SMART HOME ENERGY CONSUMPTION MONITORING SYSTEM USING IoT

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ABSTRACT

The Smart Home Energy Consumption Monitoring System Using IoT is an Internet of Things (IoT) solution that provides continuous monitoring and control of household appliance electrical energy consumption. The system has been developed using the ESP32 microcontroller module as the main central processing and communication module. The electrical values of voltage and current are measured in real time using the voltage sensor and the ACS712 current sensor. The power and energy consumption values are then calculated and sent wirelessly to a monitoring platform. With a secured and authentication-enabled mobile application, access is granted only to a single authorized person. Using this application, energy consumption as well as control of home appliances can be done remotely by the user. A fixed limit value is also defined for each appliance, and if that value is crossed by the energy consumption value, then automatically that appliance is turned-off to save energy wastage and excessive electricity bills. This project offers a secure, efficient, cost-effective, and user-friendly way to monitor energy in smart homes and aims to facilitate efficient energy management.

***KEYWORDS**: Smart Home, Energy Monitoring, Home Energy Management, IoT (Internet of Things), Energy Consumption, ESP32, Current sensor (ACS712), Voltage sensor (ZMPT101B)*

I. INTRODUCTION

The surge in population and proliferation of technology have made electric appliances more commonly used in today's household. The use of these devices leads to increased comfort and productivity but increases electricity use. As a result, effective energy management has become a necessity in the residential sector [1],[4].

Uncontrolled usage and over-reliance on electrical equipment led to wastage of energy, high electric bills as well as overloading household electrical installations. Overloads can decrease the life of appliances and creates unsafe conditions, thus it is important to monitor and control the energy used [7],[8].

Conventional power measurement devices only provide total accumulated energy consumption during a billing period and do not enable real-time monitoring or device level information. As a result, users cannot pinpoint power-consuming devices and make corrective actions before it is too late [2].

By the Internet of things (IoT), smart systems are realized to perceive real time data, analyze somewhat and control automatically. IoT-enabled energy monitoring systems offer the visibility into how power is used and how it can be more effectively managed in smart homes [3],[4].

In IoT energy monitoring devices, sensors, micro controllers and wireless communication technologies are adopted to capture and broadcast the electrical data on real time basis. These are all economical systems, and for household applications smart power management is now within reach [9][10].

In this project an IoT based Smart Home Energy Monitoring System is designed using the ESP32 microcontroller, the ACS712 current sensor and a voltage sensor. It monitors voltage and current, computes real-time power and energy usage, and sends the data wirelessly [9][10].

A secured authentication based smart phone applications that allows only authenticated users for power monitoring and to access the appliances. A predetermined threshold value is allocated for each appliance, and if the energy consumed exceeds this value, the device of interest is disconnected automatically so as not to trip power sufficiently [5][8].

The developed system is as a secure, reliable, and efficient solution for smart home energy monitoring. Through real-time monitoring, remote control, and automatic protection functions to reduce power costs, increase energy savings and help you live a more sustainable and efficient lifestyle [11][14].

II. LITERATURE STUDY

There exist many research projects on IoT-based energy monitoring systems for high-impact outcomes to achieve energy saving, reduce electricity consumption and provide real-time appliance level monitoring in a home environment

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[2]. Microcontroller based IoT enabled smart meters and energy monitoring devices (I) Microcontroller-based ESP32, Arduino, Node MCU, etc. used in smart meters and home automation systems help to monitor voltage/current/power parameters continuously. They offer instant data visualization on mobile or web applications that allow customers to monitor usage behaviours and locate high energy consuming appliances. All the studies report that appliance-level monitoring is beneficial for energy savings and increases user awareness on electricity consumption. [1] [2] [3] [4]

In smart energy monitoring systems one very important area of research is the secure data capture, transmission and user authentication. Several research use authentication based mobile or cloud platforms to guarantee that only authenticated users access the energy data and appliances. Having IoT-based systems where access is limited or encrypted communication are enabling one to ensure reliability and stop unauthorized use of the system. These works argue that secure user authentication is crucial for safe and reliable smart home energy management system. [5] [6]

Real-time monitoring and automatic control to avoid overspend of power consumption is the key point in their research. Devices based on predetermined threshold values for appliances when the power consumed exceeds safety levels, has an automatic load shedding. Such automatic protective devices contribute to a reduction in electricity costs, avoid overloading and increase the safety of an electric device. The research findings suggest that smart home energy management can be greatly improved by intelligent control algorithms and instantaneous status feedback. [7] [8]

Some works examine low-cost sensor energy monitoring solutions based on current sensors like ACS712 and voltage sensing modules. These sensors can measure electrical parameters effectively when combined with microcontrollers. The experimental results show that our sensor-based monitoring systems are reliable even with low cost and thus, they could suit for residential, individual substation level. The research indicates that low-cost sensor integration is the key to promote penetration of smart energy monitoring systems in the market. [9] [10]

Another interesting line is about mobile and cloud data visualization and user interaction. Real-time and historical energy consumption data can be displayed to users in a user-friendly manner with the help of Dashboards and Mobile Apps which are IoT enabled. These systems allow remote control of appliances and monitoring of consumption and alerts. It demonstrates through studies that user friendly interfaces will have a high positive impact on one's users, increasing his engagement and promoting responsible energy consumption. [11] [12]

Some works consider scalability and integration of smart energy monitoring system within wider smart home and smart grid settings. IoT systems using modular architectures can be scaled to support several devices and more sensors. Cloud services coupling allows long-term storage and analysis, in addition to the system scalability. These studies deduce that scalable and flexible architecture is necessary for future centric smart home energy solutions. [13] [14]

However, with the headway made so far; current smart energy monitoring systems have shortcomings including high system implementation fee, lacking of beautiful automatic features, without granular appliance level threshold control and difficult deployment. A mere monitoring without intelligent control and automatic power off is accomplished in many solutions. In addition, many systems are based on cloud infrastructure which escalates operational expenses and reliance on a web connection. Such limitations reveal an obvious research vacancy for a low-cost, safe, and smart energy monitoring system capable of real-time monitoring, automatic control, and user-friendly operation.

To close these gaps, we present the Smart Home Energy Monitoring System using an ESP32 microcontroller in conjunction with ACS712 current sensors and voltage sensor for monitoring real-time energy consumption at appliance level. Such a system features secure authentication-enabled mobile application, threshold based automatic appliance control and wireless communication for the purpose of real-time monitoring. This methodology offers an energy-smart home-based management system that is economical, simple to implement and scalable that can help in minimizing the electricity and also improving safety, providing a more sustainable solution for exploiting the resources.

III. METHODOLOGY

Emerging smart home applications are an important factor of enhancing energy efficiency, and reducing the electricity usage in urban house and building. crawler Space Under the conditions of power shortage, monitoring and intelligent scheduling of home appliances have become increasingly urgent. IoT-based smart home energy monitoring systems let people to monitor energy consumption in real-time, find out high power–consuming equipment and can make decisions towards waste reduction on timely basis. They make use of sensors, microcontrollers and cloud service platforms for safe control and remote power in appliances. Solutions like these don't just save people on their electricity bills; they encourage clean energy consumption and environmental preservation.

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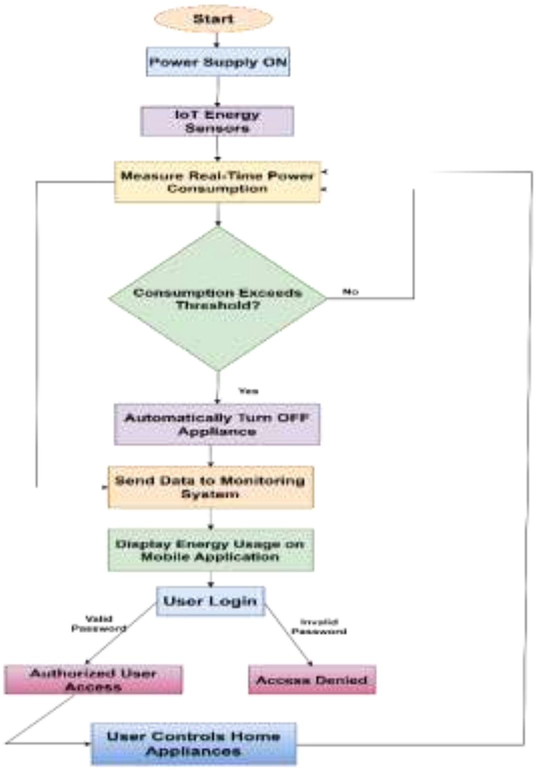

Fig.1.Flow Chart For process of Smart home energy Consumption monitoring.

The flow diagram presented below visualizes the working procedure of Smart Home Energy Monitoring System. The system starts once the power supply is switched ON and then IoT enabled energy sensors monitor real time electrical parameter values of appliances connected. Based on these sensor values, the system computes the power consumption in real time and repeatedly monitors if it crosses a pre-set threshold limit. If the value is crossed then system turns OFF automatically appliance and avoid wastage of energy and load overloading. Al the measured energy data is transmitted to monitoring system, viewable on a mobile application for user information. For security, the user needs to be authenticated in the application: for authorized users, they can check energy usage and control in-home appliances from outside while un-authorized users cannot. This procedure guarantees proper energy management, device safety and secure control at smart homes.

3. COMPONENTS DESCRIPTION

3.1ESP32(30 pin): Specifications:

- Operating Voltage: 3.3 V
- Input Voltage (recommended): 5 V (USB or VIN pin input)
- Digital I/O Pins: 30 (GPIOs have additional functions)
- Analog Input Pins: 12 (400mV of themselves to the A/D converter)
- Flash Memory: 4 MB (external)
- SRAM: 520 KB
- EEPROM: Emulated in Flash
- Clock Speed: Up to 240 MHz
- Connectivity: Wi-Fi (802.11 b/g/n), Bluetooth (Classic + BLE)

Fig.2.Esp32Module.

3.2 Current Sensor (ACS712): Specifications
- Operating Voltage: 5 V
- Current Type Measure: AC and DC
- Range: 30 A (module specific)
- Sensitivity: 66 mV/A (30 A version)
- Output Type: Analog Voltage
- Isolation: Galvanic isolation based on Hall effect
- Working Temperature is between -40°C and +85°C

Fig.3.Current Sensor (ACS712)

3.3. Voltage Sensor (ZMPT101B): Specifications
- Operating Voltage: 5 V
- Input Voltage Min 0 V AC
- Output Type: Analog Voltage
- Measurement Type: AC Voltage
- Isolation: Electrical isolation with precision voltage transformer
- Adjustable Gain: Onboard potentiometer

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- Measurement Type: AC Voltage
- Isolation: Electrical isolation with precision voltage transformer
- Adjustable Gain: Onboard potentiometer
- Frequency Response: 50 Hz – 60 Hz
- Performance: High accuracy with low phase error

Fig.4.Voltage Sensor (ZMPT101B)

3.5 Relay Module: Specifications:
- Operating Voltage: 5 V DC
- Number of Relays: 4-Channel
- Relay Type: Electromechanical (SPDT)
- Contact Rate: 10 A @ 250 VAC / 10 A @ 30 VDC
- Control signal: input with TTL level compatible (IN1-IN4)
- Contacts: Common (COM), Normally Open (NO), Normally Closed (NC)
- Isolation: Optical coupling input (JD-VCC option)

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Fig.5: Relay Module

IV. RESULTS AND DISCUSSION

Successfully implemented an IoT based Smart Energy Monitoring System using ESP32, current sensor, relay module and LCD display. Different values of loads are applied to the system, and results obtained from testing confirm that the mechanism is functioning per its desired behaviour.

Hardware Setup consists of ESP32 microcontroller interfaced with current sensor module and relay board for monitoring and controlling multiple electrical loads. The real-time measured parameters like voltage, current, power and energy consumption are shown on a 16×4 LCD screen.

From the experimental results:

- Under low load conditions, the display reports voltage ≈ 223 V, current ≈ 0.06 A and power ≈ 0 W.
- System calculations of energy consumption are now in kWh.
- Hence, the relay module is successful to control them 4 Load1–Load4.

The IoT setup with Blynk platform allows for remote monitoring. The web dashboard displays:

- Voltage (indicates simulated/processed value) =30.0±−0.005 V Voltage ≈ 350 V
- Current ≈ 19–28 A
- Power ≈ 11,796 W
- Energy consumption ≈ 5.917 kWh
- Billing units = Daily unit usage * number of days in billing cycle

A plot on the dashboard showing voltage, current and power changes over time which shows live data logging and visualisation.

4.1. Hardware prototype Implementation

Fig. 6: Proof of Concept Hardware Model of Smart Energy Monitoring System

The Fig.6 shows the developed prototype of IoT based Smart Energy consumption Monitoring System 3. The whole system is composed of an ESP32 microcontroller connected with Current sensor module, Relay module, LCD display and extra circuits assembled on a PCB board.

The sensor here senses the load current and the relay module is used to turn on/off multiple loads. The measured data is processed by ESP32 and sent to LCD screen as well as IoT platform. The hardware study to complete the sensing, control and communication modules integration.

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4.2. LCD Output Results

Fig. 7: Displaying Real-Time Parameters on LCD

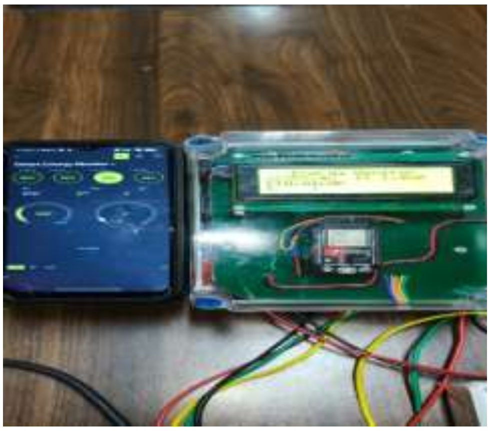

Fig:8. Mobile Controlled System

The system measures electrical parameters in real time, which are displayed on an LCD. From the observed results:

- Voltage = 223.50 V
- Current = 0.06 A
- P = 0 W (state of low load)
- Energy = 0.00 kWh

These results indicate that the system is capable of accurately measuring electrical parameters for a low-load scenario. The local instant feedback to user is given by the LCD.

4.3. IoT Dashboard Results

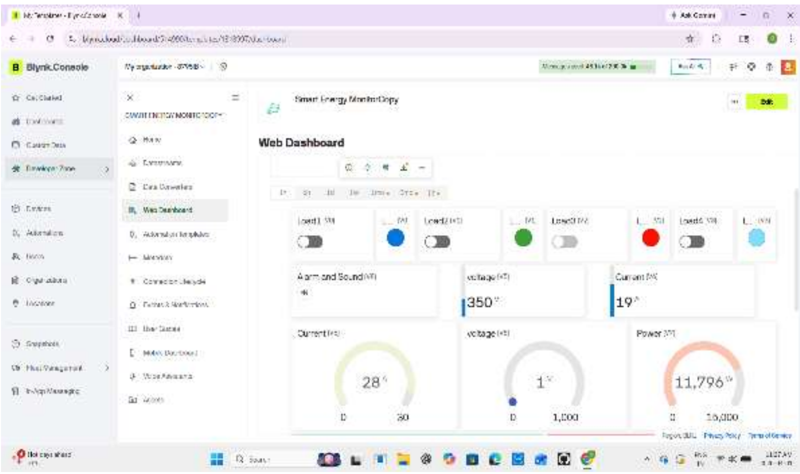

Fig. 9 - IoT Dashboard Displaying Remote Monitoring

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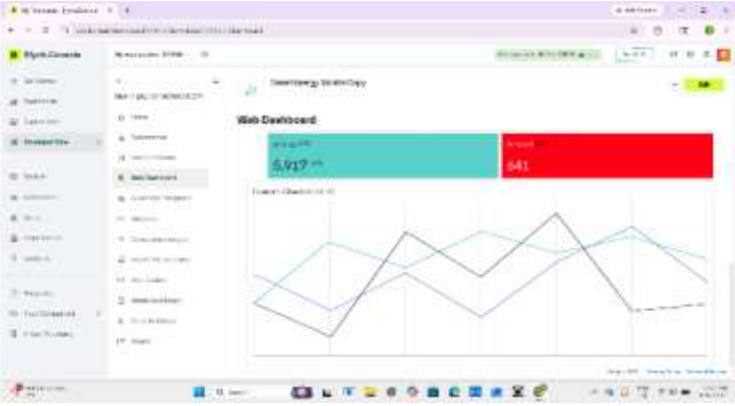

Fig.10: Observed Graph

Real-Time Monitoring and Control of Electrical Parameters Using IoT Dashboard (Blynk Platform) Data is successfully sent to the cloud and can be monitored from anywhere.
Observed values from the dashboard:
Voltage Threshold ≈ 350 V (scaled value)
Current ≈ 19–28 A
Power ≈ 11,796 W
Energy consumption ≈ 5.917 kWh
Estimated cost ≈ 641 units
The post also shows graphical representation of voltage, current and power over time which can prove real time data logging.

4.4. Relay and Load Control

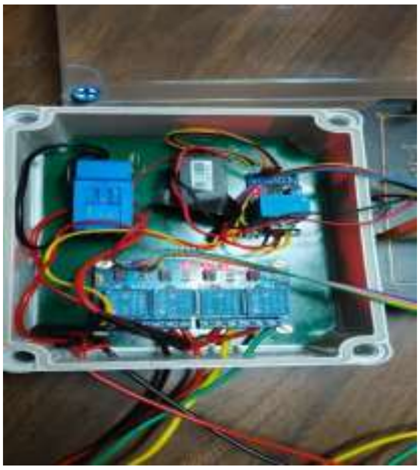

Fig.11: Relay Module and Load Control Setup

- Relay module (which controls the number of loads Load1–Load4). This system ON/OFF loads successful as per user input from IoT dashboard.
- This shows the potential of the system for remote load control and energy saving application.

4.5. Discussion

The results obtained indicate that the proposed system is functional for monitoring and controlling of electrical parameters in real-time. Sending ESP32 with IoT Esp8266 Platform Integration
Local monitoring is achieved through an LCD display, and remote access coupled with graphical visualization improves usability by means of the IoT dashboard.
A small difference in the readings at the LCD and values in IoT dashboard was observed, which can be because of:

- Sensor calibration errors
- ADC resolution limitations in ESP32
- Scaling factors in software
- Network latency during data transmission
- The system performs consistently and delivers reliable results despite such differences.
- Key benefits of the system include:
- Real-time energy monitoring
- Remote load control
- Energy consumption tracking
- Cost estimation

Therefore, the designed system is an economical and extensible approach for smart energy monitoring applications.

V. CONCLUSION

Using ESP32, current sensing module, relay unit, LCD display and a cloud-based IoT platform the proposed Smart Energy consumption Monitoring System was designed and successfully implemented. The hardware can accurately capture voltage, current, power and energy consumption which will be displayed both locally and remotely. Results of the experiment show that the designed system proves efficient for real-time monitoring; whereas, adding an IoT dashboard to which users can remotely connect and control electrical loads enhances convenience while improving energy management.

The system proves a cost-efficient and scalable solution in smart energy applications for home or industry. It showed some discrepancies due to the sensor resolution and communication delays, but in general, it worked well. Energy monitoring and cost estimates are among the various tools available to reduce energy waste through features like these. Future research directions may include transfer learning with domain adaptation for sensor recalibration, real-time alert systems and smart algorithms integration for energy efficiency and prediction.

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