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Electrifying the roads using wireless charging solutions for next-gen electric vehicles

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ABSTRACT

This paper outlines a solar charging device designed for electric vehicles (Evs), mitigating the drawbacks of conventional fuel-based transportation and environmental pollution. Because EVs are becoming more and more popular throughout the world, there are more of them on the road. Beyond environmental benefits, EVs offer cost savings by substituting expensive fuel with more economical electricity. The study introduces innovative solutions in EV charging, enabling separate charging stations, continuous motion charging, and wireless charging without external power sources. The communication and system operations are controlled by an ESP8266 controller. This advanced approach eliminates the need for intermittent charging stops, representing a solar-powered wireless charging solution for plug-in EVs in transit. This work underscores the critical importance of addressing energy and environmental sustainability.

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1. INTRODUCTION

Electric vehicles (EVs) stand at the forefront of a transformative era in transportation, offering a beacon of hope in the face of soaring oil prices and escalating carbon emissions. Unlike their fossil-fueled counterparts, which rely on internal combustion engines, EVs harness the power of electricity, ushering in a new age of sustainable mobility [1]. The capacity of renewable energy sources like wind and solar power to fundamentally transform the generation of electrical energy is immense. These sources possess the potential to significantly overhaul the methods through which electrical energy is produced. In addition to lowering dependency on finite resources and minimizing environmental effects, their endless supply and sustainable generation enable a paradigm change toward cleaner, more robust energy systems [2]. Despite the immense promise, renewable energy's contribution to global electricity production remains modest, accounting for only 18% of the overall share. The dawn of EVs ushers in a monumental shift towards greener and more environmentally conscious transportation. These are more than just automobiles; they are a manifestation of progress, embracing cutting-edge technology and innovative engineering to reshape our automotive landscape [3].

In the realm of transportation, EVs outshine their internal combustion engine counterparts. With electrified power locomotives, high voltage energy storage systems, and remarkably efficient electric motors, x-EVs surpass traditional vehicles in terms of performance [4]. This technological prowess positions them as the future of transportation, poised to lead the way in reducing both greenhouse gas emissions and air pollution [5]. As global energy consumption and greenhouse gas emissions surge, a significant share is attributed to transportation [6]. The imperative shift from vehicles with combustion engines to EVs elevates the urgency for innovative, efficient wireless charging methods. Design and production considerations now stand as pivotal players in the quest for sustainable mobility solutions [7].

2. METHOD

Wireless power transfer has emerged as a revolutionary strategy for integrating EVs with tried-and-true wireless technology. Its potential benefits for society are enormous, especially in scenarios where wiring is unsafe, impractical, or not possible at all [8]. Inductive coupling, a commonly applied technique, requires three essential components: a transmitter generating an AC signal, coils for power transmission and reception, and a receiver converting the AC signal into a DC signal for battery charging [9], [10].

This innovative method holds the potential to transform environmentally friendly transportation by effectively utilizing wireless power transfer technology. Furthermore, the integration of solar roadways with wireless power transfer becomes an essential component of this vision [11]. By converting roadways into continuous power sources, solar highways offer cheap, safe, and sustainable non-polluting energy. Despite their initial construction costs, these solar-powered roads have a remarkable longevity of up to 21 years, generating enough electricity to cover their initial cost continuously [12].

Lane-changing behavior studies have yielded lane-changing models, defining drivers' timely adjustments in driving strategies, encompassing decision-making, execution, and impact. Additionally, the optimization of wireless charging infrastructure placement along extensive highways caters to diverse vehicle battery types. The road segments split into zones with inductive emitting cables and inverters, offering an alternate route for vehicles requiring the charge, while others utilize the principal route if unnecessary [13].

Modern high-voltage off-board DC chargers with advanced power electronic components provide greater charging power levels with less strain on the grid and charger parts [14]. Despite the benefits of wireless charging, like unplugged transactions and reduced battery capacity needs, uncontrolled integration can burden the distribution grid [15]. The disadvantages of integrating EVs have yet to be sufficiently mitigated by early attempts at smart charging [16]. Experts in electrical engineering with a focus on power systems, renewable energy integration, sustainable energy technologies, electricity markets, and smart grids are also introduced in an editorial and it also showcases their roles as reviewers and associate editors for journals and conferences [17].

3. METHODS OF CHARGING

3.1. Capacitive inductive charging system

An innovative technique that transforms the transmission of energy. It does away with the necessity for conventional coils and magnets by utilizing displacement current through variations in the electric field [18]. For smooth power transfer, the procedure includes electrostatic induction, high-frequency AC production, and AC voltage adjustment. This system, operating within a frequency range of 100 to 600 kHz, delivers reliable and efficient charging while paving the way for a sustainable future [19].

3.2. Gear-driven magnetic wireless charging system

The magnetic gear wireless power transfer (MGWPT) utilizes two synchronized permanent magnets to transmit power across an air gap. The transmitter side winding receives the primary power supply, while the secondary permanent magnet collects and transmits power to the battery through the power converter and battery management system (BMS) [20]. When permanent magnets in the transmitter and receiver are synchronized and equipped with an armature winding, a magnetic gear is created. The application of an AC current to the transmitter generates torque, causing synchronous rotation of the receiver magnet. This rotational movement, when converted, produces AC power, effectively powering the battery—a novel method for efficiently converting mechanical energy into electrical output. The transmitter and receiver components of the MGWPT system are the synchronized permanent magnets and armature winding, respectively. This allows power to be sent and converted later to meet the battery's electrical requirements.

3.3. Induction-based wireless power delivery

In 1914, Nikola Tesla created the conventional inductive power transfer (IPT) method for wireless power transfer. The basis for contemporary wireless charging systems was established by this technique. Magnet charge IPT was introduced in 1996 for the Chevrolet S10 EV, which included stage 3 (50 kW) quick charging and stage 2 (6.6 kW) slow charging capabilities. This chronological sequence illustrates how wireless charging technology has changed over time.

An innovative charging mechanism operates based on Faraday's law of induction. It employs mutual induction of magnetic fields between the coils of the transmitter and receiver to transmit power wirelessly. The movement of electrons in the receiving coil induced by the AC magnetic field of the transmitter coil generates AC power. This electricity, upon rectification and filtering, charges the energy storage systems of EVs. The efficiency and amount of power transferred wirelessly depend on various factors such as frequency, mutual inductance, and the distance between the transmitter and receiver coils. Typically, these operations occur within a frequency range of 19 to 50 kHz.

3.4. Microwave/radio frequency wireless charging

Created for communication, far-field wireless power transfer, or WPT, has a rich history. Nikola Tesla's 1904 radio wave power transfer was pivotal. By 1964, Brown's wireless helicopter and Dickinson's 2.45 GHz MPT breakthrough advanced the field. Japan, especially Kyoto University, contributed to WPT's growth in Solar Power Satellite research. Shinohara's [21] collaboration with Nissan yielded a 76% efficient WPT system for EVs, while Mitsubishi later led an MPT project for EVs. The directional nature of microwaves enables long-distance power transmission. Far-field WPT has diverse applications, including solar satellites and wireless EV charging.

3.5. Wireless charging using lasers

Power beaming or wireless power transmission (WPT) with lasers, is a method of transmitting energy across long distances but has efficiency restrictions. It includes transforming electrical current into a laser beam that is directed toward a solar cell. Monochromatic light-optimized specialized photovoltaic (PV) laser power converters are employed. Because of security and energy loss issues, precision is essential, which makes it less appropriate for refueling EVs.

4. BLOCK DIAGRAM AND ITS DESCRIPTION

4.1. Solar roads

The Solar panels are designed specifically for sidewalks and roads are known as solar roads. Their main objective is to install solar panels in place of conventional asphalt roadways to provide local residences and businesses with electricity via driveways or parking lots.

4.2. Battery charging circuit

The battery charging circuit utilizes a p-n-p transistor in a reverse-biased state, enabling charging from a thermal electricity generator. Once the battery reaches full charge, it becomes forward-biased, automatically cutting off the circuit.

4.3. Inverter circuit

Inverters are essential where accessing AC power from the mains is impractical. Two main types exist: True/pure sine wave inverters, costly but suitable for delicate electronics; and modified (quasi) inverters, inexpensive but producing square waves unsuitable for such devices. A simple inverter circuit using power transistors that transforms 12 volts of direct current into 220 volts of alternating current through voltage manipulation.

4.4. Multivibrators

Multivibrators, fundamental electronic circuits for various applications, were invented during World War I by Henri Abraham and Eugene Bloch. The three types are: Astable Multivibrator: Unstable in either state, it continuously switches, functioning as a relaxation oscillator; Monostable Multivibrator (One Shot): One state is stable, the other unstable. Trigger pulse initiates the unstable state, and it returns to stability after a set time; Bistable Multivibrator (Flip Flop): Stable in either state, external trigger flips it frequently utilized in computer memory and digital logic. These circuits, crucial before low-cost integrated circuits, served as frequency dividers in systems like early electronic organs and television, ensuring synchronization.

4.5. Rectifier circuit

It converts an alternating current into a direct current, ensuring the flow of electricity in a single direction. Rectifiers exist in different types, such as vacuum tube diodes, semiconductor devices like silicon-controlled rectifiers, and older options like mercury-arc valves. Their importance lies in their pivotal roles in producing DC for power sources and high-voltage DC transmission systems. Rectifiers serve diverse applications, such as providing steady DC power for radio, television, and computer equipment. Additionally, they function as detectors in radio signal reception and flame rectification in gas heating systems. Depending on the rectifier circuit and AC supply, the output voltage may need smoothing for a consistent DC output. This smoothing is achieved through electronic filters, often involving capacitors, chokes, resistors, and sometimes voltage regulators to ensure a stable voltage output.

4.6. Filter

Filtering attenuates undesired signal components or isolates specific frequency portions in signal shaping. The circuit illustrates a Filter Circuit designed for this purpose. Filters, integral in this process, effectively eliminate unwanted signal segments at the input, a phenomenon known as attenuation. The overall working prototype is shown in Figure 1.

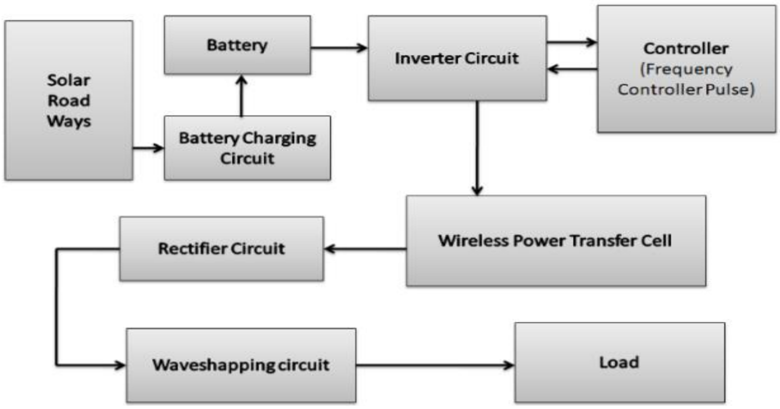

Figure 1. Block diagram

4.7. Wireless power transfer coil

WPT employs microwaves, solar cells, and resonance. This includes an AC-powered transmitter coil to create a magnetic field that causes the receiving coil to produce a voltage. The basic principle is inductive energy transmission through an oscillating magnetic field. The transmitter's specially built circuits transform DC into high-frequency AC. A magnetic field produced by AC current in a copper wire in the transmitter part causes an AC current to flow through a neighboring reception coil. The receiving device's electrons convert AC back to DC, providing operational power.

5. WORKING PRINCIPLE

The process begins with solar roadways harnessing energy, directing it to a power station through a battery charging system. An inverter transforms the battery's direct current into alternating current, controlled via pulse width modulation to regulate AC frequency. This inverted power connects to a wireless power transfer coil, generating an electromagnetic field. Equipped vehicles possess receiving coils to capture wirelessly transmitted power. Upon reception, this power is rectified, refined into pure DC through a wave-shaping circuit, and then directed to the load. Remote charging, especially in solar-rich areas, becomes recommended due to solar energy integration within the infrastructure, serving as an autonomous power source.

EVs require two types of batteries, parallel and serial, for balancing amperes and voltages. One such illustration is an alternator linked to the back wheel shaft, interconnected with batteries and the motor through a switching mechanism. This approach addresses traditional charging issues via remote power transmission, focusing on solar-controlled EV charging stations. Solar panels convert sunlight into electrical energy, transmitted to the vehicle's battery using remote power transfer technology. A solar-powered charge regulator enhances the energy output of PV cells, reducing reliance on conventional energy sources. The wireless charging system's transmitting loop utilizes DC power from source side batteries, converting it into high-frequency AC within the transmitter circuit. This AC power is transmitted as electromagnetic waves to the load side. A collector circuit in the vehicle's coil decodes these waves, generating DC output to charge the vehicle's battery efficiently. This streamlined design minimizes space requirements, enabling straightforward installation and maintenance.

The quadruple U auxiliary structure positioned beneath the transmitting coil helps maintain alignment. Misalignment alters mutual inductances, leading to unique load voltages and establishing a specific trajectory summarizing all possible misalignment positions of the receiving coil. This method utilizes the opposing lane to provide energy for EVs without affecting the vehicle's speeds in both directions. The study also details the location, deployment, and tactical operations of EVs on roads equipped with dynamic wireless charging lanes [22]. Finally, the orientation of the PV system significantly impacts its yield. Orienting the PV system at a tilt of 51° maximizes annual yield, whereas extremes like increasing the tilt to 65° reduce the annual yield by up to 20% [23].

6. SOFTWARE DESCRIPTION

Designing a versatile solar power system involves a dynamic interplay of components, orchestrated seamlessly through NI Multisim. Elevate your designs with custom instruments and analyses from LabVIEW, enhancing Multisim's simulation capabilities for precise control, audio processing, noise analysis, and power design. Unleash the potential of your circuitry with Multisim where innovation meets simulation. The performance of solar system is shown in Figure 2.

The MPPT employs MOSFET and an internal diode that runs alongside an RC circuit, introducing an innovative method featuring resistances of 1×10^2 ohms and 2×10^2 ohms, respectively. This solar-powered MPPT efficiently charges a Lead Acid battery with remarkable accuracy, operating at a duty cycle of $1\times e^{6}$ and a frequency of 1,000 Hz. Experience an enhanced EV journey infused with groundbreaking innovation.

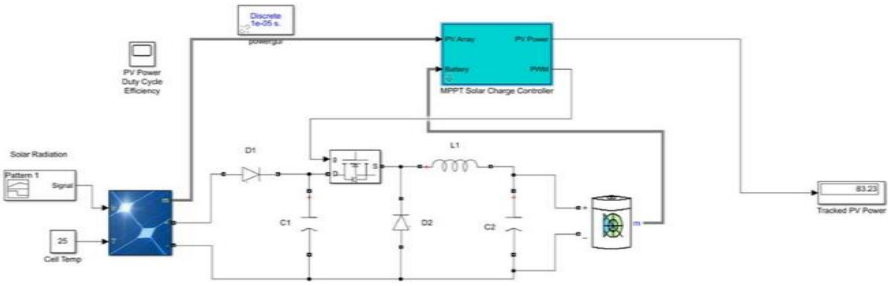

Figure 2. Performance of solar system

6.1. Solar panel to battery performance

Revolutionizing EV charging, our method employs inductive coupling for remote transmission. Unlike traditional charging, MPPT dynamically manages power, enhancing battery safety and speed. In our simulation, the algorithm ensures a 19V charge, utilizing excess voltage as a storage reservoir.

6.2. On-road charging simulated output

Using Multisim, our simulation optimizes battery charging with a 1.5A supply (PV 1). The TIP127G Darlington transistor effectively drives current to charge the battery, functioning as an automated cutoff upon attaining full charge, while a well-positioned diode inhibits reverse current. This innovative circuit design guarantees efficient battery charging, presenting a streamlined and effective solution. Energize your research with this concise and impactful exploration of our simulation approach. Therefore, the frequency is computed according to the subsequent formula. The on-road charging circuit output is shown in Figure 3.

Charging capacitor = C_3

$$T2 = R7 \times C3 \tag{1}$$

Discharging capacitor, C_2

$$T1 = R5 \times C2 \tag{2}$$

The current delay changes exponentially as R_5C_2's time constant increases. It is given as,

$$I_{c1} = \frac{Vcc+Vcc}{R5} \tag{3}$$

$$VB2 = Vcc - 2 \times Vcc \times e^{\frac{-t}{R5\times C2}} \tag{4}$$

$$0 = Vcc - 2 \times Vcc \times e^{\frac{-t}{R5\times C2}} \tag{5}$$

$$1 = 2 \times e^{\frac{-t}{R5\times C2}} \tag{6}$$

Hence, $T1 = R5 \times C2 \times ln(2)\ and\ T2 = R7 \times C3 \times ln(2)$ (7)

The total time period is determined by, $T = T1 + T2 = (R5C2 + R7C3)\, ln(2)$ (8)

Renaming the components, $R7, R5 = R, C2, C3 = C, then\ T = 1.4RC$ (9)

Frequency, $F = \frac{0.7}{RC}$ (10)

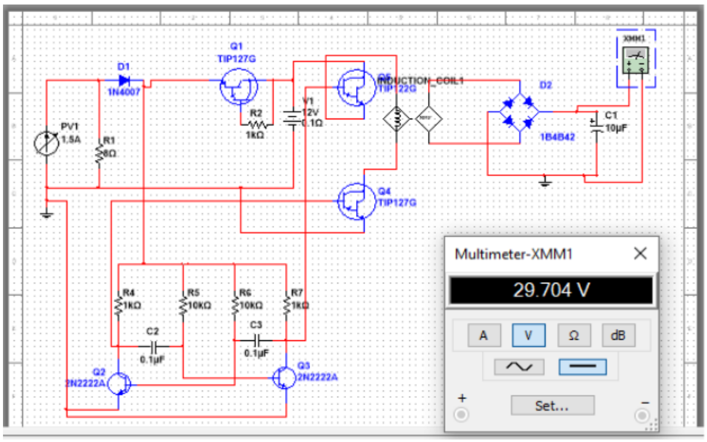

Figure 3. On-road charging circuit output

By using a multivibrator to detect the electromagnetic field (EMF) produced by an induction coil and it draws towards another coil nearby, a voltage is produced. The circuit adheres to the asserted waveform. The pulse width waveform generated by the multivibrator effectively governs and controls the current flow within the MOSFET and the simulation output is shown in Figure 4.

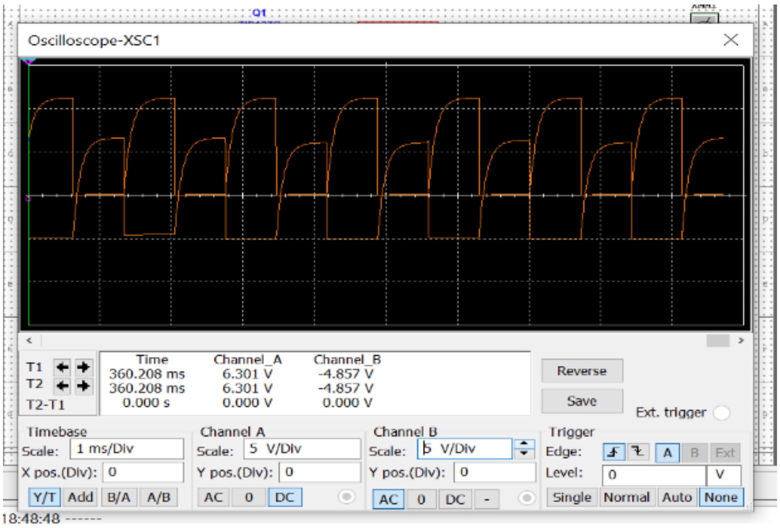

Figure 4. Output waveform

7. HARDWARE DESCRIPTION

The study provides insight into how various solar panel designs and functions work to show how solar cells convert sunlight into energy [24]. PV, aptly named from “photo” (Greek for light) and a nod to Alessandro Volta, exploits solar cells that transform photons into electrons, collectively generating volts in solar panels. Wireless charging transforms mobility in the EV space. With the help of an EV’s receiver coil and a ground charging pad that uses electromagnetic induction, physical plug-in connections are no longer necessary. As the EV nears the pad, alternating current induces a magnetic field, converting to direct current in the vehicle’s power electronics. By optimizing the use of renewable energy, smart grid integration improves sustainability within the transportation ecosystem. Drawing parallels to Nikola Tesla’s visionary work in the late 1800s, resonant inductive coupling principles underlie wireless charging in EVs. With the use of electromagnetic coils, his invention represents a major advancement toward achieving Nikola Tesla’s goal of wireless energy transmission. The evolution of wireless charging, now under unified standards like Qi, showcases increased speeds and compatibility, transforming the landscape of electric mobility. The wireless charging system comprises two main subsystems—one underneath the road surface and the other integrated into the vehicle’s underbody [25] and the hardware working model is shown in Figure 5.

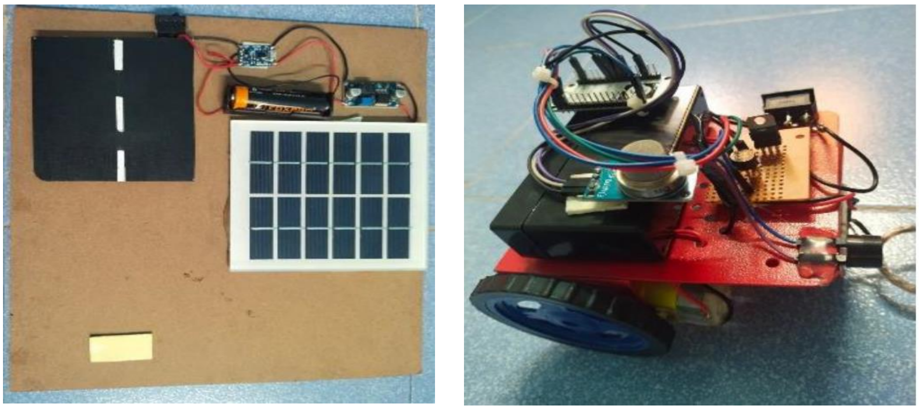

Figure 5. Hardware prototype

8. CONCLUSION

Algorithms that can effectively generate the optimum outcomes in terms of production cost and startup Our revolutionary solar-powered roads, equipped with wireless charging for EVs, completely redefine the landscape of sustainable transportation. This cutting-edge system excels in efficiency, enabling on-the-go charging and eliminating the need for fixed charging stations. Through induction coils that facilitate wireless charging, this initiative guarantees swift and convenient energy renewal. Moreover, the solar power gathered doesn't just benefit EVs; it also feeds into household and industrial power grids, presenting a comprehensive and environmentally friendly energy solution. This groundbreaking approach not only reduces wait times but also curtails power wastage, representing a significant stride towards an efficient and eco-conscious future in the realm of electric mobility. Embrace this journey with technology that not only propels us forward but does so with unmatched efficiency and environmental mindfulness.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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Ramesh Babu Muthu			✓	✓	✓			✓		✓	✓			
Lekha Shri Sasidar			✓		✓	✓		✓		✓	✓			
Malathi Mani			✓		✓	✓		✓		✓	✓			

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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