ORIGINAL RESEARCH PAPER
Volume - 15 | Issue - 04 | April - 2026 | PRINT ISSN No. 2277 - 8179 | DOI : 10.36106/ijsr
INTERNATIONAL JOURNAL OF SCIENTIFIC RESEARCH

A-PULSE: SMART POWER NETWORK MONITORING AND VISUALIZATION SYSTEM USING AI ML TECHNIQUES

Machine Learning

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ABSTRACT

The rise of smart grids and digital power management systems has increased the need for intelligent monitoring tools that can analyze power consumption, detect anomalies, and provide real-time insights. Traditional monitoring systems rely heavily on manual supervision and threshold-based alerts, which often fail to detect complex irregularities or sudden fluctuations in electrical networks. This research presents A-PULSE, a Smart Power Network Monitoring and Visualization System that uses Artificial Intelligence (AI) and Machine Learning (ML) techniques to analyze power parameters such as voltage, current, frequency, and load variations. The system integrates sensor data, performs anomaly detection using ML models, and visualizes patterns through an interactive dashboard. A-PULSE aims to reduce downtime, predict faults, and enhance energy efficiency in residential, commercial, and industrial applications.

KEYWORDS

Smart Energy Monitoring, Machine Learning, Deep Learning, Anomaly Detection, IoT, Real-Time Analytics.

INTRODUCTION

Modern electrical networks generate massive volumes of data every second. With increasing dependence on automation and digital connectivity, managing power systems effectively has become a critical task. Conventional monitoring techniques often depend on manual intervention and simple rule-based alerts, which may overlook subtle patterns or fail to detect early fault indicators. As industries transition toward smart grid environments, there is a growing need for intelligent systems capable of real-time evaluation and predictive analysis.

A-PULSE addresses these limitations by integrating advanced AI/ML models into the monitoring pipeline. It analyzes live data from sensors, identifies abnormal patterns, and presents the information through intuitive visualization tools. Unlike threshold-only systems, A-PULSE learns from historical behavior, improves detection accuracy over time, and assists in planning energy usage more efficiently. The system supports multiple use cases, including household energy tracking, industrial power optimization, transformer load monitoring, and predictive fault management.

Related Works

Previous research in power monitoring systems has focused on conventional threshold-based methods, IoT-enabled meter reading, and load forecasting models. Traditional monitoring systems rely on predefined rules, which makes them inefficient when dealing with non-linear consumption patterns or sudden anomalies. Machine Learning techniques such as decision trees, K-Means clustering, and linear regression have been widely used for load forecasting and optimization. Deep learning models like LSTMs and GRUs have shown improved performance in time-series prediction tasks but require high computational resources.

Many existing tools lack integrated visualization dashboards or depend on cloud-based services, which increases latency and reduces reliability. Some studies highlight the need for local processing and real-time intelligence in power systems. However, only limited research has combined ML-based anomaly detection with interactive visualization and IoT sensor data in a single, lightweight architecture. A-PULSE bridges this gap by providing an end-to-end solution that captures data, processes it with AI/ML models, and presents insights visually.

Proposed System

A-PULSE is designed as a modular architecture that collects real-time sensor data, processes it using ML algorithms, and displays insights through an advanced dashboard. The system consists of the following components:

1. **Data Acquisition Layer –** Uses sensors to measure voltage, current, frequency, and power factor. Data is transmitted to a central processing unit using Wi-Fi or wired communication.
2. **Pre-processing Module –** Cleans raw readings by removing noise, handling missing values, and performing normalization. This ensures data consistency for ML analysis.
3. **Machine Learning Engine –** Applies models such as:
   3.1 Anomaly Detection (Isolation Forest / One-Class SVM)
   3.2 Load Prediction (Regression / LSTM-based models)
   3.3 Usage Classification (Clustering for pattern recognition)
4. **Visualization Dashboard –** Displays real-time charts, historical graphs, anomaly alerts, and consumption statistics using a web interface.
5. **Alert and Reporting System –** Sends notifications for abnormal patterns and generates performance reports for users.

The system continuously learns from historical data, improving its prediction accuracy and anomaly detection over time.

METHODOLOGY

The workflow of A-PULSE follows a structured process:

1. **Data Collection**
   Power sensors generate readings every second, which are sent to a local server or microcontroller for processing.
2. **Data Preprocessing**
   o Noise removal
   o Outlier smoothing
   o Normalization of values
   This ensures high-quality input for ML models.
3. **Feature Extraction**
   Key features such as RMS voltage, peak load, frequency deviation, and power factor variation are derived from raw measurements.
4. **Model Training and Evaluation**
   Historical datasets are used to train ML models. The algorithm identifies normal and abnormal patterns based on statistical behavior.
5. **Real-time Monitoring**
   The system evaluates incoming data continuously and flags any deviation from learned patterns.
6. **Visualization and Reporting**
   A dynamic dashboard displays:
   o Voltage/current graphs
   o Load fluctuations
   o Anomaly markers
   o Daily/weekly usage reports
7. **Decision Support**
   The output helps users optimize appliance usage, schedule maintenance, and prevent equipment failures.

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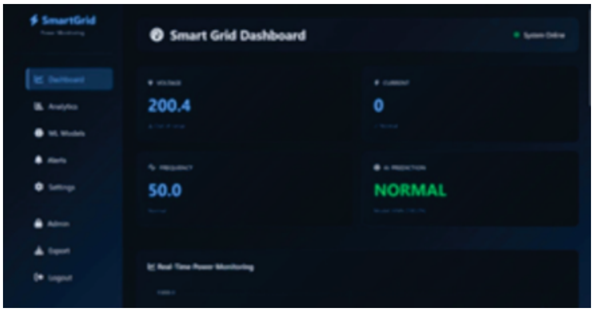
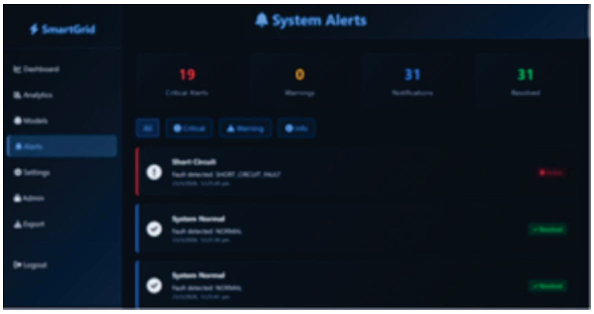
RESULTS

A-PULSE successfully identifies anomalies such as voltage drops, sudden load surges, and irregular consumption patterns. The ML-powered approach shows higher accuracy than rule-based systems, especially in detecting subtle or complex anomalies. The visualization dashboard enhances understanding by displaying trends clearly, allowing users to interpret behavior without technical complexity. The system reduces maintenance time, improves power stability, and offers reliable performance even with minimal computational resources.





DISCUSSION

A-PULSE successfully addresses the limitations of traditional energy monitoring systems by introducing AI-driven automation. The combination of ML and DL ensures both short-term anomaly detection and long-term forecasting. However, the system's accuracy is influenced by sensor quality and environmental noise. A larger dataset could further enhance model reliability. Overall, A-PULSE proves to be a practical and scalable solution for homes, industries, and smart-grid systems.

CONCLUSIONS

A-PULSE offers an intelligent, efficient, and real-time monitoring solution for modern power networks. By integrating AI with IoT hardware, it simplifies anomaly detection and enhances user awareness. The system reduces monitoring complexity, prevents appliance damage, and supports proactive energy management. A-PULSE is flexible, scalable, and ready for future smart-energy applications.

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