

Overcurrent and overvoltage protection system: Interactive medium for laboratory exercises

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Abstract: This study aims to design an overcurrent and overvoltage protection system based on a TFT LCD Human-Machine Interface (HMI) as an interactive medium for laboratory exercises in the Protection Systems course. The Research and Development (R&D) method, using the ADDIE model, was employed and included the stages of analysis, design, development, technical testing, and expert validation evaluation. This medium uses an Arduino Uno as the main controller, a PZEM-004T sensor to read electrical parameters, a relay as the protection actuator, a buzzer as a fault indicator, and a TFT LCD as the user interface. Test results show that the system is capable of detecting faults within the specified limits and displaying electrical parameters in real time. Based on the expert assessment results, this teaching aid is suitable for use. These assessment results are supported by student feedback, which also indicated that the teaching aid is sufficiently interactive and helps students learn about the time-current characteristics of relays, the setting of overcurrent and overvoltage protection limits, and the mechanism of automatic load disconnection in the Protection Systems course. This developed learning tool represents the commercialization of technology that has the potential to support quality education, as outlined in Sustainable Development Goal (SDG) 4: ensuring inclusive, equitable, and quality education.

Keywords: Learning media, Quality education, system protection

Abstrak: Penelitian ini bertujuan merancang sistem proteksi *overcurrent* dan *overvoltage* berbasis *Human Machine Interface* (HMI) LCD TFT sebagai media interaktif praktikum pada mata kuliah Sistem Proteksi. Metode *Research and Development* (R&D) dengan model ADDIE digunakan meliputi tahap analisis, perancangan, pengembangan, pengujian teknis, dan evaluasi validasi ahli. Media ini menggunakan Arduino Uno sebagai pengendali utama, sensor PZEM-004T sebagai pembaca parameter listrik, relay sebagai aktuator proteksi, *buzzer* sebagai indikator gangguan, serta LCD TFT sebagai *interface* pengguna. Hasil pengujian menunjukkan sistem mampu mendeteksi gangguan sesuai batas yang ditentukan dan menampilkan parameter kelistrikan secara *real-time*. Berdasarkan hasil penilaian ahli, media ini layak digunakan. Hasil penilaian ini didukung oleh respon mahasiswa yang juga mengatakan bahwa media cukup interaktif dan membantu mahasiswa dalam mempelajari materi karakteristik waktu-arus (*time-current characteristic*) relay, pengaturan batas proteksi *overcurrent* dan *overvoltage*, serta mekanisme pemutusan beban otomatis pada mata kuliah Sistem Proteksi. Media yang dikembangkan ini bentuk hilirisasi teknologi yang berpotensi mendukung pendidikan berkualitas sebagaimana tertuang dalam tujuan pembangunan berkelanjutan (SDGs) poin 4, yakni memastikan pembelajaran yang inklusif, merata, dan berkualitas.

Kata kunci: Media pembelajaran, pendidikan berkualitas, sistem proteksi

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INTRODUCTION

The increasing complexity of power systems requires reliable protection systems to ensure operational continuity and prevent equipment damage caused by electrical faults (Alasali et al., 2025). Faults such as overcurrent and overvoltage are two conditions that most frequently cause a decline in performance or even failure of electrical equipment if they are not promptly detected and interrupted by the protection system (Emon et al., 2025;

Wardhana et al., 2025). Therefore, an understanding of the operating principles of protection systems is one of the key competencies that electrical engineering students must possess, particularly in the course on Protection Systems (Wardhana et al., 2025).

Overcurrent and overvoltage faults are the two most common types of faults that occur in electrical power systems and require fast and selective protection mechanisms to prevent equipment damage and more widespread system disruptions (Saha, 2022). In the context of learning, students need to understand the characteristics of this disturbance firsthand by observing electrical parameters and the response of the protection system (Brahma et al., 2009). However, the reality on the ground shows that protection system laboratory courses at universities often face serious challenges. Conventional protection equipment, such as overcurrent relays and overvoltage relays used in industry, is generally bulky, expensive, and requires complex installation (Jennifer & Robert, 2013; Wang et al., 2025). Budget constraints and limited laboratory space often hinder the provision of sufficient quantities of such equipment to meet students' laboratory needs (Shahnia et al., 2016; Brahma et al., 2009). As a result, learning tends to be theoretical and lacks the hands-on experience that is essential for building technical competencies (Wang et al., 2025; Bompard et al., 2023).

Practical training in vocational education aims to provide hands-on learning experiences through students' interaction with equipment, instruments, and simulations of real-world conditions in the field (Rahman & Johari, 2022). Practicum activities enable students to understand the relationship between theory and implementation, thereby enhancing their analytical and problem-solving abilities as well as their technical skills (Hoa, 2025; Prastyaningrum et al., 2024; Zhang et al., 2025). However, the effectiveness of laboratory sessions is greatly influenced by the availability of learning media capable of presenting system processes clearly, interactively, and in an easy-to-understand manner (Kus'ilman et al., 2023; Mubai et al., 2020). The use of less informative laboratory media causes students to focus only on measurement results without fully understanding the operating mechanisms of protection systems (Rahman & Johari, 2022; Saha, 2022). Previous research has found that the use of multimedia-based learning employing an assignment-based model can enhance students' competence in understanding electrical protection systems (Sriadhi et al., 2023). Furthermore, the use of contextual learning media, such as electrical panel boxes, can also improve students' practical skills (Irawan & Ramadhani, 2023). These findings indicate that learning media integrating visual, interactive, and contextual elements can enhance students' understanding of abstract protection concepts.

Various studies have developed protection systems as a solution to improve the reliability of electrical installation safety. A PLC-HMI-based educational platform for protection relays capable of displaying IDMT characteristics in real time; however, its implementation still relies on conventional HMIs with limited screens and does not yet utilize modern graphical display technologies such as microcontroller-based TFT LCDs (Mahmood et al., 2020). Furthermore, it uses PLC devices that are relatively expensive and complex, making it less suitable for university laboratories with limited budgets. Designed a microcontroller-based multifunction protection relay that integrates the functions of an overcurrent relay and an overvoltage/undervoltage relay using a PZEM004T sensor and an LCD display (Hameed et al., 2021). The system is capable of simultaneously monitoring

electrical parameters and providing protection against several types of faults. However, the interface used is still a character-based LCD display with push-button controls, so it does not yet utilize TFT LCD touchscreen technology, which could provide students with a better interactive experience in understanding how the protection system works.

Developing an Arduino Uno-based overcurrent protection relay with reverse, highly revers, and extremely reverse characteristics for the FREEDM system (Kotb et al., 2018). However, this system focuses only on overcurrent protection and lacks overvoltage protection features and a touchscreen-based user interface, thereby failing to adequately support students' interactive understanding of voltage protection concepts. Develop an Arduino Uno-based overvoltage and undervoltage monitoring and protection system with a computer-based monitoring interface (Tung & Khoa, 2019). Previously developed systems are capable of providing protection and displaying data in real time. However, the user interface does not yet utilize a TFT LCD touchscreen as an integrated HMI, as it still relies on an external computer. Therefore, the system is considered to require further development to make it suitable for laboratory scale experiments. An effective laboratory is one that provides hands-on practice with equipment similar to that found in the field. However, the availability of such equipment is limited by the costs incurred by educational institutions. Furthermore, no research has yet been conducted to develop a protection system with a TFT LCD-based HMI that can display protection functions graphically and serve as practical training equipment in the laboratory that is both affordable and easy to use for student (Jennifer & Robert, 2013).

Based on these conditions, this study aims to develop an Overcurrent and Overvoltage Protection System equipped with a TFT LCD based HMI as an interactive tool for laboratory exercises in the Protection Systems course. This system is capable of displaying electrical parameters in real time and allows users to set overcurrent and overvoltage limits via a touchscreen. Additionally, the system automatically shuts off the load when a fault occurs. In addition to functioning as a protection device, this system is designed as a learning tool that can enhance students' understanding of the concepts of monitoring, parameter setting, and the integrated operating mechanisms of protection systems. Moreover, this prototype is expected to contribute to achieving equitable and quality education (SDG 4) by providing inclusive learning resources that are relevant to real-world needs (Prastyaningrum, et al, 2024).

METHOD

This study employed the Research and Development (R&D) method (Spatioti et al., 2022) using the ADDIE approach (Analysis, Design, Development, Implementation, and Evaluation) (Branch, 2009; Spatioti et al., 2022). The first stage involves analyzing performance gaps, determining instructional objectives, identifying the target audience, and identifying resources. In the laboratory activities for the Protection Systems course at the university, some learning aids still consist of trainers and have not yet adopted contextual learning media that align with real-world field conditions. This situation results in learning that tends to be theoretical, creating a need for essential hands-on experience to build technical competencies. Based on this, there is a need for learning media capable of bridging theoretical knowledge and practical laboratory work using contextual equipment.

The ADDIE stages followed in this study are illustrated in Figure 1. Each stage of the ADDIE model consists of two to four activities. The results of each activity support one another. Furthermore, the results of the previous stage serve as the foundation for the next stage.

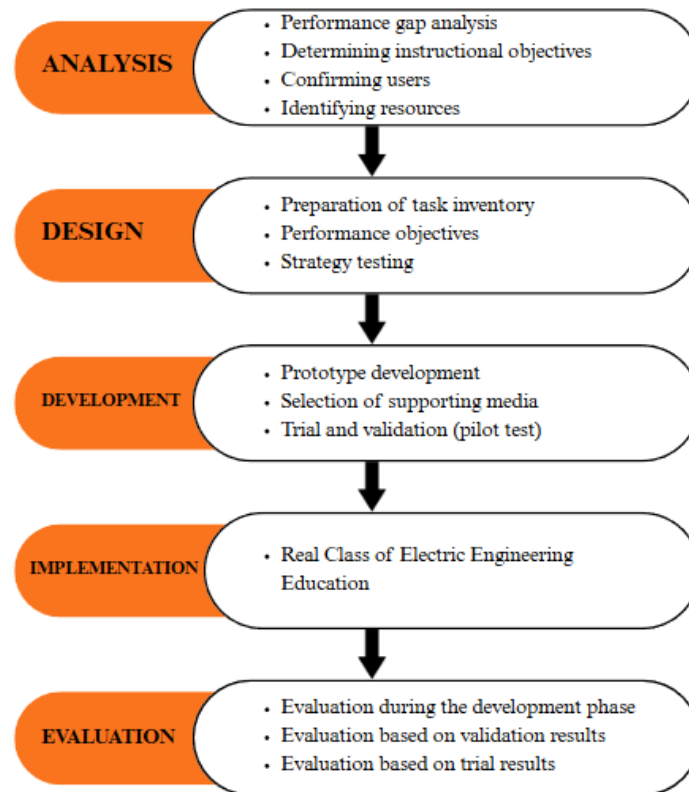


Fig. 1. Details of activities for each phase of the ADDIE model

The design phase involves developing a task inventory, performance objectives, and strategy testing. At this stage, the designed learning material is expected to visualize the concepts of overcurrent and overvoltage protection systems as contextual phenomena, facilitate students' exploration of these concepts through hands-on activities, provide feedback on users' exploration results, and support the development of critical thinking skills through contextual problem-solving. Furthermore, the learning material to be developed is aligned with learning objectives and implementation needs.

The development phase includes prototype creation, selection of supporting media, testing, and validation (pilot test). The prototype was developed to address the need for contextual learning materials for the Protection Systems course. This prototype was developed by integrating an Arduino Uno as the system controller, a PZEM-004T sensor as the electrical parameter reader, a relay as the power-cutting actuator, a buzzer as the fault alarm, and a TFT LCD as the HMI, all housed in an X5 plastic box (Figure 6). The prototype also includes several questions designed to assess students' contextual understanding of overcurrent and overvoltage protection concepts. It was further validated to obtain expert evaluations regarding the prototype's feasibility, given that one of the objectives of developing this learning medium is to bridge the gap between laboratory knowledge and

real-world experience. The validation was conducted by five experts using a 1–5 rating scale.

Implementation phase is applied for the next stage of research. Nevertheless, the media was pilot-tested on students in the Electrical Engineering program who had already taken the Protection Systems course. These students were selected on the basis that those with a conceptual understanding of protection systems would be able to connect their existing knowledge to real-world contexts (contextual learning). Furthermore, this teaching material was also tested on several members of the public (in this study, the focus was on individuals who own auto repair shops). This was done to ensure that the developed teaching material is truly capable of serving its intended purpose, namely bridging the gap between theory and practice in the laboratory and real-world contexts in the field.

The evaluation of instructional materials is the final stage of this development process. At this stage, an evaluation is conducted by comparing the results of community trials, classroom trials, and pre-assessment trials by experts. The purpose of this evaluation is to assess the quality of the product and how the instructional materials impact contextual understanding of overcurrent and overvoltage protection systems.

RESULTS AND DISCUSSION

The analysis in this study was conducted by comparing the expected ideal conditions with the actual conditions observed during the Protection Systems course. Ideally, students who have taken this course are expected to understand the basic concepts of protection systems against overcurrent and overvoltage, be able to operate the prototypes used as practical training tools in the laboratory, and possess the competence to apply this knowledge to real devices that reflect actual electrical conditions. However, the findings indicate that students' abilities are still limited to theoretical understanding of the material and the use of training equipment in the laboratory, and they lack experience with real-world equipment. This situation may be one of the factors causing students to be unprepared when faced with electrical problems encountered in the workplace. Therefore, contextual learning media is needed that can provide experiences close to real-world conditions, so that theoretical understanding can be linked to the experience of using real equipment.

Given these limitations, the objective of developing this instructional material is to enable students to acquire contextual competencies related to overcurrent and overvoltage protection systems. These competencies encompass not only theoretical understanding or laboratory scale skills but also the ability to apply these concepts to real world electrical situations in a field context.

To verify user characteristics, a user confirmation process is conducted to identify users' characteristics, needs, and limitations as a basis for designing learning materials tailored to the existing context and needs. The prospective users in this study were 21 students in the Electrical Engineering Education Study Program who had taken the Protection Systems course. The reason for selecting students who had taken the Protection Systems course was based on the consideration that these students had received both theoretical and practical instruction from a trainer. Consequently, they were able to recognize the differences between the previously used learning materials and the newly developed ones. The results of the needs assessment indicate that, in order to provide a

more contextual learning experience, course material must demonstrate actual overcurrent and overvoltage protection systems, rather than just theory. Figure 2 shows the results of the student needs assessment.

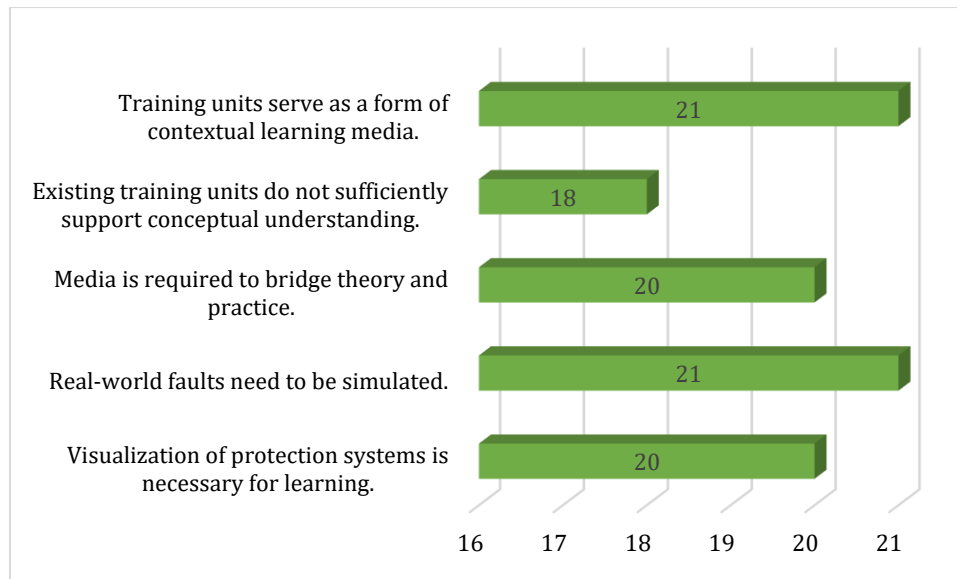


Fig 2. Results of the analysis of students' needs regarding learning materials for the Protection Systems course

The basis for creating a product that meets users' needs and suits their situations is to utilize the findings of the identification process. The human resources involved consist of instructors of the Protection System course, student in the Electrical Engineering Education program who have taken the Protection System course, a team of experts serving as validator, and members of the community who own repair shops. These human resources represent users outside the academic environment to test the application of this resource in real-world electrical contexts. The required physical resources include the Electrical Engineering Education laboratory, electronic components such as the Arduino Uno, PZEM-004T sensors, relays, buzzers, TFT LCDs, and a box to serve as the prototype casing. Technological resources include the Arduino IDE programming software for developing control systems on the Arduino Uno and the support tools needed in the prototype development process. Supporting resources include time, budget, and references related to overcurrent and overvoltage protection systems.

In the design stage, the activities were started by determining the technical specifications of the device, including identifying the components and functions of each part of the prototype. This prototype is designed using a PZEM-004T sensor to measure electrical parameters, connected to a 2.4-inch TFT LCD as the HMI to monitor electrical parameters in real-time and to set current and voltage protection limits via the touchscreen. The selection of the PZEM-004T sensor is based on its ability to read electrical parameters with high accuracy. According to (Jannah et al., 2024) reported that the PZEM-004t sensor produced a minimal deviation of only 0.31% for voltage and 0.01% for current, further confirming the sensor's suitability for real-time electrical energy monitoring. Furthermore, the results show that the PZEM-004T has an average deviation of 1.19% compared to the

reference wattmeter under a resistive load, indicating that the sensor is highly reliable for real time measurements (Timur, 2025). The Arduino Uno serve as the main control microcontroller, processing data, displaying information on the TFT LCD screen, and controlling the entrie system. Meanwhile, the buzzer serves as a warning signal in the event of overcurrent and overvoltage conditions.

This prototype has two functions: as a protection system and as a learning tool. The prototype’s algorithm begins by activating the prototype and checking the current and voltage values via the PZEM-004T sensor. If the setting button is pressed, the user can set and save the protection threshold values; if not, the system immediately checks whether the current or voltage values exceed the specified limits. If a limits is exceeded, the ralay will turn off (OFF), the buzzer will sound (ON), and the HMI will display the “OVER” status. Conversely, if the values remain below the protection limits, the relay turns on (ON), the buzzer turns off (OFF), and the system continues to monitor the parameters repeatedly. The algorithm is designed so that the prototype functions as an automatic protection system while also serving as a contextual learning tool for understanding the concepts of overcurrent and overvoltage protection. The flowchart of the prototype protection system’s algorithm is shown in Figure 3.

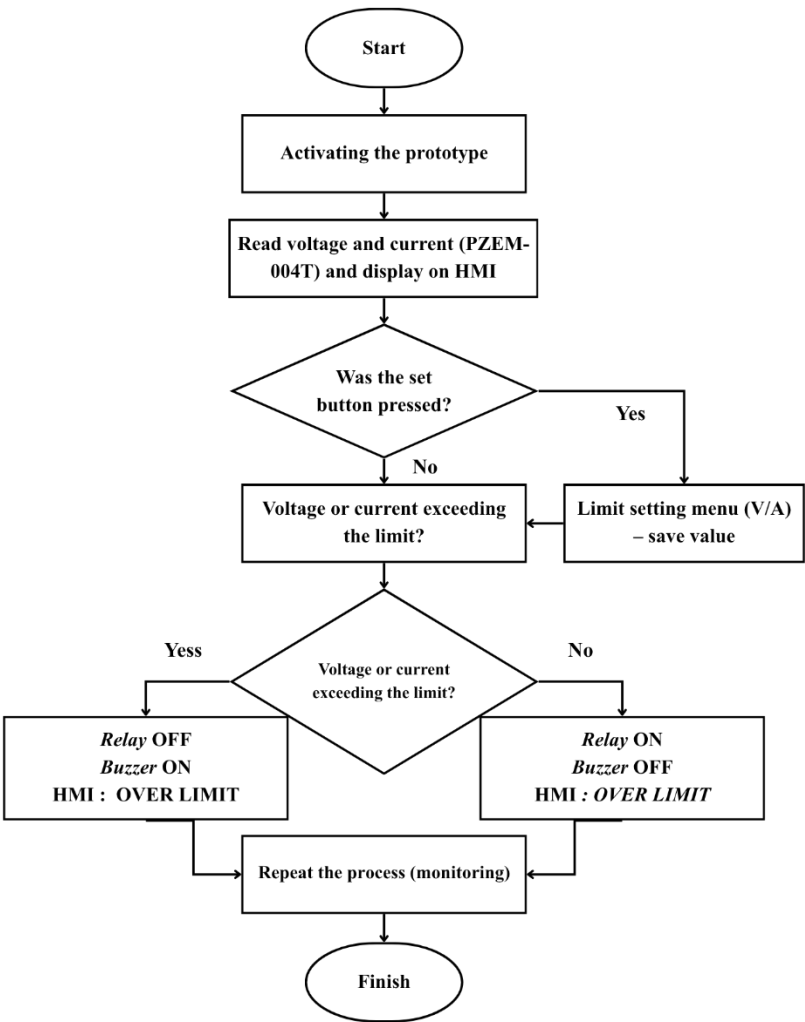
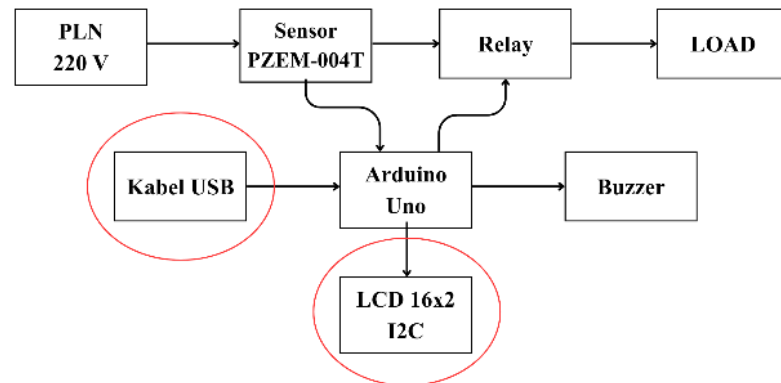


Fig 3. Flowchart of the protection system algorithm

The block diagram in previous research using the Arduino Uno still relied on a USB cable connected to a computer, so the prototype could not operate independently and was not particularly relevant for representing real-world field conditions. Additionally, electrical data was still displayed on a 16x2 I2C LCD, which could only show limited information in a one-way manner, without any user interaction (Nugroho, 2025).

The development involved replacing the USB cable power source with an AC/DC step-down circuit directly connected to a 220V mains power source, allowing the prototype to operate independently. The 12x2 I2C LCD was replaced with a 2.4-inch touchscreen TFT LCD that functions not only for monitoring but also as an HMI, allowing users to set protection limits via the TFT LCD. This development was intended to enhance the HMI's functionality, making it more interactive and supporting a hands-on learning experience, so that students not only observe measurement results but also interact by setting protection values according to the contextual needs of the learning process.

Previous research



This study

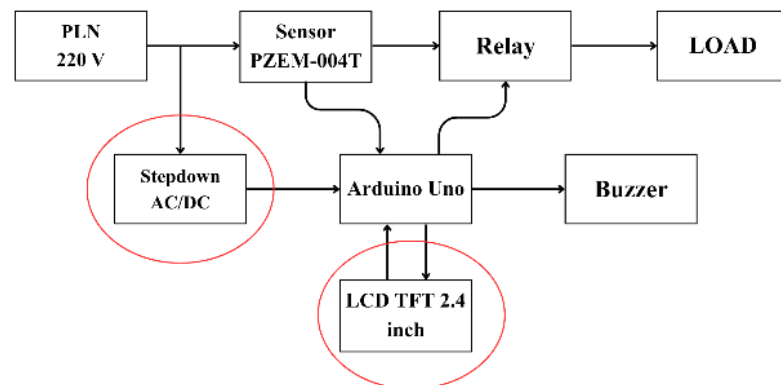


Fig 4. Differences in the block diagrams of protection systems

The electronic circuit was designed to determine the configuration and connection paths between components. The circuit begins with an AC input source connected to an AC-to-DC step-down circuit to reduce the voltage and rectify the current as the power input for the Arduino Uno. The AC input is also connected to a PZEM-004T sensor, complete with a current transformer (CT) to measure the electrical current. Data from the sensors is

transmitted to the Arduino Uno via serial communication (Satria et al., 2022). The Arduino Uno, acting as the control center, is directly connected to a 2.4-inch TFT LCD on the Arduino Uno shield, which serves as the HMI. Using the TFT LCD on the shield saves space because it eliminates the need for cables. Additionally, the Arduino Uno is connected to a buzzer and a relay, which act as actuators. This circuit is designed with a compact and efficient layout so that all components can be conveniently housed in an X5 plastic box without compromising their functionality.

The final stage of the design is to create the HMI interface that allows users to view and interact directly with the protection system via a TFT LCD screen. The main HMI screen displays electrical parameters in real time (V, I, A, W, kWh, Pf, and Hz), as well as a “NORMAL” status indicator. In addition, there is a “SETTING” button that allows users to change the protection limits in the menu. Furthermore, a warning display appears automatically when the system detects a fault.

The settings menu is used to set current and voltage protection limits the (+) and (-) buttons; this menu includes a “SET” button to save the protection limit values and a “BACK” button to return to the main screen. Additionally, a warning message indicates the nature of the fault and displays the voltage and current values at the time of the fault, along with the relay status. These two displays allow users to immediately identify the type of fault that is occurring.

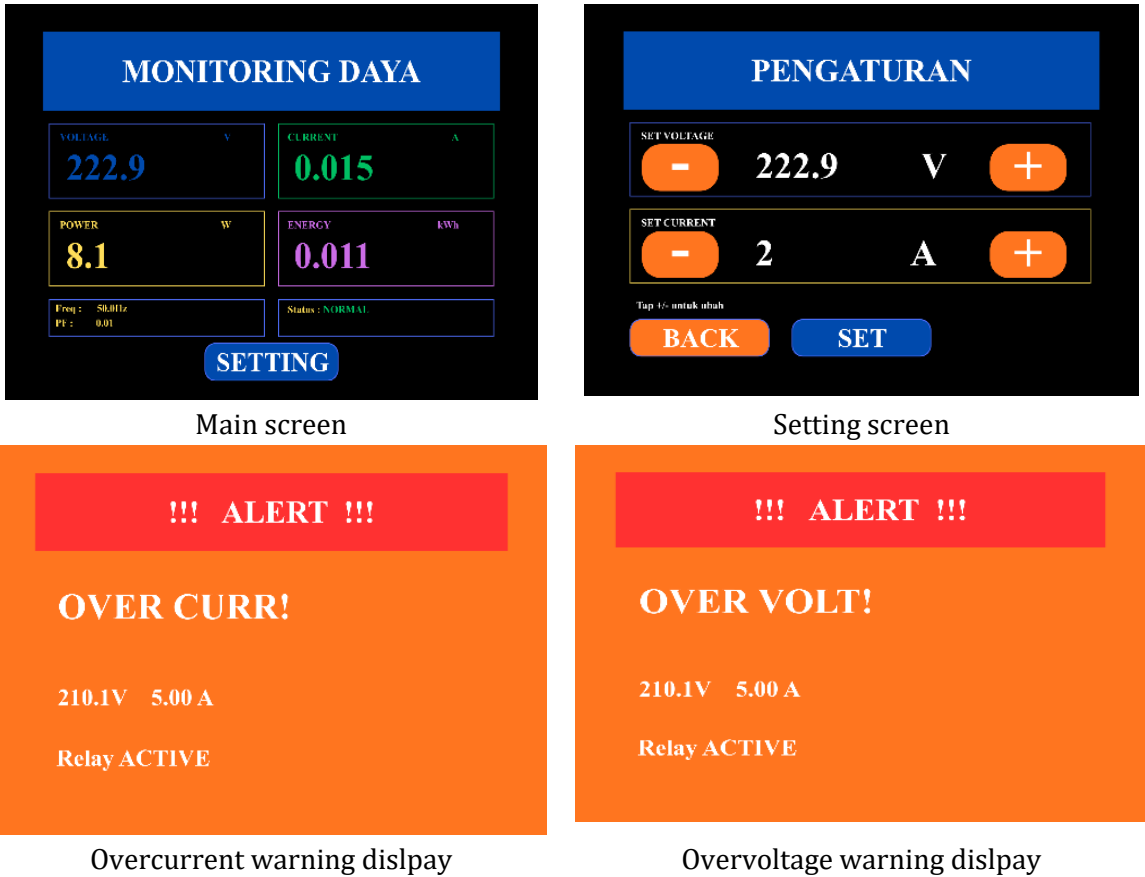


Fig 5. Human machine interface design

Technically, this prototype can be used as an overcurrent and overvoltage protection system for real-time monitoring of electrical parameters. In an educational context, this prototype serves as a contextual learning tool that bridges the gap between theoretical knowledge and practical application by facilitating hands-on laboratory activities; it also enables students to analyze the operating principles of protection systems through contextual problems.

Strategy testing was conducted by comparing the results of previous research on protection systems (Nugroho, 2025). In addition, discussions were held with the instructor of the Protection Systems course and several students who had taken the course to gather feedback on the design of the teaching aid tailored to the practical lab requirements. The initial prototype still used a character LCD to monitor electrical parameters, while the refined prototype was housed in an X5 enclosure with a TFT LCD-based HMI display, resulting in a sleek, compact final design suitable for use as both a protection system and a teaching aid.



Previous research

This study

Fig 6. The final results of the original research and its subsequent development

The manufacturing process begins with preparing components according to the established technical specifications, followed by the assembly of basic electronic circuits based on the previously designed block diagram and circuit schematics. This stage involves integrating all necessary electronic components and creating a program to ensure the system operates as designed. The resulting prototype aligns with the initial design development, and all components function as intended according to the specified workflow. The prototype is capable of performing its primary functions as an overcurrent and overvoltage protection system.

In addition, supporting materials were developed by creating operating instructions to guide users in operating the prototype correctly and systematically, from the device activation stage through to handling malfunctions. To test the suitability of the developed media in relation to the needs and background of the problem, several instruments were used for data collection, namely observation instruments, questionnaires, instrument validation by experts, and interviews with students and the community. The expert evaluation was conducted to determine the prototype's suitability as a protection system and as an interactive laboratory tool. This assesment was carried out by five experts including a university professor, one high school teacher, two electrical technicians, and one

robotic engineering expert using a 1–5 Likert scale. The aspects evaluated were appearance, technical aspects, and materials.

Table 1. The result of expert validation proses

Aspect	Validator					Average
	1	2	3	4	5	
Appearance	15	14	14	12	13	13.6
Technical	18	19	18	18	19	18.4
Material	13	15	12	13	13	13.2

Based on expert assessments (Table 1), the material aspect still requires improvement—particularly regarding the quality of the materials used—to ensure greater durability. Furthermore, material safety needs to be enhanced, as the materials currently employed are considered to pose a potential risk of electrical faults. The use of the X5 plastic box as a casing was assessed as still having limitations in terms of dimensions, which resulted in a less-than-optimal component layout due to limited space; furthermore, its durability for long-term use and resistance to impact was deemed not as good as that of enclosures specifically designed for laboratory experiments. Additionally, during the interview, Validator 3 suggested including a delay before the relay activates (when a fault occurs) to prevent electronic equipment using an inductive operating system from being damaged by an immediate power cutoff (Mihai et al., 2018; Talaq, 2022). However, overall, this prototype is considered suitable for use as an overcurrent and overvoltage protection system, as well as an interactive learning tool that supports contextual learning in the Protection Systems course.

The learning media was tested with Electric Engineering Education students who had taken the Protection Systems course. Observations were conducted by directly observing the students' process of operating the prototype during the lab simulation; overall, the students were able to operate the prototype by reading the provided instruction manual and apply their theoretical concepts regarding protection systems. In interviews, some students mentioned that during their first use, they needed time to adapt in order to understand the functions of each menu on the HMI, particularly regarding the settings for overcurrent and overvoltage protection limits. Students also noted that the X5 plastic enclosure was less effective because it was considered too small, limiting the arrangement of components and wiring. The results of a survey of 21 students indicated that this learning medium can be used as an interactive laboratory learning tool.

In addition to feedback from students, the prototype was also tested by auto repair shop owners. The assessments provided by these shop owners constitute a form of user evaluation of the developed prototype. This evaluation is essential to ensure that the prototype is suitable for use not only as a learning tool but also in real world field conditions. The repair shop owners provided assessments regarding the prototype's performance in relation to public safety. This public involvement is crucial in the research and development process, as prototype validation does not rely solely on expert assessments but requires user testing to obtain more comprehensive data (Damopolii et al., 2022; Hermawan & Agung, 2018). This aligns with the principle of contextual learning, which emphasizes that

the learning process is more meaningful when the material is directly linked to real-world situations (Hasnawati, 2012).

Table 2. Results of the student respondent survey

Students	Total	Percentage	Category
Respondent 1	46	92%	Very Good
Respondent 2	44	88%	Good
Respondent 3	37	74%	Fairly Good
Respondent 4	48	96%	Very Good
Respondent 5	49	98%	Very Good
Respondent 6	44	88%	Good
Respondent 7	47	94%	Very Good
Respondent 8	45	90%	Very Good
Respondent 9	45	90%	Very Good
Respondent 10	41	82%	Good
Respondent 11	47	94%	Very Good
Respondent 12	39	78%	Fairly Good
Respondent 13	46	92%	Very Good
Respondent 14	47	94%	Very Good
Respondent 15	44	88%	Good
Respondent 16	44	88%	Good
Respondent 17	48	96%	Very Good
Respondent 18	46	92%	Very Good
Respondent 19	47	94%	Very Good
Respondent 20	46	92%	Very Good
Respondent 21	37	74%	Fairly Good
Total	44.6	89.2%	Good

At this stage, workshop owners operate the prototype directly in real-world situations and then provide feedback based on their experience. This process is essential for workshop owners to gain real-world experience with the prototype, enabling them to provide a more objective evaluation. The evaluations derived from hands-on testing align with the principles of authentic assessment, which is considered more meaningful than test-based assessments alone, as it accurately reveals and verifies whether a product's intended functions have been achieved (Wildan, 2017). This assessment has been shown to yield more accurate data on the product's validity and practicality compared to theoretical assessments (Kustitik & Hadi, 2016; Yomaki et al., 2023). Interviews with workshop owners were also conducted to gain deeper insights and feedback to inform the further development of the prototype. Interviews were chosen because they allow for a deeper exploration of users' experiences, perspectives, and challenges (Hansen, 2020). The interview results indicated that the TFT screen needs to be pressed slightly harder to operate. This poses a challenge; given that the primary feature of such a device is its touchscreen, the screen's sensitivity must be ensured to be high to make navigation easier and more efficient.

Furthermore, users suggested that it would be better if the prototype were equipped with a digital guide accessible via a QR code. This would make it easier for users to operate the device, as the instructions would be easy to find and access. Using QR codes as a guide is considered more effective and efficient than printed documents, since the guide is stored digitally and can be accessed at any time, with no risk of damage or loss (Ulfa & Maharani, 2024). Overall, the evaluation results indicate that the prototype has high functional feasibility. However, there are still several aspects that need to be evaluated and improved. For example, the addition of easily accessible digital user guides (via QR codes) is still necessary.

Table 3. Results of the community respondent survei

Community	Total	%	Category
1	45	90	Very Good
2	40	80	Good
3	47	94	Very Good
4	47	94	Very Good
4	48	96	Very Good
5	45.4	90.8	Very Good

Tests conducted on two groups (college students and auto shop owners) yielded similar results. Both groups stated that the HMI menu was easy to use, although it took longer to adapt to it during the initial learning phase. This finding aligns with the concept of “learnability,” one of Nielsen’s usability attributes that measures how easily new users can complete tasks when first using an interface until they achieve efficiency (Juniawan et al., 2020). In other words, a longer adaptation period at the beginning is a natural part of getting acquainted with a new tool—not a sign that the interface is difficult to use. These results indicate that the prototype functions in accordance with the principles of the protection system, both in a learning context and under real-world field conditions. This finding aligns with the concept of contextual learning, which links learning material to real-world field contexts. As a result, students not only understand the theoretical concepts of protection systems but also grasp how they are applied in practice. Therefore, it can be said that this prototype also serves as an interactive and adaptive contextual learning tool.

As another form of evaluation, the assessment by the expert team (Table 1) serves as an important basis for future improvements to the prototype. We were able to implement some of the feedback immediately—for example, ensuring that all components function properly. However, we used other feedback solely as a reference for future prototype development. This feedback includes the limitations of the X5-type plastic enclosure in terms of dimensions and long-term durability, the addition of a delay feature before the relay activates, and the inclusion of a QR code for the user guide to enable digital access.

After passing the evaluation stage, the final prototype underwent no significant changes, as improvements were made only to the internal components of the prototype, without altering its external form or functionality. This prototype can still serve as a bridge between laboratory theory and real-world experience (contextual learning).

Table 4. Summary of the final results from all data sources

Source	Result	Category
Expert validation	90.4%	Highly Acceptable
Student testing	89.2%	Good
Public Testing	90.8%	Very Good

Overall test results from the team of experts, students, and workshop owners (users) showed an average score above 85%. This indicates that the developed prototype functions in accordance with the operating principles of the protection system, serves as a learning tool, and can be effectively implemented in the field. In other words, this prototype can serve as a bridge connecting theory, practice, and real-world (contextual) learning in the field.

CONCLUSION

A prototype of an overcurrent and overvoltage protection system that integrates an Arduino Uno, a TFT LCD screen, a PZEM-004T sensor, a relay, and a buzzer was deemed viable by experts, although suggestions for improvements were made in several areas. It also received positive feedback from students when tested during classroom activities. Furthermore, the prototype was also deemed highly suitable by users (automotive repair shop owners). These three evaluation results indicate that the developed prototype can serve as a bridge between theory, practice, and contextual learning. Moreover, the development of this prototype also represents a tangible contribution to supporting equitable and quality education (SDG 4) by providing inclusive learning resources relevant to real-world needs. Nevertheless, this prototype has limitations, including those related to material selection and adaptation to the needs of the Protection Systems course's laboratory sessions. Suggestions for future research include selecting higher-quality materials, utilizing more adequate space, adding a delay feature to the relay for inductive loads, integrating QR codes into the user guide for access to digital information, and implementing the prototype on a larger class scale.

REFERENCES

- Al Talaq, M., & Al-Muhaini, M. (2022). Optimal Coordination of Time Delay Overcurrent Relays for Power Systems with Integrated Renewable Energy Sources. *Energies*, 15(18), 6749. <https://doi.org/10.3390/en15186749>
- Alasali, F., Salem, M., Mustafa, H. Y., Loukil, H., El-Naily, N., Saidi, A. S., & Holderbaum, W. (2025). A clustering-based multi-setting overcurrent protection approach with optimisation and experimental validation for distribution networks. *International Journal of Electrical Power & Energy Systems*, 170, 110841. <https://doi.org/10.1016/j.ijepes.2025.110841>
- Branch, R. M. (2009). *Instructional Design: The ADDIE Approach*. Springer US. <https://doi.org/10.1007/978-0-387-09506-6>
- Damopolii, I., Febrianto Paiki, F., & Hendriek Nunaki, J. (2022). The Development of Comic Book as Marker of Augmented Reality to Raise Students' Critical Thinking. *TEM Journal*, 11(1), 348–355. <https://doi.org/10.18421/TEM111-44>
- Emon, A., Shawon, M., Molla, S., Tabassum, A., & Nowjh, S. (2025). Emerging Designs and Strategies for Overvoltage Protection in Modern Electronics. *Journal of Electrical*

- and *Electronic Engineering*, 13(6), 242–254.
<https://doi.org/10.11648/j.jeee.20251306.11>
- Juniawan, F., Laurentinus, L., & Sylfania, D. (2020). Usability Evaluation of Android-Based Lecturer Research Publication Reporting System. *Jurnal RESTI (Rekayasa Sistem Dan Teknologi Informasi)*, 4(1), 123–134. <https://doi.org/10.29207/resti.v4i1.1555>
- Hameed, A. A., Sultan, A. J., & Booneya, M. F. (2021). Design and Implementation of Multifunction Relay Based on Microcontroller. *Journal of Techniques*, 3(3), 31–43. <https://doi.org/10.51173/jt.v3i3.353>
- Hansen, S. (2020). Investigasi Teknik Wawancara dalam Penelitian Kualitatif Manajemen Konstruksi. *Jurnal Teknik Sipil*, 27(3), 283. <https://doi.org/10.5614/jts.2020.27.3.10>
- Hasnawati, H. (2012). Pendekatan Contextual Teaching Learning Hubungannya dengan Evaluasi Pembelajaran. *Jurnal Ekonomi Dan Pendidikan*, 3(1), 35–62. <https://doi.org/10.21831/jep.v3i1.635>
- Hermawan, B. D., & Agung, Y. A. (2018). Pengembangan Media Pembelajaran Menggunakan Lectora Inspire pada Mata Pelajaran Teknik Kerja Bengkel di SMK Negeri 1 Driyorejo. *Jurnal Pendidikan Teknik Elektro*, 7(1), 49–56. <https://ejournal.unesa.ac.id/index.php/jurnal-pendidikan-teknik-elektro/article/view/22748>
- Hoa, V. H. (2025). The Role Of Simulation Software In Enhancing Practical Skills For Students In Electrical Automation. *International Journal of Environmental Sciences*, 11(24), 4872–4884. <https://doi.org/10.64252/aqhga020>
- Irawan, B. B., & Ramadhani, A. K. (2023). Pengaruh Media Pembelajaran Panel Box Listrik Terhadap Keterampilan Instalasi Listrik. *Jupiter (Jurnal Pendidikan Teknik Elektro)*, 8(2), 39. <https://doi.org/10.25273/jupiter.v8i2.17904>
- Jannah, M., Hasibuan, A., Kartika, Asran, Yunizar, Z., Usrina, N., Nuryawan, & Almunadiansyah, R. (2024). Internet of things-based electrical energy control and monitoring in households using spreadsheet datalogger. *International Journal of Electrical and Computer Engineering*, 14(4), 3931–3941. <https://doi.org/10.11591/ijece.v14i4.pp3931-3941>
- Jennifer, F., & Robert, B. (2013). A power systems protection teaching laboratory for undergraduate and graduate power engineering education. *ASEE Annual Conference and Exposition, Conference Proceedings*. <https://doi.org/10.18260/1-2--19104>
- Kotb, M. F., El-Saadawi, M. M., & El-Desouky, E. H. (2018). Design of Over/Under Voltage Protection Relay using Arduino Uno for FREEDM System. *European Journal of Electrical Engineering and Computer Science*, 2(7), 1–6. <https://doi.org/10.24018/ejece.2018.2.7.44>
- Kus'ilman, H. A. K. A., Endramawan, P., & Prastyaningrum, I. (2023). Penggunaan Trainer Arduino Nano sebagai Media Pembelajaran pada Mata Kuliah Media Pembelajaran. *Jupiter (Jurnal Pendidikan Teknik Elektro)*, 8(2), 20. <https://doi.org/10.25273/jupiter.v8i2.17873>
- Kustitik, K., & Hadi, S. (2016). Pengembangan Perangkat Penilaian Autentik Mata Pelajaran Prakarya dan Kewirausahaan di SMK. *Jurnal Pendidikan Vokasi*, 6(2), 184. <https://doi.org/10.21831/jpv.v6i2.9554>
- Machidon, O. M., Stanca, C., Ogrutan, P., Gerigan, C., & Aciu, L. (2018). Power-system

- protection device with IoT-based support for integration in smart environments. *PLOS ONE*, 13(12), e0208168. <https://doi.org/10.1371/journal.pone.0208168>
- Mahmood, J. R., Ali, R. S., & Abd-Alhameed, R. A. (2020). PLC/HMI-based implementation of a real-time educational power system protective relays platform. *Electronics (Switzerland)*, 9(1). <https://doi.org/10.3390/electronics9010118>
- Mubai, A., Giatman, M., Usmeldi, Rizal, F., Effendi, H., Muskhir, M., & Karudin, A. (2020). Meta Analysis: The Effectiveness of Learning Media Based on Virtual Simulation in Technical Vocational Education. *Proceedings of the 2nd International Conference Innovation in Education Padanga Indonesia 504* (353–360) <https://doi.org/10.2991/assehr.k.201209.248>
- Nugroho A. F. (2025). *Implementasi Arduino Uno dalam Prototype Proteksi Overcurrent dan Overvoltage dengan Monitoring LCD* [Undergraduate Thesis, Universitas PGRI Madiun]. Unipma Campus Repository. <https://eprint.unipma.ac.id/3822/>
- Timur, O. (2025). *A Real-Time Low-Cost Energy Data Acquisition and Monitoring System for Household Appliances*. Preprints. <https://doi.org/10.20944/preprints202510.1691.v1>
- Prastyaningrum, I., Ardi, P., Purwandari, E., & Hidayat, W. (2024). Project-Based Learning in Smart Solar Panel System for Analysis 21st Century Skills. *Jurnal Penelitian Pendidikan IPA*, 10(9), 6756–6765. <https://doi.org/10.29303/jppipa.v10i9.7639>
- Rahman, I., & Johari, M. (2022). Students' understanding and skills on voltage and current measurements using hands-on laboratory and simulation software. *Education and Information Technologies*, 27(5), 6393–6406. <https://doi.org/10.1007/s10639-022-10890-3>
- Saha, A. K. (2022). A Real-Time Simulation-Based Practical on Overcurrent Protection for Undergraduate Electrical Engineering Students. *IEEE Access*, 10, 52537–52550. <https://doi.org/10.1109/ACCESS.2022.3175813>
- Satria, H., Lubis, M., & Putri, S. (2022). Design of Household Electricity Protection and Monitoring Automation With IoT ESP32. *Andalasian International Journal of Applied Science, Engineering and Technology*, 2(03), 133–139. <https://doi.org/10.25077/aijaset.v2i03.53>
- Spatioti, A. G., Kazanidis, I., & Pange, J. (2022). A Comparative Study of the ADDIE Instructional Design Model in Distance Education. *Information*, 13(9), 402. <https://doi.org/10.3390/info13090402>
- Sriadhi, S., Hamid, A., Siagian, S., Sutopo, A., & Adhitya, W. R. (2023). Virtual Multimedia Assisted Learning with Assignment Models to Improve the Competence of Electrical Protection Systems. *TEM Journal*, 12(2), 1110–1117. <https://doi.org/10.18421/TEM122-57>
- Tung, D. D., & Khoa, N. M. (2019). An Arduino-Based System for Monitoring and Protecting Overvoltage and Undervoltage. *Engineering, Technology and Applied Science Research*, 9(3), 4255–4260. <https://doi.org/10.48084/etasr.2832>
- Ulfa, M. H., & Maharani, D. (2024). Implementasi Quick Response (Qr) Code Instruksi Kerja Alat Laboratorium Pendidikan Keperawatan. *Jurnal Keperawatan Sriwijaya*, 11(2), 17–25. <https://doi.org/10.32539/jks.v10i1.246>
- Wardhana, A. S. J., Damarwan, E. S., Bachrun, M. A. A., & Hakim, M. L. (2025). Comparison of Over Current Relay Characteristics in Electric Power Protection Systems: A

- Comparison of Theory and Practice. *Journal of Engineering Science and Technology Review*, 18(2), 172–177. <https://doi.org/10.25103/jestr.182.21>
- Wildan, W. (2017). Pelaksanaan Penilaian Autentik Aspek Pengetahuan, Sikap Dan Keterampilan Di Sekolah Atau Madrasah. *Jurnal Tatsqif*, 15(2), 131–153. <https://doi.org/10.20414/jtq.v15i2.3>
- Yomaki, E. K., Nunaki, J. H., Jeni, J., Mergwar, S. D. I., & Damopolii, I. (2023). Flipbook based on problem-based learning: Its development to bolster student critical thinking skills. *AIP Conference Proceedings*, 2614(1), 020022. <https://doi.org/https://doi.org/10.1063/5.0126212>
- Zhang, Z., Yu, H., Ma, B., Chen, Z., Ma, H., Li, Y., Zhong, C., & Yu, X. (2025). Power System Professional Simulation Software to Help Electrical Professional Course Exeperimental Teaching Research. *Proceeding of the 2025 International Conference on Educational Innovation and Information Technology (EIIT 2025)* (pp. 230–238). Atlantis Press SARL. https://doi.org/10.2991/978-2-38476-497-6_23