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IoT-Based Smart Electrical Load Monitoring and Control System

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Abstract: *Electrical loads are often operated without continuous information about voltage, current, energy use or unsafe operating conditions. This paper proposes an Internet of Things (IoT)-based smart electrical load monitoring and control system that measures electrical parameters, estimates energy consumption, provides a mobile-accessible monitoring interface and allows authorized users to switch connected loads remotely. A controller receives data from suitable voltage and current sensing circuits, calculates power and accumulated energy, and communicates readings through a wireless network. When measured current or power exceeds a configured safe threshold, the controller can disconnect a load through an appropriately rated switching device and notify the user. The architecture is divided into four modules: user dashboard, sensing and data acquisition, processing and cloud communication, and load control and protection. The proposed system aims to improve visibility of consumption, simplify device management and support safer operation. Performance evaluation is planned; no measured results are claimed in this manuscript.*

Key Word: *Internet of Things (IoT), Smart Energy Monitoring, Voltage Sensor, Current Sensor, ESP32, Remote Load Control, Overload Protection, Energy Consumption*

I.INTRODUCTION

Electricity powers lighting, appliances and industrial equipment, but conventional switching systems give users limited information about consumption and electrical operating conditions. Manual readings can miss unusual load behavior and make it difficult to identify unnecessary energy use. An IoT-based monitoring system can combine sensing, embedded processing and a mobile interface to make electrical measurements more accessible.

The proposed system monitors voltage and current, estimates real-time power and energy consumption, and enables remote switching of connected electrical loads. It also compares measurements against configured limits and provides a protective response when an overload is detected. The design focuses on modularity, understandable user feedback and safe electrical integration.

The paper is organized into literature review, methodology, expected benefits and evaluation plan, and conclusion, following the section sequence of the supplied sample paper.

II. LITERATURE REVIEW

Smart metering research has established the value of digital measurements and two-way communication for improved visibility of electricity consumption [1]. IoT architecture studies describe how sensors, network links and application services can be combined to monitor physical systems remotely [2]. ESP32 technical documentation describes a Wi-Fi-enabled microcontroller platform suitable for connected embedded prototypes [3]. Energy-measurement design must also consider accuracy, calibration and safe isolation of the sensing circuit [4].

Research gap: Basic energy meters often provide only local readings, while simple remote switches may not monitor energy or respond automatically to abnormal loading. The proposed academic design brings monitoring, remote control, consumption tracking and overload response into a single prototype architecture. This is a design objective, not a claim that no existing product offers these functions.

III. METHODOLOGY

The proposed workflow is shown in Fig. 1. Electrical sensors collect readings from the monitored circuit. The microcontroller processes the values, sends updates to an IoT service and receives authenticated switching commands. A protection rule can override remote control and disconnect the load if unsafe thresholds are reached.

AC supply + monitored load	Voltage and current sensing
Microcontroller (ESP32 or equivalent)	Power / energy calculation + threshold check
Wi-Fi / IoT service	Mobile dashboard and alerts
Relay / contactor driver	Load ON/OFF and overload isolation

Fig. 1. Functional block-flow summary of the proposed monitoring and control system.

Module	Function	Possible tools/components
1. Dashboard	Live readings, trends, control buttons, alerts	Mobile/web UI, IoT dashboard
2. Sensing	Voltage and current measurement	Isolated sensor modules, ADC
3. Processing and connectivity	Compute values, send readings, handle commands	ESP32, Wi-Fi, MQTT/HTTPS
4. Control and protection	Switch loads, enforce overload threshold	Rated relay/contactor, driver, fuse/breaker

Table I. Summary of the four proposed modules.

A. Module 1: User Dashboard

The dashboard displays live voltage, current, estimated power, accumulated energy and load status. It can show basic history, user-defined warning limits and notification messages. Authorized users can request ON/OFF actions; the interface should clearly show when a safety lockout prevents switching.

B. Module 2: Electrical Parameter Sensing

Suitable isolated voltage and current sensors provide measurements to the controller. The circuit requires sensor calibration, filtering and appropriate sampling. Electrical wiring, isolation, protective earthing and enclosure design must be reviewed by a qualified supervisor; mains connections are not part of an unsupervised student procedure.

C. Module 3: Processing, Energy Calculation and IoT Communication

The microcontroller samples sensor values, calculates estimated real power where appropriate and accumulates energy over time. For simplified loads, apparent power is V_rms × I_rms; actual real power also depends on power factor. Energy in kWh is the sum of power in kW multiplied by each sample interval in hours. Readings may be sent to a dashboard over Wi-Fi using a secured IoT protocol. Offline conditions should be indicated and protective operation should not depend on cloud connectivity.

$$P = V_{rms} \times I_{rms} \times PF \quad (1)$$

$$E\ (kWh) = \Sigma\ [P_i\ (W) \times \Delta t_i\ (hours)] / 1000 \quad (2)$$

D. Module 4: Load Control and Overload Protection

A suitably rated switching stage receives control requests from the controller. If the sensed current exceeds a validated threshold for the configured duration, the controller commands the load to disconnect and records an alert. Hardware protection such as a properly rated fuse or circuit breaker remains essential: software-controlled relays must not be treated as replacements for certified electrical safety devices. Reconnection should follow a safe reset policy.

IV. EXPECTED BENEFITS AND EVALUATION PLAN

A. Expected Benefits

- Remote visibility of electrical operating parameters and estimated consumption.
- Convenient switching of supported loads through a mobile interface.
- Timely alerts and protective shutdown for configured overload conditions.
- Historical usage information to support energy-saving decisions.

B. Planned Evaluation

- Compare voltage and current readings against calibrated reference instruments across safe test conditions.
- Measure energy-estimation error for representative loads over a known duration.
- Record dashboard update delay and remote switching response time.
- Test overload detection and safe shutdown using supervised, low-risk test setups.
- Check behavior during Wi-Fi interruption, power restart and invalid control requests.

C. Feasibility and Limitations

The prototype can be built from commonly available embedded and sensing components, but sensor choice,

electrical isolation, relay ratings, network reliability and secure authentication affect practical performance. A single-phase prototype does not automatically generalize to three-phase installations. Without calibration and testing, the design should not be described as a certified billing meter or protective device.

V.CONCLUSION

This paper presents a proposed IoT-based smart electrical load monitoring and control system integrating electrical sensing, embedded calculations, networked visualization, remote switching and overload response. Its four-module architecture is intended to make monitoring easier and improve awareness of energy use while maintaining hardware-level electrical protection. Future work includes prototype validation, better power-factor measurement, usage analytics, multiple-load support and more reliable offline data storage.

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