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Design an IoT-Based Smart Power Outlet Integrating Digital Technology for Real-Time Electrical Monitoring

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A B S T R A C T

The rapid development of the Internet of Things (IoT) has opened new opportunities for efficient and real-time electrical monitoring. This research presents the design and implementation of an IoT-based Smart Power Outlet capable of controlling four electrical sockets and monitoring key electrical parameters such as voltage, current, power, and energy consumption. The system integrates a microcontroller, power sensor, relay module, and LCD, while utilizing the Blynk cloud platform as the primary monitoring and control dashboard. The developed system enables users to manage electrical loads remotely via a mobile application and to monitor real-time data both locally and online. Experimental results show that the system operates reliably according to the design objectives. and the PZEM-004T sensor accurately measures electrical parameters with consistent readings across both LCD and cloud interfaces. This study demonstrates that the proposed Smart Power Outlet provides a practical, low-cost, and scalable solution for intelligent energy management. It enhances user convenience, improves energy efficiency, and supports the implementation of smart and environmentally sustainable household systems.

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INTRODUCTION

Technological developments are increasingly rapid, particularly in the field of the Internet of Things (IoT), opening up new opportunities to increase efficiency and convenience in various aspects of human life. IoT allows electronic devices to be interconnected via the internet, making it easier for users to control and monitor devices remotely. One useful IoT application in everyday life is an intelligent power monitoring and control system.

In modern conditions, the need for electricity continues to increase along with the development of electronic devices used in households, offices, and industry. However, uncontrolled electricity use often leads to wasted electricity, which results in rising electricity costs and potential environmental damage due to excessive energy consumption. Therefore, a solution is needed to help users manage their power consumption efficiently and effectively.

A Smart Power Outlet is a smart electrical outlet/terminal that controls the on/off (ON/OFF) and monitors the power consumption of electronic devices connected to it. Users can control and monitor it remotely via a laptop or smartphone, or within the reach of the laptop or smartphone's Wi-Fi network.

This Smart Power Outlet has five main devices, namely the NodeMcu ESP 8266 Lolin v3, the PZEM-004T module, a 4-Channel relay module, a 5V 2A DC power supply, and an electrical terminal/outlet. The electrical switch on the Smart Power Outlet uses a relay as a switch and is controlled by a network-based microcontroller (WiFi) so that it can be connected to a smartphone that has the controller application (Blynk) installed. Furthermore, this device can be used in both indoor and outdoor environments, with adjustments to the casing or panel to ensure resistance to water, dust, and extreme outdoor temperatures.

With this background, the design of this device aims to provide a Smart Power Outlet and IoT-Based Electricity Monitoring Dashboard to provide a solution for more efficient electricity consumption management. It is hoped that the design of this device will provide tangible benefits to the community in optimizing daily electricity use.

LITERATURE REVIEW

Internet of Things

The Internet of Things (IoT) is a concept that connects physical devices to an internet network so they can communicate with each other, exchange data, and perform certain functions automatically without requiring direct human interaction. IoT consists of various devices such as sensors, data processing systems, and communication networks that enable these devices to work together in an integrated manner.

IoT enables remote monitoring and control through internet-based systems, thereby increasing efficiency, convenience, and security in various areas, including smart homes. In the context of smart homes, IoT can be used to control electrical appliances, monitor electricity usage, and improve power efficiency through systems such as Smart Power Outlets [1]. The NodeMCU ESP8266 Lolin V3 is a microcontroller widely used in IoT-based projects. This module offers the advantages of being small, affordable, and easy to program using the Arduino

IDE. The NodeMCU is capable of efficiently communicating with WiFi servers and mobile applications, making it suitable for monitoring and control systems.

In this final project, the NodeMCU is used as the main control center. The NodeMCU will control relays to turn power outlets ON/OFF and receive data from the PZEM-004T electrical sensor. This data is sent to the Blynk application for direct viewing via a smartphone, making the NodeMCU a vital component in connecting all modules into an integrated system.

Figure 1. NodeMCU

Plate Base Board is an additional breakout board for NodeMCU ESP8266 Lolin V3. This module is designed to simplify connection and power distribution when used in electronics or IoT projects. With this board, cable connections are neater, 5V and GND voltage distribution is more stable, and safer when connecting NodeMCU with components such as relays, LCDs, and PZEM-004T sensors [3]. This board provides female sockets that match NodeMCU pins as well as 5V and GND voltage distribution lines, which are generally connected to the 5V/3A DC input jack. The main purpose of using a plate base board is to simplify cable connections, reduce the possibility of wiring errors, and provide stable power distribution for various external modules such as relays, I2C LCDs, and sensors (e.g., PZEM-004T). In addition, this plate base board also functions as a physical protector and support so that the NodeMCU and other components are more stable when placed on a work table or panel box.

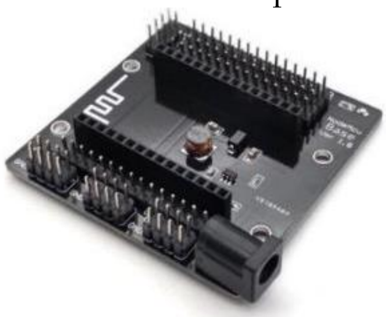

Figure 2. Plate Base Board

PZEM-004T v3.0 is a multifunctional sensor module used to measure electrical parameters such as voltage (V), current (A), power (W), and energy (kWh). This module is equipped with integrated current and voltage sensors, so it is able to provide real-time electricity usage data. PZEM-004T is often used in IoT-based energy monitoring systems because it can read electrical parameters with fairly good accuracy [4]. This module is equipped with integrated voltage and current sensors (CT), so it can provide real-time electricity usage data. PZEM-004T is designed for indoor/outdoor use but must use a casing or protection panel and can only be used for electrical loads that do not exceed the specified power limit. In this Design and Build, this module plays an important role in monitoring electricity consumption on the Smart Power Outlet and sending data to the microcontroller to be displayed on the monitoring dashboard. [5]

Figure 3. PZEM-004T

A relay is an electronic switch used to control 220V AC electrical devices using a DC voltage signal from a microcontroller. The 4-Channel Relay Module has four channels, each capable of controlling loads up to 10A. This module is equipped with NO (Normally Open), NC (Normally Closed), and COM (Common) terminals, allowing for flexible use according to system requirements [6]. In this study, a relay is used to control four electrical outlets separately. An ON/OFF command is sent from the Blynk application via NodeMCU to the relay module, which then disconnects or connects the electrical current to the outlets. This system is also widely implemented in other IoT projects, such as the tutorial on controlling lights with Blynk.

Figure 4. Relay Module

Software

The Arduino IDE is software used to write, test, and upload programs to microcontrollers such as the NodeMCU ESP8266. The Arduino IDE provides a simple interface for ease of use and supports various additional libraries such as Blynk, LiquidCrystal_I2C, and PZEM004Tv30.

In the Arduino IDE, programs are written in sketch form, then can be checked for errors and directly uploaded to the device via a USB cable. Available features include a verify button (to check for errors), an upload button (to send the program to the device), and a message box at the bottom that indicates the process status, such as success or failure during the upload. In designing this device, the Arduino IDE was used to create the main program for the Smart Power Outlet, configure the relay control logic, read PZEM sensor data, and connect the system to the Blynk dashboard.

Blynk is a cloud-based IoT platform that allows users to remotely control and monitor electronic devices. This application or website provides an interactive dashboard that is easy to create using a drag-and-drop method. Sensor data can be displayed in real time, while relays can be controlled directly through the Blynk app.

Blynk's main advantage is its ease of use, allowing users to create interactive dashboards simply by dragging and dropping, without the need for complex coding. The app is compatible with Android and iOS operating systems and can send and receive data from connected devices in real time .

METHODOLOGY

There are three methods in this research to solving the problem in designing a rooftop simulation based on PVSyst software.

1. Literature Study Method

In writing this thesis, the author studied references from various sources such as books, journals, articles related to the research that the author is researching. The various references used by the author to create this final assignment and other references related to the research.

2. Discussion or Interview Method

Collecting data by conducting direct discussions with expert

3. Observation Method

The author obtains data by coming directly to the field to observe and record the data needed to complete the thesis.

The device designed for this final project is a Smart Power Outlet system and an Internet of Things (IoT)-based electricity monitoring dashboard. This system is designed to facilitate users in controlling and monitoring electricity usage remotely using an internet connection, via the Blynk website, which can be accessed using a browser on a computer or mobile phone.

The general specifications of this device include:

1. Designed for single-phase 220-volt household electrical installations, in accordance with the electricity usage standards in most homes.
2. Can be controlled and monitored remotely via a WiFi network connected to the internet.
3. Capable of controlling four separate power outlets, based on commands from the Blynk website.
4. Displays real-time electricity data both on the LCD screen and via the Blynk website.
5. This device is designed for use with a maximum electrical load of approximately 1,760 watts, as the average home in Indonesia has an electrical capacity of 2,200 VA.

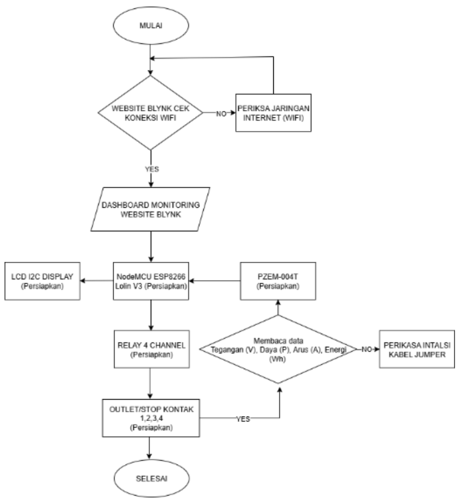

Figure 4. Research Flowchart

Data obtained through direct measurements and the assistance of existing data. Data collection will assist in the data analysis process.

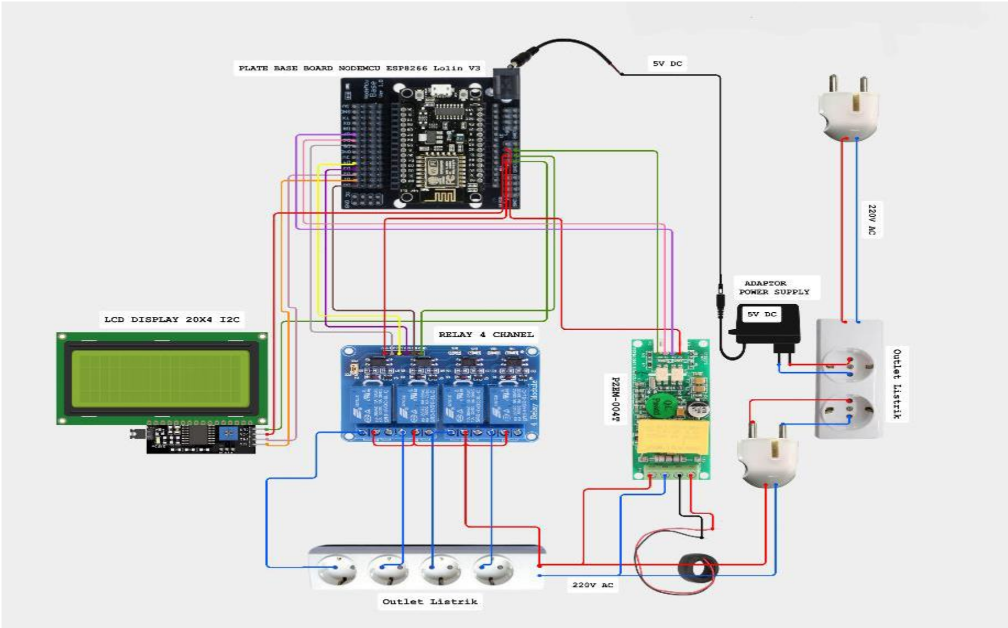

Figure 5. Wiring Diagram

The wiring diagram in this design shows the cable connections between the main components used in the IoT-based Smart Power Outlet and Dashboard Monitoring project. The NodeMCU ESP8266 Lolin V3 installed on the base plate board is connected to several modules such as the 20x4 I2C LCD, the PZEM-004T v3.0 sensor, and the 4-channel relay module using jumper cables.

This stage aims to optimize the system concept and structure in accordance with the purpose of the device, as well as ensure the device's design can run effectively and efficiently. The system block diagram for this device illustrates the relationship between each major component used. The Blynk website serves as a user interface for controlling and monitoring the system via a WiFi network. Commands from the website are sent to the NodeMCU ESP8266 Lolin V3, installed on the base plate of the board, which serves as the device's control center.

This microcontroller regulates the operation of the 4-channel relay module to turn the power supply on or off at the outlet. Simultaneously, the PZEM-004T v3.0 sensor reads voltage (V), current (A), power (W), and energy (Kwh) data and sends the data to the NodeMCU. This data is forwarded to the Blynk website for online viewing and is also displayed live on a 20x4 I2C LCD. The entire system is powered by a 5V 3A DC power supply to ensure the device's stable and safe operation.

RESEARCH RESULT

Implementation of Module Control

From the 4-channel relay module control test, it was found that all relays responded well to ON/OFF commands from the Blynk dashboard. The average response time was less than 2 seconds, indicating that the control system operates in real time and accurately. In the hardware implementation phase, we begin by assembling all the main components selected during the design phase.

Table 1. Testing the Output of Outlet

Outlet	Load Type	Voltage	Current	Power	Energy	Relay
1	Lamp 1	211.6 V	0.15 A	22 J	0.10 Wh	On
2	Lamp 2	211.6 V	0.15 A	24 J	0.10 Wh	On
3	Fan	211.6 V	0.15 A	20 J	0.10 Wh	On
4	HP Charger	211.6 V	0.15 A	29 J	0.10 Wh	On

The components used include a NodeMCU ESP8266 Lolin V3, a PZEM-004T sensor, a 4-channel relay, a 20x4 I2C LCD, and a 5V 3A power supply adapter. The entire circuit is jumpered on the baseboard plate for safety, tidiness, and ease of testing and repair if any errors occur. Once everything is installed, check the connections one by one to ensure that no cables are loose or mixed up. Afterward, test the electrical current to each component using a 5V 3A adapter to ensure the system runs stably and is strong enough to power the load via the relay.

The jumper cable connecting the outlet to the relay uses copper cable with a cross-sectional area of 2.5 mm^2 to safely carry the load current, in accordance with PUIL standards for power outlet installation. During the assembly process, ensure all connections use appropriate female-female jumper cables, and ensure that the modules and sensors are not obstructed or overlapped. This is to avoid interference with the sensors or connections, which could cause the device to fail to function properly.

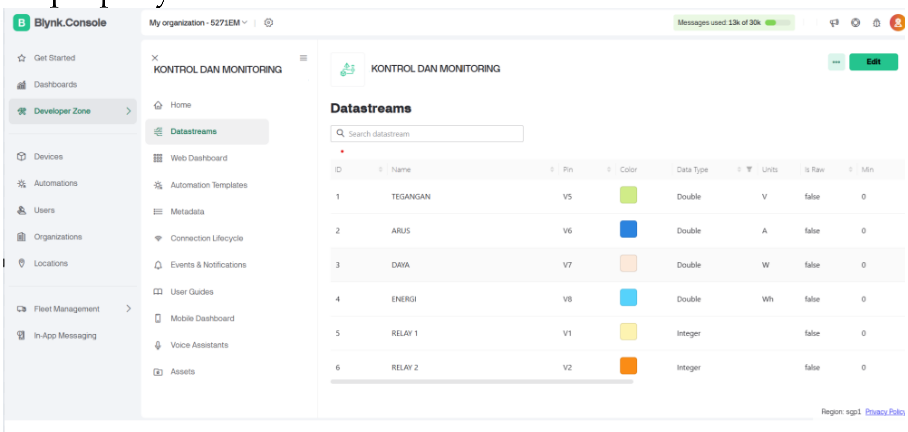

Figure 6. Datastreams Website

Implementation of Software

For software implementation, the Arduino IDE is used as the primary programming platform. The program logic is based on the previously designed system workflow, from controlling the relay, reading sensor data, sending data to the Blynk application, to displaying the results on the LCD and controlling the relay.

Here are some steps in the Arduino programming process and the Blynk website:

1. Connect the NodeMCU to the WiFi network with SSID AGILAS and password 12356789.

2. Connect the Arduino IDE software to the Blynk website with token W3MIseMKudEzJ4g5wy8kk3lFuOPF6k5n.
3. Read voltage, current, power, and energy data from the PZEM-004T sensor via serial communication (using SoftwareSerial with a baud rate of 9600).
4. Develop relay control logic that can be controlled from the Blynk website via Virtual Pins V1–V4.
5. Send data to the Blynk Virtual Pin and assemble the PZEM-004T logic with the virtual pins (V5–V8) to display on the Blynk website monitoring dashboard.

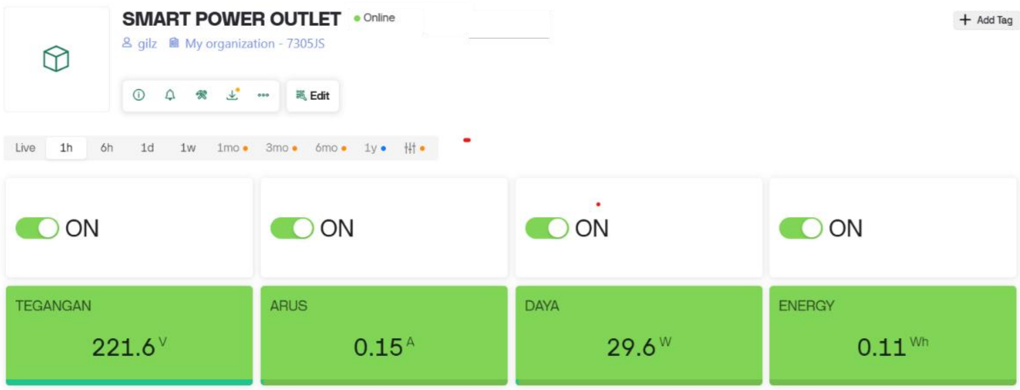

Figure 7. Smart Power Outlt Display

During the program upload process to the NodeMCU ESP8266 Lolin V3, we encountered a problem due to the CH340G driver. We tried downloading an older version of the CH340G driver, as it was more stable for uploading the program. After all the software components ran as expected, the system could read sensor data, send it to Blynk, and display it on the LCD in real time. The relay could be controlled without any significant delay, meaning all the software and website systems were working successfully.

DISCUSSION

Discussion of Relay Module Control

From the 4-channel relay module control test, it was found that all relays responded well to ON/OFF commands from the Blynk dashboard. The average response time was less than 2 seconds, indicating that the control system operates in real time and accurately. No significant delays or switching interruptions were observed, even with repeated switching. Conclusion: This system, which can control loads via relays, performed well when controlled via the internet-based Blynk dashboard.

Discussion of PZEM-004T Sensor Data

The PZEM-004T sensor successfully reads voltage (V), current (A), power (W), and energy (kWh) in real time. The values displayed on both the LCD and the Blynk dashboard are consistent and without any discrepancies. Conclusion: The sensor is capable of operating with high accuracy and stability, making it a reliable electricity monitoring tool.

Analysis of LCD Display

The LCD successfully displays all measurement data in a neat and easy-to-read format. The display displays "SMART POWER OUTLET" as the top title, followed by V (voltage), I (current), P (power), and E (energy) in a parallel and proportional layout. Value changes are displayed in real time according to load conditions. Conclusion: The LCD functions well for live monitoring, which is crucial if the internet connection is lost, so users remain informed immediately.

The design of this IoT-based Smart Power Outlet and Electricity Monitoring Dashboard aims to address the need for a more efficient and secure electrical system that can be controlled and monitored in real time. With the completion of the design and testing of the device, the expected results of this research are as follows:

1. Realization of a Smart Electrical Control System
   This device is expected to provide users with the convenience of turning electronic devices on and off remotely via the Blynk application or directly through the manual system, thereby supporting energy efficiency and operational safety.
2. Real-time monitoring of electrical parameters
   This system is expected to provide real-time and accurate information regarding the voltage (V), current (I), power (P), and energy (Wh) of the electrical load being used. This monitoring is displayed directly via a 20x4 LCD and the Blynk dashboard, making it easier for users to evaluate energy consumption.
3. Increased awareness and control of electricity consumption
   It is hoped that with transparent electricity usage information, users can manage their energy consumption more wisely, potentially reducing electricity bills and avoiding excessive power consumption.
4. Improved electrical safety for households or small industries
   With the ability to automatically or manually turn off devices, as well as easy remote-control access, this device is expected to reduce the potential for fires or damage due to forgetting to turn off electrical equipment.

CONCLUSSION AND RECOMMENDATIONS

Based on the design, implementation, and testing of the IoT-based Smart Power Outlet and Electricity Monitoring Dashboard, the following conclusions can be drawn:

1. The IoT-based Smart Power Outlet system was successfully designed and built so that it can be controlled remotely using the Blynk website with a stable WiFi network. The PZEM-004T sensor is capable of reading voltage (V), current (A), power (W), and energy (Kwh) with considerable accuracy. This data is displayed accurately on the LCD display and the Blynk website monitoring dashboard, allowing users to monitor both directly on the device and via the website.
2. This system is able to assist users in accurately controlling and monitoring electrical parameters in real time through the Blynk dashboard and 20x4 LCD, thus facilitating monitoring of electrical parameters.

ADVANCED RESEARCH

For further development, the system should be equipped with an automatic electricity monitoring history recording feature, so users can view usage data over time and periodically evaluate energy consumption. If possible, system development could be directed toward automatic control based on schedules or loads, for example, automatically turning on outlets only.

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