Published by :
https://www.ijert.org/
An International Peer-Reviewed Journal

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 02 , February - 2026

Causes of Non-Technical Losses and Reduction Measures in Power Distribution Utilities: A Review

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Abstract **-** Non-technical also-called commercial losses present a significant challenge for electric power distribution utilities, especially in developing countries. These losses are due to fraud and energy theft, such as illegal meter tampering and unauthorized connections, as well as billing errors and defective meters. Addressing non-technical losses requires targeted actions, not just general network upgrades like those used for technical losses. Reducing non-technical losses is crucial for the financial sustainability of utilities. High loss levels result in inefficient systems, poor power quality, and unreliable supply, leading to consumer dissatisfaction and adversely affecting the financial health of power distribution utilities. This paper provides a detailed resource for determining the causes and measures to reduce non-technical losses, supported by practical case studies, with a focus on developing countries.

Keywords - Non-technical Losses, Power Distribution Utilities, Causes and Reduction Measures and Developing Countries

I. INTRODUCTION

For many years, two of the biggest problems facing electric power distribution utilities have been electricity theft and energy usage fraud [1]. Due to significant energy losses in the distribution system, hardly all the electricity provided by distribution operators reaches end consumers, even with rising demand. Aggregate Technical and Commercial (AT&C) losses and Transmission and Distribution (T&D) losses are key metrics used in the power sector to evaluate the performance of utilities [2]. AT&C losses represent the difference between the energy supplied and the energy for which revenue is collected, while T&D losses refer to the difference between the energy supplied and the energy billed [3]. These Losses in general can be categorized as technical and non-technical losses. Technical losses are inherent to transmission systems and primarily involve electricity dissipation during transportation, transformation, distribution, and measurement processes [4]. The factors contributing to technical losses include harmonic distortion, long single-phase lines, unbalanced loading, losses from overloading and low voltage, as well as losses due to poor insulation and inadequate maintenance of equipment and infrastructure [5]. Non-technical losses refer to energy consumed within the distribution system that is not properly accounted for [6], [7]. The following is a breakdown of these losses into more specific categories:

i. Internal Non-Technical Losses: These occur due to issues such as improper connection management (e.g., connections granted without meters, underreporting of load, fictitious or unrecorded consumers, mismanagement of billing data), theft (e.g., meter tampering or bypassing), incorrect meter readings, inaccurate billing (due to errors like average billing from delayed or faulty readings, late bill delivery, or malfunctioning billing software), and inadequate field monitoring [8].

ii. External Non-Technical Losses: These losses result from the failure to collect dues and poor management of collections and credit, including problems such as limited collection options, lack of follow-up on defaulters, misappropriation or incorrect posting of revenue collections, delays in disconnections, and non-payment of bills [9].

The AT&C and T&D losses serve as key indicators of the financial and operational health of an electricity utility. In developing countries, a well-performing utility typically maintains AT&C losses at 10% or less [1], whereas losses in the developed countries average around 5% [10]. In developed countries, losses are primarily technical, while in developing nations with higher loss rates, they are mainly non-technical, with losses averaging about 20% [11]. Elevated losses often reflect poor management, corruption, or insufficient resources and expertise to address them, especially in areas with dense informal low-income settlements, where innovative and unconventional approaches are needed to reduce losses [12]. A utility with high losses struggles to collect sufficient revenue to cover its operating costs, leading to "decapitalization" and an inability to maintain its system assets [13]. This results in service disruptions, such as outages and voltage fluctuations, for current customers and hampers the ability to connect new ones [14]. The issue of underperforming utilities is particularly severe in Sub-Saharan Africa (SSA). According to the World Bank, in 2016, only two countries in SSA, Uganda and the Seychelles, had financially viable utilities, meaning they could cover operating and capital costs to replace existing assets (but not future ones) [15]. Most other SSA utilities rely on subsidies to cover operating expenses and/or maintain their current infrastructure. To upgrade or expand services, these utilities often depend on capital support from donors. Electricity distributors face substantial financial losses of $89.3 billion annually worldwide due to electricity theft leading to non-technical losses, with $58.7 billion lost each year in the top 50 emerging nations [16]. Non-technical losses are the primary source of commercial losses for distribution operators, largely because of the challenges in accurately measuring them [17], [18]. Non-technical losses are multifaceted and not confined to

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 02 , February - 2026

a single domain, they extend beyond physical system inefficiencies to encompass administrative errors, policy gaps, governance weaknesses, and consumer behavior [1], [19]. This article seeks to provide a comprehensive overview of causes and measures of non-technical losses in power distribution utilities. Additionally, a practical case study demonstrating the application of these measures is analyzed.

II. MATERIALS AND METHODS

This review employed a systematic approach to identify, select, and analyze relevant literature on the causes of non-technical losses and measures for their reduction in power distribution utilities, with an emphasis on developing countries. The methodology was guided by principles adapted from the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure transparency, reproducibility, and comprehensive coverage of the topic [20]. Figure 1 shows the flowchart for the documents' selection process for the non-technical losses research.

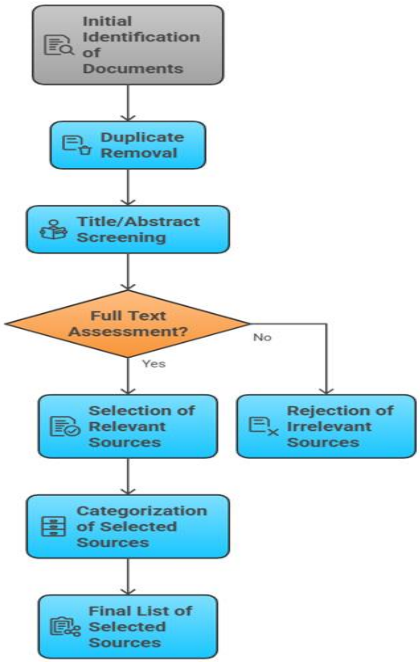

Fig.1. Flowchart of the non-technical losses' documents selection process

A. Data Sources

Literature was sourced primarily from academic databases and search engines. The main platforms used were "Google Scholar" and "Google", selected for their broad indexing of peer-reviewed journals, conference proceedings, technical reports, and gray literature from international organizations (e.g., World Bank, USAID). These sources were chosen due to their extensive coverage of energy sector research, including studies from developing countries where non-technical losses are prevalent. No additional databases (e.g., Scopus, Web of Science) were utilized in this review, as the initial searches yielded sufficient relevant documents.

B. Search Strategy

Searches were open-ended to include both foundational and recent works, with most documents published from 2010 to 2026. Key search terms and phrases included: "non-technical losses", "electricity theft", "energy fraud", "non-technical losses reduction", "power distribution utilities losses", "Aggregate Technical and Commercial (AT&C) losses", "electricity theft detection and developing countries", and combinations such as "non-technical losses" AND ("causes" OR "measures" OR "reduction" OR "case studies"). Boolean operators (AND, OR) and exact phrases (in quotation marks) were applied to refine results. The search focused on English language documents.

C. Selection Criteria

Inclusive and exclusive criteria were employed to determine the documents used in this research.

Inclusion Criteria

i. Documents addressing causes of non-technical losses (e.g., meter tampering, illegal connections, billing errors) and/or reduction measures (e.g., technological interventions, legal actions, awareness campaigns).
ii. Peer-reviewed journal articles, conference papers, technical reports from reputable organizations, or credible online resources.
iii. Studies with a focus on or relevance to developing countries, including practical case studies (e.g., from Sub-Saharan Africa, South Asia, Latin America).
iv. Documents provide empirical evidence, theoretical insights, or practical applications related to non-technical losses in power distribution systems.

Exclusion Criteria

i. Studies exclusively focused on technical losses without discussion of non-technical losses.
ii. Documents not in English or lacking full-text access.
iii. Purely theoretical models without linkage to real-world causes or reduction measures.
iv. Duplicate or low-relevance items (e.g., general energy policy papers without specific non-technical losses content).

The initial search yielded approximately 150 records. After removing duplicates and screening titles/abstracts for relevance, 88 full-text documents were assessed. Of these, 47 were selected for inclusion: 35 peer-reviewed journal articles, 4 technical reports from international organizations, and 8 credible online resources/case studies. Selection prioritized documents containing key phrases related to non-technical losses causes (e.g., "meter tampering", "direct tapping", "billing errors") and reduction measures (e.g., "smart meters", "vigilance squads", "legal measures").

D. Analytic Procedures

The selected documents were analyzed through qualitative synthesis. Content was categorized into themes:

1. Causes of non-technical losses (subdivided into direct tapping, energy theft by customers, and defective metering/billing/collection)
2. Reduction measures (e.g., preventive actions, technological upgrades, legal/institutional strategies, and supplementary approaches like AI and energy auditing)
3. Global practices and case studies from developing countries.

A narrative synthesis approach was used to integrate findings, identifying common patterns, contradictions, and gaps. Practical case studies were highlighted for illustrative purposes. No quantitative meta-analysis was performed, as the

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 02 , February - 2026

heterogeneous nature of the documents (mix of qualitative reviews, case studies, and empirical reports) precluded statistical pooling [21].

E. Validation and Reliability Measures

To enhance reliability, the selection and analysis process involves cross-verification of key findings across multiple sources. Inter-source consistency was checked for recurring causes and measures (e.g., smart metering frequently cited as effective). Potential biases, such as over-representation of certain regions, were noted and mitigated by prioritizing diverse geographic coverage. The review protocol, including search terms and criteria, was documented iteratively to allow replication. This methodology ensured a comprehensive, focused resource on non-technical losses causes and reduction measures, particularly suited to the challenges faced by utilities in developing countries [21].

III. RESULTS AND DISCUSSIONS

The reviewed literature highlights the multifaceted nature of non-technical losses in power distribution utilities, particularly in developing countries, where they often dominate overall losses and pose severe challenges to utility sustainability.

A. Review of Non-Technical Losses

Enhancing transmission and distribution systems through technological upgrades can solely address technical losses. However, upgrading the network cannot reduce the non-technical losses. Figure 2 summarizes the causes and reduction measures of non-technical losses in power distribution utilities. The need of the hour is to implement a separate plan of action for reducing non-technical losses. They are primarily caused by discrepancies in the following activities:

a) Direct Tapping by Non-Customers

Dishonest customers steal electricity through meter bypassing or connecting directly to distribution lines. In certain areas, illegal power tapping by non-customers is widespread, particularly in the domestic and agricultural sectors. Factors such as geographic remoteness, widespread theft, weak law enforcement, and the utility's inaction contribute to this issue

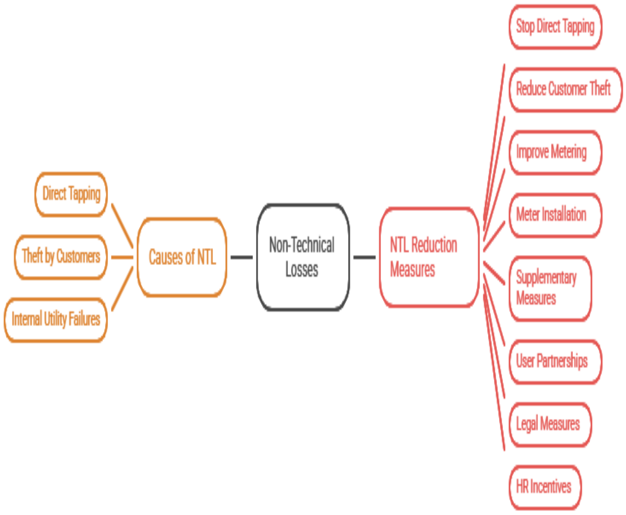

Fig. 2. Summary of causes and reduction measures of non-technical losses

. Direct theft is a significant challenge and reflects the poor performance of the utility's distribution network, undermining its operations. This issue needs to be addressed as a top priority by the utility [22], [23].

b) Energy Theft by Existing Customers

Besides the previously mentioned issue, theft of electricity by existing customers is contributing to higher revenue losses. Since it is often difficult to identify the perpetrators, the stolen energy cannot be measured or attributed to any individual, making it a part of the overall losses. Tampering with meters by existing consumers is a major cause of revenue loss for electrical power utilities [22], [24]. Meter tampering methods can be categorized into traditional and advanced techniques [25]. A few examples of these include:

i. Conventional meter tampering techniques (gaining access to meter terminals)
   - Interchange of phase and neutral
   - Interchange of phase-to-phase
   - Disconnection of voltage circuit (loss of potential)
   - Disconnection of neutral
   - Reversal of Current Transformer (CT) connections
   - Open CT
   - CT bypass or short-circuiting via shunts
ii. Advanced meter tampering techniques (external influence or access to internal meter circuitry)
   - Magnetic interference
   - Electrostatic discharge affecting the meter
   - Injection of high-frequency, high-voltage signals through the neutral from the output side
   - Installation of a remote device within the meter to control the voltage circuit
   - Connection of resistors in the voltage circuit inside the meter
   - Creation of current circuit loops or bypass shunts inside the meter

c) Defective Metering, Billing, and Revenue Collection

Apart from the external factors mentioned earlier, non-technical losses are also driven by deficiencies in the utility's internal commercial functions, such as collection, billing and metering [26]. These losses are not the result of intentional customer behavior but stem from the utility's internal shortcomings, making them easier to address. They persist because utility management are not operating with a commercial focus, despite being expected to do so. Some of these contributing factors are outlined below.

i. The installation of inaccurate metering systems on the outgoing radial distribution lines and Distribution Transformers (DT) may result in inaccuracies in loss evaluation.
ii. Slow or defective meters at customer premises
iii. Errors in the CT or Potential Transformer (PT) ratios, particularly when inaccurate ratios
iv. are applied for billing.
v. Errors in estimating consumption for consumers who are not metered, like industries.
vi. Theft of electricity by "hooking" or making illicit connections.

International Journal of Engineering Research & Technology (IJERT)
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Vol. 15 Issue 02 , February - 2026

vii. Meter manipulation, including intentional burning of the meters.
viii. Inaccurate readings and data fraud: Some utilities fail to measure electricity accurately due to negligence [27]. In some cases, meter readers collude with consumers to record lower readings than those displayed on the meter. This is particularly concerning when the consumer belongs to the high-end customer category.
ix. Customer non-settlement of payments, where the utility lacks a system for prompt disconnection.

B. Measures For Non-Technical Losses Reduction

The measures for reducing non-technical losses depend on the underlying factors that cause them, which are discussed as follows [28].

a) Measures for Preventing Direct Tapping by Non-Customers

i. The electricity supply authorities can implement the following actions to stop theft by direct tapping:
   - Establishing vigilance squads (in cases when none have already been established).
   - Inspections of Low-Tension (LT) by vigilance squads to identify unauthorized consumers and detect direct tapping from the lines. Inspections can be conducted following a preliminary analysis of users' consumption data and pre-selected zones. They may be massive, periodic, or unannounced to enhance accuracy and effectiveness.
   - Legal action against individuals involved in energy theft to secure convictions in court. The Electricity Act of 2011 for Sierra Leone emphasizes the importance of incriminating evidence. Therefore, materials, wires, and equipment involved in the theft should be preserved and presented during court hearings to prove the crime.
   - Levying large fines for energy theft.
   - Initiating a campaign to legalize unauthorized connections and streamlining the process for providing new connections to consumers.

ii. Public relations and awareness initiatives conducted by the utility
   - A shift in society's value system is also necessary. Opinion leaders and social influencers should be engaged to effectively address this widespread social issue.
   - The utility needs to engage in public relations efforts to combat this issue. It should be widely communicated that theft will lead to higher tariffs for legitimate consumers, poor voltage levels, damaged motors, failed transformers, and ruined crops. Moreover, the limited resources of the state, intended for social welfare, are being diverted to support these energy thieves.

b) Measures for Reducing Theft of Energy by Existing Customers

The following measures can be implemented to minimize such commercial losses:

i. The meter must be placed in a separate, sealed box that is out of reach for consumers.
ii. The fuse cut-outs should be installed after the meter.
iii. Strict penalties should be enforced for tampering with meter seals and related equipment.
iv. Electricity theft should be highlighted as both a social and economic offense, and the public must be made aware of the applicable sections of electricity regulations.
v. Comprehensive inspections of connections should be conducted to ensure accuracy and detect tampering or bypassing.
vi. To reduce Low-Tension (LT) usage, the network should be designed and deployed with high voltage, encompassing all consumer types.
vii. Schemes for consumer classification should be designed using ABC analysis, prioritizing action for high-end consumers initially.
viii. Meters belonging to customers can be moved outside of their own residences.
ix. The potential link should be installed within the energy meter's body instead of the thermal cover to prevent consumers from disconnecting it.
x. Energy consumption variations should be regularly monitored across all consumer categories, with suspicious consumers closely observed through targeted inspections.
xi. Meter readers' activities should be strictly controlled through close and continuous monitoring.
xii. A system for rotating duties between meter readers and ledger clerks should be implemented.

However, focusing inspections on high-end consumers can lead to more effective and immediate results. There are numerous ways to tamper with meters, and new techniques are constantly being developed. As a result, the thief often stays one step ahead of the utility.

c) Measures to Reducing Defective Metering

Distribution utilities experience significant non-technical losses due to inadequate metering and data collection systems. Common defects found in metering include malfunctioning or frozen meters, meter readings are not provided by the meter reader for significant durations, cases of consistent zero consumption reported without any explanation, inaccurate progressive readings recorded for disconnected services, discrepancy between the meter capacity and the actual load, use of incorrect Multiplication Factors (MF) for billing due to failure to notify the billing unit about changes in the MF [29]. Here are several techniques to mitigate revenue losses related to the metering system on the consumer side and its related connections:

i. During meter installation, it is important to define installation protocols and ensure that installation checkpoints are tested and followed.
ii. Deploying electronic meters equipped with tamper detection and load survey logging features for all consumer groups.
iii. Sealing meters with appropriate seals and maintaining an effective seal management system.
iv. Installing CT/PT in sealed enclosures to prevent the terminals from being exposed to tampering or bypassing.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 02 , February - 2026

v. Testing the entire metering system to verify its accuracy.
vi. Making sure that meter readings and billing are accurate by creating exception lists and addressing any discrepancies.
vii. Conducting frequent energy audits for the feeder, distribution transformers, as well as all final consumers to ensure there is no revenue loss exceeding the allowable technical losses.

d) Meter Installations

Proper attention must be given to the quality of installations to prevent revenue losses. Installation practices should consider the different types of meters and specifications. One of the primary causes of revenue loss has been gaps in installation practices that enabled tampering with metering systems. Recommended installation practices to address this are outlined as follows [30]:

i. A "visually traceable" and "joint-free" incoming cable or a shrink-wrapped sealed joint can help prevent tampering.
ii. Using clearly visible and easily accessible seals for straightforward inspection.
iii. Installing the meter and CT inside a sealed box with a transparent window, ensuring the internals are inaccessible without breaking the seal.
iv. Positioning the installation at a height and location that allows for easy meter readability.
v. Placing meters in public areas, such as on poles where service cables are routed. This positioning keeps the meters elevated and visible to the public, making it harder for dishonest customers to bypass the meters.

e) Installation of Meters with Tamper Detection and Communication Features

Advanced Metering Infrastructure (AMI) with tamper detection and communication capabilities should be installed for HT and LT CT consumers, as well as high-end three phase whole current consumers. However, simply installing meters with tamper logging capabilities is insufficient without a robust process for ongoing tamper data analysis. Therefore, it is crucial for the utility to frequently monitor and analyze meter readings online at short intervals using a desktop or laptop [31]. Along with identifying tampered meters, this analysis also tracks other operational parameters such as demand violations, poor power factors, and load utilization [32]. It has been observed that this measure could reduce non-technical losses by as much as 20%. Consequently, various techniques are being developed to identify electricity theft i AMI systems [33]. Furthermore, equal attention must be given to both the installation and accuracy aspects of CT/PT devices to avoid revenue losses. These considerations include:

- In installations involving Meters connected via CT and HT meters with both CT and PT, the size and length of CT wires, as well as the length and cross-section of PT wires, significantly affect measurement accuracy. Undersized PT wires can cause substantial voltage drops, leading to lower energy readings on the meter and resulting in revenue losses [34].
- Impact of Volt-Ampere (VA) burden: The VA burden of both CT and PT should be thoroughly evaluated before installation. For CT, the loop burden, including the CT and leads, should be accurately calculated or tested on-site. The functional load should ensure that these instrument transformers are neither overburdened nor under burdened [35].
- Impact of wiring and nameplate errors: For CT, it is crucial to ensure correct wire polarity, proper phase association, and the use of the metering core instead of the protection core

A frequent cause of error or tampering in CTs is the mismatch between the nameplate information and the actual CT ratio, which can lead to revenue losses (though seldomly, it can result in gains). Therefore, a ratio test is essential before installation. Since CT/PT meter installations handle large energy volumes, even a 1% error can result in substantial revenue losses [36].

f) Measures to Enhance Billing and Collection

Accurate billing and prompt bill delivery are essential for enhancing collections. Common billing issues include delayed or missing bills, incorrect billing, errors in readings or statuses, table readings, and miscalculations. These issues can be effectively addressed by implementing computerized spot billing. This method might be implemented gradually, starting with cities. Meter readers must have a clear understanding of meter statuses for the system to succeed. Adopting standardized billing software will enable effective control, review, and management of the consumer database [37]. Additionally, reducing bill processing time is critical to ensuring the system's efficiency and success.

In many power distribution utilities, revenue loss is primarily caused by delayed payments or non-payment. Collection efficiency measures the utility's ability to collect payments promptly for issued bills [9]. This performance is often hindered by limited options for addressing non-payment, inability to settle bad debts, or negotiating with customers. Utilities need to implement a system to promptly detect non-payers, specifying overdue amounts and timelines. Special collection drives, combined with targeted inspections in areas with poor payment history, can yield positive results [38].

To recover arrears, utilities should identify defaulters, issue reminders or notices, pursue legal action, and, if necessary, disconnect services. Enhancing customer convenience should be a priority for efficient collections. This can be achieved by offering multiple payment locations and vending options instead of restricting them to specific locations.

g) Supplementary Measures

Utilities can adopt a Management Information System (MIS), perform energy accounting and audits to minimize revenue losses, and utilize artificial techniques to identify energy reading discrepancies. These strategies are discussed below.

1. Development of Management Information System

The effective use of Information Technology (IT) can significantly reduce AT&C losses and enhance the management of distribution utilities. Utilities should establish a robust Management Information System (MIS) for efficient control and monitoring [10]. Regular updates to the asset and consumer database are essential, as outdated information, such as contract demand or CT/PT multiplication factors, can lead to revenue losses. Additionally, utilities should maintain detailed historical records of consumers involved in meter tampering, which can be identified through meter analysis. MIS can play a crucial role in managing and leveraging this information effectively.

2. Energy Accounting and Auditing

To reduce losses in the power sector, utilities must accurately calculate Aggregate Technical and Commercial (AT&C) losses, distinguish between technical and non-technical losses, and identify high-loss areas [39]. Implementing an area wise Energy Accounting System is essential for continuous monitoring and informed decision-making. Energy audits, especially when focused on high loss zones, can significantly reduce revenue losses. Effective energy accounting involves tracking electricity from generation to consumption, emphasizing proper metering at substations, feeders, and transformers. This ensures energy input aligns with consumer usage within acceptable limits. Faulty meters should be replaced, and key interface points should be metered [40].

Installation audits serve as temporary measures to detect issues like faulty installation or tampering. These audits, which also help with preventive maintenance, should follow schedules based on energy audit data, annually for 3-phase/HT consumers and at least every two years for single-phase users, as guided by regulatory bodies.

3. Artificial intelligence

Advancements in smart metering, Artificial Intelligence (AI), and machine learning enable distribution utilities to analyze customer profiles, data, and irregular behaviors, triggering inspections for abnormal electricity consumption patterns [41]. Non-technical losses are multifaceted, dynamic, and highly contextual, making AI, particularly machine learning, well-suited to develop effective, customized solutions. However, ignoring the human element can lead to performance issues, as algorithms may struggle to detect problems like dataset shifts and biases. Recently, Explainable AI (XAI) has been integrated into advanced non-technical losses detection systems, yielding remarkable results [42].

h) Users Partnerships and Franchisees for Billing and Collection

The idea of paying for consumed power can be effectively instilled if more individuals are engaged in the process and a sense of ownership and investment in the organization is fostered through user partnerships and franchisees for billing and collection. For instance, the Electricity Act of 2003 in India envisions the involvement of Users' partnerships, cooperatives, and franchisees in the distribution of electricity, particularly in rural areas [43].

i) Legal Measures

Developing laws is a key measure for countries aiming to reduce non-technical losses. These legal measures vary widely and are tailored to each country's unique circumstances. The causes of non-technical losses also differ and may be influenced by specific indicators, such as Gross National Income per capita, which reflects the total income of a country's residents. To address electricity theft, legal measures provide a transformative approach, ensuring enforcement and monitoring. For example, Part XI of the National Electricity Act of 2011 includes the following clauses [44]:

i. An individual who is dishonest:
   - abstract electricity
   - Manipulates the index of any meter or device used by an Authority or licensed installation to record electricity output or consumption; or
   - Interfering with any meter or device to obstruct the accurate recording of electricity output or consumption constitutes an offence, punishable upon conviction by a fine of at least fifty million leones, imprisonment for up to five years, or both.

ii. Any individual who intentionally damages a meter or device associated with the Authority's installation for recording electricity output or consumption commits an offence and, upon conviction, is subject to a fine of at least fifty million leones, imprisonment for up to five years, or both.

iii. Any person who intentionally or negligently diverts electricity from its intended purpose or causes it to be wasted commits an offence and, upon conviction, is liable to a fine of at least thirty million leones, imprisonment for up to five years, or both.

iv. Any person who intentionally obstructs, resists, or interferes with, or aids another in obstructing, resisting, or interfering with an officer or employee of the company or Authority performing duties under this Act commits an offence and, upon conviction, is subject to a fine of at least ten million leones, imprisonment for up to one year, or both.

j) Human Resource Incentive Schemes

Human resource incentive schemes are a useful tool for managers to match worker goals with utility objectives, such reducing non-technical losses, promoting performance gains and quicken change. Employee training programs and rewards can be linked to the number of inspected cases [45], [46]. United State Agency for International Development (USAID) has studied the development and implementation of these measures at utilities in developing countries with successful loss reductions. The results indicate that the success of this initiative relies on clear organizational objectives, robust procedures, and the strategic use of data from advanced technological systems [47].

C. Reviewing Global Practices in Non-Technical Losses Reduction Measures

The primary objective of reviewing global practices in addressing non-technical losses is to identify measures implemented by other developing countries to reduce these losses. Iran, Brazil, and Uganda were chosen as case studies due to their similarities. The primary criterion for selecting a country was the implementation of effective loss mitigation measures and the availability of relevant references. Additional factors considered included population, GDP per capita, energy consumption per capita, and other related metrics. These case studies demonstrated that successful non-technical loss reduction was achieved through integrated approaches, as summarized in Table 1 (adapted and updated from reviewed sources).

TABLE I. SUMMARY OF NON-TECHNICAL LOSS REDUCTION MEASURES IN SELECTED DEVELOPING COUNTRIES.

Country	Key Measures Implemented	Outcomes
Oman	Smart meters for real-time monitoring, 100% metering coverage, underground cabling, community awareness workshops	Rapid loss reduction below targets; enhanced investor confidence
Iran	Smart meters with remote control/alarm management, Automatic Meter Reading (AMR)	Improved billing accuracy and fault/tampering detection
Brazil	100% metering with electronic meters, low-income tariffs/subsidies, community campaigns, appliance upgrades, regularization programs	Collection efficiency from about 0% to 68% in pilot areas; 40% consumption reduction; revenue growth
Uganda	New billing systems, prepaid metering, bulk metering in high-loss areas, frequent audits, revenue cycle improvements	Mixed results initially (losses rose post-privatization due to underestimation of issues), but gradual improvements through targeted interventions

These examples illustrate that combining technology (e.g., smart metering) with social measures (e.g., subsidies for low-income users and awareness campaigns) yields significant reductions, often improving financial viability and service quality.

IV. CONCLUSION

Non-technical losses represent a complex, avoidable burden requiring multifaceted approaches. Prioritizing energy audits to pinpoint root causes, followed by customized technological and institutional reforms, is essential for effective reduction. Successful global practices reinforce the potential for substantial improvements in utility performance and sustainability in developing countries.

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