

A Survey on Tiny ML Based Electrical Arc and Loose Wire Fire Prevention System

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Publication Date: 2026/10/21

Abstract: Electrical faults such as arc faults, loose connections, overloads, and overheating can lead to serious fire hazards and equipment damage. This project presents a TinyML-Based Electrical Arc and Loose-Wire Fire Prevention System that combines intelligent fault detection, automatic protection, and IoT-based monitoring. The proposed system uses an ESP32 as the main controller to monitor voltage, current, temperature, and arc-related sound signals from multiple electrical branches. A TinyML-based detection approach is used to identify abnormal conditions such as arc faults, loose wires, and overloads, while relay-based protection isolates the affected branch without interrupting healthy branches. The system also provides real-time fire-risk assessment, OLED status display, SD-card fault logging, IoT dashboard monitoring, and mobile alerts. By integrating machine learning with electrical sensing and automatic fault isolation, the proposed system aims to provide an affordable, compact, and proactive solution for electrical fire prevention and energy monitoring. This survey discusses the existing techniques, sensing methods, machine learning approaches, IoT technologies, and research gaps related to intelligent electrical fault and fire prevention systems. TinyML, Arc Fault Detection, Loose Wire Detection, Electrical Fire Prevention, ESP32, IoT, Machine Learning, Fault Detection, Energy Monitoring.

How to Cite: P. V. Nimbalkar; Sandip Suresh Shingade; Sneha Santosh Koli; Triveni Vasant Nimbalkar (2026) A Survey on Tiny ML Based Electrical Arc and Loose Wire Fire Prevention System. *International Journal of Innovative Science and Research Technology*, 11(10), 1090-1092. <https://doi.org/10.38124/ijisrt/26oct676>

I. INTRODUCTION

Electrical systems are an essential part of modern homes, industries, and commercial buildings, but electrical faults can create serious safety risks, including equipment damage and electrical fires. Faults such as arc faults, loose-wire connections, overloads, and excessive temperature may develop gradually or occur suddenly, making early detection important for preventing major failures. Conventional protection devices such as fuses, circuit breakers, and overload relays mainly respond to excessive current and may not provide sufficient information about the early stages of certain faults.

Recent developments in Machine Learning, TinyML, embedded systems, and Internet of Things (IoT) have created opportunities for developing smarter electrical protection systems. Machine Learning can be used to identify abnormal patterns from electrical parameters such as current, voltage, temperature, and sound. TinyML enables these intelligent detection models to operate directly on resource-constrained microcontrollers, reducing the need for continuous cloud processing and enabling faster local decision-making.

The proposed TinyML-Based Electrical Arc and LooseWire Fire Prevention System integrates multiple sensors with an ESP32 microcontroller to continuously monitor electrical branches. Current and voltage sensors are used to observe electrical behavior, while a temperature sensor and microphone can provide additional information for detecting overheating and arc-related acoustic patterns. The system uses these inputs to identify conditions such as arc faults, loose wires, and overloads, and estimates the associated fire risk.

An important feature of the proposed system is its ability to perform automatic fault isolation. When an abnormal condition is detected in a particular branch, the corresponding relay can disconnect that branch while allowing other healthy branches to remain operational. The system also provides an OLED display for local status information, SD-card storage for fault logging, and IoT connectivity for real-time monitoring and alerts. The overall objective is to develop a compact, intelligent, and proactive electrical safety system that combines fault detection, automatic protection, fire-risk assessment, energy monitoring, and IoT-based supervision.

This survey reviews existing research related to intelligent electrical fault detection, TinyML-based monitoring, arc-fault detection, sensor-based fault identification, automatic protection, and IoT-enabled electrical safety systems, and identifies research gaps that can guide the development of such an integrated system.

II. LITERATURE SURVEY

➤ *Arc Fault Detection Using Signal Processing and Machine Learning*

Research on low-voltage distribution systems has investigated series arc detection using current and electromagnetic signatures. One study used Empirical Mode Decomposition (EMD) for feature extraction and a Support Vector Machine (SVM) classifier for identifying series arc faults. The study showed that arc signatures can be extracted from current-related signals and classified using machine learning. This approach demonstrates that ML can improve arc detection compared with relying only on conventional electrical protection [2].

➤ *AI-Based Arc Fault Detection*

A 2023 systematic review analyzed 63 studies related to artificial intelligence in arc-fault detection. It reported that AI methods can improve detection speed and accuracy, but also identified challenges such as missed detections, false detections, limited neural-network applicability, and insufficient datasets. These limitations are important when designing a real-time fire-prevention system.

➤ *Loose Connection and High-Resistance Fault Detection*

Loose electrical connections can create high contact resistance and localized overheating. Research on poor electrical contacts has shown that factors such as contact pressure, surface roughness, load current and air velocity influence the resulting temperature rise and fire risk. Contact pressure was identified as an important factor affecting the risk level.

➤ *Machine Learning for Series Arc Faults*

Several researchers have used machine-learning algorithms such as Random Forest, SVM and Extreme Learning Machine for arc-fault classification. For example, an ELM-based study extracted time- and frequency-domain features from high-frequency current signals and reported approximately 99 identification accuracy for series AC arc faults. This indicates that electrical waveform features can provide useful inputs for an intelligent fault-detection system.

➤ *Data-Driven Loose Contact Detection*

Recent research has also explored machine-learning approaches for detecting loose contacts. A 2025 study on smart meters proposed a data-driven method using Local Outlier Factor (LOF) and Multiple Linear Regression (MLR) to identify abnormal conditions caused by loose screw-terminal contacts, which can produce prolonged overheating and arcing. This supports the use of electrical measurements and ML for early loose-connection detection.

➤ *TinyML and Edge-Based Fault Detection*

TinyML enables machine-learning models to run directly on resource-constrained microcontrollers instead of sending all sensor data to a cloud server. Research on TinyML-based anomaly detection shows that ML models can be deployed on MCUs for real-time analysis while reducing communication requirements and response latency. This makes TinyML suitable for safety applications where rapid local decisions are important.

➤ *TinyML Application to Arc Fault Detection*

Texas Instruments' TinyML TensorLab includes an arc-fault detection example that performs binary classification between Normal and Arc conditions using current waveforms. The example is specifically designed for embedded applications such as solar inverters, battery systems and DC distribution, demonstrating that arc-fault classification can be implemented using a very small ML model on embedded hardware.

➤ *Research Gap*

The review of existing literature indicates that significant research has been conducted on electrical arc-fault detection using signal processing, machine learning, and deep learning techniques. Similarly, several studies have investigated the detection of loose connections or high-resistance faults using electrical and thermal parameters. However, most of the existing approaches primarily address these fault conditions independently rather than developing an integrated system capable of identifying both arc faults and loose-wire conditions.

Furthermore, several machine-learning and deep-learning-based approaches reported in the literature require comparatively higher computational resources and are generally evaluated using laboratory-based datasets or external processing platforms. Although TinyML has emerged as a promising approach for deploying machine-learning models on resource-constrained microcontrollers, its application to the combined detection of electrical arc faults and loose-wire conditions remains relatively limited. The use of lightweight models for real-time local inference can reduce computational and communication requirements while enabling faster fault response.

Another important gap is the integration of fault detection with preventive action. Existing studies often concentrate on classification or detection accuracy, whereas comparatively less emphasis is placed on developing a complete low-cost embedded system that can continuously monitor electrical parameters, identify abnormal conditions, generate an alert, and automatically disconnect the supply when a potentially hazardous condition is detected.

Therefore, the identified research gap lies in the development and validation of an integrated, low-cost, real-time TinyML-based system capable of detecting both electrical arc faults and loose-wire/high-resistance conditions using appropriate electrical and thermal sensing parameters. Such a system should perform local inference on a resource-constrained microcontroller and provide immediate

preventive action to reduce the possibility of electrical-fire incidents. Further evaluation under different load conditions, wire configurations, fault severities, and real-world operating environments is also required to establish the robustness and reliability of such an approach.

III. CONCLUSION

This survey reviewed the existing research on electrical arc-fault detection, loose-wire or high-resistance fault detection, machine-learning-based fault classification, and TinyML-enabled embedded systems for electrical safety. The reviewed studies demonstrate that electrical and thermal parameters can provide valuable information for identifying abnormal conditions associated with arc faults and loose connections. Machine learning and deep learning techniques have shown promising results in improving the accuracy and reliability of fault detection compared with conventional threshold-based approaches.

However, the literature also indicates that many existing methods focus on individual fault types and require comparatively higher computational resources or external processing platforms. The application of lightweight machine-learning models directly on resource-constrained microcontrollers provides an opportunity to overcome some of these limitations. TinyML can enable local, real-time inference with reduced communication requirements and potentially faster response, making it suitable for safety-critical embedded applications.

Based on the reviewed literature, an integrated system that combines arc-fault detection and loose-wire fault identification with real-time monitoring and automatic preventive action remains an important area for further research. Future studies should focus on developing lightweight and robust TinyML models, combining electrical and thermal sensing parameters, and validating the system under different load conditions, wiring configurations, and fault severities. In addition to detection accuracy, factors such as computational cost, inference latency, energy consumption, false-alarm rate, and reliability under real-world conditions should be considered. Such developments can contribute toward practical, low-cost, and intelligent electrical-fire prevention systems.

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