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DYNAMIC WIRELESS CHARGING FOR ELECTRIC VEHICLES

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Abstract-- Wireless Power Transfer (WPT) charging system for electric vehicles (EVs) is a promising technology that eliminate the need for physical cables offering a more convenient and user-friendly charging experience. This provides an overview of the benefits of wireless charging, including reduced wear and tear on charging equipment, enhanced user convenience, reduced infrastructure maintenance costs and enhanced safety and the potential for autonomous charging in the future. The techniques developed for EV dynamic charging includes inductive coupling and magnetic resonance coupling. However, Inductive Wireless Power Transfer technology (IWPT) faces the challenge of poor power transfer efficiency which can leads to high power consumption, and limited to shorter distances. The analysis of power consumption and power transfer efficiency with different frequencies are performed by using Magnetic resonance coupling technique. The results are analysed with the aid of simulation in MATLAB/Simulink software.

Keywords: *Electric Vehicles (EVs), Wireless Power Transfer (WPT), Dynamic charging, Magnetic resonance coupling, Inductive Wireless Power Transfer (IWPT) and MATLAB/Simulink software.*

I. INTRODUCTION

Large scale deployment of Internal Combustion Engine (ICE) based vehicles in transport system lead to the release of harmful fumes into an atmosphere lead to global warming and climate change, which is main concern of global community. Therefore, to lessen dependence on fossil fuel-based energy sources and to reduce its harmful impacts on the atmosphere, there is a need for alternative solutions such as EVs charged on renewable energy sources. Normally, batteries have low energy density, makes them weighty, costly, bulky. In addition, slow in charging and provides shorter lifetime. Now a days lithium-ion batteries are mostly used in EVs. Battery capacity restricts the cruise range. Adding the batteries will increase the cruise range, which further increase the weight and cost of the vehicle. Some authors presented fast battery charging methods to minimize the full charging time less than 30 min. However, available fast charging systems are costly and complex in control. Still, the charging time of battery more than time that needs to refuel a car based on fossil fuel. Another solution proposed is based on the use of “swapping stations,” where the depleted EV batteries are exchanged with fully charged batteries. For the development of EVs, charging systems are playing the main role. The currently available technology for EV battery charging consists of plug-in charging (conductive charging or wired charging) and Wireless charging (contactless) methods. Plug-in charging system further classified in to Off-Board and On-Board chargers based on charging platforms. One of the main concerns with conductive charging is high power cables, to plug EV, those are difficult to handle. Hazards can happen due to damaged cables or mishandling. Furthermore, Conductive charging methods are prone to vandalism and theft. An alternative new technology is WPT, introduced by Nikola Tesla in 19th century, with the time this technology developed and became competitive solution for wired charging systems. This technology has capability to replace the plug-in interface by transmitters and receivers, allowing power flow in a contactless manner in the form of electromagnetic or static waves as shown Fig. 1. In WPT systems the receiver transfer power to the batteries or drive system through power electronic converters.

The wireless charging system is capable of working without human intervention. It is also safe due to the fact that there are no cables present in the system. The hazards caused by using cables can be avoided. This advantage makes Wireless technology suitable for large-scale deployment. Also makes it fully automated charging infrastructure in electrified transport system. The main drawback of wireless charging system is its charging time. That can be resolved by different changes in the system. Another concern with WPT is its leakage EMF radiation at higher frequencies. This radiation is restricted by using proper shielding to make it safer [1].

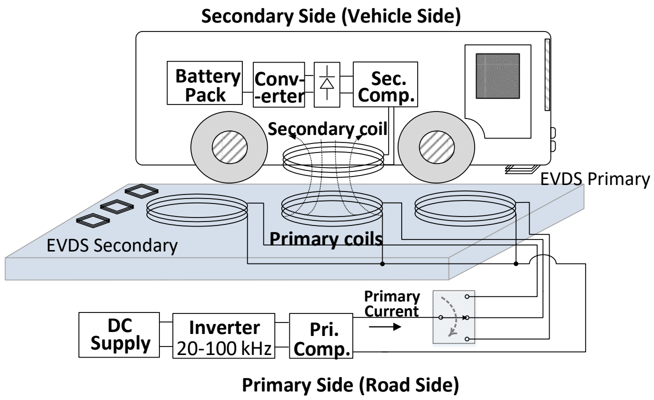


Fig. 1 Basic structure of WPT system

Dynamic Wireless Power Transfer (DWPT) expands the concept of stationary charging by allowing an EV to be charged while driving over the primary unit. Advancements in power electronics have made it possible to transfer tens of kilowatts of power wirelessly between stationary road-embedded pads and vehicle-attached modules. However, the motion of the secondary unit (receiver) imposes a new set of challenges to the design and operation of the primary unit (transmitter) which is due to the constantly varying load of the system. To maintain the maximum power transfer and high operating efficiency, an advanced level of control and intelligence needs to be integrated into the system.

In Fig. 1, a typical DWPT system with segmented coil structure at the primary is shown. On the primary side, DC voltage is converted to a to a high frequency current (20-100 kHz), which is delivered to the primary coil. This power conversion is achieved through an intermediate DC link, a phase-shift controlled full-bridge inverter, and a properly selected compensation tank. On the secondary side, there is another compensation tank, which is connected to the secondary coil. These tanks supply the reactive power for the coils inductances and filter harmonics injected by the inverter or the rectifier units. High-frequency AC power at the secondary side is rectified and then through a buck or boost converter delivered to the vehicle battery. In order to detect the position of a moving EV, some form of EV Detection System (EVDS) is typically applied. Primary coils are energized consecutively based on the position of the moving vehicle. In other words, only the coil that has the EV's receiving pad over it will be connected to the primary compensation tank and energized [2].

II. PROPOSED SYSTEM ARCHITECTURE

A typical wireless EV power charging system is studied and shown in Fig. 1. It is mainly composed of three stages:

Firstly, DC power is converted to high frequency AC power to drive the transmitting coil through a compensation network. Secondly, the primary and the secondary coil, the high frequency current in the primary side coil generates an alternating magnetic field, which induces an AC voltage on the receiving coil. By resonating with the secondary compensation network, the transferred power and efficiency are significantly improved. At last, the AC power obtained is rectified to charge the battery, and in order to improve the efficiency of the WTC magnetic resonant coupling, a DC/DC converter on the secondary side must be connected [3].

Magnetic resonance makes use of the principle of a vibrating turning fork which is an application of the sound resonance. When coil vibrates the surrounding coil having the same natural frequency is excited thereby producing energy for charging the electric vehicle. Advantages: High frequency, High power and longer charging distance. The main disadvantage is its big size Magnetic resonance wireless power transfer occurs at the point where the transmitter and the receiver coil are in resonance. This resonance can be subdivided into two; the first is self-resonance that is controlled by the self-inductance and self-capacitance of the coils and the second is external and excited resonance which is controlled by the self-inductance and the installed capacitance of the coil [4].

First, The WPT system consists of the sum of magnetically coupled primary and secondary coil, associated with a power electronic device such as an inverter, a rectifier and a Bi-directional DC-DC converter associated with their control. Resonance operation on the WPT system is employed to boost up the energy transferred between primary and secondary coil. For an efficient operating system, a typical switching frequency is requested.

The inverter used in DWPT systems operates at the resonant frequency of the primary coil and is typically chosen to be in the region of 20 kHz to generate a strong electromagnetic field and maximize system efficiency. It converts the DC power to 20 kHz high frequency. In a resonant converter, a switched voltage is input to a resonant tank, exciting a sinusoidal current. This current either lags or leads the input voltage, causing the semiconductor switches to turn on or off at zero voltage or zero current, respectively, so there is very little switching loss. Since loss tends to scale with switching frequency in hard switched converters, it is advantageous to use a resonant topology if the switching frequency is beyond some threshold, depending on the power level of the converter (less than 100 kHz). Above that threshold, relatively high efficiency is achieved compared to a hard switched converter. Moreover, a higher switching frequency makes it possible to use smaller energy storage components. This results in an increased power density and reduction in the amount of energy stored in the system, so less energy is dissipated. From these considerations, a resonant converter seems to be the best candidate to satisfy the design objectives. If, in the future, the ripple current specification can be relaxed and a lower switching frequency with comparable filtering is acceptable, a hard switched converter may also be viable.

The Magnetic Coupler design is the most important part in the whole WPT system. This design shape will impact the power capacity transferred between the two sides of the coupler. The magnetic structures are used to enhance coupling, reduce flux leakage and shape the magnetic field (Fig. 5). In the dynamic charging, the mutual inductance of the primary and secondary coils will change, which will cause a fluctuation of the magnetic flux. Several studies using different approach are carried out to offer the optimal design of the coupler respecting the functional requirement [3].

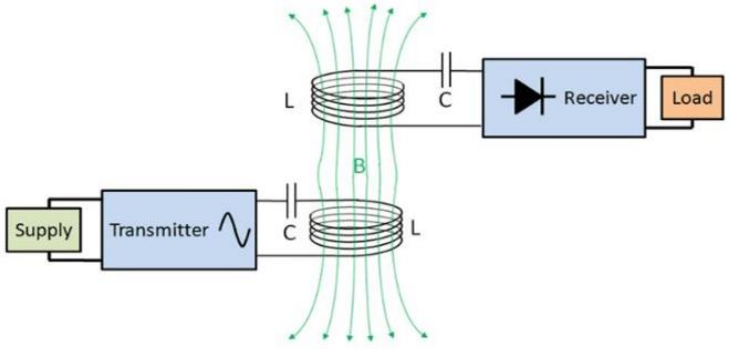


Fig. 2. Magnetic coupler for Wireless Power Transfer.

The Integrated System Level of DWPT for EV Charging can be divided into three main components and described in the following subsections.

A. Roadside

1) Solar Generation Interface: Generally, the solar power generation are situated near highways, with no interconnection to the grids of neighbouring territories. The distribution network is used to supply power to the DWPT model at 1200 V, 800 A using a 50MW substation.

2) Single Phase Inverter: The inverter used in DWPT systems operates at the resonant frequency of the primary coil and is typically chosen to be in the region of 20 kHz to generate a strong electromagnetic field and maximize system efficiency. It converts the DC power to 20 kHz high frequency at 1100 V 800 A.

3) Primary Compensation: The primary compensation ensures that the primary coil is tuned to the resonant frequency of the secondary coil by varying the capacitance of the circuit with the series-series (SS) high frequency resonant topology being most suitable.

B. In-Road

The three main primary coil loop configurations employed in DWPT for EV charging are described below.

1) Long Loop: The long loop power track allows power to be supplied with minimum use of inverters and sensors. It has a typical coupling coefficient of approximately 0.0175 when a single pickup coil is over the primary track. Unlike the spaced and sectional loops, however, it allows multiple EVs to be charged simultaneously from the same primary coil and as such it is characterized by a coil to coil efficiency of 2.23%, 4.46% and 8.91% for the low, medium and high EV densities respectively. Due to the short 1 m gap between adjacent loops, it allows for a road coverage (length of roadway covered per unit length of installed DWPT infrastructure) of 99.2%.

2) Sectional Loop: The sectional loop, unlike the long loop requires a relatively large number of inverters and sensors and supplies only one vehicle at any point in time resulting in a predictably higher coupling coefficient of approximately 0.152 with a road coverage of 92.6%. This configuration is characterized by a coil-to-coil efficiency of 45.4%.

3) Spaced Loop: The spaced loop builds on the advantages (in terms of coupling) and complexities (in terms of inverters and vehicle detection sensors) of the sectional loop leading to a predictably higher coupling coefficient than both the long loop and sectional loop with a value of approximately 0.301 and a road coverage of 33.33%. This configuration is characterized by a coil-to-coil efficiency of 53.4%.

C. Electric Vehicle

1) Secondary Coil: The secondary coil is a discrete inductive coupler or power pad mounted on the EV chassis.

2) Secondary Compensation: Similar to the primary compensation, the secondary compensation ensures that the secondary coil is tuned to the resonant frequency of the primary coil.

3) Single Phase Rectifier: The single-phase bridge rectifier allows the single-phase AC from the pick-up coil to flow through the diode bridge producing a DC output.

4) Bidirectional DC-DC Converter: Bidirectional DC to DC converters play a key role in dynamic wireless charging for the electric vehicles (EVs) by facilitating vehicle-to-grid (V2G) and grid-to-vehicle (G2V) energy exchange. These converters enable seamless bi-directional power flow between the EV's battery and the charging infrastructure, allowing the vehicle to both receive power during charging and feed excess energy back into the grid when needed. This bidirectional capability enhances grid stability, supports renewable energy integration, and enables EVs to serve as flexible energy resources, contributing to a more efficient and sustainable energy ecosystem.

5) BMS: The BMS regulates power flow to and between the battery and motor. It also ensures that regenerative braking and DWPT cannot occur simultaneously since this can adversely affect the battery due to the presence of two different sources of energy which are likely to be at different voltage and current levels.

6) EV Battery: The output power of the boost converter (described in the DWPT Input section) flows to the 400 V 20 kWh lithium-ion battery (average EV battery capacity) allowing charging and/or directly feeding the motor to provide traction power. The battery SOC and resulting change in capacity from charging or discharging [5].

III. PROPOSED SYSTEM COTROL ALGORITHM

Key Components

1. *Roadside Power Transmission Units (PTUs):* Each segment of the embedded coil network connects to a dedicated PTU. These units house power electronics components responsible for generating the high-frequency AC current that excites the coils and regulates power flow.

2. *Vehicle-Side Power Receiving Unit (PRU):* The EV carries a PRU equipped with a receiving coil that couples with the energized road segments. The PRU converts the received AC power to DC to charge the vehicle's battery.

3. *Central Control Unit (CCU):* A central control unit oversees the entire system operation. It communicates with roadside PTUs and the vehicle-side PRU, coordinating power transfer and optimizing system performance. The proposed control algorithm operates in a hierarchical manner, encompassing three levels:

A. High-Level Control (Central Control Unit):

1. *Traffic Monitoring:* The CCU gathers real-time traffic data to predict vehicle location and speed. This data can be obtained from embedded road sensors or vehicle-to-infrastructure (V2I) communication.

2. *Power Allocation:* Based on traffic information and individual EV battery needs, the CCU allocates power to each active segment. This ensures efficient energy use and avoids overloading the system.

3. *Safety Management:* The CCU monitors system parameters like voltage, current, and temperature to identify potential safety hazards. It can initiate corrective actions such as power reduction or system shutdown in case of anomalies.

B. Mid-Level Control (Roadside Power Transmission Units):

1. *Phase Synchronization*: Each PTU synchronizes its AC output with neighbouring units to create a continuous magnetic field along the road segment. This ensures efficient power transfer to the moving EV.

2. *Frequency Tuning:* PTUs can dynamically adjust the operating frequency based on vehicle speed and coil misalignment. This helps maintain optimal coupling between the road and vehicle coils, minimizing energy losses.

3. *Foreign Object Detection*: PTUs use embedded sensors or image recognition to detect foreign objects on the charging surface. The CCU is alerted if a potential safety hazard is identified, allowing for appropriate action.

C. Low-Level Control (Vehicle-Side Power Receiving Unit):

1. *Impedance Matching*: The PRU dynamically adjusts its internal impedance to match the impedance of the energized road segment. This maximizes power transfer efficiency by minimizing reflected energy.

2. *Power Regulation:* The PRU regulates the received AC power to convert it to DC at a voltage suitable for charging the EV battery. This ensures efficient energy use and prevents battery damage.

3. Communication with CCU: The PRU maintains communication with the CCU, providing real-time data on battery state-of-charge, power consumption, and any potential faults.

D. Communication Protocols

Secure and reliable communication protocols are essential for the control algorithm's functionality. V2I communication allows for data exchange between the CCU, PTUs, and the PRU. This includes traffic data, power allocation information, system status updates, and safety alerts. Standardized protocols like IEEE 802.11p (WAVE) can be utilized to ensure interoperability and efficient data exchange.

E. Algorithm Implementation

The proposed control algorithm can be implemented using various control techniques, including:

1. Model Predictive Control (MPC): This technique utilizes a dynamic model of the DWPT system to predict future behaviour and optimize power transfer in real-time.

2. Fuzzy Logic Control: This approach leverages human expertise to design control rules that account for complex system dynamics and uncertainties.

3.Neural Network Control: Machine learning algorithms can be employed to learn optimal control strategies based on training data collected from system operation.

The Model Predictive Control (MPC) is performed due to several advantages:

1. Real-Time Optimization: MPC utilizes a dynamic model of the DWPT system to predict future behaviour. This allows it to optimize power transfer in real-time based on constantly changing conditions. Factors like varying traffic flow, vehicle speed, and misalignment between the vehicle and charging coils can be accounted for, ensuring efficient energy delivery.

2. Multi-Objective Capability: DWPT control needs to balance multiple objectives like maximizing energy transfer efficiency, maintaining safety, and optimizing power allocation among multiple EVs. MPC's ability to handle these competing objectives simultaneously makes it well-suited for this complex task.

3. Adaptability to Uncertainties: Real-world conditions in DWPT systems are inherently uncertain. Unexpected events like foreign object detection or sudden changes in traffic flow can occur. MPC's predictive nature allows it to adapt control strategies on the fly, mitigating the impact of these uncertainties and maintaining system performance.

4. Improved Efficiency: By constantly optimizing power transfer based on real-time data, MPC can minimize energy losses throughout the system. This translates to a more efficient use of available power, ultimately extending the driving range of EVs.

Fig. 3 Simulation of proposed system

5. Enhanced Safety: MPC can incorporate safety constraints into its control strategy. It can monitor system parameters like voltage, current, and temperature, and predict potential safety hazards. Based on these predictions, it can take corrective actions such as reducing power transfer or shutting down the system if necessary.

6. Scalability: As DWPT systems expand, the control algorithm needs to be scalable to handle a larger number of EVs and also for charging segments. MPC's ability to handle complex models makes it suitable for large-scale deployments.

IV. SIMULATION DIAGRAM OF DYNAMIC WIRELESS CHARGER

In this study the Dynamic Wireless Charger for EV is designed in MATLAB Simulink environment. The proposed WPT dynamic charging system is based on an optimal designed, power electronic converters and a magnetic coupler. The whole system is designed for a low transferred power and for an air gap considered of 15 cm. The mechanic and thermal behaviour of the coupler will be taken into account in the design process, since the shape result obtained, the electromagnetic inference will be treated by using solutions to reduce the electromagnetic effects of the inductive wireless system charging. We have developed an accurate model of the primary side of a DWPT system. The controller will be implemented in a segmented coil 25-kW DWPT system to charge an electric vehicle. This model is verified through simulations done in MATLAB Simulation. This system provides valuable insights into the potential of this technology for dynamic EV charging. By analysing the collected data and addressing any identified challenges, researchers can continue to refine DWPT systems, paving the way for a future where electric vehicles can be charged continuously while moving, significantly improving range and promoting the widespread adoption of EVs.

V. SIMULATION RESULTS

The performance of Dynamic wireless charger for electric vehicle under conditions vehicle in motion is shown. The DC voltage is kept 1100v. The various parameters Battery Voltage (V_b), Current (I_b) and State Of Charge (SOC) are shown in Fig.4 and Fig.5 respectively.

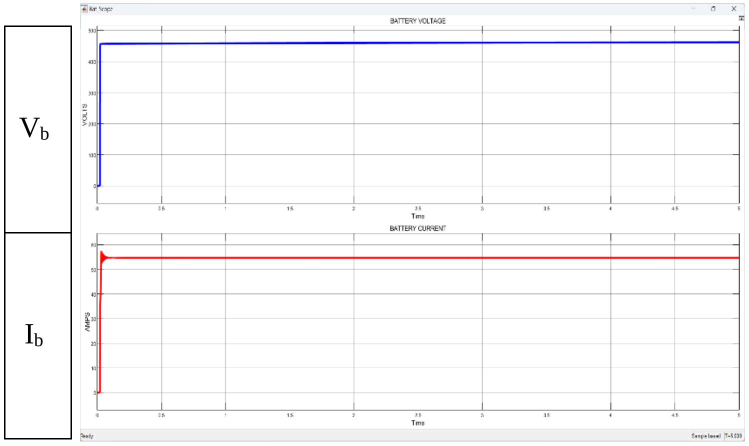


Fig. 4. Battery Voltage and Current waveform.

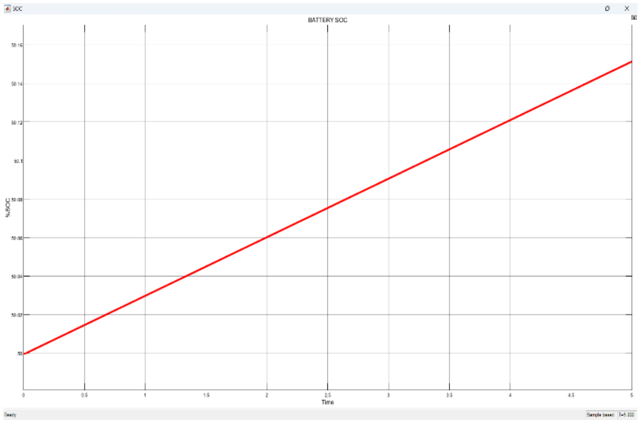
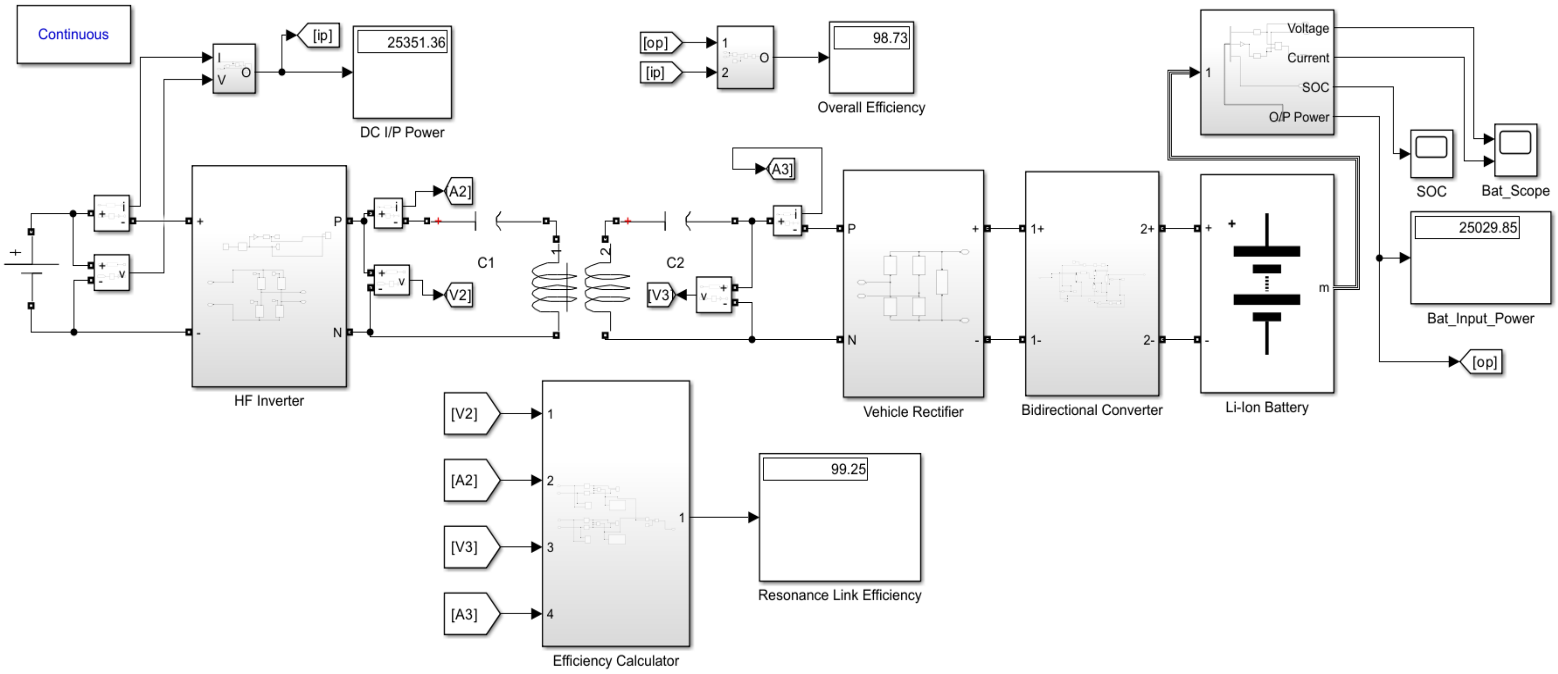


Fig. 5. Battery State Of Charge.

VI. FUTURE SCOPE

1. *Dynamic Electromagnetic propulsion:*

Dynamic wireless charging (DWC) can be utilized as a propulsion method for electric vehicles (EVs) similar to



maglev (magnetic levitation) trains. By integrating DWC technology into the road infrastructure and equipping EVs with receiving coils, electromagnetic induction can propel vehicles forward without the need for traditional electric motors. This setup simplifies vehicle design, reduces mechanical complexity, and enables continuous charging while in motion, akin to the frictionless propulsion of maglev trains. It offers potential advantages such as streamlined vehicle designs, improved efficiency, and enhanced passenger comfort. However, challenges remain in optimizing power transfer efficiency and ensuring compatibility with different vehicle designs and safety standards.

2.Vechicle to Everything (V2X):

Dynamic wireless charging (DWC) technology can be integrated into Vehicle-to-Everything (V2X) communication systems, enabling electric vehicles (EVs) to wirelessly exchange data with surrounding infrastructure and other vehicles. By incorporating DWC capabilities, EVs can not only receive power while in motion but also communicate with traffic signals, road signs, and other vehicles to optimize driving routes, enhance safety, and improve traffic flow. This integration of DWC with V2X technology offers potential benefits such as increased energy efficiency, reduced congestion, and enhanced overall mobility experiences.

3. Accident prevention:

Dynamic wireless charging (DWC) technology can serve as a means of accident prevention for future road structures through the use of electromagnetic fields. By embedding transmitting coils beneath the road surface and equipping vehicles with receiving coils, DWC systems can create electromagnetic fields that help guide and stabilize vehicles. These fields could potentially assist in maintaining safe distances between vehicles, preventing collisions, and enhancing overall road safety. However, implementing such systems would require careful consideration of technical feasibility, safety standards, and potential electromagnetic interference issues.

4. Communication Protocol:

Dynamic wireless charging (DWC) technology can serve as a communication protocol for electric vehicles (EVs) and infrastructure. By leveraging the same electromagnetic fields used for power transfer, DWC systems enable EVs to exchange data with charging infrastructure, other vehicles, and smart grid systems. This dual functionality enhances efficiency by combining power transfer and communication capabilities, paving the way for seamless integration of EVs into smart transportation networks.

VII. CONCLUSION

The main objective of this paper was to develop a dynamic WPT is conducted and the results are implemented to the design a 25- kW segmented-coil dynamic charging system for electric vehicles. This paper aims to develop a dynamic wireless power transfer (WPT) system for electric vehicles, emphasizing higher efficiency compared to inductive WPT. Simulation under resonance conditions enhances power transmission efficiency over longer distances. Considerations for real-world deployment include ecological, financial, and social impacts, alongside efficiency and stability. Bidirectional grid integration enables vehicles to store excess renewable energy. The system doubles as a propulsion method, eliminating the need for internal combustion engines or electric motors.

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