
Multifunctional IoT-Based Numerical Relay for Power System Protection

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Abstract

Conventional relays, such as electromechanical and solid-state relays, exhibit inadequate speed and flexibility, preventing their applicability in modern smart grid infrastructures. Their constrained adaptability and maintenance requirements reduce their efficiency in fluctuating power contexts. Realization of smart distribution networks demands cost-effective, adaptive, and remotely controlled protective systems. This study presents the design and development of a multifunctional numerical relay developed/working on the concept of IoT. The proposed relay module offers accurate fault detection and real-time monitoring. The Arduino UNO microcontroller serves as the central part of the relay, which takes voltage and current signals from a sensor and, based upon post-processed signals, detects the system status and sends the alert command to the circuit breaker. The built-in board is presented as a multifunctional numerical relay that can detect various faults, such as overcurrent, under/over voltage, under/over frequency, under impedance, and transmission short circuit fault. For testing, an LCD is interfaced with the relay to display electrical parameters and the system's status. For remote monitoring, a cloud-based logging mechanism is implemented. The proposed relay module is validated for various faulty conditions in the laboratory environment, and accurate responses are observed. The proposed relay can be used for the protection of evolving smart grid faults with SCADA or building management system platforms. It can serve as a cost-effective power system protection solution to safeguard electrical circuits, and sensitive power electronic devices.

Index Terms—Arduino UNO, Internet of Things, Numerical Relay, Power System Protection, Smart Grid

I. INTRODUCTION

Power system protection is vital to maintain the reliability and stability of electrical networks. It involves detecting and isolating faults and faulty sections avoid equipment damage and power outages. Protective relays are used to monitor electrical parameters and trigger circuit breakers (CBs) during abnormal conditions. With the increasing complexity of modern power grids, advanced protection schemes and mechanisms are necessary to ensure safety and efficiency.

Electromechanical protective relays are comprised of moving parts and coils to detect faults. Solid-state relays later replaced them with semiconductor-based devices that provide faster response times. Numerical relays are the most recent improvement, utilizing microprocessors and digital signal processing (DSP) to identify faults precisely. The transition from analog to digital relays increased power system protection by increasing flexibility, programmability, and communication capabilities. The transition from analog to digital relays has emerged with an increase in flexibility, programmability, and communication capabilities, thereby providing a higher power system protection. Conventional protection devices, although reliable, exhibit insufficient adaptability and precision to meet the demands of modern smart grid systems. These shortcomings are particularly visible in low-voltage distribution systems, where cost-effectiveness, real-time monitoring, and flexible control are vital. Classical relays, based on static thresholds and mechanical actions, exhibit slow response times, poor fault distinction, and increased

maintenance requirements. Additionally, they fail to integrate with existing digital technologies like the Internet of Things (IoT), which are becoming prevalent in power system management.

Although the digital relays in larger systems have been introduced, yet existing solutions are often prohibitively expensive, overly complex, or lack the adaptability needed for smaller-scale implementations. Microcontroller-based protection systems have investigated, they typically emphasize single-parameter detection or omit wireless capabilities, hindering their utility in intelligent grid contexts.

IoT enables data collection, cloud-based analytics, and planned maintenance schedules to improve the reliability of power systems. IoT-based numerical relays enable real-time monitoring and remote control, playing an important role in modern power infrastructure. Smart grids and renewable energy systems benefit from these relays by enhancing fault detection and reducing response times. Advancements in encryption and secure communication protocols are helping to mitigate risks associated with digital data available in the cloud.

II. LITERATURE REVIEW

Several studies that mention the various protection schemes for power system protection have been presented in the literature. Authors of [1] presented the importance of power system protection using TMS320F2812 DSP and made it efficient. In [2], a DSP-based overcurrent relay is implemented using the TMS320F2812 processor,

comparing MATLAB/Simulink auto-generated code and another using manually written C code. The Simulink-based method exhibited shorter execution time, and the C code method demonstrated higher accuracy and lower memory usage, especially in transient fault detection.

In [3], a protection coordination strategy is presented for a renewable energy source integrated into a bilaterally supplied distribution network, utilizing multifunctional numerical relays modeled in DIGSILENT PowerFactory. They demonstrated key protection functions such as overcurrent, over/under voltage, directional overcurrent, and frequency-based protections in coordination with real system values via characteristic curves, damage limits, and fault simulations.

In [4], an overcurrent protection relay is presented for PV system supply to an irrigation load. This relay is simulated on MATLAB/Simulink and operates only in a faulty condition, and does not operate at the starting high current of the motor.

In [5], a review on the advancement of power system protection is presented, focusing on the adopted wide area and integrated power system. Secondly presented the hierarchical protection structure was presented with local, substation/plant, and regional levels for better synchronization. The important functions are a real-time data sharing facility, introducing the defense layer, and supporting cloud processing in substations and networks.

In [6], a multifunctional numerical relay (MNR) targeting power system protection is presented using a TMS320F28335-based prototype. It protects against overcurrent, voltage, and frequency faults and also gives a response as a directional relay. MATLAB/Simulink-based evaluation verifies its performance; it effectively trips in abnormal conditions, and a single device offers protection from various faults.

In [7], an online flexible protection proportion is proposed using numerical directional overcurrent relays (DOCRs) and an AMPL-based IPOPT solver. To update the relay settings, the real-time data is used, addressing challenges from changing conditions and distributed generation. Performed on the IEEE 14-bus system, the technique enhances reliability and gives efficient results as compared with other techniques.

In [8], a hybrid Whale Optimization Algorithm (HWOA), improved with Simulated Annealing (SA), is presented for optimal combination of directional overcurrent relays (DOCRs). Applied to different IEEE test systems, HWOA enhances solution quality by changing relay settings and reducing operating time. Results show upper-level performance compared to conventional WOA and other enhanced algorithms.

In [9], a low-cost line protection scheme for a distributed generation-based power system is presented using a traditional and dual setting of directional overcurrent relay (DOCRs). Dual-setting DOCRs handle bidirectional power flow with some relays and CTs. Tested by using ETAP, the study shows minimized equipment needs without give-and-take protection quality.

In [10], a user-specified dual-setting directional overcurrent relay is proposed with hybrid time-current-voltage (UDDOR-TCV) features for RES-DG merged radial distribution networks. It relays settings using GAMS and shows major reductions in relay operation time (up to ~69%) and relay count (up to ~40%) on IEEE-33, Local-40, and

IEEE-8 bus systems. Results show enhanced pairing and performance over existing protection schemes.

Ref. [11] investigates the 7SA612 numerical relay, first used for distance protection of 220 kV transmission lines (TL). With the help of Omicron CMC 356 and Test Universe software, numerous fault schemes were simulated. Results show the selective fault clearing and fast performance of the relay, which effectively protects against both single-phase and multi-phase faults.

In [12], the value of thorough production testing for distance protection systems in smart power grids is discussed. It proposed using statistical design of experiments to enhance test selection, study influencing factors, and define robust pass/fail criteria, aligning with IEC 60255-121:2014. A step-by-step guide is provided, supporting efficient, realistic testing and encouraging methodologies for power system protection.

In [13], a real-time surveillance system is presented for relay protection equipment in distribution networks under the new power system. It utilizes simulation models to track fault types, times, and relay actions, with a 3D visual interface for human-computer interaction. The platform provides exact fault detection and control functions like quick-break and overcurrent protection, providing effective performance in tasks.

Power system protection acts as a frontier shield for electrical network infrastructures as shown in Fig. 1. These protection systems use innovative relay methods and fault-finding algorithms to identify and fix issues like short circuits and insulation failures. Modern protection systems use SCADA, IoT-based devices, and AI-driven analysis to improve grid strength through upkeep forecasting and flexible teamwork. This tech enables smart grid features such as networks that resolve themselves fitting in distributed energy sources, and better grid output.

This research addresses gaps in power system protection by developing an IoT-based multifunctional numerical relay. The primary goal of this research is to design and validate a smart relay system that improves power system protection at the distribution level while remaining affordable and simple to operate. The system design incorporates real-time monitoring, multi-fault detection, and wirelessly transferred data, using an Arduino UNO microcontroller for protection logic, a PZEM-004T sensor for precision measurements, and an ESP32 module for Wi-Fi remote control. The secondary goal is to demonstrate the potential of embedding IoT technology into traditional protective systems, demonstrating how real-time data analytics and remote accessibility can transform conventional relays into intelligent grid solutions. The relay detects and isolates faults autonomously—including overcurrent, over/under voltage, and frequency variations—and provides immediate local and cloud-based alerts. This approach improves grid stability by embedding robust hardware and scalable IoT integration, while also offering a cost-effective alternative for updating power infrastructure in resource-constrained areas.

In this study, an IoT-based multifunctional numerical relay is developed to accurately monitor real-time fault detection. The decision-making algorithm of the proposed relay is developed in an Arduino UNO microcontroller, and the full system includes a current transformer, a commercially available sensing device, a CB, and a wireless-transmission-equipped module. The organization of this study consists of the following sections: methodology, mathematical model, pin configuration, hardware implementation, and conclusion.

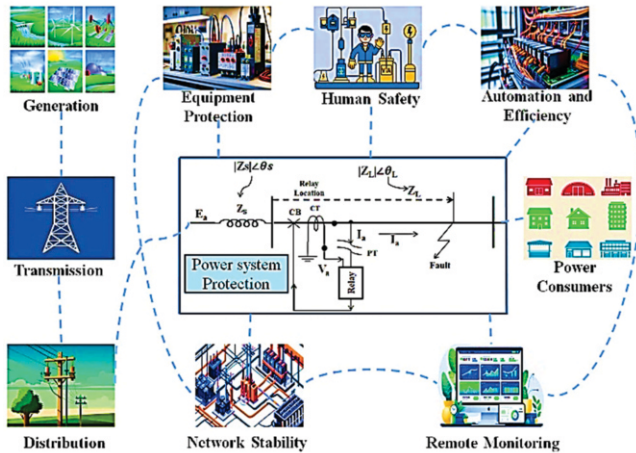


Fig. 1. Scope of power system protection: enabling safety, stability, and efficiency across the grid.

III. METHODOLOGY

A. System Architecture

The system uses a modular design combining sensors, control logic, output devices, and communication components. A single-phase multifunctional energy meter, PZEM-004T, capable of measuring AC voltage, current, power, energy, and frequency, is serially interfaced to an Arduino microcontroller. PZEM-004T takes input from the transmission line and transfers sensed data to the Arduino microcontroller, which decides whether faults exist. In this study, the Arduino microcontroller is employed as a prototype of a digital relay. The combination of PZEM-004T and Arduino analyzes electrical parameters in real time and detects overcurrent, overvoltage, undervoltage, and frequency changes. When deviation in any of these parameters occurs, the load is disconnected using a digital relay. A 16x4 I2C LCD displays real-time data, and a buzzer alerts users to any issues. An ESP32 module attached to Arduino allows for wireless connectivity and remote monitoring. Fig. 2 depicts a detailed block diagram for the proposed IoT-based numerical relay.

B. Major Components

The critical hardware components used to design the proposed IoT-based multifunctional numerical relay, such as Arduino UNO, PZEM-004T, ESP32, digital relay, and LCD, are explained below with their functionalities.

1) Arduino UNO

The Arduino UNO is an open-source microcontroller board with the ATmega328P at its core, which plays a key role in the relay system. This board reads electrical data from the sensor, runs the fault detection algorithm, and sets off protective measures like cutting off the load and signaling faults. Its easy-to-use design, strong community backing, and enough input/output pins make it a top choice to test out embedded systems. The Arduino UNO has an impact on how well the whole setup works, from spotting issues to taking action when needed.

2) PZEM-004T

The PZEM-004T is an energy monitoring module that measures voltage, current, frequency, power, and energy [14]. It gives the sensing data to Arduino UNO for processing in real time. This device gives precise readings needed to spot trouble like too much current, too high voltage, and too low voltage.

3) ESP32 Wi-Fi Module

The ESP32 is a cost-effective Wi-Fi-enabled microcontroller that is used to send wireless data to a cloud platform for remote monitoring. The cloud dashboard displays live metrics and alerts for anomalies (e.g., voltage spikes, overheating), which could enable the remedy signal accordingly. Real-time remote monitoring is an essential feature of IoT, and in this project system measurements and fault identification and detection are monitored from a distance. The proposed system has two processing cores and doesn't consume much power, which makes it suitable for integration with smart grids, especially when remote distance monitoring is required.

4) Digital Relay Module (5V, 1-Channel)

A digital relay module is employed to allow a microcontroller-based switching of AC (up to 250V, 10A) or DC (up to 30V, 10A) loads [15]. It requires a low-power signal (5V DC) to energize its coil, and its inside optocoupler isolates the driving circuit for safety and onboard status LEDs for a visual indication of relay state. When actuated, it shifts the load using its open or closed connections, making it suitable for automation and protection tasks.

5) 16x4 LCD with I2C Interface

This display unit provides real-time readings of voltage, current, power, frequency, and fault status. Using the I2C interface, it reduces the number of data pins needed. This allows easier and more effective wiring. It acts as a local interface to monitor.

C. Hardware and Logical Design

Designing the hardware required setting up all parts on either a breadboard or a PCB. The team connected the PZEM-004T module to the Arduino using UART to handle serial data communication. They set the ESP32 to work as a slave module by using software serial or assigning specific TX and RX pins. The design also included steps to regulate power, connect relays with a transistor driver circuit, and reduce noise with filtering in the circuit layout. The proposed relay circuit diagram is shown below in Fig. 3.

The logical sequence of the IoT-based numerical relay is presented in the form of a flowchart given in Fig. 4. It starts with turning on the system and collecting data from devices like transducers. These devices measure things such as voltage, current, frequency, impedance, power factor, and energy. The system checks each value against set limits. If any value goes past its allowed limit, like in the case of too much current, low voltage, or a drop in impedance, the relay activates to signal a fault. The fault type gets identified, and the details show up on an LCD screen and are sent out to the monitor. This setup protects the power system in real time and handles faults.

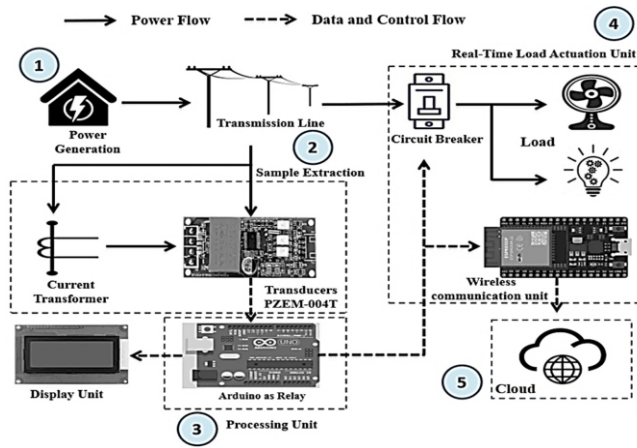


Fig. 2. Block diagram of the proposed IoT-based numerical relay.

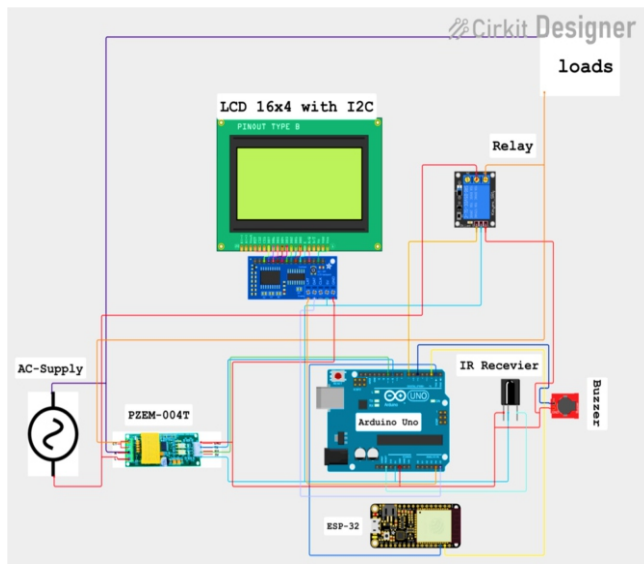


Fig. 3. Circuit diagram of IoT-based numerical relay.

IV. MATHEMATICAL MODEL

The various relay functions can be mathematically modeled. The mechanism of overcurrent fault detection can be modeled using (1). The relay continuously checks the system's current (I) against a set threshold (I_{th}). When the current goes above this threshold, it sends a trip signal indicating an overcurrent issue. If the current stays within safe levels, the system stays in the restraint mode.

$$\text{If } I > I_{th} \text{ then trip due to an overcurrent fault Else restrain} \quad (1)$$

As the voltage stability plays a crucial role in protecting equipment and maintaining power quality, under/over voltage conditions are also detected by the multifunctional relay. These conditions are detected using the following expressions:

$$\text{If } V > V_{th+} \text{ then trip due to an overvoltage fault Else restrain} \quad (2)$$

$$\text{If } V < V_{th-} \text{ then trip due to an under-voltage fault Else restrain} \quad (3)$$

Here, V , V_{th+} , and V_{th-} represent the voltage seen by the relay, the threshold voltage for over-voltage conditions, and the threshold voltage for under-voltage conditions, respectively.

Frequency fluctuations are indicators of instability in power grids. An increase in frequency signifies a sudden drop in load, whereas a decrease reflects less power generation.

$$\text{If } f > f_{th+} \text{ then trip due to an over-frequency fault} \\ \text{Else restrain.} \quad (4)$$

$$\text{If } f < f_{th-} \text{ then trip due to under frequency fault} \\ \text{Else restrain} \quad (5)$$

If Equations (4) and (5), f represents the actual frequency that is seen by the relay, f_{th+} the threshold of frequency for the over frequency condition, and f_{th-} is the under-frequency threshold.

The logic used in equation (6) detects the short-circuit faults by comparing the calculated impedance $|Z|$ between the source and load to a critical set point $|Z_{set}|$.

$$\text{If } |Z| < |Z_{set}| \text{ then trip due to an under-impedance fault} \\ \text{Else restrain} \quad (6)$$

A lower-than-expected impedance value is an indication of a direct short or a line-to-line fault. When triggered, the relay cuts off the faulty section, which helps to reduce equipment damage and boost system reliability.

V. PIN CONFIGURATION

The pin setup shows how the Arduino UNO, the PZEM-004T module, the ESP32, the LCD with I2C module, the relay module, the IR sensor, and the buzzer connect. Assigning the right pins is important to ensure stable functioning, proper data flow, and smooth execution of protection features. Pin configurations of various components are given in Tables (I, II, III, IV, V and VI).

TABLE I

Pin Configurations of Pzem-004T

PZEM-004T	Arduino Uno
VCC	5V
GND	GND
TX	D10
RX	D11

TABLE II

Pin Configurations of I2c Module

I2C	Arduino Uno
GND	GND
VCC	5V
SDA	A5

TABLE III

Pin Configurations of Relay Module

Relay Module	Arduino Uno
VCC	5V
GND	GND
I/P	D7

VI. RESULTS AND DISCUSSION

The IoT-based numerical relay underwent extensive testing across multiple fault scenarios to assess its real-time responsiveness, selectivity, and reliability in protection. The subsequent subsections discuss the experimental results for each examined condition.

A. Normal Operating Condition

The system exhibited stable electrical parameters under typical conditions. The inactive relay indicated both stability and resistance to erroneous activation. Fig. 5, and Fig. 6 depict the output in this condition, affirming the system's alertness for fault monitoring, respectively. The values of current and voltage were observed as 0.2 A and 233.1 V during normal operating condition.

B. Overvoltage and Under-voltage Detection

A variable voltage source used to created voltage anomalies in the system. The relay trips from 0 to 1 and cut the load moreover activated local buzzer alerts along with fault logging whenever the voltage crossed the set limit, like going above 253V.

In the same way, it detected and handled low voltage conditions, such as when it dropped below 205V. Fig. 7, and Fig. 8 show the LCD output and screenshot of serial monitor output when an under-voltage condition is met. Fig. 9, and Fig. 10 show the LCD output and screenshot of serial monitor output when an over-voltage condition is met. These screenshots confirm that the voltage protection worked within the defined limits. Fig. 11 shows the screenshot captured from ThingSpeak monitoring during over-voltage and under-voltage operating conditions.

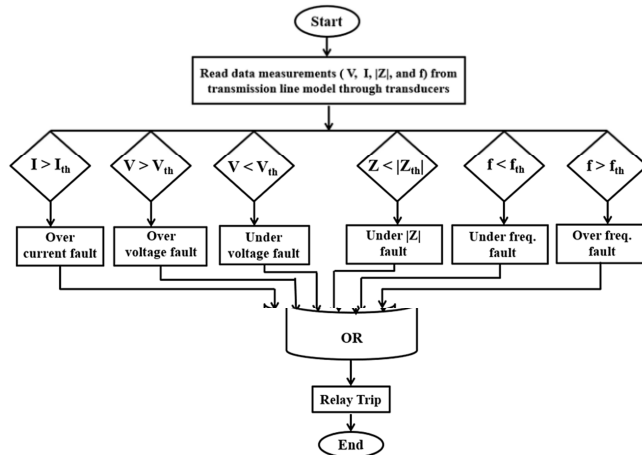


Fig. 4. Fault detection logic for relay operation using electrical parameters.

TABLE IV
PIN CONFIGURATION OF IR SENSOR

IR Sensor	Arduino UNO
VCC	5V
GND	GND
Signal	Reset

TABLE V
PIN CONFIGURATION OF BUZZER

Buzzer	Arduino UNO
Positive Terminal	D5
Negative Terminal	GND

TABLE VI
PIN CONFIGURATION OF ESP32

ESP-32	Arduino UNO
Tx2	RX (0)
Rx2	TX (1)

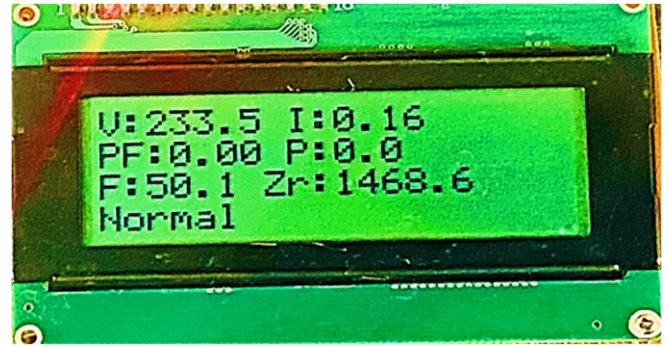


Fig. 5. LCD output during normal operating conditions.

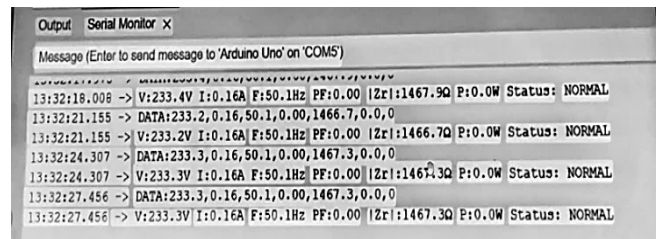


Fig. 6. Serial monitor output during normal operating conditions.

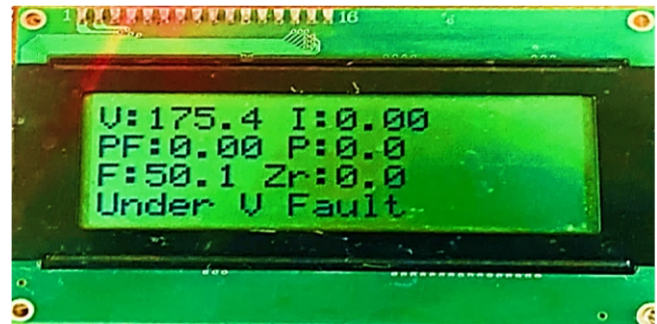


Fig. 7. LCD output during under-voltage operating conditions

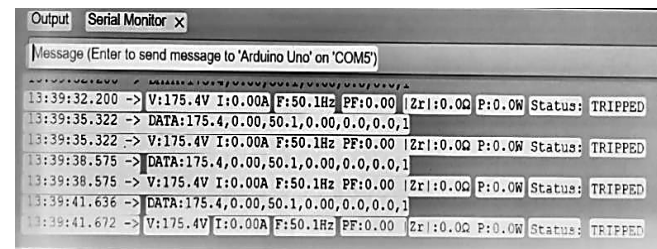


Fig. 8. Serial monitor output during under-voltage operating conditions.

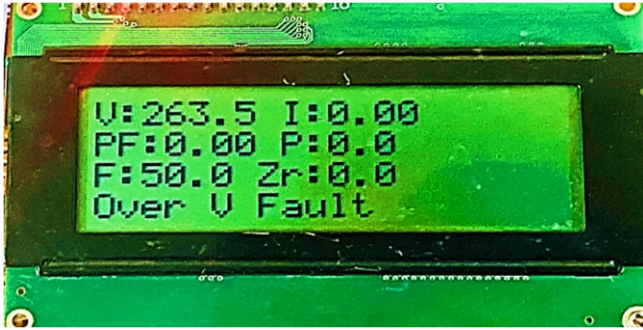


Fig. 9. LCD output during over-voltage operating conditions.

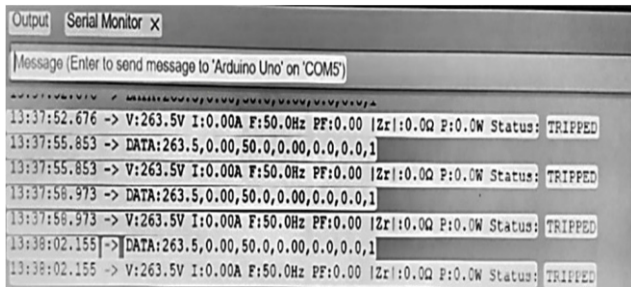


Fig. 10. Serial monitor output during over-voltage operating conditions.



Fig. 11. ThingSpeak monitoring during over-voltage and under-voltage operating conditions.

C. Overcurrent Fault

The system caused an overcurrent by using variable load that caused the system to go beyond the rated current threshold. The PZEM-004T sensor identified the surge, and the relay handled it by triggering a protective trip signal from 0 to 1 in just a few milliseconds. Fig. 12, and Fig. 13 show the display output on LCD, and serial monitor output. This indicates the type of event and confirms the disconnection status.

D. Short Circuit fault on Transmission Line (TL)

A short circuit between two lines (phase and neutral) was carried out to check the relay's ability to detect very low impedance and excessive current. The system acted right away, cutting off the load and displaying a fault message on the LCD. The LCD, Serial Monitor output, and ThingSpeak updates from the cloud all confirmed the relay's response by tripping from 0 states to 1 at the same time, this shown in Fig. 14, and Fig. 15. Fig. 16 shows the screenshot captured from ThingSpeak monitoring during over-current and TL fault

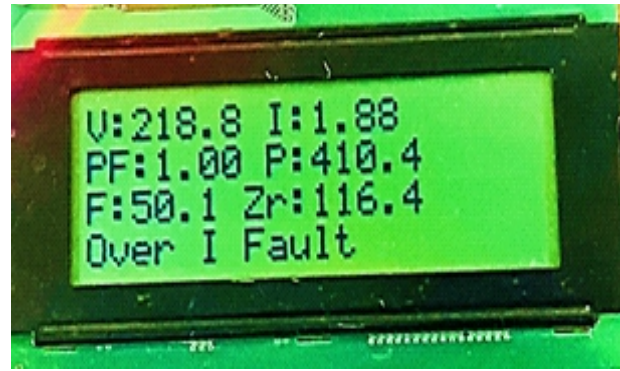


Fig. 12. LCD output during overcurrent operating conditions.

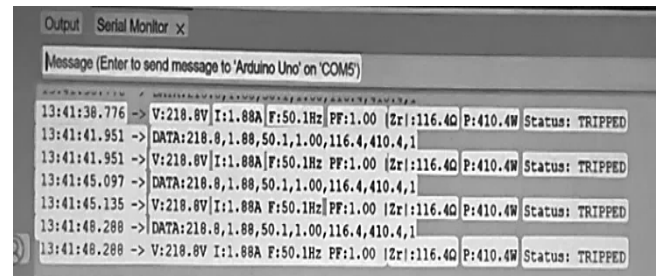


Fig. 13. Serial monitor output during overcurrent operating conditions.

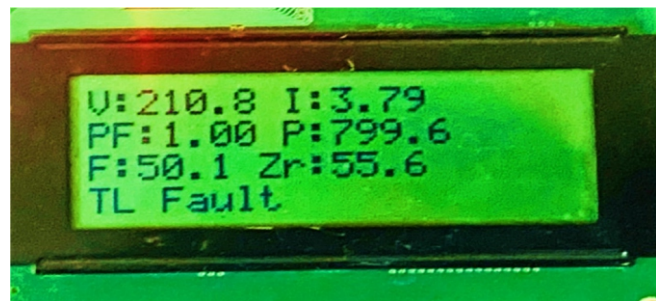


Fig. 14. LCD output during TL short circuit fault.

operating conditions.

Fig. 17 illustrates the instant operation of an IoT-based numerical relay when it encounters various faults over time. The y-axis indicates the relay status; 1 denotes the relay has tripped, and 0 denotes normal or reset. Purposely, several faults were introduced to validate the relay's performance. In the following, the crossover points captured in the screenshot are explained.

At first, the relay trips due to high voltage but returns to 0 upon reset. It then trips again due to high current, confirming its feasibility for current monitoring. When the voltage dips below the specified threshold, the proposed relay detects it. Later, it trips because of a fault on the transmission line (TL), indicating an issue in the wider grid. The graph curve finishes with a flat line at 0, informing us the system is back to normal. This validation test indicates the relay can identify and respond to a variety of faults, making it a reliable and smart module of modern power system protection.

E. Protection System Response Time Analysis

The timing diagram in Fig.18 breaks down the relay trip process into distinct stages quantifying the delays at each step. The vertical axis labels the stages, while the horizontal axis represents time in seconds

that each stage takes to complete its task. This helps us estimate the system's performance cross sensing, decision-making, and actuation.

1) **$t=0s$: Fault Instant**

At this point, the system experiences a fault. It detects this right away and moves from idle (stage 0) to the sampling stage (Stage 1).

2) **$t=0s$ to $t=1s$: Sensor Sampling (T_{ss})**

The transducer starts to gather voltage and current data in real-time. This sampling cycle takes 1.0 second to finish. The system stays in stage 1 during this time, examining the signal trend to evaluate unusual conditions.

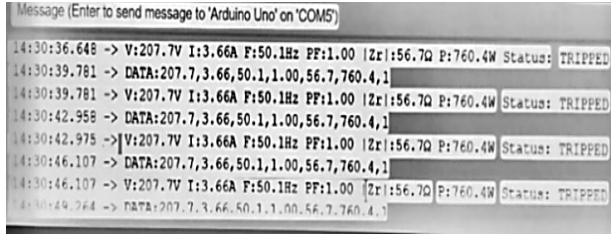


Fig. 15. Serial monitor output during TL short circuit fault.

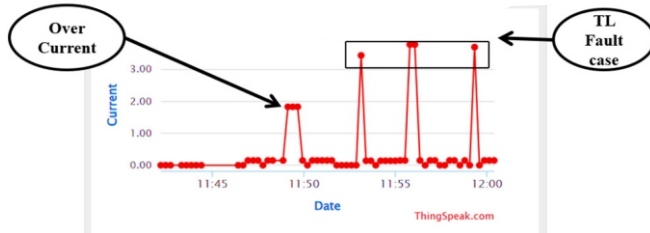


Fig. 16. ThingSpeak monitoring during overcurrent and TL short circuit fault conditions.

3) **$t=1s$ to $t=3s$: Algorithm Processing (T_{AP})**

After sampling ends, the Arduino moves from stage 1 to stage 2: algorithm-based decision-making. This stage has a 3.0-second delay set up to screen out false alarms caused by quick or brief changes. If the fault sticks around during this delay, the relay gets the signaling to trip.

4) **$t=4s$ to $t=4.02s$: CB Operation (T_{cb})**

At $t=4s$, the system verifies the fault as genuine and activates the relay. This kicks off stage 3, where the CB takes action. The mechanical trip needs about 0.02 seconds to finish. The total time of fault isolation is $T_R = 4.02s$, which can be calculated using (7).

VII. HARDWARE IMPLEMENTATION

The full hardware prototype shown in Fig. 19 brings together key parts for spotting faults and keeping an eye on things in real time. An Arduino UNO acts as the brain, making choices and running safety checks, while an ESP32 microcontroller sends data to the ThingSpeak IoT platform. A 16x2 LCD shows system info and fault messages right there. The setup uses a PZEM-004T module to precisely measure voltage, current, power, and frequency. A digital relay module cuts off the load when there's a problem, and a buzzer sounds to alert people. A 5V AC to DC converter powers both microcontrollers, making sure everything runs in a small space. An IR receiver module is added to let people reset the relay by hand, making the system easier to use. Several incandescent lamps are hooked up as loads to test real-life fault scenarios. This physical setup proves that the protection system works well and responds to different types of electrical faults.

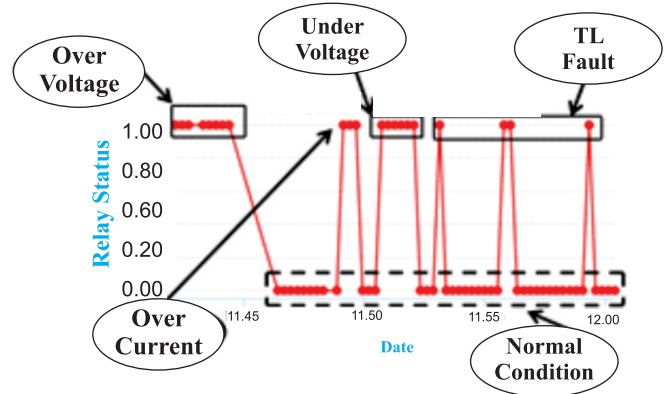


Fig. 17. Response of the IoT-Based numerical relay.

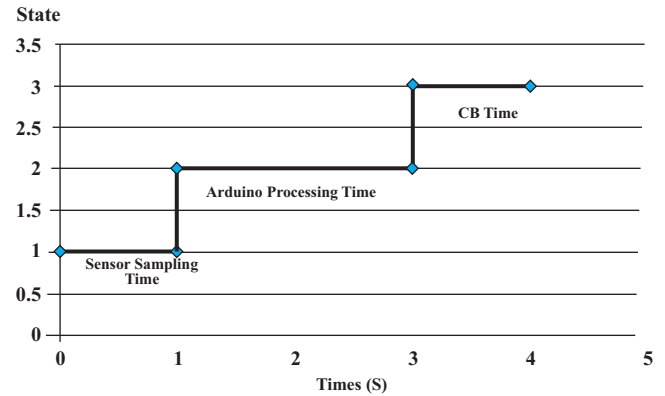


Fig. 18. Timing breakdown of the proposed relay system components during fault detection stages.

VIII. CONCLUSION

The integrity and reliability of electrical power systems is fundamental to ensure a steady and uninterrupted energy supply across different settings. This study created and put into action an IoT-based multifunctional numerical relay to protect power systems using the Arduino UNO microcontroller. The system spots and reacts to

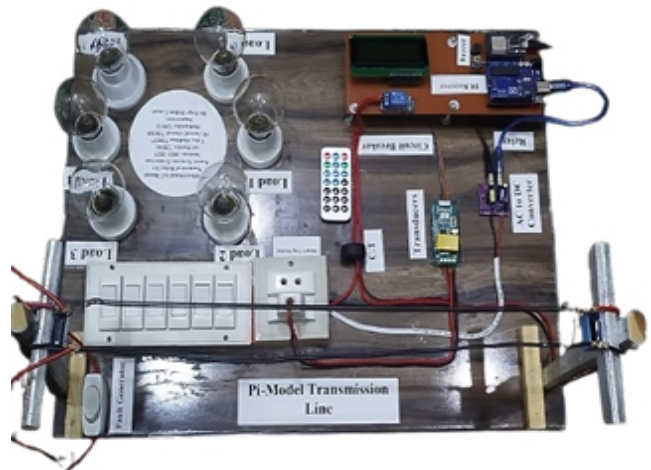


Fig. 19. Developed multifunctional numerical relay.

different faults like overcurrent, over/under voltage, impedance drops, frequency changes, and low power factor by looking at real-time data from sensors and carrying out relay trip commands. It also allows remote checking and display through wireless communication, giving better visibility and reliability for modern power networks.

Even though it works well, the prototype has some limits. It's good for single-phase systems, and how well it spots faults might depend on how accurate the sensors are and how fast the network is. Also, while the system does well in lab tests, how it behaves in tough field conditions needs more study.

Even though it works well, the prototype has some limits. It's good for single-phase systems, and how well it spots faults might depend on how accurate the sensors are and how fast the network is. Also, while the system does well in lab tests, how it behaves in tough field conditions needs more study.

Future work might involve expanding the design to three-phase systems, adding machine learning to predict faults, and implementing cybersecurity for IoT talks. Adding edge computing to make local decisions faster and make it work with smart grid rules will also make it more useful in the real world.

To cover up, this study offers a feasible and expandable solution for the growing need to protect power systems. By tackling enormous gaps in identifying and controlling faults in real time, this new relay makes operations safer and opens doors to power systems that can adapt, connect, and work better.

REFERENCES

- [1] Y. L. Goh, A. K. Ramasamy, F. H. Nagi, and A. A. Z. Abidin, "Numerical relay for overcurrent protection using TMS320F2812," in *Proceedings of the 9th WSEAS International Conference on Circuits, Systems, Electronics, Control & Signal Processing, CSECS*, 2010, vol. 10, pp. 44-50.
- [2] Y. L. Goh, A. K. Ramasamy, F. H. Nagi, and A. A. Z. Abidin, "Evaluation of DSP based numerical relay for overcurrent protection," *International Journal of Systems Applications, Engineering and Development*, vol. 5, pp. 396-403, 2011.
- [3] S. Nikolovski, M. Havranek, and P. Marić, "Numerical relay protection coordination using simulation software," in *2013 36th International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO)*, 2013: IEEE, pp. 869-873.
- [4] M. Abdel-Salam, R. Kamel, M. Khalaf, and K. Sayed, "Analysis of overcurrent numerical-relays for protection of a stand-alone PV system," in *2014 Saudi Arabia Smart Grid Conference (SASG)*, 2014: IEEE, pp. 1-6.
- [5] Z. Bo, X. Lin, Q. Wang, Y. Yi, and F. Zhou, "Developments of power system protection and control," *Protection and Control of Modern Power Systems*, vol. 1, no. 1, pp. 1-8, 2016.
- [6] M. Abdel-Salam, R. Kamel, K. Sayed, and M. Khalaf, "Design and implementation of a multifunction DSP-based-numerical relay," *Electric Power Systems Research*, vol. 143, pp. 32-43, 2017.
- [7] M. N. Alam, "Adaptive protection coordination scheme using numerical directional overcurrent relays," *IEEE Transactions on Industrial Informatics*, vol. 15, no. 1, pp. 64-73, 2018.
- [8] T. Khurshaid, A. Wadood, S. G. Farkoush, J. Yu, C.-H. Kim, and S.-B. Rhee, "An improved optimal solution for the directional overcurrent relays coordination using hybridized whale optimization algorithm in complex power systems," *IEEE Access*, vol. 7, pp. 90418-90435, 2019.
- [9] I. Evkay, S. Ashraf, M. Baysal, U. S. Selamogullari, and O. Hasan, "Single dual setting directional over-current relay based line protection logic for distributed generation integrated power systems," in *2020 2nd global power, energy and communication conference (GPECOM)*, 2020: IEEE, pp. 245-250.
- [10] L. Hong, M. Rizwan, M. Wasif, S. Ahmad, M. Zaindin, and M. Firdausi, "User-defined dual setting directional overcurrent relays with hybrid time current-voltage characteristics-based protection coordination for active distribution network," *IEEE Access*, vol. 9, pp. 62752-62769, 2021.
- [11] A. Iagăr, G. Popa, and C. Diniş, "Study about numerical relay 7SA612, the basic protection of 220 kV overhead transmission line," in *Journal of Physics: Conference Series*, 2022, vol. 2212, no. 1: IOP Publishing, p. 012021.
- [12] M. Ginocchi, T. Penthong, F. Ponci, and A. Monti, "Statistical design of experiments for power system protection testing: a case study for distance relay performance testing," *IEEE Access*, vol. 12, pp. 27052-27072, 2024.
- [13] Q. Li, Y. Zhang, Z. Zhang, and Z. Li, "Operation monitoring platform of relay protection equipment at distribution network side under the background of new power system," *Energy Informatics*, vol. 7, no. 1, p. 145, 2024.
- [14] "PZEM-004T Current Voltage Multimeter Module." <http://electrobes.com/product/pzem-0041-current-voltage-module-ac-80-260v-100a/> (accessed Mar. 3, 2025).
- [15] "5V, 1 Channel, 240V, AC Relay Module." <https://electrobes.com/product/1-channel-relay-module-10a/> (accessed Mar. 25, 2025)



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