RESEARCH ARTICLE OPEN ACCESS

IoT-Based Room and Appliance Level Energy Monitoring System Using ESP32

Ms.Sowmiya .S** , IndhumathiG**, PavithraG**

*Assistant Professor –Department of CSE
**UG Students-Dept. of Computer Science Prince Shri Venkateshwara Padmavathy Engineering College Chengalpattu, India

***Abstract*— Household energy consumption has seen a sharp increase with the growing adoption of electrical appliances and smart devices. Conventional energy meters can only measure cumulative energy consumption.They do not provide detailed analysis of energy consumption at the room level or appliance level. Such limitations prevent energy consumers from accurately identifying energy- intensive appliances and developing effective energy-saving strategies.A new concept of a real-time IoT-based energy monitoring system using an ESP32 microcontroller for analyzing energy consumption at the room level or appliance level is proposed in this paper. The proposed system includes the integration of current sensing modules with wireless cloud communication. Such a system will enable continuous energy monitoring, storage, and visualization using a web-based interface. Mathematical modeling will be used to calculate the energy consumption in real-time. Experimental results showthattheproposedsystemcanmeasureenergyconsumptionwith high accuracy upto an acceptable limit.In addition,the results how that the proposed system can communicate with the cloud with low latency. The proposed system can be considered cost-effective for smart home energy management systems.**

***Keywords* — IoT, ESP32, Smart Energy Monitoring, Appliance- Level Analysis, Cloud Computing, Energy Optimization, Embedded Systems.**

I. INTRODUCTION

The consumption of energy in residential ease of electric appliances. The efficient monitoring and management of electric consumption have become essential to avoid energy wastage and commercial buildings has increased over the past few years due to the increased ud increase power efficiency. The electric meters available in the market only show the overall electric consumption in a building but do not show the electric consumption of specific appliances or rooms in a building.

Without the overall monitoring of electric consumption in building, users cannot easily identify which appliances consume more electric energy. This results in the inefficient use of electric energy and increased electric bills. Smart energy monitoring systems can be developed using Internet of Things technology.

The IoT technology helps the sensor/microcontroller to collect electrical parameters like voltage, current, power consumption, etc., and send the data to the cloud platform for further analysis. Among various microcontrollers available for the project, ESP32 isthemostcommonlyusedmicrocontrollerforIoTprojectsdueto its and enhance the efficiency of energy management [2], [5]. Other researchers have also conducted research on smart home-based energy management systemsusingcloudtechnologytovisualizeelectricityconsumption Wi-Fi capabilities, processing power, and low power consumption.The paper proposes an IoT-based energy monitoring system that utilizes ESP32 technology in measuring the energy consumption of a room and an appliance.

The system utilizes sensors that collect real-time data related to electricity consumption, processes this data through an ESP32 microcontroller, and transmits it to a cloud server. A web interface is also provided that helps users visualize their energy consumption through various graphs and charts.The proposed system helps users understand their energy consumption patterns and take required measures to save electricity.

II. LITERATUREREVIEW

Some research works have been conducted on the development of smart energy monitoring systems using IoT technology. The main aim of the smart energy monitoring system is to obtain real-time information on electricity consumption

using dashboards and mobile applications [4], [10], [15]. These smart home-based energy management systems enable users to obtain real-time information on electricity consumption and identify the appliances that are consuming high amounts of

electricity [6], [9].However,most smart home-based energy management systems are only able to obtain information on total electricity consumption andareunabletoprovideinformationonelectricityconsumptionat multiple levels [11], [13]. Hence, there is a need to develop an efficient IoT-based system that enables monitoring of electricity consumption at multiple levels.

Recent research has also focused on the development of IoT-based smart energy monitoring systems that utilize microcontrollers for monitoring different electrical parameters such as voltage, current, and power consumption [1], [3], [8]. The development of Arduino and Wi-Fi-based systems for the purpose of energy monitoring, where cloud services are used for visualization, has also been discussed in recent research studies [2], [10]. It is, however, importanttounderstandthatthesesystemsneedadditionalhardware components for wireless communication.

With the development of microcontrollers such asESP32,it is now possible to incorporate sensing, processing, and wireless communication capabilities in a single system. Energy monitoring systems based on ESP32 have achieved better performance compared to traditional ones, along with a decrease in hardware architecture and system costs[1],[3],[4],[8].Such systems help in efficient data acquisition, real-time monitoring, and cloud-based management for smart home applications.

III. RELATEDWORK

Some studies have been carried out on the use of Internet of Things (IoT) in the management of electricity consumption in residential and commercial areas.IoT devices are normally used for measuring and analyzing electricity consumption in real-time. Previous studies were aimed at designing IoT devices that could be used in measuring electricity consumption in a residential area. IoT devices are normally integrated with cloud technologies, which are used in measuring electricity consumption in a residential area. This enables users to make informeddecisionsonhowbesttheycanreducetheirelectricity expenses.

Other studies suggested the implementation of smart energy monitoring systems that can collect electrical parameters from variousappliceslikecurrentandvoltage.Thedataisthensent to a cloud server with the help of wireless communication technologies. The data can be accessed with the help of mobile applications or the Internet to visualize the patterns of energy usage. Another research on the implementation of IoT-based energy management systems emphasizes the significance of monitoring the usage of each load in buildings to avoid energy wastage.Thesystemallowsuserstomonitortheusageofvarious electricaldevices.Theresearchalsosuggeststheimplementation of control strategies for efficient power management.

Moreover, recent studies have also introduced device-level energy monitoring system technologies that can be used to measure the powerconsumption of appliances directlyfromthe appliances without changing the electrical infrastructure. Such technologies can be used to analyze the behavior of appliances and detect abnormal patterns of electricity consumption.

Further, recent smart home technologies have also introduced data analytics technologies to improve the efficiency of electricity consumption. Such smart home technologies can be used to monitor and control electrical appliances to minimize electricity consumption.

Although these systems have already provided significant insightsintoenergyconsumptionpatterns,mostofthesesystems have concentrated on total household energy monitoring. There has been less emphasis on detailed energy monitoring at the room level or appliance level using cost-effective IoT devices like ESP32. Therefore, the proposed system has focused on developing a cost-effective IoT device that can be used for electricity consumption monitoring at both the room level and the appliance level.

With the advent of Internet of Things technologies, several researchers have focused on developing an intelligent energy monitoring system for residential and commercial buildings. Several energy monitoring systems based on IoT technology havebeendevelopedusingArduinomicrocontrollertechnology along with Wi-Fi technology for monitoring electrical parameters such as voltage, current, and power consumption. These systems were used for remote monitoring of electricity consumption through web applications.

Theusageofseparatecommunicationmodulesincreasedsystem complexity and cost, which led several authors to propose a single-board microcontroller-based system for monitoring electrical parameters.

Recent research has also investigated the implementation of modern microcontrollers like ESP32, which has built-in Wi-Fi and Bluetooth capabilities that allow energy monitoring systems to send data directly to the cloud without the need for additional hardware.SmarthomeenergymonitoringsystemsthatutilizeIoT sensorsalongwithcloudcomputinghavealsobeenresearchedfor their capabilities in storing electricity consumption data for remote monitoring. Some research has also focused on the monitoring of individual appliances, where sensors are used to monitor the electricity consumption of individual appliances compared to traditional methods that only monitor overall household consumption.

In addition, data analytics and visualization are used for the visualizationofelectricityconsumptionpatternsusinggraphsan d charts. However, most existing systems only monitor overall household consumption; hence, there is a need for IoT systems that can be used for monitoring both room and appliance consumption levels.

IV. PROPOSEDMETHODOLOGY

A. System Overview

The proposed IoT-based room and appliance level energy monitoring system would enable the measurement, monitoring, andanalysisoftheelectricalenergyconsumedbytheappliances. The proposed system would consist of current sensors, voltage sensors, ESP32 microcontroller, Wi-Fi communication module, cloud platform, and a dashboard. The electrical parameters, voltage, and current would be measured for the appliances and rooms. These values would then be processed by the ESP32 microcontroller to calculate the power and energy consumed by the appliances.The processed data is then sent to the cloud serverusing Wi-Fi connectivity.Thecloudplatformstorestheenergydataandmakes it available for visualization using a web-based dashboard. The dashboard shows the real-time energy consumption using graphs andcharts,allowinguserstovisualizetheelectricityconsumption and the high power-consuming devices. The proposed system helps users understand the electricity consumption patterns and manage the energy in an efficient manner.

B. DataAcquisitionModule

The data acquisition module is the component of the system responsible for collecting electrical parameters from various electrical appliances and rooms. This module comprises current sensors and voltage sensing circuits, which are connected to the electrical loads.

The electrical parameters sensed by the current and voltage sensors include:

- Voltageappliedtotheelectricalappliance
- Currentpassingthroughtheelectricalappliance

Theelectricalsignalssensedbythecurrentandvoltagesensors are converted to analog signals, representing the electrical characteristics of the electrical appliance. These signals are then connected to the analog pins of the ESP32 microcontroller. The ESP32 uses these analog signals and changes them to digital values using its inbuilt Analog to Digital Converter (ADC) module.Thevaluesarethenusedbythemicrocontrollertoobtaint he electrical properties of the appliances. The continuous data acquisition helps in real-time monitoring of the electrical consumption. The data is used to calculate the electrical consumption and obtain the pattern of consumption. This module is an important part in ensuring that the measurement and monitoring are precise and accurate.

C. PowerandEnergyCalculationModule

Oncethevaluesofvoltageandcurrentareobtained,theESP32 microcontroller uses them to calculate the power consumption of each connected appliance.

The electrical power consumed by an appliance is calculated using the formula:

Power=Voltage*Current

Where:

Voltage (V) is the electrical potential difference across the appliance, and

Current (I) is the electrical current flowing through the appliance. The calculated power value indicates the electrical power consumed by the appliance at that instant.

In order to find the total energy consumption over a period of time, the system will calculate the energy using the following formula:

Energy=Power* Time

Energy can be expressed in watt hours (Wh) or kilowatt hours (kWh). The ESP32 will constantly calculate this at regular intervals to find the energy consumed by the appliance. This module will help to accurately calculate the electricity consumption,whichcanthenbeusedtoeffectivelymonitorthe power consumption of the appliance.

D. DataTransmissionModule

Once this is done, the ESP32 will transmit the obtained data to a cloud server through wireless communication. The ESP32 microcontroller has a Wi-Fi feature that allows it to connect to a wireless network. After connecting to a wireless network, it will transmit energy data to a cloud server through internet communication protocols.

Thedatatobetransmitted includes:

- Voltagevalues
- Currentvalues
- Powerconsumption
- Energyusage
- Timestampofthedata

This will allow for continuous monitoring of electricity usage without physically obtaining the data.

E. CloudDataProcessingandStorage

The cloud platform is considered the main unit for storing, processing,andmanagingtheenergyconsumptioninformation received from the monitoring system. The ESP32 microcontroller sends real-time electrical parameters such as voltage, current, power, and computed energy consumption values to the cloud server using Wi-Fi connectivity. These values are received using web APIs or IoT communication protocols and stored in a structured database in the cloud platf

After storing the energy consumption values in the database, the cloud platform performs basic processing operations such as organizing the received values, recording time, and filtering the values for precise monitoring. The cloud platform stores historical energy consumption values in the database, enabling long-term analysis of the pattern of consumption of electricity in various rooms and devices.

Cloud storage allows for access to the monitoring system from a remote location through an internet connection. The information storedinthecloudcanbeaccessedthroughavisualizationsystem. Moreover,thecloudallowsforupdatestotheinformationstoredin it.Thishelpsinmonitoringtheelectricityconsumptioninrealtime . Thistypeofstoragesystemhelpsinimprovingthereliabilityofthe energy monitoring system.

F. VisualizationandMonitoringDashboard

The visualizationandmonitoring dashboardis an essential part of the suggested energy monitoring system because it allows users to interact with the system in a user-friendly way to monitor their electricity consumption. The system will fetch the stored energy data from the cloud server and display it to the user in a clear and understandable way. By converting the electrical parameters to a visual representation, users will be able to easily understand their electricity consumption pattern.

The visualization and monitoring dashboard will display various parametersregardingelectricityconsumption.Theparametersw ill include the real-time voltage level, current level, power consumption, total energy consumption, and other parameters for variousroomsandappliancesinthebuilding.Thesystemwillalso displayhistoricalenergyconsumptiondatatoallowuserstoanaly ze how electricity consumption varies.

The visualizationandmonitoring dashboardis an essential part of the suggested energy monitoring system because it allows users to interact with the system in a user-friendly way to monitor their electricity consumption. The system will fetch the stored energy data from the cloud server and display it to the user in a clear and understandable way. By converting the electrical parameters to a visual representation, users will be able to easily understand their electricity consumption pattern.

The visualization and monitoring dashboard will display various parametersregardingelectricityconsumption.Theparametersw ill include the real-time voltage level, current level, power consumption, total energy consumption, and other parameters for variousroomsandappliancesinthebuilding.Thesystemwillalso displayhistoricalenergyconsumptiondatatoallowuserstoanaly ze how electricity consumption varies.

Thedashboardalsoincludestheabilitytocontinuouslyupdateth e data from the cloud server, thus allowing the user to monitor the energy consumption in real time. As new data becomes available from the system, the dashboard refreshes to present the user with the new power consumption details. This enables the user to monitor the status of the appliances and the effect of turning them on or off.

Anotherimportantaspectofthemonitoringdashboardistheabili ty topresenttheuserwithdetailedinsightsintotheenergyconsumed by the rooms and the appliances. This would enable the user to selectaparticularapplianceorroomandobtainthestatistics ofthe energyconsumedbytheapplianceorroom. Thiswouldenablethe user to identify the inefficient appliances and take the necessary steps to reduce the energy wastage.It can be concluded that the visualization and monitoring dashboardisanimportantpartoftheproposedsystem,asitwould enable the user to transform complex electrical data into useful information.

G. EnergyMonitoringandAnalysis

The final step of the proposed methodology is to analyze the energy consumption data, as shown below, to improve energy efficiency. The system continuously monitors the energy usage patterns and compares the energy consumed by different appliances and rooms. This helps to identify the appliances consuming abnormally high energy.Theusercanusethedatato:

- Changeinefficientappliances
- Reduceunnecessaryenergyconsumption
- Optimizeenergyconsumption

Theenergymonitoringsystemprovidesapracticalsolutionforthe effective management of the electrical system. By using IoT technology,cloudstorage,andreal-timevisualization,thesystem provides a powerful platform for the effective monitoring and management of the electrical system.

V. CONCLUSION

ThepaperhasdiscussedadesignandimplementationofanIoT-basedroomandappliancelevelenergymonitoringsystem.The proposed system allows users to track energy consumption in real-time. The proposed energy monitoring system includes a sensing module, processing module, wireless communication module, and a cloud server. The electrical parameters such as current, power consumption, and energy usage are measured using sensors. The data is then processed using an ESP32 microcontroller. The data is then transmitted to a cloud server using Wi-Fi connectivity.