

## ORIGINAL ARTICLE



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## Form Factor Reduction of an Industrial Research and Development Test Setup with IoT Integration

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### Abstract

Traditional R&D setups of electrical/electronics like Robotics, Automotive, Aerospace, etc involve extensive wiring and multiple equipment interfaces, making debugging difficult, time-consuming and less efficient. The proposed novel product addresses these issues by reducing setup complexity and improving ease of testing and debugging by remote monitoring, automated safety and modular expansion features which are absent in traditional setups. The design and implementation of an Internet of Things-based isolated AC load control and energy monitoring test bench utilizing ESP32(micro controller) and phase-angle TRIAC control with the option of switching between random phase firing and zero cross firing are presented in this paper. The developed system integrates three regulated DC outputs (12 V, 5 V, and 3.3 V), two independent AC control channels for dimming and switching, high-side energy measurement using the HLW8032, wireless monitoring via Wi-Fi and automatic protection logic for enhanced safety and reliability.

**Keywords:** Integrated PCB, Internet of Things (IoT), ESP32, TRIAC Phase-Angle Control, Energy Monitoring, Galvanic Isolation, Remote Monitoring and control

## Introduction

In the field of R&D, AC load control, monitoring, and multiple regulated DC voltage supplies are required for testing and development purposes. However, direct interaction with mains voltage poses significant safety risks not to mention this requires multiple equipment which leads to lot of wiring and space requirement, as a result R&D process becomes more time consuming and harder to debug not to mention such conventional setups lack fault protection, remote accessibility, and real time data visualization, making operation less safe and less efficient. The goal of the suggested system is to offer a modular platform for electrical experimentation Test setups where users can safely control AC loads while monitoring

Electrical Parameters like mains voltage, current, Active power, Reactive power, frequency and power factor. The goal of this project is to create a small, secure AC test bench that incorporates:

1. Distribution of DC power at multiple voltages
2. Control of dimming and AC switching
3. Monitoring of high-side energy
4. Web-based interface that is wireless
5. Fault protection that is automatic
6. Neatly organized communication protocol pins

## Literature review

IoT-based energy monitoring systems and smart load control strategies have been investigated by a number of researchers<sup>(1)</sup>. An Internet of Things based home automation system was created with wireless modules to enable remote switching<sup>(2)</sup>. Nevertheless, the system lacked methods for measuring and isolating energy parameters. Digital metering integrated circuits (ICs) were used to propose smart energy monitoring systems for smart grid applications<sup>(2)</sup>. Despite their accuracy, these systems were not intended for professional use, but rather for widespread deployment. TRIAC-based phase-angle control for light dimming has been extensively researched<sup>(1)</sup>. Recent AC dimming studies have shown that controlled firing-angle techniques improve load regulation and triggering reliability under varying operating conditions, making TRIAC-based control suitable for regulated AC load applications<sup>(3)</sup>. These systems do not incorporate IoT-based monitoring and protection; instead, they mainly concentrate on power control. ESP32-based monitoring platforms for industrial IoT applications were presented<sup>(2, 10)</sup>. The majority of current systems concentrate on either: monitoring or control<sup>(4)</sup>.

Large-scale industrial uses the integration of “isolated energy monitoring, AC load dimming, remote IoT access, and electronic modularity” into a single low-cost platform has not received much attention<sup>(9)</sup>. To close this gap, the suggested system combines:

- Measurement of isolated high-side energy
- TRIAC-based dimming and switching
- Web server interface for Wi-Fi
- Logic for automatic protection
- Modular power rails with multiple voltages

## System working

### A. Overall System Description

The suggested system uses a 230 V AC mains supply to monitor and regulate an AC load. For system operation, the input AC supply is transformed into regulated DC voltage levels of 12V, 5 V, and 3.3 V<sup>(8)</sup>. The ESP32 is powered by the 5 V on Vin pin<sup>(10)</sup> from output of buck converter, and external modules can receive the 12 V, 5V and 3.3 V outputs via connectors on the board. Because of this, the system can easily connect more external circuits as needed. Data reading, output transmission to the mobile application, and AC load operation via the switching circuit are all performed by the ESP32. In order to maintain neat and understandable connections, the

ESP32's pins are arranged appropriately in accordance with communication requirement.

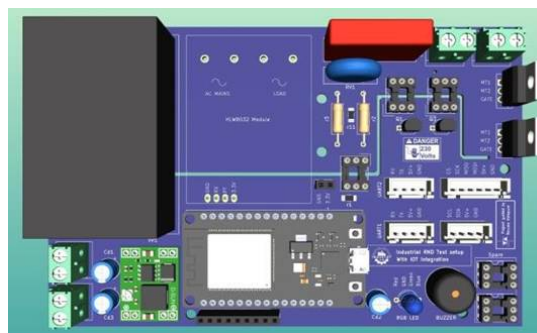


Fig. 1: system PCB top view

## B. Working Block wise

### 1. AC supply at 230 V:

The system's primary input is a 230 V AC mains supply.

#### Features:

- provides the system with power.
- supplies the SMPS module with AC supply.
- powers the section with the AC load.

### 2. SMPS Module (230 V AC to 12 V DC):

230 V AC is converted to 12 V DC by the SMPS module.

#### Features:

- Offers a controlled DC supply.
- Compact size.
- Galvanic isolation.
- Reverse polarity protection.

### 3. Controlled Voltage Outputs:

#### 5 V Output

- The ESP32 Dev Kit V1 is powered by a 5V on Vin pin from the buck module.

#### 12 V Output

- External modules receive a 12 V output via output connectors.

#### 3.3V Output

- Additionally, external modules receive 3.3V output via output connectors.

#### 4. ESP32 Dev Kit V1:

The central component of the system is the ESP32 DevKit V1.

##### Features:

- Reads data from energy meters.
- Transmits information to a mobile application.
- Switches the AC load.

For simple wiring, the pins are positioned by us in accordance with communication lines with help of external connectors.

#### 5. Energy meter

The energy meter along with zero cross detection IC calculates electrical parameters including the frequency:

- Current, voltage, reactive & active power, frequency and power factor<sup>(3)</sup>.
- ESP32 receives the measured data from Ic’s and sends to app interface via Wi-Fi.

#### 6. Switching AC Loads (mode 1)

The switching section that is connected to the ESP32 is used to operate the AC load.

Switching section uses TRIAC and optocoupler

isolation<sup>(5,12)</sup>

##### Features:

- AC load switching.
- Secure connection between the AC and low- voltage sides.

#### 7. AC dimmer control (mode 2)

The loads are varied using dimming control The zero cross detection IC is used to control the firing angle of the TRIAC and dimming control of ac loads are achieved<sup>(1, 5, 12)</sup>. Using the app interface we can switch between mode 1 and mode 2 as per user requirements.

### Experimental results

The test load was a 100 W incandescent lightbulb. Measured outcomes in relay mode (mode 1) were Voltage = 226V, Power = 100W, Current = 0.42.

In dimmer mode (mode 2) as the voltage varies, the power also varies since power is directly proportional to the voltage. Power is varied from 0 to 100% according to the slider in the app interface.

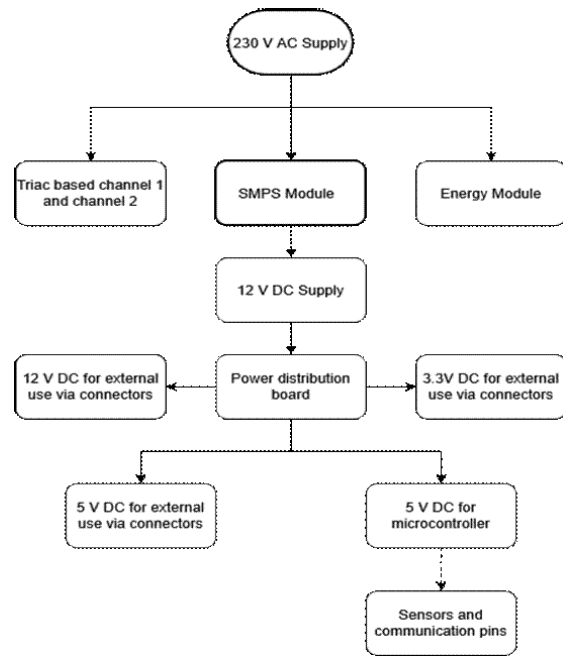


Fig. 2: System power flow

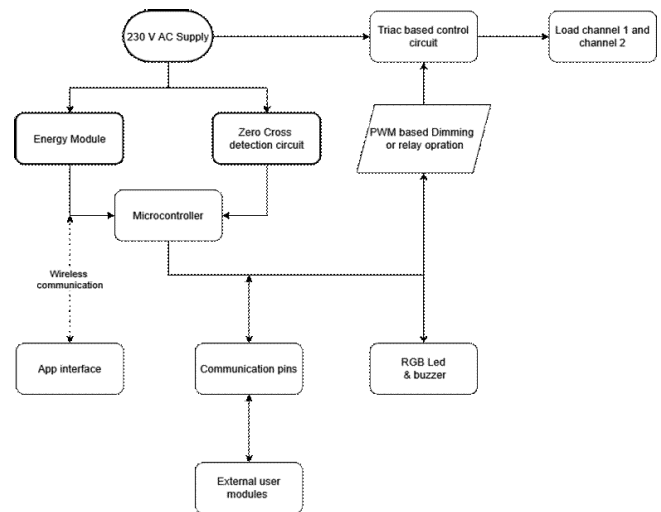


Fig. 3: System architecture

Three voltage rails are provided by the system:

- 12 V by the SMPS module
- ESP32 is powered at 5V via buck module. 3.3V provided by voltage regulator
- AMS1117.

Electrical parameters values in software to test various sensors and devices without the need for extra power supplies.

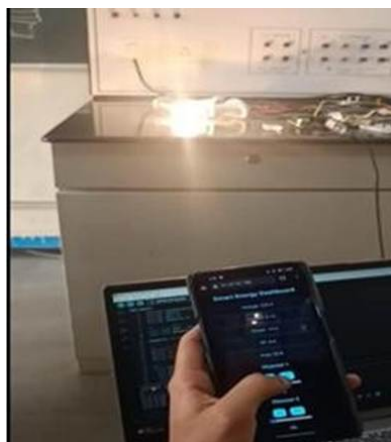


Fig. 4: AC load control through app interface



Fig. 5: AC load parameters monitoring



Fig. 6: Electrical parameters values in software

## Proposed system advantages

### 1. Secure Separation

The system makes use of electrical isolation methods (like opto-isolators and isolation transformers) between the low-voltage control circuitry and the high-voltage AC section<sup>(5, 12)</sup>. This guarantees: The microcontroller's defense against high voltage Decreased danger of electric shock increased safety and dependability of the system.

### 2. Remote Monitoring

The suggested system enables real-time tracking of variables like: The voltage The temperature Status of load Data can be viewed via an IoT interface or display, allowing for improved control and remote supervision<sup>(2)</sup>.

### 3. Dimming by firing angle control

Firing angle control via TRIAC-based switching<sup>(1, 12)</sup> is supported by the system. This permits: Easy power management Variable output voltage Accurate temperature control (helpful for AC load control, heaters, and soldering stations.

### 4. Automatic safety protection

The system has built-in safeguards like: Protection against overcurrent; Protection against overvoltage; Protection against overheating. In order to prevent component damage, the system automatically disconnects the load if abnormal conditions are detected.

### 5. Expandable Attachments

Modular connectors in the design enable: Adding new sensors is simple. Including additional modules.

Future improvements without completely redesigning the circuit. This enhances scalability and flexibility.

## Conclusion

The proposed IoT-based AC load control and monitoring test bench provides a compact and efficient solution to the complexity associated with the traditional electrical/electronics R&D setups. By integrating TRIAC-based dimming and controlling of AC loads, energy monitoring, multi regulated DC voltage outputs, systematically organized communication pins and control through app interface into a single platform the system improves testing flexibility, operational safety and debugging efficiency. Experimental results with resistive lamp loads demonstrate reliable control performance and accurate measurement, making the developed platform suitable for laboratory and prototype development applications.

## References

1. Cena G, Valenzano A, Scanzio S, Zunino C. Evaluation of Response Times in Industrial IoT Applications. *IEEE Transactions on Industrial Informatics*. 2017, 13(2), pp. 828–837
2. Alheraish A. Design and implementation of home automation system. *IEEE Transactions on Consumer Electronics*. 2004;50(4):1087-1092. Available from: [10.1109/tce.2004.1362503](https://doi.org/10.1109/tce.2004.1362503)
3. Chau KT, Yang H. Recent Developments in AC Lamp Dimming and Control. *IEEE Transactions on Industrial Electronics*. 2020, 67(5). pp. 3820–3830.
4. Wang Y, Zhang Z, Li J, Shahidehpour M. Smart Residential Energy Management System Considering RealTime Load Control and Monitoring. *IEEE Transactions on Smart Grid*. 2021, 12(3). pp. 2157–2167.
5. STMicroelectronics. *BTA16 TRIAC Datasheet*. STMicroelectronics, Geneva, 2006.
6. Rashid MH. *Power Electronics: Circuits, Devices and Applications*. Upper Saddle River, NJ: Pearson, 2014.
7. Mirani M, Awasthi R, Singh AK. Industrial IoT-Based Energy Monitoring System: Using Data Processing at Edge. *IoT*. 2024;5(4):608-633. Available from: [10.3390/iot5040027](https://doi.org/10.3390/iot5040027)
8. Wadhwa CL. *Electrical Power Systems*. New Delhi: New Age International Publishers, 2017.
9. Hannan MA, Faisal M, Ker PJ, Hussain A. A review of internet of energy based smart metering systems. *Renewable and Sustainable Energy Reviews*. 2019, 107. pp. 1–15.
10. Espressif Systems. *ESP32 Technical Reference Manual*. Espressif Systems, Shanghai, 2023.
11. HLW. *HLW8032 Energy Metering IC Datasheet*. HLW, Shenzhen, 2022.
12. ON Semiconductor. *MOC3041M Zero-Cross Triac Driver Output Optocoupler Datasheet*. ON Semiconductor, Phoenix, AZ, 2022.
13. Pawar V, Phule A, Metkari A, Takale SR. Review of Smart Energy Meter Implementations Using ESP32 Microcontroller and IoT Platforms. *International Journal of Advanced Research in Science, Communication and Technology*. 2025;:375-391. Available from: [10.48175/ijarsct-29423](https://doi.org/10.48175/ijarsct-29423)
14. Somantri M, et al.. Optimization of IoT-based monitoring system for automatic power factor correction using PZEM-004T sensor. *Indonesian Journal of Electrical Engineering and Computer Science*. 2025;39(2):860-873. Available from: [10.11591/ijeecs.v39.i2.pp860-873](https://doi.org/10.11591/ijeecs.v39.i2.pp860-873)
15. Salcedo JG, Obispo KGM, Rojas JJH. Development of an Automated Testing System for Alternators with Real-Time Monitoring Based on IoT and Electrical Analysis. *International Journal of Electrical and Electronics Engineering*. 2025;12(6):14-24. Available from: [10.14445/23488379/ijeec-v12i6p102](https://doi.org/10.14445/23488379/ijeec-v12i6p102)