

UPI-Integrated Smart Electric Vehicle Charging Estimator

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ABSTRACT

Growing adoption of electric vehicles (EVs) across India has intensified the need for payment infrastructure that is both technically robust and operationally simple. Existing charging facilities are largely dependent on grid power and rely on cumbersome payment methods such as prepaid cards and RFID tokens, which introduce friction and undermine the convenience that EV users expect. This paper proposes a UPI-driven smart EV charging estimator that removes these barriers by enabling users to trigger and settle charging sessions directly through QR code scanning or UPI intent, with no requirement for pre-registration or third-party wallet applications. A dedicated smart controller oversees energy distribution from storage and grid backup sources to guarantee uninterrupted operation, while a precision energy metering unit tracks the exact quantum of electricity supplied to the vehicle. Power delivery is gated exclusively on verified UPI payment confirmation, which strengthens transaction security and minimizes the risk of unauthorized energy consumption.

I. INTRODUCTION

The trajectory of global transportation is shifting decisively toward electrification. Electric vehicles offer compelling advantages over petroleum-powered counterparts: markedly lower lifecycle greenhouse emissions, reduced per-kilometre fuel expenditure, and superior drive-train efficiency. Despite these merits, the viability of mass EV adoption hinges on the parallel development of charging networks that are geographically distributed, financially accessible, and technically seamless.

A central challenge in this ecosystem is the absence of a unified, frictionless payment mechanism. The proposed system addresses this gap by incorporating India's Unified Payments Interface (UPI) directly into the charging workflow. A microcontroller-based smart controller coordinates energy flow, interprets metering telemetry, and conditionally enables charging based on real-time payment status. An operator-facing dashboard provides visibility into energy consumption, active sessions, and historical transaction data.

This integration reflects a convergence of digital financial infrastructure and sustainable mobility. It is directly aligned with the objectives of the Digital India initiative and the National Electric Mobility Mission Plan (NEMMP), and it holds strong potential to democratize EV charging access across urban centres, peri-urban zones, and rural communities alike.

II. LITERATURE REVIEW

1) Mishra et al. (2023) — QR-Based UPI Payment for EV Charging Prototypes

This study developed laboratory-scale prototypes linking QR-initiated UPI transactions to individual charging sessions. Although the proof-of-concept validated the payment coupling mechanism, the scope remained confined to controlled lab environments. Key limitations included the absence of renewable energy integration and insufficient architectural scalability for real-world deployment.

2) Gupta et al. (2021) — Demand-Responsive Smart Charging Architectures

This work explored predictive load-balancing strategies for smart EV charging stations. The research demonstrated that proactive demand management can significantly attenuate peak grid loads and reduce stress on distribution infrastructure. However, the study did not address digital payment integration or user-facing simplicity.

3) NPCI Reports (2020–23) — UPI Transaction Framework

Publications from the National Payments Corporation of India outlined the technical and regulatory foundations of UPI as a fast, secure, and real-time transaction mechanism with near-universal acceptance across India. While these documents establish robust guidelines for payment processing, they do not address domain-specific implementations such as EV charging session management or energy metering integration.

III. PROBLEM STATEMENT

The objective of this work is to design, build, and validate a secure, intuitive UPI-based EV charging system capable of supporting pay-at-charger transactions, real-time session control, and precise energy accounting. Two primary problems motivate this work:

First, existing public charging infrastructure imposes unnecessary complexity on the end user. Payment workflows built around proprietary cards, vendor-specific mobile applications, or subscription-based memberships create barriers that disproportionately affect casual or first-time EV users and constrain overall adoption. The proposed system resolves this by enabling any user equipped with a UPI-capable device to initiate and pay for a charging session without any account setup or dedicated application.

Second, most deployed charging stations draw exclusively from the electrical grid, making them vulnerable to supply interruptions and limiting their sustainability profile. An intelligent charging solution must be capable of managing energy storage efficiently and directing power from available sources—including battery backup—to the vehicle in a controlled and metered manner.

IV. MATERIALS AND COMPONENTS

The hardware platform for this system comprises the following key components:

- ATmega328P Microcontroller
- Relay Module / Contactor
- EV Connector — Type 2 Plug (Mennekes Standard)
- GSM Module — SIM900a
- 16×2 LCD Display
- RFID Card (Monthly Subscription Option)

4.1 ATmega328P Microcontroller

The ATmega328P serves as the central processing unit of the system. Built on the open-source Arduino platform, this microcontroller integrates 14 configurable digital I/O lines (six of which support PWM output) alongside six analog input channels. Its compatibility with the Arduino IDE simplifies firmware development and debugging, making it well-suited for embedded control applications.

4.2 SIM900a GSM Module

The SIM900a is a dual-band (900/1800 MHz) GSM/GPRS transceiver engineered for deployment in embedded communication contexts. It empowers the microcontroller to execute voice calls, exchange SMS messages, and establish internet connectivity over GPRS, enabling remote monitoring and payment status updates.

4.3 Relay Module

The relay functions as a digitally controlled electrical switch, mediating the connection between the charging supply and the EV inlet. It supports both normally open and normally closed circuit configurations and responds to low-voltage control signals (5V) from the Arduino, making it a reliable and responsive actuator for session-level power gating.

4.4 EV Connector — Type 2 Plug

The Type 2 connector, also referred to as the Mennekes plug, represents the prevailing AC charging interface for electric vehicles in Europe and India. Its widespread standardization ensures broad vehicle compatibility and physical robustness under repeated connect-disconnect cycles.

4.5 RFID Card (Monthly Subscription)

For users who charge regularly, RFID-based monthly subscription cards offer a streamlined alternative to pay-per-use transactions. These cards provide bundled energy allowances at

discounted rates, making them economically advantageous for high-frequency users while retaining the same underlying control logic.

4.6 16×2 LCD Display

This liquid crystal display module presents alphanumeric output across a 16-column, 2-row grid, supporting up to 32 simultaneous characters. It serves as the local user interface for session status, energy consumption feedback, and payment confirmation messages.

V. METHODOLOGY

The system architecture integrates four functional modules: a microcontroller-based controller core, a UPI payment integration layer, a data acquisition subsystem, and a power management stage.

Hardware Setup:

1. DC-DC converters and inverters are deployed to regulate supply voltages across subsystems.
2. A battery bank with an integrated Battery Management System (BMS) provides grid-independent backup power.
3. The EV charging outlet is configured with relay-based switching and energy metering circuitry.
4. Environmental and electrical sensors—measuring voltage, current, power, temperature, and irradiance—feed real-time data to the controller.

Software and Control Logic:

5. Each charging event is assigned a unique session identifier at initiation.
6. A dynamic QR code tied to the session ID is generated and displayed, prompting the user to complete a UPI payment. Transaction confirmation is retrieved via API callback or webhook from the payment gateway.
7. Upon successful payment verification, the controller enables the relay to connect power to the vehicle. In the event of payment failure or timeout, the relay remains open and energy flow is blocked.
8. Throughout the session, the system records telemetry including instantaneous voltage, current, power, cumulative energy delivered, battery state of charge (SoC), and available photovoltaic generation.

Operational Sequence:

The user parks adjacent to the EV Charging Station (EVCS) and connects the Type 2 charging cable. The system authenticates the user against its local database. Upon confirmation, the Arduino transmits a control signal to the relay, closing the circuit and permitting power flow. A digital energy meter continuously logs consumption data. At session termination—either

manually or upon full charge—the relay opens, current flow ceases, and a summary of units consumed and applicable charges is transmitted to the user’s registered mobile number.

VI. RESULTS AND DISCUSSION

A bench-level experiment was performed by connecting the EVCS to a single-phase AC supply, with the Arduino powered by a 9V onboard battery. Under idle conditions, the relay maintained an open circuit, effectively blocking all downstream current flow. This validated the fail-safe default behaviour of the system—no energy is delivered unless an explicit control command is issued.

In the active test scenario, the user toggled the session ON through the application interface. The Arduino received and processed this command, matched it against the current session state, and transmitted an output signal to the relay. The relay closed, completing the circuit and allowing current to reach the connected load—a battery charger in this instance. Consumption metrics were logged continuously throughout the session.

The interaction between the mobile interface and the EVCS hardware was confirmed to be reliable and latency-free under the test conditions. Relay switching behaviour was precise, and the system’s end-to-end control chain—from UPI confirmation to physical power delivery—functioned as designed. No unauthorized energy access was observed during any test iteration.

VII. PROTOTYPE

A scaled-down prototype of the complete EVCS was designed using AutoCAD and physically assembled on a breadboard platform. The prototype integrates all primary hardware components: ATmega328P, SIM900a, relay module, 16×2 LCD, and RFID card reader. Pin-level interconnections between the Arduino and peripheral components are documented in the pin configuration diagram (Figure 6), providing a reproducible reference for hardware assembly.

Testing was conducted on a 12V, 10Ah lithium-ion battery pack to simulate a scaled EV battery load. All subsystems—payment verification, relay actuation, energy metering, and display feedback—functioned cohesively within this prototype environment.

VIII. CONCLUSION

This work presents a novel approach to electric vehicle charging by embedding UPI-based digital payment directly into the charging control loop. Unlike conventional stations that depend on RFID tokens or dedicated mobile applications, the proposed architecture allows any user with a UPI-enabled device to initiate a charging session instantly, without prior registration or proprietary hardware.

At the core of the design, an ATmega328P microcontroller governs the interaction between payment confirmation signals and relay-controlled power delivery. This tight coupling between financial authorization and physical energy flow ensures that electricity cannot be drawn without a verified transaction, significantly reducing the risk of unauthorized usage.

Prototype evaluation on a 12V/10Ah Li-Ion cell confirmed reliable relay switching, accurate energy metering, and stable GSM-based communication throughout the session lifecycle. These results validate the feasibility of the core concept, even though the present version represents a laboratory-scale demonstration rather than a production-ready deployment.

Looking ahead, several enhancements can elevate the system toward commercial viability. Integration of solar photovoltaic panels with battery backup would reduce grid dependency and improve sustainability. Incorporating faster charging protocols, cloud-hosted transaction logs, and a multi-station operator dashboard would further strengthen scalability.

In essence, this project bridges two of India's most significant technology-driven initiatives—digital payments and electric mobility—into a unified, accessible, and secure charging ecosystem that holds strong promise for widespread urban and rural deployment.

IX. REFERENCES

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