**A systematic literature review of Smart Power Monitoring and Controlling Systems for smart homes**

***Abstract***

The increasing energy generation expenditure makes it become very expensive for the users. This problem directs the attention of research to either searching for new cheap sources of energy or increasing the awareness of the importance of the energy among individuals. Recently, modern living standards have been significantly changed by the quick development of technology, which has increased demand for smart homes automation solutions. However, current systems are only accessible to a select group of experts and wealthy consumers because of their high complexity, high costs, proprietary limitations, and incompatibility across different standards. This study examines several studies that tracking and controlling energy consumption in smart homes, showing their characteristics and methods. In addition, it highlights the limitations of current systems and suggests more adaptable, scalable and independent system architecture that may improve the efficiency of these systems. Most of the research inform each home of their excess consumption through a simple mobile application that anyone can understand. It serves the consumer on a personal level by rationalizing electricity consumption and also achieves rationalization of general consumption of energy.

***Keywords***

Smart homes, Power consumption, IoT ,Sensors ,AI

**1. Introduction**

Lately, the power problems have become trend in many research. Some of them focus on generating renewable energy from wind, solar and hydropower [1-2] while others search for ways to control and manage the consumptions of the power that already have [3-4]. One of these ways is using AI to reduce the loss on the power lines [5] or using machine learning to control MPPT (maximum power point tracking) to enhance the extracted energy [6]. Other ways are using sensors to measure the consumption and inform the users with the needed data to take action accordingly in smart cities [7-8].

Since smart power monitoring and control systems are becoming crucial in modern societies due to the growing demand for energy efficiency [9-14]. Consequently, a variety of current studies on power monitoring, Internet of Things (IoT) – based home automation, and smart control systems are reviewed in this research. Additionally, some modifications and components are recommended to be added to the reviewing papers then a comparison is virtually held emphasizing the special benefits and features of the suggested one.

The paper is organized as follows: Section 2 shows a brief idea of the reviewing papers with their characteristics. Section 3 illustrates some recommendations in detail for future works and comparison between the suggested system and the existing research. the conclusion and more compacted points for future work are presented in Section 4.

***2. The reviewing paper***

***T.E Babalola et al in [15]***develops smart sensors to monitor the weather in environment. The system monitors environmental changes such as temperature and precipitation. The data collected from the sensors is available to users through a website. The data is displayed as graphical statistics on the web site's design in the form of web portal information.

***L. Syafaah et al in [16]*** investigates the deployment of an IoT- based smart home system for power consumption-based monitoring and controlling of household electronics. The MQTT protocol is used to optimize bandwidth utilization, and the ESP8266 module is integrated for data transfer. A temperature and humidity sensor, current sensors, and an AC relay for power regulation are among the several sensor modules that make up the arrangement. Sensor and client nodes act as publishers and subscribers, while a MQTT broker (a Raspberry Pi 3+ and a cloud server) controls data exchange.

Both Line of Sight (LOS) and Non-Line of Sight (NLOS) scenarios were used to assess the ESP8266 module's viability. While LOS transmission remained stable up to 50 meters but degraded beyond 75 meters, the results demonstrated negligible packet loss (almost 0%) up to 14 meters under NLOS situations. Without using more electricity, the MQTT protocol successfully decreased bandwidth utilization. The study comes to the conclusion that, as long as the data size is tuned for effective communication, the ESP8266 is a dependable option for smart home applications.

***V. Nandhini et al in [17]*** emphasizes effective energy management in homes by automating power source switching and maximizing the usage of renewable energy sources, such solar electricity. By combining solar power, battery storage, and the AC grid, the system lowers electricity costs and lessens reliance on non-renewable energy sources while guaranteeing a steady supply of power. Battery State of Charge (SoC) is estimated using techniques like Open Circuit Voltage and Coulomb Counting, and automatic switching is dependent on load type, battery charge levels, and grid availability. Additionally, customers can remotely operate household appliances with an Android application that supports Bluetooth.

Results show that the system successfully gives renewable energy top priority, guaranteeing a steady supply of electricity and economical energy use. The inverter effectively transforms 24V DC from the battery into 230V AC for domestic usage, and its Bluetooth-enabled smart control adds ease for the user. All things considered, the suggested energy management system effectively strikes a balance between grid and renewable energy, making it a workable and intuitive option for contemporary households.

***A. T. Suryanto et al. in [18]*** focuses on creating an intelligent energy management system (EMS) for smart homes that is based on IoT and allows for effective switching between solar power and grid electricity. A Node-MCU microcontroller, a relay module to handle power transitions, and a number of sensors for voltage and current monitoring are all integrated into the system. A smart phone app that offers real-time energy consumption data through cloud-based communication allows users to manually or automatically regulate the switching process.

High sensor accuracy (over 98%) and quick switching times (0.74–1.33 seconds) have been proven during performance testing. By prioritizing renewable energy when it is available, switching to backup power when battery voltage exceeds 12.75V, and returning to the grid below 10.5V, the system efficiently lowers energy waste and electricity costs. This EMS is a useful and effective solution for contemporary houses because of its smooth functioning and IoT-based remote control.

***M. R. Gundavarapu et al. in [19]*** focuses on creating an affordable smart home automation solution with IoT and Amazon Alexa. With the help of Alexa, users may remotely monitor and control non-smart devices using speech and text instructions then eliminating the need for face-to-face communication. It incorporates relay modules for turning appliances on and off. It uses Node-MCU (ESP8266) for Wi-Fi connectivity, and Alexa Echo as a voice-activated hub. Device status and user commands are recorded in the cloud, and software is implemented using the Arduino IDE and Alexa Skill Kit (ASK) to integrate smart commands.

By effectively automating household appliances and shutting off unwanted ones, the system optimizes energy use. Device authentication is one of the security measures, and privacy protection will be improved in the future. It provides an effective, scalable, and user-friendly smart home solution at a minimal installation cost, making it accessible to non-smart houses.

***I. S. Balabanova et al. in [20]*** uses artificial neural networks (ANNs) and adaptive neuro-fuzzy inference systems (ANFIS) to create a voice control system for smart home automation. To replicate real-world functionality, a 3D smart home model was developed that incorporates AI-driven voice command processing for controlling the climate, lighting, power, and security. The technology uses 16 sound indicators and AI models that have been taught to accurately understand and carry out spoken orders.

Testing revealed that while ANFIS increased adaptability in lighting and climate management, ANNs reached 100% accuracy in regulating house entry and electricity systems. With a low error rate of 0.0174, the top AI model guaranteed dependable performance. Physical interaction is less necessary because of the system's safe, hands-free functioning. This AI-driven automation system provides a highly precise, flexible, and efficient solution for contemporary smart homes by fusing fuzzy logic with neural networks.

***S. Bimenyimana et al.in [21]*** focuses on creating an online smart home control system that lets consumers control electrical equipment from a distance, saving energy and increasing efficiency. The system integrates a web interface that can be accessed by PCs, tablets, or smartphones, a relay module for power control, and a Node-MCU (ESP8266) microcontroller for Wi-Fi communication. Through the web interface, users may send commands that the Node-MCU processes to control the condition of the device. LED indicators provide real-time feedback.

According to the results, the system successfully enables remote control of household appliances, guaranteeing dependable and effective operation. With possible future improvements like automatic scheduling and real-time energy monitoring for increased convenience and efficiency, it offers an affordable energy management solution.

***A. Oltean et al. in [22]*** focuses on creating a low-cost IoT power monitoring gadget that uses Arduino and Wi-Fi to track electricity in real time. In order to assess voltage, current, power, and power factor, the system incorporates sensors. The data is then sent over Wi-Fi to a cloud-based platform for analysis. In order to optimize power usage and minimize waste, users can access a web dashboard to track historical data and real-time energy consumption.

Results show precise power readings and useful power factor analysis, enabling users to spot inefficiencies. The system allows monitoring remotely using cloud storage and IoT. It is scalable and compatible with smart grid integration. With future enhancements including automated load control and AI-driven energy projections, this system offers an economical and effective method of energy management.

***J. Chandramohan et all. in [23]*** offers a flexible affordable smart home automation and security system that uses an Arduino microcontroller with Wi-Fi and an Android app to allow customers manage and monitor household equipment remotely. The system incorporates a number of sensors, such as a PIR motion sensor for security, an LM35 temperature sensor for climate management, and an LDR for automated lighting control. Electrical appliances are controlled by a relay circuit, and users are warned of unlawful movements by a buzzer alarm.

The results demonstrate that the system improves security through motion detection, enables remote appliance management with an Android app, and efficiently lowers energy use by automating lighting and fan control. Because of its scalability and affordability, the Wi-Fi-based architecture is a viable option for home automation. To further increase efficiency and usefulness, future improvements might incorporate voice control, AI-driven automation, and smart grid integration.

***I. M. Nayyef in [24]*** presents a smart power monitoring and management system based on a wireless sensor network (WSN) that uses IoT technologies to track and regulate electrical appliances in real time. The Arduino Uno, which is coupled to sensing nodes with voltage and current sensors, wirelessly sends data to a base station via ZigBee. After that, a Node-MCU (ESP8266) links the device with the cloud, enabling users to track power usage via the Blynk App - a smartphone app.

With voltage inaccuracy at ±0.3%, current at ±1.5%, and power at ±1.8%, the results demonstrate excellent measurement accuracy. By allowing remote appliance control and automated power shutdown if usage surpasses 13A, the device effectively lowers energy waste. Power factor analysis also aids in locating inefficient usage trends. With potential future enhancements like AI-driven automation, load prediction, and smart grid connectivity, this IoT-based solution provides an economical and effective method of energy management.

In conclusion, smart power management with IoT and automation technologies is covered in the presented study. It examines several methods for remotely operating electrical appliances and maximizing energy efficiency. According to the results, putting IoT-based control into practice improves energy efficiency while giving consumers more control over their usage. Table 1 shows a summary of the previous research. Consequently, some suggestions are put to track and manage power consumption within the house with higher efficiency. Numerous characteristics of the suggested system are listed later.

**3. Recommendations for future works and comparison between the suggested system and the existing research**

Some modifications are recommended. These modifications may lead to higher accuracy and efficiency. They are as follows:

*1. Microcontroller Choice*

We suggest using Arduino Mega due to its larger number of I/O ports and enhanced communication capabilities. The ESP-01 Wi-Fi module is used separately. However, most studies use Arduino Uno (simpler, fewer ports) and some of them use Node-MCU (ESP8266) which has built-in Wi-Fi. Others use Raspberry Pi for advanced processing. In other words, using Arduino Meg offers greater flexibility and supports multiple sensors and communication protocols simultaneously which may give great advantage for the system.

***Table 1: power monitoring and controlling research***

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **References** | **Technology** | **Function** | **Shutting the equipment automatically** | **Voice** | **Extra features** |
| [15] | IoT | weather monitoring system | X | X | Data can be accessed remotely using Internet enabled  devices. Sensors collect and transmit  real-time weather data to a remote web server via the internet. |
| [16] | IoT | power consumption monitoring and control of household electronics | √ | x | Using ESP8266 module's make the transmission range small. |
| [17] | an Android application that supports Bluetooth | automating power source switching | x | x | Switching between power grid and solar energy |
| [18] | IoT | switching between solar power and grid electricity | x | x | Switching between power grid and solar energy |
| [19] | IoT and Amazon Alexa | remotely monitor and control non-smart devices | √ | √ | minimal installation cost |
| [20] | Using ANNs and adaptive neuro-fuzzy inference systems (ANFIS) | Voice control system for smart home automation | √ | √ | Controlling the climate, lighting, power, and security |
| [21] | Web based system | Controlling the power of Electrical equipment | √ | x | No real-time energy monitoring |
| [22] | Arduino and Wi-Fi | Power monitoring only | x | x | remote monitoring and tracking the electricity |
| [23] | Arduino microcontroller with Wi-Fi | manage and monitor household equipment | √ | x | Climate, lighting and security management |
| [24] | WSN with IoT technology | Track and regulate electrical appliances in real time | √ | x | - |

*2. Communication & Connectivity*

It is recommended using ESP-01 Wi-Fi module for internet connectivity. Using ESP-01 provides a dedicated Wi-Fi module, reducing reliance on a microcontroller with limited ports (like Node-MCU). While many of other research use Node-MCU (ESP8266) for built-in Wi-Fi and some of them use ZigBee or MQTT protocols for data transmission.

*3. Sensors & Data Monitoring*

It is recommended using three current sensors and one voltage sensor to measure real-time electrical parameters. Data is displayed on an LCD (1602A) with I2C module. However, some of other research use hall-effect current sensors (ACS712). and others use smart energy meters with cloud integration. This means the new system has local display functionality (LCD), whereas others often rely only on web/cloud interfaces.

*4. Power Control & Safety Mechanism*

It is recommended having a voltage safety mechanism. Voltage safety range (190V-240V): If the voltage goes beyond this range, the system automatically disconnects the circuit using relays. However, some other studies monitor power but do not have safety cutoffs. Others rely on alerts/notifications without automatic disconnection. This means the new system provides real-time protection, ensuring safety before damage occurs.

*5. Relay & Load Control*

It is recommended using a 4-channel relay module to control appliances. However, some of existing projects use single relays for switching and others use smart switches with cloud control. This feature gives the new system more flexibility with multiple loads, allowing independent control.

*6. User Interface & Control*

It is recommended using LCD for local monitoring and Wi-Fi module for remote access. While many existing research use mobile apps (Blynk, MQTT, web dashboards) for monitoring, some use Alexa/Google Assistant for voice control. This feature make the system ensure real-time visibility without needing internet access, unlike cloud-dependent systems.

The previous suggestion notes can be summarized as shown in Table 2.

**Table 2: Comparison between the recommended hardware and other research**

|  |  |  |  |
| --- | --- | --- | --- |
| **Feature** | **The suggested system** | **Other research** | **Advantages of the new system** |
| ***Microcontroller*** | Arduino mega | Arduino uno, NodeMCU, Raspberry PI | More I/O ports for scalability |
| ***Wi-fi communication*** | ESP-01 | ESP8266, ZigBee, MQTT | Dedicated module , stable connection |
| **Power Monitoring** | 3 current sensors + 1 voltage sensor | ACS712, smart meters | Multi sensor setup for accerancy |
| ***Local display*** | LCD (1602A) | Web / mobile based only | Real time monitoring without internet |
| ***Voltage safety cutoff*** | Auto disconnect relay (190v – 240v) | Alerts only and no cutoff | Protection against electrical damage |
| ***Relay control*** | 4-channel relay module | Single relay or cloud based | More flexibility in controlling appliances |
| ***User interface*** | LCD + WIFI App | Web dashboards , MQTT , Alexa | Local and remote control options |

**3. Conclusion and Future work**

This work serves as valuable resources and tools for researchers and developers working on cost effective and energy efficient home automation technology as it highlights on hardware and software improvements. After analyzing the given research papers, it is good idea to try to build new system upon existing methodologies while introducing significant improvements. Unlike previous studies, the new system may integrate advanced automation, real-time data analytics, and cloud-based monitoring to optimize energy consumption more effectively.

Future work could explore deeper integration with renewable energy sources, AI-enhanced power forecasting, further automation of smart energy control mechanisms, cloud integration (e.g., Firebase, MQTT) for remote logging and analysis. Voice control integration (Alexa, Google Assistant) can be added and energy usage prediction using AI/machine learning.

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Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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Details of the AI usage are given below:

1. None

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