PROGRESS IN ENGINEERING APPLICATION AND TECHNOLOGY
e-ISSN: 2773-5303

PEAT

Vol. 6 No. 2 (2025) 184-192
https://publisher.uthm.edu.my/periodicals/index.php/peat

An IoT-Enabled Smart Energy Monitoring System to Enhance Industrial Energy Efficiency

Muhammad Shamil Suhaimi[1], Maizul Ishak[1]*

[1] *Department of Electrical Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, 84600 Pagoh, Johor, MALAYSIA*

*Corresponding Author: maizul@uthm.edu.my
DOI: https://doi.org/10.30880/peat.2025.06.02.020

Article Info

Received: 26 June 2025
Accepted: 11 August 2025
Available online: 30 October 2025

Keywords

Smart Energy Monitoring, Internet of Things (IoT), ESP 32 Microcontroller, Energy Management

Abstract

The industrial sector in Malaysia contributes significantly to the national economy but is also responsible for over 45% of total electricity consumption, leading to high operational costs and increased greenhouse gas emissions. Existing monitoring systems often lack real-time visibility and departmental-level resolution, resulting in inefficiencies and undetected wastage. This paper addresses this issue by presenting the design and development of an IoT-enabled Smart Energy Monitoring System for industrial buildings. The proposed system uses current and voltage sensors, an ESP32 microcontroller, and the BLYNK mobile application to monitor electrical parameters and provide real-time visualizations and alerts. The prototype was tested and demonstrated an average measurement error of less than ±3%, confirming its accuracy and practical applicability. Results indicate that the system successfully detects anomalies, supports informed decision-making, and promotes energy-saving practices. This solution aligns with Malaysia sustainable energy goals and presents a cost-effective approach to industrial energy management.

1. Introduction

Malaysia is currently facing significant challenges related to increasing greenhouse gas emissions and rising energy consumption, particularly within the industrial electrical sector. In 2018, the industrial sector's power consumption reached approximately 147,758 GWh, accounting for 44.8% of the nation's total electricity usage [1]. This highlights the critical importance of improving energy efficiency in this sector. Industrial buildings, often housing numerous departments equipped with energy-intensive machinery and equipment, contribute substantially to overall electricity demand. To address these challenges, there is a growing need for smart energy management systems that provide real-time consumption data, enabling industries to make timely adjustments and optimize energy use [2]. Such systems offer valuable insights into consumption patterns, helping to reduce energy costs, improve operational efficiency, and save time [3].

This project proposes a Smart Energy Monitoring System designed to measure electricity consumption in real time, giving users a clear and immediate understanding of energy usage trends. By leveraging the BLYNK application—a modern and user-friendly software platform—the system allows industrial operators to access real-time data conveniently via smartphones. This accessibility facilitates the identification of inefficiencies and supports proactive energy optimization [4]. Unlike traditional, complex, or outdated energy monitoring solutions, the proposed system emphasizes simplicity and adaptability, making it easier for industries to monitor and manage their energy consumption effectively. Ultimately, this approach aims to enhance energy efficiency, reduce operational costs, and promote sustainable energy practices within Malaysia's industrial sector [5].

This paper details the design and implementation of a Smart Energy Monitoring System (SEMS) for industrial buildings. The escalating energy consumption within Malaysia's industrial sector, exceeding 45% of the nation's total electricity usage, necessitates efficient energy management strategies to mitigate rising operational costs and environmental concerns, including greenhouse gas emissions [1], [5]. This SEMS aims to address this challenge by enabling real-time tracking of energy consumption at the departmental level within industrial buildings. The system leverages Internet of Things (IoT) technology, incorporating current and voltage sensors, an ESP32 microcontroller, and the BLYNK application for data acquisition, processing, and visualization via a user-friendly smartphone interface. The following sections will outline the project's objectives, methodology, results, and contributions to the field of industrial energy management..

1.1 Problem Statement

The industrial sector in Malaysia is a key driver of economic growth, contributing significantly to GDP and employment, yet it remains the country's largest electricity consumer, accounting for over 45% of total energy usage. In August 2024, Malaysia's power consumption reached approximately 15,956 GWh, with the industrial sector responsible for a substantial share. This heavy dependence on electricity has led to rising operational costs and increased demand on the national grid. The situation is further exacerbated by escalating electricity prices, driven by reliance on fossil fuels such as coal and natural gas for power generation. Although government initiatives promoting renewable energy adoption exist, they are insufficient to curb energy wastage within industrial facilities. Therefore, there is an urgent need for a smart energy monitoring system that provides real-time, departmental-level electricity consumption data to help industries identify inefficiencies, reduce energy costs, and minimize environmental impact, aligning with Malaysia's goals for energy efficiency and sustainability.

1.2 Objective

The purpose of this project is as listed below:

•To design a system to monitor energy usage in terms of voltage, current and power of each electrical device.
•To develop a prototype of a monitoring system that displays energy usage for electrical devices monitored through smartphone.
•To assess the system usefulness in monitoring energy usage.

1.3 The Project Scope

This project investigates a real-time energy monitoring system for industrial applications. The system employs energy monitoring devices installed between the load and distribution board to accurately measure electrical current flow and energy consumption (kWh). Data is transmitted wirelessly to a BLYNK application via IoT, providing users with remote access to a user-friendly interface for real-time monitoring and analysis. This IoT integration facilitates continuous data collection, real-time alerts, and actionable insights for optimizing energy consumption and minimizing operational costs. Prior research on IoT-based monitoring systems supports the efficacy of this approach in enhancing real-time analytics and improving energy efficiency in industrial environments.

2. Methodology

2.1 System Flowchart

This flowchart illustrates the operational sequence of a real-time energy monitoring system. The process initiates with current and voltage sensors measuring the power supply parameters. An ESP32 microcontroller receives these sensor readings, performs power consumption calculations (likely using the formula P = VI), and subsequently searches for an available Wi-Fi network. Following a successful connection, real-time energy data is displayed on the BLYNK application's user interface. Crucially, the system incorporates safety mechanisms: it monitors voltage levels to ensure they remain within the 216V-253V operational range and flags any currents exceeding 60A. In either of these fault conditions, an alert notification is sent to the designated user. The system concludes its operation after successful data transmission and the delivery of any required alerts.

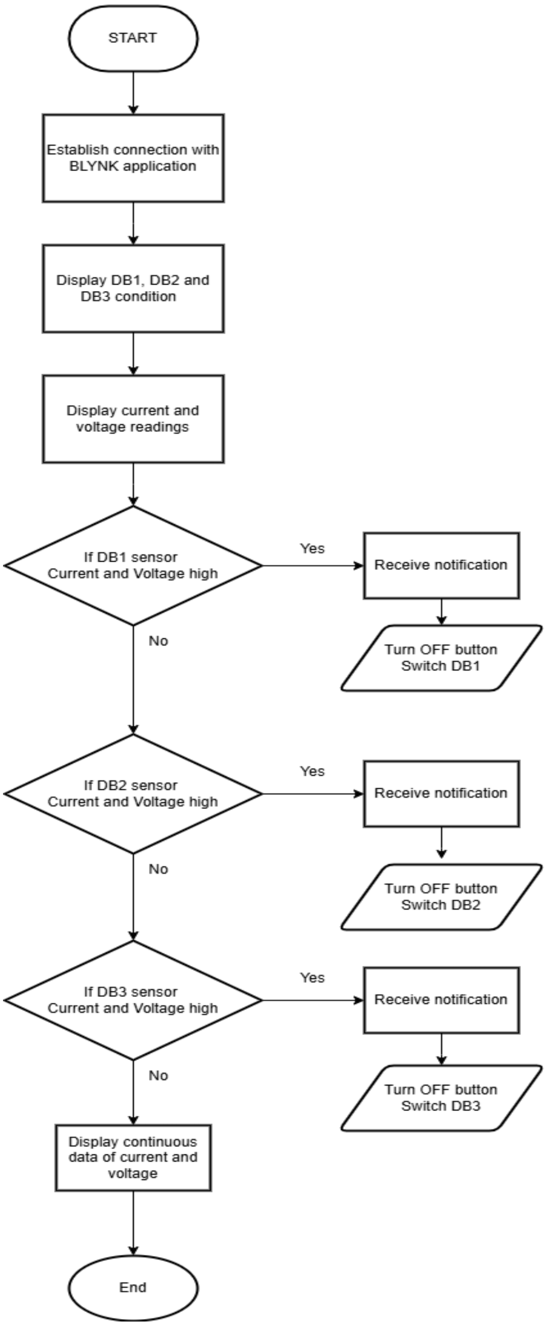
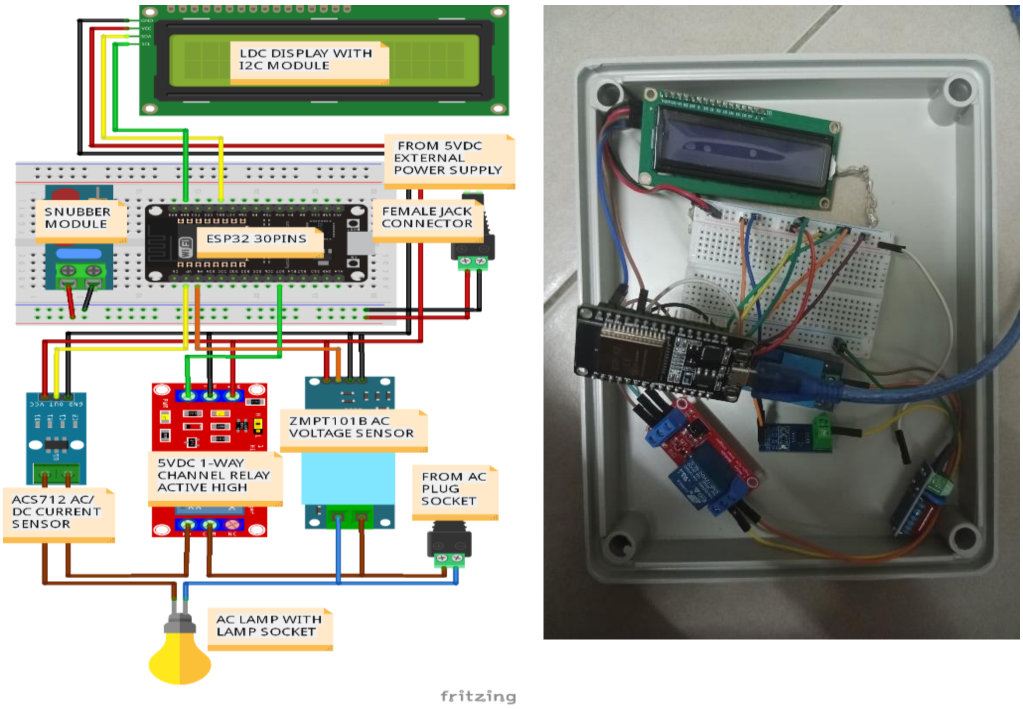


Fig. 1: System Flowchart

2.2 Project Circuit Diagram and Hardware Integration

The Smart Energy Monitoring System designed for industrial buildings aims to optimize energy consumption and improve operational efficiency across multiple departments. This system integrates both hardware and software components to collect and analyze energy data in real time. It employs sensors and smart meters to monitor power usage, with microcontrollers such as the Arduino processing the data and transmitting it to a central server for storage and further analysis. The software, developed using the Arduino IDE, ensures seamless communication between sensors, microcontrollers, and data storage units, enabling accurate and efficient energy monitoring and management. Its foundation comprises current transformers (CTs) and voltage sensors which capture precise electrical parameters at the departmental level, feeding this data to ESP32 microcontrollers that perform real-time calculations and transmit information via Wi-Fi to a central server. The system software component, developed using the Arduino IDE and for efficient data transmission, ensures seamless communication among sensors, controllers, and data storage. A key innovation is the user-friendly mobile interface provided by the BLYNK application, which facilitates real-time monitoring through custom dashboards displaying energy heatmaps and historical analytics, while also enabling remote management and providing role-based access control. Crucially, the system incorporates intelligent alert mechanisms with dynamic thresholding to notify users of energy consumption beyond established parameters, enabling prompt identification and mitigation of waste, and further integrates machine learning for baselining and prescriptive analytics to suggest load-shifting opportunities. This holistic approach, from precise sensing and robust data processing to intuitive visualization and proactive anomaly detection, aims to significantly reduce energy expenses, enhance sustainability, and guarantee optimal performance across industrial facilities by transforming raw energy data into actionable insights.



(a) Project Circuit Diagram **(b)** Project Development

Fig. 2: Development of the Project

2.3 Embedded Software Development

The ESP32 serves as the central processing unit within this smart energy monitoring system, chosen specifically for its robust capabilities essential for Internet of Things (IoT) applications. Its integrated dual-core processor provides ample computational power for real-time data acquisition and processing, while its built-in Wi-Fi module enables seamless wireless data transmission to the cloud and user interfaces. Furthermore, the ESP32 efficient power management with advance features than ESP 8266 which are critical for maintaining continuous operation in an industrial environment. System logic and control functions are developed and programmed onto the ESP32 using the user-friendly Arduino IDE, with firmware uploaded via a USB connection. All hardware components, including current and voltage sensors, are directly interfaced with the ESP32 to facilitate real-time data collection and execute specified control functions.

```
#include <ZMPT101B.h>
#include <ACS712.h>
#include <WiFi.h>
#include <WiFiClient.h>
#include <BlynkSimpleEsp32.h>
#include <Wire.h>
#include <LiquidCrystal_I2C.h>

// ----------------------------------------------------------------------
// CONSTANTS VARIABLES
// ----------------------------------------------------------------------
// === Pin definition ===
// Reference: https://www.studiopieters.nl/esp32-pinout/#google_vignette
#define VAC_PIN 39     // Pin for ZMPT101B output
#define ACS_PIN 36     // Pin for ACS712 output
#define MENTOL_PIN 27  // Pin for Mentol (relay)

// === Sensor configuration constants ===
#define NUM_READINGS 20  // Define the number of readings to average
#define AC_FREQUENCY_SIGNAL 50.0f
#define VAC_SENSITIVITY 500.0f
#define MAX_VOLTAGE 3.3f
#define MAX_ADC 4095
#define VOLTAGE_SENSITIVITY 100
```

(1)

Fig. 3: The coding setup for voltage and current sensor in Arduino IDE

The figure shows the coding software that are designed to operate on an ESP32 microcontroller, which interfaces with a ZMPT101B voltage sensor, an ACS712 current sensor with a relay for control purposes. The pin connections were established based on the ESP32 pinout diagram, with GPIO 39 assigned to the ZMPT101B voltage sensor, GPIO 36 connected to the ACS712 current sensor, and GPIO 27 designated for controlling the relay. This configuration enables accurate real-time measurement of electrical parameters and effective switching control within the energy monitoring system. To enhance measurement accuracy and mitigate noise, sensor readings are optimized by averaging 20 consecutive samples (NUM_READINGS = 20) from both the ZMPT101B voltage sensor and the ACS712 current sensor. Critical calibration parameters, including AC_FREQUENCY_SIGNAL and VOLTAGE_SENSITIVITY (100), are defined within the embedded software to ensure precise conversion of raw sensor data. The system also accounts for the ESP32's Analog-to-Digital Converter (ADC) specifications, with MAX_VOLTAGE (3.3f) representing the ADC's input voltage limit and MAX_ADC (4095) indicating the maximum digital value from its 12-bit resolution. These meticulous configurations are essential for achieving accurate and reliable data acquisition from the sensors, thereby supporting subsequent processing and control actions within the smart energy monitoring system.

2.4 Mobile/Laptop Interface and Data Visualization

The BLYNK application was employed to provide a user-friendly mobile interface for real-time monitoring and remote management. Custom dashboards were created to display energy consumption patterns, with alert mechanisms configured to notify users of abnormal usage exceeding predefined thresholds.

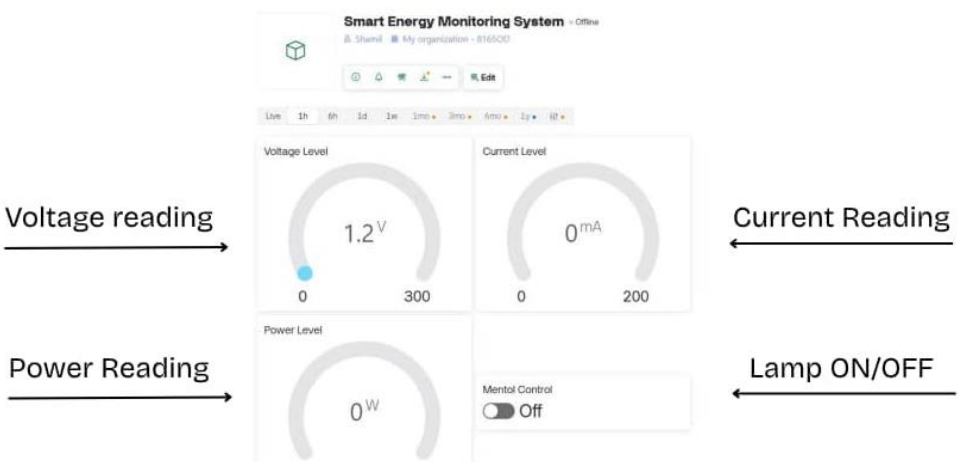


Fig 4: BLYNK Application Interface

Figure 4 illustrates the BLYNK application interface utilized in the Smart Energy Monitoring System, displaying real-time voltage, current, and power consumption through interactive gauges. The voltage and current sensors connected to the ESP32 microcontroller continuously transmit live data to the app, enabling users to remotely monitor key electrical parameters. Additionally, the interface features a switch labeled "Mentol Control," which allows users to control a lamp via a relay module, demonstrating basic home automation capabilities through internet connectivity.

2.5 Testing and Validation

The prototype underwent comprehensive testing to evaluate its performance in terms of measurement accuracy, response time, and overall system reliability under a range of load conditions typical of industrial environments. Measurement accuracy was validated by comparing sensor readings against calibrated standard meters, ensuring that voltage, current, and power consumption data were within acceptable error margins. Multiple test scenarios were conducted, including steady-state loads and dynamic load changes, to assess the system's ability to maintain consistent accuracy. Response time tests measured the latency between actual changes in electrical parameters and their reflection on the monitoring interface, confirming near real-time data transmission and processing. To verify the effectiveness of the alert mechanisms, abnormal energy consumption scenarios were deliberately simulated, such as sudden spikes or sustained over consumption. These tests confirmed that the system promptly detected anomalies and triggered notifications through the BLYNK application, enabling users to take immediate corrective actions.

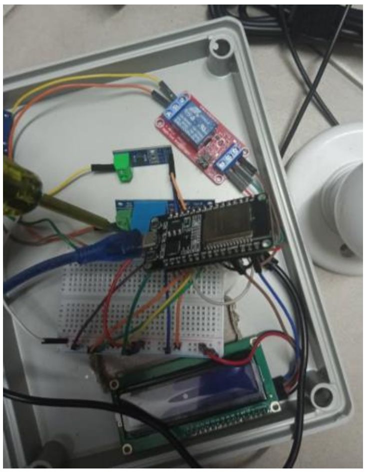


Fig. 5: Testing each component

3. Result and Discussion

The accuracy and functionality of the Smart Energy Monitoring System were assessed through testing under a range of electrical load scenarios. Current and voltage sensors were installed at the distribution board to capture real-time data, which was then transmitted to the BLYNK mobile application using the ESP32 microcontroller. The accuracy of the system was confirmed using common measuring instruments, and it was able to display voltage, current, and power data with no delay. The system capacity to identify anomalies including voltage spikes and current overloads was demonstrated throughout the test when abrupt changes in load caused timely notifications. Sensor placement didn't affect the electrical setup's ability to function normally, and users could use the apps remote-control functions to turn off linked appliances when necessary.

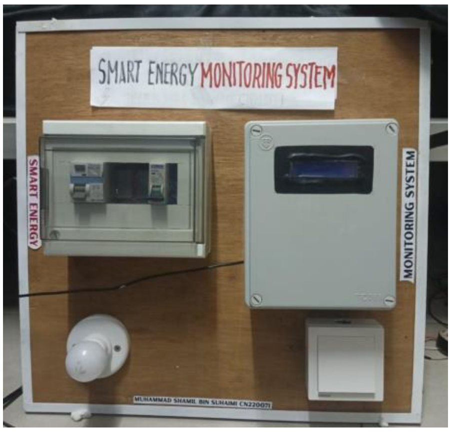


Fig. 6: Full Hardware Setup

3.1 Sensor Accuracy Validation

To validate sensor accuracy, readings from the system were compared with calibrated measuring instruments under identical load conditions. The table shows that the ESP32-based readings-maintained error margins within ±3%, which is acceptable for industrial monitoring applications.

Test No.	Parameter	Standard Reading	Sensor Reading (ESP32)	Error (%)
1	Voltage	240 V	236 V	1.67
2	Current	3 A	2.92 A	2.67
3	Power	720 W	702 W	2.50

Fig. 6: Table Data of Reading

These results demonstrate that the sensors, when calibrated correctly, are capable of providing reliable and consistent data for real-time monitoring. The small deviation is likely due to the resolution limits of the analog-to-digital converter (ADC) on the ESP32 and environmental factors such as slight voltage fluctuations. However, such deviations are negligible for the intended purpose of energy usage monitoring in industrial applications. The system successfully achieved its goal of delivering reasonably accurate energy data, making it suitable for practical deployment.

3.2 BLYNK Application Interface

The BLYNK application served as the main user interface for monitoring energy usage in real time. It displayed key electrical parameters such as voltage, current and power through digital gauges and graphs. The application also included interactive buttons that allowed users to remotely control connected appliances. During testing, the interface successfully updated data every few seconds with minimal delay, offering a smooth user experience. Alert notifications were triggered when predefined thresholds were exceeded, ensuring timely awareness of abnormal conditions such as overcurrent or voltage spikes. Overall, the BLYNK interface provided an efficient and user-friendly platform for visualizing and managing energy data.

Fig. 7: BLYNK Interface during testing

3.3 Arduino IDE Coding Integration

The system was programmed using the Arduino IDE, where code was developed to acquire, process, and transmit sensor data from the ESP32 microcontroller. Libraries for voltage (ZMPT101B) and current (ACS712) sensors were integrated to handle signal readings, while the BLYNK library enabled seamless communication between the hardware and the mobile application. The code also defined safety thresholds, average sampling, and relay control logic. Testing confirmed that the embedded code responded accurately to real-time changes in electrical input, processed calculations correctly, and maintained stable communication with the BLYNK server over Wi-Fi. The use of Arduino IDE made the system flexible and easy to debug during development. After the circuit was successfully assembled, the project proceeded to the testing phase of the Smart Energy Monitoring System prototype. The functionality of the system was verified by measuring the energy consumption of various household appliances. These appliances were connected to the system to simulate typical industrial or departmental loads. Sensor readings for voltage, current, and power were displayed in real time through the BLYNK mobile application.

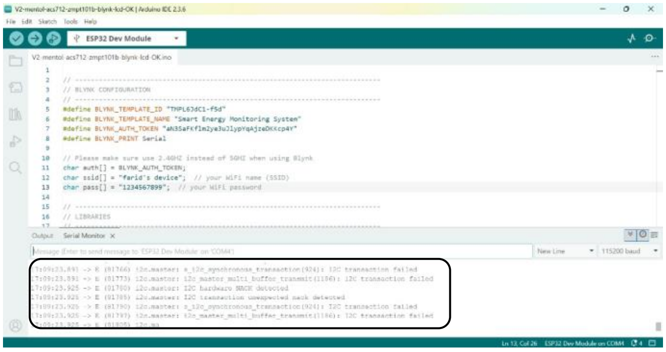


Fig. 8: Arduino IDE shows the data tracked on BLYNK in Arduino IDE

3.4 System Hardware

The hardware setup included the ESP32 microcontroller, current and voltage sensors (ACS712 and ZMPT101B), a 1-channel relay module, and a distribution board. These components were assembled on a prototype board and housed in a secure casing for safety and ease of testing. The ESP32 was selected for its dual-core processor and built-in Wi-Fi, which provided fast processing and real-time data transmission capabilities. The sensors were connected to monitor the power supply of connected loads, and the relay enabled remote on/off control. The hardware was arranged to minimize interference and ensured accurate data acquisition without affecting the normal operation of the electrical system.

Fig. 9: Enclosure Box for the Circuit

3.5 Circuit Implementation

The complete system circuit was implemented on a breadboard for testing before being soldered to a permanent board. The current and voltage sensors were connected in parallel and series respectively to the load, with their outputs linked to the analog input pins of the ESP32. The relay module was used to switch the load on or off based on commands from the BLYNK application. Power to the system was supplied using a regulated 5V adapter. During testing, the circuit operated reliably under various load conditions, maintaining accuracy and stability. The final layout ensured secure connections, proper grounding, and effective isolation to prevent damage to the components or user.

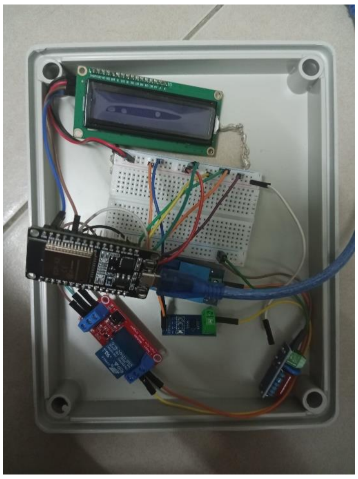


Fig. 10: Full Circuit Connection

The figure above illustrates the complete hardware setup of the Smart Energy Monitoring System, neatly assembled inside a plastic enclosure for functionality, safety, and portability. A 16x2 I2C LCD display is mounted at the top to present real-time readings, including voltage, current, and power. Below the display, a breadboard organizes the core components, with the ESP32 microcontroller serving as the central unit for data processing and wireless communication with the BLYNK application. Key modules such as the ACS712 current sensor, ZMPT101B voltage sensor, and a single-channel relay are integrated with the ESP32 to facilitate energy monitoring and remote load control. Power is supplied via a USB cable, while jumper wires ensure secure and stable connections between components. The compact layout within the enclosure demonstrates a practical and scalable design, making the system well-suited for home automation, industrial monitoring, and other energy management applications.

4. Conclusion

In conclusion, the Smart Energy Monitoring System for industrial buildings has demonstrated its effectiveness in enabling real-time energy monitoring and management. By integrating current and voltage sensors with cloud-based data visualization through a smartphone interface, the system offers practical insights that support energy efficiency and sustainable usage. The project establishes a solid foundation for future improvements, such as advanced data analytics and predictive monitoring. Overall, the system highlights the critical role of smart technology in optimizing industrial energy consumption and addressing the growing challenges of modern energy management.

Acknowledgement

The author would like to thank the Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia,for its support.

References

[1] Energy Commission of Malaysia. (2024). Malaysia energy statistics handbook 2024. https://meih.st.gov.my

[2] Mordor Intelligence. (2024). Malaysia power market size & share analysis - industry report. https://www.mordorintelligence.com

[3] Tenaga Nasional Berhad. (2024). Electricity consumption and industrial demand. https://tnb.com.my

[4] Kumar, J. (n.d.). Benefits of IoT in an energy monitoring solution. IoT Project Factory. https://iotprojectfactory.com

[5] BridgeThings. (n.d.). IoT energy monitoring system. https://www.bridgethings.com/iot-energy-monitoring-system