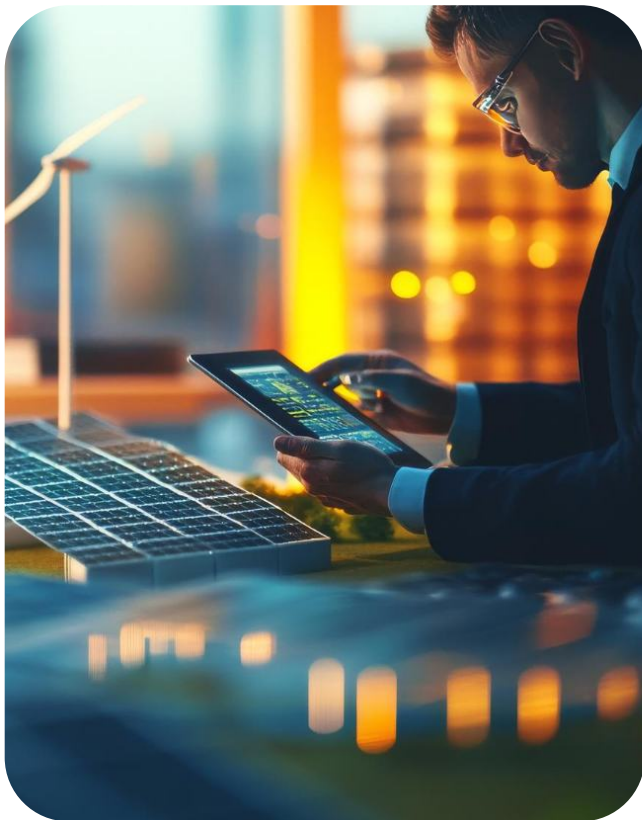


AI-Powered Industrial Energy Anomaly Detection for Smart Manufacturing Operations

Transforming industrial energy monitoring with hybrid AI models, contextual intelligence, and real-time anomaly detection.

Overview

- Developed a scalable anomaly detection framework combining STL decomposition, Prophet, LSTM, and probabilistic device state classification.
- Enabled real-time monitoring of industrial assets through cloud-native sensor ingestion, contextual anomaly analysis, and intelligent alert filtering.
- Achieved over 90% precision and recall across tested devices while significantly reducing false-positive alerts.
- Improved operational efficiency, energy optimization, and sustainability outcomes through proactive detection of abnormal machine behavior.



Client Profile

The client is a Sweden-based smart energy management startup focused on helping industrial enterprises optimize energy consumption and meet sustainability objectives. Its SaaS platform delivers actionable operational insights, anomaly detection, forecasting, and reporting capabilities that enable manufacturers to monitor, reduce, and predict energy usage across complex industrial environments.

Challenges: Building Context-Aware Anomaly Detection

Industrial equipment such as ovens, furnaces, cutting machines, surface treatment systems, foaming units, and shaping machines exhibited highly variable energy consumption patterns across production cycles. Distinguishing meaningful anomalies from expected operational fluctuations, seasonal behavior, and recurring usage patterns was critical to ensuring reliable interventions and reducing unnecessary alerts.

The client required a highly adaptive and scalable solution capable of:

- Detecting anomalies across multiple device categories with varying consumption characteristics.
- Differentiating operationally significant deviations from normal seasonal and time-based patterns.
- Accurately classifying machine states despite overlapping power usage ranges.
- Reducing false positives and alert fatigue through contextual filtering aligned with business operations.
- Supporting real-time monitoring, traceability, and long-term scalability across multiple manufacturing environments.

QBurst Solution: Hybrid AI-Powered Energy Intelligence Platform

We developed a cloud-native anomaly detection framework that combined advanced time-series analysis, probabilistic state classification, and business-aware filtering to identify operationally relevant anomalies across industrial manufacturing environments.

Our approach began with exploratory data analysis and statistical modeling to understand historical energy consumption patterns across devices. We analyzed power demand variations over time, identified different operational states, and observed recurring spikes, drops, and seasonal behaviors associated with production schedules and time-of-day dependencies.

Initial statistical approaches successfully identified basic outliers but lacked the ability to account for historical trends and sequential dependencies. We then evaluated clustering-based machine learning techniques, which proved effective for isolated anomalies but insufficient for contextual time-series analysis. These findings highlighted the need for models capable of learning both temporal relationships and seasonal trends.

To address this, we implemented a hybrid anomaly detection architecture using STL decomposition with both Prophet and LSTM models.

- STL decomposition isolated trend, seasonal, and residual components to improve anomaly sensitivity.
- Prophet modeled predictable seasonal behavior, recurring operational cycles, and long-term trends.
- LSTM neural networks captured complex temporal dependencies and contextual anomalies that traditional statistical methods could not identify effectively.
- The combined STL + Prophet and STL + LSTM approach improved anomaly coverage by detecting both abrupt deviations and gradual behavioral shifts while minimizing false positives.

The solution continuously refined model accuracy through feedback-driven tuning and adaptive learning mechanisms.

Real-Time Sensor Integration and Data Pipeline

We implemented a scalable real-time ingestion framework integrating diverse industrial sensors monitoring:

- Energy consumption
- Water flow
- Temperature
- Humidity

Edge devices, including Raspberry Pi systems, facilitated local sensor data collection and communication with gateways. MQTT was used as the lightweight messaging protocol for efficient and reliable cloud transmission, ensuring high data integrity with minimal to zero data loss.

Device State Classification and Contextual Intelligence

To improve anomaly contextualization, we developed a dedicated device state classification module capable of identifying operational states such as Off, Sleep, Standby, and Production. Traditional hard clustering methods proved ineffective because several industrial devices exhibited overlapping power ranges across different operational states. To address this complexity:

- Gaussian Mixture Models (GMM) enabled probabilistic state classification using soft clustering techniques.
- Smoothing filters minimized transient fluctuations and improved transition reliability between states.
- The classification engine was tightly integrated with the anomaly detection pipeline, enabling each anomaly to be evaluated within its operational context.

This contextual awareness significantly improved the relevance and reliability of alerts delivered to end users.

Intelligent Notification Filtering and Traceability

We designed a rule-based filtering layer in close collaboration with the client to ensure only business-critical anomalies generated notifications. This approach substantially reduced alert fatigue while improving user trust and operational usability. Configurable filtering logic incorporated:

- Operating schedules
- Duration thresholds
- Device-specific power boundaries
- Production cycle expectations
- Equipment-specific behavioral rules

All anomalies, classifications, and contextual explanations were visualized through dynamic dashboards with full traceability support, including:

- Time-series graphs
- Annotated anomaly windows
- Device-state overlays
- Historical event tracking

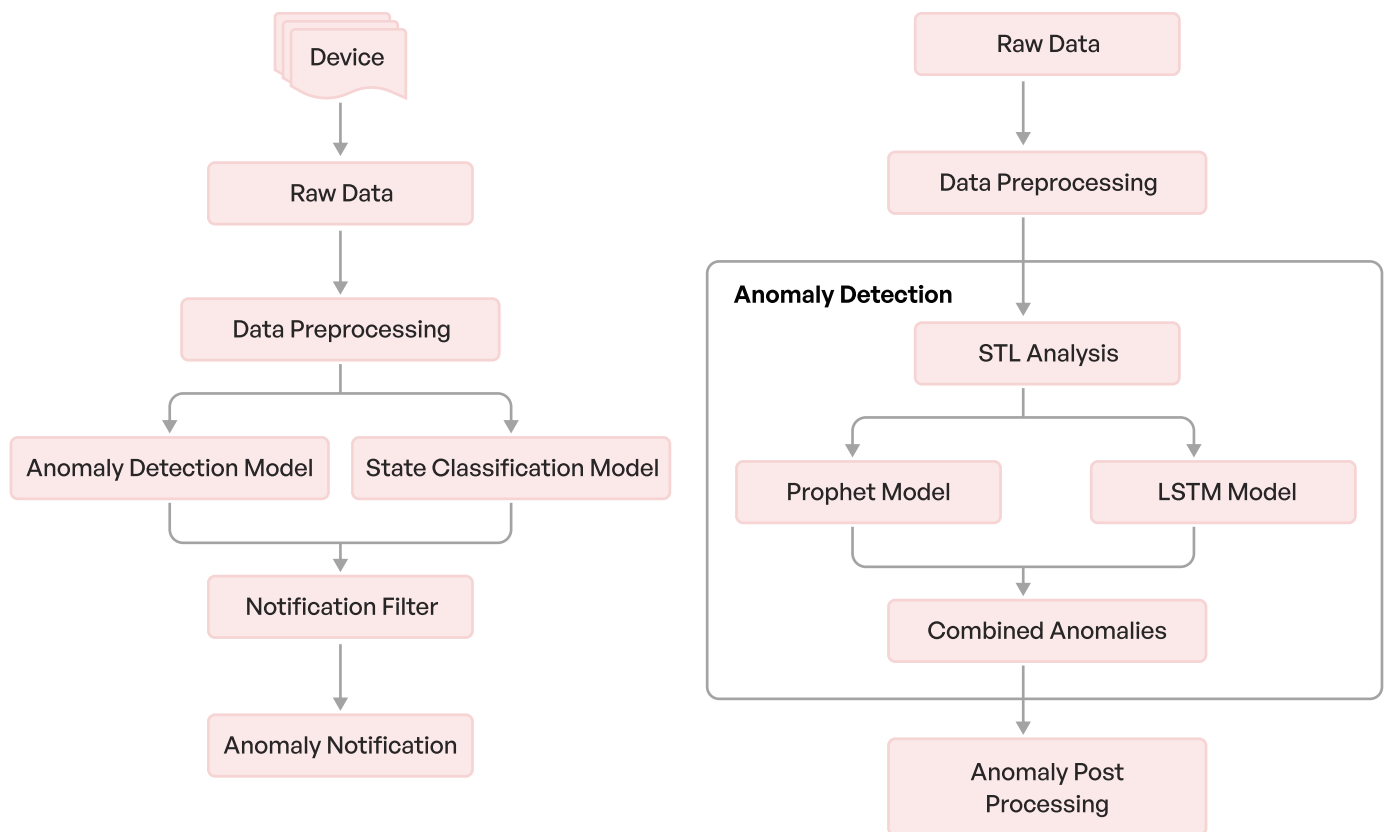
The frontend platform, built using React and HighCharts, enabled intuitive real-time and historical monitoring experiences. Integration with AWS API Gateway also supported third-party visualization and seamless Power BI exports for advanced analytics and reporting.

Scalable Cloud-Native Architecture

The platform was designed as a modular, containerized microservices architecture capable of horizontal scaling across multiple factories and device classes. This modular design enabled independent scaling and updating of system components without impacting overall platform stability. Independent services handled:

- Anomaly detection
- Device state classification
- Filtering logic
- Data ingestion
- Visualization workflows

The solution leveraged a robust AWS ecosystem including EC2, AWS MQ, RDS, S3, Lambda, API Gateway, SQS, ECR, Kinesis Data Streams, EventBridge, SageMaker, Systems Manager, Auto Scaling Groups, and Application Load Balancers to support reliability, scalability, and operational efficiency.



Anomaly Detection Workflow

Key Detected Anomalies

The system successfully identified a wide range of operationally significant anomalies, including:

- Machines running unexpectedly during weekends
- High power consumption during non-production hours
- Extended standby behavior during active production windows
- Long inactivity periods within expected production cycles
- Delayed machine starts and early shutdowns
- Continuous low-power activity outside operational schedules
- Abnormally high energy consumption during production cycles

Technical Highlights

- Hybrid STL + Prophet and STL + LSTM anomaly detection framework
- Probabilistic device state classification using Gaussian Mixture Models
- Real-time MQTT-based industrial sensor communication
- Edge-enabled data acquisition using Raspberry Pi devices
- Context-aware anomaly tagging and business-rule-driven filtering
- Cloud-native containerized microservices architecture for horizontal scalability
- Continuous model refinement through adaptive feedback loops
- Interactive React and HighCharts dashboards with Power BI integration
- Modular architecture supporting independent service updates and scaling

Impact

- Achieved over **90%** precision and recall across tested industrial devices for anomaly detection accuracy.
- Enabled real-time identification of operational inefficiencies and abnormal machine behavior.

- Reduced unnecessary alerts through contextual filtering and intelligent state-aware anomaly classification.
- Improved operational efficiency by enabling faster fault detection and proactive interventions.
- Supported sustainability initiatives by reducing energy wastage, idle machine operation, and underutilized equipment usage.
- Delivered a scalable AI framework adaptable across multiple device categories, production environments, and factory setups.