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On-road Dynamic Charging System with Wireless Power Transfer Technology for Electric Vehicles

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Abstract: Transportation can use energy in many different ways; most dominantly running cars and other vehicles by burning fuel, producing the vehicles themselves, and creating roads, airports, and pipelines. About 25% of the world's energy is used only for Transportation. According to 2015 statistics, the current estimate of when our reserves will be depleted is this; Oil: 51 years. Coal:114 years. Natural Gas: 54 years. At this high rate, it is believed that all our fossil fuels will run out by 2060. Most importantly all this is done along with the emission of greenhouse gases. These technologies, when combined with renewable energy sources, have the potential to significantly minimize the detrimental impact of road traffic on the planet's health. Electric vehicles (EVs) that are both low-cost and fully autonomous will be required for the confluence of these technologies to be effective. Wireless charging can help you achieve these qualities. But the existing Electric Vehicles have cons like; range anxiety, expensive charging infrastructure, need for large batteries making them expensive, etc. This paper is all about a revolutionary on-road dynamic wireless charging solution for an electric vehicle, branded as OLEV. The wireless dynamic charging concept and battery capacity in the range of 100 kW of power capacity are outlined. This paper also highlights the conceptual design, implementation phases, and development process for optimizing the magnetic flux field for greater energy transfer efficiency.

Keywords: Electric Vehicles (EVs), Dynamic wireless power transfer (DWPT), High Efficiency, System Optimization.

I. INTRODUCTION

Electrification in transportation technology has been emphasized heavily for several decades and is expected to grow as factors driving the change in power sources, such as better controls incited by environmental concerns and the objective is to minimize crude oil dependence impacted by energy security concerns, push the change in power sources. Internal combustion engines (ICE), hybrids, compressed natural gas (CNG), and fuel cell-powered vehicles are all crucial power sources in immediate and long-term ground vehicle technologies, which will entail even more rapid productivity gains by 2025. Electric vehicles (EVs) are a serious contender in the industrial and research sector, regardless of the current slow pace of market saturation. Having to carry the energy storage system (ESS) within an electric vehicle over the entire range of operating conditions has been a major hindrance for EVs, given the contemporary technology's heavy and bulky battery system.

The aerial wire system for the traditional public tram can be a solution, but it is only permitted for constrained operations in metropolitan regions, at the expense of the skyline. Supplying power wirelessly to running vehicles, rather than carrying the power source like a battery for the EVs over the entire traveling distance, could be a feasible design option for future electrified roads and vehicles, which could be considered a design solution for EV introduction. As a corollary, wireless charging of EVs, whether static or dynamic on-road charging, could represent a technological leap in achieving the widespread adoption of electric vehicles. This solution, however, must comply with the following requirements: transfer power capacity and efficiency, adequate levels of ease, safety, and commercial competitiveness.

N. Tesla boldly stated his idea of transmitting electrical power wirelessly across an air medium in the early 1890s, as evidenced in the Wardenclyffe tower experiment. Wireless Power Transfer technology (WPT) has attracted great attention in involving learners and related industries due to increased power and energy-efficient consumer electronics and small-capacity mobile equipment use, and the trend analysis predicts about $2 billion in wireless-power related revenues by

2025 in the aspects of economic electronics, automotive/transportation, industrial automation and heavy machinery, energy, sensors and transducers, health care and telecommunication services.

The groundbreaking tech in the realm of wireless power transfer and theoretical verification for practical applicability from a commercial standpoint of the OLEV system will be discussed in this presentation. The proposed Shaped Magnetic Field In Resonance (SMFIR) wireless power transfer technology, as well as the proposed power supply infrastructure and vehicle system, will be described in terms of their power transfer effectiveness and concept robustness for practicability and appropriateness to future green mobility.

II. PROPOSED TOPOLOGY

The OLEV is a WPT-enabled integrated system of invention and innovation that integrates automotive, power electronics, power grid, transport networks, and telecommunications. Road electrification, which will be interlinked to the smart grid and Intelligent Transportation System (ITS) technology, will be a key R&D focus in the decades to come. The system will serve as an inspiration for merging those difficult areas into a transportation system. The novel style to boosting the transmission efficiency of wireless power in the system and the architecture of the system of the power supply infrastructure, the vehicle, and related electromagnetic field (EMF) analysis will be described in the following subsections.

A. Resonant Coupled WPT and Efficiency

As noted in the beginning, modern wireless power technologies have lately grown more efficient and practical, with an emphasis on electric vehicles and consumer electronics applications. Wireless power transfer is a contactless power transmission that involves inductive and capacitive power transfer, similar to traditional transformers and capacitors. At low frequencies of 50 Hz or 60 Hz, power transfer from the primary and secondary coils of a transformer can be accomplished across a thin air gap. For the transformer above, this phenomenon is known as strongly coupled near-field inductive power transfer, or closely coupled contactless power transfer. The power transfer across the air gap can emerge if the operating frequency is high enough for the inductive coupling between two circuits to be stronger given the rapidly changing rate of the magnetic field.

However, enhancing the transfer efficiency (by maximizing the power factor) is crucial for applications with larger power requirements and longer distances between both coils, notably for dynamic wireless charging applications like OLEV. When a resonator capacitor is employed in the secondary coil circuit and the resonance frequency is calibrated to the primary circuit's operating frequency, the secondary coil's power factor is 1, and the transfer efficiency is maximized, which is referred to as resonant based power transfer.

To demonstrate this phenomenon, consider the equivalent primary and secondary circuits of the strongly coupled inductive power transfer model, as shown in Fig. 1, and its equivalent circuits, which are the same as the transformer model, as shown in Fig. 2.

Fig 1: Actual equivalent circuit

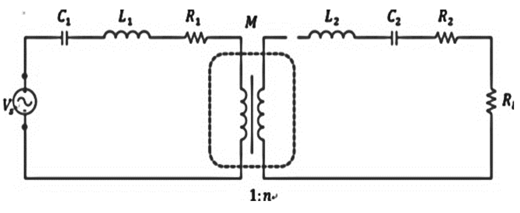

Fig 2: Equivalent circuit at a perfect resonance

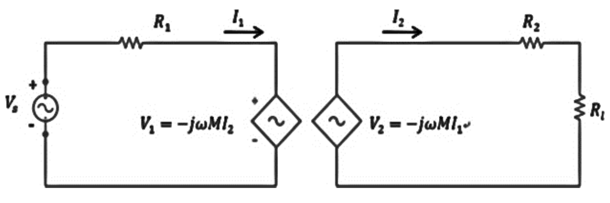

Figure 1: A loosely linked wireless power transfer system's equivalent circuit. The "primary" and "secondary" coil values of an inductor (L), resistance (R), and capacitance (C) are denoted by the subscripts "1" and "2." (C). V is the primary circuit's source voltage, which is equal to V_1, and R_1 is the secondary circuit's load resistance. The main and secondary winding ratio is referred to as n. The mutual inductance M may be calculated using the following formula when the power source's operating angular frequency is.

$$M = Vs / \omega I_1 \quad (1)$$

The mutual inductance, M, can be defined as follows by inserting the degree of coupling between two coils with the coupling coefficient, k.

$$M = k \sqrt{(L_1 L_2)} \quad (2)$$

To use mutual inductance, the circuits in Fig. 1 can be redrawn as in Fig. 2.

$$V_1 = (1 / j\omega C_1 + j\omega L_1 + R_1)I_1 - j\omega M I_2 \quad (3)$$

$$V_2 = j\omega M I_1 - (j\omega L_2 + 1/j\omega C_2 + R_T)I_2 \quad (4)$$

The total resistance of the secondary circuit is given by RT =(R2+R1). We can rearrange the current in the second circuit using (3) and (4).

$$I_2 = j\omega M / ((R_1 + 1/j\omega C_1 + j\omega L_1) \times (R_T + 1/j\omega C_2 + j\omega L_2) + \omega_2 M_2)V_1 \quad (5)$$

Given the primary circuit's power supply voltage and the secondary circuit's output induced current, we can define the transfer function between the circuits using (5). At the resonance frequency of ω_0 and the perfect resonant conditions of two circuits, the tuning of the capacitances in primary and secondary circuits should fulfill the following (6) and (7), as illustrated in Fig. 2

$$1/(j\omega_0 C_1) + j\omega_0 L_1 = 0 \quad (6)$$

$$1/(j\omega_0 C_2) + j\omega_0 L_2 = 0 \quad (7)$$

We can correctly tune the circuits for higher magnetic coupling between two circuits using two equations. At the resonant working frequency ω_0 (see Fig. 2), we can write the following connection.

$$V_1 = R_1 I_1 - j\omega_0 M I_2 \quad (8)$$

$$V_2 = j\omega_0 M I_1 - R_T I_2 \quad (9)$$

These can be represented as follows by designating the complex impedances of each circuit as Z1 and Z2.

$$Z_1 = R_1 + 1/ j\omega_0 C_1 + j\omega_0 L_1 \quad (10)$$

$$Z_2 = R_T + 1/ j\omega_0 C_2 + j\omega_0 L_2 \quad (11)$$

The delivered power to the secondary circuit, P2, and hence the transfer efficiency, may be calculated as follows at the resonance frequency, ω_0 (13).

$$P_2 = \mathrm{Re}\ \{V_2 . I_2^* \} = \omega_0{}^2 M^2 R_T . I_2 / Z_2 . Z_2{}^* \quad (12)$$

$$\eta = P_2 / P_1 = \mathrm{Re}\ \{V_2 . I_2{}^*\} / \ \mathrm{Re}\ \{V_1 . I_1{}^*\} \ = \omega_0^2 M^2 R_T \ / \mathrm{Re}\ \{Z_1 . Z_2 Z_2{}^* + \omega_0^2 M^2 . Z_2^*\} \quad (13)$$

The complex conjugate is denoted by the symbol " * ". The transfer efficiency can be stated as follows by simplifying Eq. (13) as Eq. (14).

$$\eta = \omega_0^2 M^2 / R_1 . R_T + \omega_0^2 M^2 = 1 / 1 + R_1 R_T / \omega_0^2 M^2 \quad (14)$$

The efficiency can be calculated using the Q-factors of primary and secondary circuits as follows:

$$\eta = k^2 . Q_1 . Q_2 / 1 + K^2 . Q_1. Q_2 \quad (15)$$

The following are the definitions of Q1 and Q2:

$$Q_1 = \omega_0 L_1 / R_1$$

$$Q_2 = \omega_0 L_2 / R_T$$

As a result, both circuits at resonance frequency should follow this basic principle to maximize transmission efficiency from (14).

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$$\eta \; \alpha \; R_1 R_T / \omega_0^2 \, M^2 << 1 \quad (16)$$

$$\eta \; \alpha \; k^2 \, . \, Q_1 \, . \, Q_2 >> 1 \quad (17)$$

It should be noted from (15) that a higher operating frequency and stronger magnetic coupling in two resonant circuits will result in higher power transfer efficiency (2), where a higher coupling coefficient k is required for a higher mutual inductance, M., where one of the significant factors would be the magnetic field interaction between two resonant coils. To put it another way (16). With a higher Q-factor in both circuits and a higher coupling factor, the efficiency will be higher.

B. Block diagram of the proposed system

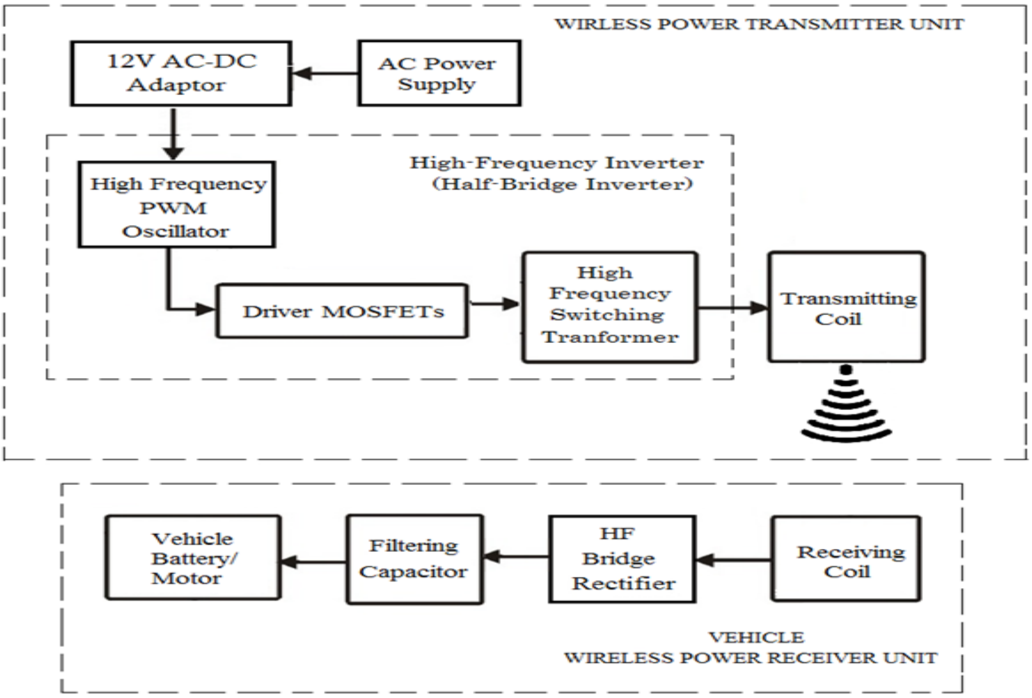

Fig 3: Block Diagram

Transmitter Section:

1. The first section of the circuit is the High-Frequency inverter which is designed using SG3525 IC. It produces High Frequency PWM signal. The frequency range is 60 – 75 KHz.
2. The second section is the Half-Bridge Driver circuit which consists of two N-channel MOSFETs. MOSFETs drivers feed the PWM signal to the primary of a HF switching transformer.
3. The third section is the High-Frequency Transformer. It converts the DC DC input fed in the primary coil by the MOSFETS into HF AC output at its secondary coil.
4. The fourth section is the transmitting coil. It converts the fed HF-AC current into electromagnetic waves.

SG3525 IC is basically a PWM oscillator chip which produces high-frequency PWM signal which can drive MOSFETs directly to switch then ON and OFF. The frequency of the PWM signal can be set and also adjusted using the timing control resistor and capacitor which are connected to the pin-6 and pin-5 (RT and CT). The IC has two PWM outputs which are pin-11 and pin-14 (out A and out B). Two pwm outputs are connected to the gate terminal of MOSFETs connected in half-bridge configuration. Transmitter coil is a centre tapped coil, so it has three terminals. The Drain terminal of the two MOSFETs are connected to two ends of the transmitter coil. Centre tap of the coil is connected to the DC source power supply which is 12v.

When power is turned ON the IC SG3525 starts oscillating and produces PWM signals. The MOSFETs connected to its outputs are switched ON and OFF alternatively. The Out A and Out B of the IC output are 90degrees out of phase. So when one MOSFET is in ON condition the other # will be in OFF condition. Here we use a oscillator frequency of 60 to 80KHz frequency range. So the MOSFETs are switched at high frequency. When on MOSFET is in ON condition the DC current will flow from the centre tap of transmitter coil through MOSFET drain terminal and reach the source terminal

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which is connected to ground. So in first half cycle the direction of DC current will be in first half coil portion of the transmitter coil. In the same way the current flow will be in second half portion of the coil during next half cycle. Thus the two MOSFETs create a current flow which are opposite in direction in each switching cycle. So as a result an alternating current is produced in the transmitting coil. This configuration thus produces a high frequency AC current from the input DC current. Transmitter coil converts the HF AC electric current into HF electromagnetic field. Thus the transmitter coil coverts electric current and transmits in the form of electromagnetic waves.

Receiver Section:

Receiver has a three section.

1. First is the receiver coil
2. Second is the High-Frequency rectifier
3. Third is the DC ripple filter

Receiver has a receiving coil which has same resonant frequency of the transmitter coil. So when placed near the transmitter coil it will pick up the electromagnetic field and converts it into the high frequency AC current. Output of receiver coil is given to a high frequency rectifier which converts HF AC to DC voltage output. A capacitor filter at the output of rectifier filters the ripple in DC and gives a stable DC output voltage. A DC output is produced at the output of receiver which is used to power any DC loads.

III. PRACTICAL APPLICATION

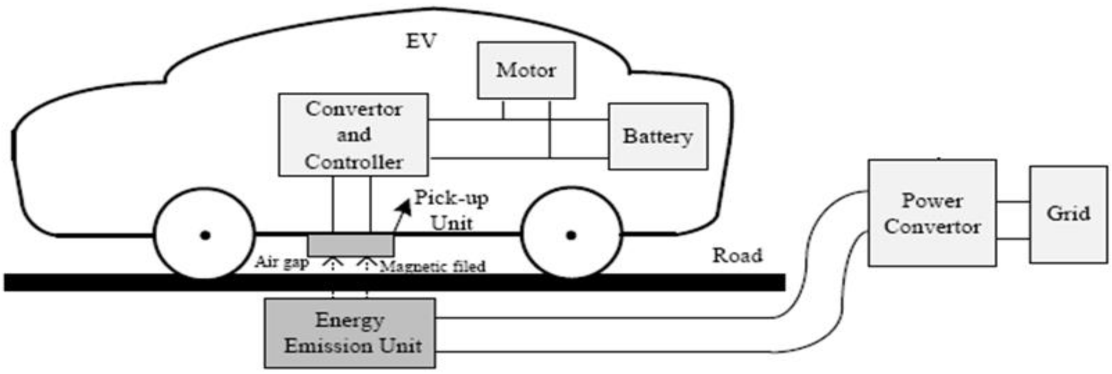

Fig 4: Practical Application Diagram of the Proposed system

The electrical power flows from the power transmitter coil inside the platform to the receiving coil inside the bottom of the electric vehicle. Electrical charging is done once the resonant frequency of both the coils matches and the vehicle charged automatically. When the vehicle is moved the charger goes to the power saving mode and cut off the charger coil.

A. Basic Design

A wireless power transfer system uses inductive coupling. One of the most important factors that must be considered in designing an inductive coupling system is the target power of the system. Voltage and current ranges, usable devices, and operating frequency of the system depend on the target power. Because the wireless power transfer system for moving electric vehicles is a public service system that is installed in a road, the use of the resonance frequency must be permitted by the government.

Generally, wireless power transfer systems for electric vehicles use 10–100-kHz frequency. In the EV system, the target power is 100 kW, and the resonance frequency is 78 kHz. The circuit is fundamentally the same as the circuit model of transformers. In the circuit, a larger mutual inductance M facilitates more effective power transfer. The mutual inductance M is determined by L1, L2, and the coupling coefficient k, as follows:

$$M = k\sqrt{L_1 L_2}$$

where k indicates the degree of coupling strength and is between zero and one.

B. System Operation

The wireless power transfer system consists of a power transmitter part and a power receiver part. The power transmitter part is composed of an inverter and power lines. The inverter provides power, and the power lines carry current and generate magnetic flux. The power receiver part is composed of pickup modules, rectifiers, and regulators. The pickup

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modules generate power from induced voltage and current, the rectifiers convert ac power to dc, and the regulators control the output voltage, which is input to batteries and motors.

The inverter receives power from an electric power company and converts 60-Hz operating frequency into 20-kHz resonance frequency. Although the inverter can be controlled to provide constant voltage, constant current control is more advantageous in dealing with changes in the load resistance or multi-pickup charging. Therefore, in the OLEV system, the inverter converts 60-Hz power to 260-A constant current at 20-kHz resonance frequency. The power line modules are installed underneath the road and along the road. Some of the transferred power is used to drive the motors, and the remainder is used to charge the batteries. When the vehicle stops, all of the power is used to charge the batteries.

IV. FREQUENCY CALCULATION OF TRANSMITTER & RECEIVER COILS

The calculations are done based on the components specifications used in hardware through online calculators. The obtained results of the calculations are mentioned as follows.

A. LC Resonance Frequency Calculation

Frequency:	0.0749	(MHz)
Capacitance:	1.50e+3	(pF)
Inductance:	3.01e+6	(nH)
	Calculate	

Design Equations:

2*pi*F= 1/sqrt(L*C)

0.0749 megahertz =

74.9 kilohertz

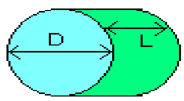
Fig 5: Frequency Calculation of Transmitter

B. Air Core Coil Inductance Calculation

The following is a design tool which calculates the inductance of an air core inductor.

L= (d^2 * n^2)/(18d+40l)

where:



L is inductance in micro Henrys,
d is coil diameter in inches,
l is coil length in inches, and
n is number of turns.

Coil: 24SWG Enamel Copper Wire

d (coil diameter in inches)	4.5	(inches)	
l (coil length in inches)	0.393701	(inches)	(1CM)
n (number of turns)	120		(60+60Turns)
	Calculate Inductance		
L (Inductance)	3014.01455	(uH)	

Microhenry ↔ Nanohenry Conversion

Microhenry:	3014.01455
Nanohenry:	3014014.55

Calculate | Clear Above | Reset All

Fig 6: Inductance Calculation of Transmitter

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C. Frequency Calculation Of Transmitter Coil

L= (d^2 * n^2)/(18d+40l)

where:

L is inductance in micro Henrys,
d is coil diameter in inches,
l is coil length in inches, and
n is number of turns.

d (coil diameter in inches)	3.5	(inches)
l (coil length in inches)	.5	(inches)
n (number of turns)	100	
Calculate Inductance		
L (Inductance)	1475.90361	(uH)

Frequency:	0.0720	(MHz)
Capacitance:	3.30e+3	(pF)
Inductance:	1.48e+6	(nH)
Calculate		

Design Equations:

2*pi*F= 1/sqrt(L*C)

F=72.0KHz

Fig 7: Frequency Calculation of Transmitter Coil

D. Frequency Calculation Of Receiver Coil

L= (d^2 * n^2)/(18d+40l)

where:

L is inductance in micro Henrys,
d is coil diameter in inches,
l is coil length in inches, and
n is number of turns.

d (coil diameter in inches)	3.0	(inches)
l (coil length in inches)	.25	(inches)
n (number of turns)	100	
Calculate Inductance		
L (Inductance)	1406.25000	(uH)

Frequency:	0.0738	(MHz)
Capacitance:	3.30e+3	(pF)
Inductance:	1.41e+6	(nH)
Calculate		

Design Equations:

2*pi*F= 1/sqrt(L*C)

F=73.8KHz

Fig 8: Frequency Calculation of Receiver Coil

V. CONCLUSION

According to this paper, the OLEV system, a new innovative technology, has been introduced in the overview level of the shaped magnetic field in resonance (SMFIR) technology, given its practical applicability, which includes a detailed description of the vehicle and the system's power supply infrastructure. The experimental verification of transmission efficiency, as well as other critical concerns in-vehicle and infrastructure technologies, are also discussed. Electric vehicles are one of the most effective applications in the growing concern about environmental protection; yet, existing technology is falling short of user adoption, and other technologies are emerging and competing.

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