# Artificial Intelligence:

# Energy Consumption Anomaly Detection with Edge AI

## Introduction

Cost effective and efficient electric power generation as well as power distribution has become a key factor for economic development and stability around the world. Technical losses as well as non-technical losses in electric power distribution systems - also known as ‘commercial losses’ - are a significant problem worldwide, particularly in countries with relatively high energy cost compared to regional income levels and GDP. They also threaten the financial stability of the energy sector and regional quality of life.

Commercial losses include all sorts of illegal energy consumption including energy theft, meter manipulation / tampering, and other types of fraud such as meter bypassing in various forms, use of magnets to slow down electro-mechanic / magnetic meters, altering the current flow direction, tampering CTs / current transformers or ratios, as ell as unauthorized resetting of meters.

In 2010 the World Bank estimated that power distribution service operators (DSO), electricity distribution utilities and municipalities lose a staggering $96 billion USD annually due to commercial losses, which includes theft, fraud, meter manipulation and billing errors. India is a case where non-technical commercial losses, capturing widespread theft and deficiencies in billing and collection, are high. In Cameroon, illegal connections of electricity and the manipulation of meter readings by unscrupulous subscribers lead to energy loss, estimated at about 25% of power generated. In Brazil, it is estimated that 42% of all losses are non-technical commercial losses - due to theft by illegal connection. These losses have significant financial consequences for the power generators, utility companies, governments, and consumers and can ultimately hinder the growth and development of the electricity sector and slow down the growth of entire national economies.

Commercial losses include energy that is not metered properly, meter installation delays, illegal connections and 3rd party connections known or unknown by the consumer, defective or tampered electricity meters as well as meter reading mistakes.

Moreover, in contrast to fraud and theft cases, other examples of technical energy losses include ground faults caused by vegetation touching overhead power lines and transformer connectors - which can lead to unusual energy losses. This occurs when the vegetation creates a low-impedance path between the conductors and the ground, allowing electrical current to flow through the plant and never reaching the meter of the energy consumers. This results in an energy loss that is not accounted for in the utility's billing process and revenue. To manage vegetation and prevent these losses, utilities can use various methods such as regular trimming or pruning, installing physical barriers between the power lines and vegetation, or using herbicides to control plant growth. Implementing such practices can significantly help reduce the occurrence of energy losses caused by vegetation.

Also the accumulation of salt sediments from seawater on powerline insulators and poles in coastal areas causes electrical leakage and technical energy loss. This phenomenon, known as salt flashover, can result in financial losses for electricity utilities that are quite significant on the long term. To avoid such technical losses, regular inspection and cleaning must be carried out to remove the salt spots. However, this can be a challenging, expensive and time-consuming task. Here monitoring systems should be installed to detect salt flashover events and provide early warning to maintenance crews. These systems can use sensors to detect frequent ground faults, changes in voltage or current levels, as well as environmental factors such as temperature, salt-in-air level and humidity, which can indicate the presence of salt deposits on insulators and poles.

That being said, distribution companies must first identify and detect the various loss cases as well as their root causes in order to combat this phenomenon. Therefore, these companies are increasingly turning to technology solutions, such as using advanced Artificial Intelligence based outlier and anomaly detection algorithms to detect anomalies in consumption patterns and identify potential instances of fraud and theft on one hand, or naturally occurring ground faults on another hand.

## Outlier Detection Optimization

Outlier detection algorithms are a critical component of many industrial smart applications related to predictive maintenance and consumption monitoring. These algorithms can be used to identify anomalies in data that indicate potential equipment failure or deviations from expected consumption patterns. To optimize these algorithms for industrial contexts, several factors should be considered, including the characteristics of the input data, the performance metrics of the algorithm, and the implementation requirements of the algorithm.

## Performance Metrics Optimization

One critical factor in optimizing outlier detection algorithms for industrial contexts is the selection of appropriate performance metrics. In industrial applications, the primary objective of outlier detection algorithms is to minimize the number of false negatives (missed anomalies) while minimizing the number of false positives (false alarms). The selection of appropriate performance metrics should, therefore, take into account both the sensitivity and specificity of the algorithm. Metrics such as precision, recall, and F1 score are commonly used to measure the performance of outlier detection algorithms.

## Input Data Optimization

Another critical factor in optimizing outlier detection algorithms for industrial contexts is the selection of appropriate input data characteristics. The input data should be selected to maximize the predictive potential of the algorithm and the accuracy of its outputs. The following are some of the critical characteristics of input data that need to be present to achieve this objective.

First, the input data should be representative of the operating conditions and environments of the equipment or system being monitored. This means that the data should be collected from a wide range of operating conditions, including normal and abnormal operating conditions. This will enable the algorithm to learn and detect anomalies that occur under a wide range of operating conditions.

Second, the input data should be clean and preprocessed to remove any noise or irrelevant data. This will ensure that the algorithm is not influenced by spurious or irrelevant data that may lead to false alarms or missed anomalies.

Third, the input data should contain both temporal and contextual information. Temporal information such as time-series data can provide valuable insights into the behavior of the system over time, allowing the algorithm to detect anomalies that occur over extended periods. Contextual information such as environmental factors can provide valuable insights into the operating conditions and environments of the equipment or system being monitored, enabling the algorithm to detect anomalies that occur under specific operating conditions.

Fourth, the input data should be diverse and include data from multiple sources. This will enable the algorithm to detect anomalies that may be missed by using a single source of data. For example, consumption monitoring algorithms may use data from multiple sensors, including temperature sensors, pressure sensors, and flow meters, to detect anomalies in consumption patterns.

Fifth, the input data should be labeled to facilitate the training and evaluation of the algorithm. Labeling the data involves identifying which data points are anomalous and which are normal. This information can be used to train the algorithm and evaluate its performance.

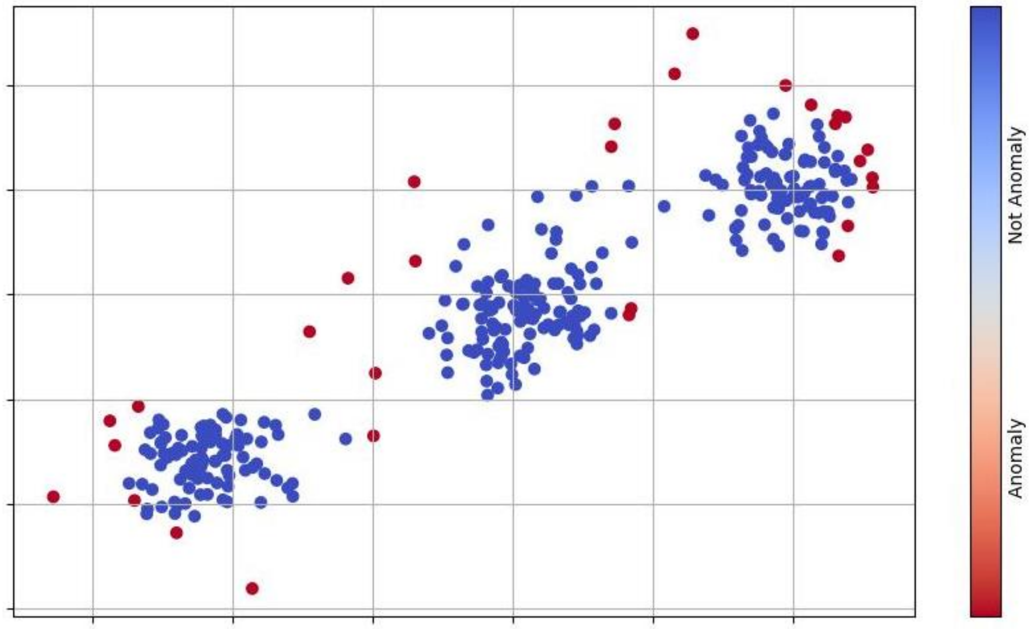


Figure 1: Customer Clusters sample and Edge AI PowerBrain™ identified Outliers

Algorithm Optimization

Once the input data has been optimized, several techniques can be used to optimize the algorithm's performance further. One of the most effective techniques is to use ensemble learning, which involves combining the outputs of multiple algorithms to improve the analytic performance substantially. Ensemble learning can help reduce the number of false alarms and missed anomalies (losses), improving the overall accuracy of the commercial loss detection process. (e.g. AI learning and detection of energy consumption patterns combined with advanced anomaly detections.)

Another effective technique for optimizing outlier detection algorithms is to use feature engineering. Feature engineering involves selecting or deriving features from the input data that are most relevant for anomaly detection. (In predictive maintenance applications, for example, features such as vibration data, temperature data, and current data can be used to detect anomalies in the behavior of the equipment.)

Operational Process Optimization

Additional business process optimizations and operational measures that could be taken into account to reduce commercial losses include:

- Installation of Smart Meters and Smart Prepaid Energy Meters with tamper and load survey logging capabilities
- Proper technical sealing of meters with seals
- Installation of CTs/PTs (current transformers/power transformers) in sealed meter boxes so that the terminals are not exposed for tampering and/or bypassing
- Performing pre-installation testing of meters to confirm their accuracy and quality
- Ensure accuracy in all meter reading and billing related process steps
- Carry out regular energy audits with commissioned auditors or revenue protection inspectors, covering the feeders and all types of consumers to ensure that there is no unexpected revenue leakage.
- Strategically choose positions for energy meter installation (e.g. at medium voltage

powerlines and Ring Main Units / RMUs) to expose any illegal activities
• Provide easy payment solutions (e.g. online payment) and an adequate number of counters and customer collection centers

## Business Benefits

Non-technical losses in electric power distribution grids, whether caused by theft, fraud, billing errors, or natural phenomena, pose a significant commercial and operational challenge to utility companies, governments, and consumers worldwide. To combat this widespread phenomenon, companies increasingly turn to technology solutions such as cost-effective Edge AI empowered data-driven anomaly detection algorithms to identify and detect various types of losses and their respective root causes with Artificial Intelligence.

The optimization of Internet-independent Edge AI algorithms for energy industry context requires consideration of several critical factors including appropriate input data characteristics and sufficiently high data sample rates, selection of appropriate performance metrics, and AI algorithm optimization techniques such as ensemble machine learning.

With cost effective Edge AI algorithms, power Distribution Network Operators can minimize the financial losses caused by non-technical 'commercial' losses and ultimately contribute to the growth and development of the electricity sector and their whole region. At the same time, Edge AI can help identify areas of technical losses as well.

Based on the World Bank estimations from 2010 that power Distribution Service Operators (DSO /DNO), electricity distribution utilities and municipalities lose a staggering $ 96 billion USD annually due to commercial losses, a reduction of only 10% would increase the total revenues by $ 10 billion USD each year. This is why identifying and continuously fighting all types of energy losses with Edge AI remains a key factor for revenue protection and continued success of all energy businesses.

By Zied Moalla



## About PowerBrain.Shop®

PowerBrainShop Holding Corporation supplies Artificial Intelligence (AI) software including an industrial AI product development and training platform for the next generation of Edge Artificial Intelligence (Edge AI) as well as powerful AI software 'brains' - so-called AI PowerBrains™ for various industry applications. The impossible is made possible by enabling and significantly simplifying the next disruptive development step - the broad adoption of Internet-independent Edge AI - including development, training, validation and quality assurance, delivery, monitoring and auditing of artificial intelligence for users and use cases in different industries, business domains and organizations. As a driving force in the artificial intelligence segment, we partner with all those who want to make our world more efficient with intelligence.

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