A Cost-Effective IoT and AI-Based System for Real-Time Detection of Low Voltage AC Distribution Overhead Conductor Breakage

Atharva Amrute[1], Somiel Gohil[2], Manav Gopinath[3], Prof. Medha Asurlekar[4]
[1,2,3] BTech Student, Dept. of AI & Data Science, K.J. Somaiya Institute of Technology, Mumbai, India
[4] Assistant Professor, Department of Artificial Intelligence and Data Science, K.J. Somaiya Institute of Technology, Mumbai, India

Abstract - This paper discusses about the design and implementation of a low-cost IoT and AI based real time conductor break-age detection of LV AC distribution overhead conductors. This system utilizes low-cost sensors to constantly measure the electrical parameters (current, voltage, and line continuity). An AI based fault detection algorithm using the XGBoost for data processing in a pipeline identifies breakage patterns from the other normal load or transient faults, thereby reducing the false alerts considerably. The system also dispatches real time alerts to KSEBL control center in case of confirmed faults through GSM networks. The prototype prototype records an accuracy ranging from 85-92% with end-to-end alert latency of below 5 seconds with the total hardware cost being around 2400.

Index Terms- LV conductor break-age; Fault detection; IoT; Edge computing; XGBoost; Machine Learning; GSM alert; power distribution

I. INTRODUCTION

Conductor breakage in LV AC overhead distribution lines is a serious issue for electricity utilities all over the world. A live brokenLV conductor falling on ground results in death of people, spread of fire, and large duration unplanned outages [1]. Conventional detection techniques such as conventional fuses, over-current relays, etc. Cannot detect high impedance faults on the LV distribution lines as the fault current is close to normal load current [1].

The new opportunity has arisen with low cost IoT sensors, microcontrollers and AI algorithms to solve the problem in low cost. The detection of the event of broken conductor is now feasible at the very low cost using low cost sensors embedded on LV distribution lines that monitor electrical characteristics at each instant and feed data into AI pipelines so that authorities are alerted for such event [7, 8].

This system provides low-cost IoT & AI based conductor breakage detector. This system monitors Current, Voltage & Continuity of the lines at 70Hz and predicts breakage events using edge-computing and sends alerts to KSEBL control center via GSM. All other systems either are too costly for a monitoring point and cost hundreds of thousands of rupees, or it can only detect the faults in the offline state and not in the real time state.

II. LITERATURE REVIEW

A number of researchers have conducted work on overhead conductor fault detection, power line monitoring etc. Utilizing signal processing, machine learning, sensor fusion techniques. In this section, a literature survey of the important contributions and the identified research gaps by proposed system is presented.

A. IoT based Power Line Monitoring Systems

IoT based power line monitoring systems have reported monitoring of LV lines in real time through cloud based analytics [2019, IEEE Access]. In these works, it has been demonstrated that continuous acquisition of characteristics from overhead lines can be achieved using low cost sensors module. But these works depend completely on the cloud and do not take in account the scenario where internet is not available and they lacks in intelligence to work at the local machine.

B. Machine Learning based Fault Classification

Some works have demonstrated potential in ML based fault classification like downed conductor detection using SVM classifier [2020, Elsevier] and reviews about AI based detection of fault [2023, IEEE TAC]. These works have presented accurate prediction of fault in different state using supervised classifiers but in no cases real time condition is accounted, and alert dispatch is discussed.

C. High Impedance Fault detection

Use of wavelet transform and neural networks to detect High impedance fault on the distribution lines has been widely explored [2017, IEEE TPWRD] with a number of methods for feature extraction and pattern recognition. Further it has been shown that AI based solution could provide real time fault detection by CNN approach [2021, IEEE IoT Journal]. Though most of these are designed for medium/high voltage networks, not for LV segments which is a major cause of public deaths.

D. Research Gap

There is no reported solution which integrates all the features like real-time edge based fault detection on cheap hardware, AI based reduction of false alarms, automated alert dispatch on GSM and finally deployment cost less than 5,000 per monitoring point.

III. SYSTEM DESIGN AND ARCHITECTURE

A. Problem Statement Framing

The design of the system is driven by the shortcomings of existing solutions. Namely, absence of low-cost, real-time monitoring and detection platforms for LV overhead lines and absence of intelligent, automated alert dispatch mechanism for such platforms. The problem statement is therefore: 'Development and design of low cost IoT-based monitoring system that acquire current, voltage and line continuity data in real-time from LV AC overhead conductor, identify fault event and subsequently trigger automatic alerts after rejection of false alarms'.

B. Overall System Architecture

The designed system consists of three stages-hardware at distribution pole (layer1), a data analysis component that run on host system (layer 2) and a presentation module for visualization (layer3). Each layer contains appropriate module with separation of task in accordance with the modern IoT architectures [7, 9].

C. Fault Processing Pipeline

Data acquisition from the sensors is done at 70Hz through USB serial at 115200baud each record contains timestamp, current, voltage, continuity and value. At DSP stage per cycle RMS are extracted. Using a Butterworth low-pass filter, the acquired signal is filtered from noises then its PSD estimated using Welch's method that can determine the harmonics distortion signature. A features vector of 12 parameters are computed from each sliding window, parameters like decrease in magnitude of current, rate of increase of current, sag depth in voltage, state of continuity signal, displacement of power factor, index of harmonics distortion etc [10, 11].

D. AI based False Alarm rejection

The primary uniqueness of the system is the transient discriminator which suspends the fault classification when a non-fault disturbance is detected like transients during startup of motor, load switching. While the threshold-based systems face huge problems regarding false alarm rate, context sensitive analysis allows for high accuracy with significantly reduced number of false alarm. Events that are found with a high confidence have immediate GSM dispatch but events with lower confidence will only be logged for trend analysis.

IV. IMPLEMENTATION

A. Hardware Stack

The hardware node for the proposed system consists of an ESP32 DevKit V1 module (240 MHz dual-core, Wi-Fi/Bluetooth, 18 ADC ports), which can perform computation efficiently and is very cheap (~500). A split core current transformer SCT-013 which performs current measurement without breaking the line and an isolated voltage sensor module ZMPT101B that determines the AC voltage level. An optical coupler is used for detecting line continuity which has zero resistance when the line is not broken and infinite when line is broken. Finally the system uses a quad-band SIM800L module which can send an SMS alert over the cellular network using the AT command over serial UART. Total cost of prototype is approximately 2400.

B. Software Stack

All the signal processing functions are developed in Python 3.x. The implementation uses SciPy for butter-worth filtering and Welch PSD method and Numpy for RMs computation and features vector construction. The XGBoost is used for four classes classification. Streamlit application is used for dynamic waveform and values display of monitoring parameters, event history of the logged data, automatic PDF report generation with ReportLab. The ESP32 microcontroller has the ESP32 firmware written in Arduino IDE that streams sensor readings through serial interface. [12, 13, 14]

C. Security and Access control

Role-based access control is implemented for distinguishing the field operators from control center operators. The access is persistent throughout the session of data acquisition. All fault logs consist of user-ids of field operator or control center administrator who registered fault along with the timestamp and type of fault. The SMS dispatching is also rate limited for repeated faults.

V. EVALUATION AND RESULTS

A. Accuracy of Classification

XGBoost classifier has been trained and tested using combination of simulated fault condition and real distribution network recorded data. Four types of line condition classes have been correctly identified and classification accuracy has been determined within range of 85%-92%. Full Conductor Breakage was detected with a highest accuracy and high certainty due to presence of a distinct concurrent signature of zero current, more than 40% voltage sag and Low on conductor continuity in sustained. Normal condition and Transient Disturbance condition were discriminated more than 90%.

B. Performance of the system

The entire DSP and classification pipeline was able to compute a signal window within 50-80 ms. There was 65% reduction in false positive alarms compared to threshold only system by employing AI based transient discriminator. End-to-end alarm dispatch with GSM SMS was recorded less than 5 seconds from fault declaration. The acquired current and voltage signals recorded at 70 Hz displayed fairly accurate RMS calculation and clean signal characteristics upon conductor breakage beginning.

C. Detection Parameter Ranges

TABLE I. DETECTION PARAMETER RANGES

Line Condition	Current Drop	Voltage Sag	Continuity
Normal	0–5%	0–3%	HIGH
Transient	5–30%	3–15%	Momentary
Partial Fault	30–70%	15–40%	Intermittent
Full Breakage	>70%	>40%	Sustained LOW

D. Comparative Analysis

TABLE II. COMPARISON WITH EXISTING SYSTEMS

Feature	Proposed	SCADA	Academic
Sensors	CT+V+C	Multi	Varies
Fault Classes	4	Threshold	2–3
ML Model	XGBoost	Proprietary	SVM/RF
Real-Time	Yes	Partial	Offline
Alert Dispatch	GSM SMS	Landline/IP	No
False Alarm Gate	AI-based	Threshold	Post-proc.
Cost	~₹2,400	>₹5L	Research
Open Source	Yes	No	Dataset

VI. CONCLUSION

This paper proposed a low cost real time IoT & AI based overhead LV AC overhead conductor breakage detection system. This system uses ESP32 microcontroller, coupled with CT current, voltage and continuity sensors. The electrical data is processed through an edge-computing DSP pipeline and fault conditions are classified with pre-trained XGBoost model. It achieves 85-92% classification accuracy, below 100ms prediction latencies, and 65% fewer false alarms than the threshold based baselines and sends GSM alert to respective field engineers with 5 sec end-to-end latency. The total cost of prototype hardware is around 2,400.

As against, a few hundred thousands of rupees per monitoring point required to install and maintain commercial SCADA systems, the work proves that AI-based fault detection & alerting at low costs is possible with commercially available off-the-shelf electronics components & open source software. The

AI based transient discriminator addresses one of the major problems in practical deployment of low cost systems, ie; correct identification & rejection of false alarms in the presence of motor start-up or load switching transients.

Future work comprises integration of 1D-CNN and LSTM deep learning models for higher classification accuracy, compacting hardware through custom PCB designing, cloud based multi-feeder analysis through AWS IoT Core, a Flutter mobile application for field engineers, and a field trial conducted in association with KSEBL for commercial certification.

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