Development of an Automated Overvoltage and Undervoltage Tripping Scheme for Power System Protection

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Abstract: Sudden voltage fluctuations such as over-voltage and under-voltage can cause severe damage to household and industrial electrical appliances. To address this issue, a microcontroller-based voltage protection system is designed that continuously monitors the input voltage and disconnects the load during unsafe conditions. In this project, a potentiometer is used to manually vary and simulate voltage levels, which are processed by the microcontroller to determine whether the input lies within the predefined safe operating range. When an abnormal voltage condition is detected, the microcontroller triggers a relay to disconnect the load, thereby preventing damage. Additionally, the system provides real-time alerts through an LED, a buzzer, and SMS notifications via a GSM module, ensuring both local and remote monitoring. The system is programmed in embedded C to achieve intelligent decision making and reliable operation. This low-cost and efficient solution demonstrates an effective method of protecting appliances such as refrigerators, air conditioners, and microwave ovens.

Keywords: Over Voltage; Under Voltage; Microcontroller; Relay; GSM; Protection System.

1. Introduction

Electric power systems are designed to deliver electrical energy safely and reliably to consumers. However, voltage variations such as over voltage and under voltage conditions can occur due to faults, sudden load changes, lightning, or switching operations in the power network. These abnormal voltage conditions can damage electrical equipment, reduce system efficiency, and may even lead to serious safety hazards. To protect electrical devices and maintain system stability, power system protection mechanisms are used. Protection systems continuously monitor electrical parameters such as voltage, current, and frequency, and disconnect the faulty section of the system when abnormal conditions are detected. Among these protections, over voltage and under voltage protection plays a vital role in safeguarding electrical appliances and industrial equipment. In this paper, a microcontroller-based protection system is designed to detect abnormal voltage levels and automatically trip the power supply when the voltage exceeds or drops below the present safe limits. The system uses voltage sensing circuits to continuously monitor the supply voltage. When an abnormal voltage condition occurs, the microcontroller activates a relay-based tripping mechanism to disconnect the load from the power source.

In many domestic, commercial, and industrial installations, traditional protection methods are either limited or require manual monitoring. In the absence of an efficient monitoring system, users may not be aware of voltage abnormalities until damage has already occurred. Moreover, existing protection systems may not provide real-time alerts or remote monitoring capabilities, which makes fault detection and response slower. This project aims to design and implement a microcontroller-based over voltage and under voltage tripping mechanism with GSM communication, which provides automatic protection and real-time fault notifications to the user. The objective of this project is to design and develop a microcontroller-based voltage monitoring and protection system that continuously measures supply voltage and detects over-voltage and under-voltage conditions. The system incorporates an automatic relay tripping mechanism to disconnect the load during abnormal conditions, thereby preventing equipment damage. Additionally, a GSM module is integrated to send real-time SMS alerts to users for remote monitoring. The overall aim is to create a low-cost, reliable, and efficient solution that enhances safety and can be widely used in domestic, commercial, and industrial applications.

a. Traditional Voltage Protection Methods

Earlier power system protection mechanisms were mainly based on electromechanical relays. These relays operate using magnetic and mechanical components to detect abnormal electrical conditions. Electromechanical relays were widely used in power systems because of their simple design and reliability. They operate by detecting changes in voltage or current levels and activating a mechanical switching mechanism to trip the circuit breaker. However, these systems had several limitations Slow response time, Large physical size, High maintenance requirements, Limited accuracy, Lack of remote monitoring capability. Due to these limitations, modern electrical systems gradually replaced electromechanical relays with solid-state and microcontroller-based protection systems.

b. Microcontroller-Based Protection Systems

With the advancement of embedded systems technology, microcontrollers have become widely used in power system protection. Microcontrollers allow precise monitoring of electrical parameters and provide faster response compared to traditional relay systems. In microcontroller-based protection systems, voltage signals are monitored through sensors or voltage divider circuits. The microcontroller continuously analyses the voltage levels and compares them with predefined threshold values. When the voltage exceeds or drops below the safe operating range, the controller activates a relay to disconnect the load. Many researchers have proposed microcontroller-based voltage protection systems for domestic and industrial applications. These systems are capable of automatically detecting faults and isolating the affected section of the electrical system.

c. Over Voltage Protection Systems

Over voltage is a condition where the supply voltage exceeds the rated value of electrical equipment. This can occur due to lightning strikes, switching operations, insulation failure, or faults in the power distribution network. Over voltage can cause several problems such as: Damage to insulation of electrical equipment, Failure of electronic circuits, Overheating of components, Reduced lifespan of appliances. To prevent such issues, over voltage protection systems are designed to detect excessive voltage levels and disconnect the power supply. Various techniques have been proposed for over voltage protection, including: Zener diode protection circuits, Surge protection devices, Voltage relay systems. Microcontroller-based monitoring circuits. Modern systems use digital controllers to continuously monitor voltage levels and provide quick response when abnormal voltage conditions occur.

d. Under Voltage Protection Systems

Under voltage occurs when the supply voltage falls below the minimum operating level required by electrical equipment. This condition may occur due to heavy loads, faults in transmission lines, or poor power regulation. Under voltage can cause serious problems such as: Motor overheating due to excessive current, Reduced performance of electrical equipment, Failure of electronic devices, System instability in industrial processes. To protect equipment from under voltage conditions, protection systems are designed to detect low voltage levels and disconnect the power supply until the voltage returns to normal levels. Several studies have focused on developing automatic under voltage protection systems using digital controllers and relay circuits. These systems improve the reliability and safety of electrical systems.

e. GSM-Based Monitoring Systems

With the rapid development of wireless communication technologies, GSM-based monitoring systems have become popular in many industrial and automation applications. GSM technology allows devices to communicate through mobile networks and send information remotely. In electrical protection systems, GSM modules can be integrated with microcontrollers to send SMS alerts whenever a fault occurs. This allows users to monitor system conditions even when they are far away from the installation site. GSM-based systems offer several advantages: Remote monitoring capability, Instant fault notification through SMS, Improved system reliability, Reduced need for manual inspection. Many researchers have developed GSM-based fault monitoring systems for power systems, transformers, and electrical substations. These systems help maintenance personnel quickly identify faults and take corrective actions.

a. Automatic Tripping Mechanisms

Automatic tripping mechanisms are designed to disconnect the power supply when abnormal electrical conditions occur. These systems play an important role in preventing damage to electrical equipment and ensuring the safety of the power system. In modern protection systems, automatic tripping is typically achieved using relay circuits controlled by microcontrollers. When the controller detects a fault condition, it sends a signal to the relay to open the circuit and isolate the load. Advantages of automatic tripping mechanisms include: Immediate response to fault conditions, Prevention of equipment damage, Improved electrical safety, Reduction in maintenance costs. Automatic tripping systems are widely used in industries, power distribution networks, and domestic electrical installations.

2. Proposed System

The proposed system is a microcontroller-based protection mechanism designed to detect and respond to abnormal voltage conditions in an electrical power supply. In many residential and industrial environments, voltage fluctuations such as over-voltage and under-voltage frequently occur due to load variations, power system faults, or switching operations. These fluctuations can damage electrical equipment, reduce the efficiency of machines, and shorten the lifespan of electronic devices. To address this problem, the proposed system uses Arduino and PIC microcontrollers to continuously monitor the input voltage and automatically disconnect the load when the voltage exceeds or drops below the predefined safe limits. The system employs a voltage sensing circuit that converts the AC supply voltage into a low-level analogue signal suitable for the microcontroller's analogy-to-digital converter (ADC). The microcontroller reads this voltage value and compares it with preset threshold values programmed in the system.

If the detected voltage is higher than the over-voltage limit or lower than the under-voltage limit, the microcontroller sends a control signal to a relay driver circuit, which activates the relay to disconnect the load from the power supply. When the voltage returns to the safe operating range, the system automatically reconnects the load. In addition, the system includes a 16×2 LCD display to show the real-time voltage level and system status, such as normal operation, over-voltage condition, or under-voltage condition. This helps users easily monitor the power supply condition and understand the protection process. The proposed system provides several advantages over traditional protection methods. Conventional systems often rely on analogy comparators or electromechanical relays, which may have limited flexibility and accuracy. In contrast, microcontroller-based systems offer higher accuracy, programmability, fast response time, and cost-effective implementation.

Therefore, the proposed system provides a reliable and efficient solution for protecting electrical equipment from voltage fluctuations in both domestic and industrial applications.

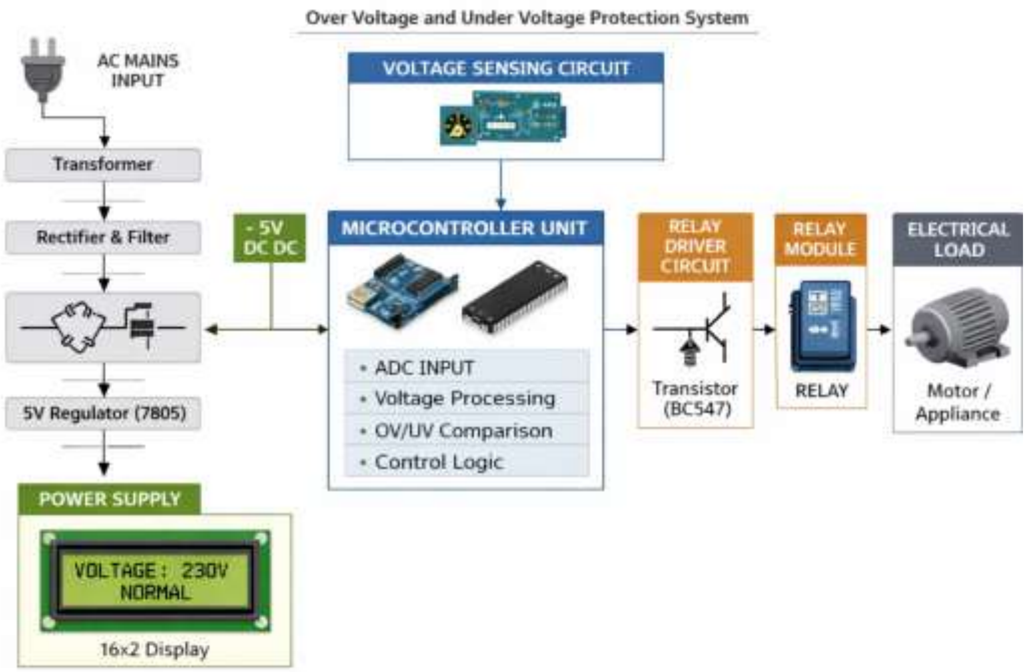


Fig:1. Overall System Architecture

The overall system architecture of the proposed over-voltage and under-voltage tripping mechanism is designed to continuously monitor the supply voltage and protect electrical loads from abnormal voltage conditions. The system integrates voltage sensing circuits, microcontrollers, and relay control mechanisms to ensure safe and reliable operation.

2. EXPERIMENTAL SETUP

The prototype development stage involves building a working model of the voltage monitoring and protection system to test its functionality before full implementation. In this stage, all hardware components are assembled and integrated to demonstrate how the system monitors voltage and controls the relay for load protection. stage, all hardware components are assembled and integrated to demonstrate how the system monitors voltage and controls the relay for load protection.

Fig:2. Prototype

The prototype typically includes a microcontroller such as Arduino Uno (ATmega328P) or PIC16F877A Microcontroller, a voltage sensing circuit, a relay driver circuit using a transistor, a protection diode, and a relay module connected to a load. During development, the voltage sensing circuit measures the input supply and sends a scaled signal to the microcontroller's ADC pin. The microcontroller processes this signal according to the programmed algorithm and determines whether the voltage is within the safe operating range. If the voltage is normal, the relay remains activated and the load continues to operate. If an overvoltage or undervoltage condition is detected, the microcontroller deactivates the relay through the driver circuit, disconnecting the load.

For easier testing and modification, the prototype is often first assembled on a breadboard. The program is written and uploaded using software such as Arduino IDE or MPLAB X IDE. Simulation and verification of the control logic may also be performed using MATLAB or Simulink before implementing the hardware.

Developing the prototype allows engineers to test the circuit operation, verify voltage detection accuracy, evaluate relay response, and make necessary adjustments to both hardware and software before final deployment.

3. Hardware Components Used

The voltage monitoring and protection system is built using several electronic components that work together to measure voltage, process the signal, and control the load through a relay. The main hardware components used in this project are listed below. The microcontroller is the main control unit of the system. It reads the voltage from the sensing circuit, processes the data, and controls the relay operation. Commonly used controllers include Arduino Uno (ATmega328P) or PIC16F877A Microcontroller. This circuit is used to measure the input voltage and reduce it to a safe level that the microcontroller can read through its ADC pin. It usually consists of resistors arranged in a voltage divider configuration. A relay is an electromechanical switch used to connect or disconnect the load based on the control signal from the microcontroller. It isolates the low-voltage control circuit from the high-voltage load circuit.

The relay driver circuit uses a transistor to amplify the microcontroller signal so that it can drive the relay coil. A protection diode is also used across the relay coil to prevent back EMF damage. A transistor (such as an NPN transistor) acts as a switching device in the relay driver circuit to control the relay operation. A diode is connected across the relay coil to protect the transistor and microcontroller from voltage spikes generated when the relay is switched off. A regulated DC power supply provides the required voltage for the microcontroller and other components in the circuit. The load represents the electrical equipment that needs protection from abnormal voltage conditions. These are used for assembling the prototype circuit and making electrical connections between all components during testing.

Fig:3. Normal Condition

The testing conditions are defined to evaluate the performance and reliability of the voltage monitoring and protection system under different voltage levels. These tests help verify whether the system correctly detects normal, overvoltage, and undervoltage conditions and responds by controlling the relay appropriately. In this condition, the input voltage is maintained within the safe operating range (for example, around 220V–230V AC). The system should operate normally without triggering any protection mechanism.

Expected Result:

- The voltage is detected as normal by the microcontroller such as Arduino Uno (ATmega328P) or PIC16F877A Microcontroller.
- The relay remains energized.
- The load stays connected to the power supply.

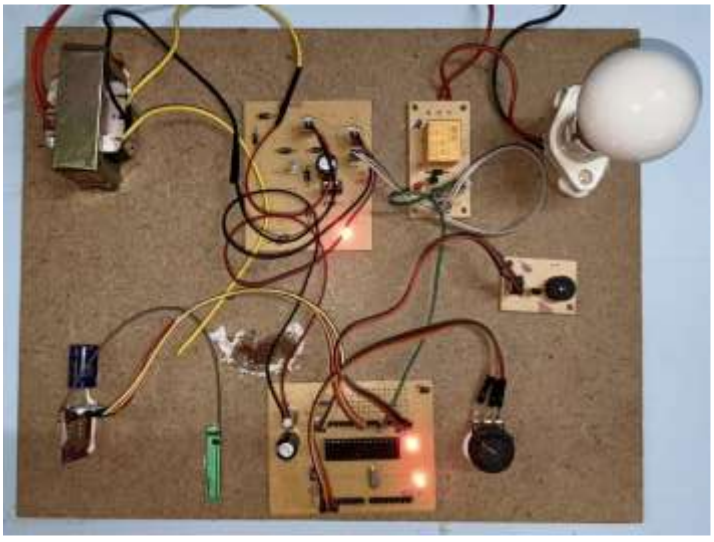


Fig: 4. Over voltage Condition

Overvoltage Condition

In this condition, the input voltage is increased above the predefined maximum limit (for example above 250V AC).

Expected Result:

- The system detects the overvoltage condition.
- The microcontroller sends a signal to deactivate the relay driver circuit.
- The relay disconnects the load from the power supply to protect the equipment.

Under voltage Condition

Fig: 5. Under voltage Condition

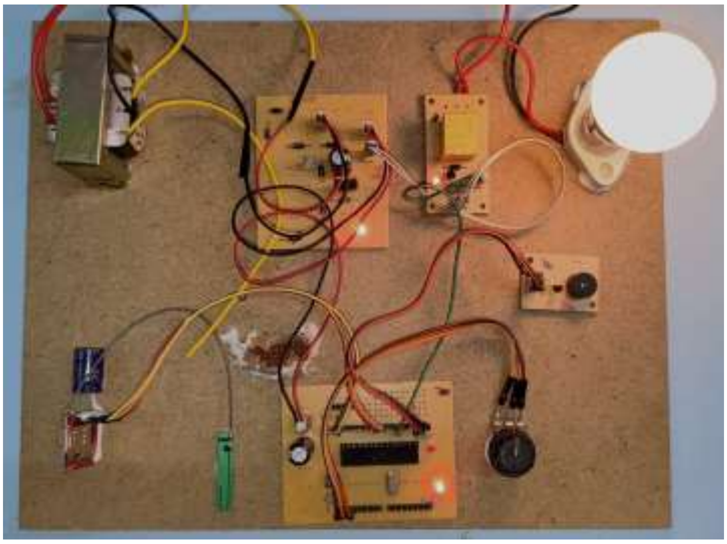
In this condition, the input voltage is reduced below the minimum threshold level (for example below 180V AC).

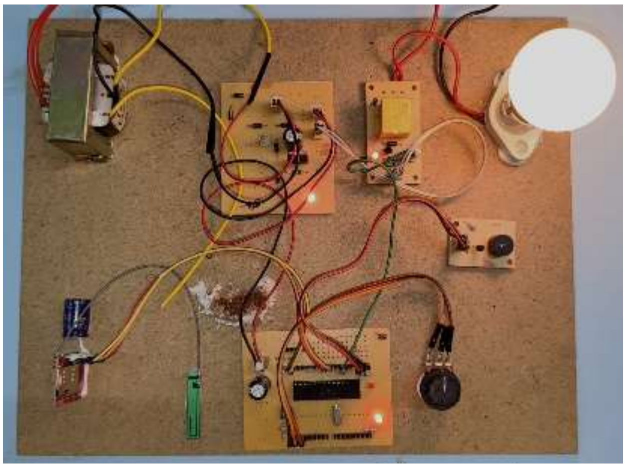
Expected Result:

- The system detects the under-voltage condition.
- The relay driver circuit is turned OFF.
- The relay disconnects the load to prevent malfunction or damage.

Continuous Monitoring Test

Fig: 6. Continuous Monitoring Test





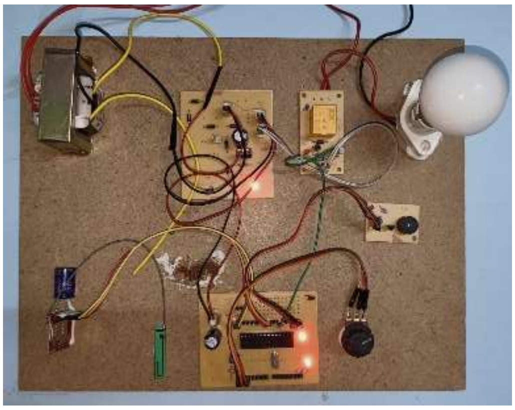
The system is allowed to operate continuously while the voltage varies between normal, high, and low levels.

Expected Result:

- The system continuously monitors voltage levels.
- The relay switches ON or OFF automatically depending on the voltage condition.

System Stability Test

The system is tested for stable operation over a longer period to ensure reliability and proper functioning of all components.



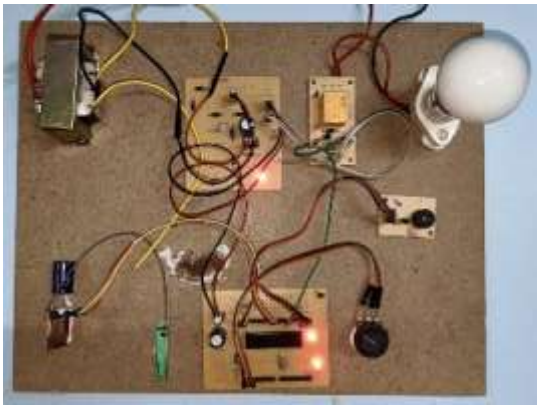
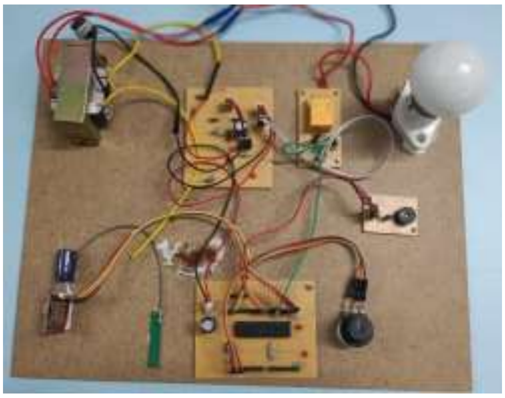


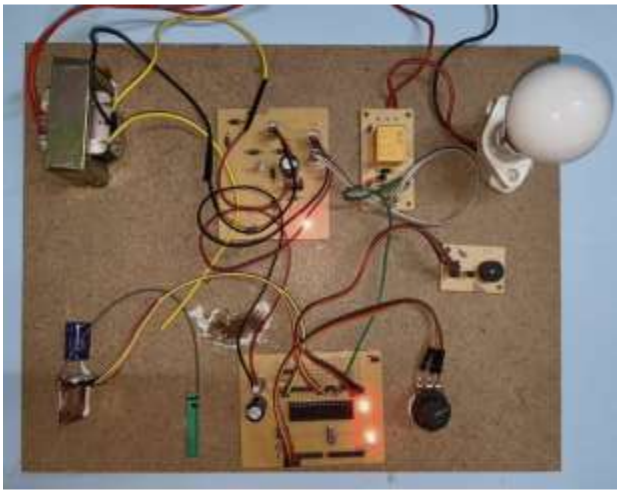
Fig: 7. System Stability

4. Results And Discussion

a. Performance of Overvoltage Tripping

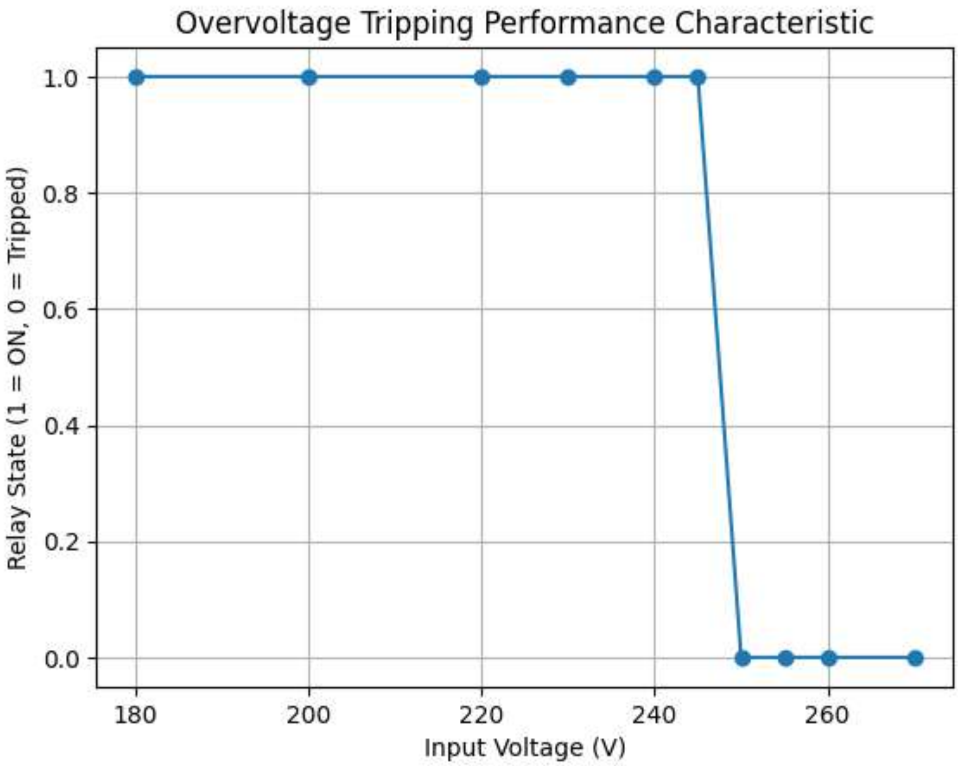
The overvoltage tripping performance evaluates how effectively the system detects excessive voltage levels and disconnects the load to protect electrical equipment. This test is important to ensure that the system responds quickly and accurately when the supply voltage exceeds the safe operating limit. During testing, the input voltage





was gradually increased above the preset maximum threshold value. The voltage sensing circuit measured the supply voltage and transmitted a scaled signal to the microcontroller. The microcontroller, such as Arduino Uno (ATmega328P) or PIC16F877A Microcontroller, continuously compared the sensed voltage with the programmed overvoltage limit. When the voltage exceeded the defined threshold level, the microcontroller immediately detected the abnormal condition. It then sent a control signal to the relay driver circuit, which de-energized the relay. As a result, the relay contacts opened and disconnected the load from the power supply. The results showed that the system responded quickly to the overvoltage condition and successfully prevented the load from operating under unsafe voltage levels. The relay tripping occurred reliably whenever the voltage exceeded the preset limit, demonstrating the effectiveness of the protection mechanism.

Fig: 8. Over Voltage Tripping Performance Characteristics



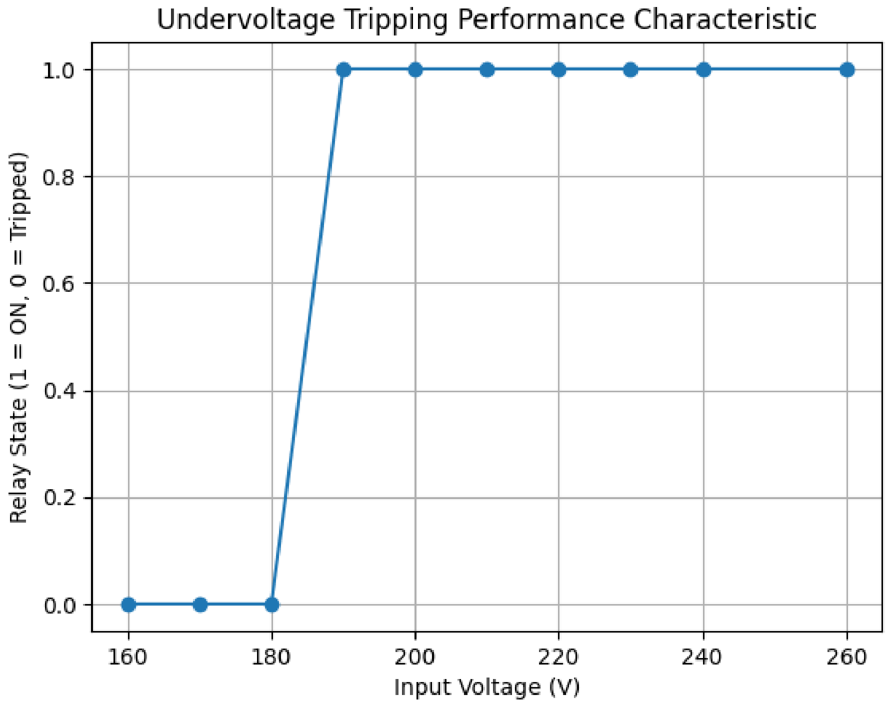
b. Performance of Under voltage Tripping

The under-voltage tripping performance evaluates how effectively the system detects low voltage conditions and disconnects the load to prevent malfunction or damage to electrical equipment. This test ensures that the protection system responds correctly when the supply voltage falls below the safe operating limit. During testing, the input voltage was gradually reduced below the preset minimum threshold level. The voltage sensing circuit continuously measured the input voltage and provided a scaled signal to the microcontroller. The microcontroller, such as Arduino Uno (ATmega328P) or PIC16F877A Microcontroller, compared the measured voltage with the predefined under voltage limit stored in the program.

When the voltage dropped below the set threshold value (for example 180V AC), the microcontroller detected the under voltage condition and sent a control signal to the relay driver circuit. The relay driver then turned OFF the relay coil, causing the relay contacts to open and disconnect the load from the power supply.

Overall, the under voltage protection mechanism worked effectively and reliably. The system successfully detected low voltage levels and isolated the load, thereby ensuring safe and stable operation of the electrical system.

Fig 7.3.1 Under Voltage Tripping Performance Characteristics



7.4 Response Time Analysis

The response time analysis evaluates how quickly the voltage monitoring and protection system reacts when an abnormal voltage condition such as overvoltage or under voltage occurs. Response time is an important parameter because a faster response ensures better protection for connected electrical equipment.

In this system, the response time mainly depends on the voltage sensing circuit, the processing speed of the microcontroller, and the switching speed of the relay driver circuit. The microcontroller, such as Arduino Uno (ATmega328P) or PIC16F877A Microcontroller, continuously reads the voltage through its Analog-to-Digital Converter (ADC) and compares it with predefined threshold limits.

When the input voltage crosses either the overvoltage or under voltage threshold, the microcontroller immediately processes the change and sends a control signal to the relay driver circuit. The relay driver activates or deactivates the relay, which disconnects the load from the power supply.

The total response time of the system includes:

- **Voltage Detection Time**
  The time required for the voltage sensing circuit to detect the change in input voltage.
- **Microcontroller Processing Time**
  The time taken by the microcontroller to read the ADC value, compare it with threshold limits, and generate a control signal.
- **Relay Switching Time**
  The time required for the relay coil to energize or de-energize and change the position of its contacts.

In practical testing, the overall response time is usually in the range of a few milliseconds to tens of milliseconds, depending on the sampling rate of the microcontroller and the relay switching characteristics.

The experimental results indicate that the system responds quickly to abnormal voltage conditions and disconnects the load in a short time, ensuring reliable protection and stable system operation.

7.5 Comparison with Conventional Protection Methods

The proposed voltage monitoring and protection system can be compared with conventional protection methods to evaluate its efficiency, accuracy, and reliability. Conventional protection systems typically use electromechanical devices such as fuses, circuit breakers, and voltage relays to protect electrical equipment from abnormal conditions. However, the microcontroller-based system provides improved monitoring and faster response.

Conventional Protection Methods

Traditional protection methods include devices such as fuses, circuit breakers, and voltage relays. These devices operate mainly based on fixed electrical or mechanical principles and are commonly used in power systems for basic protection.

Characteristics:

- Simple design and operation
- Limited flexibility in setting voltage limits
- Slower response compared to digital systems
- Mostly provide protection only after severe faults occur

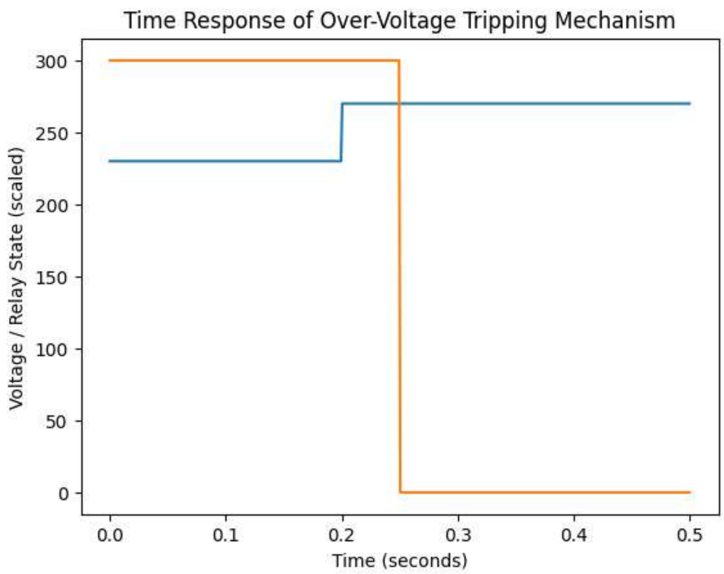
Proposed Microcontroller-Based Protection System

The proposed system uses a programmable controller such as Arduino Uno (ATmega328P) or PIC16F877A Microcontroller to continuously monitor voltage levels and control the relay automatically.

Characteristics:

- Continuous voltage monitoring
- Adjustable voltage threshold limits
- Faster response to abnormal conditions
- High accuracy due to digital processing
- Ability to integrate additional features such as display, alarms, or data logging

Fig 7.4.1 Time Response analysis



Comparison Table:

Feature	Conventional Protection	Proposed System
Monitoring Method	Mechanical / Electromechanical	Microcontroller-based digital monitoring
Voltage Threshold Adjustment	Fixed or limited	Easily programmable
Response Time	Relatively slower	Faster response
Accuracy	Moderate	High accuracy
Flexibility	Limited	Highly flexible
Expandability	Difficult	Easy to integrate additional functions

Table 7.5.1 Comparison Table

Conclusion:

The project "Design of Over Voltage and Under Voltage Tripping Mechanism" successfully demonstrates a reliable method for protecting electrical equipment from abnormal voltage conditions. The system continuously monitors the supply voltage using a sensing circuit and processes the measured signal through a microcontroller such as Arduino Uno (ATmega328P) or PIC16F877A Microcontroller.

When the voltage exceeds the pre-set upper limit (overvoltage) or falls below the minimum limit (under voltage), the microcontroller quickly detects the fault and sends a control signal to the relay driver circuit. The relay then disconnects the load from the power supply, thereby preventing damage to connected electrical devices. Additional components such as an LCD display and buzzer provide real-time voltage information and warning alerts.

The experimental results show that the system operates effectively with fast response time, accurate voltage detection, and reliable tripping performance. Compared to conventional protection methods, the microcontroller-based system offers greater flexibility, improved monitoring, and easier adjustment of voltage limits.

Overall, the proposed system provides a simple, low-cost, and efficient solution for voltage protection, making it suitable for applications in domestic, industrial, and power distribution systems.

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