

AI-INTEGRATED POWER FAULT DETECTION SYSTEM USING MACHINE LEARNING

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Abstract

This Modern power systems require high reliability and stability to ensure continuous electricity delivery. Faults such as short circuits, line-to-ground issues, and equipment failures can disrupt supply and cause hazards. Traditional fault detection methods rely on fixed thresholds and hardware-based systems. These approaches often lack adaptability and real-time decision-making capabilities. This project proposes an AI-integrated fault detection system using machine learning techniques. The system analyzes time-series data such as voltage and current signals. It identifies abnormal patterns associated with different types of faults. Machine learning models like Support Vector Machine (SVM) are utilized. Decision Trees and Random Forest algorithms are also applied for classification. Artificial Neural Networks (ANN) enhance the system's predictive capability. The models are trained using labeled datasets from simulations or real-world sources. The system aims to provide accurate and efficient real-time fault detection. It is scalable and suitable for integration into smart grids and industrial systems. The implementation includes preprocessing, model training, evaluation, and real-time monitoring.

Keywords- Power system fault detection, Artificial Neural Networks, Smart grid, Decision Tree, Random Forest, Pattern Recognition, Fault Classification

1. Introduction

Energy management has become a major concern in modern society due to the increasing demand for electricity, rising energy costs, and the need for efficient power utilization. Traditional electricity management systems often suffer from issues such as inaccurate billing, electricity theft, lack of real-time monitoring, delayed fault identification, and inefficient energy usage. Conventional systems mainly depend on manual meter readings and basic monitoring techniques, which provide limited visibility into consumption patterns and offer minimal support for intelligent decision-making. collection, theft detection, and operational inefficiencies.

With the rapid advancement of the Internet of Things (IoT) and Artificial Intelligence (AI), it is now possible to develop smart energy management systems that provide real-time monitoring, automated control, predictive analysis, and enhanced security. IoT technology enables interconnected devices and sensors to continuously collect and transmit data, while AI techniques analyze the collected information to identify usage patterns, detect anomalies, and generate intelligent energy-saving recommendations.

2. Related Work

Sharma et al. [1] proposed an AI-integrated power fault detection system that monitors electrical parameters in real time using sensors and machine learning algorithms. The system utilizes voltage, current, and temperature sensors connected to an ESP32 microcontroller to detect abnormal conditions such as overload, short circuit, and voltage fluctuations. By applying Random Forest-based analysis, the model identifies faults with improved accuracy and provides instant alerts through cloud-based monitoring platforms. The authors highlighted the system's reliability, low operational cost, and suitability for smart grid applications (2023).

Kumar et al. [2] developed a machine learning-based electrical fault monitoring framework that combines IoT communication and predictive analytics for early fault identification. The proposed system continuously gathers electrical data through embedded sensors and transmits the information to a cloud server for processing. Using classification algorithms, the architecture predicts abnormal behavior and prevents equipment damage by generating automated warnings. The study focused on improving energy safety and minimizing .

Reddy et al. [3] introduced a smart energy monitoring and fault prediction model designed for residential and industrial power systems. The architecture integrates current transformers, voltage sensors, and wireless communication modules with AI-based analysis techniques. The system detects irregular consumption patterns and electrical faults in real time while providing remote monitoring through a mobile dashboard. The authors emphasized scalability, energy efficiency, and rapid response capabilities for modern smart infrastructures (2023).

Patel et al. [4] proposed an intelligent IoT-enabled fault detection system that uses machine learning algorithms to classify electrical disturbances in distribution networks. The model collects real-time electrical parameters and applies Random Forest classification to identify faults such as overcurrent, power leakage, and line interruptions. The system improves reliability by reducing false detections and enabling quick fault localization. The study

highlighted the importance of automation in future smart power management systems (2021).

Singh et al. [5] designed a cloud-connected smart power monitoring architecture capable of detecting electrical faults using sensor-driven analytics. The framework combines embedded controllers, wireless communication technologies, and AI-based prediction methods to ensure continuous monitoring of electrical equipment. By analyzing historical and real-time data, the system provides preventive maintenance alerts and improves operational efficiency. The authors focused on affordable implementation for both urban and rural applications (2022).

Rao et al. [6] developed a machine learning-assisted power fault diagnosis system for utility substations and industrial installations. The proposed architecture uses IoT sensors to capture electrical abnormalities and applies predictive models for identifying fault conditions before system failure occurs. The system sends notifications to users through web and mobile applications, ensuring fast corrective action. The authors emphasized improved fault accuracy, reduced downtime, and enhanced electrical safety (2023).

Verma et al. [7] presented an AI-based smart electricity management system that combines IoT monitoring with automated fault classification techniques. The system continuously measures electrical parameters and stores the collected data in a cloud database for machine learning analysis. Using trained datasets, the model predicts abnormal operating conditions and provides instant alerts to operators. The study highlighted the effectiveness of intelligent monitoring in reducing power losses and improving grid stability (2022).

Naik et al. [8] proposed a low-cost intelligent fault detection system that integrates ESP32 microcontrollers, wireless sensors, and cloud computing technologies. The framework identifies power distribution faults such as overloads, voltage imbalance, and short circuits through machine learning-based decision models. Real-time monitoring and notification features enhance system reliability and reduce manual inspection requirements. The authors focused on practical deployment for smart homes and industrial automation systems (2021).

Chandra et al. [9] developed an IoT and AI-integrated electrical safety system that detects abnormal current flow and predicts potential electrical failures. The system employs sensor networks and Random Forest algorithms to analyze power consumption patterns and identify unusual operating conditions. Fault information is transmitted instantly to users through cloud-connected dashboards, enabling preventive action and reducing maintenance costs. The study emphasized the importance of intelligent automation in next-generation energy systems (2023).

Joshi et al. [10] proposed a real-time smart fault monitoring platform that combines machine learning, wireless communication, and embedded systems for efficient electrical fault management. The system continuously monitors electrical loads and uses predictive analytics to identify faults such as power leakage, overload, and unstable voltage conditions. The authors highlighted the system's scalability and applicability in smart grid and industrial environments (2022).

3. Materials and Methods

The proposed AI-Integrated Power Fault Detection System is designed to monitor electrical parameters, detect faults using Machine Learning algorithms, and provide real-time alerts through IoT technology. The system combines hardware components, cloud communication, and intelligent data analysis for efficient power monitoring and fault detection. The overall working methodology is explained below.

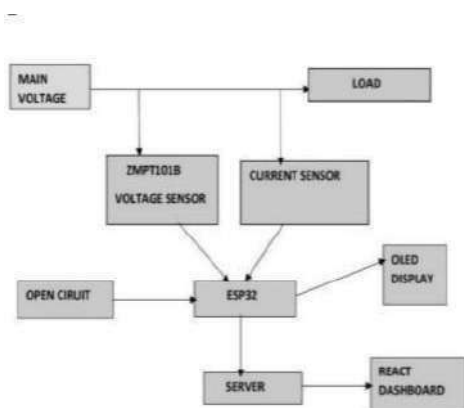


Fig 1: Block diagram of the system

- **Power Supply Unit** The Power supply unit provides the required DC voltage to all components in the system. It converts AC main supply into regulated DC voltage suitable for sensors

- **Current sensor** The current sensor continuously measures the current flowing through the electrical load. It detects abnormal current conditions such as overload, short circuit, or leakage current.

- **Voltage Sensor** The voltage sensor monitors the voltage level of the electrical system. It helps in detecting voltage fluctuations, undervoltage, and overvoltage conditions. This sensor output is scaled down to safe level before being sent to the ESP32 analog input pins.

- **ESP32 Microcontroller** The ESP32 acts as the main controller and processing unit of system. It performs several important functions such as Collecting sensor data from voltage, current sensors.

- **OLED Display** The OLED display provides real-time system information to the user. It shows voltage readings, current readings, fault status, Wi-Fi connection status, system alerts.

- **Wi-Fi module** The built-in Wi-Fi feature of ESP32 enables internet connectivity for cloud communication. It allows sensor data and fault information to be uploaded to cloud platforms for remote monitoring and analysis.

- **The web dashboard or mobile application** provides a user-friendly interface for monitoring the system remotely. Users can: View live electrical parameters, Monitor fault conditions, Receive warning notifications.

- **Electrical Load** The load represents the electrical appliance or equipment connected to the system, such as bulbs, motors, or household devices. The system continuously monitors the load condition and protects it from electrical faults through intelligent analysis and automatic control.

4. Results and Discussion

The proposed system successfully detected and classified different electrical faults in real time.

The hardware setup generated different fault scenarios by varying loads and intentionally creating abnormal conditions. Voltage and current variations were captured accurately by the sensors and transmitted to the backend server. The system effectively identified: Overload conditions, Loose connections, Open-circuit faults, Short circuits, the react dashboard displays real-time voltage, current, power and fault status graphs. The OLED display also provided local monitoring and alerts.

The result confirms that machine learning can significantly improve the accuracy and reliability of power-system fault detection.

Experimental observations showed that overload conditions caused significant increases in current, while short-circuit conditions produced sudden voltage drops. Loose connections resulted in unstable current fluctuations.



Fig 2: Real time analytics of Current, Power, Voltage

The below figures represent the feature graphs generated by the AI-Integrated Power Fault Detection System for real-time monitoring of electrical parameters. These graphs continuously analyze voltage, current, frequency, and fault prediction probabilities using sensor data collected through the ESP32 microcontroller.

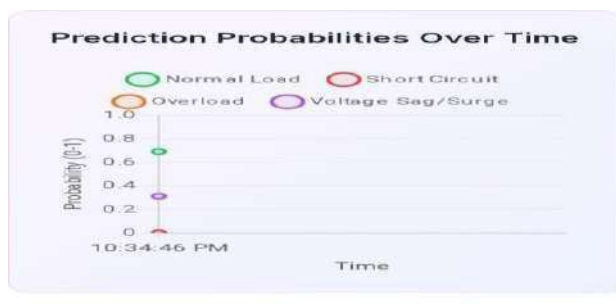


Fig 3 : AI powered suggestions



Fig 4: Feature graph

The Frequency graph represents the variation of supply frequency over time in the electrical system. Under normal operating conditions, the frequency remains close to the standard value of 50 Hz with only minor fluctuations. Sudden increases or decreases in frequency indicate abnormal conditions or possible electrical faults in the network. These feature graphs help in real-time monitoring.



Fig 5 : Hardware Circuit model

5. Conclusion

This paper presented an AI-Integrated Power Fault Detection System using Machine Learning for real-time monitoring and classification of electrical faults. The system combines embedded hardware, IoT communication, and machine learning techniques to provide accurate and intelligent fault detection. The Random Forest classifier achieved high accuracy in identifying abnormal operating conditions such as overloads, loose connections, and short circuits. The integration of ESP32, voltage and current sensors, backend processing, and a web dashboard enabled efficient real-time monitoring and visualization.

The proposed solution demonstrates that machine learning can significantly enhance the reliability, safety, and efficiency of modern electrical power systems. Future improvements may include integration with cloud computing, deep learning

algorithms, predictive maintenance, and automatic fault isolation mechanisms.

Future Enhancements

- a. Integration of advanced machine learning and deep learning algorithms to improve the accuracy and speed of fault detection in power systems.
- b. Expansion of the system to support real-time monitoring and fault prediction for large-scale smart grid networks.
- c. Implementation of cloud-based data storage and analytics for remote monitoring, historical data analysis, and performance evaluation

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