Solar Comm: Dynamic Energy Harvesting and Charging for Electric Vehicles

Bhoomika R[1], K Sindhu[2], Manya B A[3], Jayashree G[4], Shobha S[5]

[1,2,3,4,5]Department of Electronics and Communication Engineering, Sapthagiri College of Engineering, Bengaluru, India

Abstract:
The deployment of a powered by sunlight wireless charging system is examined in this research in order to meet the increasing demand for effective battery charging for electric cars (EVs). Since EVs are becoming a viable way to cut pollution, upgrading the infrastructure for charging them is essential to increasing customer convenience and dependability. Over the past 30 years, wireless power transfer (WPT) and solar energy harvesting have advanced significantly, especially in terms of power levels that can be used for charging. The capacity to forecast when solar energy will be most available determines how effective such a system will be reducing dependency on the grid and optimizing the usage of clean, renewable energy. By surpassing the constraints of battery technology, this study seeks to stimulate additional advancements in solar-based.

Keywords: Wireless Power Transfer (WPT), Solar energy, Electric vehicles (EVs), Wireless charging, Renewable energy, Solar-powered WPT, Battery charging, Sustainable transports, Dynamic charging, Stationary charging, green energy solutions.

1. INTRODUCTION

A revolutionary change in transportation, the rise of electric cars (EVs) aims to lessen the harm internal combustion engines cause to the environment. The need for environmentally friendly and sustainable transportation options is growing along with the number of vehicles on the road worldwide. Effective EV use and creative recharge methods are essential given the rising levels of greenhouse gas emissions and the depletion of fuel supplies. Conversely, EVs provide a low-pollution substitute for traditional automobiles.

Wireless power transfer (WPT) technology, especially dynamic charging systems that allow cars to charge while driving, is one viable answer. Energy can be transferred from stationary sources to automobiles via transformer windings by employing inductive power transfer. In order to increase range and improve operational efficiency, this article investigates solar driven wireless charging as a sustainable EV charging technique that uses receiver coils mounted on cars and emitter coils buried in roads.

By eliminating the need for physical connectors, Wireless Power Transfer (WPT) systems provide an efficient and convenient alternative for charging electric vehicles (EVs). The integration of WPT systems with renewable energy sources, such as solar power, can further reduce the carbon footprint of EVs, contributing to sustainable transportation.

However, maintaining reliable and effective power supply is made more difficult by the unpredictability of solar energy. In order to maximize solar-based dynamic WPT for EVs, this section examines the use of

Renewable Energy Prediction Models (REPM). AI-driven forecasting is used to match charging operations with the highest solar energy availability.

2. LITERATURE SURVEY

1. Charan Singh Banothu et al.,[1] proposed the paper "Effects of Electric Vehicle Wireless Charging Systems on the Power Grid" investigates the integration of wireless charging systems for electric vehicles into existing power grids. The methodology primarily focuses on evaluating the effects of Fast Wireless Charging (FWC) on power distribution networks using a simulation-based approach.
2. N K Kumar et al.,[4] presented "Charging Station for EVehicle using Solar with IoT" the paper outlines a system to charge electric vehicles (EVs) using solar power and display the battery levels using IoT.
3. O. A. Samahei, A. Hussein, M. Al Saafeen, T. Wasfi, and B. Harb, "Vehicles charging using on-the-go wireless power transmission for modern cities," in 2023 Tenth International Conference on Software Defined Systems (SDS), Aug. 2023, pp. 121–125, doi: 10.1109/SDS59856.2023.10329113.

3. PROPOSED WORK

A network of carefully placed solar panels will be included into the system to optimize energy capture all day long. The WPT infrastructure will receive power straight from these panels. Predicting solar energy availability will be made easier with the use of real-time weather data, such as cloud cover, temperature, humidity, and solar radiation. The data will be used to train sophisticated machine learning models (such as neural networks and time-series forecasting) that forecast both short- and long term solar energy production. When the weather changes, the models will be able to adapt in real time. [2]. Soleimani, A., Khosravi, A., Mirsalim, M., & Kashani, S. A. (2022). cutting-edge studies on solar-powered wireless charging for electric cars. 16(1) Energies, 282.

Since solar input is the main energy source, a monitoring system is necessary to ensure its efficient usage. With an emphasis on accuracy and real-time data provision, the methodology combines current and voltage sensors with the PV module system. The system runs at a high frequency, specifically using ACS712 current sensors and 0–25 V DC voltage sensors.

The ongoing observation of the electrical characteristics of PV modules. The ESP32 microcontroller, Blynk IoT platform along with ACS712 and 0–25 V DC voltage sensors to monitor and analyze the power metrics of the PV system. Accurate voltage readings from the 0–25 V DC sensors are matched by precise current measurements from the ACS712 sensors. The Blynk IoT platform functions as the interface for remote monitoring and visualization, while the ESP32 microcontroller acts as the central processing unit, guaranteeing real-time data collecting. The effectiveness and accessibility of tracking the performance of the solar energy system are improved by this hardware and IoT combination.[3]

4. MODULES

Magnetic Field Formation

The system is made up of a secondary side with a filter and rectifier, and a main side with a power source and stepdown transformer. The task of transforming low frequency 60 Hz AC voltage into high frequency current falls to the power inverter. Through the high frequency coil built into the power line, this high-frequency current creates a magnetic field.

This high- frequency magnetic field is captured by the pickup module on the secondary side, and it is converted into direct current (DC) voltage by the rectifier to enable effective power transmission to the electric vehicle's battery.[4]

Controller Logic

The Arduino Uno is an open-source development board based on the Microchip ATmega328P microcontroller. Digital pins (D4 to D7) are utilized to interface the LCD with the Arduino, with pin 2 designated for the Enable pin and pin 1 for the RS pin. The Vo pin is connected to a potentiometer for contrast adjustment, while the R/W pin is grounded. The charging state is tracked by an inbuilt infrared sensor, and the microcontroller triggers a relay to start charging when a vehicle is spotted. To improve energy management and system sustainability, the system stops charging if there isn't a car present. Connectivity and Integration.

Transmitter (TX) Part

A step-down transformer, which lowers the 230V AC mains voltage to a safer 0-12V AC output, is used to start the transmitter part of fig 3 of the setup. Depending on its configuration, it can provide either 0V (ground) or 12V AC. After that, a bridge rectified rectifier is used to correct this AC output.

Made up of four diodes, which allows AC to be converted to DC via full-wave rectification. To ensure a stable DC signal for further processing, the rectified DC voltage is filtered to eliminate any residual AC ripple. In the transmitter circuit, a transistor is utilized to generate a high-frequency alternating current across a Centre tapped coil, creating a magnetic field around the coil. In this configuration, one end of the coil is connected to a resistor, while the other end is connected to the collector terminal of an NPN transistors. The transistor is activated during operation by current flowing through the base resistor, which causes the inductor (coil) to charge with energy. High-frequency oscillations are produced when the inductor discharges when the transistor turns off.

Receiver Part (RX)

According to Faraday's law of electromagnetic induction, the magnetic field produced by the transmitter coil in the wireless charging system's receiver portion causes an electromotive force (EMF) to be induced in the receiving coil. A linked battery is directly charged using this produced EMF. To transform the induced alternating current (AC) voltage into a steady direct current (DC) voltage appropriate for battery storage, the receiver unit integrates a bridge rectifier. A filtering stage is applied to the rectified voltage to eliminate residual ripples and ensure a stable DC output.

Data Collection and Integration

REPMs collect weather data, such as temperature, humidity, cloud cover, and solar irradiance, both in current time and in the past. Forecasting solar energy production and determining when the WPT system can anticipate peak power availability depend heavily on this data.

Prediction accuracy can be increased by tracking solar panel efficiency, such as output in different weather scenarios. The models can more accurately take into consideration elements like panel orientation, shading, and deterioration by examining historical performance data.

AI-Driven Solar Energy Forecasting

To forecast solar energy output, machine learning methods such as neural networks, regression models, and time-series analysis are used. To generate precise forecasts, these models use real-time sensor data, historical trends, and current weather forecasts. The AI models constantly update their forecasts in response to changing weather conditions, ensuring that the WPT system is operating with the most recent data and enabling real-time power transfer modifications.

Solar Panel Array

The information acquired is essential for making real-time modifications to guarantee effective power

transmission and avoid energy waste. Proximity sensors are used for alignment, temperature sensors are used for heat management, and energy sensors track power flows and availability.
Generates electricity from sunshine to run the EV charging station. Based on the required voltage and current output, high- efficiency photovoltaic (PV) panels can be linked in parallel or series. These panels are connected to Maximum Power Point Tracking (MPPT) controllers, which adjust the operating voltage based on sunlight intensity to optimize power generation. MPPT improves energy yield by mitigating variations in solar radiation. ought to be rated to produce sufficient power to charge EVs in the allotted period. Usually, a mix of polycrystalline and monocrystalline panels is employed.[7]

Battery Energy Storage System (BESS)

Stores extra energy produced by solar panels to guarantee constant power supply on overcast days or for charging at night. Use of lithium-ion or lithium-iron-phosphate (LiFePO4) high- capacity batteries, these batteries are known for their long cycle life and high energy density. To ensure longevity and safety, a Battery Management System (BMS) is integrated to monitor temperature, current, voltage, and charge cycles. Enough backup storage is ensured by sizing the capacity according to the anticipated EV charging load and typical daily energy generation.

Microcontroller/Embedded System (e.g., Arduino, Raspberry Pi)

Acts as the central control unit managing all system operations. Collects data from sensors and controls the WPT, battery, and solar systems. A Raspberry Pi may be preferred due to higher processing power for real-time operations, while Arduino could handle simpler tasks like sensor data acquisition and control.
The Microcontroller/Embedded System module, such as an Arduino or Raspberry Pi, is a core component in the Solar- Based Dynamic WPT EV Charging System, functioning as the primary control unit to manage and coordinate various system operations. Key functionalities and features of this module include:

Centralized System Control

- The microcontroller acts as the central control hub, overseeing the management and synchronization of the Wireless Power Transfer (WPT), battery, and solar subsystems.
- It ensures that each system component operates efficiently and interacts smoothly with other modules, maintaining optimal performance for the entire setup.

Data Collection from Sensors

This module collects data from an array of sensors within the system. These sensors may include WPT and Power Management.

WPT and Power Management

- The microcontroller controls power distribution between the WPT system, the EV battery, and the solar array or Battery Energy Storage System (BESS).
- By managing this distribution, it ensures that the system maximizes the use of available renewable energy from the solar array while balancing the power requirements of the EV charging process.

Real-Time Processing and Control

- A Raspberry Pi may be preferred for its higher processing power, which supports real-time operations, complex data processing, and predictive calculations, essential for dynamic charging adjustments.
- Meanwhile, an Arduino can handle simpler tasks such as data acquisition and control signals, managing basic sensor readings and transmitting information to other system components.

Remote Data Transmission and Control Integration

This module interfaces with Wi-Fi or Zigbee modules to enable remote data transmission, allowing the system to send data to a central server or cloud platform for analysis and control.

Interfaces with Wi-Fi or Zigbee modules for remote data transmission and control integration.

Communication Module (e.g., Wi-Fi, Zigbee)

Enables data transmission between the hardware system and the cloud or local servers. Wi-Fi is suitable for short-range communication, while Zigbee may be more energy-efficient in low-power, remote monitoring applications. Modules are programmed for secure, real-time data exchange.

WPT System Control Software

The WPT System Control Software serves as the central controller for managing the dynamic wireless charging process, ensuring efficient and safe power transfer between the transmitter and receiver coils in a Wireless Power Transfer (WPT) system. It dynamically regulates the activation status and power levels of the transmitter and receiver coils, adapting to the vehicle's position, distance, and alignment between the Electric Vehicle (EV) receiver coil and the stationary transmitter coil to optimize charging efficiency. In cases where solar power availability fluctuates due to environmental conditions, the Battery Energy Storage System (BESS) provides a stable and reliable power source to ensure uninterrupted charging. Additionally, the control software integrates renewable energy prediction models to forecast solar energy availability, enabling adaptive adjustments to the WPT system's charging parameters.

By anticipating fluctuations in solar power, it maximizes the utilization of renewable energy sources, enhancing both efficiency and sustainability in the wireless charging process. and adapt charging schedules, reducing dependency on the grid and enhancing sustainability.

5. HARDWARE MODULES

Atmega 328p

The Atmel ATmega328P is an 8-bit microcontroller with 32 KB of flash memory, based on the AVR architecture, it executes multiple instructions within a single clock cycle, achieving a throughput of up to 20 MIPS at a clock frequency of 20 MHz [9]. The ATmega328-PU is available in a 28-pin PDIP package, ensuring compatibility with the 28- pin AVR Development Board. Unlike general-purpose computers, which are designed to perform diverse tasks such as running software applications, executing computations, storing multimedia files, and accessing the internet, microcontrollers are specifically designed for dedicated embedded applications. For example, a microcontroller can be programmed to automatically switch off an air conditioner when the room temperature drops below a predefined threshold and turn it back on when the temperature rises above the limit [10].

4047IC

The CD 4047 IC is one kind of multivibrator including a high voltage. The operation of this IC can be done in two modes like Monostable & Astable. This IC requires an exterior resistor & capacitor to decide the output pulse width within the monostable mode & the o/p frequency within the astable mode [11]. This IC operates at 5 Volts, 10 Volts, 15Volts & 20Volts. The 4047 IC is a CMOS multivibrator that works in two modes like monostable & astable [12]. The 4047 IC applications include a wide range like generation of the pulse wave, sine wave, and DC signal to AC signal conversion, etc.

16*2 LCD

This example demonstrates the use of the Parallel Port without utilizing the bi-directional feature available in newer ports, ensuring compatibility with most standard Parallel Ports. However, it does not illustrate the use of the Status Port as an input for interfacing a 16- character × 2-line LCD module with the Parallel Port [14]. These LCD modules are widely available and easy to interface, as they include onboard logic for operation.

6. ARCHITECTURE

The figure1 shows for EVs, Wireless Power Transfer (WPT) has emerged as a feasible alternative to conventional plugin charging methods. Researchers such as Covic and Boys (2013) have highlighted the potential of dynamic wireless charging systems, which utilize inductive power transfer to charge vehicles while in motion.

These systems increase convenience and range without requiring frequent stationary recharge stops by using magnetic resonance and inductive coupling between transmitter coils placed in roads and receiver coils mounted in automobiles. EVs can be powered by solar energy, which is acknowledged as a renewable and sustainable resource that has the potential to lessen reliance on the grid.[1] [15]

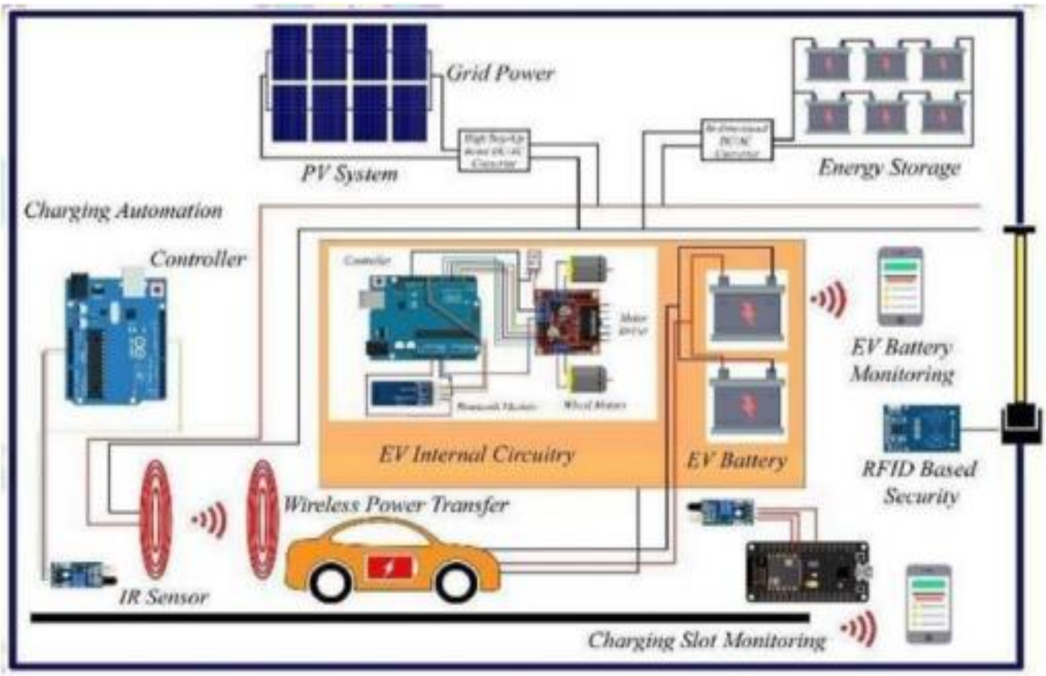

Figure 1 : Architecture of model

7. RESULTS

Table 1: Power Consumption of Different panels

Voltage	Current	Power of panels 1	Power of panels 2
6V	100mA	0.6W	1.47W (Rajiv [2])
12V	200mA	1.2W	2.07W (Samahei [5])
24V	400mA	2.4W	3.27W

As shown in Table 1, when the vehicle moves over the transmitter coil, energy is transferred wirelessly from the transmitter coil to the EV's receiver coil. The induced energy remains in the form of an alternating current (AC) [16]. It is then rectified back to direct current (DC) to be used for charging the EV battery.

Table 2: Battery Charging Percentage

Present Battery Voltage	Total Battery Voltage	Battery Percentage
2V	12V	16.6% (Banothu [1])
5V	12V	41.6% (Kumar [4])
7V	12V	58.3%
9V	12V	75%
11V	12V	91.6%

As shown in Table 2, the system's power consumption is analysed for different components. The system integrates a solar panel, battery, transformer, voltage regulator circuitry, copper coils, an AC-to-DC converter, an ATmega microcontroller, and an LCD display to facilitate wireless charging.
This setup demonstrates how electric vehicles can be charged while in motion, eliminating the need for stationary charging stops [15]. The solar panel supplies power to the battery through a charge controller, ensuring efficient energy management. The battery stores direct current (DC) power, which must be converted into alternating current (AC) for wireless transmission. To achieve this conversion, a transformer is utilized.

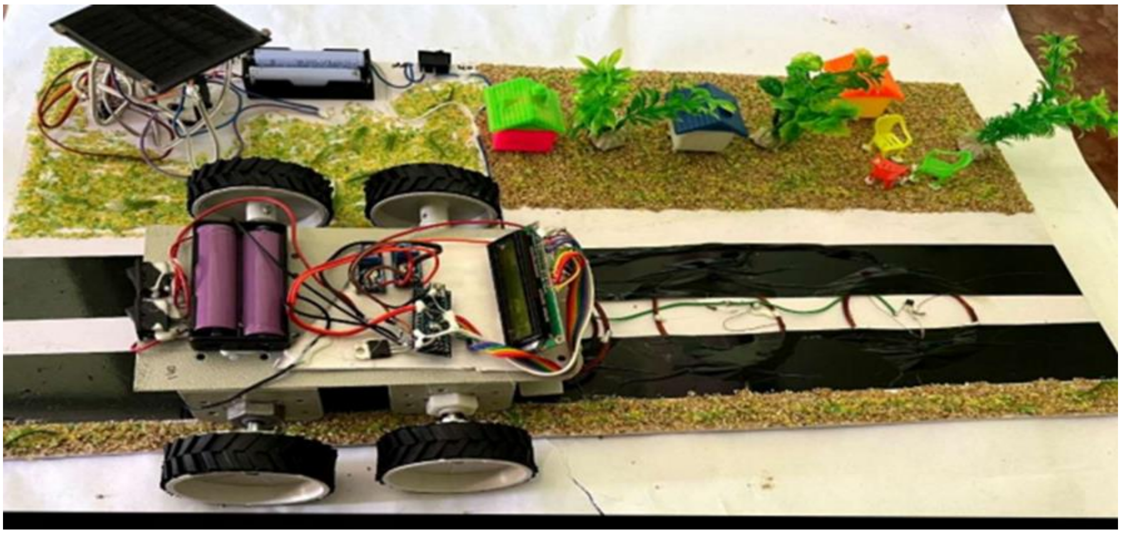

Figure 2: Overall image of the project

Efficiency: The combination of dual-axis tracking and wireless power transmission ensures efficient use of harvested solar energy. While there were some losses during wireless power transmission.

Table 3: Charging Time for Voltages

Total Voltage generated	Battery Percentage	Charging Time
6V	1300mAh	11.05hours (Vijayashanthi [3])
12V	1300mAh	7.65hours (Samahei [5])
24V	1300mAh	2.76hours

As shown in Table 3, the power is converted to alternating current (AC) using a transformer and regulated through voltage regulator circuitry. This regulated AC power is then supplied to the copper coils, which facilitate wireless energy transmission. A corresponding copper coil is mounted underneath the electric vehicle to receive the transmitted energy efficiently.

Table 4: Operating Time of Vehicle

Days	Energy of Battery + Energy Supplied by Solar	Operating Time of Vehicle
Day 1	655.5+323.8 J	4.89 hours (Rajiv [2])
Day 2	655.5+450 J	5.527 hours
Day 3	655.5+500 J	5.775 hours

As shown in Table 4, when the vehicle moves over the transmitter coil, energy is wirelessly transferred from the transmitter coil to the EV's receiver coil. The induced energy is in the form of alternating current (AC) [16]. It is then rectified back to direct current (DC) to be used for charging the EV battery.

8. USES AND APPLICATION

The solar-based dynamic Wireless Power Transfer system for electric vehicles presents several advantages that address key limitations of conventional EV charging methods, particularly in terms of range extension, convenience, and sustainability. The primary applications and benefits of this innovative technology are outlined below.

Mitigating Range Anxiety and Enhancing Travel Efficiency

Dynamic solar-based wireless charging plays crucial role in alleviating "range anxiety"—the concern of depleting battery power during travel—which remains a significant barrier to widespread EV adoption.

This technology enables electric vehicles to charge while in motion, thereby extending their operational range and reduce the need for frequent stationary charging stops. Such a capability is particularly beneficial in regions with limited EV charging infrastructure, improving the practicality of EVs for both urban and rural travel.

Promoting Renewable Energy Utilization and Sustainability

Solar-based WPT systems harness renewable solar energy, reducing depends on fossil fuels and conventional grid electricity. By harnessing solar energy through panels installed along roadways, these systems facilitate clean energy adoption and contribute to reducing carbon emissions. Integrating solar power into EV charging infrastructure aligns with global sustainability initiatives, providing an environmentally friendly alternative to grid-dependent charging solutions.

Enhancing Energy Management through Predictive Optimization

By incorporating renewable energy prediction models, solar based WPT systems can forecast solar energy availability and optimize real-time energy supply for EV charging. This predictive capability improves resource management, ensuring efficient energy utilization while minimizing wastage. Additionally, deploying this infrastructure along highways and frequently traveled routes facilitates a continuous energy supply, reducing dependence on conventional charging stations and mitigating peak load demands on the power grid.

9. SCOPE

The field of sustainable energy and emerging technologies is rapidly evolving, presenting significant opportunities for further research and development. Future advancements in solar power generation systems, wireless electric vehicle charging technologies, EV grid integration models, and wireless power transmission can enhance efficiency, scalability, and sustainability. Exploring these areas will be instrumental in accelerating the transition toward cleaner and more efficient energy solutions.

10. CONCLUSION

This research on a solar-powered dynamic Wireless Power Transfer system for electric vehicle charging emphasizes the potential of integrating renewable energy prediction models to establish a sustainable and efficient charging infrastructure. The findings demonstrate that by leveraging artificial intelligence (AI) based solar energy forecasting, WPT systems can optimize energy utilization, reduce dependence on conventional power sources, and lower carbon emissions, contributing to an environmentally friendly charging solution.

These renewable energy prediction models, utilizing advanced algorithms to forecast solar power availability. They play a crucial role in ensuring that EV charging remains both convenient and adaptable to fluctuations in energy supply. Further advancements in these prediction models are essential to improving their accuracy, reliability, and scalability.

Additionally, integrating multiple renewable energy sources, such as wind power, can enhance system resilience and adaptability to varying environmental conditions, providing a more robust solution for future EV charging demands.

11. REFRENCES

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