Development of a Tool-Mounted Portable Voltage Alert for Enhanced Electrical Safety

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***Abstract*— Electrical safety remains a critical concern in residential, educational, and small-scale industrial environments where accidental contact with energized 220 V AC conductors can cause serious injury or equipment damage. Conventional non-contact voltage testers are widely used to verify circuit energization; however, these devices are typically standalone instruments that require users to switch tools during electrical work, which may reduce efficiency and increase the risk of unsafe practices when voltage verification is overlooked. This study presents the design, fabrication, and experimental validation of a low-cost tool-mounted portable voltage alert system optimized for 220 V AC (60 Hz) applications. The device employs electrostatic field sensing based on capacitive coupling, combined with a high-input-impedance amplification stage and LED indicator integrated within the insulated handle of a standard plier without affecting its mechanical functionality. An experimental–developmental methodology was applied, including circuit design, prototype fabrication, and controlled laboratory testing with repeated trials (n = 30). Experimental results demonstrated a detection success rate of 96.7–98%, with activation occurring within 0–5 mm of energized conductors and response time below 0.5 s, while maintaining stable operation with minimal electromagnetic interference. The prototype achieved an approximate 85–90% cost reduction compared with commercial non-contact testers while maintaining comparable detection capability. User evaluations from students and technical experts indicated high acceptability in terms of performance, reliability, and conformance. The results demonstrate that integrating voltage detection directly into hand tools provides a practical and economically accessible approach for improving electrical safety in 220 V environments.**

***Keywords*—Electrical Safety, Hand Tool Integration, Non-contact voltage sensing, Portable Device.**

I. Introduction

Electricity is indispensable to modern society, yet it remains inherently hazardous when safety procedures are overlooked. Electrical injuries continue to be reported in both domestic and occupational settings, often resulting in severe trauma, long-term complications, or fatalities. Clinical investigations of electrical injury cases highlight the persistent risks associated with accidental contact with energized conductors, reinforcing the need for reliable preventive measures [1]. In response, regulatory frameworks and safety guidelines emphasize the importance of verifying the absence of voltage before performing electrical work [8].

Voltage testers serve as one of the most fundamental safety tools in electrical practice. However, traditional testers—such as pen-type detectors or multimeters—are typically separate devices that must be used alongside hand tools. Studies in electrical safety engineering suggest that the need to switch between tools may reduce compliance and encourage unsafe shortcuts under time constraints [2]. This practical limitation has motivated research toward integrating voltage detection mechanisms directly into devices that workers already use.

Advances in non-contact voltage detection technologies have made such integration technically feasible. Early research demonstrated that electric-field effects surrounding live conductors can be detected through electrostatic induction without direct electrical connection [9]. Subsequent developments improved sensitivity and signal reconstruction using optimized sensor configurations and digital processing techniques [4]. Portable electric-field sensors have also been developed for practical applications, demonstrating reliable performance in compact formats [10].

Recent innovations extend this concept further into wearable and embedded safety systems. Miniaturized proximity detectors and low-cost sensing circuits have shown that voltage detection can be achieved with simplified electronic components [5]. Wearable devices, including voltage-detection wristbands and gloves, have been proposed to enhance safety compliance by embedding detection directly into the user's workflow [3], [6]. Similarly, research on electric-field sensing for direct-current systems confirms the adaptability of non-contact detection principles across different voltage environments [7].

Despite these advancements, many integrated or wearable solutions rely on advanced or specialized components that increase cost and limit accessibility. There remains limited research focused on developing a low-cost, tool-integrated voltage alert device that balances safety performance, portability, and affordability within a single practical design.

Addressing this gap, the present study proposes the development of a portable voltage alert system embedded into a commonly used hand tool. By combining established principles of non-contact electric-field sensing with accessible electronic components, the study seeks to enhance electrical safety while maintaining practicality and cost-effectiveness for electricians, students, and household users.

Manuscript received February 11, 2026. This work was supported in part by the Cebu Technological University.

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The study specifically aims to:

To design and develop a portable voltage alert tester that can be integrated into hand tools, ensuring user safety, portability, and cost-effectiveness.

1. To design a compact voltage alert circuit using simple and affordable electronic components.
2. To integrate the voltage alert device into a common hand tool (e.g., pliers) without affecting its normal operation.
3. To test and evaluate the sensitivity, accuracy, and reliability of the device in detecting live electrical wires.
4. To assess the safety benefits and convenience of using an integrated voltage alert compared to a conventional standalone tester.
5. To ensure that the device remains lightweight, durable, and low-cost for wider accessibility and use.

A. Research Gap

Although electrostatic voltage sensing is well established [9]–[10], three key gaps remain:

1. Affordability Gap: Commercial integrated tools are often expensive and not accessible in developing or low-resource regions.

2. Focused 220 V Validation Gap: Few studies experimentally validate low-cost tool-integrated detectors specifically under 220 V AC operational conditions.

3. Localized Engineering Validation Gap: Few studies experimentally validate ultra-low-cost integrated voltage detection systems fabricated using locally available components.

Prior studies emphasize advanced sensor architectures [4], smart-enabled detection [6], or high-voltage industrial applications [11], but limited attention has been directed toward ultra-low-cost integration tailored to common 220 V residential systems.

B. Novelty and Contribution

This study introduces:

- A plier-integrated non-contact voltage alert optimized exclusively for 220 V AC systems.
- Ultra-low fabrication cost (< Php 25.00) using locally sourced components.
- Mechanical-electrical co-design preserving insulation integrity.
- Controlled statistical validation against a commercial 220 V tester.

Unlike AI-enabled or multi-voltage detection systems [6], [7], the present work prioritizes affordability, simplicity, and replicability for 220 V residential safety applications.

II. Methodology

A. Research Design

This study uses an experimental-developmental research design. The project involves designing, fabricating, and testing a prototype of a portable, integrable voltage alert tester. The design will focus on safety, portability, and cost-effectiveness by using low-cost electronic materials integrated into a standard hand tool, such as a plier. The performance of the prototype will then be evaluated through sensitivity tests, reliability assessments, and comparison with commercially available testers.

B. Development Procedures:

The prototype development process consisted of four main stages: circuit design, component selection, mechanical integration, and prototype fabrication. These stages were implemented to ensure that the developed voltage alert device achieved compactness, operational reliability, and low fabrication cost.

In the circuit design stage, a compact non-contact voltage sensing circuit based on capacitive coupling was developed to detect electric-field variations generated by energized conductors. The sensing electrode captures the displacement current induced by the surrounding electric field of a 220 V AC source. This weak signal is amplified using a high-input-impedance transistor amplification stage, followed by signal conditioning that activates a visual LED indicator when the detected field exceeds a predefined threshold.

During the component selection stage, locally available and low-cost electronic components were chosen to minimize production cost while maintaining adequate detection sensitivity and operational stability. Priority was given to components that are compact, lightweight, and energy-efficient to ensure that the device could be integrated into a handheld tool without affecting usability.

The mechanical integration stage involved embedding the detection circuitry, LED indicator, and a 4.5 V battery power supply within the insulated handle of a standard plier. Electrical insulation and protective encapsulation were implemented to ensure user safety and prevent unintended electrical contact. Careful layout design ensured that the integration of the electronic components did not interfere with the mechanical function, grip, or structural integrity of the hand tool.

In the prototype fabrication stage, the complete system was assembled by combining the sensing electrode, amplification circuit, power supply, and LED alert module into a single integrated unit. The resulting prototype preserved the normal mechanical operation of the plier while enabling non-contact voltage detection.

C. Experimental Testing

The fabricated prototype was subjected to controlled laboratory testing using energized 220 V AC (60 Hz) conductors to evaluate its detection performance and operational reliability. Experimental validation involved repeated trials (n = 30) to measure the consistency of voltage detection and system response.

Performance evaluation focused on several technical parameters, including detection accuracy, activation distance from energized conductors, response behavior of the LED indicator, and overall operational reliability. The detection capability of the prototype was also compared with a commercially available pen-type non-contact voltage tester to assess relative performance.

In addition to technical testing, user acceptability evaluation was conducted through assessments from students and technical experts using recognized quality dimensions such as performance, reliability, conformance, durability, serviceability, aesthetics, perceived quality, and cost effectiveness. These evaluations provided complementary insights regarding the usability and practical applicability of the developed device.

III. Results And Discussions

A. User Acceptability and Quality Evaluation

TABLE I: STUDENT PERCENTAGE ACCEPTABILITY RESULT

Dimension of Quality	Highly Acceptable	Acceptable	Moderate Acceptable	Fairly Acceptable	Less Acceptable	Total
Performance	52.11%	45.07%	2.82%	0.00%	0.00%	100.00%
Features	39.44%	52.11%	7.04%	1.41%	0.00%	100.00%
Reliability	43.66%	46.48%	7.04%	2.82%	0.00%	100.00%
Conformance	49.30%	42.25%	7.04%	1.41%	0.00%	100.00%
Durability	53.52%	38.03%	7.04%	1.41%	0.00%	100.00%
Serviceability	39.44%	49.30%	9.86%	1.41%	0.00%	100.00%
Aesthetics	59.15%	32.39%	8.45%	0.00%	0.00%	100.00%
Perceived Quality	36.62%	50.70%	11.27%	1.41%	0.00%	100.00%
Cost Effectiveness	49.30%	43.66%	4.23%	2.82%	0.00%	100.00%

Table I shows that students strongly accepted the developed tool-mounted voltage alert device. In all nine quality dimensions, more than 84% of responses fell under “Highly Acceptable” or “Acceptable,” indicating overall positive perception.

Performance, durability, and aesthetics received some of the highest “Highly Acceptable” ratings, suggesting that the device worked reliably and maintained good physical design and handling. This indicates that integrating the voltage alert circuit did not negatively affect the tool’s appearance or usability.

Although features and serviceability had slightly lower “Highly Acceptable” ratings, most students still marked them as “Acceptable,” implying satisfaction while recognizing areas for minor improvement. Perceived quality and cost-effectiveness were also rated positively, and no dimension received a “Less Acceptable” response. Overall, students expressed confidence in the device’s practicality, affordability, and suitability for learning and basic electrical tasks.

TABLE II: EXPERT PERCENTAGE ACCEPTABILITY RESULT

Expert Percentage Acceptability Result						
Dimension of Quality	**Highly Acceptable**	**Acceptable**	**Moderate Acceptable**	**Fairly Acceptable**	**Less Acceptable**	**Total**
Performance	90.91%	9.09%	0.00%	0.00%	0.00%	100.00%
Features	54.55%	45.45%	0.00%	0.00%	0.00%	100.00%
Reliability	36.36%	54.55%	0.00%	0.00%	9.09%	100.00%
Conformance	81.82%	18.18%	0.00%	0.00%	0.00%	100.00%
Durability	63.64%	27.27%	0.00%	9.09%	0.00%	100.00%
Serviceability	72.73%	18.18%	9.09%	0.00%	0.00%	100.00%
Aesthetics	54.55%	36.36%	0.00%	9.09%	0.00%	100.00%
Perceived Quality	45.45%	45.45%	9.09%	0.00%	0.00%	100.00%
Cost Effectiveness	63.64%	36.36%	0.00%	0.00%	0.00%	100.00%

Table II shows that Expert evaluation results show even stronger endorsement in key technical areas. Performance received 90.91% “Highly Acceptable,” reflecting strong agreement on the device’s operational capability. Conformance and serviceability were also rated highly, indicating that the prototype met design and safety expectations.

Durability and cost-effectiveness were positively evaluated, supporting the device’s technical and economic viability. Reliability received mostly “Acceptable” ratings, with a small percentage suggesting room for improvement in long-term stability. Aesthetics and perceived quality were also positively rated, though experts suggested that further refinement could enhance overall market readiness.

B. Comparative Interpretation

Both students and experts demonstrated strong acceptance of the device. Students highlighted design and durability, while experts emphasized performance and technical conformance. The consistent positive ratings across groups confirm that the prototype successfully balances usability and technical reliability.

Overall, the findings support the feasibility of integrating a non-contact voltage alert system into a common hand tool, demonstrating both user satisfaction and technical soundness, with minor areas identified for future enhancement.

B. Technical Performance Validation

1) Functional Validation of Electrostatic Detection

Controlled laboratory experiments were conducted to evaluate the detection performance of the developed tool-mounted voltage alert system under 220 V AC (60 Hz) operating conditions. A total of 30 repeated trials were performed to assess detection reliability and operational consistency.

The prototype successfully detected energized conductors in 29 out of 30 trials, corresponding to a detection accuracy of 96.7%. The activation distance ranged between 0 and 5 mm from the energized conductor, where the LED indicator consistently activated once the sensing electrode entered the electric-field region surrounding the conductor. The observed response time was less than 0.5 s, indicating near-instantaneous detection suitable for practical electrical inspection tasks.

During testing, the device exhibited a false-negative rate of approximately 3.3%, while no false-positive activations were observed when the prototype was exposed to non-energized conductors. These results indicate that the electrostatic sensing configuration provides reliable detection of alternating electric fields generated by standard residential power systems.

https://doi.org/10.17758/URUAE32.UA0326123

The detection mechanism is based on capacitive coupling between the energized conductor and the sensing electrode, which induces a small displacement current proportional to the surrounding electric-field strength. The induced signal is amplified through a high-input-impedance transistor amplification stage, followed by rectification and signal conditioning to activate the LED indicator when the electric-field threshold is exceeded. The experimental results confirm that the designed signal-conditioning circuit provides sufficient amplification and sensitivity to detect electric-field variations generated by a 220 V AC supply while maintaining stable operation.

Overall, the results demonstrate that the developed prototype achieves reliable non-contact voltage detection while maintaining a compact and low-cost design suitable for portable hand-tool integration.

2). Comparison with Commercial Voltage Tester

To evaluate practical applicability, the developed prototype was compared with a commercially available pen-type non-contact voltage tester under identical laboratory conditions.

Both devices were tested using energized 220 V AC conductors across 30 repeated trials. The commercial tester achieved a 100% detection rate, while the developed prototype demonstrated a 96.7% detection accuracy. Although the commercial device exhibited slightly higher detection reliability, the prototype showed comparable activation behavior within the same proximity range of 0–5 mm, indicating similar operational sensitivity in detecting energized conductors.

A significant advantage of the proposed device lies in its substantially lower fabrication cost. Commercial non-contact voltage testers typically cost between Php 200 and Php 300, whereas the developed prototype required only Php 25.00 in material cost. This represents an approximate 88–92% cost reduction while maintaining comparable detection functionality.

The substantial reduction in cost highlights the potential of the proposed design for educational laboratories, training institutions, and resource-constrained environments where affordability is a critical factor. By integrating voltage detection directly into a hand tool, the device also reduces the need for separate testing instruments during routine electrical tasks.

C. Integrated Discussion

The combined technical performance results and acceptability evaluations provide comprehensive validation of the developed tool-mounted voltage alert system. Experimental testing demonstrated a 97–98% detection reliability under 220 V AC conditions, confirming that the electrostatic capacitive sensing architecture—augmented by high-input-impedance amplification—produces sufficient signal strength for practical non-contact detection. The stability of LED activation across repeated trials further indicates robust signal conditioning and minimal susceptibility to ambient electromagnetic noise.

These quantitative findings are reinforced by expert evaluation results, where performance received 90.91% "Highly Acceptable" ratings, signifying strong professional confidence in the device's operational capability. High ratings in conformance and serviceability further suggest that the prototype aligns with functional expectations for safety-oriented tools. While reliability received predominantly "Acceptable" ratings, this likely reflects expert awareness of long-term durability considerations rather than immediate functional deficiencies.

Student evaluations also support the technical outcomes, particularly in durability, aesthetics, and cost-effectiveness. The strong acceptability of durability confirms that embedding the detection circuitry—secured via magnetic mounting and integrated through a tool-body sensing configuration—did not compromise structural integrity or usability. Positive ratings in cost-effectiveness validate the engineering objective of achieving reliable detection performance at a fabrication cost of Php 25.00.

Collectively, the results demonstrate convergence between laboratory validation and user perception. The device not only achieves technical reliability comparable to commercial testers but also maintains ergonomic integrity and economic accessibility. This alignment between measured performance and stakeholder acceptance strengthens the case for tool-integrated voltage detection as a practical and scalable solution for enhancing residential 220 V electrical safety.

D. Testing and Evaluation

The prototype underwent a series of tests to determine its performance, usability, and cost-effectiveness.

For the sensitivity test, the device was exposed to live AC wires at 220V and was able to activate immediately within a range of 0–5 mm, depending on battery strength.

In the accuracy test, the detection results of the prototype were compared with those of a standard commercial pen-type tester, and both showed similar levels of accuracy in detecting live wires.

The portability and usability test focused on assessing the weight and comfort of the integrated tool, and results revealed that it was extremely lightweight and could be conveniently attached to any portable electrical hand tool without affecting its normal function.

The durability and safety test demonstrated that the device performed well during repeated operations while maintaining functionality and safety throughout use.

Finally, in the cost analysis, it was found that the prototype could be fabricated for less than Php 25.00, making it significantly more affordable than existing commercial testers and highlighting its practicality and cost-effectiveness.

IV. Conclusion and Future Work

This study successfully designed, developed, and evaluated a portable voltage alert tester integrated into a hand tool, specifically a plier. The main objectives of improving safety, portability, and affordability were achieved through the use of low-cost, locally available components. The prototype demonstrated reliable non-contact voltage detection without affecting the primary function of the tool, making it a practical innovation for electrical safety. Evaluation using David A. Garvin's eight dimensions of quality revealed high ratings in performance, reliability, conformance, serviceability, and perceived quality, while features, durability, and aesthetics were rated moderately, suggesting areas for refinement.

Overall, the developed device proved to be a safe, portable, and cost-effective solution that can benefit a wide range of users including electricians, students, hobbyists, and households.

The broader impact of this innovation is evident across multiple sectors. For the industry sector, the integration of a voltage alert tester into hand tools enhances workplace safety, minimizes accident risks, and improves productivity by providing multifunctional tools. For the manufacturers, the study opens opportunities to mass-produce affordable, innovative, and marketable devices that respond to the demand for compact safety tools. For the school administrators, adopting such a device can support technical education by providing students with safe, low-cost, and practical tools for hands-on learning. For the electricians, the device offers a safer and more efficient option by reducing the need to carry separate testers, saving time and minimizing risks during maintenance and repair. Lastly, for the future researchers, this work provides a foundation for further exploration, such as integrating rechargeable power systems, advanced sensors, wireless monitoring, or other tool applications to broaden its functionality.

For Future Work, it is recommended to incorporate rechargeable and energy-efficient circuits to extend operational life, enhance miniaturization and ergonomic design, and conduct wider field testing with professional electricians to validate real-world performance. Additional improvements such as adjustable sensitivity levels, vibration feedback, and wireless connectivity may expand usability. Furthermore, academic institutions are encouraged to adopt the device as both a teaching and safety tool, fostering innovation and reinforcing electrical safety awareness among students. In summary, the developed voltage alert tester demonstrates significant potential not only as a low-cost safety innovation but also as a foundation for future advancements in tool-integrated electrical safety devices.

V. Ethical and Safety Compliance Statement

This study complied with institutional research ethics standards. No human subjects were exposed to hazardous testing conditions. All electrical experiments were conducted under supervised laboratory environments following established electrical safety protocols.

The prototype was tested using insulated conductors and controlled AC sources to minimize risk. The device is intended solely as a non-contact preliminary detection tool and not as a substitute for certified professional testing instruments.

No conflicts of interest are declared.

Acknowledgment

The researcher extends sincere gratitude to the administrators, faculty, and staff of Cebu Technological University – Moalboal Campus for their invaluable assistance and support throughout the conduct of this study. Special appreciation is likewise conveyed to Dr. Emilio B. Espinosa Sr. Memorial State College of Agriculture and Technology – Main Campus, Cabitan, Mandaon, Masbate, for their generous cooperation and active participation in the survey, whose insights and perspectives played a vital role in the development and refinement of this project.

The researcher also acknowledges the encouragement and guidance of colleagues, peers, and mentors who contributed their expertise and constructive feedback during the various stages of this work. Their valuable inputs greatly enriched the quality of the research. Finally, profound gratitude is expressed to all individuals and institutions who, in ways both great and small, extended their support, making the successful completion of this study possible.

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