Electric Vehicle Wireless Charging Station using Solar Energy

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Abstract- Electric vehicles (EVs) have grown rapidly due to their widespread adoption, which has raised the need for highly effective, easily accessible, and environmentally friendly charging infrastructure. This work introduces a new EV charging station that makes use of solar energy and wireless charging, which can both speed up charging and be a green energy source. The concept employs inductive power transfer technology (IPT) to provide frictionless energy transfer while also requiring no connectors and minimal wear and tear, making it simple to maintain. The primary source of energy is solar photovoltaic (PV) panels; the control system can be integrated with a hybrid energy management system capable of operating reliably in the face of sunlight fluctuations. A smart charge controller optimizes power transmission between the solar array, storage battery, and wireless charging unit.

Keywords-*Electric Vehicle (EV), Wireless Charging, Inductive Power Transfer, Solar Energy, Photovoltaic (PV) System, Renewable Energy, Smart Charging Infrastructure, Energy Management System, Sustainable Transportation, Green Mobility.*

I. INTRODUCTION

The global transition to electric transportation is accelerating and becoming a reality as a result of environmental concerns, the depletion of non-renewable energy sources, climate change, and the urgent need to cut carbon emissions. Futuristic electric vehicles (EVs) are driving this shift by providing a cleaner and more efficient alternative to the fossil-fuel-powered internal combustion engine car. However, the broad adoption of electric vehicles is strongly reliant on the availability of safe, dependable, and convenient charging infrastructure. However, plug-in connections may be the user's biggest turn-off, which is by far the most annoying.

This has led to the presentation of IPT wireless charging as a substitute, which is regarded as an excellent technological answer. Despite the significant benefit, wireless charging methods typically have issues beyond their reliance on grid electricity, which isn't always renewable. However, using solar energy to power an electric automobile has a lot of other advantages. It secures the chance to have an entirely green mode of transportation, such as electric cars (EVs), in addition to reducing the overall carbon footprint and grid addiction.

This work provides a detailed description of the system architecture for an off-grid wireless solar-powered electric vehicle charging station. The system's components include a solar PV array, a PWM charge controller, a 12V 7Ah battery bank, and an inductive wireless power transfer device. The power of the power electronics interface, together with the voltage regulation and system control, adjusts and matches the coils of the transmitter and receiver, resulting in a high level of energy transfer efficiency. This study focuses on the creation of an off-grid prototype powered by solar energy, which could be an effective approach to maintain sustainable transportation.

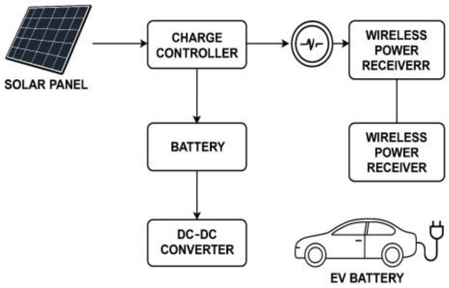

Figure 1. Block Diagram of Solar EV Charging System

II. LITERATURE REVIEW

Wireless charging technology for electric vehicles (EVs) is growing dramatically, with increasing demand for cleaner energy solutions and convenient charging. The recent research has focused on the improvement of efficiency, mobility, security, and sustainability of wireless power transfer systems. Sharma et al. [1] present a review of wireless electric vehicle charging developments, notably on trends including dynamic charging and smart energy management. They mention key challenges like electromagnetic safety and thermal issues. Dynamic wireless charging (DWC) is becoming increasingly popular because of its capability to charge EVs on the move. Wang et al. [2] present a deep reinforcement learning method of placing mobile charging units with enhanced energy delivery efficiency on urban roads. Sun et al. [3] expand DWC by enhancing coil alignment with RFID sensing, greatly improving the accuracy of power transfer. In tandem, Bianchi et al. [4] mitigate cybersecurity, with a quantum-secure authentication protocol to secure communication between EVs and charging stations. Standards of communication and interoperation with intelligent grids are fundamental components. Ma et al. [5] conduct a survey of existing protocols and underscore the necessity for low-latency, reliable systems to facilitate wireless charging infrastructure. Renewable integration is addressed by Lee et al. [6], who developed a solar-powered wireless charging station with reduced grid dependency. Pioneering work by Li and Mi [7] and Kurs et al. [8] laid the groundwork for inductive and resonant charging systems in the present day.

Overall, the literature shows a dramatic move toward intelligent, mobile, and sustainable wireless electric vehicle charging systems.

II. PROBLEM IDENTIFICATION

The growing global deployment of electric vehicles (EVs) has shifted attention to the construction of efficient, convenient, and environmentally friendly charging infrastructure. Traditional plug-in charging solutions have some drawbacks, including limited access, long charging times, connector aging, and grid saturation, which are not always based on renewable energy. Wireless charging technology is an excellent alternative since it allows for contactless energy transfer while also providing higher user convenience and reduced mechanical wear. However, the present wireless charging solutions are severely constrained, with one example being low efficiency when subjected to high power levels. Other difficulties to address include misalignment sensitivity, range limitation, and high infrastructure expenses.

Introducing and implementing a solar-powered wireless electric vehicle charging station necessitates addressing a number of important technological difficulties, including power transfer efficiency, alignment sensitivity, energy storage, and system reliability.

IV. WIRELESS CHARGING STATION

The invention of a wireless charging station for electric vehicles (EVs) is a formidable step in the energy transfer technology and the green transportation infrastructure. The specialized charging system, which is based on inductive power transfer (IPT), is not dependent on physical connectors and cables but rather on the principle of IPT, which enables power to be transmitted across an air gap. The core of a wireless charging system is a pair of magnets that are attached to the coils: the primary (transmitter) coil, embedded in a pad that is placed on or under the parking surface, and the secondary (receiver) coil, which is bolted to the bottom of the electric vehicle. As the EV is properly set up above the charging pad, the system is powered, and the transmitter coil outputs high-frequency alternating current, and a time-varying magnetic field is created. This magnetic field causes a like-current to pass through the receiver coil by electromagnetic induction, which is then rectified and prepared through the onboard power electronics for the battery charging of the vehicle. The wireless charging station system contains some important parts. Among them are power conditioning circuits, for example, DC-DC converters, which help in voltage transition from one level to another to meet the requirements of the battery.

A typical solar-powered wireless EV charging station comprises the following key components:

1. Solar Photovoltaic (PV) Module: The Working Principle of the Photovoltaic Effect The photovoltaic (PV) effect is the physical process by which a solar cell is able to convert the energy from sunlight into an electric form. When sunlight hits the semiconductor material (usually silicon), it can release electrons and create holes. Such electrons are then guided by a solar cell towards an electric field, thus making the direct current (DC) electricity.

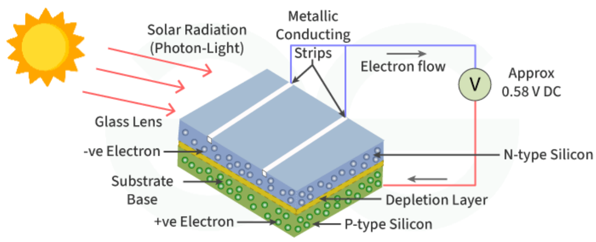

Figure 2. Principle of Solar system

Solar Cells: The smallest unit, made of semiconductor materials. Common types: Monocrystalline, Polycrystalline, and Thin-film.

2. Energy Storage System (Battery Bank): An Energy Storage System (ESS) is essential for balancing supply and demand in solar-powered systems. Since solar energy is intermittent and time-dependent, storing excess energy ensures continuous operation of the wireless charging system, even during periods of low sunlight or at night. A Battery Bank acts as a reservoir of electrical energy that can power the charging station when the PV array is not actively generating electricity. In this project, a 12V 7Ah Sealed Lead Acid (SLA) or Valve-Regulated Lead-Acid (VRLA) battery, commonly used in Uninterruptible Power Supply (UPS) systems, was chosen.

3. Power Electronics Interface: The Power Electronics Interface plays a critical role in managing, conditioning, and converting electrical energy from the solar photovoltaic (PV) system and battery bank to the wireless power transmitter coil, and ultimately to the EV. It ensures efficient energy transfer across different stages from solar generation to wireless power delivery by using a series of converters, inverters, controllers, and protection circuits.

It includes DC-DC converters, inverters, and high-frequency resonant inverters. Conditions solar energy and drives the primary (transmitter) coil with an appropriate frequency and voltage.

$$\text{Charging Voltage} = V_{PV} \times \text{Duty Cycle}$$

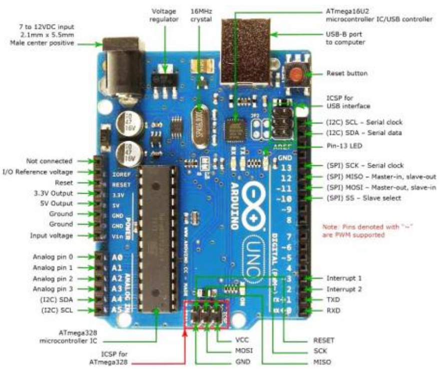

Figure 3. Arduino UNO microcontroller

3. Arduino UNO: The Arduino UNO R3 is a versatile microcontroller board based on the ATmega328P, offering 14 digital input/output pins (6 PWM), 6 analog inputs, and a 16 MHz ceramic resonator. With its USB connection and power options, it provides a user-friendly interface for programming and experimenting, making it ideal for beginners and advanced users alike in electronics and prototyping projects.

4. Transmitter and Receiver Coils: Wireless EV charging systems are based on Inductive Power Transfer (IPT), where power is transferred from a transmitter coil to a receiver coil through a magnetic field, without physical contact. These coils form the core of the WPT system.

The transmitter coil is embedded in the ground or charging pad. The receiver coil is installed in the vehicle. Both are tuned to the same resonant frequency for efficient energy transfer. Working Principle:

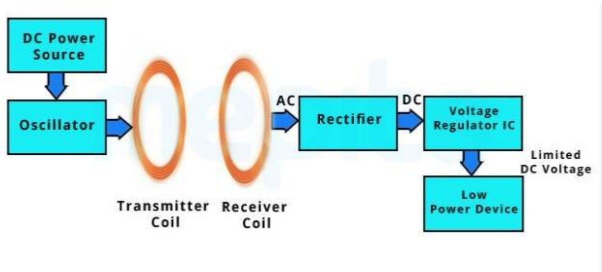

Figure 4. Working Principle of Wireless Charging System

The technology powering the wireless charging system is called Inductive Power Transfer (IPT) or Magnetic Resonance Coupling. Thus, the system allows the electric vehicle to get energy from a charging pad wirelessly. Either the electric vehicle can be moving or already parked during the process of energy transfer; no physical contacts between the pad and the car are required.

5. Inductive Power Transfer (IPT): Inductive Power Transfer (IPT) is the fundamental technology of wireless electric vehicle (EV) charging systems that enables the energy transfer without wires. This part discusses the operating principle, key components, types, advantages, and limitations of IPT.

The technology is based on the principle of magnetic induction, which Faraday discovered.

This mechanism is governed by Faraday's Law of Induction, which states that the induced electromotive force (EMF) in a coil is proportional to the rate of change of magnetic flux linking the coil.

Mathematically:

$$e = N\frac{d\emptyset}{dt} \qquad \text{.......(1)}$$

Where:

e = induced voltage

N= number of turns in the coil

dϕ/dt = rate of change in magnetic flux

Key Components in IPT Systems:

1. Primary (Transmitter Coil): The transmitter coil is a critical component in an Inductive Power Transfer (IPT) system. It serves as the primary element responsible for generating the oscillating magnetic field that wirelessly transfers power to the receiver coil embedded in the electric vehicle (EV). The transmitter coil is energized by high-frequency alternating current (AC), typically in the range of 20 kHz to 150 kHz. This AC current produces a time-varying magnetic field, which extends across the air gap to the receiver coil.

Integration in Solar Wireless Charging Station in a solar-powered system:

(a) The solar energy is first conditioned and converted to high-frequency AC by the power electronics module.

(b) This AC drives the transmitter coil, creating the magnetic field required for IPT.

(c) The transmitter coil is typically embedded in a pad installed on the ground, in parking lots, or on roads (for dynamic charging).

Figure 5. Transmitter coil

2. Secondary (Receiver Coil): The receiver coil is an essential part of the Inductive Power Transfer (IPT) system. It picks up the energy generated by the imported coil and converts it to electrical power, which in turn is used for the charging of the electric vehicle's battery. The receiver coil is located at the bottom of the electric vehicle. The vehicle is placed on top of the transmitter pad, and the receiver coil can be seen on the electric vehicle. The former will generate an alternating magnetic field that will, in turn, affect the receiver coil, making use of the electromagnetic induction process.

Serving the Solar EV Charging Station.

Alignment Sensitivity

1. The receiver coil must be aligned vertically and horizontally with the transmitter coil for optimal energy transfer.
2. Misalignment can reduce efficiency by 20–50% or more.
3. Many systems include automatic alignment guidance using sensors, magnetic markers, or vehicle-based feedback systems.

Figure 6. Receiver Coil

V. TEST AND PROCEDURE

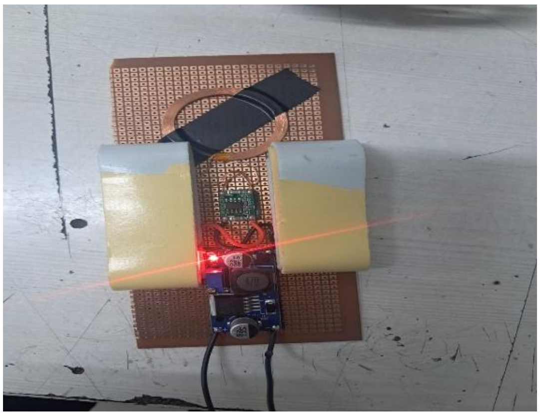

Figure 7. Hardware design

1. Transmitter & Receiver Coil Testing:

Measured the coil inductance, resistance, and alignment sensitivity using an LCR meter and oscilloscope. Verified output voltage at various distances and positions.

2. Solar Panel and Battery Check:

Evaluated solar panel output under natural sunlight. Tested battery charging and discharging capacity with load banks.

3. Power Electronics Validation:

Confirmed inverter output frequency and waveform. Checked for DC-DC converter efficiency and rectifier performance.

4. System Efficiency Measurement:

Calculated the wireless power transfer efficiency at different coil gaps and misalignments. Recorded power input vs. output using energy meters.

5. PWM and Solar Integration Test:

Simulated varying light conditions to test the PWM response. Verified the battery charging through solar with backup grid support.

6. Control and Safety Checks:

Validated microcontroller operation for voltage, current, and temperature regulation. Tested foreign object detection and overload protection functions.

7. Complete System Trial:

Ran a full charging cycle using solar input. Monitored key parameters (voltage, current, time, temperature).

8. Data Collection:

Logged test data using digital meters for efficiency analysis and system optimization.

Figure 8. Final Designed Model

VI. CONCLUSION

The wireless charging station for EVs is a forward-looking solution that aligns with global goals for sustainable development, renewable energy adoption, and next-generation mobility. Simulation and experiments validate the basis of the notion. Through the green-friendly user-oriented EV infrastructure, the system is depicted as capable of transforming both green mobility and renewable energy. This system is a significant achievement since it integrates low-emission and environmental elements of urban transportation infrastructures.

VII. FUTURE SCOPE

Future enhancements, such as dynamic wireless charging (where vehicles charge while moving), AI-based alignment systems, and blockchain-enabled billing and data security**,** are likely to make wireless EV charging even more attractive and widespread in the coming years. This will indeed make the entire system more convenient and reliable.

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