems as the switches have to be much bigger and more expensive to keep the system efficient. This approach is also less suited to capacitive WPT because it requires multiple switchable compensating inductors, which are bigger than capacitors.

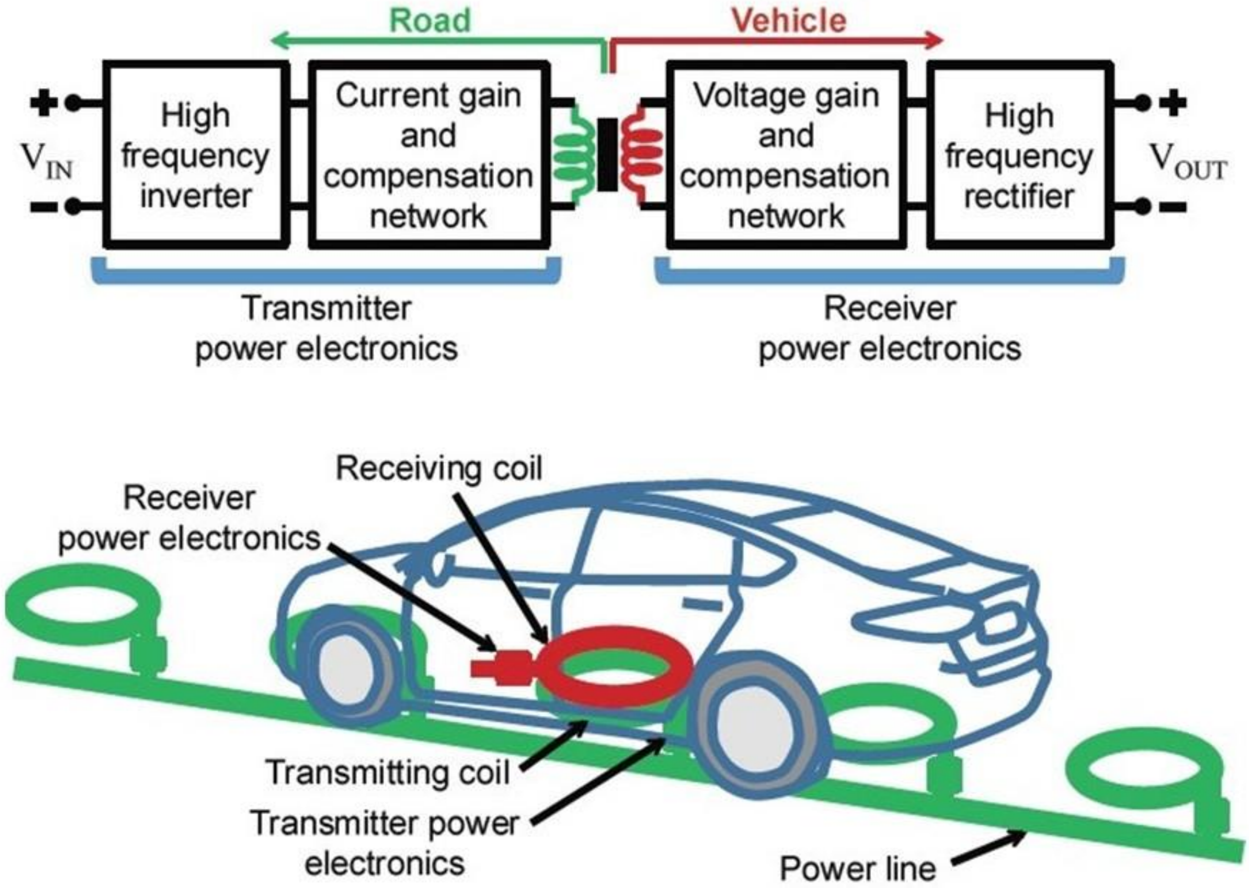

Fig- 2: Working Principle of Wireless Charging.

III. ACHIEVING SAFE AND EFFICIENT POWER TRANSFER

The size of the couplers in WPT systems can be reduced and the power transfer density increased by designing the systems to operate at higher frequencies. In inductive systems the increase in induced voltage with higher frequency compensates for the reduced mutual inductance of the smaller coils, and in capacitive systems the increase in displacement current with higher frequency compensates for the smaller plates' lower capacitance. Higher operating frequencies also enable smaller power electronics associated with WPT systems thanks to a decrease in energy storage requirements. But achieving high efficiencies at high switching frequencies is very challenging. And the fringing fields of WPT systems must be within safe levels (as defined by the International Commission on Non-Ionizing Radiation Protection; in areas occupied by people and animals (e.g., the vehicle cabin and outside the perimeter of the chassis). These requirements for capacitive WPT systems can be met through circuit stages that provide appropriate voltage and current gain (to reduce displacement currents) as well as reactive compensation. An active area of research is the design of these circuit stages Our work in this area has explored approaches utilizing multistage matching networks that can simultaneously provide gain and compensation. We have discovered that, depending on the ratio of the system input and output voltages, there is an optimal number of stages that maximizes efficiency, and we have identified the optimal distribution of gain and compensation among these stages. To further reduce fringing fields in capacitive WPT systems, various coupler design approaches have been considered. Those that use dielectric materials for field guidance introduce additional losses and have limited success in medium-range applications. We have been exploring techniques traditionally used for beam forming in radars and other far field applications. We have developed a near-field phased-

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array field-focusing approach that uses multiple phase-shifted capacitive WPT modules to achieve dramatic reductions in fringing field. We have shown that a 180°-out phased configuration yields a progressive reduction in fringing electric fields as the number of modules increases.

IV. Intelligent Transportation

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In the era of Big Data and attendant advances in intelligent transportation system (ITS), it is a natural step to incorporate wireless charging EVs with ITS. Real-time traffic conditions and the locations of the wireless charging lanes and stations can be shared with EV drivers. The development of real-time routing algorithms for wireless charging EV drivers is one example of a topic with great potential; evaluation of optimal velocity profiles for drivers for a given route, with real-time traffic conditions, and information about charging lanes and stations, is another. In such systems, the operations of wireless charging EV are coupled with internal information, such as the driver's habits and patterns and the vehicles battery level, and with external information, such as traffic conditions and charging infrastructure locations. Because the role of ITS is to provide drivers with these internal and external data points, and eventually to assist drivers in making good decisions, a number of interesting topics and ideas on wireless charging operations can be proposed in conjunction with ITS. Environmental and energy issues are a great concern these days. Although there are numerous government reports and considerable media coverage discussing the environmental and energy effects of dynamic wireless. Charging EVs, analyses performed with a rigorous model and scientific approaches are limited. As mentioned earlier, are the pioneers investigating the energy and environmental issues related to wireless charging EV systems with scientific modelling approaches. Extending their work is definitely a good research area. For instance, the battery replacement issues in the environmental assessment might provide insight into wireless charging EVs. Furthermore, the environmental and energy impacts of the entire wall-to-wheel process is a promising research area.

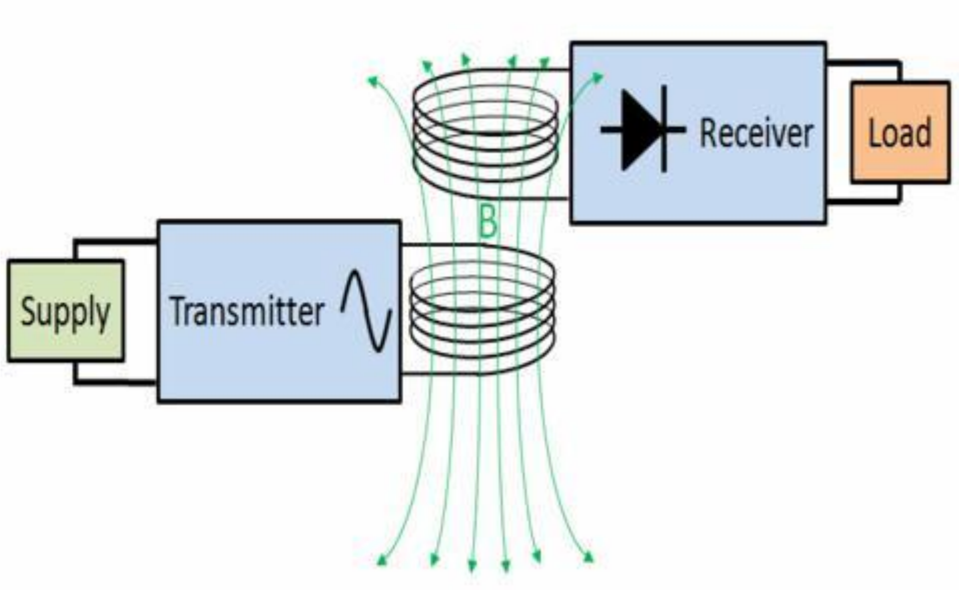

Fig- 4: Wireless Power Transfer

V. Future Scope Of Electrified Road

It is looking increasing likely that electric vehicles will play a major role in the future of road transportation. While Commercial electric vehicle exists, their uptake has been limited due to high purchase costs, limited battery range, and a lack of charging convenience. Furthermore, while developments are underway, electric and hybrid drive trains are yet to be efficiently integrated with a heavy goods vehicle. A novel way to overcome such challenges are Electric Road Systems; a branch of technologies that allow vehicles to charge while in motion. Limited information exists regarding the comparative performance of ERS solutions, market readiness, costs, and implementation issues. To this end, the World Road Association commissioned TRL to undertake a state-of-the art review and feasibility study of ERS concepts; focusing on ERS implementation from the perspective of a road administration.

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VI. APPLICATIONS OF PIEZOELECTRIC MOTOR

The application of WPT in transportation is not necessarily limited to transit or passenger vehicles. Yoon (2017) introduces the application of WPT to special purpose transportation systems, such as cargo transportation in airports, container transports at harbors, and cargo transporters in warehouses to a large extent, material handling systems in factories are also transportation systems for which WPT technologies have been adopted for more than 10 years, particularly in semiconductor and LCD factories (Hwang et al., 2016, Jang et al., 2005). There is plethora of interest in research for these applications. Another area that can be explored is systems design for wireless charging-based autonomous vehicles. With the rapid development of autonomous driving technology, it is also projected that electric charging will be introduced for autonomous vehicles in the near future. At such point, it will be a natural step that autonomous EVs to adopt automated charging mechanisms (it would be somewhat absurd to imagine the driving being done autonomously but charging still being performed manually). Wireless charging will be integral to such vehicles operations

VII. CONCLUSION

This survey provides the first overview of the state-of-the-art in operations and systems research into wireless charging EVs. The technology is still in early developmental stages, and operations and systems-related research has yet to fully mature, so investigations into current research activities is critical. This survey work has broad applications for the research community, industry, and regulators and policymakers. The survey first discussed the current state of wireless charging EV systems deployment and commercialization projects, so that readers understand the actual technological development status. Therefore, some researchers have claimed that the battery swapping solution might be a threat to wireless charging EVs. At this point, it might be too early to conclude which technology is more competitive. A cost and performance analysis comparing these two technologies might be good research topics for the future. Some scholars have also argued that ultra-fast charging technology and the advancement of battery technology might make dynamic wireless charging redundant. However, it is also true that fast charging might significantly reduce the cost of wireless charging infrastructure because the charging amount per length of wireless charging lane would be increased more power could be transmitted with a shorter charging lane. The effect of fast charging on the economics of wireless charging EVs is also an interesting topic. In summary, there are numerous threats as well as opportunities related to WPT applied to EVs. Investigating these issues with analytical rigor is a task for the future. Research into the operations and systems of wireless charging EVs is still evolving. Most methods have not yet been tested on actual systems. The cost figures also may not be correct because wireless charging EVs have not yet been mass produced. Therefore, the numerical results and conclusions drawn in most papers should be treated as preliminary. However, this too should be considered a research opportunity; the validation of methods and results is a primary responsibility for the academic community.

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