Arduino-Based Real-Time Monitoring and Automatic Protection of AC Loads Against Voltage and Current Abnormalities

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Abstract— Electrical appliances and AC loads can be adversely affected by abnormal voltage and current conditions, including under-voltage, over-voltage, under-current, and over-current. This paper presents an Arduino-based protection system designed to continuously monitor these electrical parameters and automatically disconnect an AC load during unsafe operating conditions. The proposed system uses an Arduino ATmega328P/Arduino Uno as the main controller, a ZMPT101B voltage sensor for AC voltage measurement, an ACS712-type current sensor for load-current measurement, a 16×2 LCD for real-time display, and a relay module for automatic load switching. A 60 W AC bulb is considered as the demonstration load. The normal operating voltage is defined as 210–240 V, while a prototype current range of 0.20–0.35 A is selected according to the load rating. The controller continuously compares measured voltage and current with the predefined limits. When both parameters remain within the permissible range, the relay keeps the load connected. If any abnormal condition is detected, the relay disconnects the load and the corresponding fault is displayed on the LCD. The calculated rated current of the 60 W bulb at 230 V is approximately 0.261 A. The results demonstrate that the proposed system provides integrated, programmable, and low-cost protection against four electrical fault conditions and can serve as a foundation for future IoT-enabled monitoring and intelligent electrical protection systems.

Keywords— Arduino ATmega328P; AC Load Protection; Under/Over-Voltage Protection; Under/Over-Current Protection; Automatic Relay Control.

I. INTRODUCTION

Electrical power quality is an important factor in the safe and reliable operation of domestic appliances, laboratory equipment, and small electrical loads. Variations in supply voltage and abnormal current conditions can cause malfunction, overheating, reduced equipment life, or permanent damage. Therefore, continuous monitoring and automatic protection are important requirements in modern electrical systems. Conventional protective devices such as fuses and circuit breakers primarily provide protection against excessive current, but they may not provide continuous measurement, detailed fault identification, or user-friendly information regarding the electrical condition of a connected load.

Microcontroller-based protection systems provide an economical approach for integrating electrical measurement, decision-making, indication, and automatic switching. Arduino platforms are particularly suitable for prototype development because they can acquire sensor signals, execute programmable protection logic, control relay modules, and communicate measured information to display or monitoring systems. Tung and Khoa developed an Arduino Uno-based system for single-phase electrical monitoring and protection against over-voltage and under-voltage. Their system used the ZMPT101B voltage sensor and ACS712 current sensor, calculated RMS electrical quantities, and controlled the load according to predefined voltage limits [1].

Voltage abnormalities can occur in the form of under-voltage or over-voltage. Under-voltage may affect the normal operation of electrical equipment, whereas over-voltage can increase electrical stress and may damage sensitive components. The Arduino-based approach reported by Tung and Khoa demonstrated that measured RMS voltage could be compared with minimum and maximum limits to automatically control a connected load [1]. Such a measurement-and-trip architecture provides a useful foundation for developing compact protection systems.

Current monitoring is also essential because abnormal current can indicate overload, wiring problems, short-circuit conditions, or an unexpectedly low load condition. Syukriyadin, Sara, and Mashuri developed a digital standard-inverse overcurrent relay using an Arduino Uno and ACS712 current sensor. Their experimental results demonstrated that an Arduino-based relay could implement an inverse overcurrent characteristic and respond to different fault-current levels [2]. This demonstrates the capability of low-cost microcontrollers to perform current-based protection functions.

More recent work has investigated the integration of voltage and current protection in a single microcontroller system. Uddin, Rashid, and Salam developed a microcontroller-based over-voltage and over-current

protection system using a PIC18F2550, current transformers, potential transformers, relay switches, and a graphical monitoring interface. The controller compared measured voltage and current against predefined thresholds and activated the relay when abnormal conditions were detected [3]. These developments demonstrate the feasibility of combining multiple protection functions using programmable controllers.

Despite these developments, there remains scope for a simple and low-cost prototype integrating under-voltage, over-voltage, under-current, and over-current protection within a single Arduino-based architecture with local LCD indication. The proposed research addresses this requirement by using an Arduino ATmega328P/Arduino Uno, ZMPT101B voltage sensor, ACS712-type current sensor, 16×2 LCD, and relay module. A 60 W AC bulb is considered as the demonstration load. The selected normal voltage range is 210–240 V, while a prototype current range of 0.20–0.35 A is selected according to the load rating. The controller continuously evaluates both parameters and permits load operation only when all programmed conditions are satisfied. During any abnormal condition, the relay disconnects the load and the corresponding fault is displayed. Thus, the proposed system combines measurement, protection, indication, and automatic switching into a compact and programmable electrical protection platform.

II. PROBLEM IDENTIFICATION

- Voltage Fluctuations: AC loads may experience under-voltage or over-voltage conditions that can affect equipment performance, reliability, and operating life.
- Abnormal Current: Under-current may indicate load disconnection or abnormal operation, while over-current can result from excessive loading and may cause overheating or equipment damage.
- Limited Conventional Monitoring: Conventional protection devices may disconnect the supply during faults but generally provide limited real-time information about measured voltage, current, and fault type.
- Separate Protection Requirements: Voltage and current abnormalities are often addressed using separate protection arrangements, increasing system complexity and reducing centralized monitoring capability.
- Delayed Fault Identification: Without continuous measurement and clear indication, users may not immediately know whether an electrical problem is caused by low voltage, high voltage, low current, or high current.
- Need for Automatic Protection: A low-cost programmable system is required to continuously monitor electrical parameters, identify abnormal conditions, automatically disconnect the AC load, and display the corresponding fault condition.

A. Existing System

The existing electrical protection system mainly uses conventional devices such as fuses, MCBs, overload relays, and separate voltage protection circuits. These devices protect electrical loads primarily by disconnecting the supply when an abnormal electrical condition occurs. Voltage monitoring may be performed using dedicated voltage relays, while current protection is generally provided through fuses or circuit breakers. In many conventional arrangements, voltage and current parameters are not continuously displayed together. Fault identification and system monitoring therefore depend largely on individual protection devices and manual inspection.

B. Drawbacks

- Limited Monitoring: Conventional devices generally do not provide continuous display of voltage and current values.
- Separate Protection: Different protection devices may be required for voltage and current abnormalities.
- Limited Fault Identification: Users may not clearly identify whether the fault is under-voltage, over-voltage, under-current, or over-current.
- No Real-Time Display: Conventional systems generally lack an LCD-based parameter display.
- Manual Inspection: Fault conditions may require physical checking of individual devices.
- Limited Programmability: Fixed protection devices provide less flexibility for changing operating thresholds.

III. LITERATURE REVIEWS

A) Literature Survey:

1. Uddin, Rashid and Salam (2025), developed a microcontroller-based overvoltage and overcurrent protection system for improving electrical-system safety and reliability. The proposed system used a PIC18F2550 microcontroller, current transformers, potential transformers, relay switches, and a graphical monitoring interface. Voltage and current measurements were compared with predefined threshold values, and the relay disconnected the circuit when abnormal conditions were detected. Experimental testing demonstrated successful protection at 4.7 A against a 4.5 A current threshold and at 214 V against a 210 V voltage threshold. The study demonstrated effective automatic fault detection and rapid relay-based isolation.

2. Bharat Singh et al. (2024), presented an Overvoltage and Undervoltage Intelligent Protection System based on Arduino. The objective was to protect electrical and electronic equipment from harmful voltage fluctuations. The system incorporated an Arduino microcontroller, voltage regulator, bridge rectifier, step-down transformer, relay module, and LCD display. The controller continuously monitored the supply voltage and operated the relay when the voltage exceeded the defined safe range. The LCD provided information about the operating condition. The study showed that Arduino-based voltage monitoring can provide a relatively simple and economical method for automatic load protection against under-voltage and over-voltage conditions.

3. Md. Sajjad Hossain Chowdhury et al. (2025), developed an Arduino-based AC over- and under-voltage protection and monitoring system. The system employed an Arduino Nano, ZMPT101B AC voltage sensor, 5 V relay module, and 16×2 LCD display. The voltage sensor measured the AC mains voltage, while the Arduino compared the measured value with predetermined voltage limits. When an abnormal voltage condition occurred, the relay disconnected the load. LEDs and a buzzer were also incorporated to provide visual and audible indications. The experimental results demonstrated that the proposed system could accurately monitor AC voltage and activate protective action during

abnormal voltage conditions, providing a low-cost approach to appliance protection.

4. Doan Duc Tung and Ngo Minh Khoa (2021), proposed an Arduino-based system for monitoring and protecting against overvoltage and undervoltage in a single-phase power supply. The experimental setup used an Arduino Uno, ZMPT101B voltage sensor, ACS712 current sensor, and relay-based load switching. RMS voltage and current were calculated and monitored, while the measured voltage was compared with minimum and maximum allowable values. The relay automatically switched the load according to the protection limits. A computer-based graphical interface was also developed to display RMS voltage, RMS current, active power, and trip signals. The experimental results confirmed correct operation of the proposed protection and monitoring system.

5. Abir Muhtadi (2023), developed a GSM module–Arduino–relay-based smart and cost-effective protection system for overvoltage, undervoltage, and overcurrent faults. The study recognized that voltage and current can deviate significantly because of load changes, switching operations, and electrical faults. An Arduino Nano was interfaced with a GSM module and relay to create an interactive single-phase protection system. The system was experimentally tested under overvoltage, undervoltage, and overcurrent fault conditions. The results demonstrated successful fault detection and relay operation. The incorporation of GSM communication also provided an additional approach for user interaction and remote notification, making the system more advanced than conventional standalone protection arrangements.

6. P.O. Otasowie and A.I. Edeoghon (2025), designed and developed a microcontroller-based undervoltage and overvoltage protective electrical device. The system used an AT89C52 microcontroller to monitor the supply voltage and control a relay when predefined voltage limits were exceeded. The design included an input-voltage monitoring circuit, power supply, regulator, relay driver, and LCD unit. The developed system allowed the user to select predetermined voltage limits and automatically disconnected the electrical apparatus during abnormal voltage conditions. The researchers reported that the device performed satisfactorily, provided precise voltage regulation/protection, and could be used for protecting electrical and electronic appliances against undesirable voltage fluctuations and supply disturbances.

7. Michael Oluwatosin Omojoyegbe (2024), investigated the development of a low-cost microcontroller-based under- and over-voltage protection device. The system employed a PIC16F877 microcontroller, transistor circuitry, integrated circuits, relay control, and an LCD display. The controller compared the measured supply voltage against preset limits and activated the relay to disconnect the load when an abnormal voltage was detected. The developed device was designed to accommodate loads up to approximately 2 kVA, with an operating voltage range of 200–240 V. The study demonstrated that microcontroller-based protection can provide an economical solution for refrigerators, televisions, and other appliances exposed to undesirable voltage fluctuations and transient conditions.

8. Akinlolu Adediran Ponnle and Oluwatosin Omojoyegbe (2024), presented a low-cost microcontroller-based under- and over-voltage protection device for electrical loads. Their system used a PIC16F877 microcontroller to continuously compare supply voltage with preset lower and upper limits. A relay mechanism was employed to isolate the load when the voltage moved outside the acceptable range. The researchers emphasized that voltage irregularities are an important power-quality problem capable of damaging electrical equipment. Their design incorporated automatic cut-off and time-delay functions, providing additional protection against transients and abnormal supply restoration. The study demonstrated the usefulness of programmable microcontrollers for developing adjustable and relatively inexpensive voltage-protection systems.

9. Zhijun Gan, S. Elangovan and A.C. Liew (2020), developed microcontroller-based overcurrent and directional-overcurrent relays with ground-fault protection for three-phase subtransmission and distribution systems. Their design used an Intel 8096BH microprocessor to process current signals and estimate fundamental-frequency components using discrete Fourier transform techniques. The relay provided configurable operating characteristics, time-dial settings, plug settings, and instantaneous overcurrent operation. Although the work predates Arduino-based systems, it established an important foundation for digital and microprocessor-based protection. The study demonstrated that programmable controllers can provide flexible protection functions compared with conventional electromechanical relays and can support sophisticated fault-detection and decision-making algorithms.

10. S.Y. Sayais et al. (2024), presented an overvoltage and undervoltage load protection system using Arduino Uno. The study focused on protecting household electrical appliances from supply-voltage fluctuations. The Arduino continuously monitored voltage and controlled a relay to disconnect the load whenever the measured voltage exceeded the permissible operating range. An LCD was incorporated for real-time status indication, making the protection system easier to monitor. The work highlighted Arduino's usefulness for developing economical and programmable voltage-protection systems. The study is particularly relevant to the proposed project because it combines voltage sensing, Arduino processing, relay-based load isolation, and LCD monitoring in a compact protection arrangement.

B) Literature Summary

- Microcontroller Protection: Previous studies demonstrate that microcontrollers can effectively monitor electrical parameters and control protective relays for AC loads [1]–[3].
- Voltage Protection: Arduino-based systems using ZMPT101B sensors have been developed for detecting under-voltage and over-voltage conditions and automatically disconnecting loads [1].
- Current Protection: Arduino and ACS712-based systems have demonstrated overcurrent detection and digital relay protection for electrical circuits [2].
- Integrated Protection: Recent research has combined voltage and current sensing with microcontrollers, relay switching, and user interfaces [3].

- Overall Finding: The literature confirms that programmable controllers provide flexible, low-cost monitoring and automatic protection capabilities.

C) Research Gap

- Limited Four-Way Protection: Most reviewed systems concentrate primarily on voltage protection or overcurrent protection rather than simultaneously addressing all four conditions.
- Integrated Architecture: Limited work combines under-voltage, over-voltage, under-current, and over-current protection within one simple Arduino-based platform.
- Local Indication: Some systems provide protection without clearly displaying all measured electrical parameters and fault conditions to the user.
- Low-Cost Implementation: There is scope for a compact system using commonly available Arduino, voltage/current sensors, LCD, and relay components.
- Proposed Contribution: This research addresses the gap by integrating four protection functions, real-time LCD monitoring, programmable thresholds, and automatic relay-based load disconnection.

IV. RESEARCH METHODOLOGY

A) Proposed System

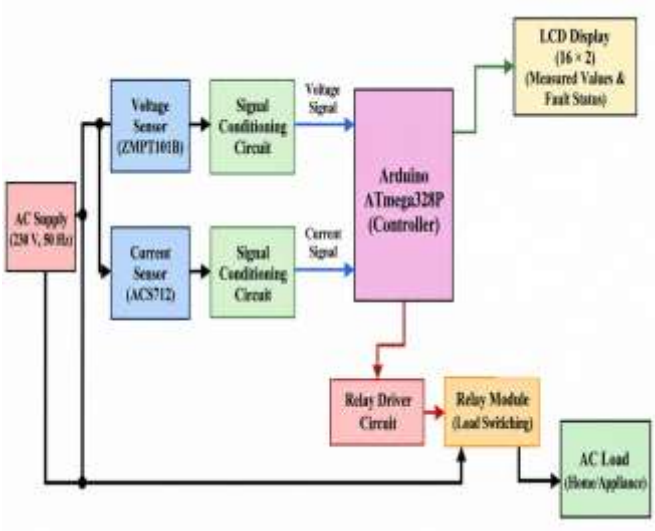


Figure 2. Block Diagram

- Power Supply: The AC mains supply provides electrical power to the protection circuit and connected AC load. An AC-to-DC power supply provides the required low-voltage supply to the Arduino and electronic components.
- Voltage Sensing: The voltage sensor continuously measures the AC supply voltage and provides a proportional signal to the Arduino ATmega328P for monitoring.
- Current Sensing: The current sensor measures the current flowing through the connected AC load and sends the corresponding signal to the Arduino controller.
- Signal Processing: The Arduino ATmega328P receives the voltage and current signals, processes them, and compares the measured values with predefined operating limits.
- Voltage Protection: The programmed voltage range is 210–240 V AC. If the voltage falls below 210 V, an undervoltage fault is detected. If it exceeds 240 V, an overvoltage fault is detected.
- Current Protection: The measured load current is compared with the selected lower and upper current limits. A value below the lower limit is identified as undercurrent, while a value above the upper limit is identified as overcurrent.
- Normal Operation: When both voltage and current are within their specified permissible ranges, the Arduino keeps the relay activated and the AC bulb remains ON.
- Fault Protection: If any one of the four abnormal conditions occurs, the Arduino immediately deactivates the relay, disconnecting the AC load to protect it.
- LCD Monitoring: The LCD continuously displays the measured voltage, current, normal operating condition, fault type, and load status.
- Continuous Monitoring: After activation, the system continuously repeats the sensing and decision-making process. The load can be restored only when the electrical parameters return to the permitted range and the protection logic allows reconnection.

B) Hardware Used

- Arduino Uno/ATmega328P: Acts as the main controller. It receives voltage and current sensor signals, processes the measured values, compares them with programmed limits, and controls the relay according to the detected condition.
- ZMPT101B Voltage Sensor: Measures the AC supply voltage and provides an isolated, scaled signal to the Arduino for monitoring under-voltage and over-voltage conditions.
- ACS712 Current Sensor: Measures the current flowing through the AC load and provides an electrical signal proportional to the load current for under-current and over-current detection.
- 16×2 LCD: Displays the measured voltage, current, load condition, and detected fault such as under-voltage, over-voltage, under-current, or over-current.
- 5 V Relay Module: Acts as the switching element between the controller and AC load. It disconnects the load whenever an abnormal electrical condition is detected.
- 60 W AC Bulb: Serves as the demonstration load for testing the protection system under different voltage and current conditions.
- AC-to-DC Power Supply and Voltage Regulator: Provide regulated low-voltage DC power for the Arduino, sensors, LCD, and relay circuitry.
- Buzzer, LEDs, Fuse/MCB and Enclosure: Provide additional fault indication and electrical safety for the prototype.

C) Software Used

- Arduino IDE: Used for writing, compiling, and uploading the Arduino control program.
- Arduino C/C++: Implements sensor reading, protection logic, threshold comparison, LCD control, and relay operation.
- Proteus: Used for circuit simulation and preliminary verification of controller and protection operation.
- Fritzing: Used to prepare the hardware connection and circuit wiring representation.
- Serial Monitor: Used for debugging and observing voltage, current, and relay-status values during testing.
- Microsoft Excel: Used to record experimental readings, organize test results, perform basic calculations, and prepare graphs for analysis.

V. CALCULATION

For the Arduino-Based Under-Voltage, Over-Voltage, Under-Current and Over-Current Protection System, the following calculations can be used for the prototype. The demonstration load is a 60 W, 230 V AC bulb, with a normal voltage range of 210–240 V.

1. Load Current Calculation
The rated current of the 60 W bulb is:

$$I = \frac{P}{V}$$

Where:
P=60 W
V=230 V

$$I - \frac{60}{230}$$

Therefore, the expected current of the 60 W bulb at 230 V is approximately:

$$I \approx 0.26\ A$$

2. Load Resistance Calculation
The resistance of the bulb at its rated operating point is approximately:

$$R = \frac{V^2}{P}$$

$$R = \frac{230^2}{60}$$

$$R = \frac{52900}{60}$$

$$R - 881.67\,\Omega$$

Thus, the approximate operating resistance of the 60 W bulb is:

$$\boxed{R \approx 882\,\Omega}$$

3. Current at Minimum and Maximum Normal Voltage
For a resistive load:

$$I = \frac{V}{R}$$

At 210 V:

$$I_{210} = \frac{210}{881.67}$$

$$\boxed{I_{210} \approx 0.238\ A}$$

At 240 V:

$$I_{240} = \frac{240}{881.67}$$

$$\boxed{I_{240} \approx 0.272\ A}$$

Therefore, approximately:

Supply Voltage	Expected Current
210 V	0.238 A
220 V	0.249 A
230 V	0.261 A
240 V	0.272 A

These values can be used as reference values during testing.

4. Under-Voltage and Over-Voltage Limits
The selected normal operating range is:

$$210V \leq V \leq 240V$$

Therefore:
Under-voltage condition:

$$V < 210V$$

Normal condition:

$$210V \leq V \leq 240V$$

Over-voltage condition:

$$V > 240V$$

For example, if the sensor measures:

$$V = 195V$$

then:
195<210
Therefore:

$$\boxed{\text{UNDER-VOLTAGE} \rightarrow \text{RELAY OFF}}$$

Similarly, for:

$$V = 255V$$

$$255 > 240$$

Therefore:

$$\boxed{\text{OVER-VOLTAGE} \rightarrow \text{RELAY OFF}}$$

5. Proposed Current Protection Limits
Because the load is only 60 W, a practical prototype current range can be selected as approximately:

$$0.20A \leq I \leq 0.35A$$

Hence:
Under-current:
I<0.20A
Normal current:

$$0.20A \leq I \leq 0.35A$$

Over-current:
I>0.35A
For example, at:
I=0.08A
the system identifies:
0.08<0.20
UNDER-CURRENT → RELAY OFF
At:

$$I = 0.45A$$

$$0.45 > 0.35$$

$$\boxed{\text{OVER-CURRENT} \rightarrow \text{RELAY OFF}}$$

These are prototype thresholds and should be calibrated according to the actual bulb and sensor.

6. Electrical Power Calculation
At normal operating conditions:

$$P = VI$$

$$P = 230 \times 0.261$$

$$\boxed{P \approx 60\,W}$$

Thus, the calculated electrical input power is approximately equal to the rated bulb power.

7. Arduino ADC Calculation
The Arduino Uno/ATmega328P has a 10-bit ADC.
Therefore, the ADC has:

$$2^{10} = 1024$$

levels, from 0 to 1023.

For a 5 V reference:

$$\text{ADC Resolution} = \frac{5}{1023}$$

$$\boxed{\text{ADC Resolution} \approx 4.89\,mV}$$

The sensor output is therefore converted into a digital value between 0 and 1023.
The approximate input voltage corresponding to an ADC value is:

$$V_{ADC} = \frac{ADC \times 5}{1023}$$

For example, if:
ADC=512
then:

$$V_{ADC} = \frac{512 \times 5}{1023}$$

$$\boxed{V_{ADC} \approx 2.50V}$$

The actual AC voltage is obtained using the sensor calibration factor.

8. Voltage Sensor Calculation
The ZMPT101B provides an isolated, scaled representation of the AC input voltage.
The software can use a calibration relationship:

$$V_{AC} = K_v \times V_{sensor}$$

where (Kv) is the experimentally determined voltage calibration factor.
For example, if calibration gives:
Kv=100
and the measured sensor-equivalent value is:

$$V_{sensor} = 2.30V$$

then:

$$V_{AC} = 100 \times 2.30$$

$$\boxed{V_{AC} = 230V}$$

In the actual prototype, (Kv) should be obtained by comparing the sensor reading with a calibrated multimeter.

9. Current Sensor Calculation
For an ACS712-type current sensor, the current can generally be calculated from the sensor output using:

$$I = \frac{V_{OUT} - V_{OFFSET}}{S}$$

where:

- V_{OUT} = sensor output voltage
- V_{OFFSET} = zero-current output voltage
- S = sensor sensitivity in V/A.

For example, assuming a 5 V-powered sensor with approximately 2.5 V zero-current offset and a 185 mV/A sensitivity:

$$V_{OFFSET} = 2.5V$$

$$S = 0.185V/A$$

If:

$$V_{OUT} = 2.548V$$

then:

$$I = \frac{2.548 - 2.5}{0.185}$$

$$\boxed{I \approx 0.259A}$$

This is close to the calculated bulb current of 0.261 A.

10. Relay Load Calculation
The bulb current at rated voltage is:

$$I_{load} = 0.261A$$

Therefore, a properly rated AC relay with a contact rating significantly greater than 0.261 A can safely switch the prototype load.
For example, a relay rated at:

$$10A,\ 250V\,AC$$

has a nominal contact-current rating much greater than the 0.261 A demonstration load.
The relay should nevertheless be selected according to the applicable electrical safety requirements and actual load type.

11. Input Power Supply Calculation
The Arduino and sensors require low-voltage DC power.
Assuming the electronics consume approximately:

$$I_{DC} = 0.15A$$

at:

$$V_{DC} = 5V$$

then:

$$P_{DC} = VI$$

$$P_{DC} = 5 \times 0.15$$

$$\boxed{P_{DC} = 0.75W}$$

Considering conversion losses, a 5 V supply rated around 0.5–1 A or higher provides sufficient capacity for the controller, LCD, sensors, relay module, LEDs and buzzer, subject to the actual module consumption.

12. Overall Protection Decision
The Arduino can implement the following logic:

$$(210 \le V \le 240)\quad AND\quad (0.20 \le I \le 0.35)$$

If both conditions are satisfied:

$$\boxed{\text{RELAY ON} \rightarrow \text{BULB ON}}$$

If any condition is violated:

$$\boxed{\text{RELAY OFF} \rightarrow \text{BULB OFF}}$$

Voltage	Current	Condition	Relay
230 V	0.26 A	Normal	ON
205 V	0.26 A	Under-voltage	OFF
250 V	0.26 A	Over-voltage	OFF
230 V	0.10 A	Under-current	OFF
230 V	0.45 A	Over-current	OFF
220 V	0.25 A	Normal	ON

Final Design Values

Parameter	Calculated/Selected Value
Bulb rating	60 W
Nominal voltage	230 V AC
Nominal current	0.261 A
Approx. bulb resistance	881.67 Ω
Normal voltage range	210–240 V
Proposed under-current limit	0.20 A
Proposed over-current limit	0.35 A
Arduino ADC	10-bit
ADC resolution at 5 V	4.89 mV/count
Controller supply	5 V DC
Demonstration load	60 W AC bulb
Protection action	Relay OFF during fault

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VI. ADVANTAGES AND APPLICATIONS

A) Advantages

- Four-Way Protection: The system simultaneously detects under-voltage, over-voltage, under-current, and over-current conditions, providing comprehensive protection for connected AC loads.
- Automatic Disconnection: The relay automatically disconnects the load whenever any electrical parameter exceeds the programmed safe operating range, reducing the risk of equipment damage.
- Real-Time Monitoring: Voltage, current, and operating status are continuously measured and displayed on the 16×2 LCD for easy observation.
- Programmable Operation: Protection limits can be modified through Arduino programming according to the requirements of different electrical loads.
- Low-Cost Design: The system uses commonly available Arduino, sensors, LCD, and relay components, making it economical for prototype and educational applications.
- Fault Identification: The controller can identify the specific abnormal condition and display the corresponding fault message, making troubleshooting easier.

B) Applications

- Domestic Appliances: The system can protect household electrical appliances from abnormal voltage and current conditions by continuously monitoring supply parameters and automatically disconnecting the appliance during unsafe operation.
- Laboratory Equipment: It can be used in electrical and electronics laboratories to protect experimental equipment from supply fluctuations and abnormal current conditions during practical testing.
- Small Industrial Loads: The proposed system can be adapted for small industrial machines, control panels, and electrical loads requiring programmable voltage and current protection.
- Educational Projects: It is suitable for engineering laboratories and academic projects for demonstrating voltage sensing, current measurement, Arduino programming, relay control, and automatic electrical protection.
- Workshop Equipment: Small electrical tools and workshop equipment can be monitored and protected against abnormal electrical operating conditions.
- IoT Protection Systems: The architecture can be extended with Wi-Fi, cloud connectivity, data logging, and mobile notifications for developing advanced smart electrical protection systems.

VII. CONCLUSION

The developed Arduino-Based Under-Voltage, Over-Voltage, Under-Current and Over-Current Protection System for AC Loads provides an effective and economical approach for monitoring and protecting electrical loads. The system integrates an Arduino ATmega328P/Arduino Uno, ZMPT101B voltage sensor, ACS712-type current sensor, 16×2 LCD, and relay module to continuously monitor voltage and current conditions. For the 60 W demonstration bulb, the calculated current at 230 V is approximately 0.261 A. The selected voltage range of 210–240 V and prototype current range of 0.20–0.35 A allow the controller to distinguish normal and abnormal operating conditions. During normal operation, the relay keeps the load connected, whereas under-voltage, over-voltage, under-current, or over-current conditions cause automatic relay disconnection. The LCD provides real-time electrical measurements and fault information, improving system monitoring and user awareness. The results demonstrate that a single programmable microcontroller can integrate sensing, decision-making, indication, and automatic switching in a compact protection system. The proposed prototype is therefore suitable for educational, laboratory, domestic, and small-load applications and provides a foundation for developing more advanced intelligent electrical protection systems.

VIII. FUTURE SCOPE

- IoT Integration: Add Wi-Fi/cloud connectivity for remote monitoring, data logging, fault notifications, and smartphone-based control.
- Advanced Protection: Develop automatic recovery, adjustable thresholds, industrial-grade sensors, contactors, and higher-capacity protection for practical electrical systems.

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