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Design and Implementation of an Arduino Based Undervoltage Relay

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ABSTRACT: All human activity is highly dependent on the stable availability of electrical energy. Electrical distribution disruptions, such as over/under voltage spikes or drops, can disrupt daily activities. To anticipate this, an Arduino-based over/under voltage control system was designed that utilizes the PZEM-004T sensor to monitor AC voltage in real-time from a power source or variable transformer. The system uses an on-off control method on the relay with three operating conditions: under voltage (voltage <142.5V), normal voltage (142.5V–157.5V), and overvoltage (voltage >157.5V). SMPS (Switched-Mode Power Supply) is integrated as a stable power supply for Arduino Uno microcontrollers and other electronic components, ensuring that system performance remains optimal despite input voltage fluctuations. The sensor reading results and voltage condition status can be displayed locally via a simple interface such as an LCD or LED indicator, without relying on internet communication. By combining the reliability of Arduino Uno and SMPS efficiency, the system is able to protect electrical devices from damage due to voltage instability while ensuring energy-efficient operation.

KEYWORDS: Arduino Uno, Over/Under Voltage Relay, Microcontroller, PZEM-004T sensor.

INTRODUCTION

The quality of the electricity supply is a fundamental aspect of the electric power distribution system, especially to ensure the operational reliability of electronic devices and infrastructure. However, voltage fluctuations such as over voltage or undervoltage often occur suddenly in low-voltage distribution networks (220V AC). In the Standard of Electrical Installation General Requirements (PUIL) the standard is Undervoltage which is -10% and Overvoltage is +5% (General Requirements for Electrical Installation, 2000). To overcome Over Voltage and Under Voltage disturbances, a Voltage Stabilizer Prototype tool was made to overcome Over/Under Voltage disturbances based on Arduino UNO. This disorder not only interfering with the performance of electrical equipment but also potentially damaging the system permanently if it exceeds the limit nominal voltage tolerance. Even though Recloser (automatic breaker) has been used as a standard protection on distribution poles, the system is not yet able to provide specific responses based on real-time data, so monitoring is still centralized at the control substation and response is often delayed.

Based on these challenges, this study designed a systems Over/Under Voltage Time Lag Relay 1 Phase based on Arduino Uno, which integrates the PZEM-004T sensor for precise voltage and current measurement. The system is designed to detect voltage faults in real-time, with the relay as a power shut-off actuator activated after a period of time lag (0.5 – 5 seconds) to avoid incorrect responses due to momentary fluctuations. SMPS (Switched-Mode Power Supply) is used to stabilize the power supply to the microcontroller and sensor, while LCD and Keypad Provides a local interface to display voltage, current data, as well as set protection limit parameters. The LED indicator provides a visualization of the network status through different colors (green: normal, yellow: Under Voltagered: About voltage), allows for quick diagnosis without dependence on a central system This combination of components results in a self-protection system that not only improves response to voltage faults but also provides monitoring Real-time through an interactive interface. By utilizing an Arduino Uno microcontroller and a PZEM-004T sensor, the system is able to accurately identify interference and secure the network before damage occurs. The test results using VARIAC and the PLN home source show the ability of the tool to detect voltage fluctuations and cut off power automatically according to the set parameters. Presence of features Time lag on the relay also ensures the stability of operation by preventing false interference (False Trip), so that this system becomes an effective solution to improve the reliability of low-voltage distribution networks [1].

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MATERIALS AND METHODS

A. Basic Theory

The basic theory in this study includes the concept About voltage and Under Voltage, Working Principle Relay protection, as well as the use of Arduino in voltage protection systems. **voltage** is a condition in which the electrical voltage exceeds a predetermined safe limit. The main causes of over voltage include voltage spikes due to lightning, transient switching, and insulation failure. Impact of About voltage can cause damage to electronic equipment, insulation degradation, as well as increased risk of fire. According to research by **Baneriya et al. (2020)**, About voltage may cause overheating of electronic devices and increase the risk of system failure [2].

Under Voltage occurs when the electrical voltage drops below the limit required for the normal operation of the device. Main causes Under Voltage including overload, disruption to the electricity distribution system, and load imbalance. Under voltage may cause a decrease in the efficiency of the electric motor, Overheating, and the failure of the operation of electronic devices. Widarsono et al. (2022) shows that an Arduino-based voltage protection system can detect and address under voltage disturbances with high accuracy [3]. According to research by Karaarslan (2020), Relay Voltage protection may undergo changes in operating characteristics if the received voltage has significant harmonic components. This study shows that relays can work slower or faster than expected under stress conditions Non-sinusoidal [4].

a. Voltage Protection Relay

Relay Voltage protection serves to detect and respond to abnormal voltage changes. Relay It works on the principle of voltage monitoring and disconnects the flow of electricity if the voltage is outside the safe limit. There are several types of voltage protection relays, including Relay microcontroller-based such as Arduino, which offers high flexibility and accuracy in data processing. According to research by Widarsono et al. (2022), the Visual Basic and Arduino Mega2560-based protection system has a tolerance of ±10% and -5% of set point voltages, allowing for easier monitoring and analysis of faults [2].

b. Arduino in Voltage Protection System

Arduino is Microcontroller which is widely used in voltage protection systems due to its ability in real-time data processing and flexibility in programming. Using a voltage sensor, the Arduino can read the voltage value, compare it to the predetermined limit, and activate the relay in the event of a voltage failure. According to research by Baneriya et al. (2020), Arduino-based protection systems can improve reliability in detecting voltage faults and provide better protection for electrical equipment [2].

c. Results of Previous Research

Several previous studies have discussed Arduino-based voltage protection systems and voltage protection relays. Research by Baneriya et al. (2020) developed a voltage protection system using a voltage comparator. The results show that this system is effective in protecting electrical equipment from voltage fluctuations by using Relay operated by microcontroller. The system is designed to provide protection against voltage surges that can damage electronic devices[2]. Meanwhile, Widarsono et al. (2022) designed a voltage protection system based on Visual Basic and Arduino Mega2560. The system has a tolerance of ±10% and -5% of the set point voltage, allowing for easier monitoring and analysis of faults. This study shows that the use of Visual Basic interface can improve the ease of monitoring and analysis of voltage faults. With this system, users can more easily identify and resolve voltage faults before they cause damage to the device [3].

Research by Karaarslan (2020) examines the performance of Relay over/under voltage under non-sinusoidal stress conditions. The results of the study show that the harmonics of the voltage can affect the speed of operation Relay So it is necessary to make more precise arrangements in the voltage protection system. This study highlights the importance of considering harmonic effects in the design of voltage protection systems to ensure the reliability of relays under various conditions Operational. In addition, research by Nugraha, Bagus Arya (2021) designed a protection system Undervoltage and Overvoltage Based microcontroller. This study shows that the use of Arduino Uno as a controller Relay Automation can improve the reliability of the protection system, especially in household and industrial applications. With this system, electronic devices can be protected from voltage disturbances that can cause damage or degradation efficiency [4].

d. Research Framework

This research framework focuses on the relationship between the variables studied, namely:

- Independent variables: Input voltage (over voltage and under voltage).
- Dependent variable: Relay disconnection delay time .

- Control variables : Arduino microcontroller , voltage sensor, and relay.

The relationship between these variables can be illustrated in the following diagram:

- The input voltage is detected by the voltage sensor.
- Voltage data is processed by Arduino to determine if the voltage is outside the safe limit.
- In the event of a voltage breakdown, the relay will be activated with a certain delay time according to the predetermined parameters.

Research by Mahdianto et al. (2019) developed an over/under voltage relay control system based on STM32F103C8T6 microcontroller. The system uses ZMPT101B sensors to read AC voltage and control the relay based on the on/off method. The results of the study show that this system is able to detect abnormal voltage and transmit data to the database via ESP-01 for remote monitoring [5]. In addition, research by Siringoringo et al. (2019) designed a microcontroller-based voltage protection system at 1 phase voltage 220V. This study shows that the use of relays as actuators can increase the reliability of the protection system against voltage disturbances [1]. Research by Widarsono et al. (2020) developed a voltage protection system based on Visual Basic and Arduino Mega2560. The system has a tolerance of ±10% and -5% of the set point voltage, allowing for easier monitoring and analysis of faults [3].

B. Research Methodology

a. Time and location

The time used for this research is 5 months, which was carried out from February 2025 to May 2025 which was carried out at the protection system laboratory and the Electrical Engineering Microprocessor Laboratory of the Samarinda State Polytechnic.

b. Data Types and Resources

This research is divided into three stages, namely planning, work, and testing. The data sources used during planning and work are obtained from scientific journals, books, Arduino's official website, related research reports, and also datasheets from the equipment used and also using software such as Exercise and Circuit Designer to simulate the tool to be worked on. At the time of testing, the data was taken directly from the results of the overcurrent relay test at the Samarinda State Polytechnic laboratory.

c. Research Approach

This study uses an experimental method with a quantitative approach to test a voltage protection system based on Relay and Microcontroller Arduino. This method aims to measure and analyze the characteristics of the disconnection delay time Relay in condition About voltage and under voltage. According to research by Mahdianto et al. (2019), the experimental method was used to test a microcontroller-based voltage protection system STM32F103C8T6 with a ZMPT101B sensor. The results showed that this system was able to detect abnormal voltages and transmit data to the database via ESP-01 for remote monitoring [5].

d. System Design

The design of this voltage protection system consists of two main parts, namely hardware design and software design.

e. Hardware Design

The main components used in this study include:

- The Arduino Uno microcontroller as the main controller of the system.
- SMPS 12V is used to convert AC mains voltage (from PLN) to 12volt DC voltage with high efficiency
- PZEM 004-T voltage sensor to read AC voltage values.
- Module relay to disconnect the power flow in the event of a voltage breakdown.
- 20x4 LCD: Displays information in text form of up to 20 characters per line and 4 lines. It is commonly used to display sensor data, system status, or messages from microcontrollers.
- 4x4 Keypad: As an input tool for entering data or commands into a microcontroller. Consists of 16 buttons (4 rows x 4 columns), often used for navigation menus, system settings, or number input.

Indicator LED: Provides a visual signal (on/off) to indicate the status of the system, such as normal condition, error, on/off, or voltage status (over/under voltage).

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f. System Design

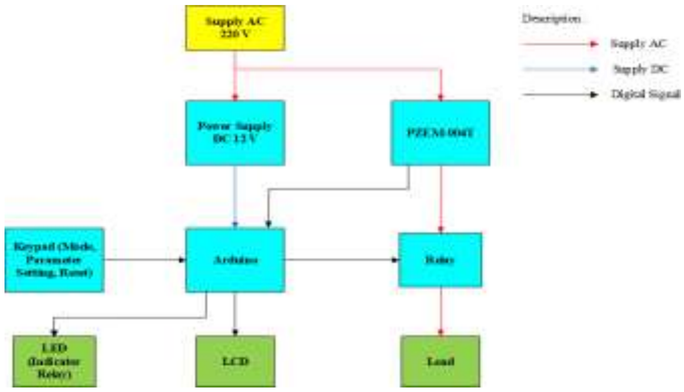

Fig. 1. Functional block diagram of the electric power use protection and monitoring system

Figure 1. There are 8 main parts of the diagram system, namely Arduino uno microcontroller, PZEM-004T VOLTAGE SENSOR, SMPS, LED, Keypad, LCD, and relay module. Each part has a different function. As for the explanation

- AC Supply 220V
  It is an alternating current (AC) power source with a voltage of 220V which is the main input of the system. This component is connected to the 12V DC Power Supply for power conversion and to the PZEM 004T as the measurement object.
- Power Supply DC 12V
  It is in charge of converting AC voltage of 220V to DC 12V to deliver power to electronic components such as Arduino, sensors, and interfaces.
- Arduino One
  These microcontrollers act as data processing centers. The Arduino receives input from the PZEM 004T and Keypad, then controls the Relay and LCD based on pre-programmed logic.
- LCD
  Displays real-time information such as voltage, current, system status (normal/over/under voltage), and set parameters. Arduino Uno was used as the main controller in this study. As a microcontroller-based platform with a RISC (Reduce Instruction Set Computer) architecture, Arduino Uno is designed to execute instructions efficiently.
- PZEM 004T
  This sensor replaces the functions of ACS712 (current sensor) and ZMPT101B (voltage sensor) in the system. The PZEM 004T measures voltage, current, and power in an integrated manner, and then transmits the data to the Arduino via serial communication (Modbus).
- Keypad (Mode, Parameter Setting, Reset)
  It serves as an input interface for setting system parameters (over/under voltage limit, delay time) and resetting configurations.
- Relay
  Automatic switch that disconnects/connects power to Load based on Arduino instructions after a time lag to prevent false trips.
- LED (Indicator Relay)
  Provides a visual indication of the status of the system:
  Green: Normal voltage (142.5–157.5V).
  Yellow/Red: Voltage outside safe limits.

Through a large number of registers. This architecture enables fast data processing and real-time response, making it ideal for voltage protection system applications that require high precision and reliability.

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g. Diagram Wiring

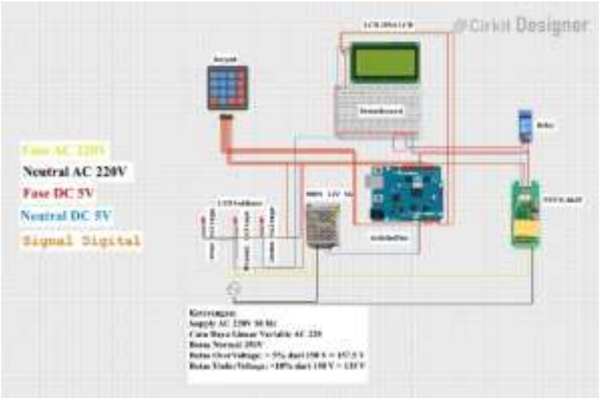

Figure 2. There are 8 main parts of the diagram system

There are 8 main parts of the diagram system, namely Arduino uno microcontroller, PZEM-004T VOLTAGE SENSOR, SMPS, LED, Keypad, LCD, and relay module. Each part has a different function. The explanation:

- The 220V AC source goes into the system and is converted to DC for power of the electronic components.
- The sensor (PZEM 004T) measures voltage/current and sends data to the Arduino.
- Arduino processes the data, comparing it to safe limits (Over: >157.5V, Under: <142.5V), and Added time lag to avoid false trips.
- If the voltage is outside limit, Arduino activates the Relay to disconnect power to Load.
- LCD displays status, while Keypad allows setting parameters. The system monitors voltage, automatically disconnects power in case of danger, and displays information via LCD.

h. Flowchart Hardware Design

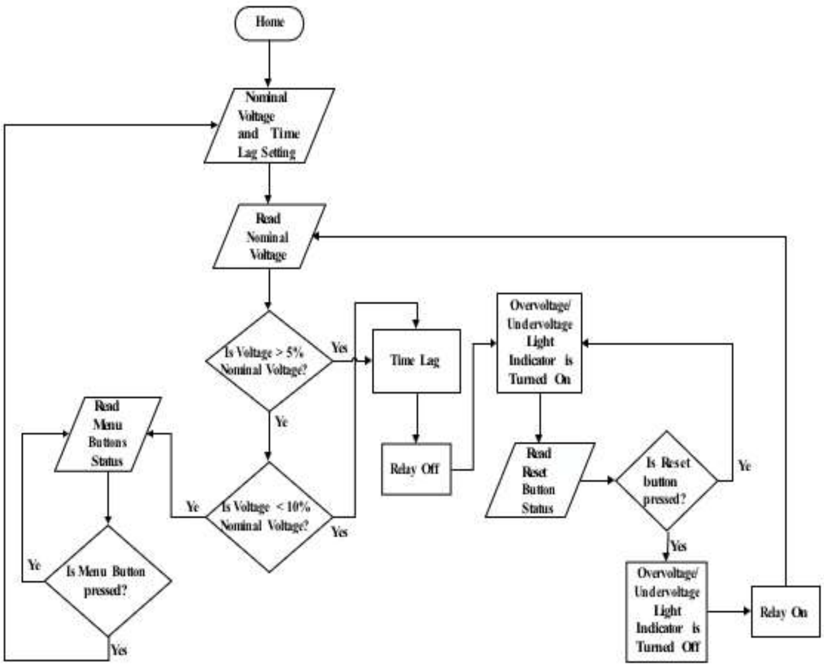

Figure 3. Flow Chart Design Over and Undervoltage Type Time Lag Relay

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Implementation

- Figure 3. Shows the flowchart of the tool's work system processes. The 5V DC adapter provides power to all circuits, especially the Arduino Uno. SMPS 12V phase and its neutral are connected to the Arduino Uno Vin and GND to supply 5V DC, which is also distributed to other components as needed
- The Arduino Uno acts as the control unit in this system receiving input from a voltage sensor (PZEM-004T), processing it and controlling the relay module and LED. It uses analog and digital pins to interact with various components.
- The PZEM-004T sensor is an electronic module specially designed to measure electrical parameters in alternating current (AC) systems, including voltage, current, active power, and electrical energy. This module uses a UART (Universal Asynchronous) serial communication interface
- Receiver/Transmitter) to digitally transmit the measurement data to a microcontroller, such as an Arduino Uno. In the process of integration, the VCC and GND pins on the PZEM-004T module are connected to the 5V and GND pins on the Arduino for the provision of power supply.
- Meanwhile, the TX (transmit) and RX (receive) pins on the module are cross-connected to the Arduino's RX and TX pins (TX module to RX Arduino, and RX module to TX Arduino), to ensure two-way communication can run smoothly Compared to ZMPT101B sensors that only provide analog signal output for voltage measurement, PZEM-004T offers advantages in terms of accuracy, completeness of data, as well as the ease of information acquisition through digital communication. Therefore, this sensor is more suitable for use in microcontroller-based voltage monitoring and protection systems that require real-time and comprehensive electrical data.
- The relay module is used to control the connection to the load. The relay acts as an arduino controlled switch based on the voltage level, the relay's signal input is connected to pin 7 of the arduino digital output. The power and ground pins of the relay are connected to the 5v and GND Arduino.
- The 20 X 4 LCD screen displays real time-time readings and status messages such as ("Over voltage, Normal Voltage, Under Voltage, Time Lag and reset"). VCC and GND LCD pins are connected to Arduino 5V and GND.SDA and SCL LCD pins are connected to Arduino Pins 8 and 9. Three LEDs provide a visual indication of the status of the system.
- The 4x4 keypad has 8 pins connected to the Arduino digital pin. 4 row pins and 4 column pins, 4 row pins are connected to the arduino digital pins and 4 column pins are connected to analog pins. The keypad here functions to reset and set the over/under and time lag delay on the system.

i. Working Process of Arduino Based Voltage Protection

The voltage protection system designed in this study works automatically in monitoring and responding to electrical voltage conditions. The working mechanism of the system is described into five main stages, namely: voltage monitoring, voltage comparison to threshold, relay control, visual indication through LEDs, and system setup via keypad.

j. Voltgae Monitoring

The initial process of the system begins with the measurement of electrical parameters by the PZEM-004T sensor. This sensor is specifically designed to perform electrical data acquisition on alternating current (AC) systems, including voltage, current, active power, and electrical energy. The PZEM-004T sensor uses the UART (Universal Asynchronous Receiver/Transmitter) serial communication protocol that allows digital transmission of data to an Arduino Uno microcontroller. In the process of integration, the VCC and GND pins of the sensor are connected to the Arduino's 5V and GND pins for power supply needs, while the TX and RX pins are cross-connected to the Arduino's RX and TX to ensure communication runs bidirectionally. Compared to analog sensors such as ZMPT101B, PZEM-004T provides more accurate and comprehensive data, and facilitates the signal processing process due to minimal noise (noise).

k. Voltage Comparison

The voltage data received from the sensor will be processed by Arduino Uno to be compared to the predetermined threshold value in the system. The threshold value consists of an undervoltage of 200V and an overvoltage of 240V. The Arduino performs a continuous reading, then evaluates whether the current voltage value is within the safe range or not. This process becomes the basis for the next decision-making, whether the system needs to disconnect power or maintain a power connection to the load.

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l. Relay Control

If the detected voltage value is outside the safe range, then the Arduino will activate the relay module to cut off the flow of electricity to the load. The relay module acts as an electronic switch controlled by the Arduino via digital pins, specifically the D7 pin. Under normal conditions (stable voltage), the relay remains closed and the load obtains a normal power supply. However, when an overvoltage or undervoltage occurs, the relay will open, severing the connection between the power source and the load, to prevent damage to the connected equipment.

RESULTS

A. PZEM-004T Voltage Calibration

Table 1. Sensor Calibration PZEM-004T

No.	Reference Voltage (V)	PZEM Voltage (V)	Correction Coefficient (K) = V_ref / V_PZEM
1	80	78.2	1.023
2	90	87.3	1.031
3	100	97.5	1.026
4	110	107.1	1.027
5	120	116.9	1.026
6	130	126.7	1.026
7	140	136.5	1.026
8	150	146.4	1.025
9	160	156.3	1.024
10	170	166.2	1.023
11	180	176.1	1.022
12	190	186.0	1.022
13	200	195.8	1.021
14	210	205.7	1.021
15	220	215.5	1.021
16	230	225.4	1.020

The PZEM-004T voltage sensor test was carried out by comparing the AC voltage read by the sensor through a microcontroller with the AC voltage read by a digital multimeter. The results of the measurements and readings of the respective voltage sensors can be seen in Table 2. Based on Table 2.2, the average reading error of the PZEM-004T sensor voltage is 3.47V or 2.18%.

- VKcalibration formula voltage calibration=VPZEM × K
  With:
  Calibration = Corrected voltage
  VPZEM = Voltage read PZEM-004T sensor
  K = Correction Ratio (average of the table)
- K mean = 1.024
  Programming Code:

```
float voltage = pzem.voltage() * 1.024;
```

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This test aims to calibrate the PZEM-004T sensor, which is a power/energy metering module. This calibration is intended to determine the level of accuracy of the sensor voltage measurement by comparing it to the reference voltage value that is considered accurate. The test is carried out using a direct comparison method:

- Setting up a regulable voltage source (variable)
- Set the voltage at a specific value (80V to 230V) as a reference value
- Measuring the same voltage value using the PZEM-004T sensor
- Record both measurement values (reference voltage and PZEM voltage)
- Calculates the correction coefficient for each voltage value

B. PZEM-004T Calibration Analysis Results

Based on the data obtained, it can be seen that the PZEM-004T sensor consistently shows lower readings compared to the reference voltage values across the entire measurement range. At a reference voltage of 80V, the PZEM-004T sensor reads 78.2V with a correction coefficient of 1.023. While at the highest value of 230V, the sensor reads 25.4V with a correction coefficient of 1.020. This consistent reading pattern suggests that the sensor is systematically underreporting about 2-3% of the actual value. Interestingly, there is a trend pattern in the correction coefficient that tends to decrease along with the increase in voltage values, starting from 1.031 at 90V until it drops to 1.020 at 230V. This indicates that the degree of sensor deviation is slightly reduced at higher voltage ranges. The value of the correction coefficient obtained from this test ranges from 1.020 to 1.031, with an average value of about 1.024. The relatively consistent stability of the correction coefficient values indicates that the PZEM-004T sensor has fairly linear and reliable measurement characteristics throughout its operating range. This consistency allows for the application of relatively simple correction factors to improve measurement accuracy. For practical implementation, corrections can be made with two approaches: using an average correction coefficient of 1.024 for all measurement ranges, or using a specific correction coefficient according to the measured voltage range for more precise results.

C. Conclusion

This PZEM-004T sensor calibration test successfully characterized the measurement behavior of the sensor and resulted in a correction coefficient that can be used to improve the accuracy of the reading. Although the sensor shows systematic irregularities with underreporting of about 2-3%, these irregularities are consistent and predictable so they are easy to correct. With the application of appropriate correction factors, the PZEM-004T sensor can provide more accurate and reliable voltage measurements for a wide range of power and electrical energy monitoring applications.

D. Condition of Testing

Voltage condition testing is carried out by utilizing a variable transformer to adjust the input voltage as needed. Voltage is classified into three categories, namely under voltage, normal voltage, and over voltage. As seen in Table 3, the test using a variable transformer covers a voltage range of 80V to 220V. The test results show the compatibility between the implementation and the program that has been designed.

E. Tool Testing

Before testing the Arduino-based one-phase overvoltage and undervoltage time lag relay design tools, several stages of preparation were carried out to ensure that the entire system functions properly and safely. The stages of preparation are as follows:

- Circuit and Component Connection Checks are carried out on all electronic connections and circuits, including the connection between the Arduino Uno, PZEM-004T sensor, relay module, 4x4 keypad, and 20x4 LCD. This check aims to ensure that there are no loose cables, short circuits, or pin installation errors.
- Power Supply CheckingThe SMPS 12V power supply is checked first to ensure that the output voltage is appropriate and stable. This voltage is used to power Arduino modules and other components that require external supply.
- Verification of the Arduino Program (sketch) used to detect over- and undervoltage, read inputs from the keypad, and control the relay and display the information on the LCD is checked and tested using serial monitors. Adjustment of voltage limit parameters and delay time is carried out as required.
- Setting Initial Parameters Through the 4x4 keypad, the initial setting of the over voltage and under voltage threshold values is carried out, as well as the time lag before the on/off relay. The value of the parameter is displayed on the LCD.

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- System Safety Checks To prevent the risk of short circuits and component damage, cable insulation checks are carried out, and ensure that no circuit parts are exposed or in direct contact with conductive metals.

After several stages of preparation are carried out to ensure that the entire system functions properly and safely. Next, we'll start testing Arduino-based single-phase overvoltage and undervoltage time lag relays. The preparations made for the testing of the tool are as follows: This program is an Arduino-based voltage protection system that is in charge of monitoring electrical voltage using the PZEM004Tv30 sensor. This sensor is connected to the Arduino via SoftwareSerial communication on the Rx (10) and Tx (11) pins, which are used to read the voltage value from the power source. The read voltage data will be displayed on the 20x4 I2C LCD, which is connected via SDA and SCL pins (A4 and A5 on Arduino Uno) using the I2C communication protocol.

The user interface is created using a 4x4 keypad, which is connected to pins 2 through 9. This keypad allows users to select menus and set parameters such as undervoltage, overvoltage, and time lag. These parameters are used in the monitoring process to determine whether the voltage is still in a safe condition or needs to be disconnected. When the system is under normal conditions, the voltage is between the predetermined lower and upper limits. In this condition, pin 12 Arduino will be set HIGH to activate the relay, which serves to deliver electrical current to the load. In addition, the normal indicator LED, which is connected to pin A1, will illuminate to indicate the system is in a safe state. Conversely, if the voltage drops below the lower limit, then pin A0 will be set HIGH, turning on the undervoltage LED. When the voltage exceeds the upper limit, then pin A2 will illuminate, turning on the overvoltage LED.

The program also regulates time lag logic, where when an abnormal voltage occurs, the system does not immediately disconnect the relay. Instead, the system will record the initial time of the abnormal condition and wait for a predetermined duration (e.g. 2 seconds). If after that time the voltage still remains out of bounds, then the relay will be switched off by setting pin 12 to LOW, and the system will enter protection mode. The latest status and voltage information will be displayed on the LCD to let the user know the latest condition of the system. User can adjust the undervoltage and overvoltage limits as a percentage of the nominal voltage (e.g. 90% for the bottom, 105% for the top), as well as set the duration of the time lag. These values will be stored for as long as the system is running and used in the calculation of protection logic.

The system also provides a reset function via the keypad button, which will set all LEDs and relays to the default state, as well as remove the protection status. If needed, the parameters can also be restored to their default values by pressing a special button in the settings menu, which will reset the lower limit to 90%, the upper limit to 105%, and the time lag to 2 seconds. With this combination, the program not only reads and displays voltage data, but also controls the relay, indicator LEDs, and LCDs to provide real-time feedback to the user, as well as provide manual control of the system settings via the keypad. This allows the system to automatically protect equipment from damage due to unstable voltage.

Table 2. PZEM-004T SENSOR DATA READING

No.	Reference Voltage (V)	PZEM Voltage (V)	Difference (V)	Error (%)
1	80	78.2	1.8	2.25%
2	90	87.3	2.7	3.00%
3	100	97.5	2.5	2.50%
4	110	107.1	2.9	2.64%
5	120	116.9	3.1	2.58%
6	130	126.7	3.3	2.54%
7	140	136.5	3.5	2.50%
8	150	146.4	3.6	2.40%
9	160	156.3	3.7	2.31%
10	170	166.2	3.8	2.24%
11	180	176.1	3.9	2.17%
12	190	186.0	4.0	2.11%
13	200	195.8	4.2	2.10%

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14	210	205.7	4.3	2.05%
15	220	215.5	4.5	2.05%
16	230	225.4	4.6	2.00%

Table 3. Variable Voltage Condition Testing

No.	Power Supply Voltage Variable (V)	LED Under (On)	LED Normal (On)	LED Over (On)
1	140	flame	die	die
2	142	flame	die	die
3	144	die	flame	die
4	146	die	flame	die
5	148	die	flame	die
6	150	die	flame	die
7	152	die	flame	die
8	154	die	flame	die
9	156	die	flame	die
10	158	die	die	flame
11	160	die	die	flame

DISCUSSION

A. Over and Under Voltage Testing

Based on Figure 4, it can be seen that the rated voltage is 100V and has entered the undervoltage condition. The results have been displayed on the LCD and the indicator light under is on.

Figure 4. LCD Under Voltage

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Based on Figure 4, it can be seen that the rated voltage is 154V and has entered the under-voltage condition. The result has been displayed on the LCD and the normal indicator light is on.

Figure 5. Normal Voltage

Based on Figure 5, it can be seen that the rated voltage is 158V and has entered the under-voltage condition. The results have been displayed on the LCD and the undervoltage indicator light is on.

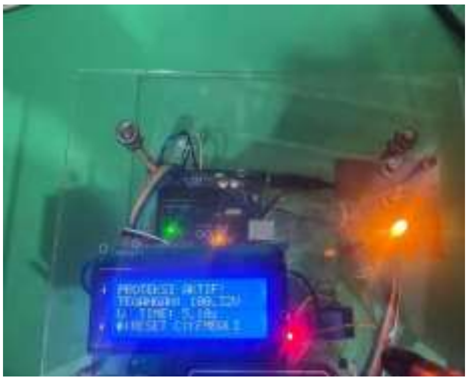

Figure 6. LCD Over Voltage

In addition to testing by providing voltage variations. This test is performed to determine the reliability of the designed tool.

B. Over and Under Voltage Test Data

Table 4. Under & Over Voltage Relay Test Result Data (Nominal Voltage: 150 V)

Time Delay (s)	Type	Parameters (%)	Voltage Setpoint (V)	Voltage Measured (V)
0.5	UV	95	142.5	139.3
0.5	UV	90	135	132
0.5	UV	85	127.5	121.1
0.5	UV	80	120	116.6
0.5	UV	75	112.5	109.6
0.5	UV	70	105	102.9
0.5	OV	105	157.5	159
0.5	OV	110	165	166
0.5	OV	115	172.5	177.5
0.5	OV	120	180	188.8
0.5	OV	125	187.5	192.9
0.5	OV	130	195	200

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1	UV	95	142.5	139.8
1	UV	90	135	132.2
1	UV	85	127.5	123.4
1	UV	80	120	115.8
1	UV	75	112.5	108.2
1	UV	70	105	101.3
1	OV	105	157.5	161.4
1	OV	110	165	170.5
1	OV	115	172.5	174.7
1	OV	120	180	182.3
1	OV	125	187.5	190.2
1	OV	130	195	200.5
2	UV	95	142.5	140
2	UV	90	135	133.3
2	UV	85	127.5	123.7
2	UV	80	120	117.2
2	UV	75	112.5	108.9
2	UV	70	105	102.3
2	OV	105	157.5	161.9
2	OV	110	165	168.8
2	OV	115	172.5	177.5
2	OV	120	180	185
2	OV	125	187.5	192.6
2	OV	130	195	200.1
3	UV	95	142.5	135.4
3	UV	90	135	130.5
3	UV	85	127.5	120.2
3	UV	80	120	117.7
3	UV	75	112.5	110.5
3	UV	70	105	100.4
3	OV	105	157.5	160.8
3	OV	110	165	170
3	OV	115	172.5	180.7
3	OV	120	180	185.5
3	OV	125	187.5	190.8
3	OV	130	195	200
4	UV	95	142.5	140.3
4	UV	90	135	130
5	UV	95	142.5	141
5	UV	90	135	128
5	UV	85	127.5	123
5	UV	80	120	117
5	UV	75	112.5	115.5
5	UV	70	105	100.5
5	OV	105	157.5	160.3

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5	OV	110	165	170.5
5	OV	115	172.5	177
5	OV	120	180	188
5	OV	125	187.5	192
5	OV	130	195	201

C. Analysis

The evaluation of system performance is carried out based on three main aspects, namely the level of detection accuracy, the speed of response to abnormal conditions, and the functionality of the user interface. The system designed using an Arduino microcontroller demonstrates efficient and economical performance, with the ability to release the load in less than 500 milliseconds when detecting a voltage outside the safe limit. This speed indicates that the system has a fairly fast response in handling potential interference. In addition, the use of LCD screens as an interface provides convenience in real-time system monitoring, with a clear and easy-to-understand display of information. This feature supports increasing the user-friendly aspect in the implementation of the protection system, so it is very feasible to apply to the household environment.

CONCLUSION

This project has demonstrated success in the development of an Arduino Uno-based over/under voltage protection system designed to maintain the stability of the 220V AC power grid. With the PZEM-004T sensor, the system is able to perform real-time monitoring of three voltage conditions: under voltage (<142.5V), normal voltage (2142.5– 157.5V), and over voltage (>157.5V). The system response is activated through a relay that cuts off power after a time lag of 0.5–5 seconds, preventing false interference due to momentary fluctuations.

SMPS 12V 5A support as a stable power supply ensures optimal performance of electronic components such as Arduino, sensors, and user interfaces, despite input voltage variations. The PZEM-004T sensor calibration process using an average correction coefficient of 1.024 resulted in measurement accuracy with an average deviation of 2.18%, which has been validated through comparison with a digital multimeter. The user interface that includes LCD for real-time data display, colored indicator LEDs (green, yellow, red) as visual markers of voltage conditions, and 4x4 keypads for parameter configuration, provide operational ease and adaptability in the adjustment of protection limits. Tests using variable transformers (VARIAC) and home PLN sources showed the consistency of the system in responding to voltage variations, both in the low range (142.5V) and high (157.5V), with a steady tap delay time of 0.5 seconds. The system not only effectively protects electronic devices from the risk of damage due to voltage instability, but also increases user awareness through an intuitive information interface.

The successful implementation of the system proves that a combination of simple components such as Arduino Uno and PZEM-004T can be adapted as a self-protecting, energy-saving, and economical solution for household and small-scale industrial applications. However, further development is needed to improve accuracy over extreme voltage ranges, integrate remote communication (IoT) features, and optimize the design to be more compact and resistant to environmental disturbances. Overall, this system is a promising foundation in an effort to improve the reliability of the electricity distribution network amid the increasingly complex challenge of voltage fluctuations

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