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Implementation of Prototype Solar- Powered Wireless Electric Vehicle Charging Station

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Abstract

The rapid adoption of electric vehicles (EVs) has increased the demand for efficient, safe, and sustainable charging infrastructure. Conventional conductive EV charging systems rely on physical connectors, which are prone to corrosion, safety risks, and high maintenance requirements, particularly in tropical climates. In addition, grid-dependent charging contributes to peak load stress and continued reliance on fossil fuel-based electricity generation. This study presents the development of a prototype solar-powered wireless electric vehicle charging station integrated with an intelligent control and monitoring system. The proposed system combines photovoltaic energy harvesting, resonant inductive wireless power transfer, and an Arduino-based control unit with Internet of Things (IoT) monitoring capabilities. Vehicle detection and authorization are achieved using infrared and RFID sensors, while a servo-assisted alignment mechanism ensures efficient energy transfer between transmitter and receiver coils. Real-time monitoring of voltage, current, temperature, and battery state-of-charge is implemented through a cloud-based interface. Experimental results demonstrate that the system can achieve wireless power transfer efficiency of up to 71.6% under optimal alignment conditions while operating independently from the electrical grid. The integration of solar energy reduces grid dependency and supports sustainable mobility initiatives. Overall, the prototype validates the feasibility of a compact, renewable-powered, wireless EV charging solution suitable for small-scale applications and future expansion toward smart charging infrastructure.

1. Introduction

The global transportation sector is undergoing a major transition toward electric vehicles (EVs) to reduce greenhouse gas emissions and dependence on fossil fuels [1]. As EV adoption increases, the availability of reliable and user-friendly charging infrastructure becomes a critical factor influencing user acceptance [2]. In Malaysia, national initiatives such as the Low Carbon Mobility Blueprint and the National Automotive Plan emphasize the expansion of EV charging networks while promoting the integration of renewable energy sources [3], [4].

Previous studies have explored various aspects of EV charging, including solar-powered charging systems, wireless power transfer (WPT), battery management systems, and IoT-based monitoring platforms. Alam et al. demonstrated efficient solar charging using Arduino-based controllers [10], while Sample and Lee showed that resonant inductive coupling can achieve high wireless power transfer efficiency for EV applications [8]. Other researchers have validated cloud-based monitoring and intelligent charging control using IoT platforms [5], [7]. However, most existing studies focus on individual subsystems rather than a fully integrated charging solution.

Despite these advancements, several issues remain unresolved. Conventional wired charging systems are vulnerable to corrosion and electrical safety risks in humid environments [6], while grid-dependent chargers increase peak demand stress and carbon emissions [3]. Furthermore, limited charging infrastructure in rural and off-grid areas restricts widespread EV adoption [9].

Based on these limitations, a research gap exists in the development of an integrated system that combines solar energy harvesting, wireless charging, and intelligent monitoring within a single prototype. Therefore, this study proposes a solar-powered wireless EV charging station with Arduino-based control and IoT monitoring. The main objective is to design and validate a proof-of-concept system that enables cable-free charging, reduces grid dependency, and enhances safety and usability for sustainable mobility applications.

2. Methodology

This project adopts a system-based methodology that integrates solar energy harvesting, wireless power transfer, and intelligent control to enable a fully automated electric vehicle (EV) charging process. The overall operation of the system is illustrated using a system flowchart and block diagram to clearly describe the sequence of processes and interaction between hardware and software components.

The system begins with solar energy collection, where a photovoltaic (PV) panel converts sunlight into direct current (DC) electrical energy. This energy is regulated by a solar charge controller and stored in a lithium-ion battery to ensure continuous operation even under low irradiance conditions. The stored energy then supplies power to the control unit and wireless charging module through appropriate DC–DC conversion stages.

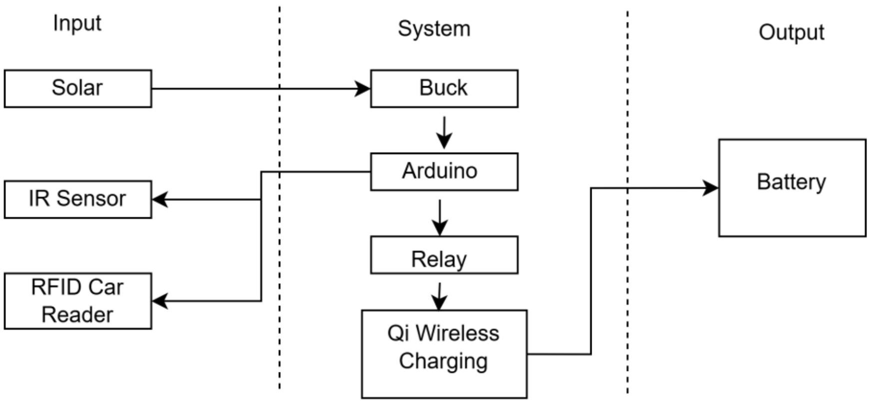

Fig. 1 Block diagram of the project

The block diagram in Figure 1 illustrates the functional architecture of the proposed system. Solar energy acts as the primary input source and feeds into the charge controller, which regulates charging of the battery storage unit. The battery serves as a buffer to stabilize power supply and support off-grid operation.

The Arduino Uno functions as the central control unit, receiving input data from sensors such as the INA219 current sensor, IR sensor, and temperature sensor. Based on programmed logic, the Arduino controls output devices including the servo motor, relay, and wireless charging module. A buck converter is used to step down voltage levels to meet the operating requirements of low-voltage components.

For monitoring purposes, an ESP8266 WiFi module transmits real-time system data to a cloud-based IoT platform. This enables users to observe charging status, power levels, and system conditions remotely. The wireless power transfer block consists of a Qi transmitter and receiver coil pair, which transfers energy through resonant inductive coupling without physical connectors.

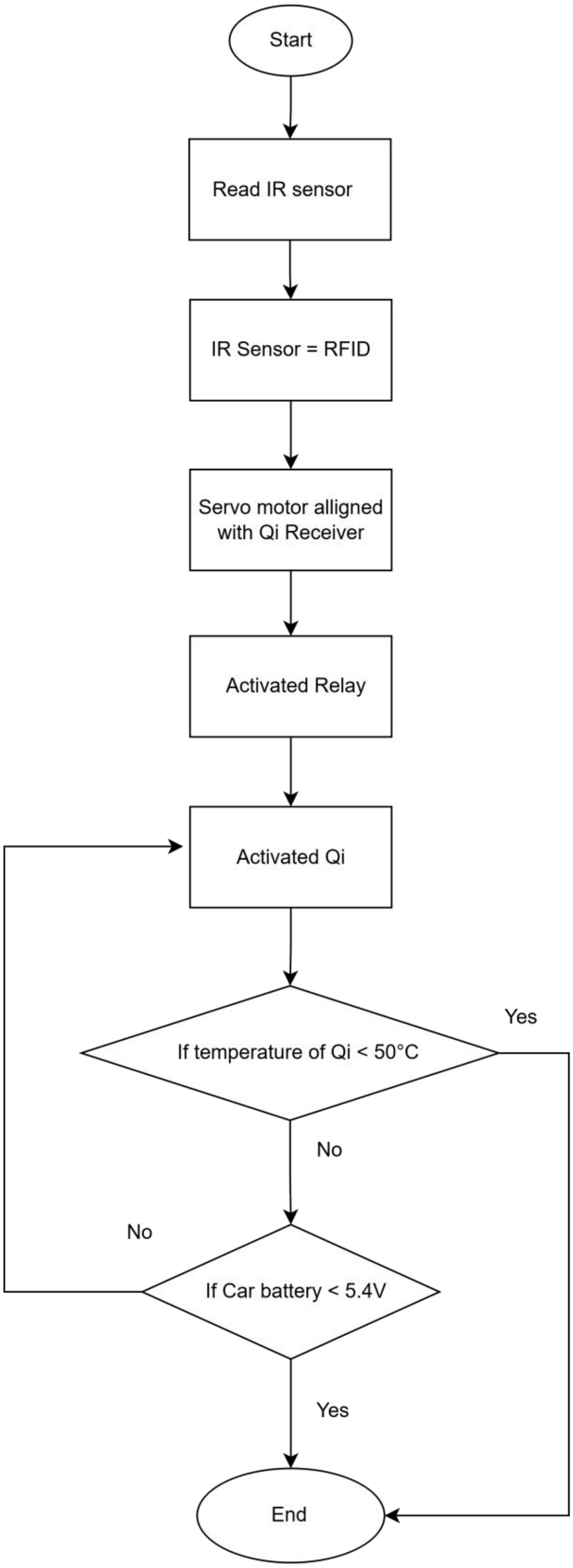

Fig. 2 Flowchart of the system.

Based on the flowchart in Figure 2, the system operates in a continuous monitoring loop. Initially, the system checks the availability of solar power and battery charge level. Once sufficient power is available, the system enters standby mode and waits for vehicle detection. An infrared (IR) sensor is used to detect the presence of the vehicle above the charging pad. When a vehicle is detected, RFID authentication is performed to ensure authorized access before charging begins.

After successful authentication, the Arduino Uno activates the servo motor to adjust the position of the wireless charging transmitter coil. This alignment process is crucial to maximize inductive coupling efficiency between the transmitter and receiver coils. Once alignment is achieved, the relay is triggered to activate the Qi wireless charging module, initiating energy transfer to the vehicle battery.

During the charging process, sensors continuously monitor voltage, current, temperature, and battery state-of-charge (SoC). If the battery reaches full charge or if abnormal conditions such as overheating are detected, the system automatically terminates charging to ensure safety. The system then returns to standby mode, ready for the next charging cycle.

3. Result and Discussion

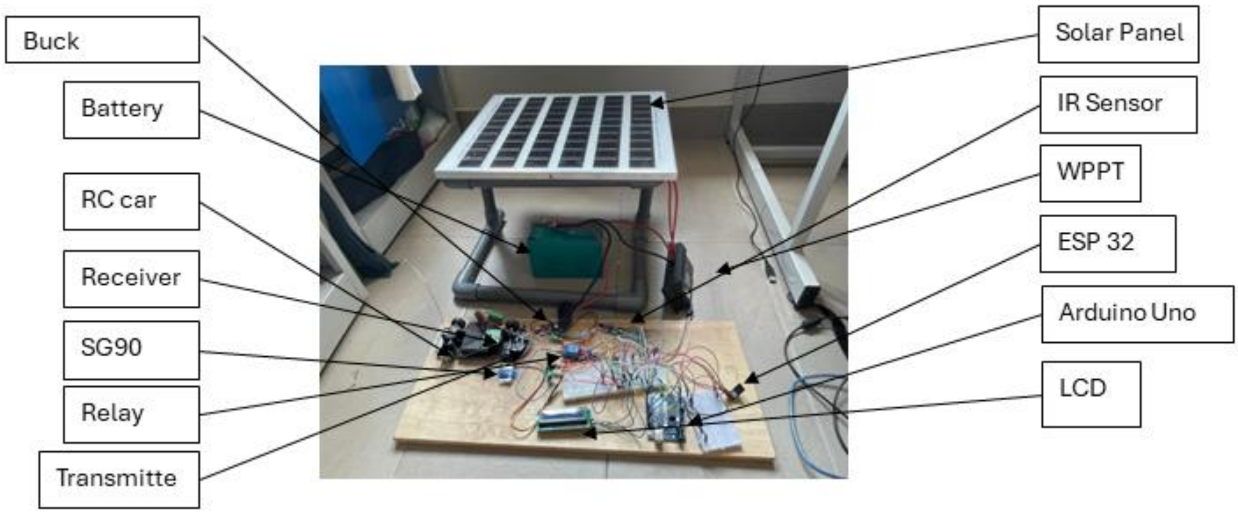

Fig. 3 Hardware prototype of solar-powered EV charging station.

After finishing the hardware and software configuration, the proposed system was tested to ensure overall functionality. The solar panel successfully powered the charge controller and battery storage device. The Arduino Uno accurately processed sensor inputs and controlled system outputs, such as relay activation, servo motor movement, and wireless charging. Real-time system parameters were successfully communicated to the IoT platform, demonstrating proper connection between hardware and the cloud interface.

3.1 Solar Power System Performance Analysis

Table 1 presents the measured solar panel output voltage under different weather conditions and times of the day. Higher voltage values were recorded during midday hours under sunny conditions, with a peak voltage of approximately 7.4 V. Lower voltage values were observed during late afternoon and cloudy conditions, confirming the direct relationship between sunlight intensity and solar output.

These results demonstrate that the solar panel is capable of providing sufficient voltage to support battery charging and system operation during daylight hours. Minor voltage fluctuations observed in the graph are attributed to transient cloud cover and environmental shading, which are common limitations in small-scale photovoltaic systems.

Table 1 The harvesting solar power during the day

Date	Time	Voltage (V)	Weather
23/12	17:30	6.5	Cloudy
24/12	17:15	3.4	Sunny
25/12	14:00	7.2	Sunny
26/12	16:45	6.9	Sunny
27/12	13:56	6.9	Sunny
28/12	12:15	7.4	Sunny
29/12	15:29	6.7	Sunny

3.2 Wireless Power Transfer Analysis

Table 2 summarizes the wireless charging performance, including transmitter voltage and current, receiver voltage and current, efficiency, coil alignment, and distance. To analyze this data effectively, two graphs were plotted: wireless charging efficiency versus coil distance, and efficiency versus alignment quality.

The results indicate that wireless power transfer efficiency decreases as the distance between transmitter and receiver coils increases. At a coil distance of 0.3 cm with excellent alignment, the system achieved a maximum efficiency of 71.6%. As the distance increased to 1 cm and alignment quality reduced, efficiency dropped significantly to below 65%.

This trend confirms that coil alignment and proximity are critical factors influencing inductive power transfer performance. The servo-assisted alignment mechanism implemented in the system plays an important role in maintaining optimal charging conditions and improving overall efficiency.

Table 2 The wireless power transfer for seven day

Date	Time	TX Voltage (V)	TX Current (A)	TX Voltage (V)	TX Current (A)	Efficiency (%)	Alignment	Coil Distance (cm)
23/12	17:30	2.82	0.45	2.41	0.33	62.6	Fair	1
24/12	17:15	3.03	0.5	2.62	0.34	58.8	Fair	0.8
25/12	14:00	3.43	0.8	3.02	0.5	55	Good	0.5
26/12	16:45	3.35	0.73	2.74	0.54	60.5	Good	0.5
27/12	13:56	3.23	0.63	2.84	0.37	51.6	Good	0.5
28/12	12:15	3.19	0.56	2.9	0.25	40.6	Excellent	0.3
29/12	15:29	3.45	0.83	3.06	0.67	71.6	Excellent	0.3

From the data, it shows that the wireless charging substation successfully show the technical practical of the solar powered wireless energy transfer for a small scale electric car for 7 days. While operating at the optimal voltages, the system archive efficiency around 71.6%, which are equivalent to commercial wired solution.

During the system intergration, standalone validation was performed to isolate power-path and control logic issue. Relay logic polarity and current sensing placement were verified before enabling full autonomous operation. The INA 219 sensor is used to monitor the charging and current delivered to the vehicle wirelessly, with real-time feedback displayed locally on an LCD for system validation.

4. Result and Discussion

Overall, the experimental findings validate the effectiveness of the proposed system design. The solar energy subsystem successfully supports off-grid operation, while the wireless charging module demonstrates reliable energy transfer for low-power EV applications. Although the efficiency is lower than wired charging systems, the achieved performance is acceptable for proof-of-concept implementation and aligns with values reported in related literature. The integration of automated alignment and real-time monitoring enhances system reliability and user safety. However, performance limitations remain due to power losses in wireless transmission and environmental variability affecting solar generation. These limitations provide opportunities for future improvements, such as higher power wireless modules and advanced power management algorithms.

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