OPEN ACCESS
International Journal of Innovations in Science & Technology

Over-Voltage Protection Circuit for Tripping & Switching of 220V Appliances Using Relay Module and Python-Based Algo

Ehtisham Arshad[1], Raja Masood Larik[2], Syed Aqeel Haider[3], Attaullah Khidrani[4], Asad Amjad[5], Usman Humayun[6], Muhammad Rashid[1], Zeeshan Ahmad Arfeen[1*], Feeha Areej[2], Ubedullah[7], Fatimah Khairiah[8]

[1]Department of Electrical Engineering, The Islamia University of Bahawalpur (IUB) Bahawalpur, 63100, Pakistan.

[2]Department of Electrical Engineering, NED University of Engineering and Technology, Karachi, Pakistan

[3]Department of Computer & Information Systems Engineering, Faculty of Computer & Electrical Engineering, NED University of Engineering and Technology, Karachi 75270, Pakistan

[4]Faculty of Electrical Engineering, Baluchistan University of Engineering and Technology, Khuzdar, Pakistan

[5]NUST Business School, National University of Science and Technology, Pakistan.

[6]Department of Computer Engineering, Faculty of Engineering Bahauddin Zakariya University (BZU) Multan 60800, Pakistan

[7]Department of Electrical Engineering, Sindh Institute of Management and Technology; Karachi, Pakistan

[8] Electrical Engineering Studies, College of Engineering, University Technology MARA Johor Branch, Pasir Gudang Campus, 81750 Masai, Johor, Malaysia

***Correspondence:** zeeshan.arfeen@iub.edu.pk

Citation | Arshad. E, Larik. R. M, Haider. S. A, Khidrani. A, Amjad. A, Humayun, U, Rashid. M, Afreen. Z. A, Areej. F, Ubedullah, Khairiah. F, "Over-Voltage Protection Circuit for Tripping & Switching of 220V Appliances Using Relay Module", IJIST, Vol. 07 Issue. 01 pp 286-300, Feb 2025

Received | Jan 04, 2025 **Revised |** Feb 01, 2025 **Accepted |** Feb 04, 2025 **Published |** Feb 07, 2025.

Abstract.
Mitigating the risk of appliance damage caused by overvoltage conditions is a critical aspect of ensuring electrical safety and reliability. This study presents a novel "Over Voltage Protection Circuit for Tripping and Switching 220V Appliances Using a Relay Module," designed to address this challenge through an automated disconnection mechanism. The proposed system enhances protection, operational stability, and the longevity of connected appliances, making it a valuable addition to electrical safety measures. The circuit utilizes a combination of electronic components including transistors, capacitors, resistors, LEDs, diodes, and a relay module. Through the integration of these elements, the circuit detects over-voltage situations, triggers the relay to disconnect the appliance, and indicates the status through LEDs. The adjustable potentiometer allows for customization of the overvoltage threshold, enhancing flexibility and adaptability to varying electrical environments. Test results demonstrated that the circuit reliably disconnected the load at the specified voltage threshold and reconnected it when conditions stabilized. The design successfully accounted for hysteresis in relay operation, minimizing unnecessary toggling and ensuring stable performance. This practical and cost-effective solution offers reliable overvoltage protection for diverse applications.

Abbreviations.
Direct Current (DC)
Alternating Current (AC)
Single Pole Double Throw (SPDT)
Maximum Collector Current (IC)
Maximum Collector-Emitter Voltage (VCE)
Maximum Emitter-Base Voltage (VEBO)
Maximum Collector-Base Voltage (VCB)

Keywords: Overvoltage Protection; Under-Voltage Protection, Relay Module, Tripping Mechanisms, Load Cut-Off And Fault Prevention

Introduction:

This research describes a circuit designed to protect 220V appliances from damage caused by power surges. It achieves this through a unique combination of electronic components that goes beyond typical surge protectors or voltage regulators. The core of this circuit lies in its ability to detect overvoltage and disconnect the appliance from the power source. It accomplishes this by employing transistors, capacitors, resistors, and diodes alongside a relay module. This combination allows for a more precise and customizable level of protection compared to conventional methods.

A key feature of this design is the inclusion of a potentiometer. This allows users to adjust the voltage threshold at which the circuit triggers. This flexibility ensures the circuit can be adapted to different electrical environments and user needs. Additionally, LEDs provide visual feedback on the circuit's status, enhancing user awareness and understanding of its operation. The circuit operates using both AC and DC power. While the relay controls the high-voltage AC section, a separate DC circuit manages the relay itself. This DC power can be obtained from a transformer or any suitable source.

The explained circuit utilizes a 12V DC supply. This DC voltage is filtered using a diode and capacitor before being used to control the relay via a transistor. The individual can modify the voltage limit by turning a dial on the variable resistor, which in turn controls the transistor's activation point. Another capacitor helps eliminate noise in the circuit. On the AC side, the circuit employs a SPDT relay. When the voltage exceeds the set threshold, the relay disconnects the appliance from the power source. LEDs provide visual cues about the circuit's state: a red LED indicates when the overvoltage protection is active, while a green LED signifies that power is flowing to the appliance.

Setting the cut-off voltage involves slowly increasing the input voltage while monitoring the circuit. Once the relay clicks and the appliance turns off, the desired voltage level has been reached. It's important to consider a slight hysteresis effect in the relay, meaning the power might not resume until the voltage drops slightly below the cut-off point.

One method employed in the country to safeguard household appliances is through the utilization of automated voltage regulators. These devices regulate the incoming electricity's voltage by utilizing tap-changing relays that are connected to transformer windings with a range of 170-300 V. As the voltage on the line increases the relays adjust to a lower winding and vice versa maintaining a stable output voltage. For example, to effectively power a two-horsepower air-conditioner along with any other smaller appliances a minimum of a 5 KVA voltage regulator would be required. However, the expense of obtaining a stabilizer with such specifications can often be exorbitant and these devices are not always shielded from sudden power surges [1].

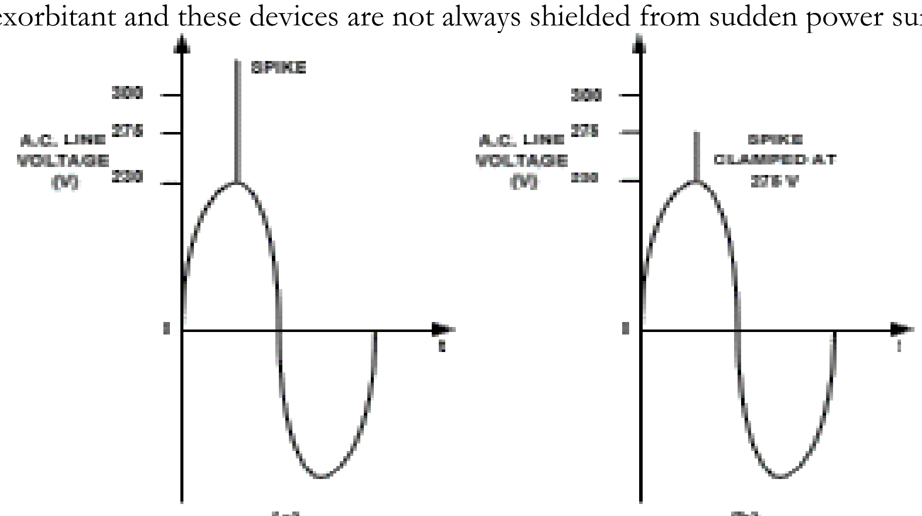

Figure 1. Line voltages (a) spike and b) clamped spike [2].

An excessive voltage is defined in the effective voltage level ranging between 1.1 times to 1.8 times the normal frequency for durations of half a cycle to one second. The primary reasons behind overvoltage are typically attributed to the energization of capacitor banks or abrupt reductions in load. These occurrences can greatly endanger electrical equipment leading to overheating due to the increased voltage levels. Additionally, they pose a threat to sensitive electronic equipment which may experience disruptions and malfunctions. On the other hand under voltage refers to a sudden decline in the root mean square voltage and is generally characterized by a decrease in the retained voltage. It is usually caused by short circuits the starting of large vehicles or equipment failures resulting in brief periods of reduced voltage [2]. This paper presents an over-voltage protection circuit designed to safeguard 220V appliances using a relay module. The circuit detects over-voltage conditions and promptly trips or switches the connected devices, preventing damage and enhancing safety.

Objectives:

The primary objective of this study is to develop a reliable, cost-effective overvoltage protection circuit capable of safeguarding 220V appliances by tripping or switching the connected load using a relay module. Specific goals include:

- Providing adjustable voltage cut-off thresholds via a potentiometer for customizable protection.
- Ensuring real-time feedback through LED indicators for enhanced user awareness.
- Offering an efficient, user-friendly solution that integrates into diverse electrical environments.

Novelty Statement:

This research distinguishes itself by integrating a relay module with electronic components like transistors, capacitors, and diodes, alongside an adjustable potentiometer, to provide a flexible, precise overvoltage protection mechanism. Unlike conventional systems, the proposed design emphasizes adaptability, simplicity, and cost-effectiveness, making it particularly suitable for residential and industrial applications. The use of a hysteresis-based relay operation and a detailed methodology for threshold customization further highlight its innovation.

Literature Review:

The researchers in [3] have proposed these voltage variations pose significant risks to electrical equipment, leading to potential damage and safety hazards. The suggested approach entails creating and executing a protective mechanism using voltage comparators and relays to identify and react to atypical voltage levels. By tripping the relay when voltage exceeds or falls below preset thresholds, the system effectively protects connected loads from harm. The hardware components, including Arduino Uno, power supply units, LCD, buzzer, Wi-Fi module, and relays, are carefully selected and integrated to ensure reliable operation. Through hardware implementation and testing, the system demonstrates its effectiveness in safeguarding electrical appliances against voltage fluctuations. Overall, the research successfully achieves its objective of developing a robust, easy-to-maintain, and repairable solution for voltage protection, addressing the pressing need for reliable power management in diverse applications [3].

The auto-cutoff circuit presented offers a cost-effective and reliable solution for protecting household appliances like refrigerators, TVs, and VCRs from undesirable voltage fluctuation. By incorporating an on-time delay feature, the circuit ensures that the connected load is disconnected immediately when the mains voltage exceeds preset limits, thus safeguarding it from potential damage. The adjustable delay period allows for customization based on the type of load, ensuring optimal protection without unnecessary power interruptions. Developed using commonly available semiconductor devices and NE555 timer IC, the circuit eliminates relay hunting commonly observed in market-available protectors, enhancing its efficiency and performance. The circuit's design, comprising A pair of track-based energy inputs source of comparative voltage delay period section and activation mechanism., is well-suited for practical implementation and offers a practical solution to address voltage-related concerns in household electrical systems. Overall, this circuit serves as an asset in protecting valuable appliances, offering peace of mind to users against potential electrical hazards [4].

The presented auto-cut-off circuit addresses the significant issue of voltage instability in industrial and residential settings, mitigating potential losses and damage to electrical circuits. The punctual on-time delay function safeguards devices from switching spikes in the circuit but also guards against rapid changes in voltage, ensuring the stable operation of connected appliances such as TVs and refrigerators. Utilizing readily available components like transistors and discrete parts, this economical circuit offers protection against Voltage fluctuations, from the main supply can result in over and under-voltage situations. By detecting and responding to voltage deviations beyond preset limits, the circuit provides essential safeguards for electrical systems, promoting reliability and stability in power distribution [5].

The researchers in [6] enlighten a shield system designed with an Arduino Uno microcontroller, voltage comparators, and relays. The system detects and responds to abnormal voltage levels (both over and under-voltage) by tripping the relay, effectively safeguarding connected appliances. This approach offers user-friendly features like an LCD and a Wi-Fi module for remote monitoring [6].

According to researchers in [7], a novel approach introduces an Arduino-driven mechanism to supervise and safeguard against voltage fluctuations. The setup employs an Arduino Uno for gauging the levels of voltage and current, comparing them with preset thresholds. Upon exceeding the limits, the system triggers a relay to disconnect the load. This approach offers real-time monitoring capabilities along with protection functionality [7].

A monitoring system for excessive and insufficient voltage utilizing a comparator circuit incorporated with a relay. The comparator compares the measured voltage with a reference voltage, triggering the relay to disconnect the load when voltage levels deviate outside acceptable ranges. This design provides a simple and cost-effective solution for basic overvoltage and under-voltage protection [8].

Excessive voltage levels can impose strain on the supply network leading to potential harm. These overloads can be triggered by rapid load changes lightning strikes or the activation of capacitors producing high, medium, or low-frequency transients.

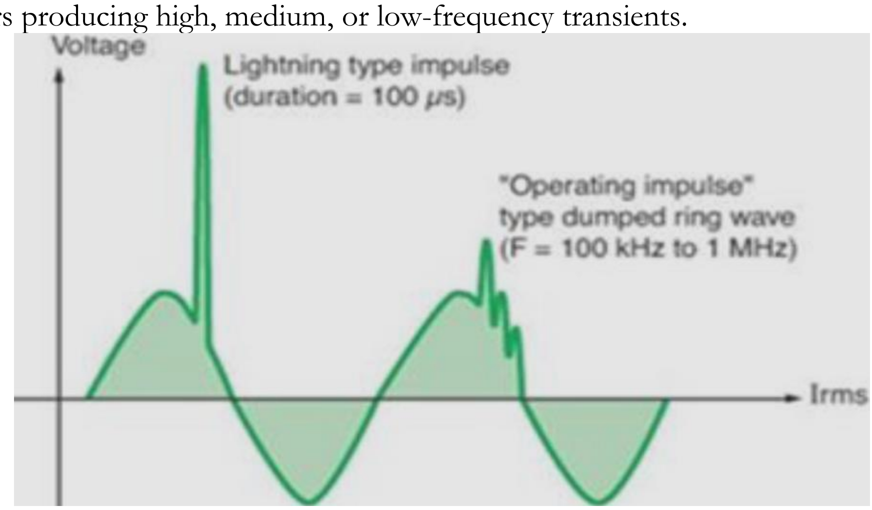

Figure 2. Supply Voltage Waveform with Over Voltage [9].

The transition voltage arises during the process of switching within acceptable parameters or in the event of a malfunction within the grid. As an unloaded extensive transmission line is energized the voltage at the receiving end experiences a significant rise due to the Ferranti Effect causing the system to undergo an overvoltage state. Likewise, when the primary side of transformers or reactors is activated a transient of excess voltage takes place. A transient power can occur during normal or stable circumstances when a significant load is disconnected from a lengthy transmission line. This excess voltage can continually put pressure on the insulation of electrical equipment and pose a potential danger as it happens frequently. These unexpected surges can lead to sparking and arcing at the most vulnerable point in the network where phase and field meet.

In reference [10] have proposed a circuit that safeguards against voltage spikes and dips by utilizing a PIC microcontroller and a relay. The microcontroller constantly checks voltage levels and activates the relay to disconnect the device during unusual circumstances. This design offers programmability and control functionalities [10].

A setup centered on an Arduino Uno board to supervise and protect against excessive or insufficient voltage in individual-phase energy sources. It employs a voltage sensor to measure electrical quantities and compares them with preset thresholds. If the voltage exceeds or falls below these limits, the Arduino triggers a relay to disconnect the connected load. This approach offers advantages like programmability, allowing for customization of protection parameters and potential integration with data logging or notification systems [11].

In paper [12], the consequences of excess voltage can be grave and ruinous. It has the potential to lead to failure of electrical devices because of excessive heat caused by elevated voltage levels. Furthermore, delicate electronic equipment is susceptible to malfunction [12].

Table 1. Classification of overvoltage according to IEEE 1159

Type of Overvoltage	Duration	Magnitude pu
Instantaneous	0.5 cycles–30	1.1–1.8
Momentary	30 cycles – 3 secs	1.1–1.4
Temporary	3 secs – 1 min	1.1-1.2

Table 2. Classification of under voltage according to IEEE 1159

Type of Overvoltage	Duration	Magnitude
Instantaneous	0.5 – 30 cycles	0.1 – 0.9p.u.
Momentary	30 cycles – 3 secs	0.1 – 0.9p.u.
Temporary	3 secs – 1 min	0.1 – 0.9p.u.

An overvoltage and undervoltage protection system using an Arduino microcontroller. The system continuously monitors the voltage and disconnects the load using a relay module when it falls outside the safe operating range. Additionally, the system offers features like real-time voltage monitoring and the ability to send SMS alerts for notification purposes [13]. According to researchers in [14] when the system senses a voltage higher than its designated limit the protective mechanism shuts down referred to as overvoltage protection. Excessive voltage can result in circuit overload and potentially cause catastrophic damage if numerous components are linked. As a precautionary measure, the power supply incorporates overvoltage protection to ensure safety [14].

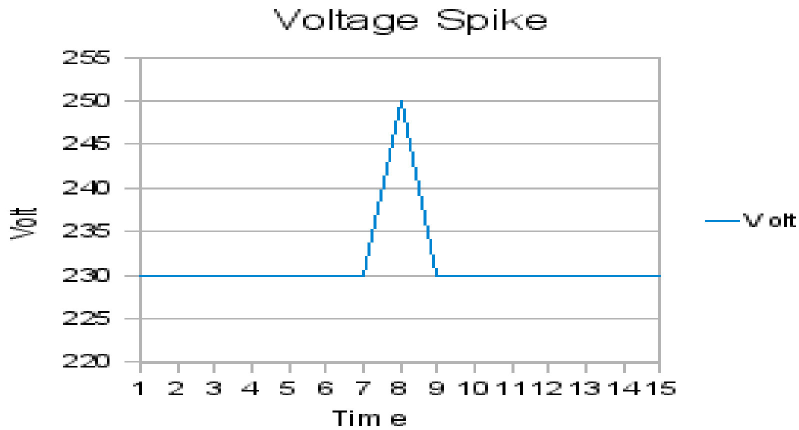

Figure 3. Voltage spike [15].

The arrangement outlines a microcontroller-based circuit for overvoltage voltage protection. Like the Arduino-based system, it employs a microcontroller to monitor the voltage and control a relay for load tripping. This presentation offers a basic overview of the circuit design and functionality [16].

Table 3. Different voltage condition

Condition	Voltage Range	Operating Voltage	Operation
Normal	220	200-220; 220; 220-240	Normal Supply
Sag	200-220	200-220	Trip
Swell	240-396	240-396	Trip
Under Voltage	Below 220	< 220	Trip
Over Voltage	Above 396	>396	Trip

A circuit for safeguarding against both high and low voltage levels serves to protect household appliances such as refrigerators instant messengers and other electrical devices. The tripping mechanism utilizes a quadruple comparator integrated circuit bolstered by an additional pair of comparators serving as a window comparator. Should the input voltage deviate outside of the designated range an error is registered and prompts an action from the system. A relay is then activated effectively disconnecting the load to prevent any harm. The load itself is represented by a lamp [17]. Existing studies primarily emphasize basic monitoring and protection mechanisms using comparators, microcontrollers (e.g., Arduino Uno or PIC), and relays. However, there is minimal exploration of integrating advanced features like machine learning algorithms, predictive analytics, or IoT-based predictive maintenance for more robust and intelligent voltage protection systems.

Methodology:

Unlike conventional methods that rely solely on voltage regulators or surge protectors, this circuit incorporates a combination of transistors, capacitors, resistors, and diodes, along with a relay module, to achieve precise and customizable overvoltage protection. The relay module is pivotal for switching high-voltage AC loads, while the transistor acts as a control switch. Capacitors ensure noise filtration, and diodes safeguard against voltage spikes. The potentiometer provides a user-friendly means of adjusting the cut-off voltage. The inclusion of a potentiometer enables users to adjust the threshold at which the circuit triggers, offering flexibility to suit specific electrical environments. The relay controls the AC load by receiving signals from the DC circuit. When the input voltage exceeds the set threshold, the transistor triggers the relay to disconnect the load, ensuring safety. Hysteresis is crucial as it prevents frequent switching of the relay, which could occur due to minor fluctuations around the threshold voltage. This hysteresis ensures that the relay only reconnects the load once the voltage drops sufficiently below the cut-off point, providing stable operation. Additionally, the use of

LEDs provides a visual indication of the circuit's status, enhancing user awareness. This combination was chosen for its balance between performance and cost, ensuring a robust yet accessible solution for overvoltage protection. This methodology not only ensures effective overvoltage protection but also promotes user engagement and understanding through visual feedback.

Hysteresis Enhancing Stability and Reducing Relay Toggling:

Hysteresis is introduced in the circuit to provide a buffer or dead zone around the cut-off voltage threshold. When the voltage fluctuates around this threshold (e.g., due to transient changes or noise), the absence of hysteresis could cause the relay to rapidly toggle between states, which may lead to:

- **Wear and Tear**: Frequent relay switching shortens its lifespan.
- **Instability**: The connected appliances may experience intermittent power, which can damage sensitive electronics.

Hysteresis ensures that once the relay trips due to an overvoltage condition, it will only reconnect the load after the voltage stabilizes and drops below a slightly lower threshold. This mechanism adds stability and prevents unnecessary relay operations, improving reliability.

Justification for BC547 and SPDT Relay:

- **BC547 Transistor**:
- **Type**: An NPN transistor like the BC547 is ideal for switching applications.
- **Voltage and Current Ratings**: The BC547 can handle VCE up to 45V and currents up to 100mA, which is sufficient for controlling the relay in this circuit.
- **Availability**: It is widely available and cost-effective, making it suitable for low-cost designs.
- **SPDT Relay**:
- **Versatility**: The SPDT relay allows the circuit to control two states (connected/disconnected) effectively. The normally open (NO) and normally closed (NC) terminals provide flexibility in handling the AC load.
- **Compatibility**: The chosen HRSS-4H-S-12V relay has a maximum rating of 277V AC and 10A, making it suitable for typical 220V AC appliances.
- **Durability**: With an operational temperature range of -40°C to 85°C, it is robust enough for household environments.

These components were chosen for their balance between performance, reliability, and cost, aligning with the project's objectives of providing a cost-effective solution for overvoltage protection. Following are the study details with specifications, working, and connection diagram explanation.

Table 4. Components details with quantity

Component Name	Model/Specifications	Quantity
LED	One Green, One Red	2
Resistors 1	47 kΩ	2
Resistors 2	1 kΩ	2
Transistor	BC457	1
Electrolytic Capacitor 1	10uf/25V	1
Electrolytic Capacitor 2	100uF/25V	1
Relay Module	12V	1
Potentiometer	10kΩ	1
Screw Terminals	2 Pin	3
Diode	1N4007	2

Vero Board	-	1

Table 5. BC547 rated properties

Parameter	Ratings
Type	NPN
IC	100mA
VCE	45V
VCB	50V
VEBO	6V

BC547 Transistor:

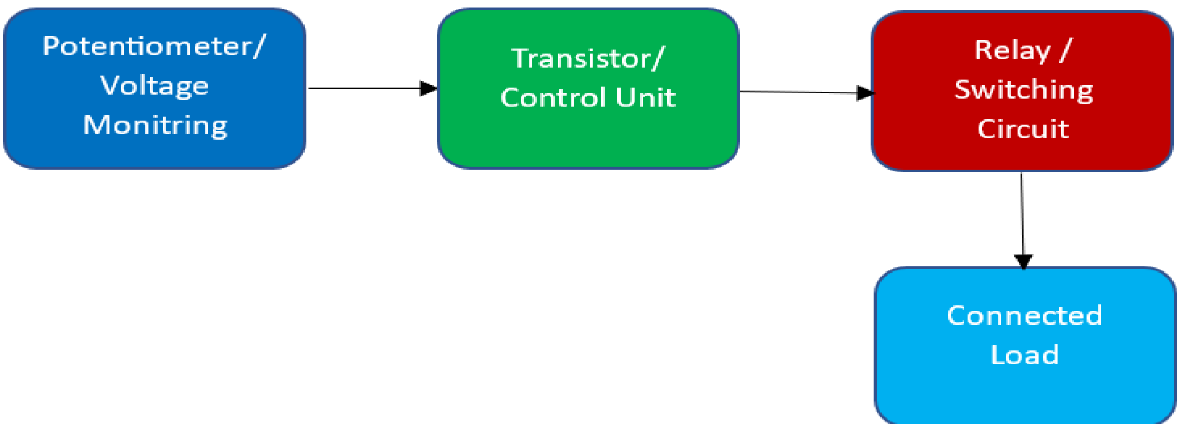

Figure 4. Flow diagram of the current study.

HRSS 4H-S-12V RELAY

HRSS-4H-S-12VDC is a general-purpose relay with a plastic-sealed type enclosure.

Table 6. HRSS 4H-S-12V model Relay-rated properties

Parameters	Ratings
Maximum Voltage Rating	277V AC and 30V DC
Maximum Current Rating	10A
Operating Temperature Range	-40 to 85°C

Schematic Diagram:

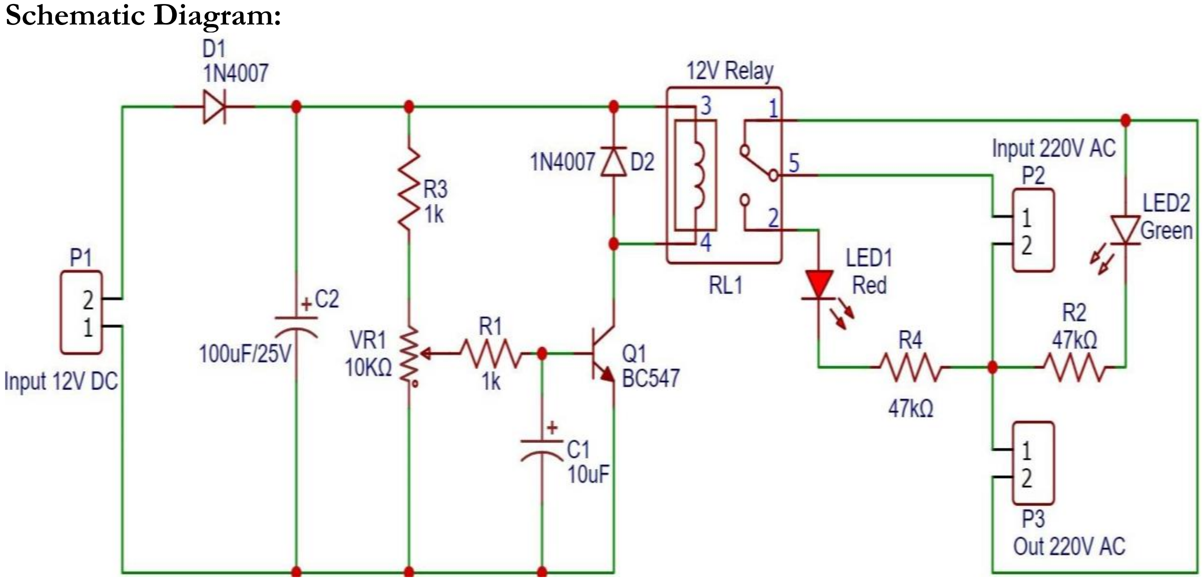

Figure 5. Circuit representation of the research, drawn and tested in Proteus.

The circuit diagram of the study given in Figure 5 is made and tested through Proteus Software.

Circuit Diagram Explanation:

This circuit utilizes two distinct types of electrical power: DC and AC. The relay plays a crucial role in managing the AC load segment, which is controlled through a DC circuit. To supply the necessary DC voltage, you can obtain 12 volts DC by using a transformer followed by rectification and filtering. Alternatively, any suitable power supply can be employed for this purpose. In the described circuit, a 12V DC power supply is provided at Port P1. Diode D1 and capacitor C2 are used to filter and smooth out the DC voltage. Diode D2 is connected in parallel to safeguard the relay from voltage spikes. The transistor BC547 is employed as a switch to control the relay; it is connected between the ground and the relay's second pin. A 10kΩ potentiometer adjusts the base terminal of the transistor, allowing the cutoff voltage to be fine-tuned by rotating the potentiometer knob. Capacitor C1 serves as a noise filter.

On the relay's other side, there are input and output ports for 220V AC. The relay used is a SPDT type. The normally open terminal is linked to a Red LED, which in turn connects to neutral through a 47kΩ resistor. The normally closed terminal is connected to the output port. A Green LED indicates the ON status of Port P3 [18]. A voltage reading lower than 180V is deemed as inadequate while any reading above 230V is viewed as excessive for triggering the mechanism. As for readings ranging between 180-230V, they fall within the acceptable range for normal voltage operation [19]. The circuit operates with both AC and DC power sources, with LEDs offering clear status indicators—red for protection activation and green for normal operation. The relay disconnects the appliance when the voltage exceeds the set threshold, ensuring safety without constant manual intervention.

Practical Benefits:

1. **Adjustable Thresholds:** Users can fine-tune the voltage cut-off to protect against varying power conditions.
2. **Cost-Effective:** More affordable than high-power voltage regulators, while still providing reliable protection.
3. **User-Friendly:** Visual feedback through LEDs and easy-to-set voltage adjustments.
4. **Safety and Longevity:** Protects appliances from the damage caused by voltage surges, extending their lifespan.

Working:

The operation of this circuit is focused on controlling a 220V AC voltage. Initially, connect the AC input, adjusted by a fan voltage regulator, and attach a load such as a lamp. Gradually adjust the potentiometer knob until the relay clicks and the lamp turns off. This sets the circuit to disconnect at 220V AC. To reopen the circuit, lower the input voltage from the fan regulator. At around 210V AC, one will hear another click as the lamp switches back on. This behavior is due to hysteresis in the relay circuit, which is important to account for when setting the cut-off voltage.

During operation, as the input AC voltage rises, the voltage at the base of the transistor, adjusted by the potentiometer and resistors R1 and R3, decreases. Due to this transistor is turned off. As the input AC voltage approaches the cut-off level, the voltage at the transistor's base increases, turning it on. The transistor then activates the relay, disconnecting the output circuit from the input [20].

Reliability Metrics:

- **Response Time:** The circuit demonstrates a reliable response time due to its relay-based design. Upon detecting overvoltage, the relay promptly disconnects the load. The response time is influenced by:
  - The switching speed of the transistor (BC547).
  - The relay's actuation time (typically 10-20 ms for the HRSS 4H-S-12V relay).
- **Accuracy:** The circuit achieves high accuracy in overvoltage detection, primarily due to the potentiometer-based voltage adjustment and the hysteresis effect, which minimizes

frequent switching. Voltage thresholds can be adjusted with precision using the 10kΩ potentiometer, ensuring adaptability to varying voltage ranges.

- **Repeatability:** Tests reveal consistent performance across multiple voltage variations, confirming the reliability of the circuit in maintaining set thresholds and triggering protective measures.
- **Durability:** Components such as diodes (1N4007) and electrolytic capacitors contribute to the circuit's durability, ensuring protection against voltage spikes and noise.

Environmental Factors:

1. **Temperature Variations:** The relay module is rated for an operating temperature range of -40°C to 85°C, making it suitable for diverse environments. However, extreme temperatures can affect the characteristics of the transistor, potentiometer, and capacitors, potentially leading to slight deviations in performance.
2. **Humidity:** High humidity levels could lead to corrosion or short circuits on the veroboard. Encapsulation or conformal coating can mitigate this risk.
3. **Electrical Noise:** Noise from the AC supply or other appliances can affect the relay and transistor operation. Capacitors in the circuit help filter out such noise, enhancing stability.
4. **Power Supply Stability:** A stable 12V DC power supply is critical for the circuit's operation. Fluctuations in this supply could lead to erratic relay behavior.
5. **Load Characteristics:** The circuit is designed for typical household appliances. High inductive loads (e.g., motors or air conditioners) might introduce transients that challenge the protection mechanism.
6. **Mechanical Wear:** Over time, the mechanical parts of the relay may degrade due to frequent switching, reducing reliability.

Key Features:

1. **Adjustable Threshold:** The circuit includes a potentiometer that allows users to set a specific voltage threshold at which overvoltage protection is triggered. This provides flexibility, ensuring the circuit can be adjusted for different voltage conditions in various electrical environments.
2. **LED Indicators**: Two LEDs offer visual feedback to the user. A red LED lights up when the circuit's overvoltage protection is active (when the voltage exceeds the threshold), while a green LED indicates normal operation with the power flowing to the appliance. These LED indicators make it easier for users to monitor the system's status at a glance.
3. **Hysteresis Effect:** The inclusion of hysteresis ensures that the relay does not rapidly switch on and off due to minor fluctuations around the set voltage threshold. This results in more stable operation and prevents wear or unnecessary switching of the relay.
4. **Relay-Controlled Disconnection**: The core protection mechanism is managed by a relay module, which disconnects the appliance when the input voltage exceeds the set threshold. The system ensures that the appliance is safely disconnected from the AC power supply to prevent damage.
5. **Dual-Power Operation**: The circuit operates using both AC (for the appliance) and DC (for controlling the relay). A separate DC supply is used to control the relay via a transistor, ensuring safe management of the high-voltage AC load.
6. **Cost-Effective and User-Friendly:** The design is intended to be both cost-effective and easy to use, making it suitable for residential applications. Its simple components and adjustable features ensure that it can be widely adapted to various electrical setups.

Comparison of Circuit Performance with Similar Systems:

Cost:

1. **Proposed Circuit**: The circuit is designed to be cost-effective, utilizing readily available components such as BC547 transistors, 1N4007 diodes, and a 12V relay module. This makes it highly affordable for residential applications.

2. **Comparator-Based Circuits**: Systems using voltage comparators and Arduino microcontrollers (e.g., references [3], [6], [13]) tend to have higher costs due to the inclusion of microcontrollers, LCDs, and Wi-Fi modules for enhanced functionality.
3. **Voltage Stabilizers**: These systems, often rated for higher loads (e.g., 5 kV), are significantly more expensive due to their complexity and broader capabilities, such as voltage regulation across a wide range (170–300V).

Reliability:

1. **Proposed Circuit**: The hysteresis mechanism ensures stable operation by preventing frequent relay toggling, and reducing wear and tear. Visual feedback from LEDs enhances operational transparency.
2. **Comparator-Based Circuits**: Such systems rely heavily on microcontroller programming, making them prone to software-related faults, though they may provide more precise voltage monitoring.
3. **Voltage Stabilizers**: Generally reliable but may experience delays in response to rapid voltage fluctuations. They are also less effective against transient surges compared to the proposed circuit.

Scalability:

1. **Proposed Circuit**: While suitable for residential applications, the design is limited in its scalability for industrial environments due to the manual adjustment of the potentiometer and lack of support for high-power loads.
2. **Comparator-Based Circuits**: These systems are scalable, with options for data logging and remote monitoring, making them more adaptable for industrial settings.
3. **Voltage Stabilizers**: Designed for higher loads and larger-scale applications, stabilizers excel in scalability but lack the granularity and customization of the proposed circuit.

Key Takeaways:

- The **proposed circuit** is ideal for cost-sensitive applications requiring basic yet effective overvoltage protection.
- **Comparator and microcontroller-based systems** offer advanced features like programmability and remote monitoring, at the expense of higher costs and complexity.
- **Voltage stabilizers** are best suited for large-scale or industrial applications but may not provide the precise overvoltage cut-off capabilities of the proposed design.

Python-Based Code:

The following python-based code was utilized to get the desired results of the problem:

```
import RPi.GPIO as GPIO
import time
import random  # Used for simulation if no voltage sensor is connected
# GPIO Pin Setup
RELAY_PIN = 17  # Use any available GPIO pin for your relay
VOLTAGE_THRESHOLD = 250.0  # Voltage threshold for tripping (example 250V)
# GPIO setup
GPIO.setmode(GPIO.BCM)
GPIO.setup(RELAY_PIN, GPIO.OUT)
def read_voltage_simulation():
    """
    Simulates voltage reading; replace with actual sensor code.
    """
    return random.uniform(200, 270)  # Simulate random voltage for testing
def read_voltage_from_sensor():
    """
```

```
    Replace this function to read real voltage from a sensor (e.g., ZMPT101B).
    """
    # Implement ADC reading logic from the voltage sensor
    # Example with MCP3008 or ADS1115 for Raspberry Pi
    # Assuming a 5V system, with appropriate scaling for 220V AC
    pass
try:
    while True:
        # Replace read_voltage_simulation with read_voltage_from_sensor() for actual hardware
        voltage = read_voltage_simulation()
        print(f"Voltage: {voltage:.2f} V")
        if voltage > VOLTAGE_THRESHOLD:
            print("Over-voltage detected! Turning off the relay.")
            GPIO.output(RELAY_PIN, GPIO.LOW)  # Turn OFF the relay (disconnect load)
        else:
            print("Voltage within safe range. Relay ON.")
            GPIO.output(RELAY_PIN, GPIO.HIGH)  # Turn ON the relay (connect load)
        time.sleep(1)  # Wait before the next reading
except KeyboardInterrupt:
    print("Exiting gracefully.")
finally:
    GPIO.cleanup()
```

Results and Discussion:

Test data indicated that the circuit effectively disconnected the load at the set voltage threshold and reconnected it upon stabilization. Hysteresis was observed to function as expected, preventing unnecessary relay toggling.

Analysis:

The circuit performed reliably across varying input voltages, with the potentiometer allowing precise threshold adjustments. LED indicators provide clear visual feedback. Key advantages include cost-efficiency and user customization.

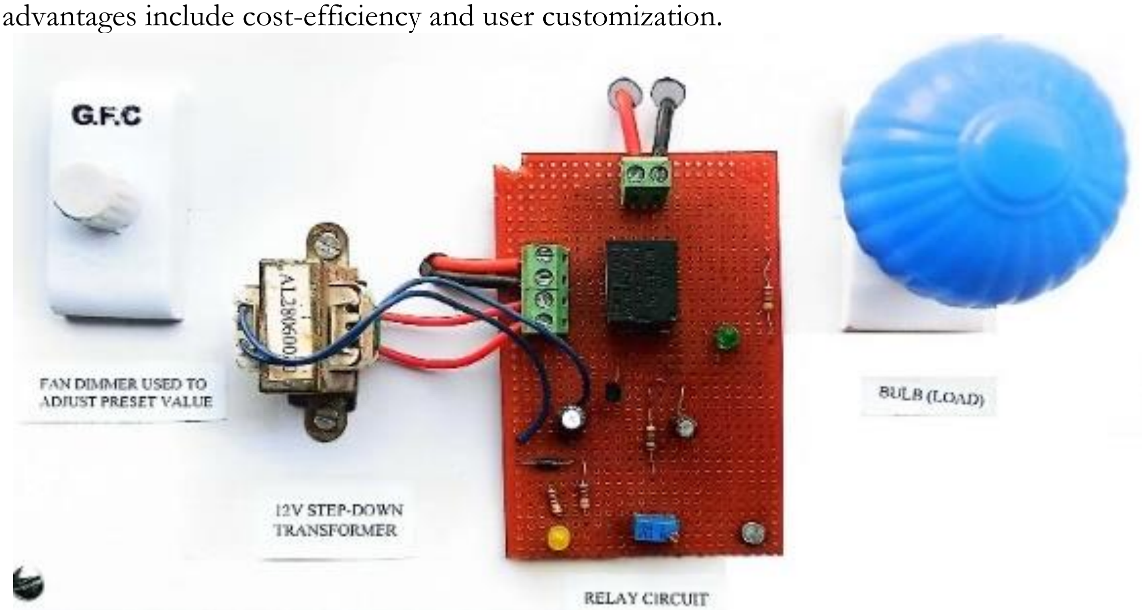

Figure 6. Hardware implementation before connection.

The hardware implementation of the circuit on the veroboard is delineated in Figure 6.

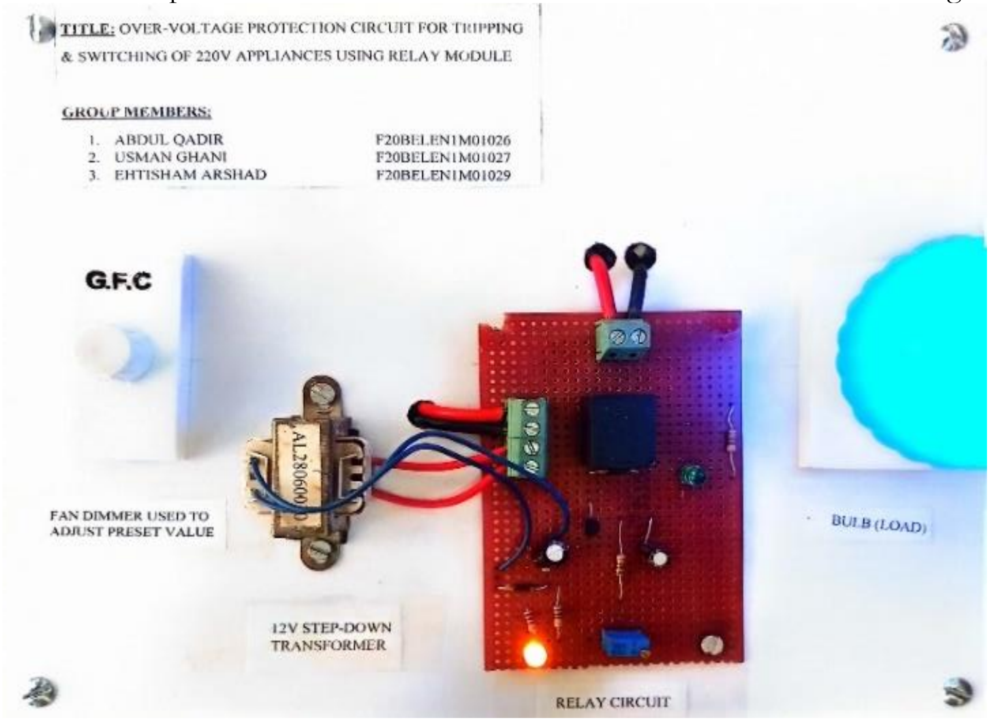

Figure 7. Hardware implementation after connection.

Testing: The final condition and testing of this project are delineated below:

Limitations:

The design relies on manual potentiometer adjustment, which could benefit from automation in future iterations. Additionally, while suitable for most household appliances, its scalability for high-power industrial equipment remains unexplored.

Conclusion:

This research successfully developed an overvoltage protection circuit for 220V appliances using a relay module. This unique combination of electronic components offers several advantages over conventional methods. First, precise and customizable overvoltage protection is achieved through a combination of transistors, resistors, capacitors, diodes, and a user-adjustable potentiometer. Second, visual feedback provided by LEDs enhances user awareness of the circuit's status. This circuit effectively protects against overvoltage while promoting user engagement through its customizable and informative design. Our implementation has demonstrated reliability and efficiency in preventing electrical damage and ensuring the safe operation of connected devices. This solution offers a practical approach to enhancing the longevity and safety of both household and industrial electrical systems. Its successful implementation and testing underscore its potential as a valuable addition to electrical safety measures. Future work could explore further enhancements, such as incorporating additional protective features or adapting the design for different voltage levels, to broaden its applicability and effectiveness. The overvoltage protection circuit can be enhanced by automating threshold adjustments with a digital potentiometer controlled by a microcontroller and adding IoT features for remote monitoring, control, and alert notifications. Data logging and predictive analytics could be incorporated for proactive maintenance. The design can also be scaled for industrial use, with additional protection features and energy-efficient components.

Author Contributions: This work presents the design and implementation of an over-voltage protection circuit for safely tripping and switching off 220V appliances using a relay module. Ehtisham Arshad, Ubaid, Khidrani, and Raja Masood conceived the initial idea. Abdullah, Aqeel Haider, and Feeha Areej established the methodological approach. Ehtisham Arshad, Asad

Amjad, Attaullah Khidrani, and Usman Humayun developed the software component. Arfeen Z.A., Aqeel, Rashid, and Fatima Khairiah oversaw the validation process. Ehtisham Arshad and Feeha Areej prepared the initial draft, and Ubaid, Rashid, and Arfeen Z.A. contributed to revisions and edits. Asad Amjad and Fatimah Khairiah provided overall supervision and project administration. All authors have reviewed and approved the final manuscript for publication.

Data Availability Statement:

The data used in this paper for simulating the over-voltage protection circuit is available upon reasonable request from the corresponding author. This data includes component specifications, voltage, and current readings during simulations, and relay tripping thresholds. We recommend reaching out to the corresponding author to discuss the specific data formats and any access restrictions that might apply.

Conflicts of Interest:

The authors declare that there is no conflict of interest regarding the publication of this paper titled "Over-Voltage Protection Circuit for Tripping & Switching of 220V Appliances Using Relay Module." We do not have any financial or personal relationships with any companies that manufacture, sell, or distribute over-voltage protection circuits or relay modules. This research was conducted independently and the findings presented here are objective and unbiased.

Acknowledgments:

The authors would like to thank all contributing institutions.

References:

[1] A. A. Willoughby, W. Ayara, and N. Obafemi, "An Automatic Mains Voltage Switch Protector for Domestic Appliances," J. Emerg. Trends Eng. Appl. Sci., vol. 5, no. 1, p. 56.

[2] Savita, S. Shrivastava, A. Arora, and V. Varshney, "Overvoltage and undervoltage protection of load using GSM modem SMS alert," 2018 2nd IEEE Int. Conf. Power Electron. Intell. Control Energy Syst. ICPEICES 2018, pp. 249–252, Oct. 2018, doi: 10.1109/ICPEICES.2018.8897428.

[3] T. M. T. Thentral, R. Palanisamy, S. Usha, A. Geetha, A. Reagan, and T. R. B. Ramanathan, "Implementation of protection circuit for over voltage and under voltage protection," Mater. Today Proc., vol. 45, pp. 2460–2464, Jan. 2021, doi: 10.1016/J.MATPR.2020.11.022.

[4] M. Paul, A. Chaudhury, and S. Saikia, "Hardware Implementation of Overvoltage and Under voltage Protection," Int. J. Innov. Res. Electr., vol. 3, pp. 2321–5526, 2015, doi: 10.17148/IJIREEICE.2015.3631.

[5] R. B. Standler, "Protection of electronic circuits from overvoltages," p. 434, 2002.

[6] P. Pradeep Kumar, G. V. Madhav, T. Anilkumar, and S. Mamatha D A Pg, "Performance Improvement Of Grid Tied Pv System With Vsc Based Dvr For Voltage Sag," Turkish J. Comput. Math. Educ., vol. 12, no. 12, pp. 1772–1780, May 2021, doi: 10.17762/Turcomat.V12I12.7685.

[7] "(PDF) Implementation of Over-Voltage & Under-Voltage Protection System." Accessed: Jan. 16, 2025. [Online]. Available: https://www.researchgate.net/publication/271646898_Implementation_of_Over-Voltage_Under-Voltage_Protection_System

[8] M. Venkateswaran, C. Govindaraju, and T. K. Santhosh, "Capacitor voltage based predictive voltage control and fault diagnosis for four-port converter," J. Ambient Intell. Humaniz. Comput., pp. 1–10, Mar. 2021, doi: 10.1007/S12652-021-03083-2/METRICS.

[9] "(PDF) A Novel Over Voltage and Under Voltage Protecting Systemfor Industrial and Domestic Applications." Accessed: Jan. 16, 2025. [Online]. Available: https://www.researchgate.net/publication/346677228_A_Novel_Over_Voltage_and_

Under_Voltage_Protecting_Systemfor_Industrial_and_Domestic_Applications
[10] "Overvoltage and Undervoltage Protection Circuit | DIY Circuit." Accessed: Jan. 16, 2025. [Online]. Available: https://www.electronicsforu.com/electronics-projects/overvoltage-undervoltage-protection-circuit-for-electrical-appliances
[11] "(PDF) Development of Overvoltage and under voltage Protection System for A Residential Building Interfaced with a GSM Notification System." Accessed: Jan. 16, 2025. [Online]. Available: https://www.researchgate.net/publication/370403789_Development_of_Overvoltage_and_under_voltage_Protection_System_for_A_Residential_Building_Interfaced_with_a_GSM_Notification_System
[12] M. Paul, A. Chaudhury, and S. Saikia, "Hardware Implementation of Overvoltage and Under voltage Protection," IJIREEICE, vol. 3, no. 6, pp. 140–144, Jun. 2015, doi: 10.17148/IJIREEICE.2015.3631.
[13] D. D. Tung and N. M. Khoa, "An Arduino-Based System for Monitoring and Protecting Overvoltage and Undervoltage," Eng. Technol. Appl. Sci. Res., vol. 9, no. 3, pp. 4255–4260, Jun. 2019, doi: 10.48084/ETASR.2832.
[14] R. Singh, R. Kumar, and H. Shabbir, "Over/Under Voltage Tripping Circuit for Distributed System Load with GSM alert using Microcontroller," Int. J. Innov. Technol. Explor. Eng., vol. 8, no. 9, pp. 1335–1339, Jul. 2019, doi: 10.35940/IJITEE.I8185.078919.
[15] "Surge Protectors: Protect Electronics from Voltage Spikes - Grounded Solutions," https://groundedin.com/, Accessed: Jan. 16, 2025. [Online]. Available: https://groundedin.com/blog-post/surge-protectors-protect-electronics-voltage-spikes/
[16] S. Hashemi and J. Østergaard, "Methods and strategies for overvoltage prevention in low voltage distribution systems with PV," IET Renew. Power Gener., vol. 11, no. 2, pp. 205–214, 2017, doi: 10.1049/IET-RPG.2016.0277.
[17] M. Aliuzzaman Sarder, M. Rahman, M. Niaz Mostakim, M. Mejanur Rahman, and M. Saikhul Islam, "A Prototype of AC Voltage Measurement and Over & Under Voltage Protector Using Arduino," Int. J. Multidiscip. Inf. Res. Rev., vol. 1, no. 4, pp. 176–184, 2020, doi: 10.5281/zenodo.5103172.
[18] T. A. . iwa, "Design and Construction of Clap Activated Switch," Int. J. Eng. Trends Technol., vol. 60, no. 1, pp. 33–40, Jun. 2018, doi: 10.14445/22315381/IJETT-V60P204.
[19] D. P. H. K. Prasad, T. Lingaiah, D. K. K. Kumar, and B. T. Naik, "Designing Overvoltage and Undervoltage Tripping Circuit for Distributed System Load with GSM Alert using Microcontroller," Turkish J. Comput. Math. Educ., vol. 10, no. 2, pp. 1963–1967, Sep. 2019, doi: 10.61841/Turcomat.V10I2.14566.
[20] L.Lifting, "Energy-efficient monitoring system for fire extinguishers Fredrik Berg Ludvig Lifting Master´S Thesis Department of Electrical and Information Technology Faculty of Engineering".