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Research Article

Design and Implementation of an IoT-Based Smart Grid Monitoring System for Real-Time Energy Management

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Abstract:

This research project implements and designs an IoT-based smart grid and monitoring system. The main goal of this technology is energy efficiency. The system manages LCD panel output, voltage, and current sensor input using an Arduino Uno microcontroller board as the main processing unit. The design uses a ZMPT101B voltage sensor and an ACS712 current sensor. Sensor data is shown on a 16 x 2-character LCD screen in real time. When current and voltage thresholds are surpassed, MQTT messages are sent to the user's phone. The system is efficient since it can connect to the internet and communicate with the MQTT broker. This is done using the NodeMCU Wi-Fi module. The suggested technology reduces energy inefficiency and allows real-time energy monitoring. The experimental findings show that the proposed energy management system works and has several applications.

1. Introduction

As both the population of the world and the energy demand continue to rise, there is an increasing need for the development of monitoring technologies that make optimal use of energy. Developing intelligent power grids and monitoring systems that make the most of today's cutting-edge technology has emerged as a primary focus for energy industry researchers and service providers. In this setting, the technology known as the (IoT) has made it possible to make use of newly available avenues for the development of intelligent energy management systems.

In this study, we show an (IoT)-based smart grid and monitoring system that makes use of an Arduino Uno, current and voltage sensors, an LCD, and the MQTT protocol. In addition, we discuss the implications of these developments. More specifically, each current and voltage sensor detects current and voltage differently. The system monitors the electrical grid's current and voltage, displays real-time data on the LCD screen, and sends phone notifications when those numbers surpass a threshold. Our solution is practical and cost-effective for decreasing energy waste and monitoring energy consumption in real-time.

Our system has two primary parts: current and voltage monitoring. A monitoring area on the Arduino Uno contains the current sensor coupled with particular sensitivity and offset voltage settings. The voltage sensor connects to the electricity supplier's primary power source. Sensor data displays real-time voltage and current on a 16 x 2 LCD panel.

Users assess their system's performance and compare it to literature-cited systems. The technology efficiently tracks and reduces energy waste. The concluding debate emphasizes the significance of establishing sophisticated smart grids and monitoring systems utilizing IoT technology. We address future study topics in this discipline.

The user created a simple IoT-based smart grid prototype and monitoring system. The system is ideal for both households and businesses due to its easy setup, operation, and maintenance.

1.1 User-friendly interface

The prototype has a user-friendly interface that shows real-time current and voltage information on a 16 x 2 LCD screen. The display accurately shows energy usage information. The system uses the MQTT protocol to send notifications to the user's phone when current and voltage levels exceed a set threshold, enabling convenient energy usage monitoring and quick response.

1.2. Simple installation process

The installation process for the prototype is fast and can be finished in a few minutes. Prototype sensors have been used due to minimal adjustment and calibration. Where (LCD) liquid crystal display screen and Arduino Uno board which is known well for its durability & reliability. It's long-lasting which ensures minimal need for replacement. The prototype of this smart grid and monitoring system is intuitive, which is simple in process and it’s minimal to have maintenance. It is suitable for tracing energy which is useful for both residential and commercial uses. The prototype can undergo further development and improvement.

1.3 Low maintenance

The prototype's sensors require minimal calibration, requiring low maintenance. The liquid crystal display and Arduino Uno board are reliable and durable, requiring minimal replacements. IoT-based smart grid monitoring system prototype offers user-friendly installation, low maintenance, and intuitive interface for energy efficiency in residential and commercial buildings, promising further development.

2. Literature Review

Investigators and energy suppliers worldwide are increasingly focusing on smart grid and surveillance technologies. Cutting-edge technology like IoT, detectors, and data statistics are used to improve the effectiveness and dependability of the power system. Research has explored the application of intelligent grids as well as tracking systems in different settings, such as households and industrial sectors.

The research describes a smart grid and monitoring system that utilizes an Arduino Uno. It incorporates current and voltage sensors, and an LCD screen, and operates using the MQTT protocol. The system monitors and displays real-time power grid information on a display with LCD technology. The system sends notifications via text message when certain values exceed a set threshold. Our developed system effectively tracks energy usage and minimizes energy waste.

Zhang et al. (2019) created a smart grid monitoring system that used wireless sensors and cloud computing to gather and analyze energy information text provided [1]. Please rewrite the user's text as a summary. The system uses indicators to measure energy usage and identify irregularities in the energy grid. The system developed by the authors can detect anomalies in real-time, which improves the reliability of the electrical grid and reduces the risk of power outages. IoT is used in different application [2,3]. Kumar et al. (2020) proposed a smart grid monitoring system that utilizes machine learning to predict and enhance energy consumption. Please provide more information or context for me to rewrite the text into a summary [4]. The system utilized a neural network and sensors to predict energy usage patterns and measure temperature, humidity, and energy consumption. The authors demonstrated that their system could potentially reduce energy consumption by up to 15% compared to traditional monitoring systems. IoT has emerged as a new communication technology paradigm over the course of several decades. The philosophy of "anywhere, anytime, any media" inspired the development of communication technology that enables easy device connectivity in a network. The rapid development of communication technologies among equipment and the increased requirements for system optimization are driving the desirability of IoT technology, according to B. Yuxin and M. Yun's research. IoT enables the connection of numerous devices to a network, allowing for innovative applications.

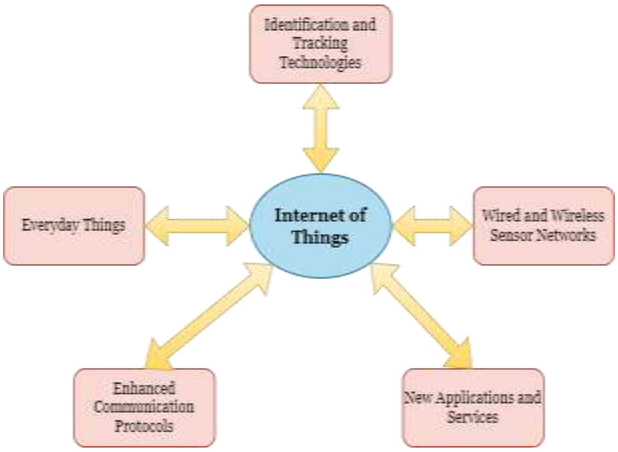

Figure 1. *IoT technology Diagram*

The connection of all of its components to Internet services is the primary idea behind the IoT [4], it involves various elements connected by a common protocol, such as Radio Frequency Identification Devices (RFID), infrared sensors, global positioning systems (GPS), laser scanners, and internet networks. This makes information transmission and communication between devices easy and effective, enabling system monitoring and position tracking. IoT systems can range from small-scale internet networks to big and complicated systems depending on the purpose and intended usage.
The author [4] has highlighted three crucial features of IoT systems.

- (IoT) collects data from physical objects using technologies like RFID, sensors, and two-dimensional codes to provide comprehensive and up-to-date information. The ability to create a network of autonomous devices has the potential to revolutionize various industries.
- Reliable transmission is crucial in the IoT as it ensures accurate data is sent to provide real-time information from objects. Telecommunications networks and the internet are integrated to create a reliable data transfer network.
- The IoT uses intelligent processing to manage large amounts of data and information. Intelligent computing technologies, such as cloud computing and fuzzy identification, are examples of advanced computing systems. The study suggests that implementing intelligent control for the item can improve effectiveness and efficiency. IoT devices can enhance operations and improve user experience through the use of cognitive processing to identify data patterns and trends.

The IoT is based on three key ideas: "things-oriented," "internet-oriented," and "semantic-oriented." All IoT-connected hardware, such as sensors, tags, and actuators, is categorized under the concept of "things-oriented." Being "Internet-oriented" refers to something that is related to the Internet network, encompassing the Internet protocol and the Internet of things. The final idea for the network that connects all IoT devices is a "semantic-oriented" network. It is the best technology to connect various devices to a network system. It's an intelligent process & developing technology.

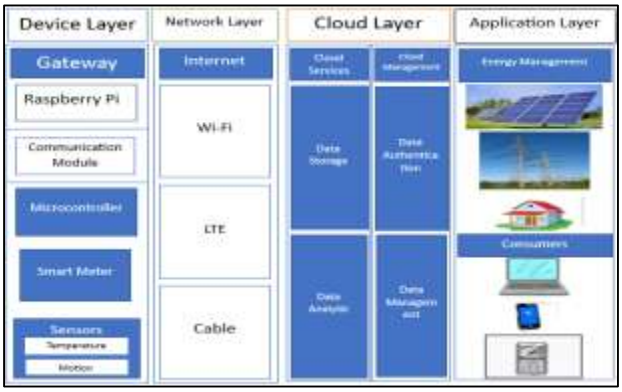

Figure 2. *IoT Layers*

MQTT is a lightweight, portal and is popularly used as one of the IoT applications for compact communication protocol. It has interaction between devices and low speed. It aims to minimize internet bandwidth & power consumption. Figure 1 is IoT technology diagram and figure 2 is IoT Layers.

3. Design Model

3.1 Arduino Uno Microcontroller Board

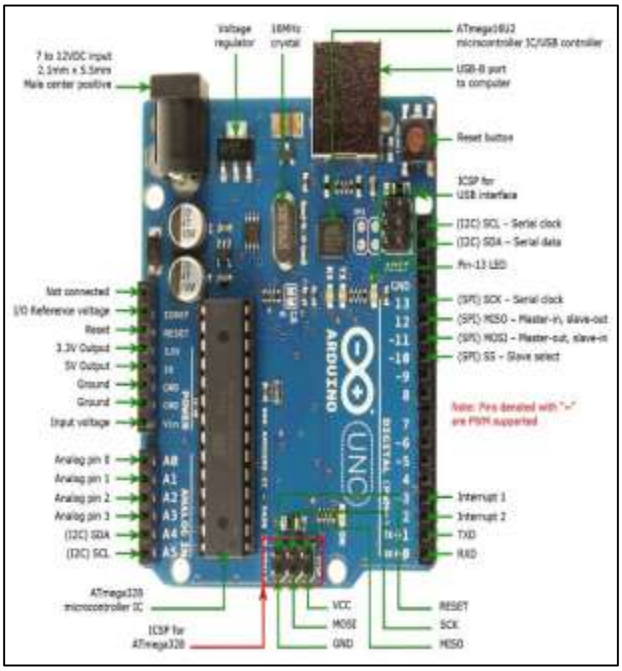

Figure 3. *Arduino Uno Microcontroller Board*

The ATmega328P is universal is widely used in microcontrollers and is found popularly in Arduino Uno, which features 16MHz quartz crystals, power connections,14 digital input & output pins, and also in ICSP headers. Arduino board is highly compatible with this software and it's also excellent for self-build projects and prototyping. The Arduino Uno board is responsible for processing sensor data and managing output to the LCD screen and MQTT protocol. The design approach centres around utilizing the Arduino Uno board as the primary processing unit.

3.2 Voltage and Current Sensors:

To measure the voltage & current values in the power grid voltage & current sensors are utilized. ZMPT101B sensor is used in this model.
It has an input range of 1—5v and it can measure from 0 to 250v of AC voltage. The ACS712 sensor has a voltage output of 2.5v and when it has no current it can measure from -5 to +5 A. Arduino Uno board has been connected to sensors to measure to see the inputs. These sensors are connected to the power system sources.

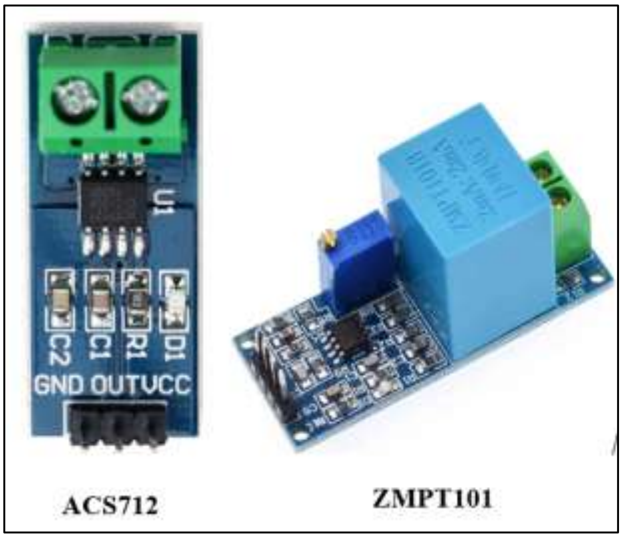

Figure 4. *Voltage and Current Sensors*

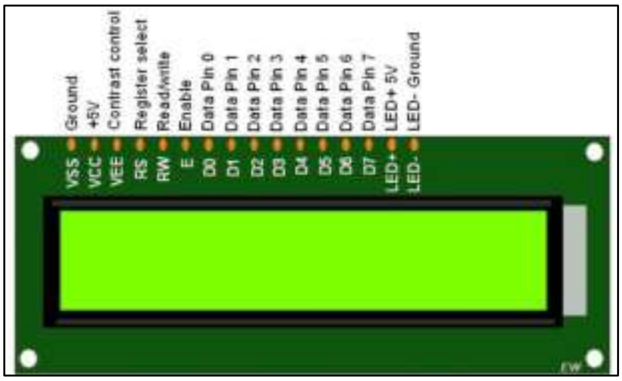

Figure 5. *LCD Display 16 x 2*

3.3 LCD Screen

The design model's LCD panel displays real-time data from sensors with a 16 x 2-character resolution. The Arduino Uno board is connected to the LCD screen using the Liquid Crystal library to display the data. The LCD panel displays real-time metrics such as voltage, current, power, and energy usage.

3.4 MQTT Protocol

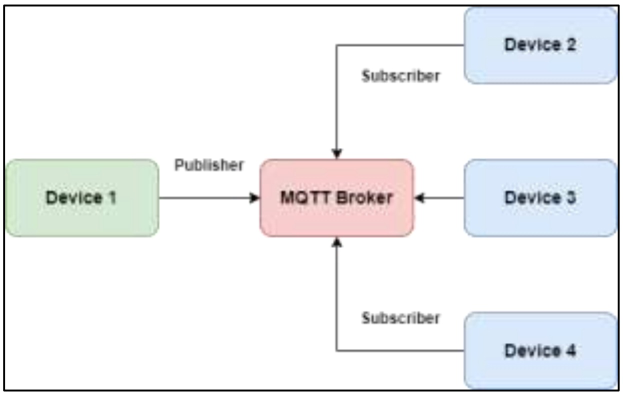

Figure 6. *MQTT Broker*

MQTT is commonly used in IoT applications for its lightweight communication protocol. It is ideal for smart grid monitoring systems due to its compatibility with low-bandwidth, high-latency, or unreliable networks. The design concept uses the MQTT protocol to send alerts to the user's phone when the current and voltage levels reach a specific threshold value. The PubSubClient library is used to implement the MQTT protocol.

3.4 NodeMCU Wi-Fi Module

Figure 7. *NodeMCU*

ESP8266 Wi-Fi module is by NodeMCU which is an open-source kit. It's a cost-friendly & simple method to connect a microcontroller to the internet and is also used to connect the hardware to the internet and to communicate with MQTT. The Arduino Uno board and NodeMCU are connected through a serial connection. Our system is effective in monitoring energy and its consumption in a real lifetime. And also reduces the wastage of energy and it provides an alert system to high current & voltage level flows. This research defines a paradiagram system which could be useful as a foundation for creating the same kind of models in the future.

4. IoT-Based Smart Grid Monitoring (SGM) System Challenges:

4.1 Prototype Design

The successful creation and deployment of a functional prototype posed a notable challenge in the course of developing the smart grid tracking system. To meet the requirements of the project, it was necessary to develop a prototype that was both cost-effective and reliable, while also being user-friendly. The design process encompassed the meticulous selection of compatible components and a comprehensive evaluation of the overall system's performance and functionality. The successful creation and testing of a working prototype have provided evidence of the feasibility studies of the suggested technology, despite the encountered challenges.

4.2 Power Management

In the development of the SGM system, the challenges of maintaining a stable and disturbed power & current supply couldn't be overstrained when considering the function & reliability of various components of the system like sensors& micro-controllers, and interaction modules. The usage of the low power supply & effective components is coupled with power-saving systems. The subsequent creation and implementation of the system will continue to rely heavily on the importance of power management.

4.3 Communication Reliability

The issue of dependability when communicating within the different parts of the smart grid's monitoring system has been widely recognized and studied in research. In this study, various protocols including MQTT, Wi-Fi, and serial communications were employed to establish connections between the microcontroller sensors, and communication module. The design of the system incorporates mechanisms to effectively address and mitigate hiccups and effectively recover from instances of communication breakdowns. Dependability continues to be a significant concern, especially in the context of massive constructions.

4.4 Data Security and Privacy

The protection of critical data, such as energy usage patterns, is a fundamental concern that necessitates the attention of the monitoring system within the smart grid. To accomplish this objective, it is crucial to incorporate stringent safety and confidentiality protocols that efficiently deter unauthorized entry. The protection of critical data, such as energy usage patterns, is a fundamental concern that necessitates the attention of the monitoring system within the smart grid. To accomplish this objective, it is crucial to incorporate stringent safety and confidentiality protocols that efficiently deter unauthorized entry.

4.5 Cost Limitations

The advancement of the smart grid monitoring system encountered substantial economic limitations, impeding its progress. The increase in the overall cost of the system can be attributed to the requirement for modified firmware and the utilization of premium components. The design of the system involved the utilization of cost-effective components and the development of tailored firmware to effectively tackle the identified problem. The cost of the structure remains a crucial factor to consider, especially when implementing it on a large scale.

5. Results and Discussion

Where Arduino Uno uses a smart grid monitoring system. Both current & voltage sensors are successfully attained in real–life usage of power monitoring. The system accurately measured voltage and current on the display screen and notified the user when a certain threshold had been exceeded. To validate the precision of the device's data, an external commercial energy monitor was employed. The utilization of technology in different settings, including business, manufacturing, and residential properties has been studied extensively to explore its potential to improve energy efficiency and mitigate electrical hazards. In this study, current and voltage readings were systematically collected from a single grid at regular intervals of two seconds. The

Table 1. *Current and Voltage Readings*

Time In Sec	Current in Amp	Voltage in Volts
02 sec	10.08	238.32
04 sec	8.88	236.08
06 sec	9.31	238.13
08 sec	8.73	236.48
10 sec	8.36	238.13
12 sec	7.62	235.88
14 sec	6.51	236.48
16 sec	9.12	240.13
18 sec	6.95	236.48
20 sec	8.05	236.48

presented data in the table represents the collected information. The IoT-based smart grid and monitoring system successfully tracked current and voltage values from the supply and alerted the user when these values exceeded certain criteria. Threshold values of 1 Amp for current and 200 Volts for voltage were chosen for demonstration purposes. The system notified the user when the voltage exceeded 200 volts and the current exceeded 1 amp. The notice was delivered to the user's registered device using the MQTT Protocol.

The system could log voltage and current values over time to track trends and patterns. Table 1 presents the gathered information.

Graphs of voltage and current were created using the collected data. Figure 3 shows the voltage graph, while figure 4 shows voltage and current sensors and figure 5 shows the current graph. The user used OCTAVE to plot two graphs. Table 2 is MATLAB code for voltage graph. Table 3 is MATLAB code for the current graph. Figure 6 is MQTT broker and figure 7 is NodeMCU and also figure 8 shows voltage readings. Figure 9 displays the current values entered an octave terminal. The hardware configuration for the IoT-based smart grid monitoring system includes a

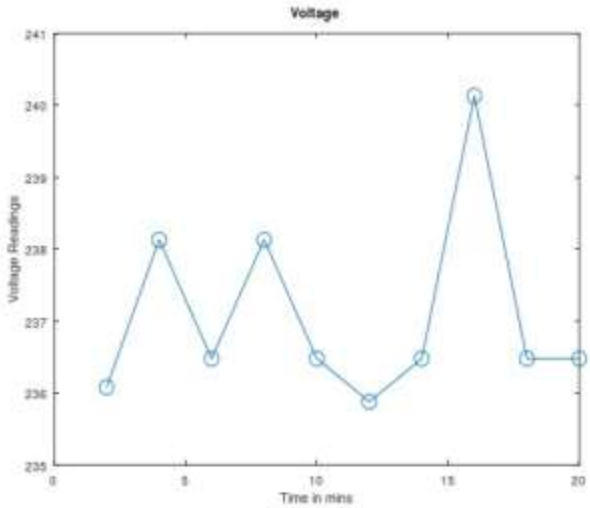

Figure 8. *Voltage Readings*

Table 2. *MATLAB code for voltage graph*

```
% Define x and y values
x = [2 4 6 8 10 12 14 16 18 20];
y= [236.08 238.13 236.48 238.13 236.48 235.88 236.48
240.13 236.48 236.48];

% Create a new figure and plot the graph
figure;
plot(x, y,'-o');

% Add title and axis labels
title('Voltage ');
xlabel('Time in mins');
ylabel('Voltage Readings');
```

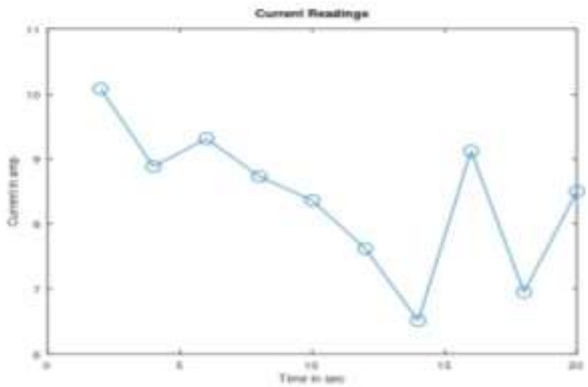

Figure 9. *Current Readings*

Table 3. *MATLAB code for the current graph*

```
% Define x and y values
x = [2 4 6 8 10 12 14 16 18 20];
y= [10.08 8.88 9.31 8.73 8.36 7.62 6.51 9.12 6.95 8.5];

% Create a new figure and plot the graph
figure;
plot(x, y,'-o');

% Add title and axis labels
title('Current Readings');
xlabel('Time in sec');
ylabel('Current in amp');
```

microcontroller unit (MCU), a Wi-Fi module, a current sensor, and a voltage sensor. The MCU collects data from the sensors and transmits it to the cloud server via the Wi-Fi module. The hardware configuration was developed and tested to ensure accurate and reliable data collection for efficient monitoring and control of smart grids. Figure 10 shows the current sensor simulation and Figure 11 shows the voltage sensor simulation. The IoT-based smart grid monitoring system effectively monitored supply voltage and current, notifying the user when certain thresholds were exceeded. The system can be improved by adding additional sensors to monitor temperature and power factors.

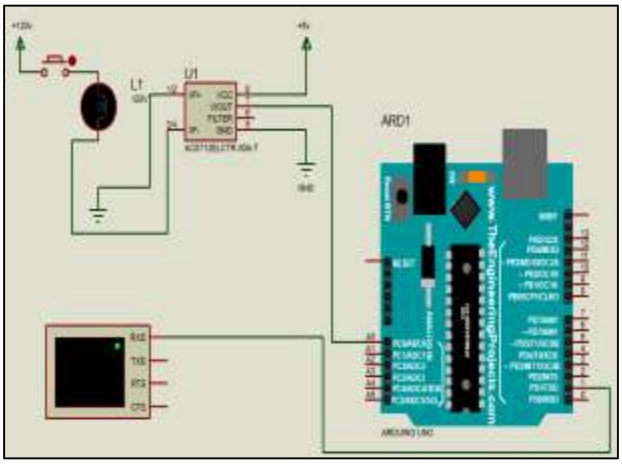

Figure 10. *Current sensor simulation*

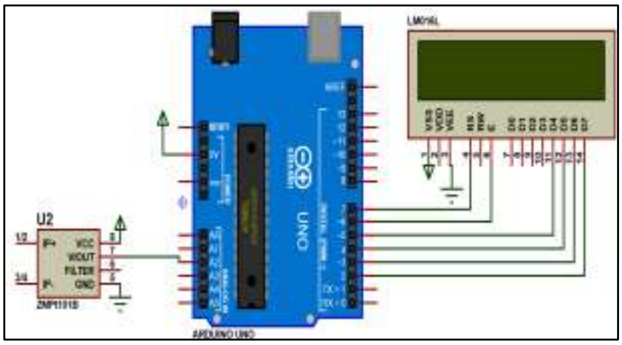

Figure 11. *Voltage sensor simulation*

6. Conclusion

This research article discusses an IoT-based smart grid monitoring system that enables real-time monitoring and reduction of energy use. The system utilizes an Arduino Uno, voltage and current sensors, an LCD screen, MQTT protocol, and a NodeMCU Wi-Fi module to accurately measure and display energy consumption data. It also notifies users when certain threshold values are exceeded. The system is a versatile solution for home and business applications, as it can connect to the internet via Wi-Fi and MQTT protocol, allowing for remote access and control. The suggested smart grid monitoring system has the potential for future development and adoption due to the increasing need for sustainable energy solutions and the potential benefits of reducing energy waste.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
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- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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