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An AI-Enabled System for Early Detection and Protection of Electrical Faults

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Abstract- Electrical faults such as arc faults, overcurrent, short circuits and abnormal electrical conditions can cause serious damage to electrical equipment and may lead to electrical fires. Conventional protection devices mainly operate when electrical parameters cross predefined threshold values, which may not be sufficient for detecting certain intermittent and unpredictable faults at an early stage. The proposed AI Based Smart Electrical Protection System Aims to provide intelligent and real-time monitoring of electrical conditions for early fault detection and protection. The system continuously monitors electrical parameters and analyses their variations to distinguish between normal operating conditions and abnormal fault conditions. An Artificial Intelligence-based fault detection approach is used to identify abnormal patterns and improve the reliability of protection. When a potentially dangerous fault is detected, the controller generates a tripping signal to operate a relay and disconnect the electrical supply, thereby reducing the possibility of equipment damage and electrical fire. An alarm indication can also be provided to alert the user about the detected fault. The proposed system is inspired by the reference study, in which current variations and high-frequency signal energy were used as important features for arc-fault identification using a weighted least-squares support vector machine, followed by relay-based circuit interruption. The reference system demonstrated real-time fault detection and interruption of the supply before an electrical fire could occur. The proposed AI-based system extends this concept toward a smart electrical protection framework capable of intelligent fault identification, rapid isolation and improved electrical safety.

Keywords— Artificial Intelligence, Electrical Fault Detection, Fault Diagnosis, Power Systems, Predictive Maintenance, Machine Learning, Deep Learning, Electrical Protection, Smart Grid, Real-Time Monitoring, Anomaly Detection, IoT, Sensor Networks, Power Quality, Fault Classification, Early Warning System, Intelligent Protection System, Condition Monitoring, Automation, Electrical Safety.

I. INTRODUCTION

Electrical fires are a serious safety problem that can cause damage to electrical equipment, buildings, and human life. The major causes of electrical fires include arc faults, overcurrent, short circuits, leakage currents, and damaged electrical wiring. Among these, arc faults are considered one of the important causes of electrical fires. An arc fault is an unintended electrical discharge in a circuit. It can occur due to loose connections, damaged wires, aged or worn insulation, excessive bending, heating, or improper electrical equipment. During an arc fault, a large amount of energy and heat can be produced, which may ignite nearby combustible materials and lead to an electrical fire. Conventional protection devices such as overcurrent protection and ground-fault protection may not always detect arc faults because arc-fault currents can be lower than the normal operating or short-circuit current levels. Arc faults can also be intermittent, random, and transient, making real-time monitoring important for early fire prevention. The reference study developed an Arc Fault Detector (AFD) using current and high-frequency signals.

High-frequency energy and current variations were extracted as important features, and a weighted least squares support vector machine (WLS-SVM) was used for fault identification. The developed detector was able to identify arc faults in real time and interrupt the power supply before an electrical fire could occur. Based on this concept, the proposed AI Based Smart Electrical Fire Protection System aims to provide intelligent and early detection of electrical faults. By using sensors to monitor electrical parameters and an AI-based detection technique to identify abnormal patterns, the system can provide an early warning and initiate protective action. Such a smart system can improve electrical safety, reduce fire risk, and protect electrical equipment and human life.

Objective

- Voltage, Current & Temperature Monitoring: To continuously monitor
- electrical parameters for safe and reliable system operation.
- AI-Based Fault Detection: To detect and identify electrical faults such as overcurrent, short circuit, overvoltage, and overload using AI techniques.
- Fault Classification: To accurately classify different types of electrical faults and determine abnormal operating conditions.
- Automatic Protection: To automatically disconnect the faulty section or load to prevent equipment damage and electrical hazards.
- Real-Time Monitoring & Alerts: To provide real-time monitoring of the electrical system and generate alerts during abnormal conditions.

II. LITERATURE REVIEW

PAlhanaf et al. (2023) proposed an intelligent fault detection and classification scheme for smart grids using Deep Neural Networks (DNNs). The study showed that deep learning can automatically learn important features from electrical signals and accurately classify different types of faults. This approach can improve the speed and reliability of fault identification.

Alonso et al. (2020) investigated the role of smart sensors in smart-grid reliability. Smart sensors continuously measure electrical parameters and provide real-time information to the control system. The study highlighted that accurate and timely sensor data can help in early fault detection, monitoring, and improving overall grid reliability.

Bakkar et al. (2022) presented a review of AI-based protection techniques for smart grids. The authors discussed how AI and ML can support protection systems by detecting abnormal conditions and making faster protection decisions. The study also highlighted the limitations of conventional protection techniques in modern smart grids.

Bawayan and Younis (2021) studied adaptive overcurrent relay coordination in microgrids. Since microgrid operating conditions

Change due to distributed energy resources, fixed relay settings may not always provide proper protection. Their work focused on adapting relay settings according to changing system conditions.

Chandraratne et al. (2020) investigated adaptive protection of microgrids containing distributed energy resources. The researchers explained that renewable sources can change fault-current characteristics and power-flow conditions. Therefore, adaptive protection is required to maintain reliable relay operation under different operating conditions.

Franco et al. (2022) studied a cyber-physical approach to residential energy management. The research emphasized the importance of communication, sensing, monitoring, and intelligent control in modern energy systems. These technologies provide the foundation for developing more intelligent and automated smart-grid systems.

Ji et al. (2021) developed a power-grid fault diagnosis system based on multiple data sources. Instead of depending on only one electrical parameter, the system combines information from different sources for fault diagnosis. This approach can improve the accuracy and reliability of fault identification.

Kulikov et al. (2022) investigated relay protection and automation using simulation and machine-learning methods. Their work demonstrated that machine-learning techniques can be combined with conventional protection systems to improve fault recognition and protection decisions.

Mumtaz et al. (2022) proposed a harmonic-content-based protection method for microgrids using a one-dimensional recursive median filtering algorithm. The method uses harmonic information present in electrical signals to identify abnormal and fault conditions, showing that signal characteristics can be useful for intelligent protection.

Santos-Ramos et al. (2023/2024) investigated microgrid protection coordination using clustering and metaheuristic optimization. Their research used optimization techniques to improve coordination between protective devices under different operating conditions. This can help reduce unnecessary tripping and improve protection selectivity.

Zhang et al. (2024) reviewed intelligent fault-diagnosis techniques for rotating machinery. Although the study is not directly focused on smart-grid protection, it provides useful information about condition monitoring, feature extraction, and intelligent fault diagnosis that can be applied to electrical equipment.

III. METHODOLOGY

The proposed AI-based smart electrical protection system continuously monitors the electrical system to detect faults at an early stage. The system starts with a 230 V AC supply, which passes through the MCB and is monitored by different sensors. The ACS712, ZMPT101B, MQ-series, and DHT11 sensors measure current, voltage, gas concentration, temperature, and humidity.

These sensor readings are sent to the ESP32, where the data is processed and checked using AI/logic-based analysis. The system compares the measured values with safe limits to determine whether the electrical condition is normal or abnormal. If all parameters are within the safe range, the loads continue to operate normally and the LCD displays the live readings and "ALL OK" status. If any parameter exceeds its safe limit, the system identifies the type of fault, such as overcurrent, overvoltage, undervoltage, gas leakage, overheating, or short circuit.

The ESP32 then sends a control signal to the appropriate relay, which disconnects the affected load to prevent further damage. At the same time, the buzzer gives an alert and the fault information is displayed on the LCD. The fault data can also be recorded for future analysis. After taking the necessary protection action, the system continues monitoring the remaining parameters and repeats the process continuously.

Equipment Details

- ESP32: Main controller that collects sensor data and processes it for real-time monitoring.
- ACS712: Measures the AC/DC current flowing in the system.
- DHT11: Measures temperature and humidity.
- ZMPT101B: Measures AC supply voltage and detects overvoltage or undervoltage.
- MQ-Series Sensor: Detects gas leakage or high gas concentration.
- 4-Channel Relay: Automatically switches OFF the faulty electrical load.
- 16×2 LCD: Displays voltage, current, temperature, humidity, and fault status.
- 230V AC to 5V DC Converter: Converts 230V AC into 5V DC for the electronic components.
- MCB: Protects the circuit from overload and short circuits. J] Buzzer: Gives an audible warning when a fault is detected.
- LED Bulbs/Loads: Represent the electrical loads protected by the system

IV. RESULT

The proposed system successfully monitors important electrical parameters such as voltage, current, temperature, humidity, and gas level in real time. When any parameter goes beyond the safe limit, the ESP32 detects the abnormal condition. It then gives an alert through the buzzer, shows the fault on the LCD, and switches OFF the affected load using the relay. Thus, the system provides quick and automatic protection against electrical faults.

V. CONCLUSION

The project shows that an AI-based smart electrical protection system can improve electrical safety by continuously monitoring the system and detecting abnormal conditions early. It can automatically disconnect the faulty load and alert the user, which helps to prevent equipment damage and reduce the risk of electrical fires. Overall, the system provides a simple, fast, and reliable approach to smart electrical protection.

Future Scope

- Integration of IoT connectivity for remote monitoring through a mobile application or web dashboard.
- Development of a more advanced AI/ML model for accurate fault classification.
- Detection of additional faults such as arc faults, earth faults, leakage current and phase faults.
- Addition of real-time notifications through mobile applications, SMS or email.
- Implementation of predictive maintenance by analyzing changes in electrical parameters over time.

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