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Dynamic Wireless EV Charging System

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Abstract: This paper proposes an electric vehicle powered with a dynamic on-road wireless charging system utilizing solar energy. The system involves integrating the photovoltaic panels with inductive coils beneath road surfaces, consequently enabling continuous energy transfer when vehicles are moving. In the power management unit, solar-generated DC power is converted to AC for efficient wireless transmission. We present the architecture of a system that includes the coil design, the vehicle-mounted receiver, and control algorithms for adapting to different speeds and power demands. Simulation and prototype evaluations show transfer efficiency up to 90 % and significant range extension without station stops. This sustainable solution addresses range anxiety and supports renewable integration for greener transportation.
Keywords: Wireless charging, electric vehicles, solar energy, dynamic charging, inductive power transfer, photovoltaic panels, road-embedded coils, power management, energy transfer efficiency, sustainable transportation.

I. INTRODUCTION

Electric vehicles promise zero tailpipe emissions but face limitations from long charging times and range anxiety due to finite battery capacities. Dynamic wireless charging, also called in-motion inductive power transfer, embeds coils beneath road surfaces to transfer energy to vehicles while they drive, eliminating the need for stops. When coupled with solar photovoltaic panels, this approach harnesses renewable power directly, reducing grid dependency and greenhouse gas emissions. Solar arrays convert sunlight into DC electricity, which is then inverted to high-frequency AC for efficient inductive transmission. Vehicle-mounted receivers convert this energy to recharge batteries in real time, enabling lighter battery packs and lower costs. This paper introduces a solar-powered, on-road wireless charging architecture, detailing coil design, power electronics, and control strategies to optimize reliability and efficiency in urban settings.

In automotive applications, the internal combustion engine (ICE), hybrids, CNG and fuel cell powered vehicles will yet be core power sources in current and future ground vehicle technology which requires further rapid steps of efficiency enhancement for fuel efficiency until 2020 [1]. Despite the current slow pace of market penetration, electric vehicle (EV) is one of strong candidates in the industry and research sectors.

While the rapid progress is currently being made in the global electric vehicle market, substantial barriers to massive EV adoption still exist. Those can be summarized as batteries, charging infrastructure, electric power interface and customer acceptance [2]. With the widespread lithium-ion battery technology, the power density and specific power capacity have been grown significantly, yet batteries have not been able to compete with the tremendous energy density of petroleum fuels [3].

This paper will present the innovative technology in the field of wireless power transfer and experimental verification for practical applicability in commercial point of view of the OLEV system. The suggested innovative concept of wireless power transfer technology, called as Shaped Magnetic Field in Resonance (SMFIR) will also be described, in addition to the actually demonstrated power supply infrastructure and vehicle system in the perspective of their power transfer performance and design robustness for feasibility and applicability to future green mobility.

II. LITERATURE REVIEW

Carrying the energy storage system (ESS) within an electric vehicle during the entire operation distance has been a significant roadblock to EVs, mainly because of the heavy and bulky battery system with the current technology. The overhead wire system for the traditional public tram can be a remedy, but it also provided limited operations within urban application of public transportation, with the sacrifice of the city landscape.

Rather than carrying the power source like battery for the EVs during entire travel distance, delivering the power wirelessly to operating vehicles can be a competitive design solution for future electrified road and vehicle, which can be considered as a design solution to EV introduction [4]. Thus, wireless charging of EVs, either stationary or dynamic on-road charging can be a technology innovation to achieve the massive EV introduction. However, this technology should meet the following requirements; transfer power capacity and efficiency, appropriate level of convenience, safety, and business competitiveness.

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In earlier 1890s, N. Tesla boldly proposed his idea to transmit the electrical power wirelessly through air medium, as tried in Wardenclyffe tower experiment [5-6]. With the increased power and energy efficient consumer electronics and small-capacity mobile equipment use, the Wireless Power Transfer technology (WPT) has drawn significant attraction in technology group and related industries, and the market forecast predicts about $2 billion in wireless-power related revenues by 2020 in the area of consumer electronics, automotive/transportation, industrial automation and heavy equipment, energy, sensors and transducers, medical and healthcare, and other applications [7].

In WPT field, three main types of WPT have been commercially viable at this time: 1) electromagnetic inductive coupling, 2) resonant magnetic coupling, and 3) microwave based wireless power transfer. Power beaming by laser concept by NASA or space-based solar power is noticeable in WPT field, but both are either at the conceptual level or little early for commercial application yet [8-9].

In the inductive coupling area, besides many application technologies developed in consumer electronics area, the California PATH Program and a group of researchers in Oakland University, New Zealand, are worthwhile to be noted in their contribution related with the surface transportation or electric vehicle charging. The wireless power transfer performance from the PATH program can be summarized with the transferred power capacity of 60 kW, the operating frequencies of inductive power transfer of 400 Hz and 8500 Hz, and the maximum measured power transfer efficiency from commercial electricity source to the output of paired receiver system of 60 % at 2-3 inches of air gap [10-11]. However, the program had not been fully commercially successful due to limited level of efficiency and lesser competitive in business calculation, as described in with various parametric simulation studies on the efficiency, economic analysis and electromagnetic field exposure issue to human.

To integrate smart and efficient billing system it is very important to smartly control the access to the charging lane. Hence a suitable technology is required for that. This paper presents an approach by which a vehicle can be identified using its registration plate by using computer vision technology and access to the lane can be controlled based on that. Using OpenCV system can detect vehicle number using Optical Character Recognition (OCR) [12-15].

In this paper, the innovative technology in wireless power transfer field and experimental verification for practical applicability in commercial point of view of the OLEV system will be discussed. The suggested innovative concept of wireless power transfer technology, called as Shaped Magnetic Field in Resonance (SMFIR) will also be described, in addition to the actually demonstrated power supply infrastructure and vehicle system in the perspective of their power transfer performance and design robustness for feasibility and applicability to future green mobility.

III. METHODOLOGY

The OLEV is an integrated system of invention and innovation combining automotive, power electronics, power grid, road infrastructure, and Information Technology (IT), applying WPT. The road electrification will be a key R&D area for the next decades linking together with the smart grid and the Intelligent Transportation System (ITS) technology. In ITS we propose a separate access-controlled charging lane and smart billing system, access to which will be managed autonomously by using computer vision technology. The system will provide a good example to integrate those complex areas into a transportation system.

In this chapter, the unique approach of enhancing the transmission efficiency of wireless power in the system will be discussed, in addition to the systematic architecture of the power supply infrastructure, the vehicle and related electromagnetic field (EMF) investigation.

A. Resonant Coupled WPT and Efficiency

As reviewed in the introduction, the currently available wireless power technologies become more and more efficient and practical recently with the emphasis on EV and consumer electronics applications. Followed by Bolgar, numerous inventors have come up with the new ideas of electric vehicle application; some have proposed to use the road as a power supplying system.

Typical conductive power transfer happens on a closed circuit with the direct power flow across the conductor. The wireless power transfer can be regarded as a contactless power transfer, which includes the inductive or capacitive power transfer, like traditional transformers and capacitors. It is noted that the power transfer from the primary and secondary coil of a transformer can be achieved through a narrow air gap at low frequencies of 50 Hz or 60 Hz. This phenomenon has been called as strongly coupled near-field inductive power transfer, or closely coupled contactless power transfer for the transformer above. If the operating frequency is high enough that the inductive coupling between two circuits can be stronger due to the rapid changing rate of the magnetic field, then the power transfer across the air gap can be happened. However, for the applications with higher power requirement and longer distance between both coils, improving the transfer efficiency (by maximizing the power factor) is required, especially for the dynamic wireless charging applications. A resonator capacitor can be used in the secondary coil circuit and the resonance frequency can be tuned to the operating frequency of the primary circuit, then the power factor of the secondary coil is 1 and the transfer efficiency can be maximized, which can be called as a resonant based power transfer.

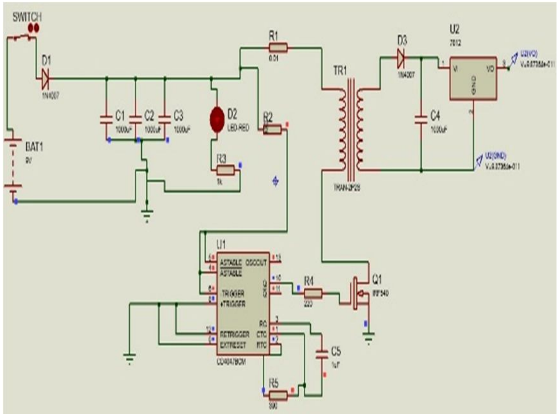

Fig. 1. Circuit for Wireless Power Transfer

Fig.1. demonstrates the complete circuit diagram for Wireless Power Transfer (WPT). In order to explain this phenomenon, we can consider the following equivalent primary and secondary circuits of closely coupled inductive power transfer model as shown in Fig. 2, and its equivalent circuits in Fig.3, which is the same as the transformer model.

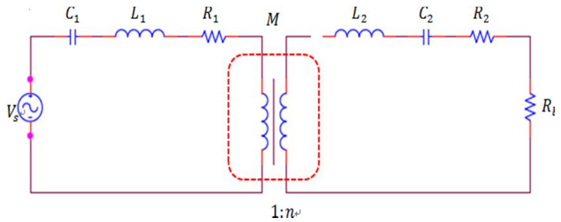

Fig.2. Actual equivalent circuit for WPT

It can be seen that when ac signal passes through an inductor it generates a magnetic field equivalent to the current flowing through it.
The turn ratio decides how much voltage is resulted at output. We keep higher turn on the secondary side to increase or step up the voltage.

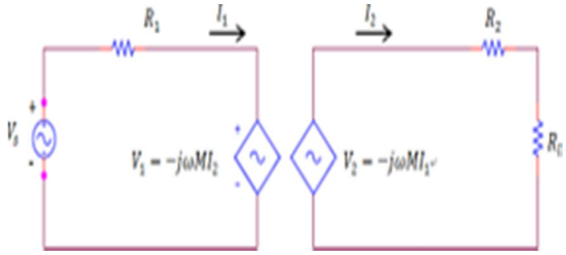

Fig. 3. The equivalent circuit of a loosely coupled WPT system

B. *User Interface for managing and paying bills*

A responsive user interface is created using MERN stack with JSON Web Token (jwt) based authentication for users. The customers can create an account by using their vehicle number. They will be allowed to the proposed charging lane only if they have this account. Once logged in they can manage their vehicles, can keep track of charging and average and can also pay the bills seamlessly. Bills are calculated using the time spent in charging lane and the specifications of the vehicle. All the vehicle related data is stored in firebase cloud and is updated in real time.

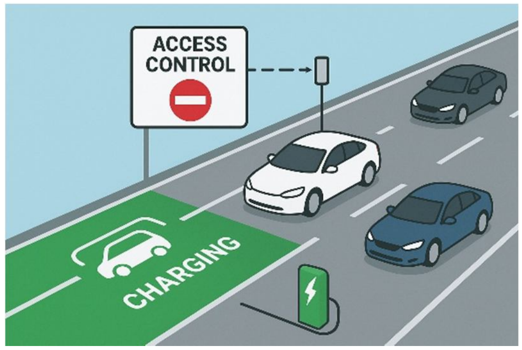

Fig. 4. proposed lane system

Fig. 4. Shows the diagram demonstrating the proposed lane design to incorporate smart and access-controlled charging and billing system.

IV. RESULTS

This section contains the experimental results obtained from the proposed system. We created a Wireless Power Transfer (WPT) prototype to demonstrate the proposed idea and performed various experiments. We also created a smart billing system which utilizes computer vision technology to smartly control the access of the charging lane and calculate the bill based on the total charging time and the specifications of the vehicle. The equation Eq.1. calculates how quickly the capacitor charges and discharges through the resistors, which determines the frequency of the output waveform.

With the 1k and 10k resistors and 0.1 uF capacitor values, the circuit generates a square wave at approximately 686 Hz.

$$f = \frac{1.44}{(1000 + 2 * 10000) * 0.1 * 10^{-6}}$$

Eq.1. Square wave frequency calculation

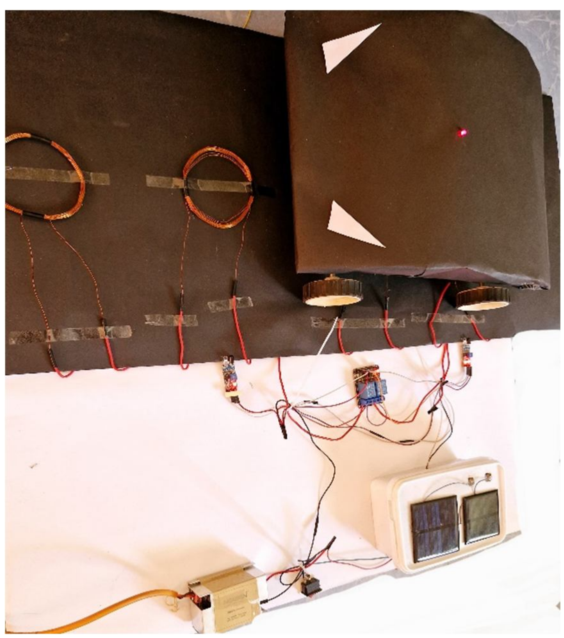

Fig. 5.WPT system prototype

Fig5. demonstrates the top view of Wireless Power Transfer system. It can be seen that coils are attached to the road and one coil is attached to the vehicle. Whenever vehicle passes on these coils power is transferred from these coils to the vehicle.

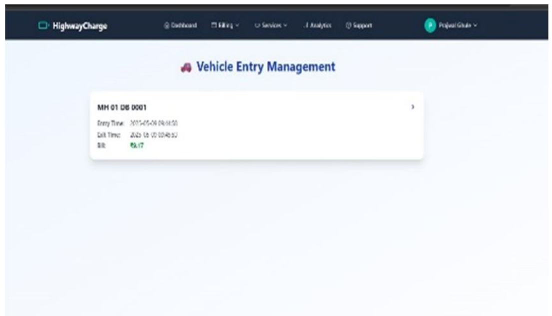

Fig. 6. Dashboard for Billing System

Fig.6. demonstrates the dashboard for billing system. Users can manage all their bills and can keep track of charging history, vehicle entry/exit time in charging lane on this platform.

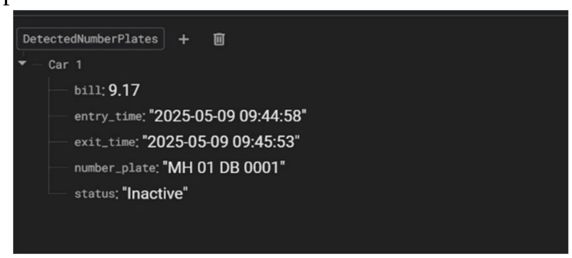

Fig. 7. Firebase Storing and updating value

Fig.7. shows the data being updated on firebase cloud in real time. We can see the bill amount, vehicle entry time and exit time in charging lane being updated seamlessly.

In this project, we used a 555-timer circuit to generate a square wave signal at around 686 Hz. This signal was used to drive the primary coil of a wireless power transfer system. We tested the system with two different primary coil windings—20 turns and 30 turns—while keeping the secondary coil constant at 50 turns. When we used 20 turns on the primary, the output voltage measured at the secondary was about 3 volts, and the LED connected at the output glowed brighter. With 30 turns on the primary, the output voltage dropped to around 2 volts, and the LED was dimmer. This showed that using fewer turns on the primary coil resulted in better power transfer to the secondary.

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