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Blynk-Enhanced Wireless Smart Meter with Cloud Integrated Energy Management

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Abstract: The increasing demand for electrical energy and the need for efficient energy utilization have emphasized the importance of real-time electricity monitoring and management systems. Conventional electricity meters rely on manual readings, which are time-consuming, prone to human error, and lack real-time visibility of energy consumption. To overcome these limitations, this project presents the design and implementation of a Blynk-enhanced wireless smart energy meter with cloud-integrated energy management. The system utilizes an ESP32 microcontroller as the core processing unit, interfaced with a ZMPT101B voltage sensor and an SCT-013 current sensor to measure real-time electrical parameters such as voltage, current, power, and energy consumption accurately. The measured data is transmitted wirelessly to the Blynk cloud platform using Wi-Fi connectivity, enabling remote monitoring through mobile and web applications. Cloud integration ensures secure data storage, real-time visualization, and historical data analysis, allowing users to track consumption trends and make informed energy-saving decisions. Instant alerts and notifications further enhance system functionality by indicating abnormal power usage or system faults. The proposed system minimizes human intervention, improves billing accuracy, and promotes energy conservation. Its low-cost design, wireless operation, and user-friendly interface make it suitable for residential and small-scale industrial energy monitoring applications.

Keywords: Smart energy meter, IoT, ESP32, Blynk platform, cloud computing, energy management.

I. INTRODUCTION

This system is designed as an efficient and intelligent smart energy monitoring solution that enables real-time measurement and management of electrical energy consumption using Internet of Things (IoT) technology, thereby reducing manual intervention and improving billing accuracy [1]. The proposed system employs an ESP32 microcontroller integrated with a ZMPT101B voltage sensor and an SCT-013 current sensor to accurately measure electrical parameters such as voltage, current, power, and energy consumption. The measured data is transmitted wirelessly to the cloud through Wi-Fi connectivity, ensuring continuous monitoring and remote accessibility [2]. The entire system is monitored through a Blynk-enabled mobile application, allowing users to remotely visualize live energy data, track historical consumption trends, and receive instant alerts for abnormal power usage [3]. The ESP32 microcontroller functions as the central processing unit of the system, processing sensor data, performing power and energy calculations, and coordinating wireless communication with the cloud platform in real time. The smart energy meter is designed to be compact, reliable, and user-friendly, making it suitable for applications such as residential buildings, educational institutions, and small-scale industrial environments [4]. The design emphasizes accuracy, ease of operation, and minimal maintenance. Key advantages of the proposed system include automated energy monitoring, remote accessibility, improved energy awareness, and cost-effective implementation.

II. LITERATURE REVIEW

A. IoT-Based Smart Energy Metering Systems

- Several studies have proposed IoT-based smart energy meters using microcontrollers and electrical sensors to measure voltage, current, power, and energy consumption in real time.
- These systems focus on automating meter readings, reducing human errors, and improving billing accuracy compared to traditional manual metering systems.

B. Wireless Energy Monitoring Technologies

- Wireless communication technologies such as Wi-Fi, GSM, and Bluetooth have been integrated with smart meters to enable remote energy monitoring.
- These systems allow real-time data transmission to cloud platforms, ensuring uninterrupted monitoring without physical access to the meter.

C. ESP32-Based Smart Meter Implementations

- Various research works utilize the ESP32 microcontroller due to its built-in Wi-Fi capability, low power consumption, and high processing speed.
- ESP32-based smart meters demonstrate reliable data acquisition, real-time cloud connectivity, and cost-effective implementation.

D. Voltage and Current Sensing Techniques

- Several studies discuss the use of voltage and current sensors such as ZMPT101B and SCT-013 for accurate and safe measurement of AC electrical parameters.
- These sensors provide electrical isolation and high accuracy, making them suitable for household and industrial energy monitoring applications.

E. Cloud-Integrated Energy Management Systems

- Research highlights the importance of cloud computing in smart energy systems for secure data storage and advanced analytics.
- Cloud-based platforms enable historical data analysis, consumption trend visualization, and remote access to energy usage information.

F. Mobile Application-Based Energy Monitoring

- Mobile applications have been widely used to display real-time energy consumption data through graphical interfaces and dashboards.
- Such applications improve user awareness, provide instant notifications, and support better energy-saving decisions.

G. Blynk-Based Smart Meter Solutions

- Several studies employ the Blynk IoT platform to visualize energy parameters using widgets such as gauges, graphs, and alerts.
- Blynk simplifies IoT application development and enables fast deployment of real-time energy monitoring systems.

H. Automated Billing and Energy Awareness Systems

- Research has focused on integrating smart meters with automated billing systems to reduce billing delays and eliminate manual calculations.
- These systems improve transparency and help users understand their electricity consumption behaviour.

I. Energy Monitoring During Emergency Situations

- Studies conducted during pandemic conditions highlight the limitations of manual meter readings and emphasize the need for contactless smart meters.
- IoT-enabled energy meters ensure uninterrupted monitoring and billing during restricted access scenarios.

J. Low-Cost Smart Energy Meter Designs

- Several works propose low-cost smart meter designs using open-source hardware and software platforms.
- These designs aim to make smart energy monitoring affordable for residential users and small-scale industries.

III. TOOLS AND TECHNOLOGIES

A. *Architecture*

The architecture of the proposed smart energy meter is designed using a modular hardware–software framework to ensure accurate energy measurement, reliable communication, and efficient data management. The system architecture consists of the following components:

1. Power Architecture
   - o The system is powered using a regulated AC–DC power supply module that converts 230V AC mains into required DC levels.
   - o A regulated 5V and 3.3V supply is provided to the ESP32 microcontroller, voltage sensor, current sensor, and peripheral modules.
2. Control Architecture
   - o The ESP32 microcontroller serves as the central processing unit of the system.
   - o It acquires real-time analog signals from the voltage and current sensors.

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- The microcontroller performs calculations for voltage, current, power, and energy consumption.

3. Sensing Architecture
   - ZMPT101B voltage sensor is used to measure AC mains voltage with electrical isolation.
   - SCT-013 current sensor measures load current in a non-invasive manner.
4. Communication Architecture
   - Wi-Fi communication is used to transmit measured energy data to the cloud.
   - The ESP32 connects to the Blynk cloud platform for real-time data synchronization.
5. System Integration Architecture
   - Integration of sensing, processing, cloud communication, and user interface modules
   - Ensures real-time monitoring, remote accessibility, and reliable energy data management.

This architecture enables accurate, wireless, and cloud-integrated smart energy monitoring suitable for modern energy management applications.

B. *Compilation*

In embedded system development, compilation refers to converting the application program into executable machine-level instructions for the microcontroller. The compilation process for the smart energy meter includes:

- Writing the embedded program using Arduino IDE in Embedded C/C++.
- Verifying the program for syntax errors, logical correctness, and timing constraints.

The compiled program performs the following functions:

- Reading analog voltage and current sensor data
- Calculating RMS voltage, RMS current, power, and energy
- Transmitting data to the Blynk cloud platform
- Updating real-time values on mobile and web dashboards

The compiled firmware is uploaded to the ESP32 using USB, enabling the hardware to execute real-time energy.

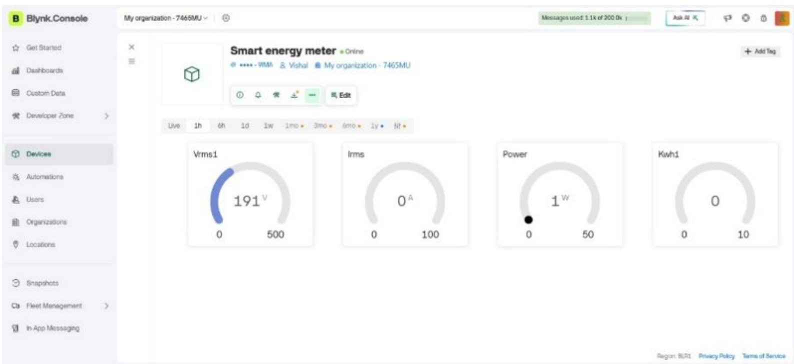

Fig1: Blynk Web Application

C. *Training*

Although the system does not involve machine learning or artificial intelligence, the concept of "training" is interpreted as system calibration and parameter tuning to ensure measurement accuracy and reliability. This includes:

1. Voltage Sensor Calibration
   - Adjusting calibration constants for accurate RMS voltage measurement.
   - Verifying readings under different supply voltage conditions.
2. Current Sensor Calibration
   - Calibrating SCT-013 sensor output for accurate current measurement.
   - Testing performance under varying load conditions.
3. Power and Energy Calibration
   - Verifying power calculations using the relation $P = V \times I$.
   - Ensuring accurate energy accumulation over time.
4. Wi-Fi and Cloud Communication Testing
   - Ensuring stable connectivity between ESP32 and Blynk cloud.
   - Eliminating data transmission delays or packet loss.
5. System Stability Testing
   - Monitoring long-term operation for consistent performance.
   - E Ensuring reliable data storage and retrieval.

Through repeated calibration and testing, the system achieves optimal performance, accuracy, and operational reliability.

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D. *Deployment*

System deployment involves integrating hardware and software components into a fully functional smart energy monitoring unit. Deployment steps include:

1. Hardware Assembly
   - Mounting ESP32, sensors, power supply module, and display on a secure platform.
2. Electrical Connections
   - Proper wiring of voltage and current sensors with AC supply and load.
3. Firmware Uploading
   - Uploading the compiled program to the ESP32.
4. Functional Testing
   - Verification of voltage, current, power, and energy readings.
   - Testing real-time data visualization on Blynk application.
5. Field Deployment
   - Testing the system under real household or industrial load conditions.

After deployment, the system enables continuous and remote energy monitoring through cloud-connected applications.

E. *Evaluation*

System evaluation assesses the performance and effectiveness of the developed smart energy meter. The evaluation is based on the following criteria:

1. Measurement Performance
   - Accuracy of voltage and current measurement
   - Stability of power and energy calculations
2. Communication Performance
   - Reliable Wi-Fi connectivity
   - Real-time cloud data updates
3. Energy Monitoring Efficiency
   - Accurate energy accumulation (kWh)
   - Long-term monitoring capability

IV. SYSTEM IMPLEMENTATION

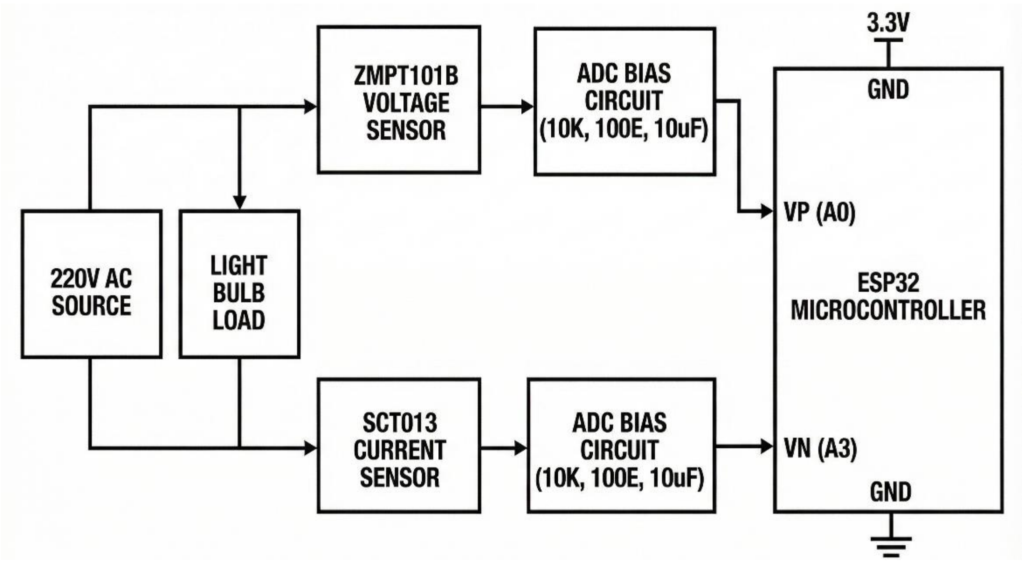

Fig 2: Functional block diagram

The system implementation involves integrating the voltage and current sensing unit, embedded processing unit, power supply module, and cloud-based communication interface into a functional smart energy monitoring system capable of measuring and transmitting real-time electrical parameters.

A. Power Supply and Energy Interface

The system operates using a regulated AC–DC power supply connected to the 230V AC mains. The power module converts the mains voltage into regulated 5V and 3.3V DC outputs required for system operation. The ESP32

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microcontroller operates at 3.3V, while peripheral components such as sensors and display modules are powered through regulated supply lines. This power architecture ensures stable operation of all electronic components and protects the system from voltage fluctuations.

B. Voltage and Current Sensing System

Electrical parameters are measured using dedicated sensing modules interfaced with the AC supply and load. The ZMPT101B voltage sensor is connected in parallel with the AC mains to measure supply voltage while providing electrical isolation. The SCT-013 current sensor is clamped around the live wire to measure load current in a non-invasive manner. Both sensors generate analog signals proportional to the measured electrical quantities, enabling safe and accurate data acquisition.

C. Embedded Processing and Computation Unit

An ESP32 microcontroller functions as the core processing unit of the system. The analog outputs from the voltage and current sensors are sampled through the ESP32's ADC channels. The microcontroller processes the sampled data to compute RMS voltage, RMS current, instantaneous power using the relation $P = V \times I$, and total energy consumption expressed in kilowatt-hours (kWh). The processing ensures accurate real-time monitoring and reliable energy calculation.

D. Wireless Communication and Cloud Integration

The ESP32 utilizes its built-in Wi-Fi capability to transmit processed energy data to the Blynk cloud platform. The measured parameters are updated in real time on mobile and web dashboards, allowing users to remotely monitor electricity consumption. The wireless communication architecture enables continuous data synchronization, instant alerts, and remote accessibility without the need for physical meter interaction.

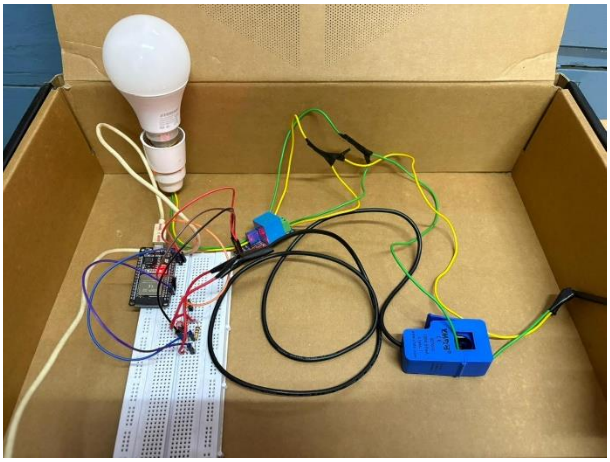

Fig 3: Working Model of proposed prototype

E. Wi-Fi Based Wireless Communication Unit

The system uses Wi-Fi–based wireless communication through the ESP32 microcontroller to enable real-time data transmission and remote energy monitoring.

- The ESP32 establishes a secure Wi-Fi connection with the local network.
- Electrical parameters measured by the sensors are processed internally by the microcontroller.
- The processed data is transmitted to the Blynk cloud server using internet connectivity.
- The Blynk cloud synchronizes the data with mobile and web dashboards in real time.

F. Hardware Assembly and Physical Setup

The smart energy meter hardware is assembled on a compact and stable platform to ensure safe operation and ease of installation. The setup includes the ESP32 development board, voltage sensor, current sensor, power supply module, and display unit. All components are securely mounted to prevent loose connections and mechanical damage. Proper insulation and spacing are maintained to ensure electrical safety during high-voltage AC operation. Clear wiring paths and labelled connections are provided to simplify maintenance and troubleshooting.

G. Integration and Testing

After assembly, all sensing, processing, and communication modules are interconnected using appropriate wiring and connectors. System testing includes:

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- Verification of voltage measurement accuracy
- Verification of current sensing under different load conditions
- Validation of power and energy calculations

V. CONCLUSION

The development of the IoT-based smart energy meter demonstrates an effective integration of embedded systems, sensing technology, and cloud-based communication for efficient electricity monitoring and management. The system successfully measures and monitors real-time electrical parameters such as voltage, current, power, and energy consumption with minimal human intervention, thereby eliminating the need for manual meter readings. The integration of Wi-Fi communication and the Blynk IoT platform enables wireless data transmission and remote monitoring, enhancing user convenience and accessibility. Cloud-based data storage and real-time visualization further improve system reliability and support informed decision-making. Overall, the proposed system provides a reliable, accurate, and cost-effective alternative to conventional electricity metering systems. It contributes to improved energy awareness and efficient resource utilization, representing a practical solution for smart homes, educational institutions, and small-scale industrial energy management applications.

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