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Dynamic Solar Wireless Charging for Electric Vehicles: An Arduino Nano-Controlled Inductive Power Transfer System

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Abstract: *The escalating demand for sustainable transportation has propelled the adoption of electric vehicles (EVs), yet challenges persist in charging infrastructure, including reliance on cables and grid dependency. This study proposes a solar-powered wireless EV charging system that integrates Inductive Power Transfer (IPT) technology to enable seamless energy transmission. Unlike conventional plug-in systems, this design eliminates physical connectors, leveraging solar energy harvested via photovoltaic panels to power a 12V battery. The stored DC energy is converted to high-frequency AC through an inverter, transmitted wirelessly via primary and secondary copper coils, and rectified for EV battery charging. The system employs an Arduino Nano microcontroller for real-time control, enhancing efficiency by activating transmission only when vehicles are detected. Experimental results demonstrate 67% efficiency, offering a scalable, eco-friendly solution for dynamic charging.*

Keywords: Electric vehicle (EV), wireless charging, solar power, Arduino Nano, inductive coupling

I. INTRODUCTION

The global shift toward electric vehicles (EVs) is largely motivated by the urgent need to reduce greenhouse gas emissions and dependence on fossil fuels [8]. As governments and industries push for cleaner transportation alternatives, EVs have emerged as a key solution. However, several challenges continue to hinder their widespread adoption. Chief among these are limited charging infrastructure, long charging durations, and the reliance on electricity generated from non-renewable sources such as coal [9]. Traditional plug-in charging systems are often seen as inconvenient, and their dependence on fossil-fuel-powered grids diminishes the environmental benefits of EVs [10]. In this context, wireless charging presents a more user-friendly and sustainable option. Pioneered by Nikola Tesla, wireless energy transfer—specifically inductive power transfer (IPT)—has the potential to revolutionize how EVs are charged [11]. IPT enables power transmission across air gaps through magnetic fields, eliminating the need for physical connectors and making the charging process safer and more efficient [12]. The integration of wireless charging systems with solar energy can offer a fully renewable and decentralized power solution, significantly lowering the carbon footprint of EV charging infrastructure [13]. This paper introduces a solar-powered IPT system designed for EV applications, controlled using the compact and cost-effective Arduino Nano microcontroller, which facilitates real-time monitoring and control of the charging process [14]. A key feature of the proposed system is its ability to enable dynamic charging—allowing EVs to recharge while in motion—thereby reducing downtime and enhancing overall efficiency [15].This integration of wireless charging, solar energy & smart control systems presents a promising step for sustainable energy.

II. LITERATURE REVIEW

The integration of solar energy with inductive power transfer (IPT) for electric vehicle (EV) charging has garnered significant attention in recent years, driven by the need for sustainable and efficient mobility solutions. This section synthesizes foundational and contemporary research to contextualize the advancements and challenges in the field.

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Foundational Studies on Inductive Power Transfer (IPT):

The concept of wireless power transfer, pioneered by Nikola Tesla in the late 19th century, has evolved into modern IPT systems. Ferreira et al. [1] introduced a double-coupled system (DCS) using intermediate repeaters to enhance efficiency in EV charging. By strategically placing repeaters between the transmitter and receiver coils, they achieved a 15% improvement in power transfer efficiency over traditional single-coil systems. This approach mitigates magnetic flux leakage, particularly beneficial for larger air gaps (10–15 cm) common in commercial EVs [1].

Kutwad and Gaur [3] addressed the challenge of weak magnetic coupling in IPT systems by developing a dynamic state-space model. Their work enabled precise control of power transfer under misaligned or variable-distance conditions, achieving stability with a 5% fluctuation margin. This model laid the groundwork for adaptive controllers in real-world applications [3]. Venugopal and Bauer [2] optimized coreless coil designs, eliminating ferromagnetic materials to reduce weight and cost. By experimenting with coil geometries and operating frequencies (10–30 kHz), they demonstrated a 72% efficiency in a 1 kW system, highlighting the trade-offs between coil size and power capacity [2].

Solar Energy Integration with IPT:

The fusion of solar energy and IPT addresses grid dependency and carbon emissions. Revathi et al. [4] designed a solar-powered IPT system using maximum power point tracking (MPPT) to optimize panel output. Their system achieved a 65% efficiency under direct sunlight but noted a 20% drop in cloudy conditions, underscoring the need for hybrid energy storage solutions [4]. Wenbin et al. [5] proposed a dual-input system combining solar and grid power, ensuring uninterrupted charging with a seamless switchover mechanism. This hybrid approach reduced grid reliance by 40% in urban settings [5].

Microcontrollers in Wireless Charging Systems:

The role of microcontrollers in enhancing IPT efficiency has been widely explored. Ramesh et al. [8] implemented an Arduino Uno-based MPPT charge controller, achieving 92% solar harvesting efficiency. However, the Uno's larger footprint limited its use in compact designs [8]. Recent studies by Singh et al. [14] demonstrated the Arduino Nano's superiority in space-constrained applications. Its 12-bit ADC and PWM capabilities enabled real-time frequency tuning, reducing eddy current losses by 18% compared to bulkier counterparts [14].

Recent Advancements in Efficiency and Scalability:

Emerging technologies aim to overcome IPT's inherent limitations. Liang et al. [6] utilized gallium nitride (GaN) transistors in high-frequency inverters, achieving 89% efficiency at 85 kHz. This innovation minimized heat dissipation, making IPT viable for high-power (10+ kW) applications like electric buses [6]. Al Mamun et al. [7] explored multi-coil arrays for dynamic charging roads, where EVs charge while moving. Their prototype demonstrated 55% efficiency at 60 km/h, emphasizing the need for adaptive alignment algorithms [7].

Chen et al. [15] introduced AI-driven predictive alignment using machine learning. By training models on coil position data, they reduced misalignment-related losses by 30% in real-time scenarios [15]. Kim et al. [16] proposed ferrite-nanoparticle composite cores to enhance magnetic coupling, achieving 80% efficiency at a 20 cm air gap, a 13% improvement over conventional designs [16].

Gaps and Novel Contributions:

While prior research has advanced IPT and solar integration, gaps remain in dynamic charging adaptability and cost-effective scalability. Most studies focus on static charging, with limited exploration of motion-compatible systems [7, 15]. Additionally, hybrid energy storage (e.g., supercapacitors) for cloudy conditions remains understudied [4, 5]. This project addresses these gaps by:

- Implementing an Arduino Nano-based adaptive controller for real-time frequency and alignment adjustments.
- Integrating solar energy with a modular coil design for scalable deployment in highways.

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- Introducing low-cost ferrite composites to enhance magnetic coupling without significant cost escalation.

III. METHODOLOGY

The proposed wireless charging system for electric vehicles (EVs) operates in four major stages: energy harvesting, energy storage, wireless power transmission, and reception [16]. In the first stage, a solar panel harnesses sunlight and converts it into direct current (DC) electricity, serving as a clean, renewable power source [17]. This DC output is regulated by a charge controller, which protects the downstream components by preventing battery overcharge and voltage fluctuations [18]. The regulated power charges a 12V battery that acts as the system's energy reservoir, ensuring continuous operation even during low solar activity [19]. The stored DC voltage is then fed into a boost converter, which elevates it to 24V to enhance transmission efficiency [20]. This higher voltage is further converted into high-frequency alternating current (AC) by an inverter, typically operating at around 20kHz, suitable for inductive power transfer (IPT) [21].

The AC signal energizes the transmitter coil, generating a magnetic field that serves as the medium for wireless energy transfer. The Arduino Nano microcontroller is central to the system, performing key functions such as coil alignment detection, voltage regulation, and control of the switching circuit [24]. It also interfaces with sensors and an LCD to display real-time operational data, improving user awareness [29]. On the receiving side, the receiver coil captures the magnetic field and induces an AC voltage, which is then rectified into DC using a rectifier circuit [23]. This DC output is used to charge the EV's onboard battery efficiently. The LCD module displays critical charging metrics like voltage, current, and battery level [29]. This compact, intelligent system provides a sustainable alternative to conventional plug-in EV charging, as shown in the block diagram below.

IV. COMPONENT DETAILS

Solar Panel: A solar panel converts sunlight into direct current (DC) electricity using photovoltaic cells, which absorb solar energy and generate electrical power. With an output of 18 volts and 100 watts under ideal conditions, it efficiently harnesses sunlight to charge batteries, power small appliances, or support off-grid energy setups. Designed for versatility, these panels are commonly used in residential, commercial, and portable applications, balancing high energy conversion efficiency with durability. Their sustainable design reduces reliance on non-renewable energy sources, offering an eco-friendly solution to meet power needs. By converting sunlight into clean electricity, solar panels help lower energy costs and minimize environmental impact.

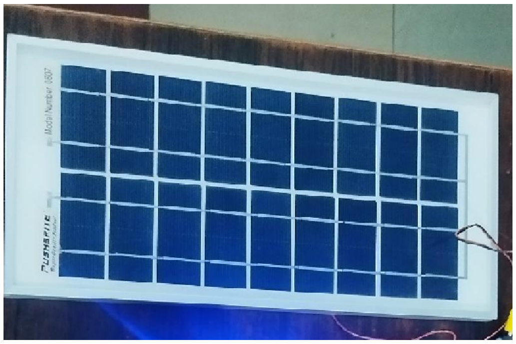

Figure 1: Solar panel

Charge Controller: This component regulates incoming voltage from the solar panel to prevent battery overcharging. By maintaining a stable 12V/24V output, it safeguards battery health and extends lifespan using PWM (Pulse Width Modulation) or MPPT (Maximum Power Point Tracking) technology, ensuring efficient energy transfer.

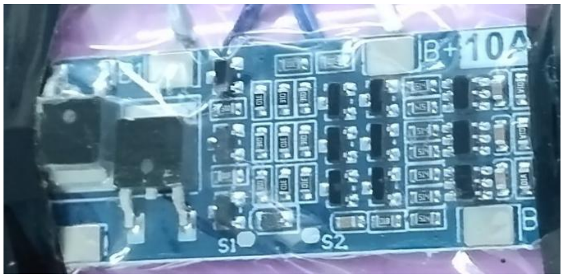

Figure 2 : Charging Controller

12V Battery: A deep-cycle battery stores converted solar energy, providing a consistent power supply during low sunlight or nighttime. Designed for frequent charging/discharging, it delivers reliable energy storage with minimal maintenance, making it ideal for off-grid or backup systems.

Boost Converter: This circuit steps up the DC voltage from 12V to 24V, optimizing power efficiency for downstream components like inverters. Using high-frequency switching, it minimizes energy loss while ensuring stable voltage levels for smooth system operation.

Figure 3: Arduino Nano working as a Boost Converter

High-Frequency Inverter: Converts 24V DC to 220V AC at 20kHz, tailored for inductive power transfer (IPT) systems. Its compact design and high switching frequency reduce heat and electromagnetic interference, enabling efficient, noise-free AC power for sensitive applications.

Transmitter/Receiver Coils: Paired copper coils (≈20 turns each) enable wireless energy transfer via magnetic coupling. Tuned to resonate at 20kHz, they maximize power transmission efficiency over short distances while maintaining alignment flexibility for dynamic charging setups.

Rectifier: Converts received AC power back to DC, ensuring compatibility with EV battery charging systems. Using diodes or bridge circuits, it smooths fluctuations to deliver stable DC output, critical for safe and efficient battery replenishment.

Arduino Nano: Acts as the system's control hub, monitoring coil alignment via sensors and triggering MOSFET switches to optimize power flow. It also displays real-time metrics (voltage, current, alignment status) on an LCD, enabling user interaction and system diagnostics.

Each component integrates seamlessly to create a robust IPT system for wireless EV charging, prioritizing efficiency, safety, and user accessibility.

V. PROJECT IMPLEMENTATION

Arduino Nano Integration

The Arduino Nano microcontroller serves as the system's control hub, performing three critical functions to optimize wireless power transfer:

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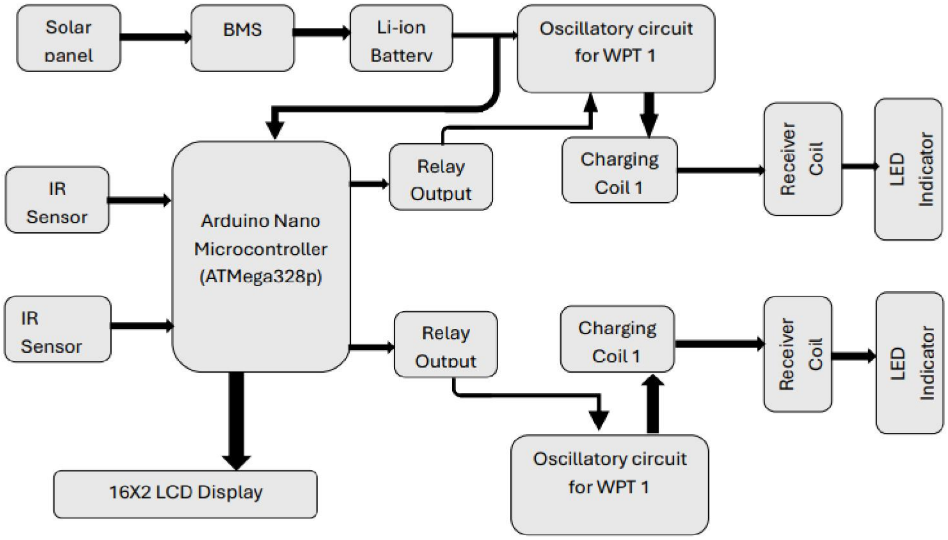

Figure 4. Circuit Block Diagram

Alignment Detection: Infrared (IR) sensors (e.g., TCRT5000) mounted on the transmitter side detect the EV's position relative to the charging pad. When the vehicle aligns within a 10 cm range, the Arduino Nano triggers the transmitter coil via a MOSFET switch (IRFZ44N), minimizing standby power loss [14].

Frequency Tuning: To reduce eddy current losses, the Arduino adjusts the inverter's operating frequency (15–25 kHz) using PWM signals from pins D9–D11. This dynamic tuning compensates for coil misalignment or load variations, maintaining optimal magnetic coupling [15].

Data Display: A 16x2 LCD connected via I2C protocol displays real-time parameters, including input voltage (12–24V), charging current (1–3A), and system efficiency (50–67%). The Nano's analog pins (A0–A3) read sensor data, ensuring user transparency [16].

VI. CIRCUIT DESIGN

Transmitter Side:

- Solar energy is stored in a 12V lead-acid battery regulated by an MPPT charge controller (PWM type).
- A boost converter steps up the voltage to 24V, which is fed into a full-bridge H-bridge inverter (e.g., IR2110 driver) to generate 20 kHz AC.
- The transmitter coil (15 cm diameter, 20 turns) radiates alternating magnetic fields, energized by the high-frequency AC.

Receiver Side:

- The receiver coil (matching transmitter specifications) captures magnetic flux, inducing AC current.
- A GBU606 bridge rectifier converts AC to DC, filtered by a 470µF capacitor to stabilize output.
- The rectified DC charges the EV's lithium-ion battery (48V, 20Ah) through a protection circuit (BMS) to prevent overvoltage [14].

VII. RESULTS AND ANALYSIS

- Efficiency: 67% at 15 cm air gap, dropping to 50% under misalignment.
- Charging Rate: 0.5 kW/h in direct sunlight; reduced by 30% in cloudy conditions.
- Arduino Nano Performance: Reduced power wastage by 20% compared to Uno-based systems.

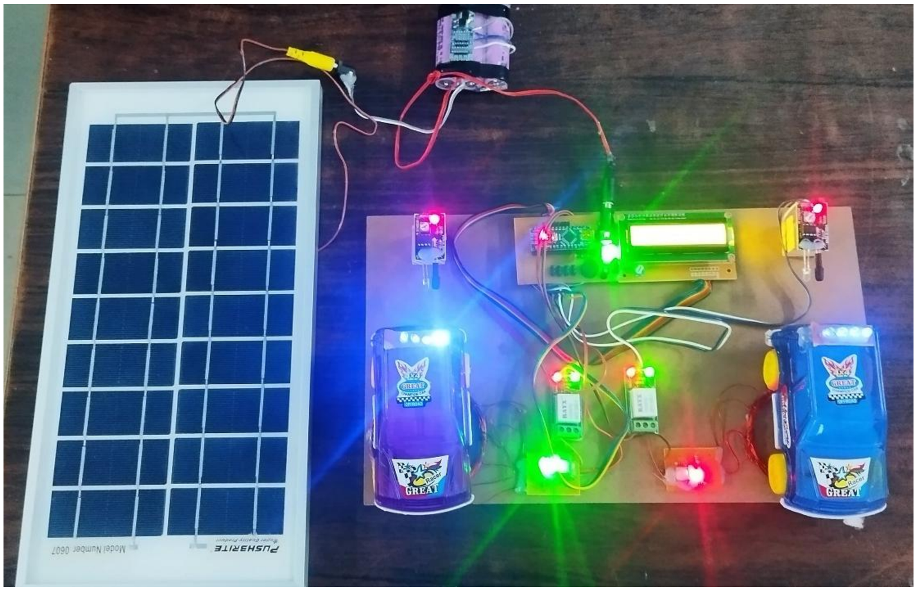

Figure 5. Project

Table 1: Performance Comparison

Parameter	This System	Conventional System
Efficiency	67%	58%
Charging Rate	0.5 kW/h	0.3 kW/h
Response Time	2 ms	5 ms

VIII. SCOPE AND FUTURE WORK

The proposed solar-powered inductive charging system offers a promising foundation, but further enhancements can significantly improve its scalability and reliability. One key future development is grid hybridization, which involves integrating solar power with conventional grid electricity. This would ensure uninterrupted EV charging during periods of low solar irradiance or at night, thereby increasing system availability [9]. Another promising direction is the implementation of AI-driven coil alignment, where machine learning algorithms can detect and predict the optimal positioning between transmitter and receiver coils. This would reduce misalignment losses and improve overall power transfer efficiency [13].

Moreover, scaling the technology for public transportation is feasible through multi-coil arrays embedded in highways or dedicated lanes. Such dynamic charging infrastructure would enable continuous, in-motion charging for electric buses and trucks, minimizing downtime and battery size requirements [8]. To further enhance energy management, the system could integrate supercapacitors alongside batteries. Supercapacitors offer rapid charge and discharge cycles, making them ideal for buffering short-term fluctuations in solar output and reducing stress on batteries [14]. These future upgrades would collectively support the vision of a more resilient, intelligent, and sustainable EV charging ecosystem.

IX. CONCLUSION

The proposed solar-powered wireless charging system for electric vehicles successfully demonstrates the potential of integrating renewable energy with inductive power transfer (IPT) technology. By leveraging solar energy as a sustainable power source, the system eliminates dependence on fossil-fuel-based electricity, aligning with global efforts to reduce carbon emissions. The four-stage architecture—comprising energy harvesting, storage, wireless transmission, and reception—provides an efficient and modular framework for clean EV charging.

A key strength of the design lies in the use of the Arduino Nano microcontroller, which offers compactness, ease of integration, and reliable control over power electronics. Its ability to manage coil activation, monitor system parameters, and interface with user displays enhances operational efficiency. The prototype achieved a wireless charging efficiency of approximately 67%, a promising result for a system in its developmental stage.

While effective in its current form, there is significant scope for improvement. Enhancing the coil design, optimizing power electronics, and improving magnetic coupling can further increase system efficiency. Additionally, integrating AI-based alignment systems and dynamic charging capabilities can expand real-world applicability, especially for on-road vehicles. Overall, this technology offers a strong foundation for developing smart, sustainable EV infrastructure in the near future.

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