

Smart Meter Data Analytics for Loss Reduction in Power Distribution Systems in Nigeria

Israel Temitayo Ogundele

Faculty of Engineering Department of Engineering Management
Uskudar University Istanbul, Türkiye
Oluwatemitayoj@gmail.com

Mehmet Savsar

Professor of Industrial Engineering
Uskudar University Istanbul, Türkiye
msavsar@gmail.com

Abstract

The Nigerian Electricity Supply Industry (NESI) faces high Aggregate Technical, Commercial, and Collection (ATC&C) losses, averaging 35.22% in late 2024. This research proposes a framework leveraging smart meter data analytics to identify and mitigate these losses. By using high-frequency data from Advanced Metering Infrastructure (AMI), the study distinguishes between technical and non-technical losses (NTL). The methodology integrates machine learning (Random Forest, SVM) with load flow analysis. Findings provide a strategic roadmap for Distribution Companies (DisCos) to transition from reactive to proactive loss reduction, enhancing revenue and supply reliability.

Keywords

Smart Meters, Data Analytics, Loss Reduction In Nigeria, Machine Learning

1. Introduction

The electrical power distribution system in Nigeria is characterized by systemic inefficiencies and financial instability. The transition to “Smart Grids” via Smart Meters allows for two-way communication and high frequency data collection. For Nigerian Discos, adopting smart meter analytics is essential to stop revenue leakage and operational decline.

1.1 Background and Problem Statement

Aggregate Technical, Commercial, and Collection (ATC&C) loss is the primary metric for distribution efficiency. In Nigeria, these losses are exacerbated by overloaded feeders, widespread electricity theft (meter bypassing), and poor collection rates. Traditional methods lack the granularity to pinpoint these losses. There is an urgent need for a data-driven framework leveraging the National Mass Metering Program (NMMP) data to optimize operations.

1.2 Objectives

1. Audit current ATC&C loss profiles across the 11 Nigerian DisCos.
2. Design a multi-layered data analytics architecture for real-time monitoring.
3. Develop machine learning algorithms to detect anomalous consumption indicative of theft..

4. Formulate mathematical models for precise technical loss estimation.
5. Evaluate the financial impact of the proposed framework.

2. Literature Review

2.1 Theoretical Framework

Loss analysis is governed by the Law of Conservation of Energy ($P_{in} = P_{out} + P_{loss}$) and Power Flow Theory. Information Theory helps identify anomalies by analyzing the entropy of consumption data. The Theory of Planned Behavior explains the socio-economic drivers of electricity theft.

2.2 Global and Local Context

While developed nations use smart meters for demand-side management, emerging economies like India and Brazil use them primarily for loss reduction. In Nigeria, the Meter Asset Provider (MAP) and NMMP regulations aim to close the metering gap. Studies by Oluleye et al. (2023) and Nwafor (2022) highlight that AI algorithms significantly outperform manual inspection in detecting non-technical losses.

3. Research Methodology

3.1 Research Design

The study adopts a mixed-methods design, combining quantitative AMI data analysis with qualitative regulatory and operational reviews. Data is sourced from representative DisCos (e.g., Ikeja and Jos) to cover urban and rural contexts.

3.2 Data Analysis Pipeline

1. Data Acquisition: Collecting 15-60 minute interval data (kWh, V, I, Power Factor).
2. Pre-processing: Handling missing values via interpolation and removing outliers.
3. Technical Loss Modeling: Calculating I²R line losses and transformer core/load losses.
4. Machine Learning: Training Random Forest, XGBoost, and LSTM models on labeled datasets to classify “Theft” vs. “Normal” consumption.

4. Data Analysis and Results

Analysis shows a clear correlation between feeder length and technical loss. Rural feeders with low load density exhibit losses up to 23%, while industrial urban feeders average around 4% (Table 1).

Table 1. Technical Loss Breakdown by Feeder Type

Feeder Type	Avg. Line Length	Total Tech. Loss (%)
Industrial	12.5 km	4.0%
Urban Res.	4.2 km	10.0%
Semi-Urban	1.8 km	16.0%
Rural Res.	0.5 km	23.0%

4.2 Machine Learning Performance

Random Forest and XGBoost models achieved F1-scores of 0.853, demonstrating high reliability in identifying theft while minimizing false positives (Table 2).

Table 2. Algorithm Performance Comparison

Model	Accuracy	Precision	Recall	F1-Score
Random Forest	94.8%	88.5%	82.4%	0.853
XGBoost	95.2%	89.2%	81.8%	0.853
LSTM	93.4%	82.6%	85.5%	0.840

4.3 Financial Impact

For a medium-sized DisCo, a 10% reduction in ATC&C losses could recover approximately 28.8 Billion Naira annually. The implementation costs are estimated to be recovered within the first month of operation, yielding a massive ROI.

5. Conclusion and Recommendations

The “Smart Grid Analytics Hub” (SGAH) framework is proposed to integrate AMI data with utility operations. Success requires IT/OT convergence and workforce capacity building.

5.1 Key Recommendations

1. Performance Incentives: Implement a “Carrot and Stick” approach for loss reduction targets.
2. Standardization: Establish national standards for AMI communication protocols.
3. Consumer Education: Address socio-political resistance through transparent billing. Digital grid modernization is no longer optional; it is a strategic necessity for the financial survival of the Nigerian power sector.
4. Mandatory Data Reporting: NERC should mandate audited AMI-based loss reporting.

References

- Olajuyin, E. A., & Olubakinde, E, Reliability and Maintenance of Assets in Electric Power Distribution Network. Current Journal of Applied Science and Technology, 43(2), 1-15, 2024.
- Okoli, C., Uhunmwangho, R., & Kingsley, E, Reliability centered maintenance for distribution system infrastructure in Nigeria. The International Journal of Engineering and Science (IJES), 13(1), 10-25, 2024.
- Madueme, T. C, Maintenance Culture in Electrical Power Industry in Nigeria. Journal of Engineering and Applied Sciences, 19(3), 5-20, 2024.
- Adoghe, A. U., et al, Performance evaluation of power generation and distribution in Nigeria. Heliyon, 10(4) , 2024.
- Oluleye, G. F., et al, Mitigation Strategies of Technical and Commercial Energy Losses in Nigeria. Journal of Engineering Logic, 2023.
- NERC , Quarterly Report Fourth Quarter 2024. Abuja: Nigerian Electricity Regulatory Commission, 2024.
- Nwafor, O, Reducing non-technical losses using AI algorithms. Sustainable Energy Technologies.2022.
- Odje, M., et al, Aggregated technical commercial and collection loss mitigation. Frontiers in Energy Research, 2021.
- World Bank , Nigeria Power Sector Recovery Program (PSRP) Report, 2024.
- IEA , Africa Energy Outlook 2023. Paris.

Biographies

Israel Temitayo Ogundele obtained a Bachelor’s degree in Electrical and Electronics Engineering from Ekiti State University, Nigeria. He has over five years of professional experience working in the power distribution sector, where he has been involved in electrical operations, maintenance, and power systems management. He is currently pursuing a Master’s degree in Engineering Management at Uskudar University. His research interests

include operations management, inventory optimization, energy systems, and process improvement.

Prof. Dr. Mehmet Savsar is a Professor of Industrial Engineering and the Head of the Industrial Engineering Department as well as the Engineering Management Master's Program at Üsküdar University. He obtained his Bachelor's degree from Karadeniz Technical University in 1975 and earned both his Master's degree (1978) and Ph.D. (1982) in Industrial Engineering and Operations Research from Pennsylvania State University, USA. Over the course of his academic career, he has served in several international institutions, including King Saud University and Kuwait University, before becoming a Professor in 2003.

Prof. Dr. Savsar's research interests include manufacturing systems modeling and management, simulation, maintenance planning, quality control, and engineering management. He has supervised numerous graduate theses and published extensively in the fields of industrial engineering and operations research. In addition to his academic contributions, he actively participates in international conferences and academic development activities aimed at advancing engineering education and research