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Transmission Line Fault Detection and Protection

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Abstract—Electrical networks are exposed to environmental conditions that may contribute to insulation deterioration, equipment damage, and unsafe operating conditions. This paper presents a low-voltage educational model for demonstrating environmental hazard sensing and relay-based load isolation. The proposed arrangement combines a rain/moisture sensor and an infrared (IR) flame sensor with two relay channels. Sensor-module outputs, generated according to their configured thresholds, are intended to actuate the corresponding relay channel and disconnect a demonstration load. The design illustrates a hardware-oriented sensing and switching concept without requiring a programmable microcontroller. The paper describes the system architecture, component functions, operating sequence, design considerations, and validation plan. The supplied project documents do not contain measured response-time, accuracy, or repeatability data; therefore, the discussion distinguishes expected operation from experimentally verified results. Importantly, the present sensor combination detects selected environmental conditions and does not independently measure overcurrent, earth fault, or line impedance. The prototype is consequently intended for supervised, isolated low-voltage educational demonstration and is not a substitute for certified power-system protection equipment.

Index Terms— Transmission line, environmental monitoring, rain sensor, IR flame sensor, comparator, relay, load isolation, hardware logic.

I.INTRODUCTION

Transmission and distribution systems transfer electrical energy from generating stations to consumers. Their reliable operation is important for domestic, commercial, and industrial activities. Electrical faults and adverse environmental conditions can interrupt supply, damage equipment, and create safety risks. Conventional protection systems use protective relays, circuit breakers, and fuses to detect abnormal electrical quantities and isolate the affected section [1], [2].

This project presents a compact hardware model that demonstrates how selected environmental inputs can initiate an automatic switching action. A rain/moisture sensor responds to water on its sensing surface, while an IR flame sensor responds to infrared radiation associated with flame. Their output signals are intended to control separate relay channels. The relay contacts are arranged to interrupt the path to a low-voltage demonstration load.

The main contribution is an educational integration of two sensor channels and relay-based isolation without a programmable controller. The model is design-oriented: the available project documents describe the intended circuit concept but do not provide a measured experimental dataset. Accordingly, no quantitative claims about detection speed, reliability, or superiority are made.

II. LITERATURE REVIEW

Several researchers have proposed different techniques for detecting faults and improving the protection of transmission lines.

Huang and He (2016) presented a comprehensive review of fault detection, classification, and location methods for transmission and distribution systems. Their study discussed different signal-processing techniques and the importance of voltage and current measurements for identifying and locating faults in electrical networks [1].

Bindi et al. (2023) reviewed various fault diagnosis and prognosis techniques used in high-voltage and medium-voltage electrical power lines. Their study discussed conventional protection devices, relay coordination monitoring techniques, and advanced methods

for improving power system reliability [2].

Chincholkar et al. (2024) proposed a transmission line fault detection system using a flame sensor and Arduino. Their approach uses flame detection and relay-based switching to disconnect the power supply during hazardous conditions. This study demonstrates the usefulness of sensor-based monitoring for improving electrical safety [3].

Gashteroodkhani et al. (2021) studied fire hazard mitigation in distribution systems through high-impedance fault detection. Their research evaluated different detection algorithms and discussed the importance of identifying electrical faults that may create fire and safety hazards [4].

Blackburn and Domin (2014) explained the principles and applications of protective relaying. Their work provides important information about protective relays and their role in detecting abnormal electrical conditions and isolating faulty sections of power systems [5].

Bondre et al. (2024): The researchers reviewed IoT-based innovations in power system monitoring and transmission line fault detection. Their study discussed the use of current sensors, voltage sensors, wireless communication, and monitoring systems for real-time fault detection and indication [6].

Shingare et al. (2025): The authors proposed an Arduino-based transmission line fault detection and protection system with GSM alerts. Their work focused on detecting electrical faults in a low-voltage three-phase transmission line model and providing fault information through communication technology [7].

III. PROBLEM STATEMENT AND MOTIVATION

Moisture, contamination, and fire near electrical equipment can contribute to insulation problems and hazardous operating conditions. A simple demonstrator can help students understand the relationship between sensing, threshold comparison, relay actuation, and load disconnection. However, environmental sensing must not be confused with direct electrical fault measurement. A rain sensor and a flame sensor alone cannot identify all transmission-line fault types or establish that a short circuit has occurred. The proposed model therefore focuses on the demonstration of two external hazard inputs and a visible trip response. A dedicated current- or voltage-measurement stage would be required to extend the design toward electrical fault detection.

IV. OBJECTIVES AND RESEARCH GAP

The objectives of the model are: (1) to demonstrate moisture/rain sensing; (2) to detect flame-related IR radiation using a sensor module; (3) to initiate relay switching when a sensor output crosses its configured threshold; (4) to disconnect a low-voltage demonstration load; and (5) to study a basic hardware-only protection concept. The scope limited to a controlled, low-voltage educational prototype. The terms “fault detection” and “protection” refer to the selected environmental trigger and load-isolation demonstration. The arrangement does not implement utility-grade overcurrent, earth-fault, distance, differential, or three-phase protection.

V. SYSTEM REQUIREMENTS

The hardware described in the project documents includes an FC-37-type rain/moisture sensor, an IR flame sensor, a two-channel 5 V relay module, a compatible DC supply, connecting wires, switches, a fuse for the demonstration setup, and a low-voltage lamp or equivalent indicator load. Sensor modules may include comparator circuitry such as the LM393. No microcontroller program is required for the basic switching concept.

A supply marked 3.7 V in one part of the synopsis and a 5 V relay module elsewhere should not be assumed compatible. The supply arrangement must be selected only after checking the ratings of each module and the required current. The demonstration load must also remain within the safe ratings of the test circuit.

VI. SYSTEM ARCHITECTURE AND METHODOLOGY

A. Functional architecture

The model is divided into four functional stages: environmental sensing, signal conditioning/compa-

rison, relay switching, and load indication. The rain/moisture sensor provides a moisture-related signal. The IR flame sensor provides a signal associated with flame-related radiation. The sensor modules generate output states according to their circuit configuration and threshold settings. These outputs are intended to operate separate relay channels.

B. Rain/moisture sensing stage

The rain sensor uses a sensing plate with conductive tracks. When moisture is present, theelectrical characteristics of the plate change. The associated module converts this change into an output signal. Depending on the module design, the output may be analog, digital, or both. The active output polarity is not universal and must be verified for the exact module used. Surface contamination, corrosion, water coverage, and threshold adjustment may affect the response.

C. IR flame sensing stage

The IR flame sensor detects infrared radiation associated with a flame within its effective response band. The supplied synopsis describes a photodiode-based module with a nominal sensitivity range of approximately 760–1100 nm. The module may provide an adjustable digital output. Orientation, line of sight, distance, obstruction, and ambient IR sources influence detection. The sensor is not a certified fire-alarm device.

D. Signal conditioning and comparator

A comparator compares a sensor-derived signal with a reference level. When the input crosses the set threshold, the module output changes state. The LM393 is identified in the project documents as a comparator used in common sensor modules. The actual output behaviour depends on the complete module circuit, supply, pull-up arrangement, and output polarity.

E. Relay interface and load isolation

The two-channel relay module provides electrically controlled contacts. The project concept uses relay contacts in a series-break arrangement so that activation of either channel is intended to interrupt the load path. A relay is only a switching element; its presence does not by itself establish suitability for high-energy circuits. Contact ratings, coil supply, driver design, isolation distances, and switching category must be confirmed for the exact module.

F. Operating sequence

Under normal conditions, both sensors monitor their respective inputs and the demonstration load remains in its normal state. If moisture is detected, the rain-sensor output changes and is intended to actuate relay channel 1. If flame-related IR is detected, the flame-sensor output changes and is intended to actuate relay channel 2. The associated relay contact changes state, opening the series load path and turning the demonstration indicator OFF. The exact sequence depends on the selected module's active-high/active-low logic and wiring configuration.

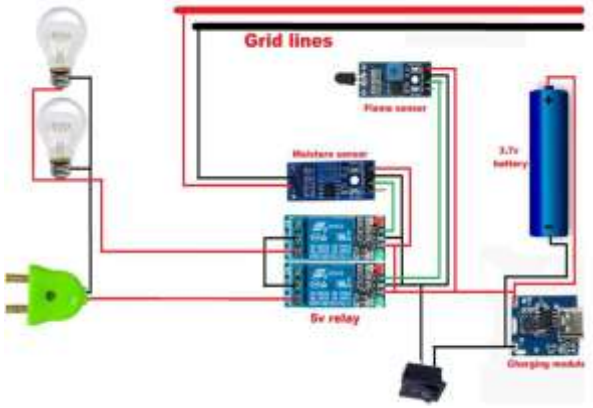


Fig.1. Circuit Diagram

VII. COMPONENT FUNCTIONS AND DESIGN CONSIDERATIONS

A. Rain/moisture sensor module

The sensing plate responds to water through a change in conductivity. Its control board converts the change into an electrical output. In this model, it represents a moisture-related environmental input. Prolonged exposure to water may cause corrosion or inconsistent readings; the plate should be inspected and handled according to the manufacturer's guidance.

B. IR flame sensor module

The flame sensor responds to infrared radiation in the band supported by the device. The output threshold may be adjustable. Its response is affected by the sensor's field of view and the surrounding environment. Any demonstration should use an approved, supervised method and should not involve improvised open-flame testing.

C.Two-channel relay module

The relay module contains two switching channels. Each channel is intended to respond to one sensor output. Relay modules vary in trigger polarity, input current, coil voltage, contact rating, and isolation. A generic 5 V marking is not sufficient evidence that a module can switch mains voltage or fault current.

D.Power supply and demonstration load

The supply must meet the voltage and current requirements of every connected module. The project synopsis mentions both a 3.7 V source and a 5 V relay module; compatibility must be checked rather than assumed. A regulated supply appropriate to the selected modules and a low-voltage, current-limited indicator load should be used.



Fig.2.Components list

VIII. RESULTS AND DISCUSSION

The proposed Transmission Line Fault Detection and Protection System was successfully designed and tested. The voltage sensor monitors the supply voltage, while the IR sensor detects obstacles or fault conditions in the transmission line model. Under normal conditions, the relay remains in its normal state and the bulb glows. When a fault is detected, the relay disconnects the load and the bulb turns OFF. LEDs indicate the system status. The results show that the system provides automatic fault detection and protection. It is simple, economical and useful for improving the safety and reliability of the transmission line model.

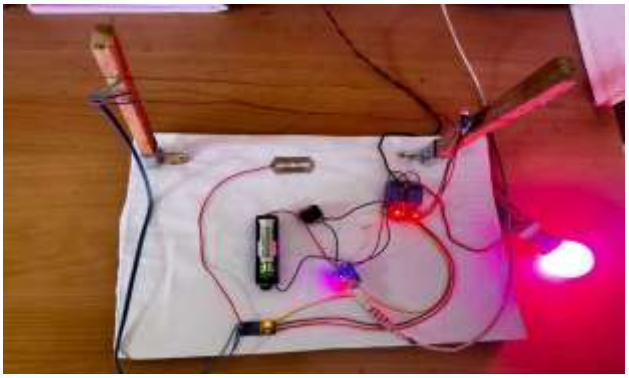


Fig.3.Result

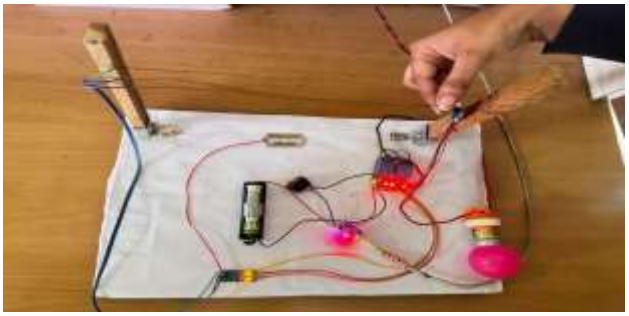


Fig.4.Output

IX. ADVANTAGES

The main advantages of the proposed educational model are: (1) a simple hardware-oriented operating principle; (2) integration of moisture and flame sensing in one arrangement; (3) visible load switching through relay contacts; (4) no microcontroller program for the basic operation; and (5) use of commonly available sensor and relay modules. These advantages relate to learning and demonstration and should not be interpreted as verified utility-level performance.

X. APPLICATIONS AND FUTURE SCOPE

The model can be used in supervised laboratory demonstrations of sensor interfaces, comparator-based switching, relay operation, and basic load-isolation concepts. It can support classroom discussion of moisture and fire hazards around electrical equipment. The prototype itself is not suitable for deployment on utility transmission lines. Future work may include a properly engineered current-sensing stage for overcurrent detection, voltage monitoring, clear trip indication, event logging, and remote status reporting. A future

experimental study should measure response time, repeatability, false-trigger behaviour, and performance under defined environmental conditions. Any extension must include suitable isolation, correctly rated components, and qualified engineering review.

XI. CONCLUSION

This paper presented a hardware-based educational model for environmental hazard sensing and relay-controlled load isolation. A rain/moisture sensor and an IR flame sensor provide two independent inputs, while comparator-based circuitry generates switching signals for a two-channel relay arrangement. The relay contacts are intended to disconnect a low-voltage demonstration load when either selected environmental condition is detected. The design illustrates sensing, threshold comparison, relay actuation, and load isolation without requiring a programmable microcontroller. The supplied project documents support the design concept and expected qualitative behaviour but do not provide measured experimental results. Moreover, the two environmental sensors do not directly measure electrical fault current or voltage and therefore cannot independently establish short-circuit or other electrical fault conditions. The prototype should be treated only as a supervised low-voltage educational demonstrator. Additional electrical sensing, validation, and professional safety engineering would be necessary for any broader protection application.

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