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

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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.

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Introduction

The electrical power distribution system in Nigeria is characterized by systemic efficiencies 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.

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.

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.

Literature Review

Theoretical Framework

Loss analysis is governed by the Law of Conservation of Energy (Pin = Pout + Ploss) 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.

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 and Nwafor highlight that AI algorithms significantly outperform manual inspection in detecting non-technical losses [1,2].

Research Methodology

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.

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 I^2R 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.

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: Technical Loss Breakdown by Feeder Type

Feeder Type	Avg. Line Length	Total Tech. Loss (%)
Industrial	12.5 km	4.00%
Urban Res.	4.2 km	10.00%
Semi-Urban	1.8 km	16.00%
Rural Res.	0.5 km	23.00%

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: Algorithm Performance Comparison

Model	Accuracy	Precision	Recall	F1-Score
Random Forest	94.80%	88.50%	82.40%	0.853
XGBoost	95.20%	89.20%	81.80%	0.853
LSTM	93.40%	82.60%	85.50%	0.84

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.

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.

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 [3-10].

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