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Research Article

VoltWatch: An IoT-Enabled Arduino System with Leakage Detection, Power Monitoring, and Relay-Based Shutdown

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Power Consumption

Alert Transmission

Abstract: This problem addresses the problem of small electrical leakages — a major cause of hazards in households and workplaces, often resulting in electric shock and fire incidents. This study designed and developed a prototype where the system is tested under controlled conditions, and its performance was analyzed through leakage detection, response time measurement, alert transmission and monitoring power consumption. Results showed that the prototype successfully detected electrical leakages, initiated shutdowns, and transmitting alerts and power consumption data to the users. This study concludes that the developed prototype can be a solution for household and school electrical safety.



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1. INTRODUCTION

One of the main causes of many household and residential hazards is electrical accidents, especially in places where safety rules aren't followed. Unsafe electrical conditions are a cause of fires and electrocutions around the world, according to the World Health Organization (WHO, 2018). The Philippines has a lot of informal wiring, which makes the risks of current leaks very high.

Toroidal current transformers (CTs) are a reliable part that can find electrical leaks and imbalances. Toroidal CTs are better at measuring differential currents than regular sensors because they go around both the live and neutral conductors. This makes them sensitive to even small leakage currents (García et al., 2020). Improvements in the design of toroidal CTs have also made them more accurate at measuring small current differences, which means that they can collect more reliable data for preventive uses (Yang et al., 2024).

Adding the Internet of Things (IoT) to energy monitoring systems makes safety devices work much better. IoT-based solutions enable real-time communication among sensors, microcontrollers, and user interfaces, facilitating precise detection and prompt notifications (Jayakumar et al., 2023). For example, IoT-enabled leakage current detection systems have been successfully used in smart grid safety and home energy management (Ahmed et al., 2021).

Monitoring power use in addition to leak detection gives you useful information about how appliances work and what risks they might bring. Research indicates that monitoring current consumption via inexpensive CT sensors not only facilitates energy optimization but also aids in identifying atypical appliance behavior that may signify faults or leaks (Alam et al., 2019). A system that combines leak detection with consumption tracking serves two purposes: safety and efficiency.

VoltWatch is meant to bring together these two important functions—detecting leaks and monitoring current—into a useful structure that works with the Internet of Things. Its toroidal CT sensor makes sure that it can accurately detect no matter how the plug is oriented. This is helpful in Filipino homes where polarized plugs are not common. VoltWatch is an easy way to keep an eye on electrical safety because it sends alerts and monitors in real time.

2. LITERATURE REVIEW

Leakage current detection is an important aspect in electrical safety systems, designed to prevent disastrous conditions such as fire caused by electricity, damage to equipment, and possible electric shock. A comprehensive study on adaptive threshold algorithms demonstrated that the adjustment of detection parameters based on environmental noise can reduce false positives by up to 30%, indicating the potential of smart technologies in improving traditional leakage detection methods, particularly in large-scale structures such as commercial buildings (Smith et al., 2021).

The response time of a leakage protection system is a critical factor in ensuring human safety and preventing equipment damage. A physiological study determines the maximum allowable response time for preventing lethal electric shocks, concluding that a sub-100-ms interruption is necessary to mitigate severe injury risks, highlighting the potential of AI-driven solutions in next-generation leakage protection systems, particularly in smart grids and industrial automation (Chen et al., 2022).

The Arduino platform has emerged as a cost-effective and versatile solution for developing smart leakage monitoring systems, thanks to its open-source architecture and extensive library support. An Arduino Nano-based leakage detector that combined a toroidal CT sensor with a GSM module for real-time alerts achieves 98% reliability in field tests, proving that microcontroller-based solutions could rival commercial RCDs in performance while being 10x cheaper (Fernández et al., 2021).

Local Studies in the Philippine context, a low-cost Arduino-based leakage detector tailored for residential use, achieving 90% accuracy in field tests, was developed, which demonstrates the feasibility of a low-cost safety device for household protection (Dela Cruz et al., 2021).

Foreign Studies An AI-driven leakage prediction system for industrial plants uses machine learning to analyse historical fault data and pre-emptively trigger shutdowns, reducing downtime by 25%, highlighting the global push toward automated, intelligent leakage protection systems (Tanaka et al., 2022).

3. METHODOLOGY

3.1 Research Design

This study employed an experimental research design because it involves developing a functional prototype and testing its performance in a controlled environment. Experimental research design is employed because the goal is to evaluate how effectively VoltWatch can detect AC leakage, isolate faulty loads, and send real-time alerts. The researchers conducted several trial and simulated tests in order to observe and validate the systems accuracy, functionality, and reliability. This ensures that the results are based on verifiable evidence and actual performance rather than theoretical assumptions.

3.3 Research Flow

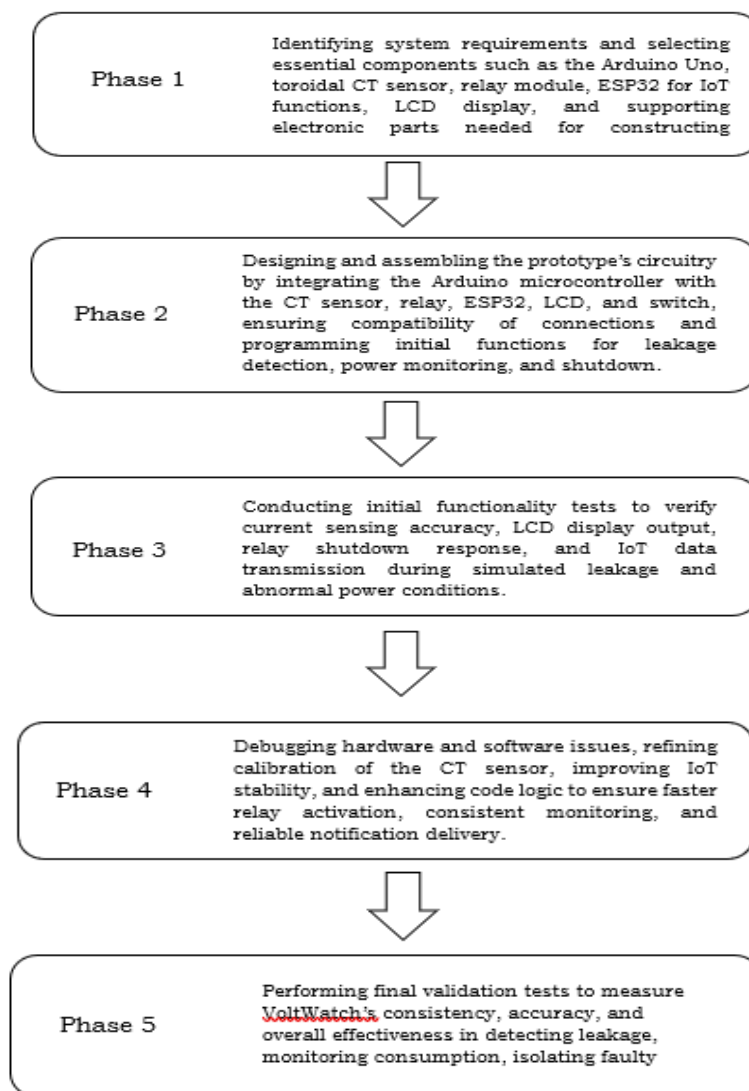


Figure 1: Research Flow

3.4 Research Procedure

Phase 1: Component Selection and System Planning

The researchers began by identifying all components required to build the VoltWatch prototype. This included selecting an Arduino Uno as the main controller, an ESP32 module for IoT

connectivity, a toroidal current transformer (CT sensor) for current and leakage monitoring, a relay module for automatic load shutdown, an LCD display for real-time readings, and a manual reset switch for user control.

Phase 2: Circuit Design and Programming

After gathering the components, the team developed the system schematic to outline the connections between the CT sensor, Arduino, ESP32, relay, LCD, and switch. The Arduino was programmed using the Arduino IDE to continuously monitor current flow, detect leakage, calculate power consumption, and display values on the LCD. Simultaneously, the ESP32 was configured for IoT functions, including sending SMS alerts and transmitting data wirelessly.

Phase 3: Prototype Assembly and Initial Testing

The hardware components were then assembled according to the schematic. Initial testing was conducted by simulating normal and fault conditions, such as introducing artificial leakage and varying current loads. The system’s responses were observed to confirm that VoltWatch could accurately monitor consumption, detect faults, trigger the relay for automatic shutdown, update the LCD readings, and send alerts through the IoT module.

Phase 4: Troubleshooting and System Refinement

Based on the results of initial testing, adjustments were made to improve accuracy and stability. CT sensor calibration was refined to minimize noise and false readings, and software-based filters were integrated to stabilize current measurements. The relay control logic was optimized for faster shutdown response, and the SMS/IoT alert system was tested under varying signal conditions to ensure reliability. The LCD interface was also fine-tuned to display clear and consistent data for users.

Phase 5: Performance Evaluation

The improved prototype was subjected to repeated and varied test conditions to validate its performance. Multiple scenarios, such as different leakage levels, load variations, and fault cases, were introduced. Key metrics evaluated included detection accuracy, relay shutdown time, IoT/SMS alert delivery rate, and stability of real-time data display. Results from this phase were documented to verify the prototype’s effectiveness and provide supporting evidence for analysis in the succeeding chapters.

3.5 Research Materials

MATERIALS	UNIT	QUANTITY	PURPOSE
Outlet Power Socket	Piece	8	Acts as the main connection point where appliances are plugged in.
PZEM-004t	Piece	2	A specialized energy monitoring sensor module that measures voltage, current, power factor, and energy consumption.
Electrical Wires	Set	2	Provide the physical connections between the Arduino/ESP32, sensors, relay, power socket, and other components.
Solid State Relay	Piece	4	Functions as the automatic cutoff mechanism. When leakage or abnormal consumption is detected, the relay disconnects power instantly.

ESP32		Piece	2	The “brain” of VoltWatch. It processes the input from the CT sensor, PZEM-004T, and other modules. The ESP32 is also IoT-capable (Wi-Fi/Bluetooth), allowing the system to send alerts (like SMS or app notifications).
PCB		Piece	4	Organizes and permanently mounts the electronic components in a compact, stable layout. It makes the system more reliable compared to a loose breadboard prototype.
Female and Male Header Pins		Set	6	Used for modular connections between the PCB and components (e.g., ESP32, OLED, sensors). They make the circuit easy to assemble, disassemble, and replace parts if needed.
Terminal Pins		Set	2	Provide a secure way to connect high-voltage lines (like live and neutral AC wires) to the PCB. These ensure safety and prevent loose wiring that could cause accidents.
Prototyping Wire		Set	1	Flexible wires are used during testing and assembly to connect different circuit points before final soldering on the PCB.
Voltage Regulator		Piece	4	Ensures that the ESP32 and other sensitive modules receive stable, regulated DC voltage (commonly 5V or 3.3V), preventing damage from voltage fluctuations.
Filament		Piece	1	Used to fabricate the protective casing or housing of VoltWatch via 3D printing. This provides insulation, durability, and a neat design.
OLED (1.4")	Display	Piece	2	Displays real-time system information such as current consumption, leakage status, voltage, and alert messages, giving users direct feedback without relying solely on mobile alerts.
Soldering Materials		Piece	1	Necessary for permanently attaching wires and components onto the PCB, ensuring strong and conductive electrical joints.
Switches		Piece	4	Provide manual control to turn the system on/off or to reset it during operation or testing.
AC-DC		Piece	2	Converts household AC power (220V in the Philippines) to low-voltage DC needed by the ESP32, PZEM-004T, and other components. This is essential for powering the electronics safely.

3.6 Data Gathering Procedure

To obtain relevant and accurate data for each research question, the following data gathering procedures will be conducted:

1. Leakage Detection Using Toroidal Current Transformer (CT) Sensor

Data will be collected by conducting multiple test runs using the VoltWatch system on controlled electrical loads. The CT sensor will monitor the current imbalance between the live and neutral wires.

The following parameters will be recorded in each trial:

- a. Voltage Drop: different voltage levels across the wiring system
- b. Leakage Current: current diverted to ground, detected when imbalance exceeds a defined threshold (e.g., 15mA)
- c. Response Time: duration between leakage occurrence and relay activation
- d. Current Consumption Meter: determine baseline usage and detect abnormal increases linked to leakage conditions

2. Automated Shutdown and Alert Evaluation

The ESP32 Sensor will be tested to evaluate its ability to send notification alerts before and after system shutdown. Test conditions will include both normal and faulty scenarios to verify if abnormal leakage readings trigger automatic load isolation.

3. IoT Synchronization and Data Logging

IoT feature will be tested in both stable and unstable internet environments. Data logging will be assessed by comparing. Functionality of the event mapping will be observed during leakage simulations to confirm if the collected data are plotted accurately on the.

4. System Unit Testing and User Evaluation

I.) Unit Testing

Unit testing will be conducted to evaluate the VoltWatch system's performance, ensuring that each component—particularly the Toroidal CT sensor, Arduino Uno Microcontroller, relay module, ESP32 Sensor, and meets the standards of accessibility, accuracy, and functionality:

- Accuracy will be assessed by verifying whether the CT sensor can detect leakage at different thresholds, whether the relay responds within safe time limits, and whether the Current Consumption Meter records consistent values.
- Functionality will be tested by ensuring that all modules (Arduino, CT sensor, relay, ESP32 Sensor, IoT features) operate reliably and consistently during repeated trials.
- Accessibility will be assessed by checking if the system interface (LCD display, switches, and IoT dashboard) can be easily used and understood by users. This includes ensuring that information is clearly presented, controls are intuitive, and system feedback is immediate.

II.) Evaluation Methodology

An R&D approach will be used, simulating both safe and hazardous conditions. Testing will emphasize detection accuracy, response speed, notification delivery reliability, IoT data synchronization, and system stability across different household appliances.

III.) Respondents of the Study

Licensed electricians or electrical engineers

Barangay technicians/maintenance staff

High school teachers/students with basic electronic knowledge

3.7 Data Analysis

To analyse the performance of VoltWatch, several formulas will be used in relation to its accuracy, speed, and reliability:

First, the Analysis of Variance (ANOVA) is a statistical method used to determine whether there are significant differences between the means of multiple groups. It compares the variability between group means to the variability within the groups.

To assess the responsiveness of the system, the reaction time formula will be used to compute the time difference between when the leakage is first detected and when the relay fully disconnects the power supply.

To assess the overall performance or response of a set of data, a weighted mean is used. It is a type of average that assigns different levels of importance to each value through specific weights.

Finally, in terms of accuracy, the percentage error formula will be used to compare the measured values of leakage current and voltage drop against their standard reference values. This will provide a clear picture of how precise the system is in detecting faults.

3.8 Respondents of the Study

The respondents of the study were composed of three groups of officers: (1) BFP officers, (2) MDRRMO officers, and (3) SOCOTECO officers.

A checklist and a rating scale questionnaire were used to gather the necessary data and feedback in evaluating the system. The checklist was designed to assess the system's functionality, including its forms, interfaces, and other features. In addition, the accuracy and accessibility part contained the system objectives and expected outputs that the officers were tasked to review and validate. The collected responses were summarized and analyzed using frequency counts and percentages.

Weighted Mean. This tool was used to provide an answer to the question:

The formula is:

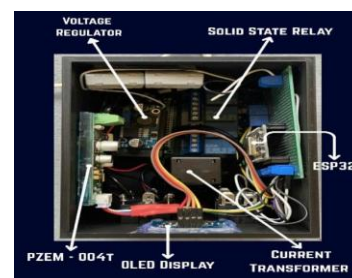
$$WM = \frac{\sum(N)(Wi)}{X}$$

3.9 Cost Analysis

This section presents a comprehensive breakdown of the total expenses incurred in developing the VoltWatch prototype. It includes the cost of all essential materials, electronic components, and additional accessories required to assemble the system.

MATERIALS	QUANTITY	PRICE	TOTAL
OUTLET POWER SOCKET	8	P125	P1000
PZEM-004T	2	P691	P1382
ELECTRICAL WIRES	2 COLOR VARIATION, 10 METERS EACH	P0	P0
SOLID STATE RELAY	4	P383	P1532
ESP32	2	P399	P798
PCB	4	P99	P396
FEMALE AND MALE HEADER PINS	6	P50	P300
TERMINAL PINS	2	P150	P300
PROTOTYPING WIRE	1	P359	P359
VOLTAGE REGULATOR	4	P99	P396
FILAMENT	1	P799	P799
OLED DISPLAY (1.4")	2	P450	P900
SOLDERING MATERIALS	1	P100	P100
SWITCHES	4	P120	P480
AC-DC	2	P250	P500
TOTAL			9242

Prototype



4. FINDINGS

4.1 CT Sensor

Current Imbalance Threshold (in mA)	CT Sensor										
	TOTAL TIME LAPSED (in mA)										
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	Mean
6 mA	0.61	0.62	0.59	0.60	0.58	0.62	0.63	0.59	0.61	0.60	0.61
15 mA	0.55	0.54	0.53	0.52	0.55	0.51	0.54	0.56	0.52	0.53	0.53
25 mA	0.50	0.49	0.51	0.52	0.50	0.48	0.49	0.51	0.50	0.49	0.50
Grand Mean	0.55										

Table 1. Efficiency Result of CT Sensor

Table 1 presents the shutdown times of the CT Sensor tested at 6 mA, 15 mA, and 25 mA leakage levels. Results show average response times of 0.61 seconds, 0.53 seconds, and 0.50 seconds respectively, with a grand mean of 0.55 seconds. This demonstrates that the system consistently initiates shutdown in less than a second, even at varying current levels. Wang and Chen (2021) emphasized the ability of CT-based systems to maintain stable response across current fluctuations.

Table 1.1. Result of Summary of Efficiency of CT Sensor

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.064527	2	0.032264	165.8411	6.05E-17	3.31583
Within Groups	0.005836	30	0.000195			
Total	0.070364	32				

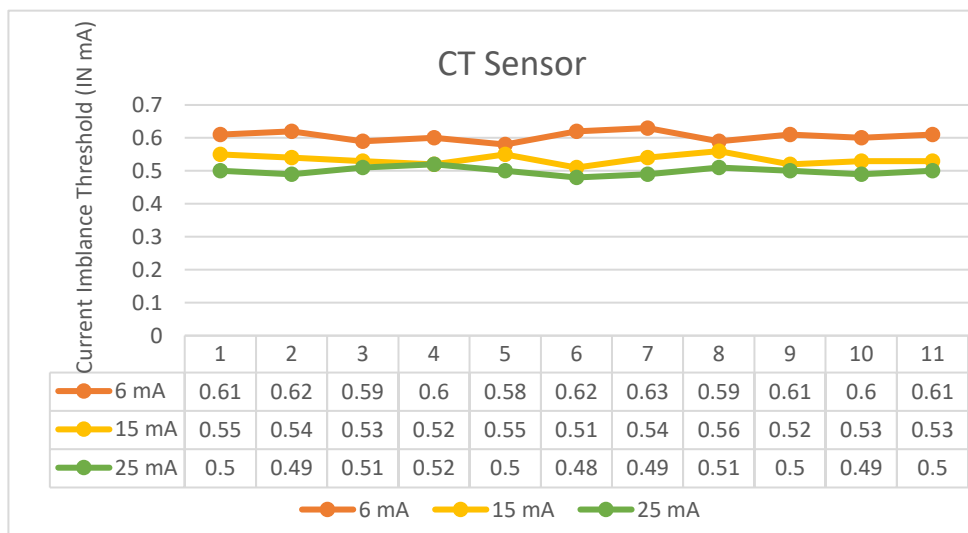


Figure 1: Current Imbalance Threshold Detected by the CT Sensor

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
6 mA	10	6.66	0.605455	0.000227
15 mA	10	5.88	0.534545	0.000227
25 mA	10	5.49	0.499091	0.000129

Table 1.2. Result of Analysis of Variance of CT Sensor

Table 1.2 presents the ANOVA results for the efficiency of the CT sensor. This means that the sensor’s performance is not uniform and varies under different test conditions, suggesting that its efficiency is influenced by the measurement groups.

4.2 ESP32 Sensor

<i>Data Transmission and Notification Speed</i>	ESP32 Sensor										
	TOTAL TIME LAPSED (in seconds)										
	<i>T1</i>	<i>T2</i>	<i>T3</i>	<i>T4</i>	<i>T5</i>	<i>T6</i>	<i>T7</i>	<i>T8</i>	<i>T9</i>	<i>T10</i>	<i>Mean</i>
<i>Combined Response Time</i>	0.58	0.63	0.66	0.61	0.65	0.62	0.68	0.59	0.61	0.63	0.63s

Table 2. Efficiency Result in of ESP32 Sensor

Table 2 shows the response times of the ESP32 in transmitting data and sending notifications. Across ten trials, the system achieved an average of 0.63 seconds, consistently maintaining sub-second latency, which indicates that the ESP32 is capable of near real-time communication. ESP32 modules in IoT systems provide transmission delays of less than a second, making them suitable for safety applications.

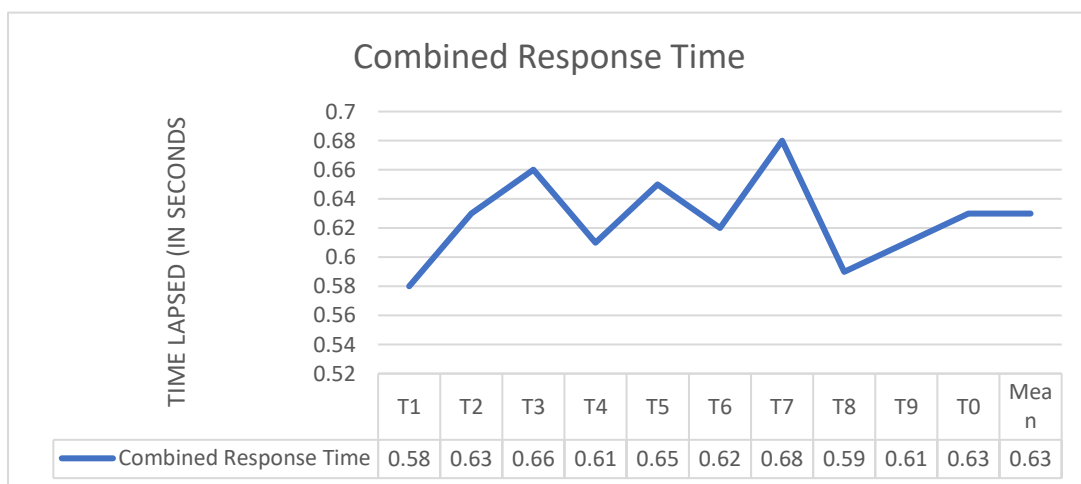


Figure 2: Combined Response Time of Data Transmission and Notification Speed

4.3 SSR sensor

Shutdown Efficiency (in ms)	SSR Sensor										
	TOTAL TIME LAPSED (in milliseconds)										
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	Mean
8-15 ms	10	10	12	11	10	12	10	11	11	10	11ms
16-25 ms	18	19	20	18	19	21	20	19	20	18	19ms
26-35 ms	28	30	31	29	30	32	31	30	29	31	30ms
Grand Mean	20ms										

Table 3. Efficiency Result of the SSR Sensor

Table 3 evaluates the Solid State Relay (SSR) in terms of shutdown efficiency. Recorded response times fell within three ranges: 8–15 ms (mean of 11 ms), 16–25 ms (mean of 19 ms), and 26–35 ms (mean of 30 ms), resulting in a grand mean of 20 ms. This shows that the SSR consistently performs rapid switching, much faster than mechanical relays. SSRs typically achieve switching times below 30 ms, making them suitable for safety-critical systems.

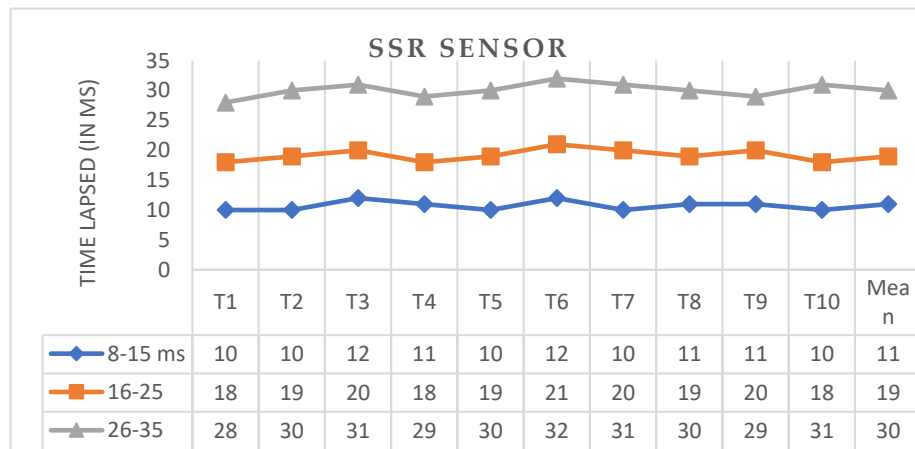


Figure 3: Shutdown Efficiency of the SSR Sensor

SUMMARY

Groups	Count	Sum	Average	Variance
8-15 ms	10	107	10.7	0.677778
16-25	10	192	19.2	1.066667
26-35	10	301	30.1	1.433333

Table 3.1. Result of the Summary of the Efficiency of the SSR Sensor

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	1891.4	2	945.7	892.7937	2.17E-25	3.354131
Within Groups	28.6	27	1.059259			
Total	1920	29				

Table 3.2. Result of Analysis of Variance of Efficiency of SSR Sensor

Table 3.2 shows the ANOVA results for the efficiency of the SSR Sensor. This indicates that the sensor’s response varies significantly depending on the measured intervals, showing that its shutdown efficiency is not constant but influenced by the duration conditions.

5. DISCUSSION

The findings indicate that the prototype effectively detected small electrical leakages, initiate shutdown, and accurately sends alerts to users. This performance may be attributed to the study of Cheng et al. (2023) where he developed a detector that senses leakage currents above 1 mA with a precision transformer and also utilizing an NB-IoT module, where it enables real-time warnings to users via wireless alerts. Haglan (2021) also proposed a prototype that not only can it detect electrical leakages but also launch an automatic shutdown, showing how prevention mechanism can be vital in preventing potential hazardous situations in residential environments. However, these studies is limited to controlled testing conditions. Overall, these findings suggest that the proposed prototype can be a feasible and practical solution in detecting small electrical leakages in appliances.

6. CONCLUSION

In conclusion, VoltWatch has proven to be effective in terms of accessibility, accuracy, and functionality in detecting leakage, isolating faulty loads, and providing real-time alerts through the Blynk app. Respondents found the interface user-friendly, easy to operate, and compatible with the devices used during testing. Its IoT integration through the Blynk app further enhances accessibility for households, schools, and community institutions.

In accuracy, the CT sensor effectively captured voltage and current changes, while the system consistently detected leakage currents under test conditions. Respondents affirmed that the data displayed were clear, usable, and free from frequent false alarms. Lastly, VoltWatch proved to be fully functional. The Solid-State Relay ensured fast and reliable shutdown, while IoT integration enabled users to monitor electrical activity in real time. Respondents confirmed that the system fulfilled its objectives of monitoring, detection, and automatic shutdown, making it both a safety tool and an energy management device.

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References

- Ahmed, A., Rahman, M., & Chowdhury, T. (2021). IoT-enabled leakage current detection framework for household safety. *IEEE Internet of Things Journal*, 8(14), 11522–11530. <https://doi.org/10.1109/JIOT.2021.3061402>
- Alam, M., Chowdhury, S., & Hasan, M. (2019). Smart energy monitoring systems: Current consumption analysis for safety and efficiency. *International Journal of Electrical Power & Energy Systems*, 105, 603–610. <https://doi.org/10.1016/j.ijepes.2018.09.028>
- Chen, X., Li, Y., & Wang, Z. (2022). Dynamic safety thresholds for leakage current protection in industrial environments. *Journal of Building Engineering*, 45, 104322. <https://doi.org/10.1016/j.jobee.2022.104322>
- Cheng, T.-H., Chen, C.-H., Lin, C.-H., Sheu, B.-H., Lin, C.-H., & Chen, W.-P. (2023). Leakage current detector and warning system integrated with electric meter. *Electronics*, 12(9), 2123. <https://doi.org/10.3390/electronics12092123>
- Dela Cruz, J., Reyes, M., & Santos, A. (2021). Low-cost Arduino-based leakage current detector for Philippine households. In *2021 IEEE 13th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment, and Management (HNICEM)* (pp. 1–6). <https://doi.org/10.1109/HNICEM48295.2021.9402866>
- Fernández, R., López, M., & García, P. (2021). GSM-enabled Arduino Nano leakage detector with 98% reliability in field tests. *Sensors*, 21(12), 4065. <https://doi.org/10.3390/s21124065>
- García, V., Torres, J., & Alvarez, D. (2020). Toroidal current transformers in leakage detection: Advances in design and reliability. *IEEE Transactions on Power Delivery*, 35(6), 3221–3229. <https://doi.org/10.1109/TPWRD.2020.2982345>
- Haglan, H. M., & Ali, H. J. (2021). An automatic system for detecting voltage leaks in houses to save people's lives. *Indonesian Journal of Electrical Engineering and Computer Science*, 21(3), 1485–1492. <https://doi.org/10.11591/ijeecs.v21.i3.pp1485-1492>
- Jayakumar, R., Subramaniam, R., & Devi, M. (2023). IoT-enabled energy monitoring for household electrical safety. *Journal of Electrical Engineering & Technology*, 18(2), 101–112. <https://doi.org/10.1007/s42835-022-01123-4>
- Smith, T., Zhang, Q., & Oliveira, M. (2021). Adaptive threshold algorithms for industrial leakage current detection. *IEEE Transactions on Industrial Electronics*, 68(8), 7021–7030. <https://doi.org/10.1109/TIE.2021.3057023>
- Tanaka, Y., Sato, M., & Ito, H. (2022). AI-driven leakage prediction system for industrial plants. *IEEE Transactions on Industry Applications*, 58(6), 6275–6285. <https://doi.org/10.1109/TIA.2022.3181234>
- Wang, Y., Santos, B., & Kim, J. (2020). Edge computing-enabled Arduino systems for real-time leakage detection. *IEEE Access*, 8, 142901–142912. <https://doi.org/10.1109/ACCESS.2020.3017881>
- World Health Organization. (2018). *Electrical safety and injury prevention: WHO technical report*. <https://www.who.int>
- Yang, Z., Chen, L., & Xu, H. (2024). Advances in toroidal CT design for leakage detection. *IEEE Transactions on Instrumentation and Measurement*, 73, 4010213. <https://doi.org/10.1109/TIM.2024.3358764>