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The Impact of Magnetic Resonance Coupling in Electric Vehicle Power Transfer Systems

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Abstract: This research investigates the innovative use of Magnetic Resonance Coupling (MRC) in Electric Vehicle (EV) power transfer, focusing on its potential and challenges. Key objectives include understanding MRC's operational principles, optimizing efficiency, and tackling real-world EV charging issues. Essential components like coil design, resonance frequency tuning, and power control are covered, utilizing MATLAB and Simulink for performance simulation under various conditions. The impact of MRC on EV charging infrastructure is highlighted, emphasizing advancements in power transmission and efficiency. The findings promise to revolutionize EV charging, leading to more efficient, convenient, and sustainable power transfer methods.

I. INTRODUCTION

The advent of Magnetic Resonance Coupling Wireless Power Transfer (MCR-WPT) technology has revolutionized various industries by enabling the transmission of substantial power with high efficiency and over extended distances. This technology, with its wide-ranging applications in electric vehicles, medical devices, robots charging, and rails transition power supply, has particularly garnered attention in the electric power industry, where it is instrumental in enhancing safety and efficiency.

However, one significant challenge faced by electric inspection robots, Essential for guaranteeing safe and reliable power systems., has been the existing

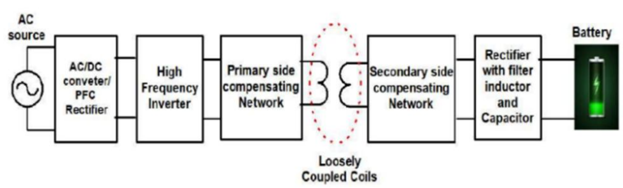

Fig .1 Overview of Wireless Power Transfer Charging (WPTC)

contact-based charging methods. These methods are plagued by issues like electric sparks, leakage, and cable deterioration, posing serious threats to power system operation. This technology emerges as a promising solution, offering wireless charging capabilities that mitigate these challenges, ensuring seamless power supply to robots, vital for independent and uninterrupted operation.

This research explores the integration of WPT into the charging systems for electric inspection robots. aiming to optimize charging processes. Traditionally, charging batteries involves complex stages like constant currents (CC) and constant voltages (CV) charging, which necessitate precise control mechanisms. Current methods, though effective, often involve intricate communication systems between primary and secondary sides, increasing complexity and cost. To overcome these limitations, this study proposes an innovative T-type resonance compensation network coupled with hybrid self-switching resonant networks (LCL-LCL/S) for wireless charging..

A. Operation of Wireless Charging System

The resonance wireless charging system operates by converting a standard AC source into a form suitable for wireless power transfer and ultimately charging a battery efficiently. The process begins with an AC source at 325V,(as per Qi standards) 50A, and 50Hz frequency.

B. Rectification

The AC power is first converted into DC using a bridge rectifier. The output of the rectifier is 280V DC at 20A. The rectification process is governed by the formula:

$$V_{DC} = \frac{2Vpeak}{\pi}$$

Where V_{peak} =325V * $\sqrt{2}$ = 460V therefore,

$V_{dc} = \frac{2*460V}{\pi}$ = 292V

In practical terms, considering losses, the rectified voltage is approximately 280V.

C. High-Frequency Inversion

This DC voltage is fed into a high-frequency inverter with PWM switching at 3000Hz, outputting a voltage range of 180-400V and up to 30A. The inverter's role is crucial for creating the high-frequency AC necessary for effective resonant wireless power transfer.

D. Resonance and Power Transfer

The inverter output is connected to a series resonance capacitor and primary coil, forming a resonant circuit. The primary coil has a self-inductance L1, and it couples with the secondary coil with self-inductance L2 and mutual inductance M . The resonance frequency f_0 is determined by:

$$f_0 = \frac{1}{2\pi\sqrt{L1C}}$$

where C is the capacitance of the series resonance capacitor.

The efficiency of power transfer is maximized at this resonant frequency. The coupling coefficient k and the air gap d between the coils are critical parameters. The power transferred P and efficiency ( ) can be expressed as:

$$Efficiency = \frac{k^2 Q_1 Q_2}{1 + K^2 Q_1 Q_2}$$

$$P = \frac{V_1^2 k^2 Q_1 Q_2}{R_L(1 + K^2 Q_1 Q_2)}$$

where Q_1 and Q_2 are the quality factors of the primary and secondary coils, and R Lis the load resistance.

There are two common definitions for Q (quality factor), which, while not exactly equivalent, converge as Q increases and the resonator becomes less damped. One of these definitions relates to the frequency-to-bandwidth ratio of the resonator.

$$Q = \frac{\sqrt{LC}}{\frac{R}{L}} = \frac{W_O}{\frac{R}{L}} = \frac{W_0 L}{R} = \frac{1}{W_0 R}$$

For series RLC:

$$Q = \frac{1}{W_0 RC}$$

$$B = \frac{R}{L} = \frac{w_0}{Q}$$

E. Secondary Side and Rectification

The secondary coil receives the power via magnetic coupling. The induced high-frequency AC is rectified using a secondary rectifier to provide 400V DC at 13A, totaling a power output of 5200W. The rectifier output follows the equation:

$P_{dc} = V_{dc} * I_{dc}$

P_{dc} = 400v * 13A = 5200

F. Battery Charging

Finally, the rectified DC power is used to charge a battery. The charging process ensures that the battery receives a stable 400V at 13A, maintaining the necessary voltage and current levels for safe and efficient charging. The battery charging efficiency and longevity are optimized through this wireless power transfer system.

II. DESIGN SPECIFICATION

. DESIGN PARAMETERS

Parameters	Designator	Value
Input Voltage	I_{in}	325V
Output Voltage (Rated)	V_{out}	350-400v
Output Current(Rated)	I_{out}	13A
Output Power(Rated)	P_{out}	5.2KW
Turns ratio	n	3.6

Table.1

Primary Turns	R_1	44
Secondary Turns	R_2	12
Resonant frequency	t_p	50KHz
Minimum switching frequency	tm	30KHz
Magnetizing Inductor	P_1 P_2	$260 * 10^{-6}$ H $250 * 10^{-6}$
Resonant Capacitor	C_r	$105 * 10^{-9}$ F
Quality factor	Q	0.4
Mutual inductance	M	$85 * 10^{-3}$ H
Proportional gain	Kp	500

Table.2

The following specifications are part of the design process for the Converters;

- Hold-up time (TH): 20ms (50 Hz line frequency)
- Maximum Output Power (Po): 5.2k Watts
- Rated Output Voltage (Vo): 300-400V DC
- Maximum Input Voltage (Vin): 320V DC

III. SIMULATION MODEL AND RESULTS

The Simulink model in Figure 1 depicts the Magnetic Resonance Coupling circuit, showcasing the performance of various parameters.

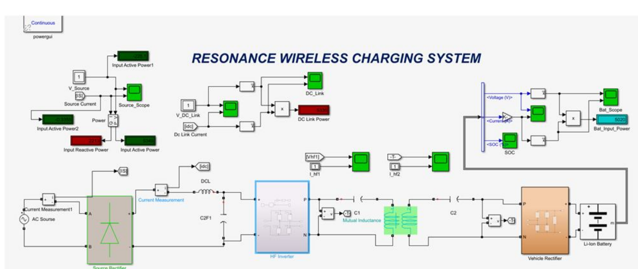

Fig.2

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This simulation of the WPT system for charging electric inspection robots showed seamless wireless charging with partial stable current and voltage output. The results validate the reliability and effectiveness of resonance-based strategy for practical use.

A. Source Voltage And Source Current

Source voltage is the electric potential difference from the power source, measured in volts (V), driving the electric current through a circuit.

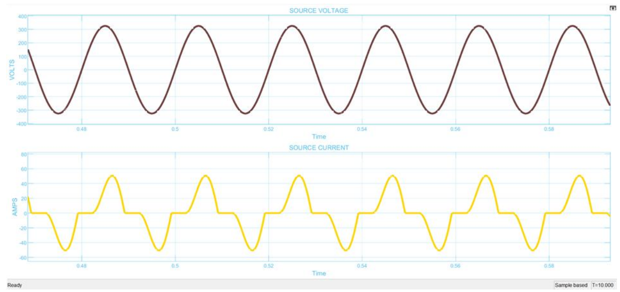

fig.3

Source current, measured in amperes (A), is the flow of electric charge in the circuit. Controlling these parameters is essential for efficient and safe power distribution.

B. DC LINK V &I

DC Link Voltage (V): DC Link Voltage refers to the steady voltage level in a direct current (DC) which is from source rectifier.

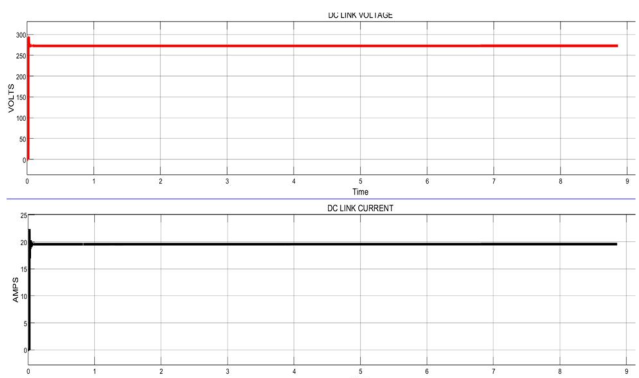

Fig.4

.DC Link Current (I): DC Link Current represents the flow of electric charge in the DC circuit. which is from source rectifier.

C. Primary Side Or Ground Side

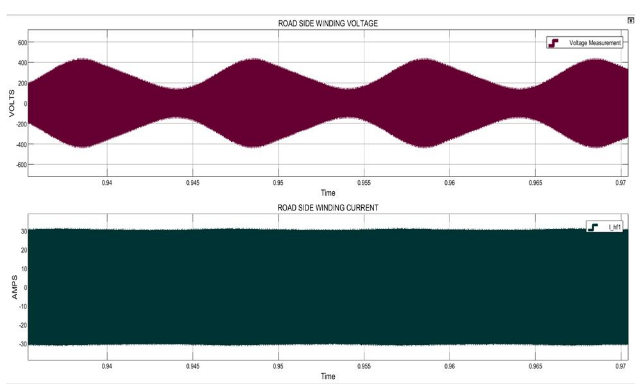

Fig.5

D. Secondary Side Or Vehicle Side

The secondary side is latter segment of inductive device. It is where the electromagnetic energy received from the primary side

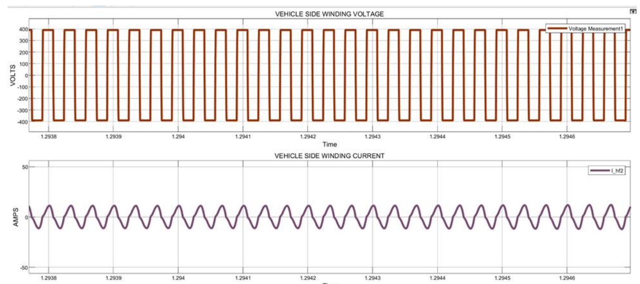

fig.6

E. Battery Input

Charging Battery Voltage: Charging battery voltage represents the electrical potential difference applied to a battery during the charging process, measured in volts (V)..

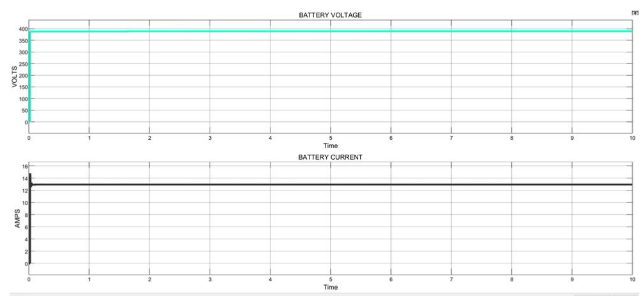

fig. 7

Charging Battery Current:Charging battery current refers to the flow of electric charge into the battery during the charging process, measured in amperes (A). It signifies the rate at which the battery is being charged. Proper current control is essential

Fig. 8

Linear soc (state of charging) the battery to maintain good specific gravity and life of battery.

IV. CONCLUSION

The project effectively showcases the potential of a resonance wireless charging system for electric vehicles. By leveraging magnetic resonance coupling and high-frequency power electronics, the system achieves efficient and reliable wireless power transfer. This innovative approach significantly enhances power transmission efficiency and distance, offering a convenient alternative to traditional wired charging. Comprehensive analysis and simulation, supported by practical implementation, validate the system's effectiveness. This work paves the way for future advancements in EV charging technology, promoting a sustainable and user-friendly charging infrastructure that can revolutionize the electric vehicle industry.

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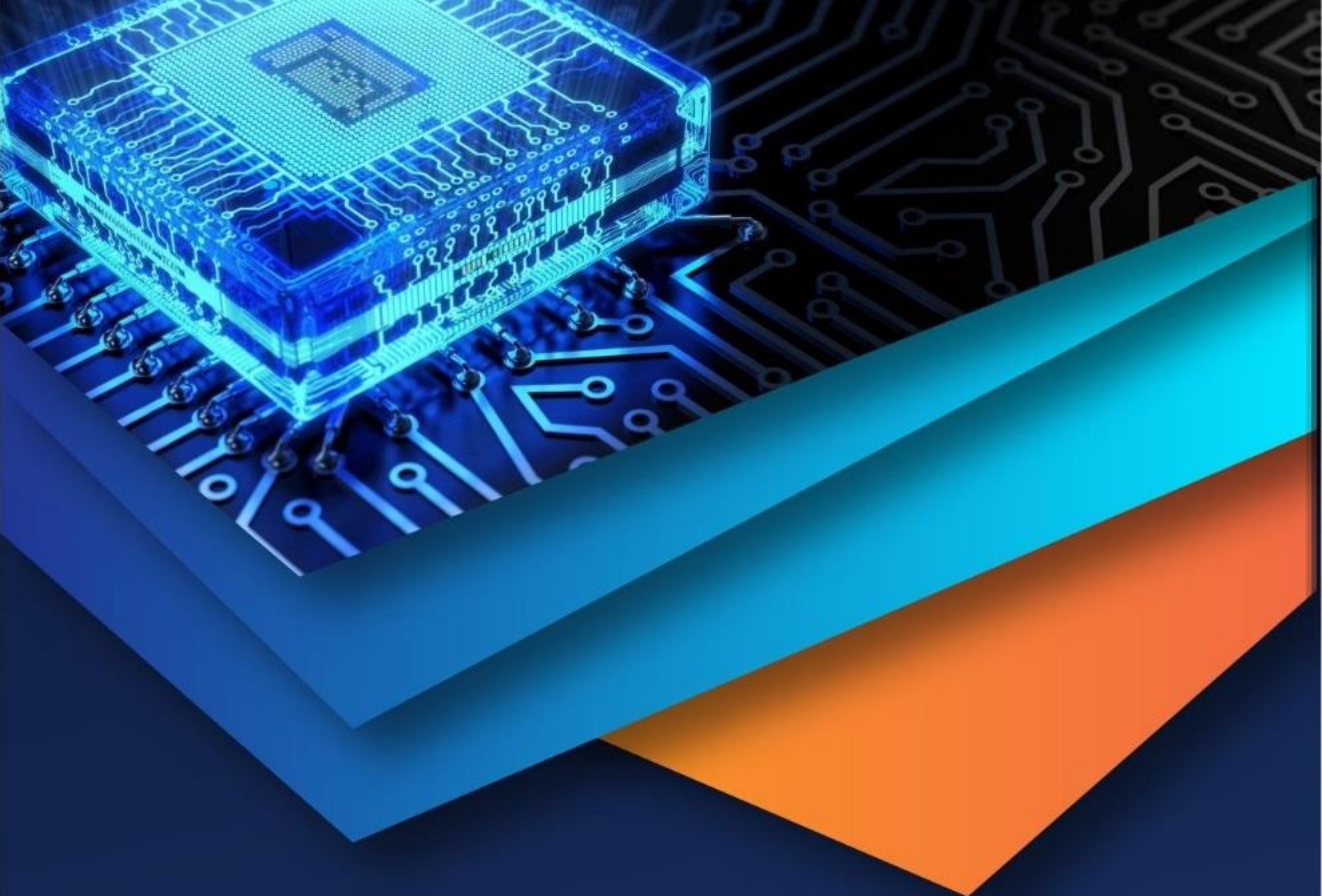

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