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IoT Based Energy Monitoring and Billing System

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Abstract: *The rapid increase in energy consumption and the limitations of conventional electricity billing systems have created a need for smarter and more efficient energy management solutions. This research presents the design and implementation of an Internet of Things (IoT)-based energy monitoring and billing system that enables real-time tracking of electricity usage and automated billing. The proposed system utilizes smart sensors and microcontrollers to measure electrical parameters such as voltage, current, and power consumption. The collected data is transmitted over the internet to a cloud platform, where it is processed, stored, and made accessible to users through a web or mobile interface.*
The system allows consumers to monitor their energy usage in real time, promoting awareness and encouraging energy conservation. Additionally, it enables automated and accurate billing based on actual consumption, reducing human errors and operational costs associated with traditional meter reading methods. The integration of IoT technology ensures scalability, remote accessibility, and improved efficiency in energy management. The proposed solution is cost-effective, user-friendly, and suitable for both residential and industrial applications. This work contributes to the development of smart grid technologies and supports sustainable energy utilization..

Keywords*:* internet of Things (IoT), energy monitoring, smart meter, automated billing system, power consumption, real-time data, wireless communication, cloud computing, energy management system, smart grid, remote monitoring, and embedded systems

I. INTRODUCTION

The need for effective energy management systems has been brought to light by the rising demand for electrical energy, which is being driven by rapid urbanization and industrial growth. Conventional electricity monitoring and billing techniques mainly rely on manual meter readings, which are frequently laborious, prone to human error, and do not provide customers with real- time feedback. Users find it challenging to efficiently monitor their energy consumption and reduce wasteful use as a result of these restrictions The development of the Internet of Things (IoT) has made smart and automated energy monitoring and management solutions possible. Real-time analysis and remote accessibility are made possible by IoT, which enables physical devices like sensors and meters to gather and send data over the internet. IoT integration makes it feasible to continuously track electricity consumption, identify anomalies, and deliver accurate billing without the need for human intervention.

The IoT-based energy monitoring and billing system relies on continuous data acquisition from the energy meter and sensing units such as current and voltage sensors. The system cannot function effectively without accurate measurement of electrical parameters, as these values are essential for calculating real-time power consumption and energy usage. Any malfunction in the sensing components may lead to incorrect readings, resulting in inaccurate billing and inefficient energy management. he proposed system consists of an IoT node integrated with multiple components including sensors, microcontroller units, communication modules, and cloud-based services. The current and voltage sensors continuously monitor electrical parameters, while the energy meter provides cumulative consumption data. These inputs are processed by the IoT node, which acts as the central control unit of the system. The IoT node typically

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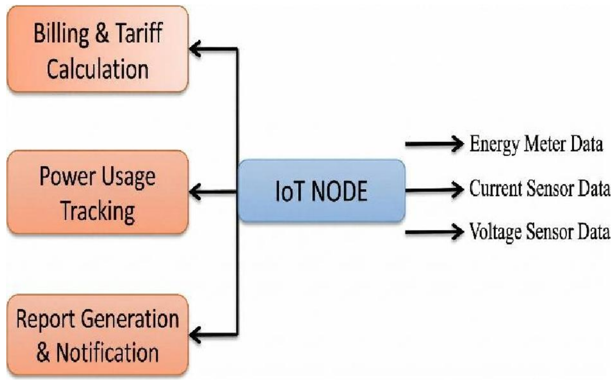
includes embedded hardware such as a microcontroller (e.g., NodeMCU or Arduino), along with communication interfaces for transmitting data over the internet.



This block diagram represents a multi-layered IoT- based system designed for real-time electrical energy monitoring and automated billing. The architecture is structured hierarchically, beginning at the physical layer where the AC Power Supply/Grid connects to the functional components. The system's data acquisition starts with the Energy Meter / V & I Sensors block, which is responsible for directly sampling voltage (V) and current (I) from the grid. This sensor unit transduces these physical electrical parameters into a normalized data stream that is fed directly into the system's core processing unit.

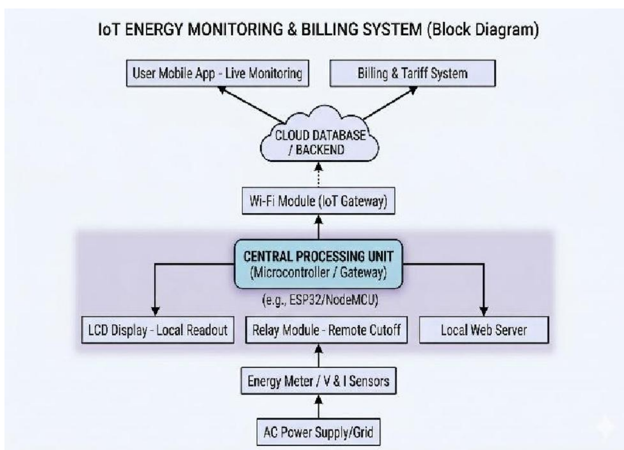


Fig. 2. Block diagram of Monitoring and Billing System

The central component of the hardware architecture is the Central Processing Unit (Microcontroller / Gateway), highlighted within the diagram's purple- shaded processing zone. For this implementation, a 32- bit microcontroller like an ESP32 or NodeMCU is specified, chosen for its dual capability of high-speed data processing and integrated wireless connectivity. This CPU performs critical double duty: first, it acts as a metrology engine, receiving the raw sensor data to calculate root-mean-square (RMS) voltage, current, active power, and cumulative energy consumption in kilowatt-hours (kWh); second, it functions as a local gateway managing all peripheral communications.

Simultaneously, the Microcontroller manages several essential local interactions through direct hardware interfaces. It drives an LCD Display to provide an immediate, real-time Local Readout of energy parameters directly at the physical installation point. Crucially, the CPU controls a Relay Module dedicated to Remote Cutoff, which serves as the system's primary control actuator, allowing the connection to the grid to be physically engaged or disengaged based on commands from the processing logic. Furthermore, the CPU hosts a basic Local Web Server, offering a redundant pathway for monitoring and control directly over the local network, independent of the main cloud connection.

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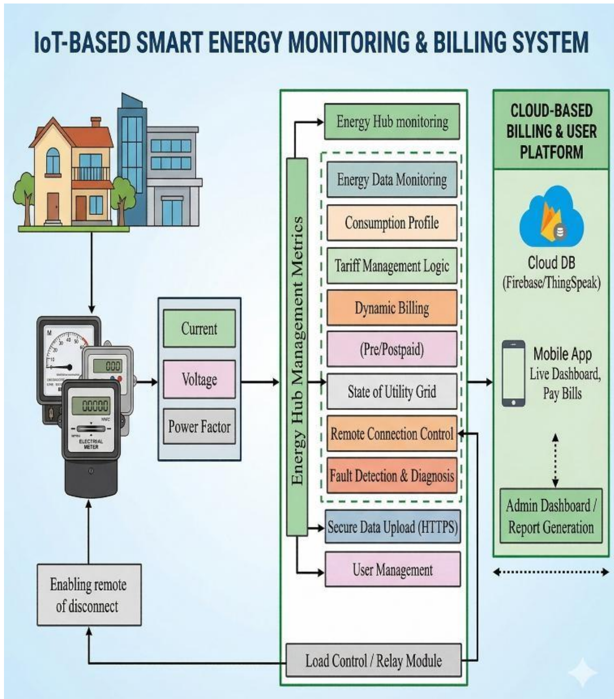
The upper portion of the diagram details the system's wide-area communication and service layers. The Microcontroller connects to the internet via an integrated Wi-Fi Module, which functions as the primary IoT Gateway. A dotted communication link indicates this wireless connection, bridging the local hardware to the Cloud Database / Backend. This cloud infrastructure serves as the central data repository and application server, responsible for storing historical energy usage data, executing the Billing & Tariff System logic, and managing real-time data synchronization with the user-facing User Mobile App for Live Monitoring.



The proposed IoT-based smart energy monitoring and billing system is designed to provide real-time energy tracking, automated billing, and remote control functionalities using cloud integration and intelligent processing. The system architecture consists of four major components: energy meter and sensing unit, energy hub (IoT processing unit), cloud-based platform, and user interface.than traditional methods, accounting for temperature variations, load fluctuations, and battery ageing.

1. High-Level System Overview

The proposed "IoT-Based Smart Energy Monitoring & Billing System" follows a layered and end-to-end architecture designed to bridge the gap between physical consumption and digital management. The system transforms physical electricity consumption at the consumer endpoint into structured data, uploads this data securely to the cloud, executes advanced billing analytics, and provides real-time visualizations and control actuators back to the user.

This architecture can be categorized into four functional segments: Data Acquisition, Edge Processing (Gateway), Cloud Application, and Actuation/Control.

2. Detailed Component Breakdown

The block diagram can be analyzed through its key functional segments:

SEGMENT A: DATA ACQUISITION (THE PHYSICAL LAYER)

This layer represents the initial interface between the smart system and the utility consumer.

• Consumer Load (Houses/Buildings): This represents the active electrical load being measured.

• Sensors & Meter (Transducing Element): While a physical "Electrical Meter" is shown, its core functional capability is broken out. The system relies on precise current and voltage transformers (CT/PT) to sample the basic electrical parameters.

• Primary Metrics (Metrology Data): The transduced analog signals are converted into a normalized digital format to deliver fundamental values: Current, Voltage, and Power Factor (the phase angle difference between V and I, crucial for calculating real power).

1. Energy Meter and Data Acquisition Layer

The system begins with the energy meter, which is installed at the consumer premises (residential or commercial). It measures the total electrical energy consumption. Along with the energy meter, additional sensing parameters are collected, including:

• Current: Measured using current sensors (e.g., ACS712)
• Voltage: Measured using voltage sensors
• Power Factor: Indicates efficiency of power usage

These parameters are essential for accurately determining real-time power consumption and analyzing energy usage behavior.

2. Energy Hub Management (IoT Processing Unit)

The collected data is transmitted to the Energy Hub, which acts as the core processing unit of the system. This hub typically consists of a microcontroller (such as NodeMCU, ESP8266, or Raspberry Pi) with internet connectivity.

The energy hub performs multiple intelligent operations:

Energy Data Monitoring

Continuously monitors incoming data from sensors and energy meters for real-time analysis.

Consumption Profiling

Analyzes usage patterns over time (daily, weekly, monthly), helping users understand their energy consumption behavior.

Tariff Management Logic

Imlements tariff rules based on units consumed, time- of-use pricing, or slab-based billing systems.

Dynamic Billing (Prepaid/Postpaid)

Supports both prepaid and postpaid billing systems by calculating charges dynamically based on consumption.

Utility Grid State Monitoring

Tracks grid conditions such as availability, outages, or fluctuations.

Remote Connection Control

Allows remote switching (ON/OFF) of supply using relay modules.

Fault Detection and Diagnosis

Detects abnormal conditions such as overvoltage, overcurrent, or faults and triggers alerts.

Secure Data Upload :

Ensures secure transmission of data to cloud servers using protocols like HTTPS.

User Management

Maintains user profiles, authentication, and access control.

Billing Estimation Algorithm

The IoT-based energy monitoring and billing system's working algorithm, which carries out real- time energy tracking, billing estimation, and cloud data synchronization, is depicted in the flowchart. With IoT connectivity, the algorithm guarantees precise electricity consumption calculations and automated billing.

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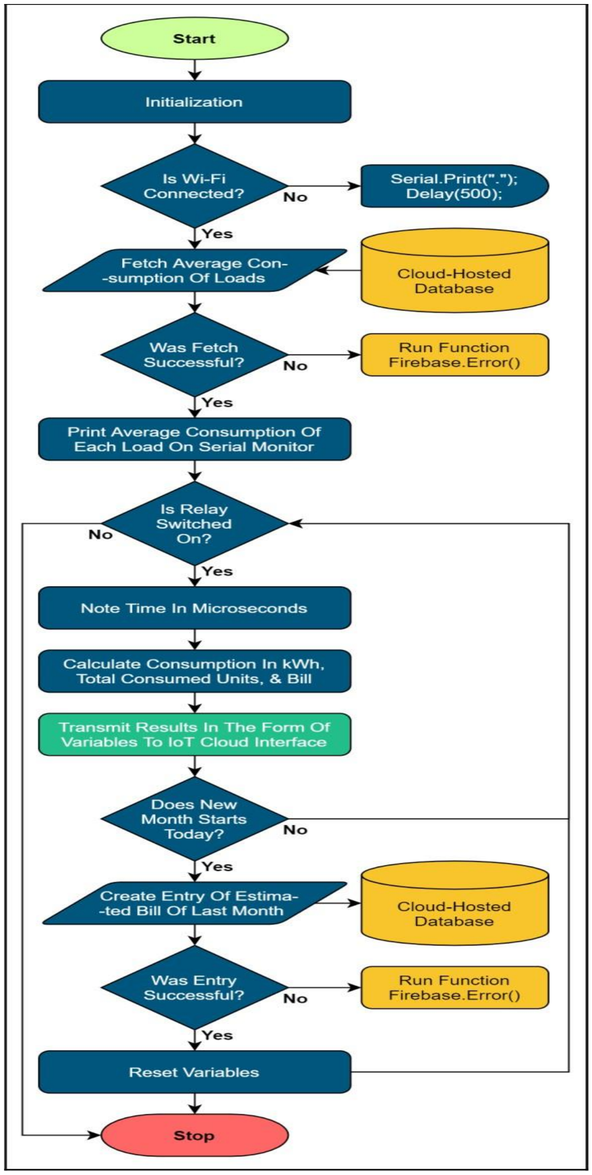

1. Start and Initialization

The process begins with the Start block. Next is the initialization phase. During this phase, all system components, including the microcontroller (NodeMCU), sensors, Wi-Fi module, and relay connections, are initialized. We also define the necessary variables for energy calculation and billing.

2. Wi-Fi Connectivity Check

The system checks whether the Wi-Fi connection is established:

- If No, the system continuously attempts to reconnect by executing delay functions and retrying.
- If Yes, the system proceeds to fetch data from the cloud database.

3. Fetching Data from Cloud Database

Once connected to the internet, the system retrieves the average consumption data of loads from the cloud-hosted database (e.g., Firebase or ThingSpeak). This data is used for analysis and comparison.

- If the fetch operation fails, an error-handling function (Firebase.Error()) is executed.
- If successful, the system proceeds further.

4. Display of Consumption Data

The fetched data is printed on the serial monitor, allowing developers or users to observe average consumption values of each connected load.

5. Relay Status Check

The system checks whether the relay (load switch) is ON:

- If No, the system loops back and continuously monitors the relay status.
- If Yes, the system begins energy consumption calculation.

6. Time Measurement

When the relay is ON, the system records the time duration in microseconds for which the load is active. This time is essential for calculating energy consumption.

7. Energy and Billing Calculation

Using the measured parameters, the system computes:

- Energy consumption (kWh)
- Total units consumed
- Estimated electricity bill

This calculation is based on standard formulas and predefined tariff rates.

8. Data Transmission to Cloud

The calculated results (energy usage, units, and billing data) are transmitted to the IoT cloud platform. This enables real-time monitoring and remote access for users.

9. Monthly Billing Check

The system checks whether a new month has started:

- If No, the system continues monitoring and updating data.
- If Yes, the system proceeds to generate the monthly bill.

10. Monthly Bill Entry

An entry of the estimated bill for the previous month is created and stored in the cloud database.

- If the entry fails, an error-handling function is triggered.
- If successful, the system proceeds to reset variables.

11. Resetting Variables

After storing monthly data, all variables (such as units consumed and billing values) are reset to prepare for the next billing cycle.

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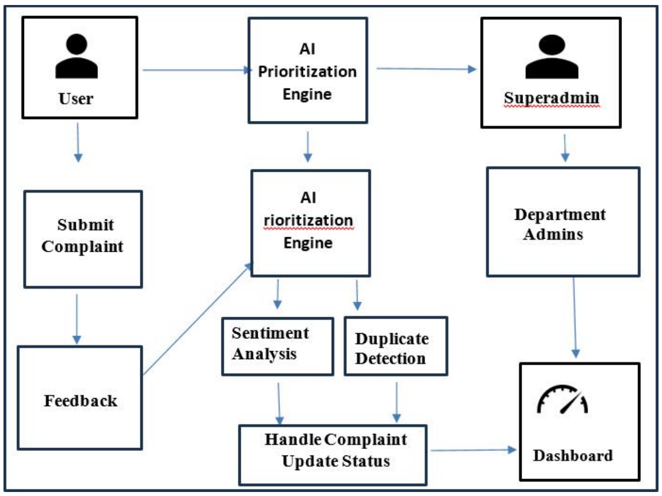
12. Stop / Loop Continuation
The process reaches the Stop block; however, in practical implementation, the system runs continuously in a loop for real-time monitoring and billing updates.

Conclusion of Algorithm
The proposed algorithm provides reliable and automated energy monitoring and billing. It achieves this by using IoT connectivity, real-time data processing, and cloud storage. It reduces human intervention, increases billing accuracy, and allows for efficient energy management. With error handling and continuous monitoring, the system is sturdy and fits well with smart grid applications.



II. CONCLUSION

The IoT-based energy monitoring and billing system described in this work offers a clever and effective way to get around the drawbacks of conventional electricity monitoring techniques. Real-time power consumption monitoring and automated billing are made possible by the system's integration of sensors, microcontrollers, and cloud-based communication. This method guarantees accurate and transparent billing, minimizes human error, and does away with the need for manual meter reading. Users can effectively track their electricity consumption thanks to the system's continuous collection and processing of voltage, current, and energy usage data. User convenience and operational efficiency are further improved by the use of automated tariff calculation and report generation. Sending alerts and notifications also aids users in controlling their energy consumption and preventing overconsumption.

All things considered, the suggested system is affordable, scalable, and easy to use, making it appropriate for commercial, industrial, and residential uses. Incorporating IoT technology not only enhances energy management but also advances smart grid systems and sustainable energy use. To further maximize system performance, future improvements may include enhanced security features, advanced analytics, and integration with renewable energy sources.

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