

IOT- Based Smart Energy Meter for Appliance Monitoring and Control

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Abstract — The increasing demand for electrical energy and the need for efficient power utilization have created a requirement for intelligent energy monitoring systems. Conventional electricity meters generally provide information about total household energy consumption, making it difficult for users to identify the individual contribution of different appliances to the electricity bill. This paper proposes an IoT-Based Smart Energy Meter for Appliance-Wise Electricity Monitoring and Control, designed to monitor the energy consumption of household appliances individually and provide real-time information through a software dashboard. The proposed system integrates energy measurement sensors, a microcontroller, IoT communication, and a user-friendly monitoring interface. It records appliance-wise power consumption, calculates electrical energy usage in kilowatt-hours (kWh), estimates electricity costs, and presents historical consumption data. The system also supports remote appliance switching and configurable alerts for excessive energy consumption. By providing detailed consumption information for appliances such as fans, lights, refrigerators, air conditioners, televisions, washing machines, and other household electrical devices, the proposed approach helps users identify energy-intensive appliances and adopt more efficient electricity usage practices. The system aims to improve energy awareness, support informed decision-making, and contribute to household energy conservation.

Keywords— Internet of Things (IoT), Smart Energy Meter, Appliance-Wise Monitoring, Electricity Consumption, Energy Management, Remote Control, Real-Time Monitoring, Smart Home.

I. INTRODUCTION

Background

Electrical energy is an essential requirement in modern households, where multiple appliances operate throughout the day. Devices such as refrigerators, air conditioners, fans, televisions, washing machines, water heaters, lighting systems, and kitchen appliances contribute to overall electricity consumption. However, conventional energy meters generally display the cumulative electricity consumed by an entire household without clearly identifying how much energy is used by each individual appliance.

The absence of appliance-level information makes it difficult for consumers to understand their electricity usage patterns and determine which devices contribute most significantly to their monthly bills. Internet of Things technology provides an opportunity to improve energy monitoring by connecting electrical measurement devices to microcontrollers, communication networks, and software applications. Such systems can collect consumption data, process measurements, and present useful information through digital dashboards.

The proposed system focuses on appliance-wise electricity monitoring and control. It enables users to observe the energy consumption of individual appliances, compare their operating

costs, monitor historical usage, and control compatible appliances remotely. By making electricity consumption more transparent, the system supports energy conservation, improved household management, and more informed decisions regarding the use of electrical devices.

2. Existing System and Proposed Approach

In the conventional electricity monitoring system, a meter measures the total electricity consumed by a household. Although this approach is suitable for billing purposes, it does not directly provide detailed information about the consumption of individual appliances. Consumers generally need separate measuring instruments or additional monitoring equipment to identify the energy usage of specific devices. Manual observation also makes continuous monitoring and timely identification of excessive consumption difficult.

The proposed system introduces an IoT-enabled monitoring approach that collects appliance-level electrical measurements and displays them through a centralized software dashboard. Individual appliances or their dedicated electrical circuits are monitored using suitable sensors and measurement modules. A microcontroller processes the collected readings and transfers the data to a monitoring application through

Wi-Fi or another supported communication interface.

The dashboard displays parameters such as instantaneous power, accumulated energy consumption, operating duration, and estimated electricity cost. Users can compare appliances, review consumption trends, and configure alerts when energy usage exceeds predefined limits. Compatible appliances can also be switched remotely through appropriately rated control devices.

Unlike a conventional meter that mainly reports total household consumption, the proposed approach emphasizes detailed appliance-wise information. The system is intended to complement the existing electricity meter rather than replace the utility's certified billing meter

II. SYSTEM ARCHITECTURE AND METHODOLOGY

The proposed system consists of electrical measurement units, a microcontroller, an IoT communication module, a data-processing and storage component, and a software dashboard. Each monitored appliance or dedicated circuit is connected to an appropriate measurement arrangement. The sensors measure the required electrical parameters, and the controller processes the readings to estimate energy consumption.

The processed information is transmitted to the software platform, where readings are stored and presented in a user-friendly format. Users can view live measurements, compare appliances, inspect historical records, and operate supported control functions. The overall methodology follows four major stages: measurement, processing, communication, and monitoring or control.

1. Hardware Components

The hardware components are selected according to the required monitoring accuracy, number of appliances, electrical ratings, and communication requirements. Microcontroller: An ESP32 or ESP8266 can serve as the central processing unit. It receives measurement data, performs basic calculations, and communicates with the monitoring software over Wi-Fi. The ESP32 is suitable when additional processing capacity and communication interfaces are required.

Energy Measurement Sensors: Suitable voltage and current sensors or dedicated energy-monitoring modules measure the electrical characteristics of connected appliances. Modules capable of measuring real power, power factor, and accumulated energy are preferable for accurate energy estimation, particularly with appliances that do not operate at a unity power factor.

Switching Devices: Appropriately rated relays or contactors can be used to switch compatible appliances. Their voltage, current, load type, and switching capacity must be selected according to the appliance specifications.

Power Supply: A suitable regulated power supply provides the required low-voltage DC power to the controller and electronic modules while maintaining appropriate electrical isolation.

Communication Interface: Wi-Fi enables the controller to send measurements to the software dashboard and receive authorized control commands. Alternative communication methods may be considered where network availability is limited.

Protection and Enclosure: Proper insulation, fuses or circuit breakers, protective enclosures, and electrical isolation are necessary to improve system safety and reliability.

2. Appliance-Wise Energy Measurement

Appliance-wise measurement is the primary function of the proposed system. Each appliance under monitoring must be associated with a dedicated measurement channel or another suitable method of identifying its electrical consumption. A single sensor measuring the entire household supply cannot directly determine the exact consumption of every appliance without additional measurement channels or a separate load-identification technique.

The measurement module collects voltage and current readings for each monitored appliance. Real power is calculated using the measured electrical quantities, while accumulated energy is obtained by integrating power over time. For a measurement interval in which average power is approximately constant, energy consumption can be estimated as:

$$\text{Energy (kWh)} = \text{Power (W)} \times \text{Time (hours)} / 1000$$

For example, an appliance operating at an average power of 100 W for five hours consumes approximately 0.5 kWh of electrical energy.

For accurate measurement of AC appliances, the system should use real-power measurements rather than relying only on the product of nominal voltage and current. This distinction is important for motors, compressors, and electronic devices that may have varying power factors or non-sinusoidal current waveforms.

The system records consumption for individual appliances such as lighting systems, ceiling fans, refrigerators, televisions, washing machines, air conditioners, water heaters, and kitchen appliances. Actual readings depend on appliance ratings, operating conditions, usage duration, and measurement accuracy.

3. IoT Communication and Software Dashboard

The IoT communication layer connects the measurement hardware to the software monitoring platform. The microcontroller transmits readings through Wi-Fi using a suitable protocol, such as MQTT or HTTP. The application receives the data, associates each measurement with its appliance identifier, and stores the information for further analysis.

The software dashboard provides a centralized view of household electricity consumption. Each appliance can be represented through a separate monitoring panel displaying its current power, cumulative energy usage, operating status, and estimated electricity cost. Graphs and charts help users compare consumption across appliances and identify changes in usage patterns.

The dashboard can also provide daily, weekly, and monthly summaries. Historical records help users understand the relationship between operating duration and energy consumption. The estimated electricity cost can be calculated using the applicable tariff, although actual utility bills may also include fixed charges, taxes, time-of-use rates, and other adjustments.

A suitable software implementation may use a web application, database, and server-side processing. Data validation, authenticated access, secure communication, and appropriate storage practices should be incorporated to protect household monitoring information.

4. Remote Appliance Control and Alerts

In addition to monitoring, the proposed system can provide remote control for compatible appliances. An authorized user sends a switching command through the dashboard, which is forwarded to the microcontroller. The controller operates the corresponding relay or contactor and updates the appliance status on the interface.

The system can generate alerts when an appliance operates beyond a specified duration, consumes more energy than an established threshold, or exhibits an unexpected change in its

measured consumption. Notifications can help users identify unnecessary operation and review potentially abnormal usage. For example, a user may receive an alert when a monitored appliance exceeds a predefined daily energy limit. The dashboard can then provide the relevant measurement history so that the user can decide whether to switch off the appliance or modify its usage schedule. Remote switching must be implemented with appropriate electrical protection and fail-safe behavior. Critical appliances, including medical or safety-related equipment, should not be switched automatically without suitable safeguards. The system should also account for communication failures and ensure that control commands are authenticated.

III. ENERGY CONSUMPTION ANALYSIS

Energy consumption analysis enables users to understand the contribution of individual appliances to total household electricity usage. The proposed system collects energy readings over a defined period and uses these measurements to compare appliance consumption, operating duration, and estimated electricity costs. For each appliance, the accumulated energy consumption is calculated from its measured power over time. The total monitored consumption can be determined by adding the energy readings from all monitored channels. This total represents the consumption of the monitored appliances and may differ from the utility meter reading if some circuits or devices are not included.

Chart 1: Comparison of Electricity Consumption Among Household Appliances

Household appliance	Parameters monitored	Purpose
Lighting system	Power, energy, operating duration	Identify unnecessary lighting usage
Ceiling fan	Power, energy, operating duration	Compare consumption across usage periods
Refrigerator	Power, energy, operating patterns	Monitor continuous and cycling operation
Television	Power, energy, operating duration	Estimate consumption during entertainment use
Washing machine	Power, energy, operating cycle	Determine energy used per operating cycle

Air conditioner	Power, energy, operating duration	Evaluate the effect of cooling usage
Water heater	Power, energy, operating duration	Monitor high-power heating operation
Kitchen appliances	Power, energy, operating duration	Compare consumption during cooking activities

A bar chart can be used to compare the electricity consumption of household appliances over a common period, such as one day or one month. The horizontal axis represents the appliances, while the vertical axis represents measured energy consumption in kilowatt-hours (kWh).

The chart may include refrigerators, air conditioners, fans, lighting systems, televisions, washing machines, and water heaters. Actual measured readings should be used to generate the final chart. If measurement data is not yet available, illustrative values may be used for a prototype demonstration, provided that they are clearly labelled as hypothetical rather than experimental results.

The comparison helps identify appliances that contribute substantially to household energy usage. However, consumption varies according to appliance capacity, efficiency, operating duration, environmental conditions, and user behavior. Therefore, the chart should be interpreted using the actual monitoring period and recorded operating conditions.

Household Appliances: Electrical devices such as lights, fans, refrigerators, televisions, washing machines, and air conditioners.

Energy Measurement Units: Voltage and current sensors or dedicated energy-monitoring modules associated with the appliances or their circuits.

Microcontroller: An ESP32 or ESP8266 processes the readings and manages communication and control operations.
IoT Communication: A Wi-Fi connection using MQTT or HTTP transfers measurement data and authorized control commands.

Server and Database: The software backend processes, organizes, and stores appliance-wise energy records. **Software Dashboard:** A web or mobile interface displays consumption, estimated costs, historical charts, alerts, and appliance status.

Remote Control and Notifications: Authorized users can control compatible appliances and receive configured alerts.

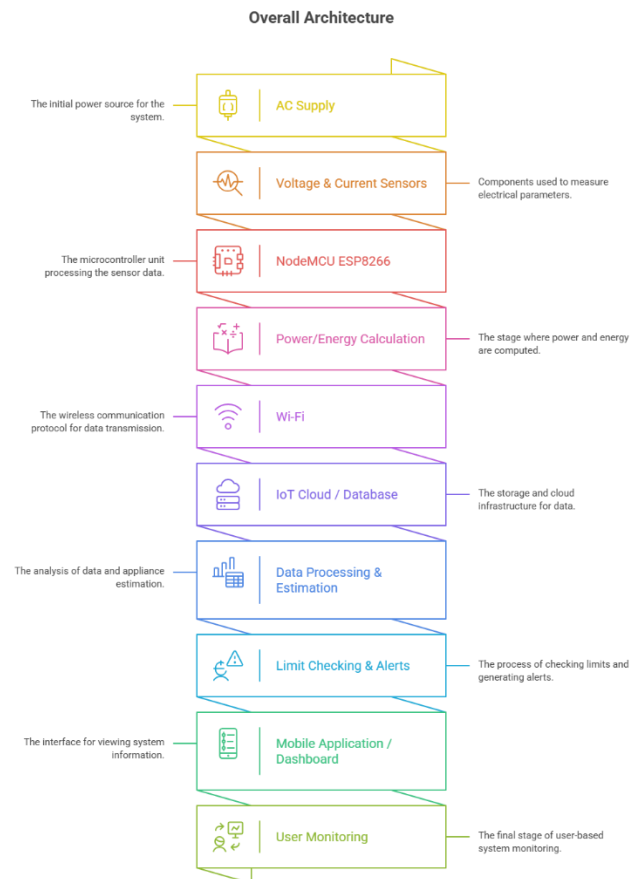


Figure 1: Proposed System Architecture The proposed architecture consists of the following interconnected components:

Data flow: Household Appliances → Energy Measurement Units → Microcontroller → Wi-Fi/IoT Communication → Server and Database → Software Dashboard.

Control flow: User Dashboard → Authenticated Control Command → Microcontroller → Switching Device → Compatible Appliance.

The measurement and control sections should be electrically isolated and installed using suitable protection. The final hardware arrangement depends on whether monitoring is performed through individual plug-in modules, dedicated appliance circuits, or a centralized multi-channel unit.

Table 1: Household Appliance Monitoring Parameters

Household appliance	Parameters monitored	Purpose
Lighting system	Power, energy, operating duration	Identify unnecessary lighting usage
Ceiling fan	Power, energy, operating duration	Compare consumption across usage periods
Refrigerator	Power, energy, operating patterns	Monitor continuous and cycling operation
Television	Power, energy, operating duration	Estimate consumption during entertainment use
Washing machine	Power, energy, operating cycle	Determine energy used per operating cycle
Air conditioner	Power, energy, operating duration	Evaluate the effect of cooling usage
Water heater	Power, energy, operating duration	Monitor high-power heating operation
Kitchen appliances	Power, energy, operating duration	Compare consumption during cooking activities

The table lists parameters that the proposed system can monitor; it does not represent measured experimental results. Actual appliance coverage depends on the number of measurement channels and the electrical installation. For electricity cost estimation, the system can apply the relevant tariff to the accumulated energy readings. For a simple constant-rate tariff, the estimated energy charge is calculated as:

$$\text{Estimated Energy Cost} = \text{Energy Consumption (kWh)} \times \text{Tariff (₹/kWh)}$$

The final bill may differ because of additional charges and tariff conditions. Recording actual measurements over several days

or weeks would enable more meaningful comparisons and evaluation of the system's performance.

IV. CONCLUSION

The proposed IoT-Based Smart Energy Meter for ApplianceWise Electricity Monitoring and Control provides an approach to improving household energy management through detailed monitoring of individual electrical appliances. By integrating energy measurement sensors, a microcontroller, IoT communication, and a software dashboard, the system can present real-time power readings, accumulated energy consumption, operating duration, and estimated electricity costs. Appliance-wise charts and historical records help users identify highconsumption devices and understand household energy usage patterns. The remote control and alert functions can further support efficient appliance operation by enabling authorized switching and notifying users about predefined consumption limits. The system's practical performance depends on measurement accuracy, communication reliability, sensor coverage, and safe electrical integration. Future development may include machine-learning-based consumption prediction, abnormal-usage detection, automated energy-saving schedules, and integration with renewable energy systems. Overall, the proposed approach can contribute to greater energy awareness, improved monitoring, and more informed household electricity management.

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