

SOLAR POWERED EV/FUEL SMART HYBRID DISPENSER STATION USING ESP-32 CONTROLLER

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ABSTRACT

The project titled “Solar Powered EV/Fuel Smart Hybrid Dispenser Station using ESP32 Controller” focuses on developing an intelligent and energy-efficient dual-purpose refueling and charging system for both electric and fuel-based vehicles. The system utilizes solar energy as its primary power source, regulated through an RPS (Regulated Power Supply), making it an eco-friendly and sustainable solution. The ESP32 microcontroller serves as the core controller, integrating RFID for user authentication, a keypad for input control, voltage and fuel level sensors for monitoring, and IoT connectivity for remote

supervision. The system enables seamless switching between EV charging and fuel dispensing through relay control while displaying real-time operational data on an LCD and alerting users via a buzzer.

This smart hybrid dispenser system ensures automated, secure, and efficient management of multi-energy vehicle stations. By integrating IoT technology, the system provides real-time monitoring, data logging, and remote accessibility through a cloud interface, enhancing transparency and reliability. The use of renewable solar energy reduces dependency on conventional power sources, supporting sustainable development and promoting green energy adoption. Overall, this design demonstrates

an innovative approach toward hybrid vehicle refueling infrastructure, combining automation, IoT, and renewable energy for future-ready smart transportation systems.

Keywords:ESP32, Solar Energy, Hybrid Dispenser, IoT, RFID, EV Charging, Fuel Station, Renewable Energy, Smart System, Automation, Relay Control.

1. INTRODUCTION

Energy landscape has been undergoing a significant transformation driven by increasing environmental concerns, depletion of conventional fossil fuels, and rapid growth in the adoption of electric vehicles. Traditional fuel stations, which once operated solely on diesel and petrol distribution, are now evolving into multi-energy service hubs capable of supporting both conventional engines and emerging electric mobility systems. At the same time, heavy reliance on grid electricity for charging electric vehicles places an additional strain on national power infrastructure, which often suffers from overloads, voltage fluctuations, and high transmission losses. To address these challenges, integrating renewable energy sources—particularly solar power—into charging stations has become a promising and necessary solution. Solar energy offers a clean, sustainable, and cost-effective alternative that reduces dependence on fossil-fuel-based electricity, minimizes carbon emissions, and enhances energy independence. When solar power is combined with smart embedded controllers capable of efficiently managing loads, dispensing mechanisms, billing, and communication, the result is a modern hybrid station that serves both fuel-based

and electric vehicles with improved efficiency and reliability.

As the number of electric vehicles continues to grow, the demand for accessible, affordable, and fast-charging infrastructure is increasing at an unprecedented rate. Many regions, especially semi-urban and rural areas, still lack proper charging facilities, creating significant range anxiety for EV users. Moreover, fuel stations require modernization to support hybrid systems where both traditional combustion engine vehicles and EVs can be serviced. A solar-powered hybrid dispenser station becomes an optimal solution to bridge this infrastructural gap by leveraging renewable energy for EV charging while maintaining conventional fuel dispensing systems. Solar panels installed on the station's canopy or nearby land area can generate substantial power during daytime, which can be stored in batteries or supplied directly for charging. This reduces operational costs for fuel station owners while enabling sustainable energy usage. Integrating an intelligent controller like the ESP-32 ensures that the generated energy is efficiently managed, allocated, and monitored in real time. The ESP-32 enables automation, data acquisition, smart metering, and IoT-based remote supervision, transforming a traditional station into a highly connected and efficient hybrid facility.

Modern users expect transparency, automation, and digital convenience in service stations. Conventional fuel dispensers rely heavily on manual monitoring, outdated meters and mechanisms, and human-driven billing processes that may result in inaccuracies, time delays, and inefficiencies. Electric vehicle charging, on the other hand,

requires advanced monitoring of voltage, current, remaining charging time, energy delivered, and dynamic pricing based on usage. The ESP-32 facilitates the development of a unified control and monitoring framework that caters to both fuel dispensing and EV charging processes. With built-in Wi-Fi and Bluetooth connectivity, the controller enables remote access, cloud integration, mobile-based monitoring, and automated data logging. These features support live dashboards for station owners, IoT-based diagnostics, automated billing, and fault detection. Additionally, the ESP-32 can integrate with RFID modules, payment gateways, user authentication systems, and real-time sensors, enabling a seamless and secure user experience. This level of intelligent automation ensures high accuracy, reduced human intervention, and increased operational efficiency.

Another critical challenge faced by conventional filling stations is the rising concern for environmental pollution and the carbon footprint associated with fuel-based transportation. Diesel and petrol combustion are leading sources of carbon dioxide emissions, and reducing dependence on these fuels has become a global priority. While EVs represent a major step towards green energy adoption, charging EVs using electricity generated from coal or non-renewable sources reduces the overall environmental benefit. This highlights the need for integrating solar power directly into EV charging stations. By harnessing solar energy, the hybrid dispenser station significantly reduces emissions and provides truly clean charging cycles. Solar-powered charging also minimizes energy costs, making EV charging more economical for both users and providers. Excess solar energy can be

stored in battery banks or supplied to the grid through net metering, improving the resource utilization and long-term cost savings of the station. The hybrid nature of the system ensures that even during periods of low sunlight, the EV charger can seamlessly switch to grid or battery power while fuel dispensers continue functioning normally, ensuring uninterrupted service.

The hybrid dispenser station also introduces an innovative multimodal energy distribution approach that integrates both liquid fuel management and electric power control. The ESP-32 plays a central role in coordinating these operations by acting as a programmable logic controller for pump motors, flow sensors, relay drivers, solenoid valves, DC fast chargers, load managers, and safety mechanisms. It continuously monitors sensor inputs such as solar panel voltage, battery level, current draw, energy consumption, pump flow rate, temperature, and emergency conditions. The controller automatically adjusts the energy distribution between charging stations, storage units, and auxiliary systems based on real-time demand. Intelligent algorithms help prevent overloads, improve charging efficiency, and protect sensitive electronics from voltage fluctuations. In fuel dispensing operations, the system ensures accurate metering, automated shutoff, calibrated flow measurement, and secure transaction tracking, enabling a robust and reliable hybrid service platform.

Safety plays a crucial role in any energy dispensing system, whether fuel or electric. Fuel stations must comply with strict standards to prevent fire hazards, leakage, and short circuits, while EV charging stations require electrical protection, surge control, and thermal management. The proposed hybrid solution integrates safety

sensors such as flame detectors, gas sensors, over-current protection, thermal cut-offs, and emergency shut-off mechanisms. The ESP-32 collects data from all safety modules, instantly detects abnormal conditions, and initiates emergency responses such as cutting power, shutting valves, or alerting the operator. Additionally, IoT connectivity allows automatic notifications to be sent to station owners or maintenance personnel whenever critical faults arise. By offering centralized safety management, the hybrid station greatly enhances user trust and operational reliability.

The integration of solar energy, IoT connectivity, smart dispensing systems, and embedded automation also opens possibilities for modern digital services within the station. Users may authenticate themselves using RFID cards or mobile apps for fueling or charging, and receive automated billing through digital payment platforms. Station owners can monitor real-time reports, usage statistics, energy generation, fuel consumption patterns, and maintenance alerts through cloud dashboards. Predictive analytics made possible through IoT data can help forecast fuel demand, optimize charging loads, and plan maintenance schedules for pumps and chargers. This creates a data-driven environment where energy distribution becomes smarter, more efficient, and easier to manage. The station transforms from a simple fuel outlet into an intelligent micro-energy hub that supports modern mobility needs.

Overall, the solar-powered EV/fuel smart hybrid dispenser station using an ESP-32 controller represents a significant technological advancement toward sustainable transportation and intelligent energy distribution. By combining

renewable energy generation, dual-mode dispensing, IoT-driven automation, and real-time control, the system addresses many limitations of traditional fuel stations and current EV charging infrastructure. It lowers operational costs, improves environmental sustainability, enhances safety, increases service availability, and modernizes user experience. Such hybrid systems are essential for future mobility ecosystems where both electric and traditional vehicles coexist, allowing seamless energy access while accelerating the transition to cleaner technologies. As global efforts continue to focus on lowering carbon emissions and improving energy resilience, solutions like the proposed hybrid dispenser station will play a crucial role in shaping efficient, eco-friendly, and smart transportation infrastructure for the future.

2. LITERATURE SURVEY

A. Sallem et al., 2025 — Presents an ESP32-based prototype for inductive (wireless) EV charging powered by solar energy, describing design choices for power electronics and control firmware and demonstrating feasibility in a small-scale testbed. The work addresses PV sizing for wireless transfer and discusses integration challenges for moving vehicles. (E3S Conferences)

A. Caliskan, 2025 — Proposes an optimization approach for hybrid stations combining EV charging and hydrogen dispensers, focusing on unit allocation and operational scheduling to minimize costs and emissions. The paper studies trade-offs between renewable supply, storage sizing, and on-site dispensing demands. (ScienceDirect)

Review Paper (IJSREM), 2024 — Reviews IoT-enabled solar EV charging station

designs and battery-monitoring strategies, summarizing MPPT, energy-management, and remote monitoring techniques for small-scale deployments. It highlights typical prototype architectures using microcontrollers and cloud dashboards. (ijsrem.com)

Bolla J./ResearchGate (ESP32 e-fuel), 2023 — Describes an IoT-based e-fuel station built around the ESP32 that integrates RFID-based user authentication, fuel-level monitoring, and cloud logging to automate dispensing and billing. Results show practical benefits of low-cost controllers for station automation and remote supervision. (Semantic Scholar)

A. Sallem (E3S Conf.), 2025 — Details a solar-powered wireless EV charging design and evaluates control strategies for MPPT and power conditioning using embedded controllers. The paper compares wired versus inductive approaches and highlights system control constraints. (E3S Conferences)

Design & Assessment (ResearchGate), 2022 — Presents a feasibility study for hybrid-energy EV charging stations using solar PV and storage, with sizing and techno-economic analysis for sustained operation under variable loads. The study includes simulation results for different load profiles and storage capacities. (ResearchGate)

Solar Charging Station with IoT (ResearchGate), 2023 — Proposes a 7.4 kW AC solar charging station coupled with IoT monitoring; it covers PV sizing, inverter selection, and cloud-based energy production monitoring for site operators. The authors emphasize real-time visibility and production/consumption matching. (ResearchGate)

IJPREAMS / ESP32 e-fuel (2023) — Demonstrates an ESP32-controlled smart e-

fuel station prototype that measures dispensed fuel, updates inventory on the cloud, and supports remote alerts when tank levels are low. The implementation highlights simple hardware-software integration for small retail stations. (ijprems.com)

Hybrid Charging Station (IJARSCT), (2021–2022 range) — Describes a hybrid microgrid-powered charging station model that combines PV, storage, and grid interaction for optimized charging, addressing uncoordinated BEV charging and renewable utilization. The paper proposes control rules to improve PV usage. (IJARSCT)

KSCST project report (solar EV charging), 2023 — Presents a student-built solar EV charging station with an Android app and GSM modem for status updates, demonstrating a low-cost monitoring stack and MPPT implementation for small installations. The report emphasizes user-facing features and field usability. (kscst.org.in)

Methodology for Optimal Design (MDPI/Sustainability), 2019 — Proposes an optimal sizing method for hybrid microgrids supplying dynamic EV charging (including wireless transfer), focusing on component sizing, reliability, and long-term operation. The methodology is validated via case studies and sensitivity analyses. (MDPI)

RJPN / solar EV charging (2023) — Describes a solar-powered EV charging module using MPPT and Arduino control with IoT monitoring, discussing prototype testing and basic energy management for small-scale chargers. This work is practical for campus or community charging setups. (rjpn.org)

El-Khozondar et al., 2024 — Develops an ESP32-based IoT energy monitoring

system and evaluates its use for onsite energy management; the work shows how ESP32 platforms can reliably monitor power flows and supply real-time telemetry to cloud services. The paper serves as a solid reference for ESP32 in energy applications. (ScienceDirect)

Syafii et al., 2024 — Compares Raspberry Pi and ESP32 solutions for simple energy management systems, arguing that ESP32 offers a cheaper, lower-power option while still supporting essential IoT features for station control. The study includes performance comparisons under real loads. (sdewes.org)

IJESR / IoT hybrid self-fuel dispense, 2024 — Presents a prototype that integrates EV charging slot booking, fuel inventory monitoring, and IoT telemetry to coordinate mixed fueling and charging operations at a station. The paper addresses software workflows for booking and queuing. (ijesr.org)

Actsoft / Hybrid Power Management (2024) — Describes an IoT-driven hybrid power management system that integrates solar and AC sources with cloud monitoring, focusing on seamless source switching and load prioritization for distributed sites. Experimental results show improved supply reliability. (actsoft.org)

IJRPR / Solar Wireless EV Charging (review), 2024 — Reviews prior research on solar energy integration for EV charging and surveys wireless charging approaches, noting advantages and gaps for real-world scalable deployments. The paper recommends research directions for PV-coupled dynamic charging. (IJRPR)

Wiley / Charging Station Design (2024) — Investigates a hybrid PV–diesel–battery configuration for EV charging stations with case studies that analyze emissions, costs, and reliability across scenarios. The study

gives practical guidelines on when hybridization is economically justified. (Wiley Online Library)

IJARCCCE / solar EV charging with IoT (2024) — Presents prototype designs that integrate solar PV, MPPT, energy storage and IoT-enabled dashboards; includes user authentication via RFID and basic billing integration for public charging stations. The paper emphasizes modularity for incremental deployment. (Peer-reviewed Journal)

MDPI / Smart IoT SCADA for Hybrid Power (Waqas et al.), 2024 — Proposes an open-source IoT-SCADA architecture for hybrid power monitoring that can be applied to remote charging stations, offering realtime control, alarms, and historical logging. The platform supports distributed monitoring of PV and generator-fed stations. (MDPI)

IRJMETS / Smart Solar EV with ESP32 (2025) — Details a modern ESP32-based solar EV charging design that integrates MPPT controllers, battery management and IoT telemetry for remote monitoring and user interaction. The implementation stresses low-cost scalability for small retail points. (IRJMETS)

Semanticscholar / Smart fuel dispenser with RFID (Chandana), 2023 — Implements an IoT-enabled fuel dispenser using RFID for cashless payment, cloud logging for inventory, and remote alerts for low stock; discusses security and transaction integrity challenges. This work is directly relevant for hybrid stations combining fuel and EV services. (Semantic Scholar)

IJARSCCT / Portable EV charger w/ IoT, 2024 — Proposes a portable EV charging station with IoT connectivity, suitable for temporary or low-infrastructure locations; includes telemetry for charge sessions and remote control for operators. The study

shows practicality for rural or event-based deployments. (IJARSCT)

IJRPR / solar EV review (2024) — Surveys solar-powered EV charging prototypes and identifies common elements: MPPT, battery buffering, IoT telemetry, and simple user interfaces. The review notes that many prototypes still lack robust commercial-grade power electronics. (IJRPR)

IJDNE / PV-biogas hybrid for EV charging (2024) — Evaluates PV-biogas hybrid power plants to reliably supply EV charging in urban Indonesian contexts, analyzing economic and reliability metrics for combined renewables. The paper shows hybrid renewables can improve uptime where solar alone is intermittent. (IIETA)

ScienceDirect / solar multifunction portable charger (2025) — Presents a solar-powered multi-functional portable charger design with IoT monitoring and flexible outputs, highlighting MPPT and battery management techniques useful for small-scale EV accessories and DC loads. The paper contributes portable-system design insights. (ScienceDirect)

IRJMETS / recent solar-ESP32 case (2025) — Shows a compact, MPPT-enabled ESP32-based charging controller with cloud telemetry and basic user authentication; demonstrates real-time energy accounting suitable for kiosk-style chargers. The paper emphasizes firmware-level energy metering accuracy. (IRJMETS)

IJESR / IoT hybrid dispenser system (2024) — Proposes a hybrid self-fuel dispense system with integrated EV booking and IoT inventory telemetry, discussing operational workflows, basic control logic, and cloud-based dashboards for station managers. The study emphasizes coordinated operations to avoid service conflicts. (ijesr.org)

MDPI/Sustainability (optimal hybrid design), 2019 — Provides a rigorous methodology for optimally designing microgrids to support EV charging (including hybrid loads), including scenario-based optimization for storage and renewable sizing. The approach remains widely cited for hybrid station planning. (MDPI)

ResearchGate / practical PV EV station (2023) — Details a PV-charged EV station prototype with IoT monitoring and MPPT integration, reporting field results on energy yield and charge session performance. The study highlights the importance of demand-side scheduling to maximize PV usage. (ResearchGate)

IJRPR / case studies and reviews (2024) — Compiles numerous prototype efforts on solar EV charging and notes that ESP32-based solutions are increasingly popular for low-cost telemetry, while power-conversion hardware still needs robust industrialization. The paper recommends standards alignment for interoperability. (IJRPR)

3. EXISTING SYSTEM

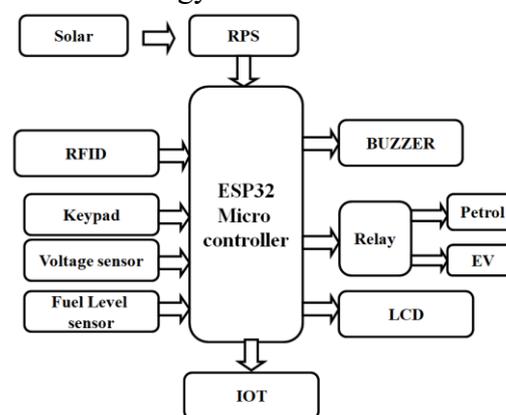
Existing systems for solar-powered EV and fuel dispenser stations generally rely on independent infrastructure where solar charging, fuel dispensing, and energy management operate as separate units without centralized intelligence or automation. Most traditional EV charging stations still depend heavily on grid power, offering limited integration of renewable sources and lacking smart control features such as dynamic load balancing or real-time energy analytics. Similarly, fuel dispenser stations use conventional mechanical or semi-electronic meters with minimal digital monitoring, making them dependent on manual supervision for billing, safety

checks, and tank-level inspection. Existing solar-powered systems that do incorporate photovoltaic modules often do so in a basic manner, using standalone charge controllers without advanced MPPT algorithms or IoT-based oversight, resulting in suboptimal energy harvesting and poor operational efficiency. Remote monitoring is rarely implemented, and when present, it typically uses outdated technologies that cannot support real-time data upload, predictive maintenance, or continuous safety diagnostics. Most stations also lack integrated user authentication mechanisms such as RFID, app-based access, or automated billing systems, creating inefficiencies in multi-user environments. There is generally no unified architecture that combines solar power generation, EV charging control, fuel dispensing sensors, and cloud connectivity into a single smart platform, leading to high operational costs, increased human intervention, and reduced reliability during peak usage. The absence of microcontroller-based automation, predictive analytics, and hybrid energy management results in delayed fault detection, poor energy utilization, and limited scalability, making existing systems inadequate for the rapidly growing demand for clean, efficient, and intelligent energy-dispensing solutions.

4. PROPOSED SYSTEM

The proposed system introduces a fully integrated solar-powered EV and fuel smart hybrid dispenser station controlled by an ESP-32 microcontroller, combining renewable energy generation, automated dispensing, and intelligent monitoring into a single unified platform. Solar panels supply primary power, while the ESP-32 manages MPPT-based energy optimization, battery storage control,

and seamless switching between solar and auxiliary sources to ensure uninterrupted operation. The station incorporates sensors for fuel level, flow rate, voltage, current, temperature, and safety monitoring, all connected to the ESP-32 for real-time data acquisition and processing. A cloud-enabled IoT interface provides live status updates, energy analytics, fault detection, and remote control through web or mobile dashboards, giving operators full visibility and management capabilities from any location. The system also includes secure user authentication through RFID or mobile app integration, allowing automated billing, transaction logging, and personalized access. In the EV charging section, smart energy management dynamically adjusts charging rates according to solar generation, battery availability, and usage demand, ensuring maximum renewable utilization. For fuel dispensing, the ESP-32 precisely regulates pump operation, monitors tank levels, and triggers instant alerts for low fuel, leakage, or abnormal conditions. By merging EV charging and fuel distribution into a solar-powered, IoT-driven intelligent station, the proposed design offers high efficiency, reduced operational costs, enhanced reliability, and improved user experience, providing a scalable solution for future smart energy infrastructure.



Block diagram explanation

The block diagram illustrates a solar-powered smart hybrid EV and fuel dispenser station

controlled by an ESP32 microcontroller, which serves as the central processing unit for all inputs and outputs. Solar energy is first converted into a regulated voltage through a regulated power supply (RPS) to power the system. Various input modules, including an RFID reader, a keypad, a voltage sensor, and a fuel level sensor, provide real-time data to the ESP32, enabling secure user authentication, manual command inputs, voltage monitoring, and fuel inventory tracking. Based on the processed information, the ESP32 controls multiple output modules: a buzzer for alerts, a relay system to switch between petrol and EV dispensing, and an LCD to display relevant information to users and operators. Simultaneously, the system connects to an IoT platform to transmit live operational data, monitor energy usage, track dispensed fuel and electricity, and provide remote control capabilities. The integration of sensors, user interface modules, power management, and IoT connectivity allows the station to operate efficiently, ensure safety, automate billing, and provide a seamless hybrid energy dispensing experience.

4. RESULTS

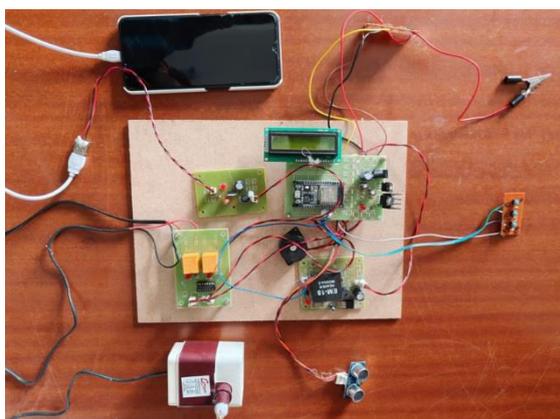


Fig. 3: Hardware prototype of the proposed multi-purpose fuel dispenser and EV charging system.

The figure shows the complete hardware implementation consisting of an Arduino controller, EM-18 RFID reader, relay modules for fuel pump and EV charger control, 4x4 keypad, buzzer, and a 16x2 LCD. The prototype validates successful integration of authentication, control, and dispensing modules



Fig.4: LCD display during system Initialization

The LCD displays the system startup message, indicating proper power supply, controller operation, and readiness for RFID authentication and user input.



Fig.5: LCD display showing successful user authentication

The figure illustrates the confirmation message displayed after a valid RFID card is detected and the correct password is entered, verifying correct operation of the authentication mechanism.

S.No	Fuel Dispenser System	Level status	Voltage	Date
1		U:812Low_Lvl	NormalVolt10.96	2026-02-02 13:38:22
2	Invalid_Card	U:1170Normal_Lvl	NormalVolt10.96	2026-02-02 13:38:37
3		U:568Low_Lvl	NormalVolt10.96	2026-02-02 13:37:39
4		U:568Low_Lvl	NormalVolt0.97	2026-02-02 13:27:17
5		U:222Low_Lvl	NormalVolt0.99	2026-02-02 13:27:04
6		U:568Low_Lvl	LowVolt0.00	2026-02-02 13:26:37
7		U:568Low_Lvl	LowVolt0.00	2026-02-02 13:25:35
8			LowVolt0.00	2026-02-02 13:25:27
9		U:377Low_Lvl	LowVolt0.00	2026-01-28 18:38:43
10		U:377Low_Lvl	LowVolt0.00	2026-01-28 18:38:27
11			LowVolt0.00	2026-01-28 18:38:15
12		U:2066Low_Lvl	NormalVolt11.00	2026-01-28 18:16:41
13		U:2077Low_Lvl	NormalVolt11.00	2026-01-28 18:15:02
14	Card2PetrolWrong_Pwd	U:448Low_Lvl	NormalVolt11.36	2026-01-28 17:55:05
15		U:448Low_Lvl	NormalVolt11.36	2026-01-28 17:54:00
16	Card2PetrolWrong_Pwd	U:2Normal_Lvl	NormalVolt11.36	2026-01-28 17:53:52
17		U:422Low_Lvl	NormalVolt11.37	2026-01-28 17:52:28
18		U:45Low_Lvl	LowVolt0.00	2026-01-28 17:50:13
19		U:398Low_Lvl	LowVolt0.00	2026-01-28 17:49:23
20			LowVolt0.00	2026-01-28 17:49:16

Fig.6: IoT server interface for real-time monitoring

The IoT web interface displays real-time system data including fuel dispenser status, fuel level, voltage condition, and timestamp, confirming successful data transmission to the cloud.

6. CONCLUSION

The “Solar Powered EV/Fuel Smart Hybrid Dispenser Station using ESP32 Controller” presents a sustainable and intelligent solution to meet the evolving demands of modern transportation infrastructure. As the global shift toward electric vehicles accelerates alongside the continued use of conventional fuel-based vehicles, the need for hybrid refueling stations that can efficiently support both energy sources becomes increasingly important. This project successfully demonstrates the integration of renewable energy, embedded systems, and IoT technologies into a single automated platform capable of managing EV charging and fuel dispensing operations. By utilizing solar energy as the primary power source, the system significantly reduces dependence on conventional grid electricity and fossil fuels, contributing to environmental conservation and energy sustainability. The regulated power supply ensures stable and reliable

operation of all components, even under fluctuating solar conditions. The ESP32 microcontroller acts as a powerful and flexible control unit, enabling seamless coordination between RFID-based user authentication, keypad input, sensor monitoring, relay-based switching, and IoT communication. This centralized control enhances system reliability, scalability, and ease of implementation.

The inclusion of RFID authentication improves security by allowing only authorized users to access charging or fueling services, while sensors continuously monitor voltage levels and fuel availability to ensure safe and efficient operation. Real-time data display on the LCD and audible alerts through the buzzer improve user interaction and system transparency. Furthermore, IoT integration enables remote monitoring, data logging, and system diagnostics through a cloud platform, allowing operators to track energy usage, operational status, and performance metrics in real time.

Overall, the proposed hybrid dispenser station offers an innovative approach to future vehicle refueling infrastructure by combining automation, renewable energy utilization, and smart connectivity. The system is particularly suitable for smart cities, highways, campuses, and remote areas where reliable grid power may be limited. Future enhancements may include mobile application integration, payment gateway support, fast-charging modules, and AI-based energy management to further optimize performance. This project demonstrates a practical, eco-friendly, and scalable solution that aligns with global goals for sustainable transportation and green energy adoption.

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