

ANOMALY DETECTION IN POWER CONSUMPTION USING MATLAB

1. Objective

The objective of this project was to detect and classify anomalous energy consumption patterns across residential and commercial properties using smart meter data. The goal was to improve grid reliability and identify unauthorized electricity usage or system faults, using automated anomaly detection algorithms built in MATLAB.

2. Client and Use Case

Client Type: A regional energy distribution company serving over 100,000 smart-meter-equipped customers in the Midwest, United States.

Use Case: The utility provider was experiencing unexplained fluctuations in energy distribution and needed a scalable, automated way to flag abnormal consumption behavior. Manual review was inefficient and reactive. The client sought an algorithmic solution to monitor real-time data feeds and trigger alerts based on statistical deviations and usage irregularities.

3. Dataset Overview

Source: Smart meters installed in residential and small commercial buildings

Time Period: January 2022 – March 2023

Volume: ~2.1 million meter readings from 12,500 meters (hourly resolution)

Variables Included:

- Meter ID
- Timestamp
- Energy Consumed (kWh)
- Tariff Type
- Region Code
- Customer Classification (Residential/Commercial)

4. Methodology

4.1 Data Preparation

- Imported and preprocessed time-series data using MATLAB's timetable and retime functions.
- Missing values handled using spline interpolation (fillmissing with method = 'spline').
- Consumption patterns normalized using Z-score transformation per customer class and hour-of-day.

4.2 Anomaly Detection Approach

Model Used: Hybrid Statistical + Machine Learning Approach

1. Statistical Control Limits:

- Applied moving-window analysis to define control limits dynamically.
- Flagged observations beyond ± 3 standard deviations from hourly rolling means.

2. Isolation Forest (MATLAB Custom Implementation):

- Applied to high-resolution data clusters (residential vs. commercial) to capture contextual anomalies.
- Trained using 90% baseline data; validated using known outage/misuse incidents.

3. Rule-Based Layer:

- If energy consumption > historical 95th percentile on non-working days → trigger alert.
- Region-wide flatline readings for > 4 hours → flag as outage risk.

5. Key Findings

- Detected **3,072 anomalous patterns**, 41% of which aligned with historical fault or tampering logs.
- Identified **energy theft** patterns among 28 commercial clients (e.g., abrupt zero-to-peak spikes).
- Real-time dashboards built using animatedline and heatmap for hourly updates.

Validation Accuracy:

- Precision: 0.89

- Recall: 0.82
- F1 Score: 0.85

6. Visualizations and Tools

- **Control Chart Overlays:** Hourly consumption charts with upper and lower bounds
- **Heatmaps:** Usage anomalies per region and hour
- **Dashboard:** Real-time alert panel built in MATLAB App Designer

7. Deliverables

- Cleaned and annotated dataset (CSV + .mat format)
- MATLAB scripts (.m files) for anomaly detection pipeline
- 18-page PDF report outlining methodology, findings, and recommendations
- MATLAB-based GUI tool for internal operations team
- Deployment plan for integrating detection with SCADA system alerts

8. Strategic Outcomes

- Reduced grid downtime investigation time by 36%
- Enabled near real-time detection of meter faults and unauthorized usage
- Facilitated preventive action against 6 potential overload events in January 2023
- Helped transition from manual review to an automated anomaly scoring system

9. Tools and Libraries Used

- MATLAB R2023a
- Statistics and Machine Learning Toolbox
- Signal Processing Toolbox
- App Designer for dashboard UI
- Python integration via matlab.engine for API consumption from AWS smart meter repository