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Iot Based Smart Energy Meter

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Abstract - This project is about building a smart energy meter using IoT technology to precisely measure electricity consumption and combat power theft. It uses microcontrollers along with current and voltage sensors, plus wireless communication, to keep track of energy use in real time. The system is smart enough to spot any unusual usage like unauthorized consumption or excessive reactive power, and it sends instant alerts and useful data to a cloud platform.

Keywords - Smart Energy Meter, IoT-Based Monitoring, Electricity Consumption Measurement, Power Theft Detection, Microcontroller.

I. INTRODUCTION

Effective energy management is becoming increasingly vital in the modern era. Since energy cannot be produced or destroyed but only transformed, the main challenge lies in accurately tracking how energy is consumed to avoid unnecessary wastage. One major difficulty in this process is the high expense involved in detecting electricity theft, which can sometimes be greater than the actual losses caused by the theft itself.Additionally, when theft is detected, utility companies incur extra expenses associated with power generation, grid maintenance, and managing the balance between supply and demand.Typically, electricity theft occurs through methods such as tampering with or bypassing meters, and conventional inspection and sealing approaches often fall short because they can be easily overridden.Smart metering solutions offer a reliable way to accurately track energy usage and utilize data analytics to detect unusual consumption patterns that could signal tampering or fraudulent activity.

These systems enhance billing precision, streamline data gathering, and help identify wiring issues or unauthorized connections at an early stage. Despite this, vulnerabilities in the distribution network and ongoing cybersecurity threats remain major challenges to maintaining the security of the power grid.Therefore, implementing smart meters alongside sophisticated monitoring technologies is essential for protecting electrical infrastructure and promoting equitable and efficient electricity distribution.

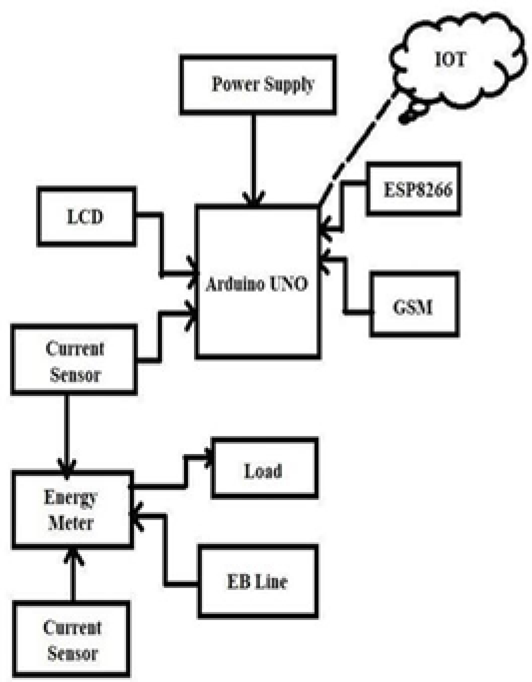


Fig 1 - Block Diagram

II. LITERATURE SURVEY

Our research review highlights important advancements in IoT-based energy monitoring systems. It emphasizes microcontroller-driven approaches that transform raw meter data into continuous, reliable streams of verified energy consumption metrics, enabling real-time tracking and improved accuracy in energy management.
Our research review identified significant contributions to IoT-based energy monitoring.they detail microcontroller-driven methods that convert raw meter outputs into a continuous stream of verified energy usage metrics. Their research presents amicrocontroller-implemented energy meter capable of remote anomaly detection, enabling users to identify meter tampering or unauthorized usage from any location through IoT connectivity.

III. METHODOLOGY

Block Diagram Description Power Supply
This conversion process involves rectifying the AC into a pulsating DC signal, which is subsequently smoothed through filtering to deliver a stable and continuous voltage.

Current Sensor
A current sensor is a device that detects A gadget that recognizes a measurable output voltage proportionate to the current flowing via the measured route from the measured current. Each type of sensor has been specifically designed for a certain current range and ambient condition.

Iot Cloud
The term "IoT cloud" refers to a sizable network that hosts IoT devices and applications. Real-time operations and processing require the underlying infrastructure, servers, and storage that is provided.

ESP8266
As an all-in-one wireless SOC, the ESP8266 handles Wi-Fi communication and TCP/IP networking protocols, providing any microcontroller with instant network connectivity.

Arduino Uno
The Arduino UNO is a fantastic board for beginners learning electronics and programming. Its ease of use and comprehensive documentation make it an ideal starting point for new comers .Being the most popular and extensively supported board in the Arduino series, the UNO providesAn ideal base for beginners starting to learn and work with the platform.

Energy Meter

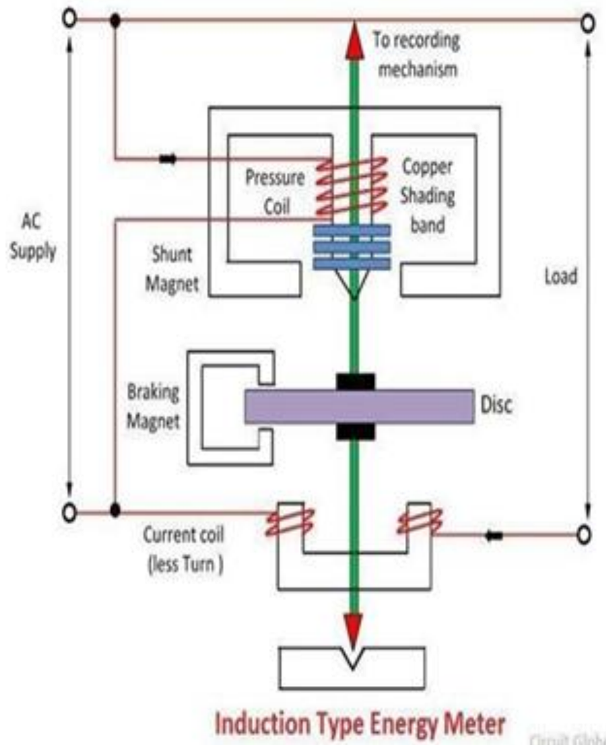


Figure 2 – Induction type Energy meter

The quantity of energy used by an electric load is measured using an energy meter. Energy is the collective amount of power that the load is using at any given time. Both household and commercial AC circuits use it to keep an eye on power usage. Both the cost and the accuracy of the meter are lower.technique for reading electricity energy meters. At the core of this energy meter lies an IoT framework that transforms conventional metering into a networked sensor platform.The Arduino is key to this entire method The internet of things (IoT)

In this configuration, the energy meter is integrated with the internet through IoT technology.Consequently, users have a means of monitoring their energy usage. This method eliminates therequirement for human interaction during the uploading of connection and disconnection data, Any theft in the sensor must be reported to the provider immediately.

Diagram of Power Supply

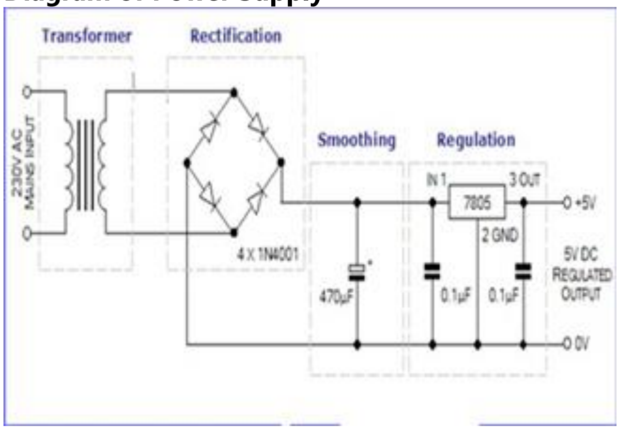


Figure 3 – Power supply circuit diagram

The Provision of electricity units provide the system with a 5v regulated power source.

Energy Meter's

A rotating aluminum disc inside the energy meter's casing measures the power consumption of the load. This disc is positioned between the air gaps of two electromagnets: the series electromagnet, which contains the current coil, and the shunt electromagnet, which contains the voltage (pressure) coil.The pressure coil creates a magnetic field based on the supply voltage, while the current coil generates a magnetic field corresponding to the current flow The magnetic field from the pressure coil lags the current coil's field by 90 degrees, which generates eddy currents in the aluminum disc. These eddy currents experience a force that creates torque, causing the disc to start rotating.

Working Process

In this study, we explain an IoT-based LCD:

A standard 16x2 LCD displays 16 characters on each of its two lines. It uses a 5x7 pixel matrix to render each character and includes both command and data registers for controlling its functions.The command register holds instructions that direct the LCD to perform specific actions, such as initializing, clearing the screen, setting the cursor position, and managing display settings. Commands are requests sent to the LCD to control these functions. The data register stores the information to be shown on the LCD, with each character represented by its corresponding ASCII valueLiquid crystals (LCs) are used in liquid crystal displays (LCDs) to manipulate light color. An LCD is a small, flat electronic display that does not emit light directly. Instead, it controls light passing through the liquid crystals. LCDs have a wide range of applications, including signal lights, televisions, instrument panels, aircraft cockpit displays, and computer monitors. They have largely replaced cathode ray tube (CRT) displays in most uses due to being easier to view, lighter, smaller, more portable, more affordable, and more reliable.

Figure-4 LCD display

Software Description

The Arduino Uno board is built around the ATmega328P microcontroller.

The board includes 14 digital input/output pins, with six capable of PWM output, along with six analog input pins.

The board operates with a 16 MHz quartz crystal oscillator and includes a USB interface, a power connector, an ICSP header, and a reset switch. Power can be supplied via USB, an AC-to- DC adapter, or a battery. The microcontroller is easily replaceable, allowing users to experiment freely without concern for damage, as the chip can be swapped at low cost. The name "Uno," meaning "one" in Italian, was chosen to celebrate the launch of Arduino Software (IDE) version 1.0.The Uno board and this IDE version jointly signified the official beginning of the Arduino platform, serving as its original models.The Arduino Uno went on to become the standard design for a series of USB- based Arduino boards. An official Arduino board index keeps track of all current, legacy, and discontinued boards.

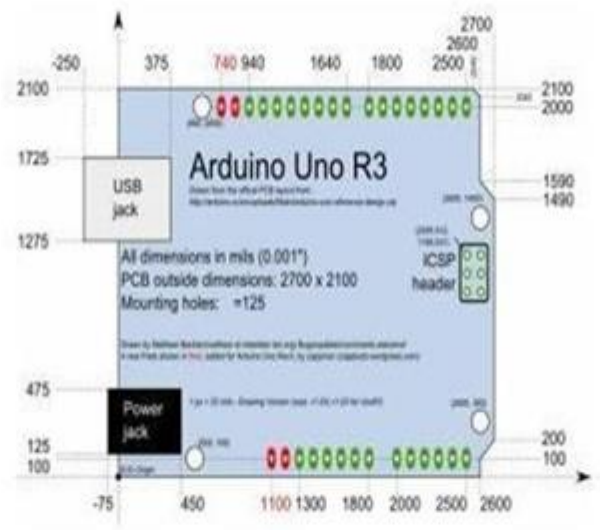


Figure-5 Arduino Uno R3

IV. PROPOSED METHODOLOGY

The proposed system aims to develop a smart energy meter that uses IoT technology to monitor energy consumption in real time, provide remote access to data, and detect power theft. The methodology includes the following steps:

Requirement Analysis and Component Selection

- Identify the necessary hardware and software components:
- Microcontroller: ESP32 or Arduino combined with ESP8266 for Wi-Fi connectivity
- Energy Metering IC: examples include ADE7757 or HLW8012 for accurate power measurement
- Current & Voltage Sensors: CT sensors for current and voltage divider circuits

Circuit Design and Hardware Integration

- Create the circuit design for:
- Interfacing the energy metering IC with the microcontroller
- Connecting sensors to measure real-time voltage, current, and energy consumption
- Implementing tamper detection methods such as monitoring sudden load changes or sensor bypass attempts
- Assemble all components on a breadboard or PCB

Embedded System Programming

- Develop embedded code (using C/C++ or Arduino) to:
- Read sensor data and calculate energy usage
- Detect abnormal patterns indicating theft
- Transmit data periodically to the cloud
- Send alerts to users or authorities if theft is detected

IoT Integration

- Utilize Wi-Fi or GSM modules to transmit smart meter data to an IoT platform
- Set up IoT dashboards to show:
- Real-time measurements of voltage, current, and power
- Consumption history on daily, weekly, and monthly basis
- Theft alerts through notifications such as email or SMS

Theft Detection Mechanism

- Monitor for irregularities like:
- Discrepancy between load current and sensor readings
- Unauthorized opening of the meter enclosure
- Tampering with sensors
- Generate alerts and log events upon detecting anomalies

Cloud Data Management

- Store data securely in cloud databases
- Enable users and utility companies to:
- Monitor consumption trends
- Receive billing alerts and notifications
- Analyze data for efficient energy management

Testing and Validation

- Conduct tests with varying load conditions and usage scenarios.
- Assess the system’s overall reliability, measurement
- precision, and network connectivity performance.

Deployment and User Interface

- Install the system in a real environment such as a home or laboratory setup.
- Develop a user-friendly interface, available as a mobile or web application, providing:
- Live monitoring of energy consumption
- Alerts related to theft attempts and billing information
- Access to past consumption data and reports

System Architecture

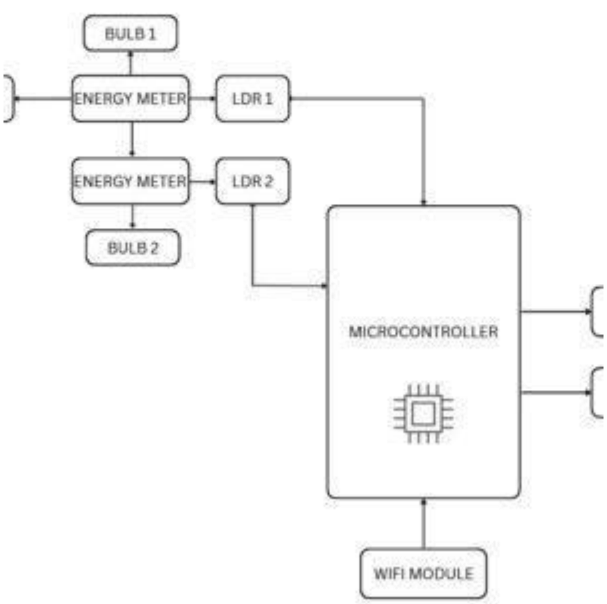
The architecture consists of four primary layers:

Sensing Layer – responsible for the hardware components that detect and measure physical parameters.

Processing Layer – involves the microcontroller that processes the collected data.

Communication Layer – manages data transmission through IoT technologies.

Application Layer – includes the cloud services and user interfaces for data visualization and interaction.



System Architecture IoT-Based Smart Energy Meter

Real-Time Model Implementation

The real-time implementation of an IoT-based Smart Energy Meter integrates both hardware components and embedded software to monitor energy usage, detect power theft, and send data to an IoT platform for remote access and analysis.

Hardware Setup

Microcontroller: ESP32, favored for its built-in Wi-Fi capabilities

Sensors:

Current Sensor: Current Transformer (CT) sensor Voltage Sensor: Voltage divider or ZMPT101B module The entire setup is powered by an AC to DC converter

circuit. To show live values like voltage, current, and energy usage, a display module such as an OLED or a 16x2 LCD is typically used.Communication Module: Wi-Fi (built-in ESP32) or external GSM module Tamper Detection: Switch or vibration sensor to detect physical tampering

Software Development

Firmware is written in Arduino IDE or PlatformIO using C/C++ The program performs:

Sensor calibration

Continuous reading of voltage and current Energy and power calculation

Theft condition checks (e.g., current = 0 but voltage ≠ 0)

Data formatting and transmission to cloud

Theft Detection Logic

Theft detection in energy meters can be identified through several signs such as unusual power consumption that does not correspond with any measured current, bypassing of the current transformer (CT) sensor which results in no current being detected, and activation of a tamper switch.

Upon detecting theft, the system logs an alert and promptly sends a notification to the user or relevant authorities.

Output Display and Logging

Local display via LCD/OLED shows: Voltage (V)

Current (A) Power (W) Energy (kWh)

Cloud dashboard shows:

Real-time sensor values Theft alerts Daily/monthly consumption graph

Pseudo Code

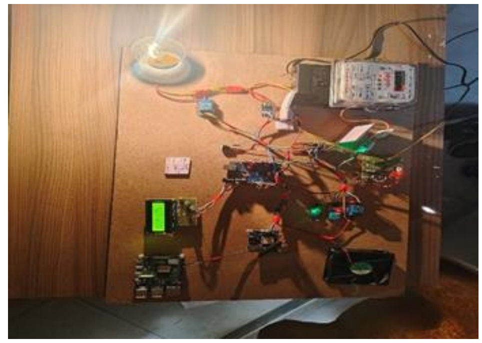
Begin
// Initialization
Initialize the microcontroller (e.g., ESP32). Initialize the voltage and current sensors.
Initialize the Wi-Fi or GSM communication module.
Connect to the IoT cloud platform (e.g., ThingSpeak, Firebase, or Blynk).
Set threshold values for theft detection. LOOP **Indefinitely:**
Read voltage from the voltage sensor. Read current from the current sensor.
Calculate power as voltage multiplied by current.
Update energy consumption (kWh) by adding power times the time interval.
IF current equals zero AND power exceeds the threshold THEN: Set theft_flag to TRUE.
Record the theft event with a timestamp. Send a theft alert to the cloud.
END IFIF sudden drop in sensor readings OR a mismatch is detected THEN: Set theft_flag to TRUE.
Log the theft incident. Send an alert notification. END IF

Prepare a data packet containing:
Voltage
Current
Power
Energy consumption
Theft flag status
Timestamp

Send the data packet to the cloud server.
Show voltage, current, power, and energy consumption (kWh) on an LCD or OLED display.
// 5. Wait before the next measurement
Pause for a fixed duration (e.g., 1 second or 1 minute).
End Loop End

V. RESULTS & CONCLUSION

The project clearly illustrates a comprehensive smart home system with various automation and monitoring capabilities. It produced the following key outcomes.



Smart Energy Meter

Light Automation: In these lights will ON/OFF automatically based on the environment.

Light Automation

Temperature-Controlled Fan Automation: The fan automatically activates when the ambient temperature exceeds a set threshold and turns off as the temperature drops, helping maintain a comfortable environment.

fan

Real-time Monitoring: The LCD screen displays live voltage and current readings, offering users instant insight into their power consumption.

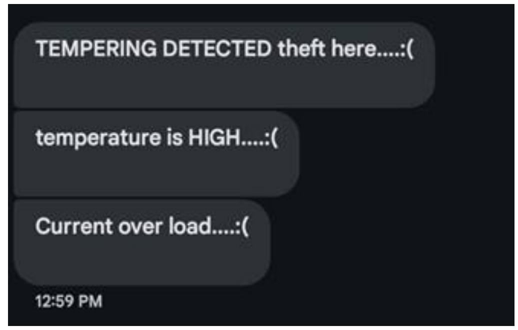
Rel-Time Monitoring

Safety and Security: The system reliably detects tampering and overload conditions, serving as a safeguard against potential risks.

Alerts Notification

Remote Notifications: The system's connection to a mobile application sends instant notifications to users about important incidents such as tampering or overloads, facilitating remote supervision and management.

Remote Notification



Notification

Future Scope

The future development of this project involves transforming it from a simple rule-based system into an advanced, intelligent smart ecosystem.

This can be achieved by integrating artificial intelligence and machine learning, enabling the system to learn user habits and proactively automate tasks rather than just reacting to sensor inputs. Furthermore, adding sophisticated security measures—such as biometric authentication using unique identifiers like fingerprints or facial recognition—and incorporating live camera monitoring would greatly strengthen the system's protection. Linking the system to a centralized cloud dashboard would provide comprehensive data storage and enable more refined remote control. Additionally, expanding the platform to support voice commands via popular assistants like Amazon Alexa or Google Assistant would make user interaction more intuitive and convenient. The ultimate goal is to develop a flexible platform that can effortlessly interact with numerous smart devices, fostering a completely integrated, energy-saving, and customized smart home experience.

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