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(Research Article)

Design and implementation of a smart apartment electrical training model using WIFI-based relay controllers

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Abstract

The rapid development of the Internet of Things (IoT) has transformed modern residential electrical systems and smart home infrastructures. However, many electrical engineering laboratories still rely on traditional training platforms focused on individual circuits and fail to represent integrated residential electrical systems adequately. This paper presents the design and implementation of an apartment electrical power supply training model for engineering education. The proposed platform simulates a typical residential electrical system, including lighting circuits, electrical outlets, water heater loads, and air-conditioning loads. Smart functionality is implemented using two WiFi-based relay controllers with Sonoff 4CH R3 modules, enabling remote monitoring and control via a mobile application. Experimental results demonstrate reliable operation in both manual and smart control modes. The developed platform provides a practical training environment for studying electrical systems in buildings and IoT-based smart home technologies.

Keywords: Building Electrical Systems; Smart Building Training; Apartment Electrical Model; IoT Relay Controller; Engineering Education

1. Introduction

Digital technologies have significantly transformed modern industrial systems and residential infrastructures during the Fourth Industrial Revolution. Technologies such as artificial intelligence, cloud computing, and the Internet of Things (IoT) are increasingly integrated to develop intelligent and interconnected systems. Global reports show that the number of connected IoT devices continues to grow rapidly, enabling a wide range of smart services and applications worldwide [1], [2]. These developments have accelerated the adoption of intelligent monitoring and control systems across various sectors, including residential environments.

One of the most important applications of IoT technology is the development of smart homes. Smart building infrastructures integrate electrical installations with communication networks and automation platforms to improve operational efficiency and energy management [3]. Recent international studies highlight that digital technologies can significantly improve energy efficiency, sustainability, and operational performance in modern buildings [4]–[6]. IoT-based smart home systems also allow users to remotely monitor and control household electrical devices through mobile applications and cloud-based services [7]–[9].

Despite these technological advances, the integration of smart building technologies into engineering education remains limited. Traditional electrical laboratories often focus on individual circuits and basic experiments, which do not adequately represent the complexity of modern residential electrical systems. Recent research in engineering education emphasizes the importance of experiential and project-based learning environments that allow students to interact with real engineering systems and practical applications [10]–[12].

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Several recent studies have explored laboratory platforms for smart home automation and IoT-based control systems [13]. These platforms typically use microcontrollers, embedded processors, and wireless communication modules to implement intelligent control functions. However, many existing solutions rely heavily on complex programming and embedded system development, which may increase the learning difficulty for students studying building electrical installations rather than embedded system design.

To address this limitation, this study proposes the design and implementation of an apartment electrical power supply training model for engineering laboratories. The proposed system simulates a residential electrical infrastructure and integrates conventional electrical wiring with a Wi-Fi-based smart relay controller using the Sonoff 4CH R3 module [14], [15]. The platform supports both manual switching and IoT-based remote control, allowing students to study traditional electrical installations and modern smart home technologies within a unified experimental environment.

The main contributions of this study include:

- Design of a practical apartment electrical training model for laboratory education.
- Integration of a WiFi-based multi-channel relay controller for smart load control.
- Development of a hybrid control architecture combining conventional switches and IoT-based control.
- Implementation of a laboratory platform for studying building electrical systems and smart home technologies.

2. Materials and Methods

2.1. System Architecture

The proposed training model simulates the electrical power supply system of a residential apartment while integrating IoT-based intelligent control. The model represents a simplified apartment layout with functional areas such as a living room, bedroom, kitchen, and bathroom, creating a realistic environment for studying building electrical systems. Figure 1 illustrates the apartment layout used in the training model.

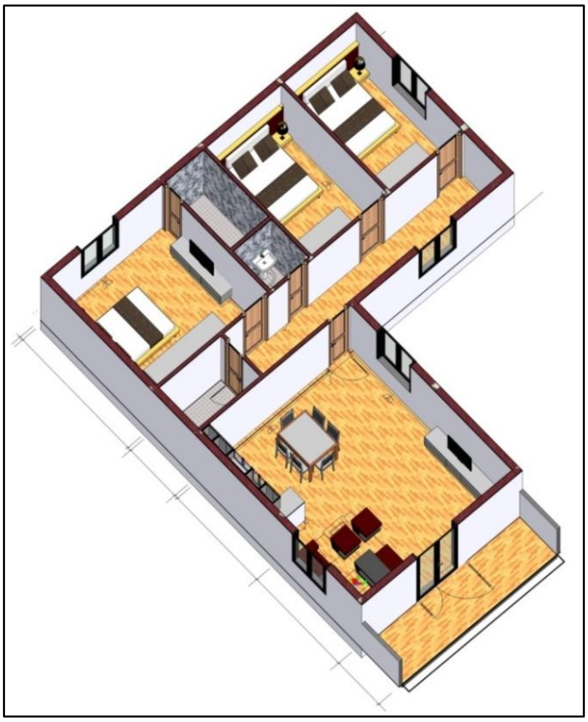

Figure 1 Apartment layout used in the training model.

The electrical system includes lighting circuits, electrical outlet circuits, water heater loads, and air-conditioning loads. The wiring configuration follows common residential electrical installation practices to ensure safe operation during laboratory exercises.

To support both conventional and intelligent control technologies, the system adopts a hybrid architecture consisting of three main subsystems: power distribution, load control, and intelligent communication. Electrical loads can be operated either through mechanical switches or through relay-based smart control via an IoT platform. Figure 2 shows the smart home electrical training model used in the laboratory.

Figure 2 Smart home electrical training model

This architecture allows the simulation of modern residential electrical systems while supporting practical training in both traditional electrical installations and smart home technologies.

2.2. Smart Relay Controller

To implement smart control in the training platform, the system integrates Wi-Fi-based relay controllers designed for IoT applications. In this study, two Sonoff 4CH R3 modules are used to form the main smart control unit of the apartment model.

Each module provides four independent relay channels. By combining the two modules, the system achieves eight control channels for managing lighting circuits, power outlets, and auxiliary devices in the training model.

The controllers communicate via Wi-Fi, enabling monitoring and control of electrical loads through a mobile application. In addition to wireless operation, the modules also support manual switching through physical buttons, allowing students to compare conventional control methods with IoT-based smart control. Figure 3 shows the smart relay controller integrated into the apartment training model.

Figure 3 Smart relay controller using two Sonoff 4CH R3 modules

2.3. Experimental Training Model

The proposed training model represents a simplified residential electrical system designed for practical teaching purposes. The model simulates a typical building electrical infrastructure and allows students to study both conventional electrical systems and IoT-based smart control technologies.

Several electrical loads are integrated into the model, including lighting circuits, electrical outlet circuits, water heater loads, and air-conditioning loads. These loads are connected through a power distribution system consisting of protective devices, distribution panels, and branch circuits.

Each load can be controlled either through a conventional wall switch or through the smart relay controller described in Section 2.2. This hybrid control architecture enables students to compare traditional electrical control methods with IoT-based smart control systems.

The training model is implemented on a laboratory training panel integrating wiring components, relay controllers, and simulated electrical loads. Smart control is achieved through Wi-Fi communication between the relay controllers and a mobile application, allowing users to remotely monitor and control electrical loads. Table 1 summarizes the main components used in the proposed training model.

Table 1 Main components of the training model

Component	Function
Main circuit breaker	Electrical protection
Distribution board	Power distribution
Lighting lamps	Lighting load simulation
Power outlets	Appliance load simulation
Water heater loads	Load simulation
Air-conditioning loads	Load simulation
Sonoff 4CH R3 controller	Smart relay control

3. Experimental Results

3.1. Laboratory Implementation

Based on the system architecture presented in Section 2, the proposed residential electrical training model was implemented and tested in a laboratory environment. The experimental system integrates a power distribution panel, wiring circuits, smart relay controllers, and electrical loads into a practical training platform.

The implemented system includes typical residential loads such as lighting circuits, electrical outlet circuits, water heater loads, and air-conditioning loads. These loads are connected through relay switching channels and conventional wall switches, allowing both manual operation and smart control through IoT-based relay controllers. Figure 4 shows the electrical control panel of the training model, including the distribution panel, wiring components, and smart relay controllers used to manage the electrical loads.

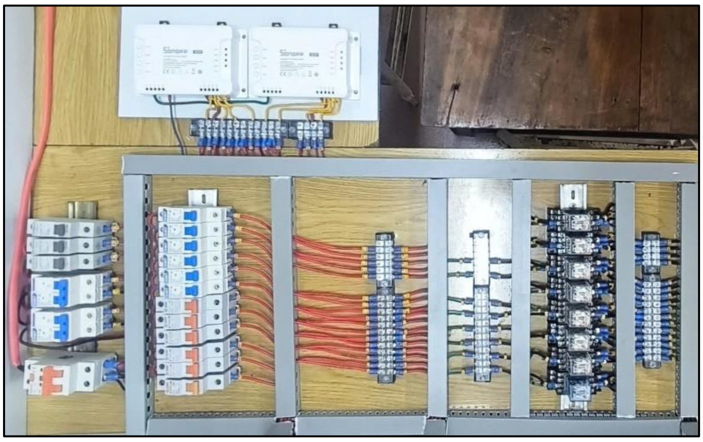

Figure 4 Electrical control panel of the residential electrical training model with integrated smart relay controllers

3.2. Smart Control Operation

To evaluate the smart control capability of the proposed system, the relay controllers were connected to a wireless network and operated through a mobile application interface. Through this interface, users can remotely monitor and control the electrical loads integrated into the training model.

The mobile application allows individual switching of electrical loads as well as simultaneous control of multiple devices. Experimental observations show that the relay controllers respond reliably to remote commands transmitted through the wireless network, demonstrating stable operation of the smart control system. Figure 5 illustrates the mobile application interface used to control the electrical loads of the training model.

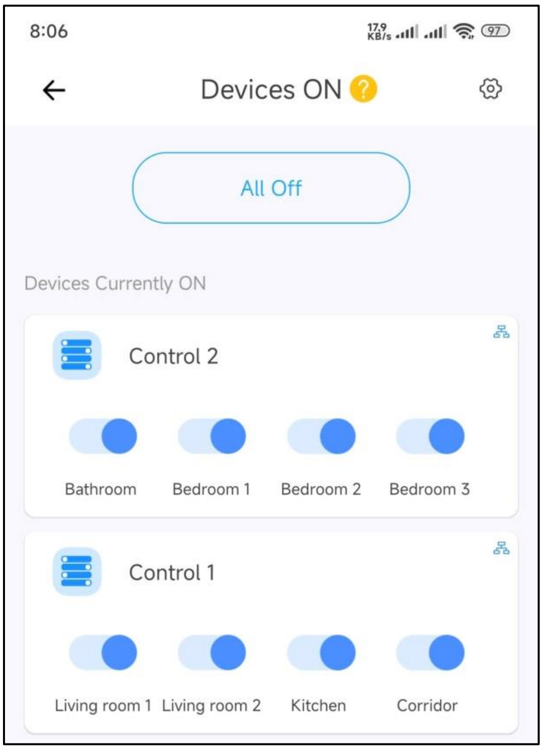

Figure 5 Mobile application interface for smart load control

The operating modes of the proposed training platform are summarized in Table 2, which presents the different control methods supported by the system.

Table 2 Control modes of the training platform

Control Mode	Description	Operation Method
Manual control	Conventional switching	Wall switches
Smart control	Remote switching	Mobile application
Hybrid control	Combined operation	Manual + IoT

4. Discussion

Experimental results show that the proposed training model provides an effective environment for studying building electrical systems and smart home technologies. By integrating conventional electrical wiring with IoT-based smart control, the system enables students to understand both traditional electrical installations and modern automation technologies.

A key advantage of the proposed platform is its hybrid control architecture, which combines manual switching with IoT-based remote control. This configuration allows students to directly compare conventional electrical control methods with smart home automation systems. In the event of a smart control system failure, the electrical loads can still be operated through conventional control methods.

Another advantage is the use of commercially available IoT hardware. The Sonoff 4CH R3 controller provides a cost-effective and practical solution for implementing smart control functions in educational laboratories. Compared with traditional microcontroller-based systems, the proposed platform reduces system complexity and enables students to study smart control technologies without requiring advanced embedded programming skills.

The training model also supports various practical activities such as electrical wiring exercises, load control experiments, and smart building automation demonstrations. Furthermore, the platform can be extended by integrating sensors, energy monitoring modules, or advanced automation algorithms.

Overall, the proposed residential electrical training model provides a practical educational platform that bridges traditional electrical engineering training with modern smart home technologies.

5. Conclusion

This paper presents the design and implementation of a residential electrical training model integrating a Wi-Fi-based smart relay controller for building electrical education. The platform was developed to represent a typical residential electrical system while incorporating IoT-based smart control functions.

Experimental results show that the system can reliably control multiple electrical loads, including lighting circuits, electrical outlets, water heater loads, and air-conditioning loads. The integration of the Sonoff 4CH R3 controller enables remote monitoring and control through a mobile application.

The proposed platform provides a practical educational tool that connects traditional electrical installation training with modern IoT-based smart home technologies. Future work will focus on integrating additional sensors and energy-monitoring modules to support advanced energy management and smart building research.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no conflict of interest regarding the publication of this paper.

References

[1] International Telecommunication Union. Measuring digital development: Facts and figures 2023. Geneva: ITU; 2023.

[2] Statista. Number of Internet of Things (IoT) connected devices worldwide. 2024. Available from: https://www.statista.com

[3] Al-Azzawi AR, Farhan M. IoT-based smart home automation systems: Recent advances and challenges. IEEE Access. 2022;10:1-15.

[4] International Energy Agency. Digitalisation and energy efficiency in buildings. Paris: IEA; 2023.

[5] European Commission. Smart buildings and energy efficiency technologies. Brussels: European Commission; 2023.

[6] Kumar A, Singh S. IoT-enabled energy management in smart buildings: A review. Sustain Cities Soc. 2023;92:104486.

[7] Sharma H, Kumar P. Design of smart home automation using IoT and cloud technologies. Sensors. 2022;22(18):1-15.

[8] Khan R, Khan SU, Zaheer R, Khan S. Smart home automation using IoT technologies: A review. Future Internet. 2023;15(2):45.

[9] Li Y, Zhao J. IoT-enabled smart home technologies for energy management. Energy Rep. 2023;9:1120-1130.

[10] Johri A, Olds B. Engineering education research: New directions in experiential learning. IEEE Trans Educ. 2022;65(3):315-322.

[11] Lattuca LR, Terenzini PT. Project-based learning in engineering education. J Eng Educ. 2023;112(1):120-138.

[12] Nadelson SB, et al. Experiential learning and laboratory innovation in engineering education. Educ Sci. 2024;14(3):215.

[13] Rahman AM, et al. Development of an IoT-based smart home laboratory platform for engineering education. IEEE Access. 2022;10:24560-24572.

[14] ITEAD Studio. Sonoff 4CH R3 smart switch user manual. Shenzhen: ITEAD Studio; 2022.

[15] Sonoff. Smart home solutions. Available from: https://sonoff.tech.