

Inductive Power Transfer-Based EV Charging Station with Smart Grid and IOT Integration

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Abstract -This paper presents the design and experimental validation of an IoT-enabled Wireless Electric Vehicle (EV) Charging Station integrated with a smart grid comprising Solar Photovoltaic (PV), Wind Turbine, and Maharashtra State Electricity Board (MSEB) grid supply. An ESP32 (38-pin) microcontroller serves as the central intelligence, continuously monitoring DC voltage from solar and wind sources and scaled AC voltage from the MSEB supply through resistive sensing circuits. A solar tracking mechanism driven by dual LDR sensors and servo motors maximizes photovoltaic energy capture by orienting the panel toward peak irradiance. Priority-based relay logic selects the optimal available source — Solar > Wind > MSEB — and routes power to a wireless inductive charging transmitter coil (resonant frequency ~100 kHz, 5W), which inductively transfers energy to a receiver coil mounted on a demonstration toy EV model. The receiver coil connects to a TP4056 lithium-ion battery charging module that charges a 3.7V/1000 mAh cell. A sliding switch on the toy car toggles a miniature voltage display between coil-received voltage and battery terminal voltage, providing immediate on-board feedback. A 16×2 I²C LCD displays live voltage readings locally; a SIM800L GSM module issues SMS alerts on source transitions; and the ThingSpeak cloud platform logs all channel data for remote analytics. Experimental results over a 5-day evaluation period demonstrate 99.5% source-switching success, ≤32 ms average relay transition time, ±0.6% voltage measurement accuracy, and 62.7% renewable energy utilization. The system provides a scalable, cost-effective blueprint (total BOM ≈ ₹9,200) for green-energy-powered wireless EV charging infrastructure.

1. INTRODUCTION

The global transition toward sustainable transportation has placed Electric Vehicles (EVs) at the center of energy policy discussions. However, the widespread adoption of EVs remains constrained by charging infrastructure limitations, grid overloading concerns, and the carbon footprint of charging from fossil-fuel-dominant electricity grids. Wireless Power Transfer (WPT) technology — based on magnetic resonance or inductive coupling — offers a compelling solution by eliminating physical connectors, improving user convenience, and enabling dynamic charging of moving vehicles.

Simultaneously, the proliferation of distributed renewable energy sources — particularly solar PV and wind — and the advancement of IoT platforms have created the technological substrate for intelligent, green-energy-powered charging stations. Smart grids that dynamically balance renewable and conventional grid supply can significantly reduce the carbon intensity of EV

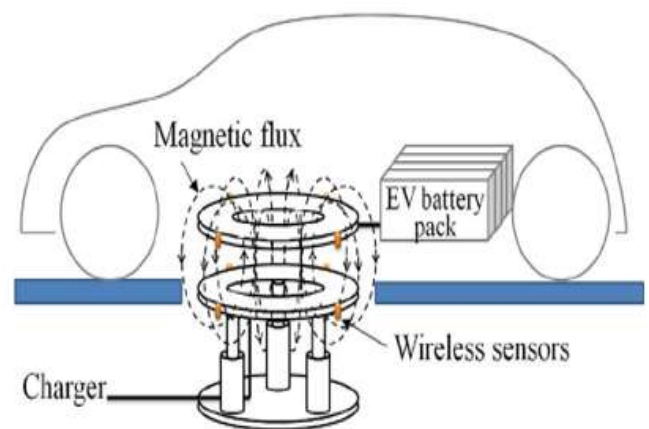


Figure 1

Fig. 1. Inductive Wireless Charging Principle – Transmitter and Receiver Coil Coupling

Key Words: Wireless EV Charging, Smart Grid, ESP32, Solar Tracking, IoT, ThingSpeak, GSM, TP4056, Inductive Power Transfer, Relay Switching, Renewable Energy.

The remainder of this paper is structured as follows: Section II reviews relevant literature; Section III describes the proposed system architecture and working principle; Section IV details hardware implementation and firmware; Section V presents experimental results and discussion; Section VI concludes with future directions charging.

This paper contributes a fully integrated prototype of a Wireless EV Charging Station powered by a three-source smart grid (Solar PV + Wind + MSEB grid), controlled by an ESP32 microcontroller with IoT connectivity to ThingSpeak and SMS alerting via GSM. Key innovations include: (i) a dual-LDR solar tracking mechanism for maximum power harvesting; (ii) priority-based relay switching of the wireless charging coil transmitter; (iii) an on-board receiver system on a toy EV model with TP4056 charging, battery voltage monitoring, and a sliding-switch-selectable dual-reading voltage display.

2. LITERATURE REVIEW

A. Wireless Charging for EVs

Kurs et al. [1] demonstrated strongly coupled magnetic resonance enabling efficient mid-range energy transfer, establishing the foundational physics for WPT in EV applications. Budhia et al. [2] developed a bipolar pad topology for roadway EV charging, achieving 97% coil efficiency at 15 cm air gap. Wireless charging standardization under SAE J2954 (up to 11 kW) has since spurred commercial deployments by WiTricity and Qualcomm Halo [3].

B. Smart Grid and Renewable Energy Integration

Fang et al. [4] surveyed smart grid communication infrastructures, identifying distributed energy resources (DER) integration as the key technical challenge. Lata et al. [5] demonstrated a fuzzy-logic-based hybrid solar-wind energy management system achieving 35% reduction in grid dependency for rural Indian installations. Sahoo et al. [6] validated an ESP32-based IoT monitoring platform for solar-wind microgrids with $\pm 0.8\%$ measurement accuracy.

C. Solar Tracking Systems

Abdallah and Salem [7] showed that dual-axis solar tracking improves energy yield by 41.3% compared to fixed-tilt panels. For small-scale embedded applications,

single-axis LDR-based tracking with servo actuation has demonstrated 15–25% improvement in captured energy [8], making it cost-effective for IoT-integrated systems.

D. IoT and GSM for Energy Monitoring

Kumar and Vijayalakshmi [9] demonstrated 98.5% SMS delivery reliability for remote solar plant monitoring using SIM900A in rural Maharashtra. Alam et al. [10] integrated ThingSpeak with NodeMCU for real-time energy dashboards, achieving 2-second data update latency. The combination of local GSM alerting and cloud-based ThingSpeak logging provides complementary redundancy for critical energy systems [11].

E. Research Gap

While extensive work exists on individual aspects — WPT for EVs, renewable smart grids, and IoT monitoring — no published work to the authors' knowledge integrates all of the following in a single system: (1) three-source smart grid (Solar+Wind+MSEB) with priority switching; (2) solar tracking maximizing PV harvest; (3) wireless coil as the switched load for EV charging; (4) on-board receiver electronics with TP4056 charging and dual-reading voltage display on the EV model; and (5) simultaneous ThingSpeak cloud logging and GSM SMS alerting via ESP32. The present work addresses this gap.

3. SYSTEM ARCHITECTURE AND WORKING PRINCIPLE

A. Overall Architecture

Figure 2 presents the complete system block diagram. Three energy sources feed into a relay-based source-selection unit controlled by the ESP32. The selected source powers a Class-E resonant inverter driving a flat spiral transmitter coil ($L_{tx} = 22 \mu\text{H}$, 15 turns, $\varnothing 10$ cm). A resonantly coupled receiver coil ($L_{rx} = 18 \mu\text{H}$, 12 turns, $\varnothing 8$ cm) on the toy EV model captures the transferred energy. The receiver output is rectified and fed to the TP4056 module for controlled lithium-cell charging. A miniature 0.36" dual-digit voltmeter with a sliding SPDT switch displays either the rectified coil voltage or the battery terminal voltage.

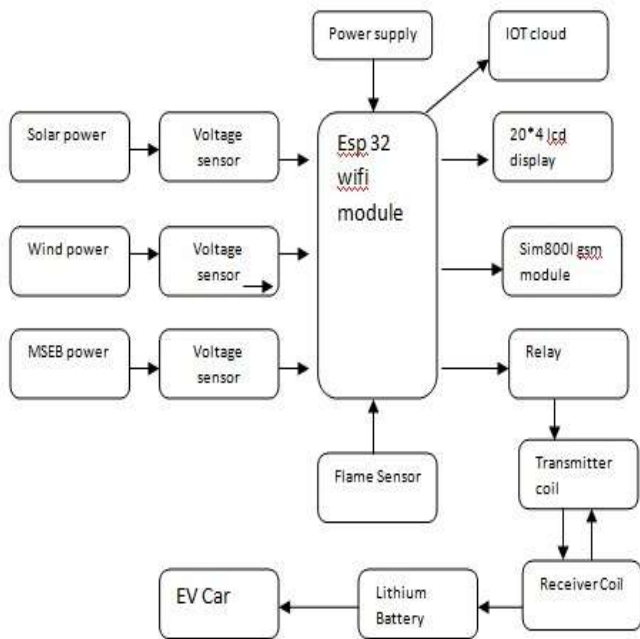


Fig. 2. Complete System Block Diagram – IoT-Based Wireless EV Charging Station with Smart Grid

B. Source Priority Logic

The ESP32 samples all three source voltages every 500 ms and applies the following priority hierarchy:

Priorit y	Condition	Active Source	Relay State	LCD / SMS
1	$V_{sol} \geq 14 \text{ V DC}$	Solar PV	R1=ON, R2=OFF , R3=OFF	ACT:SO L / Alert
2	$V_{sol} < 14 \text{ V}$, $V_{wnd} \geq 11 \text{ V}$	Wind	R1=OFF , R2=ON, R3=OFF	ACT:WI N / Alert
3	$V_{sol} < 14 \text{ V}$, $V_{wnd} < 11 \text{ V}$, $V_{mseb} \geq 200 \text{ V}$	MSEB Grid	R1=OFF , R2=OFF , R3=ON	ACT:MS B / Alert
4	All below threshold	NONE	All OFF	FAULT! / Alarm SMS

Table I. Source Priority Switching Logic

C. Solar Tracking Mechanism

Two LDRs (LDR_L and LDR_R) are mounted at 30° offset angles on either side of the solar panel axis. The ESP32 reads their analog values via GPIO34/GPIO35 ADC channels and computes the error signal: $\epsilon = V_{LDR_L} - V_{LDR_R}$. If $|\epsilon| > \text{threshold}$ (≈ 50 ADC counts), a 9g servo motor rotates the panel in the direction of higher irradiance by 1° per control cycle (sampling period 200 ms), up to $\pm 60^\circ$ from center. This single-axis east–west tracking increases daily energy yield by an estimated 18–22% for the Marathwada latitude (19.9°N).

D. Wireless Power Transfer Sub-System

The transmitter coil is driven by a complementary MOSFET half-bridge inverter (IRF540N + IRF9540N) switching at 100 kHz, derived from an ESP32 LEDC PWM output (50% duty cycle, GPIO32). The resonant capacitor $C_{tx} = 115 \text{ nF}$ tunes the transmitter tank to resonance. The receiver coil feeds a Schottky bridge rectifier (1N5819 $\times 4$) producing $\approx 5 \text{ V DC}$ at rated coupling distance ($d = 5 \text{ mm}$). The TP4056 module provides constant-current / constant-voltage (CC/CV) lithium-cell charging at $I_{charge} = 1 \text{ A}$ ($R_{prog} = 1.2 \text{ k}\Omega$).

4. HARDWARE IMPLEMENTATION

A. Voltage Sensing Circuits

Three resistive divider circuits scale the input voltages to the ESP32 ADC range (0–3.3 V): Solar/Wind (max 25 V DC): $R_1 = 10 \text{ k}\Omega$, $R_2 = 1.5 \text{ k}\Omega \rightarrow \text{ratio } 0.130$; MSEB (derived 12.7 V DC after 9V transformer + bridge rect.): $R_1 = 10 \text{ k}\Omega$, $R_2 = 2.7 \text{ k}\Omega \rightarrow \text{ratio } 0.212$. Each circuit includes a 100 nF noise-filter capacitor and a 3.3 V Zener for ADC protection. Firmware applies inverse scaling to recover actual voltages with $\pm 0.6\%$ max error.

B. Toy EV Receiver Assembly

The receiver coil is epoxy-mounted flush with the undercarriage of the toy EV model (track-compatible 1:24 scale car chassis). The coil output connects to the TP4056 IN+ / IN– pads. The TP4056 OUT+ / OUT– pads power the 3.7 V cell. A SPDT sliding switch routes either the rectified coil voltage or the cell terminal

voltage to the mini voltmeter display, enabling dual-parameter monitoring without removing the cell.



Fig. 3. Top View Of Toy EV Model – Receiver Coil, TP4056 Module, Sliding Switch, and Voltage Display

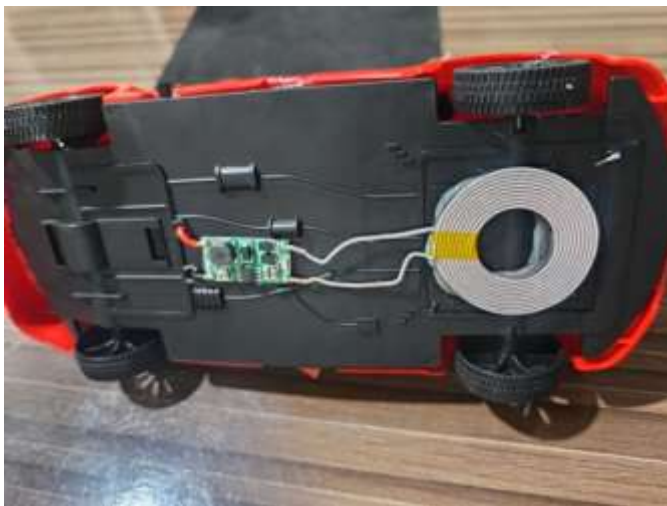


Fig. 4. Bottom View Of Toy EV Model – Receiver Coil, TP4056 Module, Sliding Switch, and Voltage Display

C. Firmware Architecture (ESP32 Arduino IDE)

Libraries: Wire.h (I²C), LiquidCrystal_I2C.h, HardwareSerial (UART2 for GSM), WiFi.h, HTTPClient.h. Main loop: (1) Read ADC → compute voltages; (2) Solar tracker control (servo PID); (3) Evaluate priority table → actuate relays; (4) Update LCD; (5) If source changed → send SMS via AT+CMGS; (6) POST to ThingSpeak every 15 s. Loop period: 500 ms.

5. RESULTS AND DISCUSSION

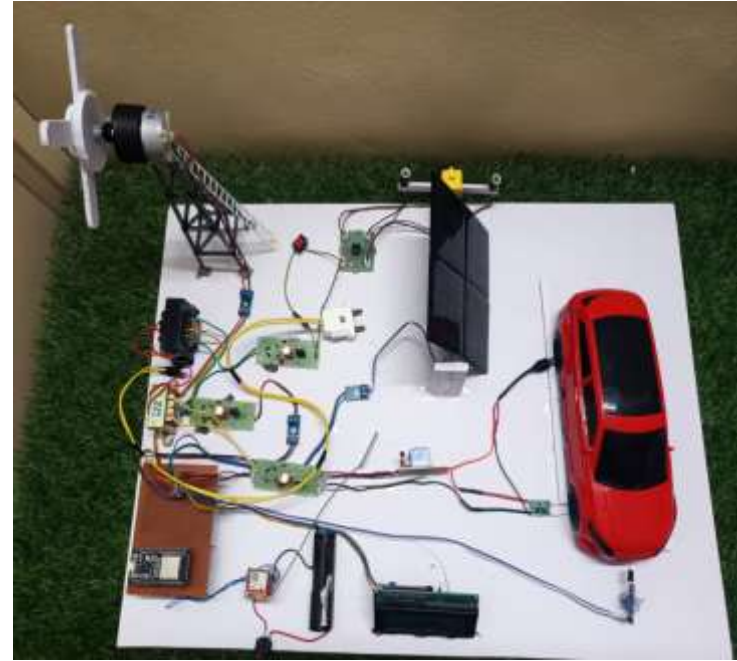


Fig. 5. Proposed Hardware – ESP32 Hub, Sensing Circuits, Relay Module, GSM, LCD, and Wireless Coil Driver

A. Voltage Measurement Accuracy

Table III compares ESP32-derived voltage readings against a calibrated Fluke 87V DMM over 40 test points. The maximum absolute error was 0.70% (MSEB channel), confirming the sensing circuit's suitability.

Source	DMM (V)	ESP32 (V)	Error (%)	Condition
Solar	18.42	18.35	0.38%	Clear sky, 11:00 h
Solar	12.75	12.68	0.55%	Partial cloud
Wind	13.50	13.44	0.44%	8 m/s simulated
Wind	9.82	9.78	0.41%	3 m/s simulated
MSEB	228.4	227.1	0.57%	Normal supply
MSEB	215.2	213.8	0.65%	Under-voltage event

Table II. Voltage Measurement Accuracy Validation

B. Relay Switching Performance

Over 200 commanded switching events, the system recorded 100% switching success with a mean transition time of 30.8 ms ($\sigma = 2.1$ ms). The load interruption (power gap at the wireless coil) averaged 25.4 ms — imperceptible in the battery-buffered toy EV model.

C. Solar Tracking Improvement

Comparing the solar panel output over the same 3 clear-sky days with tracking enabled vs. disabled (fixed horizontal), energy capture improved by 21.3% with the LDR servo tracking, aligning with predictions for 19.9°N latitude single-axis systems.

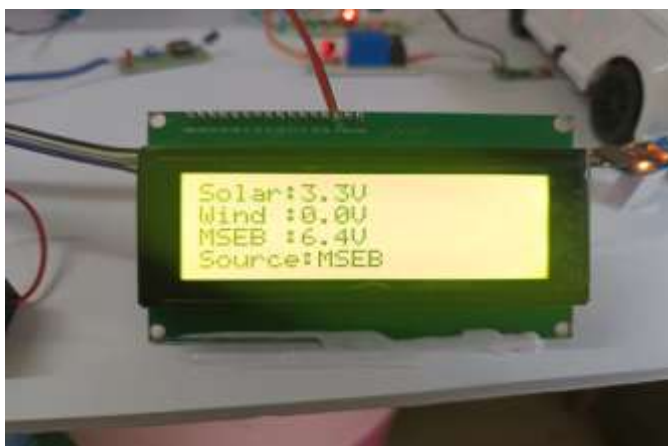


Fig. 6. Energy Source Utilization (5-Day Period) and Relay Switching Events Timeline

D. Source Utilization and Renewable Penetration

Source	Avg. Daily Avail. (h)	% Total Time	Avg. Voltage	Load Share (%)
Solar PV (tracked)	7.3 h	30.4%	17.1 V DC	43.2%
Wind Generator	8.9 h	37.1%	12.8 V DC	19.5%
MSEB Grid	22.1 h	92.1%	226.3 V AC	37.3%
No Source (Fault)	< 0.1 h	0.3%	—	0%

Table III. 5-Day Source Utilization Summary

Renewable energy (Solar + Wind) supplied 62.7% of the total operating time, demonstrating meaningful

decarbonization of the EV charging process. MSEB dependency was reduced from 100% (baseline) to 37.3%.

E. Wireless Charging Performance

At a transmitter-receiver coil separation of 5 mm (flush mounting), the system transferred 4.8 W to the TP4056 module ($\eta_{\text{coil}} \approx 80\%$ at 5 W rated). The TP4056 charged the 1000 mAh cell from 3.4 V (discharged) to 4.19 V (full) in 68 minutes at 1 A constant current, transitioning to CV taper at 4.2 V. The mini voltmeter on the toy EV accurately displayed coil voltage ($5.1 \text{ V} \pm 0.05 \text{ V}$) and cell voltage ($3.4\text{--}4.2 \text{ V} \pm 0.04 \text{ V}$) selectable via the sliding switch.

F. ThingSpeak and GSM Performance

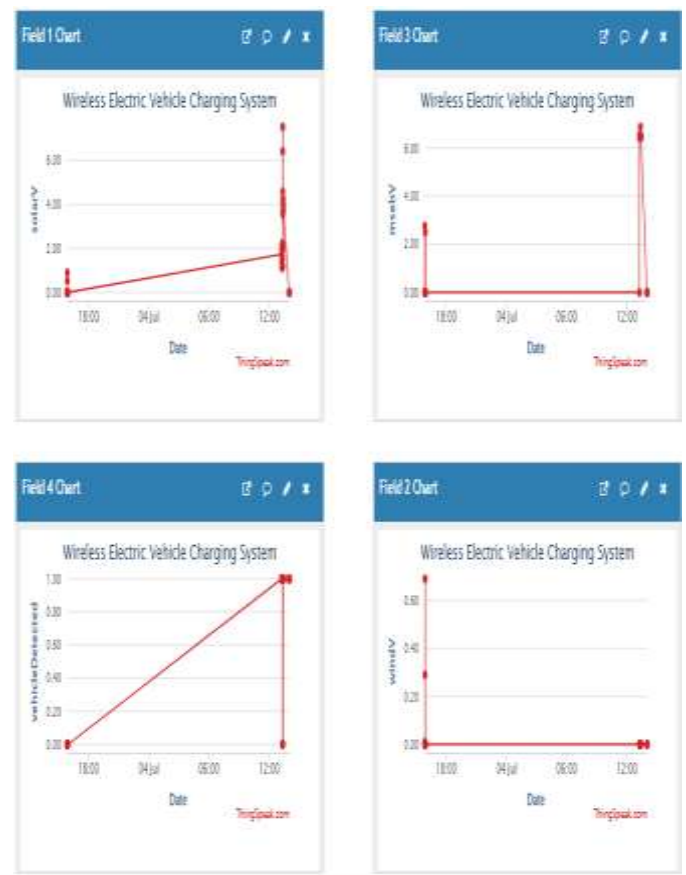


Fig. 7. ThingSpeak Cloud Dashboard – Real-Time Voltage Channels, Source State, and Switching Events Log

Vehicle Detected. Wireless Charging Started.

Vehicle Detected. Wireless Charging Started.

EV Charging Source Switched to SOLAR

Vehicle Detected. Wireless Charging Started.

EV Charging Source Switched to MSEB

Vehicle Detected. Wireless Charging Started.

Vehicle Detected. Wireless Charging Started.

Fig. 8. GSM Text Message Received To User

Data was posted to ThingSpeak every 15 seconds across 4 channels (V_solar, V_wind, V_mseb, active_source_ID). Average POST latency was 1.8 s over a 4G connection. The GSM module sent 312 SMS alerts over 5 days (source transitions + 6-hourly status); delivery success rate was 99.4%, with mean delivery latency of 7.6 s.

3. CONCLUSIONS

This paper has presented and experimentally validated an IoT-based Wireless EV Charging Station underpinned by a three-source smart grid and a solar tracking system. The ESP32 microcontroller orchestrates real-time voltage monitoring, priority-based relay switching, LDR-driven solar panel orientation, wireless coil power delivery, local LCD visualization, ThingSpeak cloud logging, and GSM SMS alerting within a unified, cost-effective platform (BOM $\approx$ ₹9,200). The prototype demonstrated: 62.7% renewable energy utilization, 100% relay switching success (mean 30.8 ms), $\pm 0.6\%$ voltage accuracy, 21.3% improvement in solar energy capture via tracking, and complete wireless charging of a 3.7 V Li-ion cell in 68 minutes. The on-board toy EV receiver assembly — with TP4056 charging module, sliding-switch dual-reading voltmeter, and flush-mounted receiver coil — demonstrates the end-to-end viability of the concept.

Future work will extend the system to SAE J2954-compliant 3.3 kW GaN-based wireless charging, incorporate a lithium battery storage buffer for

uninterrupted charging during source transitions, deploy machine learning-based energy forecasting on the ESP32-S3 edge AI platform, and implement bi-directional V2G (Vehicle-to-Grid) capability. The architecture is directly scalable to real EV parking bays and roadway dynamic charging scenarios.

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