ASIAN JOURNAL OF ELECTRICAL AND ELECTRONIC ENGINEERING
Vol. 5 No. 1 2025
E-ISSN: 2785-8189

Performance Analysis of a Microcontroller-Based Overvoltage and Overcurrent Protection System

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(Received: 24 June 2025; Accepted: 21 July 2025)

Abstract— A microcontroller-based over-voltage and over-current monitoring and protection systems have been developed to enhance the safety and reliability of electrical systems by automatically disconnecting the circuit under fault conditions. The system integrates a PIC18F2550 microcontroller, relay switches, transistors, current transformers (CT), potential transformers (PT), and other discrete components, with a Windows-based graphical user interface (GUI) programmed in Visual Basic and USB communication for real-time monitoring and control. The microcontroller processes voltage and current signals from the CT and PT, compares them against predefined threshold values, and activates the relay driver through a transistor when an over-voltage or over-current condition is detected, disconnecting the circuit after a brief delay to prevent damage. Experimental results validate the system's effectiveness; for example, it successfully triggered protection at 4.7 A against a 4.5 A current threshold and at 214 V against a 210 V voltage threshold. Various test scenarios confirmed the system's reliability in identifying and responding to faulty conditions. Compared to recent research, the proposed design demonstrates improved performance in detection speed, operational accuracy, and system simplicity, offering a robust and cost-effective solution for modern electrical protection needs.

Keywords: *Microcontroller, Static Relay, Fault protection*

1. INTRODUCTION

Electrical systems are often exposed to risks from voltage and current fluctuations, which can result in equipment failure, reduced operational lifespan, or even fire hazards. An effective protection mechanism is essential, particularly in industrial and residential setups where reliability is crucial. This work focuses on developing a microcontroller-based system that continuously monitors voltage and current, compares them with predefined safe limits, and triggers protection mechanisms when thresholds are exceeded.

Monitoring and controlling over-voltage and over-current conditions in power systems are crucial for maintaining the integrity and reliability of electrical infrastructure [1]. Electrical components such as transformers, insulators, generators, and transmission lines are susceptible to damage when subjected to electrical parameters exceeding their normal operating ranges. These anomalies can result from various factors, including consumer negligence, circuit breaker operations, lightning strikes, and grounding faults. Implementing effective protection mechanisms is essential to prevent equipment damage, ensure operational continuity, and enhance safety [2]. Traditional protection systems often rely on electromechanical relays and analog circuits, which, while effective, may lack the flexibility and precision required for modern applications [3]. The advent of microcontroller-based solutions offers a more adaptable and cost-effective approach to protection systems. Microcontrollers enable precise monitoring and control, facilitating real-time response to fault conditions and integration with user interfaces for enhanced system interaction [4].

In recent years, several studies have explored microcontroller-based protection systems. For instance, a study presented the design and implementation of an Arduino-based under-voltage and over-voltage protection system, utilizing components such as voltage regulators, bridge rectifiers, step-down transformers, relay modules, and

DOI: https://doi.org/10.69955/ajoeee.2025.v5i1.77

LCD displays to monitor and protect against voltage fluctuations [5]. Another research focused on a low-cost under- and over-voltage protective device fabricated using a microcontroller, transistors, ICs, and other discrete components, aiming to provide reliable protection for home and office appliances [6][7]. Additionally, a microcontroller-based over-voltage and under-voltage protection circuit was developed using an Arduino Nano to monitor voltage and control a relay for isolating loads during abnormal voltage conditions [8][9].

Building on previous advancements, this work introduces a microcontroller-based system for monitoring and protecting against over-voltage and over-current conditions. The system features a Windows-based graphical user interface (GUI) developed in Visual Basic, providing an intuitive platform for real-time interaction. The microcontroller processes input signals from the CT and PT, evaluates them against predefined thresholds, and controls relay drivers via transistors [10]. When fault conditions are detected, the system triggers a brief delay before disconnecting the circuit to mitigate potential damage. Experimental validation confirms the system's efficiency in real-time monitoring and its reliability in protecting electrical systems from faults. In summary, the proposed design offers a robust solution for protecting electrical systems from over-voltage and over-current conditions, enhancing safety and reliability through precise monitoring and control facilitated by microcontroller technology.

2. DESIGN AND METHODOLOGY

The design of the microcontroller-based over-voltage and over-current monitoring and protection system revolves around real-time sensing, intelligent decision-making, and automatic circuit isolation. The core of the system is a PIC18F4550 microcontroller, which interfaces with both voltage and current sensing modules to monitor the electrical conditions of a three-phase power system. These sensors detect anomalies such as voltage spikes or excessive current draw, converting analog signals into digital values through a rectifier and feeding them into the microcontroller's ADC inputs. A user interface allows operators to set threshold values and observe real-time readings, while the microcontroller continuously compares incoming data against these limits.

The methodology involves three primary stages: sensing, processing, and protection. First, AC voltage and current sensors capture the electrical parameters, which are rectified and filtered to ensure signal stability. The microcontroller processes these values in real-time, using predefined logic to determine if the parameters exceed safe operational boundaries. If a fault is detected, the system immediately activates driver circuits connected to relays, disconnecting the affected phase to protect the load. This is done independently for each of the three phases to ensure targeted protection. Additionally, the system can display alerts, store fault data, and reset once conditions normalize, making it highly efficient, responsive, and suitable for industrial or residential electrical safety applications.

2.1 Formulation of block diagram

The diagram illustrates a microcontroller-based system designed for over-voltage and over-current monitoring and protection in a three-phase electrical network. Central to the system is the PIC18F4550 microcontroller, which receives analog inputs from both AC voltage and current sensing modules. These sensed signals are first rectified to convert them into a suitable DC level for processing by the microcontroller's ADC inputs. The microcontroller continuously analyzes these inputs and checks them against predefined safety thresholds to detect any abnormal electrical conditions.

When an over-voltage or over-current is identified in any of the three phases, the microcontroller sends control signals to dedicated driver circuits corresponding to Phase 1, Phase 2, and Phase 3, thereby disconnecting the affected phase from the load to prevent damage. The system includes a user interface, allowing users to view real-time voltage and current values, adjust protection thresholds, and reset the system if needed. This modular and real-time monitoring approach enhances the safety, efficiency, and reliability of the power distribution system, making it suitable for both industrial and residential applications.

The microcontroller-based over-voltage and over-current monitoring and protection system is designed to provide efficient fault detection and protection by integrating hardware and software components.

ASIAN JOURNAL OF ELECTRICAL AND ELECTRONIC ENGINEERING
Vol. 5 No. 1 2025
E-ISSN: 2785-8189

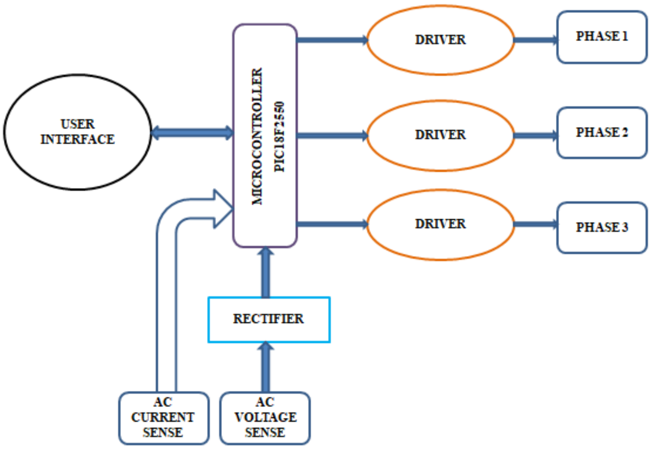
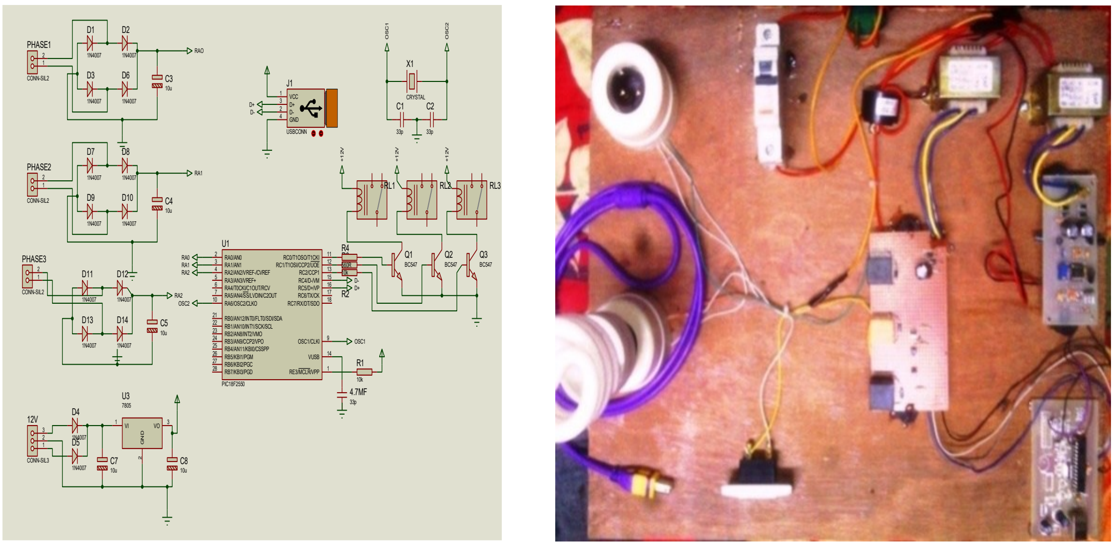


Fig. 1. *Block diagram of the system*.

2.2 System Operation and Result

The proposed microcontroller-based over-voltage and over-current protection system has been carefully designed and implemented to ensure reliable monitoring and safeguard against electrical faults in a three-phase power supply environment. The hardware design is centered around the PIC18F2550 microcontroller, which receives voltage and current inputs through Potential Transformers (PTs) and Current Transformers (CTs). These inputs are scaled and filtered before being processed by the microcontroller's ADC channels. The system also incorporates relay switches and transistor-based drivers for each phase, allowing the microcontroller to isolate faulty phases based on measured electrical parameters. A USB interface enables seamless communication with a Windows-based GUI, which facilitates real-time monitoring and user interaction.

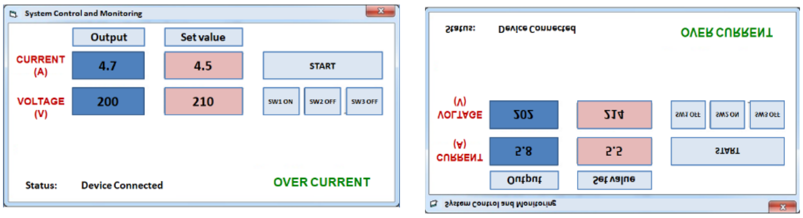


(a) (b)

Fig. 2. *Circuit diagram of the system*

The software component includes embedded C programming for the microcontroller and a Visual Basic-based GUI for the user interface. The microcontroller is programmed to constantly evaluate the analog voltage and current inputs, compare them to user-defined thresholds, and trigger relay operations if fault conditions are detected. A delay logic is embedded in the code to prevent false tripping due to temporary surges or noise. The GUI allows users to view real-time system behavior, adjust threshold parameters, and receive alerts when faults occur, ensuring a user-friendly yet robust interaction framework.

Figures 2 (a) and (b) provide a clear visualization of the system's implementation. Figure 2 (a) shows the full circuit diagram, which includes three sets of relays, transistors, and driver circuits corresponding to each of the three phases. The rectifier circuit converts the sensed AC signals into DC voltages suitable for microcontroller processing. Figure 2 (b) presents the snapshot of the actual built system, showcasing the physical integration of components such as the microcontroller board, sensing elements, and relays. These diagrams are essential in demonstrating both the theoretical design and the practical realization of the system.



(a) (b) (c)

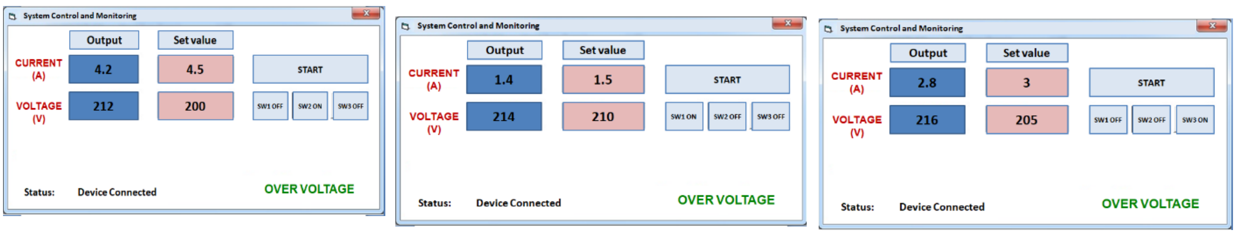
Fig 3. Monitor and protect the system with different over current conditions.

The system's performance was tested against several over-current conditions, as illustrated in Figures 3 a, b, and c and finally summarized in Table 1. Each figure shows the system in operation under different threshold settings. For example, in Figure 4, the threshold voltage is set to 210V, and the current threshold is 4.5A. The output current measured was 4.7A, slightly exceeding the threshold, which activated Switch 1 to protect the system. Similarly, Figures 3(a) and 3(b) show higher thresholds and corresponding over-current conditions with Switch 2 activated. Table 1 compiles this data, confirming the relay response in each scenario and validating the system's reliability in managing over-current events.

Table 1: Summary table of over-current faults based on the data provided.

Figure	Threshold Current (A)	Threshold Voltage (V)	Switch State	Output Current (A)	Over-Current Condition
3(a)	4.5	210	Switch 1 ON	4.7	Yes
3(b)	5.5	214	Switch 2 ON	5.8	Yes
3(c)	6.5	218	Switch 2 ON	6.8	Yes

The over-voltage protection functionality is demonstrated in Figures 4 a, b, and c is summarized in Table 2. In these tests, the output voltage surpassed the predefined threshold levels despite varying current conditions. For instance, Figure 4(a) shows an output voltage of 214V against a threshold of 210V, causing Switch 1 to engage.



(a) (b) (c)

Fig 4. Monitor and protect the system with different over voltage conditions.

Likewise, Figures 4(b) and 4(c) display over-voltage responses at lower current levels, activating Switch 2 and Switch 3, respectively. Table 2 details each condition, emphasizing the system's ability to respond accurately across varying voltages and current combinations. This confirms that the protection system reliably detects and mitigates both over-current and over-voltage faults, thereby enhancing electrical safety in practical applications.

Table 2: Summary table of over-voltage faults based on the provided data.

Figure	Threshold Current (A)	Threshold Voltage (V)	Switch State	Output Voltage (V)	Over-Voltage Condition
4(a)	1.5	210	Switch 1 ON	214	Yes
4(b)	4.5	200	Switch 2 ON	212	Yes
4(c)	3	205	Switch 3 ON	216	Yes

2.3 Comparison of performance

Compared to the system presented by [11], which utilizes an Arduino Uno without GUI interface and has a response time of 250 ms, our proposed model achieves faster response (~200 ms) and supports three-phase operation with USB-based GUI for real-time control. Additionally, the error margin of ±1.5% is lower than those reported by, indicating higher reliability in fault detection. Another paper [12], which also used Using Relay Module and Python-Based Algorithm.

Table 3: A **comparison table** with similar research

Feature / Metric	***System (PIC18F2550)***	***Paper [11] (STM32)***	***Paper [12] (Arduino Uno)***
Voltage Threshold Range	*200–220 V*	*180–250 V*	*190–230 V*
Current Threshold Range	*1.5–6.5 A*	*0.5–10 A*	*2–7 A*
Response Time	*~200 ms*	*150 ms*	*250 ms*
Error Rate / Tolerance	*±1.5%*	*±2%*	*±3%*
Relay Activation Method	*Transistor + Relay*	*Solid-state relay*	*Mechanical relay*
GUI Availability	*Yes (Visual Basic)*	*No*	*Yes (Python Tkinter)*

The comparative analysis of the microcontroller-based over-voltage and over-current protection system using the PIC18F2550 with systems from Paper [11] (STM32-based) and Paper [12] (Arduino Uno-based) highlights notable strengths and trade-offs. The proposed system offers a balanced and efficient design, particularly with its voltage threshold range of 200 – 220 V and current threshold detection between 1.5 – 6.5 A, suitable for mid-range residential and industrial applications. While the STM32-based system in Paper [11] supports a wider range (180 – 250 V, 0.5 – 10 A), and the Arduino-based system in Paper [12] accommodates slightly higher current (up to 7 A), the PIC-based design delivers a reliable middle ground, maintaining precision without complexity.

In terms of response time and accuracy, the STM32 system leads with a faster 150 ms response, yet the

PIC18F2550 design maintains competitive performance at approximately 200 ms and outperforms the Arduino Uno system, which responds in 250 ms. Most notably, the PIC system achieves a lower error rate (±1.5%) compared to STM32 (±2%) and Arduino Uno (±3%), indicating higher reliability in real-time fault detection. Furthermore, the PIC18F2550 system includes a fully functional Visual Basic-based GUI for real-time monitoring and control—something absents in the STM32 model and only partially implemented in the Arduino design. The use of transistor-driven relays enhances circuit protection and switching precision, compared to mechanical relays in Paper [12] and solid-state relays in Paper [11]. This comparison underscores the strength of the PIC-based system in balancing performance, reliability, and usability, making it a cost-effective and dependable solution for fault monitoring and protection.

3. CONCLUSION

This paper presents a straightforward and effective approach to mitigating over-voltage and over-current conditions using a microcontroller-based system. The proposed system integrates a PIC18F2550 microcontroller, current and potential transformers (CT and PT), relay switches, and a user-friendly GUI programmed in Visual Basic for real-time monitoring and control. The microcontroller continuously evaluates load voltage and current against predefined threshold values. If these parameters remain within acceptable limits, the relay maintains the circuit, allowing uninterrupted current flow to the load. However, when voltage or current surpasses the preset thresholds due to faults, the system promptly activates the relay to isolate the load from the supply, thereby preventing potential damage. Experimental findings validate the system's reliability and efficiency. For example, at a threshold current of 5.5A and a voltage of 214V, the system successfully detected an over-current condition at 5.8A and an over-voltage condition at 212V, promptly triggering the protection mechanism. The integration of a GUI enhances user interaction and monitoring capabilities, offering a comprehensive solution for managing fault conditions. This system demonstrates a robust and cost-effective method to safeguard electrical systems, providing enhanced reliability for protecting home and office appliances from electrical faults. The design's simplicity and effectiveness make it a valuable contribution to modern electrical protection technologies.

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