International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-13 Issue-12, November 2024

Design and Implementation of An Energy-Efficient Extension Board with Integrated Overcurrent Protection for Home Appliances

Stephen Eduku, Joseph Sekyi-Ansah, Martey Prosper Tetteh, Ofori Bernard Johnson

***Abstract:** Electrical extension boards are a significant cause of electrical fires in homes, university hostels, offices, and other key applications worldwide, often due to overloading beyond their rated capacity. Additionally, users usually forget to turn off appliances such as televisions, portable fans, or electric irons, resulting in unnecessary energy waste. These Extension boards, commonly used to power multiple electrical appliances, are widely used in homes and universities; however, overloading them can lead to overheating, burning, and potential fire hazards. This is often due to exceeding the board's rated capacity, which reduces load resistance and increases current flow, particularly in parallel-connected domestic loads. To address this risk, this paper presents an innovative energy-efficient extension board equipped with overcurrent protection. The system continuously monitors the current drawn by connected appliances and automatically isolates them via a relay mechanism when the load exceeds the rated capacity of 13 amperes. The overcurrent status is displayed on an LCD. A microcontroller, interfaced with a current sensor and relay, manages the process, ensuring the safety of the extension boards and home appliances. Additionally, a buzzer notifies the user of the system's status. Furthermore, the system features a timer function to manage energy consumption based on user-defined settings. Both simulation and experimental prototype were employed to verify the design, and the results showed a strong correlation between the expected and actual performance, demonstrating the practicality of the proposed system.*

***Keywords:** New Extension Board, Overcurrent Protection, Energy-Efficient, Microcontroller, Relay.*

I. INTRODUCTION

Modern technology has driven the rapid development of smart home appliances, but these advanced devices lose their convenience if users rely solely on fixed socket outlets.

Manuscript received on 14 September 2024 | Revised Manuscript received on 03 October 2024 | Manuscript Accepted on 15 November 2024 | Manuscript published on 30 November 2024.

*Correspondence Author(s)

Stephen Eduku*, Department of Electrical and Electronic, Engineering, Faculty of Engineering Takoradi Technical University, Takoradi Ghana. Email:5103180335@stmail.ujs.edu.cn, ORCID ID: 0000-0002-9210-8187

Ing. Dr. Joseph Sekyi-Ansah, Department of Oil and Natural Gas Engineering, Faculty of Engineering, Takoradi Technical University, Takoradi, Ghana. Email: joseph.sekyi-ansah@ttu.edu.gh

Martey Prosper Tetteh, Department of Electrical and Electronic Engineering, Faculty of Engineering, Takoradi Technical University, Ghana. Email: prospermartey@gmail.com

Ofori Bernard Johnson, Department of Electrical and Electronic Engineering, Faculty of Engineering, Takoradi Technical University, Ghana. Email: oforibernard614@gmail.com

Thus, electrical extension boards are essential for extending the power supply beyond fixed socket outlets. Despite significant investment in smart devices, users often overlook the critical role of electrical extension boards, which can either protect or damage these appliances and significantly impact their lifespan. Additionally, many users forget to turn off devices such as refrigerators and televisions, resulting in wasted energy and higher electricity bills. Furthermore, frequent fires often occur due to negligence, oversight, or failures in the safety features of appliances and household electrical systems [1].

While cost-effective technologies exist that could reduce energy consumption, they have not been widely implemented. As a result, energy resources are not being utilized as efficiently as they should be [2]. Additionally, a microcontroller-based system was developed to protect home appliances from voltage and current fluctuations, utilising sensors to measure current levels and activating a relay when these values deviate from a preset threshold. A GSM module was also used to notify users of faults [3]. In contrast, the proposed system will integrate home automation features and include a buzzer to alert users when faults are detected or a preset time has been reached. However, an Electronic Circuit Breaker (ECB) was introduced to provide faster protection against short circuits and overloads compared to traditional mechanical circuit breakers, such as the Miniature Circuit Breaker (MCB), which relies on a slower thermal bimetal mechanism. In the event of a short circuit, the ECB detects current flow through a low-resistance series element. A voltage comparator assesses the voltage drop across this element and sends a signal to the microcontroller if it exceeds a preset threshold.

The microcontroller then activates a MOSFET, which controls the relay, quickly tripping the circuit [4]. Raj et al. [5] proposed a Wi-Fi-enabled power extension board for controlling devices and optimizing energy usage. Their approach utilized wireless sensor networks (WSNs) and cloud computing to create an efficient wireless communication framework within the home. The goal was to achieve energy savings for smart home applications while establishing a smart home environment without altering the existing electrical wiring or infrastructure. Besides, Gupta et al. [6] introduced a smart extension board capable of controlling electrical appliances through Google Assistant and a mobile app. Unlike traditional extension boards, which only allow manual operation via physical switches, this smart extension board offers remote control through a mobile app in addition to the manual switches integrated into the board.

Nonetheless, extensive research has focused on developing a protection system using the Internet of Things (IoT) to monitor and analyze voltage levels, aiming to prevent damage to loads connected to an extension board. The system employs the ZMPT101B sensor to detect voltage variations and transmit alerts via Wi-Fi modems managed by the ESP8266 NodeMCU microcontroller. Additionally, the Arduino Uno processes the voltage data, which is then displayed on an LCD screen [7]. Moreover, a protection system for electrical appliances utilizing an automatic tripping mechanism for under-voltage and over-voltage conditions was proposed in [8]. The system, designed with components such as a relay, transistor, and operational amplifier, demonstrated that the load (a lamp) would turn off when the voltage dropped below 210V or exceeded 240V, indicating under-voltage and over-voltage situations. The study suggested that incorporating GSM technology could further enhance the system by sending SMS alerts to notify users of the system's status.

Nevertheless, as outlined in [9], an overvoltage and undervoltage protection system was developed using a comparator and relay to disconnect the power supply during voltage fluctuations. The system was designed to trip the relay when high or low voltage conditions were detected, effectively protecting both industrial and household electrical appliances. Additionally, Statistical analysis depicts that electrical products are highly prone to causing fires, with wires and cables leading in terms of fire incidents, casualties, and property damage. The primary causes of conductor overheating are typically overloads or short circuits [10].

Based on the analysis above, this research proposes the design and implementation of an energy-efficient extension board with integrated overcurrent protection, ensuring both device safety and effective energy management.

A.Novelty of the Proposed Design

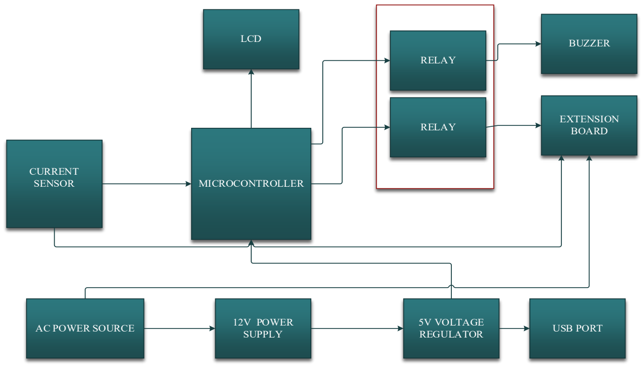
The proposed home automation protection system introduces an innovative solution for safeguarding electrical appliances by automatically tripping the circuit or cutting off power in the event of an overcurrent exceeding 13 amperes. The system also features a timing mechanism that allows users to set a predetermined shut-off time, effectively reducing energy waste and lowering electricity consumption for both prepaid and postpaid meter users. Additionally, the energy-efficient extension board, integrated with overcurrent protection, offers the flexibility to reset or bypass the timing function for continuous operation, offering enhanced security compared to traditional extension boards.

II. MATERIALS AND METHODS

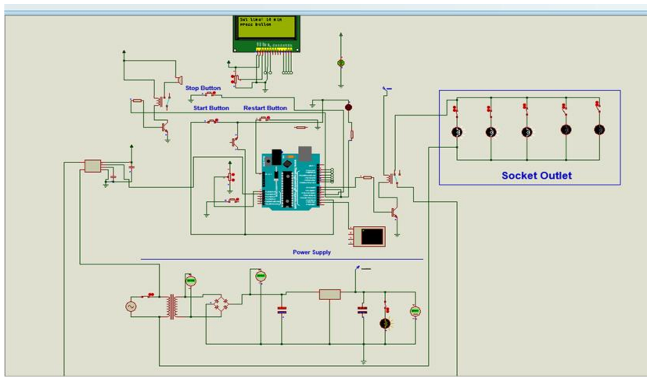
A. Design Topology and Simulation Analysis

The design and implementation of an energy-efficient extension board with integrated overcurrent protection were first modelled using a block diagram, as shown in Figure 1. The selected power supply, rated at 220V/12V, was stepped down to 5V DC after rectification and smoothing through a filter capacitor, allowing the microcontroller, the system's core, to function. The current sensor, buzzer, and loads were connected to the microcontroller, which was programmed to coordinate all components to achieve the design objectives. Figure 1 illustrates the simulated circuit diagram of the energy-efficient extension board with overcurrent protection for home appliances.

Using the Arduino Integrated Development Environment (IDE), a Universal Serial Bus (USB) programmer was employed to upload the operating instructions to the Arduino Uno. The Arduino IDE provided a user-friendly platform for writing, compiling, and debugging C/C++ programs. After programming, the compiled code was tested in Proteus to simulate real-world conditions and verify the system's operation. Proteus Design Suite (PDS) was used for simulation, schematic capture, and printed circuit board (PCB) layout design.



[Fig.1: The Block Diagram of the Energy-Efficient Extension Board with Integrated Overcurrent Protection for Home Appliances]



[Fig.2: The Circuit Diagram of the Energy-Efficient Extension Board with Integrated Overcurrent Protection for Home Appliances]

B. Design Construction Analysis

As shown in Figure 3, a miniature circuit breaker (MCB) was used as a switch for the entire system, preventing any transient current or voltage during switching. The output of the MCB was connected to a socket outlet and power supply, which were first mounted on a breadboard to generate the 5V DC power required for the microcontroller, sensor, and LCD.

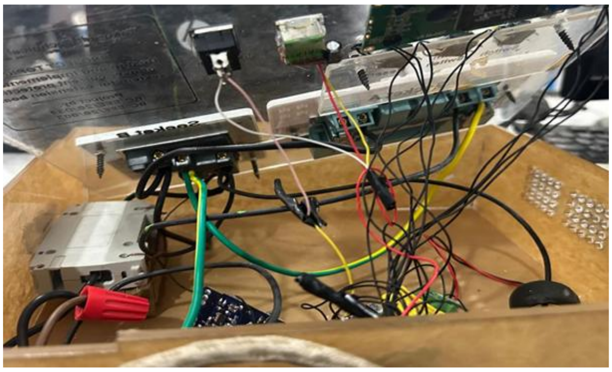
The sensor, relay, LCD, and buzzer were all configured to work with the microcontroller, ensuring the system met its design objectives.

To provide proper cooling and prevent thermal issues, a rectangular acrylic casing with cooling fins was used to house the components of the energy-efficient extension board with integrated overcurrent protection, as shown in Figure 3. This casing not only protects the circuitry but also

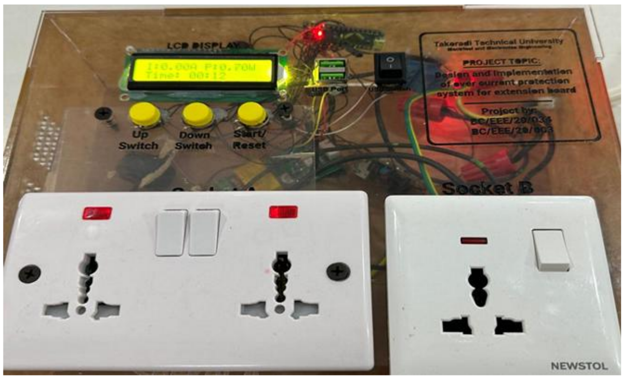
Retrieval Number: 100.1/ijitee.K999113111024
DOI: 10.35940/ijitee.K9991.13121124
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

allows clear visibility of the internal components. After soldering the components on the breadboard, they were secured in the acrylic casing to prevent movement. Figure 4 illustrates the final packaging of the design, ensuring both functionality and protection for the system.



[Fig.3: Picture of the Experimental Setup]

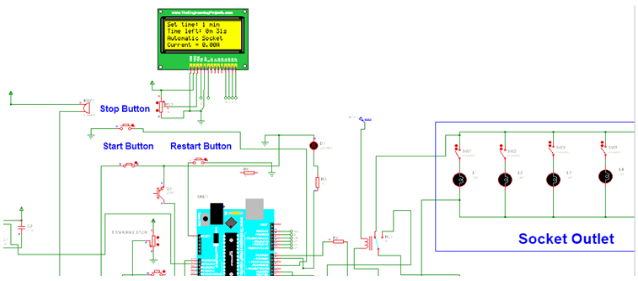


[Fig.4: Picture of the Final Proposed System]

III. RESULTS AND DISCUSSION

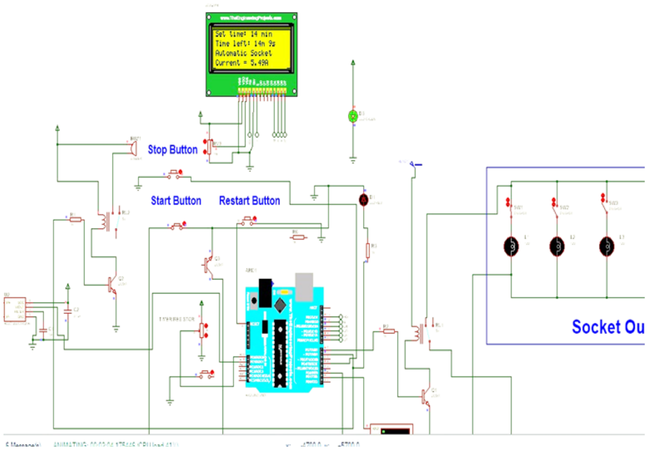
A. Simulation Results

The results were obtained from simulating the design system using Proteus Software and testing the system under load conditions. When the current in the extension board exceeded the maximum allowable value, the relay activated to sound a buzzer and disconnected the supply until the overcurrent fault was resolved. The no-load current, as shown in Figure. 5, was 0.00A.



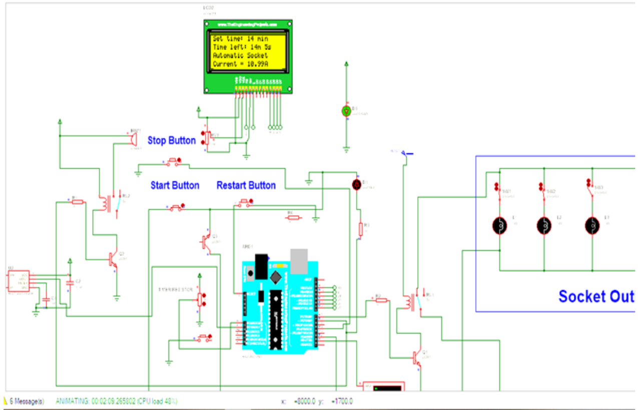
[Fig.5: State of the System for no-Load Current]

The initial load, as shown in Figure. 6, revealed a current of 5.49A. This indicates that the first load drew 5.49A of current. Therefore, the load current reflects the amount of current absorbed by the connected load.



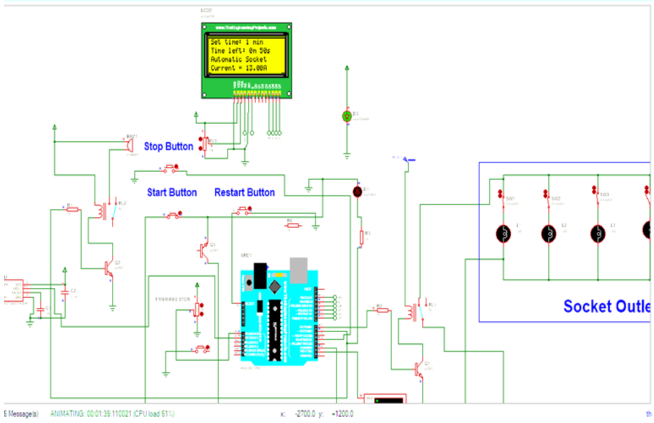
[Fig.6: State of the System for Load Current of 5.49A]

Following the addition of the loads, a correspondingly larger amount of current was drawn when the second load was added. As shown in Figure. 7. The load current displayed on the LCD is 10.99 A, indicating that the second load has increased the total load current to 10.99 A.



[Fig.7: State of the System for Load Current of 10.99A]

The addition of the third load resulted in a higher current consumption. As shown in Figure. At 8, the load current displayed on the LCD increased to 13.00 A, indicating the effect of the third load.



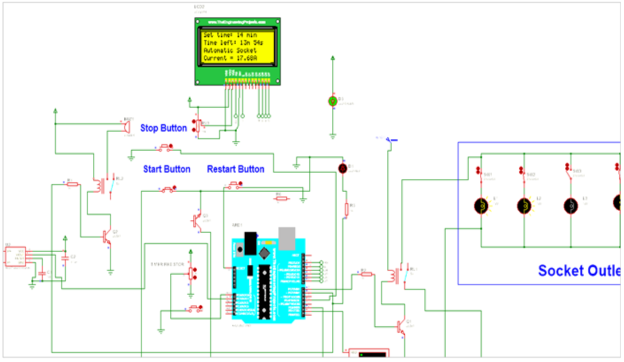
[Fig.8: State of the System for Load Current of 13.00A]

Ultimately, when the fourth load was connected, the current increased to 17.68A, triggering the buzzer and the relay.

Retrieval Number: 100.1/ijitee.K999113111024
DOI: 10.35940/ijitee.K9991.13121124
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

As shown in Figure. 9, the relay disconnects the extension board from the power source, while the buzzer sounds an alarm to alert users to the overcurrent fault.



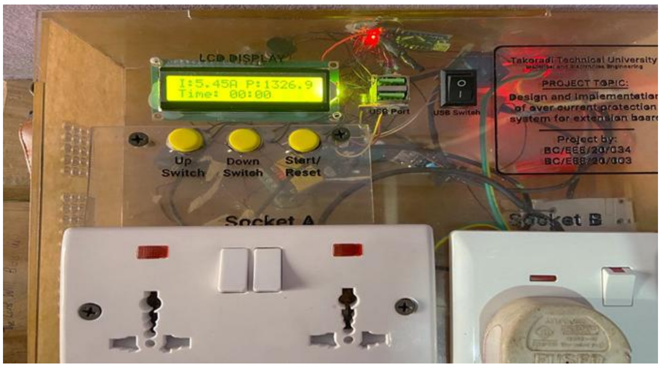
[Fig.9: State of the System for Load Current of 17.68A]

B. Experimental Results

The circuit's practical trials are illustrated in Figures 10-14, which validate the simulation results. As the load is added, the LCD's current reading rises until it reaches the predetermined value point. The simulation and the experimental performance, as shown, are closely related. Figure 10 depicts the system under no stress, while Figure 14 depicts the system under overload. The results were obtained from constructing the design and testing the system under no-load conditions. The no-load current is shown in the Figure. 10, was 0.00A.

[Fig.10: Picture of the Implemented System at No-load]

The initial load, as shown in Figure 11, revealed a current of 5.45 A. This indicates that the first load drew 5.45A of current.

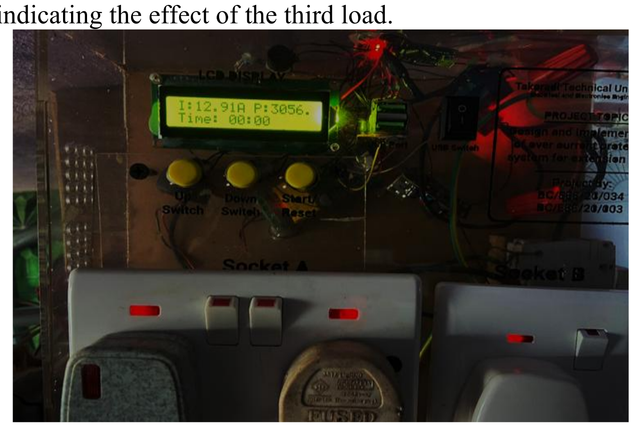


[Fig.11: Picture of the Implemented System for Current of 5.45A]

In the third test, another load was added, and a correspondingly larger amount of current was drawn. As shown in Figure. 12, the load current displayed on the LCD is 10.93A, indicating that the second load increased the total load current to 10.93A.

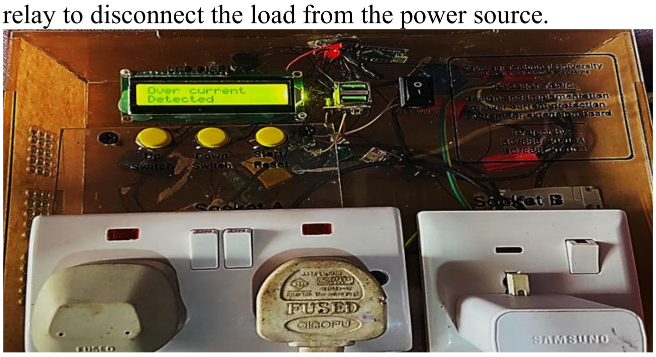
[Fig.12: Picture of the Implemented System for Current of 10.93A]

In the fourth test, an addition of the third load resulted in a higher current consumption. As shown in Figure 13, the load current displayed on the LCD increased to 12.91 A, indicating the effect of the third load.



[Fig.13: Picture of the Implemented System for Current of 12.91A]

Finally, when the fourth load was connected, the current increased to 17.56 A, exceeding the system's threshold value. The system detects "OVER CURRENT" as indicated by the LCD in Figure. 14. At this point, the buzzer sounds to alert the user of a malfunction. Additionally, a signal is sent to the relay to disconnect the load from the power source.



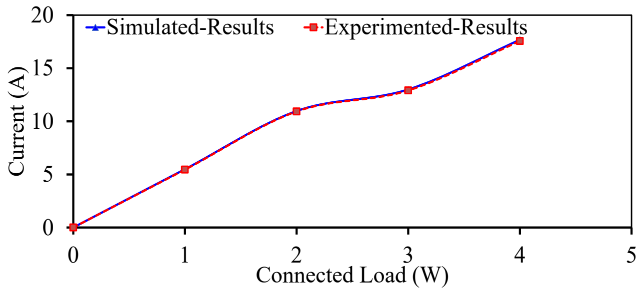
[Fig.14: Picture of the Implemented System in an Overloaded Condition]

Retrieval Number: 100.1/ijitee.K999113111024
DOI: 10.35940/ijitee.K9991.13121124
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

Table 1: Shows the Design Comparison for Both the Experimental and Simulated Findings

No. of connected loads	Simulated load current (Amp)	Experimented load current (Amp)	State of relay	State of buzzer
None	0.00	0.00	Close	Off
1	5.49	5.45	Close	Off
2	10.97	10.93	Close	Off
3	13.00	12.91	Close	Off
4	17.68	17.56	Open	On



[Fig.15: Represents the Graph of the Energy-Efficient Extension Board with Integrated Overcurrent Protection for Home Appliances]

C. Discussion

The design results revealed that the current flowing through the extension board increased as the number of connected loads grew. This relationship is illustrated in Table 1, where the increase in sensor output voltage results in corresponding increases in current values displayed on the LCD. Five tests were conducted, with each test adding a load or appliance. Overcurrent was detected when the current surpassed the 13-ampere threshold.

Both simulated and experimental tests were performed, yielding similar results. Simulated current values ranged from 0 A to 17.68 A (Figures 5–9), while experimental current values ranged from 0 A to 17.56 A (Figures 10–14). In both cases, it was observed that as more loads were added, the current measured on the LCD increased proportionally.

In the fifth test, when the fifth load was connected, the system's relay triggered, isolating the loads from the power source. A warning alarm sounded from the buzzer, accompanied by the LCD reading “overcurrent detected.”

These findings demonstrate that the energy-efficient extension board with integrated overcurrent protection functions as designed. As shown in Figure 14, as the number of connected loads increases, the current rises until it surpasses the preset 13-ampere limit. At that point, the relay, controlled by the current sensor and microcontroller, trips to isolate the circuit and prevent overload. Microsoft Excel was used to analyze the experiment results.

IV. CONCLUSION

This research paper introduces a newly designed energy-efficient extension board with integrated overcurrent protection for home appliances. The relay serves as the primary switch, disconnecting the system both in the event of an overload and after a predetermined time has elapsed. Additionally, the design incorporated an auxiliary device to provide warning messages in the event of an overcurrent issue.

The use of a few locally sourced components results in a relatively low implementation cost, making the project cost-effective. Compared to other configurations reported in the literature, this system’s integration of an alarm enhances its functionality by offering immediate awareness and home automation capabilities. Consequently, the proposed design is superior to many existing designs.

DECLARATION STATEMENT

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

- **Conflicts of Interest/Competing Interests:** Based on my understanding, this article does not have any conflicts of interest.
- **Funding Support:** This article has not been funded by any organizations or agencies. This independence ensures that the research is conducted with objectivity and without any external influence.
- **Ethical Approval and Consent to Participate:** The content of this article does not necessitate ethical approval or consent to participate with supporting documentation.
- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
- **Author's Contributions:** The authorship of this article is contributed equally to all participating individuals.

REFERENCE

1. Kilis, B., Tuegeh, M., Dako, R., Memah, V. and Ticoh, J., 2023. Analysis of the Human Body's Resistance to AC Voltage. *JURNAL EDUNITRO Jurnal Pendidikan Teknik Elektro*, *3*(1), pp.55-62. https://doi.org/10.53682/edunitro.v3i1.5764
2. Henriques, J. and Catarino, J., 2016. Motivating towards energy efficiency in small and medium enterprises. *Journal of Cleaner Production*, *139*, pp.42-50. https://doi.org/10.1016/j.jclepro.2016.08.026
3. S. Y. Radin, B. Sarker, S. H. Zahedee, T. T. I. Shanto, M. Islam and A. S. N. Huda, "Microcontroller-Based Automatic Home Appliances Protection System from Voltage and Current Disturbances," *2022 International Conference on Energy and Power Engineering (ICEPE)*, Dhaka, Bangladesh, 2022, pp. 1-5, doi: https://doi.org/10.1109/ICEPE56629.2022.10044881
4. T. V. Deokar, O. Y. Salunkhe, G. J. Ankalgi and V. D. Kare, "Ultra-fast acting Electronic Circuit Breaker for overload protection," *2017 Third International Conference on Advances in Electrical, Electronics, Information, Communication and Bio-Informatics (AEEICB)*, Chennai, India, 2017, pp. 29-32, doi: https://doi.org/10.1109/AEEICB.2017.7972377
5. K. M. Raj, N. Balaji, M. Abaraajith, S. L. Kumar and M. P. G. Kumar, "Wi-Fi Enabled Power Extension Board for Energy Optimization and Control of Devices," *2022 International Conference on Power, Energy, Control and Transmission Systems (ICPECTS)*, Chennai, India, 2022, pp. 1-3, doi: https://doi.org/10.1109/ICPECTS56089.2022.10046865
6. S. N. Gupta, R. Dev, A. Samad, A. Asadullah, R. Bhardwaj, and D. Gupta, "IoT Based Smart Extension Board," *2023 International Conference on Disruptive Technologies (ICDT)*, Greater Noida, India, 2023, pp. 325-327, doi: https://doi.org/10.1109/ICDT57929.2023.10150457
7. Ayub, M.A.B.M., Shaharuddin, M.R., Hussian, A.H., Hat, A.N.M., Zalizan, M.I.H.M. and Shaaidi, W.R.W., 2022, August. Overvoltage and undervoltage protection system using IoT. In *Journal of Physics: Conference Series* (Vol. 2319, No. 1, p. 012009). IOP Publishing. https://doi.org/10.1088/1742-6596/2319/1/012009
8. Bakar, N.H.A., Asry, A.M.M. and Mustafa, F., 2020. Electrical Appliance Protection Using an Auto-Cut Under-Voltage and Over-Voltage Tripping Mechanism. *Journal of Electrical Power and Electronic Systems*, *2*(1).

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

9. Bhosale, G., Vakhare, A., Kaystha, A., Aher, A. and Pansare, V., 2018. Over-voltage and under-voltage protection of electrical equipment. *International Research Journal of Engineering and Technology (IRJET)*, *5*(2), pp.29-32. https://www.irjet.net/archives/V5/i2/IRJET-V5I208.pdf
10. Grigorieva, M.M., Ivanova, E.V. and Strizhak, P.A., 2015. Forecasting investigation of the mode of fire hazard of electrical overload of cable lines. In *EPJ Web of Conferences* (Vol. 82, p. 01031). EDP Sciences. https://doi.org/10.1051/epjconf/20158201031

AUTHORS PROFILE

Stephen Eduku, a member of IEEE, attained his HND in Electrical and Electronic Engineering from Takoradi Technical University, Ghana, in 2010. Subsequently, he pursued his passion by earning a B.Sc. and M.Tech. Degree in Electrical and Electronics Engineering from the University of Education, Kumasi Campus, Ghana, in 2014 and 2016, respectively. Driven by a quest for knowledge, he furthered his education and obtained a Ph.D. degree in Power Electronics and Power Drives from Jiangsu University, China, in 2022. Since 2012, Stephen has been an integral part of Takoradi Technical University, Ghana, where he currently serves as a Senior Lecturer in the Electrical and Electronic Engineering Department. A keen interest and expertise in areas such as the design and optimisation of fault-tolerant permanent magnet flux-switching machines, power electronics, and drives have marked his professional journey.

ING. Dr. Joseph Sekyi-Ansah is a Senior Professional Engineer. He received a Diploma in Education, a B.Sc., and an M.Tech from the University of Education, Winneba, Kumasi (2008-2015), and a Ph.D. in Mechanical Engineering from Jiangsu University (2016-2020). He has been at Takoradi Technical University (TTU) for the past nine years as a Senior Lecturer and Head of the Department of Oil and Natural Gas Engineering, and a visiting scholar at IITR for the 2023-2024 academic year. He is currently a researcher in computational fluid dynamics, Finite Element Analysis (FEA), Image Processing, Cloud Image Processing, Cavitation, Non-Destructive Testing, and Material Characterisation.

Martey Prosper Tetteh received his Bachelor of Technology in Electrical and Electronics Engineering in 2024 at Takoradi Technical University, Ghana. He began working as an attachment personnel at Prinan Engineering Enterprise, which specialises in both residential and commercial wiring, in 2021 and 2022. He then worked at the Volta River Authority (VRA) as an attachment technician in 2023, in the Department of Electrical Maintenance and Controls and Instrumentation, which focuses on thermal power generation—currently serving his National Service with AKSA Energy Company Ghana Limited.

Ofori Bernard Johnson earned his Bachelor of Technology degree in Electrical and Electronics Engineering from Takoradi Technical University, Ghana, in 2024. In 2021, he began his career as an attachment technician with DBS Company. Since then, he has worked with an engineering firm specialising in both residential and commercial electrical wiring systems.