A Synopsis Report
on

Design of Smart Energy Meter for Home Automation

Submitted in Partial Fulfillment of the Requirements
for the 5th Semester Mini Project

Bachelor of Technology
In
Electrical Engineering

by

Project Group Code: PGEE33

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Abstract

The proposed project, *"Design of Smart Energy Meter for Home Automation"*, focuses on developing an intelligent and automated energy monitoring system that integrates Internet of Things (IoT) technology with embedded hardware for efficient power management. The objective is to design a system capable of real-time measurement, analysis, and wireless communication of household electrical parameters such as voltage, current, power, and energy consumption.

The core of the system is the PZEM-004T energy meter module, which accurately senses AC parameters and transmits them via the UART (Universal Asynchronous Receiver/Transmitter) to an ESP32 microcontroller. The ESP32 acts as the processing and communication unit, providing Wi-Fi-based connectivity to relay live data to a mobile or cloud interface. The OLED display provides an on-site visual representation of instantaneous values, while a Current Transformer (CT) ensures safe and isolated current measurement.

The system architecture emphasizes safety, low cost, scalability, and user convenience. With seamless integration between hardware and software. The prototype thus transforms the conventional metering system into a smart, automated, and data-driven solution aligned with modern home automation trends.

This project not only bridges the gap between traditional metering and IoT-based monitoring but also demonstrates the potential of embedded systems. The implementation paves the way for smart grid compatibility, predictive energy analytics, and future enhancements in automated power distribution.

Problem Statement:

In most households and small-scale industries, energy consumption is monitored using traditional analog or digital meters that require manual reading and provide only cumulative energy data. Such meters lack real-time monitoring, data storage, or remote accessibility, which are essential for efficient energy management.
The absence of intelligent communication and automation results in delayed fault detection, inefficient usage patterns, and increased energy wastage. Furthermore, there is no immediate way for users to visualize how much power individual appliances consume at any given time.

As energy demand continues to rise, it becomes increasingly important to adopt smarter and more sustainable methods of energy usage. This project addresses these issues by developing a Smart Energy Meter that integrates IoT capabilities to monitor, analyze, and communicate energy data in real-time. The system aims to empower users with actionable insights, remote accessibility, and automation, leading to optimized energy utilization.

Objectives of the Project:

The primary aim of this project is to design and implement a reliable, IoT-enabled energy monitoring system capable of collecting, processing, and transmitting energy data efficiently.
The specific objectives are as follows:

1. To design and develop a smart energy meter capable of accurately measuring voltage, current, active power, power factor, and total energy consumption in real-time.
2. To implement wireless communication between the energy meter and a user interface (mobile or web dashboard) using the ESP32 microcontroller and built-in Wi-Fi module.
3. To integrate an OLED display for on-site visualization of real-time energy parameters, ensuring easy user accessibility without external devices.
4. To enhance electrical safety and energy efficiency by employing a Current Transformer (CT) for current isolation and by monitoring power factor variations to prevent overloads.

Methodology:

The methodology adopted for the design and implementation of the Smart Energy Meter for Home Automation is based on an integrated hardware–software framework. The project combines the precision of embedded hardware components with the flexibility of IoT-based data communication. The proposed system measures, processes, and transmits real-time electrical parameters, enabling users to monitor and manage energy consumption effectively.

1. System Overview

The Smart Energy Meter is designed as a modular system consisting of five major functional blocks:

1. Power Supply Unit (PM01 AC–DC Converter)
2. Sensing and Measurement Unit (PZEM-004T Energy Meter Module and Current Transformer)
3. Control and Processing Unit (ESP32 Microcontroller)
4. Display Unit (OLED Display)
5. Communication and Data Transmission Unit (Wi-Fi Interface)

Each module plays a specific role in achieving precise measurement, data acquisition, and remote monitoring.

2. Hardware Design

a. PM01 AC–DC Converter

This converter acts as the power supply module for the system. It converts 230V AC mains power into a stable 5V DC output required by the ESP32 and PZEM-004T modules. The conversion process includes:

1. Rectification: AC power is converted to pulsating DC using diodes.
2. Filtering: Capacitors smooth out voltage ripples.
3. Regulation: The voltage is maintained at a constant 5V DC using internal regulation circuits. This ensures reliable and noise-free operation of the microcontroller and sensors.

b. PZEM-004T Energy Meter Module

The PZEM-004T is the core sensing component of the system. It continuously measures AC voltage, current, active power, power factor, and energy consumption using internal sensing circuits.

1. It uses a voltage divider network to measure AC voltage and a CT and Burden Resistor for current measurement.
2. The data is stored in internal registers and transmitted via UART, which ensures accurate and noise-immune data transfer to the ESP32 controller.

c. Current Transformer (CT)

The Current Transformer is used to safely measure high AC currents. It operates on the principle of electromagnetic induction**.**

1. The primary winding carries the line current.
2. The secondary winding produces a proportional current at a reduced level suitable for measurement by the PZEM-004T module.
   This setup provides isolation and safety between the high-voltage circuit and the low-voltage control electronics.

d. ESP32 DevKit Microcontroller

The ESP32 serves as the brain of the entire system. It performs the following functions:

- Communicates with the PZEM-004T using UART for real-time data acquisition.
- Processes incoming data to calculate energy usage patterns and instantaneous values.
- Controls the OLED display to show local readings.
- Connects to a Wi-Fi network to transmit data to a cloud platform or mobile interface for remote monitoring.

The ESP32 features a dual-core processor, integrated Wi-Fi and Bluetooth capabilities, multiple ADC channels, UART ports, and enabling easy integration of libraries for Modbus communication and OLED interfacing.

e. OLED Display (0.96" I²C)

The OLED (Organic Light-Emitting Diode) display provides a high-contrast, low-power method to visualize data.
It displays instantaneous voltage, current, power, and energy readings in a user-friendly format. Unlike LCDs, OLEDs do not require a backlight, which makes them efficient and compact. The display communicates with ESP32 using the I²C interface.

Tools and Technologies Used

Tool / Component	Purpose / Function
ESP32 DevKit	Microcontroller for processing and Wi-Fi communication
PZEM-004T Module	Measurement of AC parameters using UART
Current Transformer (CT)	Safe current measurement through electromagnetic induction
OLED Display (I²C)	Real-time data display
PM01 AC–DC Converter	Stable DC power supply

Block Diagram

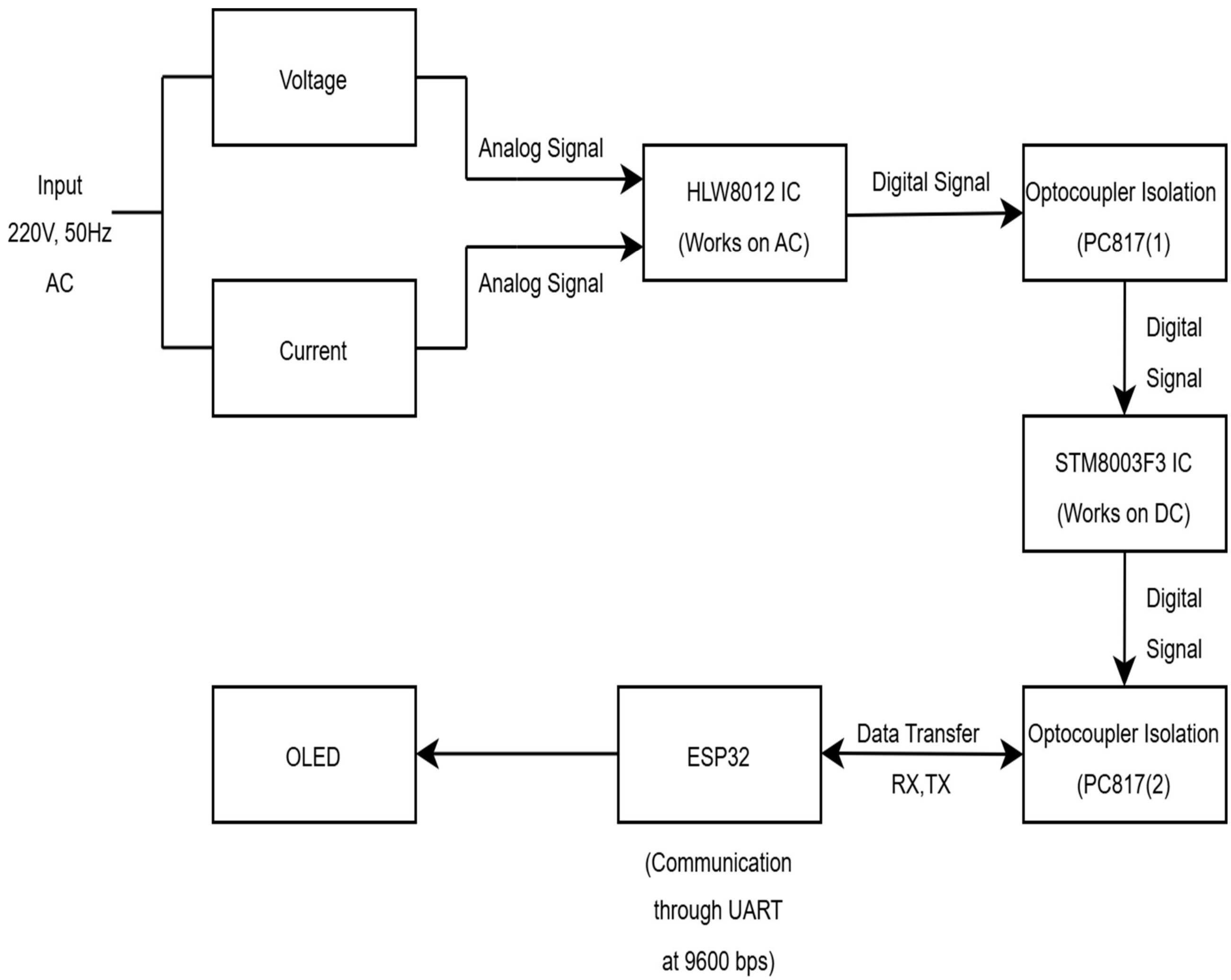


Figure 1: Block Diagram of Smart Energy Meter

Work Plan:

The implementation of the Smart Energy Meter for Home Automation project was carried out through a series of systematic stages, combining both hardware and software development. Each stage was carefully planned to ensure proper synchronization between design, testing, and performance evaluation. The entire process can be divided into six major phases — from conceptual design to prototype validation.

Stage 1: Literature Review and Feasibility Study

The initial stage focused on conducting a comprehensive study of existing energy monitoring systems and related IoT applications. Research papers, online documentation, and open-source projects were analyzed to understand:

1. The limitations of conventional energy meters
2. Communication protocols such as UART
3. Sensor interfacing techniques and calibration methods
4. Available microcontrollers with built-in Wi-Fi (e.g., ESP8266**,** ESP32)

After comparing various designs, the ESP32-based PZEM-004T system was chosen for its flexibility, accuracy, and suitability for IoT-based energy monitoring.

Stage 2: System Design and Planning

In this phase, the entire system architecture was conceptualized. The block diagram, power supply configuration, and communication flow were designed on Breadboard.

Key design considerations included:

1. Ensuring safe isolation between high-voltage and low-voltage sections.
2. Minimizing power losses through efficient converter design.
3. Choosing an appropriate communication interface (UART) for data integrity.
4. Incorporating both local display (OLED) and remote data transmission (Wi-Fi).

A Gantt chart was also prepared to track the weekly progress of hardware assembly, coding, and testing activities.

Stage 3: Hardware Implementation

This stage involved assembling all the electronic components according to the designed circuit.

1. AC Supply (230V) was connected through the PM01 AC–DC Converter to provide a stable 5V DC output.
2. The Current Transformer (CT) was connected to the PZEM-004T module for safe current sensing.
3. The PZEM-004T was interfaced with the ESP32 microcontroller using UART communication lines (Tx/Rx and GND).

4. The OLED Display was interfaced with the ESP32 via I²C pins (SCL, SDA) to display real-time readings.

The hardware layout was later refined into a PCB design using Kicad software, enabling a compact and reliable prototype suitable for further expansion.

Stage 4: Testing and Validation

Once the hardware and software subsystems were integrated, the prototype was tested under controlled conditions. The setup involved connecting various loads such as:

Bulb 1 (60W)
Bulb 2 (15W)

During testing, parameters such as voltage, current, active power, and energy were measured simultaneously using both the Smart Energy Meter and a standard commercial energy meter for comparison.

The system exhibited a measurement accuracy within ±1% deviation from the reference meter, validating its effectiveness. Furthermore, the Wi-Fi-based data transmission was successfully verified using a smartphone dashboard, where live readings were updated every second.

Stage 5: Documentation and Demonstration

After successful testing, the final prototype was documented thoroughly. The circuit diagram, PCB layout, and flowchart were compiled for academic submission.
A live demonstration was conducted to show:

1. Real-time energy monitoring on the OLED display
2. Wireless data visualization through a connected device

This phase also involved creating comprehensive records of readings, wiring diagrams, and calibration data for inclusion in the final report.

Experimental Setup

The experimental setup was arranged on an insulated testing platform to ensure operator safety. The connections were made using male-female jumper wires and breadboards for prototyping. The ESP32 and OLED were mounted on a low-voltage section, isolated from the high-voltage sensing circuit of the PZEM and CT.

The entire setup included:

1. 230V AC input connected through a fuse and switch.
2. Load connected across the output of the PZEM module.
3. Data cables linking PZEM-004T and ESP32 through UART communication.
4. OLED display connected via I²C pins.

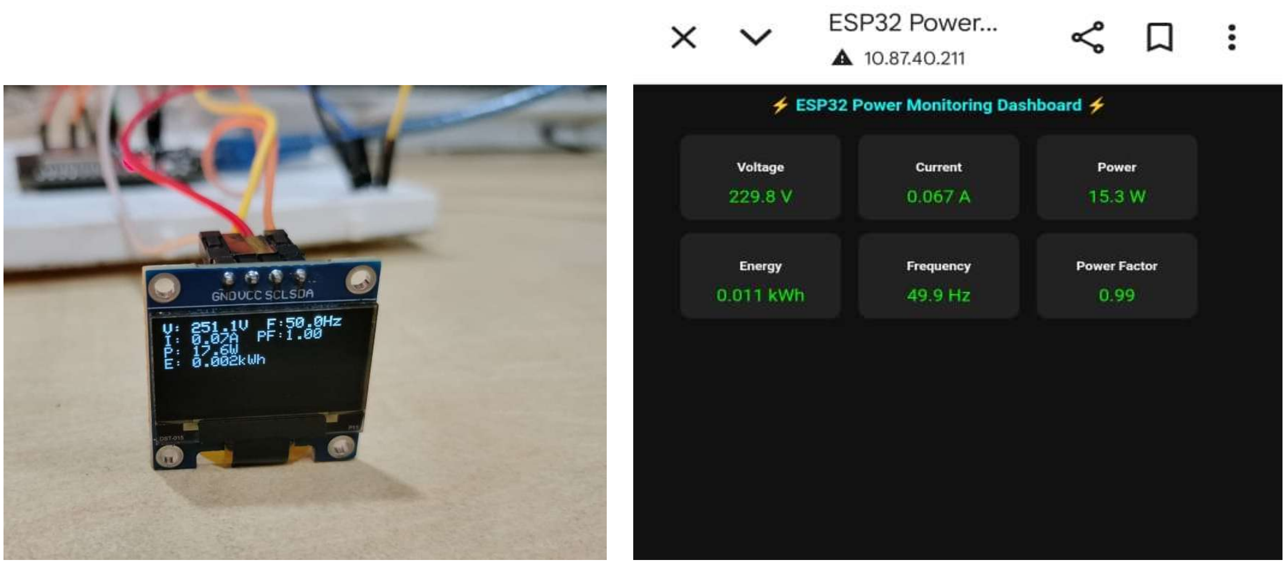
Each stage of implementation was validated with incremental testing — ensuring hardware safety, communication integrity, and accurate measurements before final integration.

Hardware Results:

The expected outcomes include:

1. Enhanced energy awareness and efficient power usage at the household level.
2. Real-time display and wireless accessibility of consumption data.
3. Reduction of manual meter reading and data-entry errors.
4. Scalability for multi-load or industrial energy monitoring.

Overall, the developed prototype demonstrates an accurate, and user-friendly approach to modern energy management and automation.



Picture1: Output of the Project

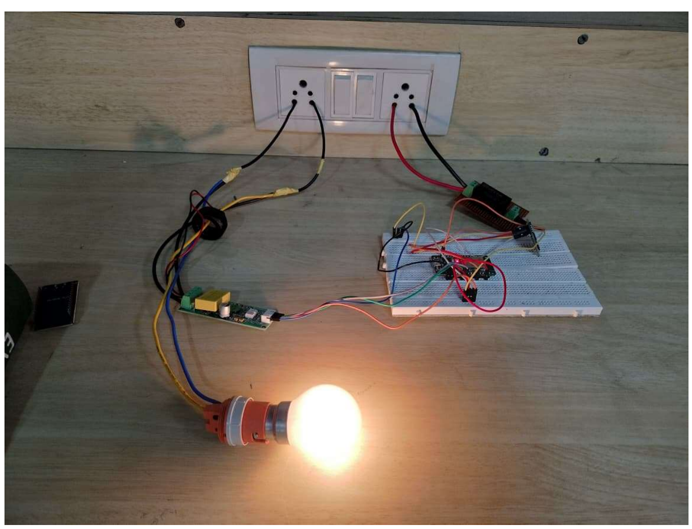


Figure 2: Working Condition of Project

Conclusion and Future Scope

This project concludes that the integration of IoT with energy measurement technology can revolutionize traditional electricity monitoring. The designed Smart Energy Meter successfully achieves accurate measurement, real-time data transmission, and local visualization in a compact and affordable setup. The project highlights the potential of embedded systems and wireless technologies to create energy-efficient and connected homes.

In the future, this system can be enhanced by:

1. Incorporating cloud-based data logging and analytics for long-term energy trend evaluation.
2. Adding smart load control features for automatic switching of appliances based on consumption thresholds.
3. Implementing mobile notifications and voice assistant integration for smart-home compatibility.
4. Extending the design to three-phase power systems and integrating with smart grids for large-scale deployment.

Thus, the Smart Energy Meter prototype serves as a stepping stone toward a fully automated, sustainable, and intelligent energy ecosystem.

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