Efforts to Reduce Non-Technical Losses by Maintaining Kwh Meters at PT. PLN (PERSERO) ULP Panarukan

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This study aims to analyze the effectiveness of kWh meter maintenance as an effort to reduce non-technical losses in the electricity distribution system at PT. PLN (Persero) ULP Panarukan. Non-technical losses, which are often caused by meter inaccuracy, recording errors, and illegal usage, have a direct impact on the company's revenue. Using a quantitative descriptive approach, this study compares the level of non-technical losses before and after the implementation of a structured kWh meter maintenance and replacement program. Data were collected through field observations, interviews, and documentation from PLN's internal systems (ACMT, AP2T, EIS). The results show that maintenance activities successfully improved measurement accuracy, which led to a decrease in unrecorded energy. Thus, non-technical losses were reduced and resulted in significant financial savings. In addition, the study proposes an age-based meter replacement Operational Target (TO) as a strategic framework for determining maintenance action priorities. It is concluded that optimizing the maintenance program for aging kWh meters is a crucial operational step in controlling non-technical losses and securing PT. PLN's revenue.
Keywords: Non-Technical Losses, kWh Meter, Maintenance, Distribution System Efficiency, PT. PLN

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1. Introduction

A reliable and efficient electricity distribution system is the backbone of meeting the energy needs of the community and industry. The reliability of this system is often quantitatively measured using indices such as SAIDI and SAIFI, which reflect the duration and frequency of outages experienced by customers.(Lubis et al., 2024). In addition to supply reliability, the financial aspects of a distribution system are highly dependent on the accuracy of energy measurements. Inaccurate measuring instruments, such as kWh meters, can cause non-technical energy losses that directly impact a company's revenue. Previous research has shown the importance of comparing the performance of different types of kWh meters to ensure measurement accuracy and protect revenue.(Tharo, Kusuma, et al., 2021). Furthermore, a program of rejuvenation or regular maintenance of prepaid kWh meters has been identified as a crucial step to improve the reliability of the overall electric power system.(Idris et al., 2025). Therefore, monitoring and maintaining measurement assets is a vital first intervention in efforts to minimize revenue leakage.

To effectively address non-technical losses, an approach beyond reactive maintenance is required. Proactive strategies through increased technical competency and technology implementation can produce more sustainable impacts. Technical training for the workforce, such as the use of Programmable Logic Controllers (PLCs) and the maintenance of motor protection systems, has been shown to improve operational efficiency and prevent damage that could potentially lead to disruptions and energy losses.(Erivianto & Dani, 2024)On the other hand, innovation in monitoring and control systems also plays a significant role. Implementing an Arduino-based monitoring system to detect faults such as short circuits in home installations can prevent more extensive damage and potential energy loss.(Fauzi et al., 2025)This combination of increased human resource capacity and the adoption of simple monitoring technologies forms an effective second line of defense in reducing non-technical causes of losses.

A long-term solution to improve distribution system performance while reducing reliance on conventional sources is to integrate renewable energy. Research conducted by Tharo and colleagues has extensively explored this potential, including the design and implementation of solar panel-based generators and an analysis of electricity cost savings using a hybrid PLN-PLTS source.(Tharo & Syahputra, 2023). The integration of Solar Power Plants (PLTS) is not only an alternative source, but can also be used to increase efficiency on certain loads, such as in public street lighting systems, thereby reducing network load and potential losses in that segment.(Tharo, Sutejo, et al., 2023)Meanwhile, feasibility studies and optimization of renewable energy use, including analysis of the energy potential of palm oil waste, provide a scientific basis for the development of a more independent and efficient energy system.(Dani & Erivianto, 2024b). Thus, the transition to renewable energy not only supports national energy security, as examined in the context of dependence on fossil fuels(Sihite et al., 2025), but also contribute to the creation of a more resilient distribution system with minimal energy losses in the long term.

2. Literature Review

Electrical Energy Loss

Technical energy losses in electricity distribution systems are an inherent consequence of the physical characteristics of the network and equipment. Research by Zuraidah Tharo and colleagues has examined various technical aspects that affect system efficiency, including an analysis of voltage drops in low-voltage networks that directly contribute to technical losses.(Ardiansyah et al., 2025). Furthermore, load imbalance in distribution transformers was also identified as a significant cause of technical losses and losses, as analyzed in a study on transformer load balancing to reduce technical losses in distribution substations.(Zega et al., 2025). Systematic failure analysis approaches, such as the Failure Mode and Effect Analysis (FMEA) method applied to low-voltage networks, provide a framework for identifying critical points causing technical losses and improving system reliability.(Bahr et al., 2025). These findings confirm that data-driven asset management and preventative maintenance are key to mitigating technical depreciation.

On the other hand, non-technical losses, which primarily stem from measurement inaccuracies and illegal usage, require a different approach. The work of Dino Erivianto and his collaborators has highlighted the importance of reliable control and monitoring systems. Performance analysis of overcurrent protection (OCR) systems in industrial installations, for example, not only ensures safety but also limits uncontrolled energy flows that can lead to measurement errors.(Ahmad et al., 2025). Microcontroller-based innovations, such as the short circuit detection system in home installations developed by(Herdianto, 2020), potentially preventing damage that could disrupt the performance of the measuring instrument. Meanwhile, the evaluation of relay protection coordination using ETAP simulation, as done(Tharo, Anisah, et al., 2021), is an example of how in-depth systems analysis can optimize network security, thereby reducing the likelihood of disruptions that lead to energy recording errors. These efforts directly address the non-technical root causes of losses by strengthening the integrity of the measurement and security systems.

A long-term strategic solution to minimize both types of energy losses simultaneously is through the integration of renewable energy and holistic system efficiency improvements. Zuraidah Tharo consistently explores this, such as in the design of a solar-wind hybrid power plant as a learning tool demonstrating a more distributed and efficient energy supply system.(Tharo et al., 2024). The implementation of PLTS for various applications, ranging from public street lighting (PJU) to residential homes, has been proven to

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reduce dependence on long central distribution networks, which proportionally also reduces the potential for technical and non-technical losses in this segment.(Tharo, Tarigan, et al., 2023). From a systems development perspective,(Dani & Erivianto, 2024a)contributes significantly through training to improve technical competency, such as the use of PLCs, which are the foundation for building efficient industrial automation systems that minimize energy waste. Thus, the synergy between renewable energy adoption, increased technological efficiency, and enhanced human resource capacity forms a comprehensive strategy to reduce electricity losses from upstream to downstream.

KWh Meter

The accuracy of kWh meters, the point of transaction between electricity providers and customers, is a critical foundation in the distribution system. Inaccuracy of these devices directly contributes to non-technical losses and financial losses. Research by(Tharo, Kusuma, et al., 2021)specifically analyzed the performance comparison between prepaid and postpaid kWh meters, highlighting the importance of selecting and managing the right type of meter to ensure valid energy recording. This finding is reinforced by a study(Idris et al., 2025)which confirms that periodic rejuvenation of prepaid kWh meters has a significant impact on improving the reliability of the overall electric power system. From the perspective of a control system that supports measurement integrity, the work(Erivianto & Dani, 2023)regarding training on the implementation of electric motor protection systems, it is emphasized that a thorough understanding of electrical equipment, including measuring instruments, is a prerequisite for minimizing disturbances and dysfunctions that can cause recording errors.

Given its central role, a structured kWh meter maintenance and replacement program is an effective operational intervention to reduce non-technical losses.(Idris et al., 2025)emphasized that kWh meter rejuvenation not only solves the problem of decreasing accuracy over time, but is also an investment in maintaining the health of the metering asset. This proactive approach is in line with the study(Dani & Erivianto, 2024a)regarding training on replacing power electronics components for induction motor speed control, which is essentially a preventative measure to maintain optimal equipment performance. Furthermore, analysis of protection system performance, such as evaluating the coordination of OCR and GFR relays, was conducted.(Tharo, Anisah, et al., 2021), provides a systemic perspective that the reliability of a single component (such as a kWh meter) is also affected by the performance of the surrounding protection system. Comprehensive maintenance must encompass the ecosystem of supporting equipment.

A long-term strategy to optimize metering and distribution systems involves a convergence between conventional asset maintenance and the adoption of renewable energy and technology. The integration of small-scale solar power plants (PLTS), such as those designed for residential homes by(Hadi et al., 2023), can reduce reliance on long distribution networks that are vulnerable to shrinkage, while creating more decentralized and potentially more manageable measurement points. On the other hand, human resource capacity development through training, such as training on solar power plant design based on Helioscope software by(Erivianto & Dani, 2025), preparing technical personnel to design and maintain more efficient future energy systems. Thus, a holistic approach that combines active meter maintenance, technical competency enhancement, and energy source diversification has the potential to create a more resilient distribution system with minimal non-technical losses.

3. Research Methods

This study employed a mixed methods approach, combining quantitative and qualitative methods with a descriptive design. The quantitative approach was used to analyze the magnitude of non-technical losses, losses, and savings achieved after kWh meter maintenance. The qualitative approach supported the

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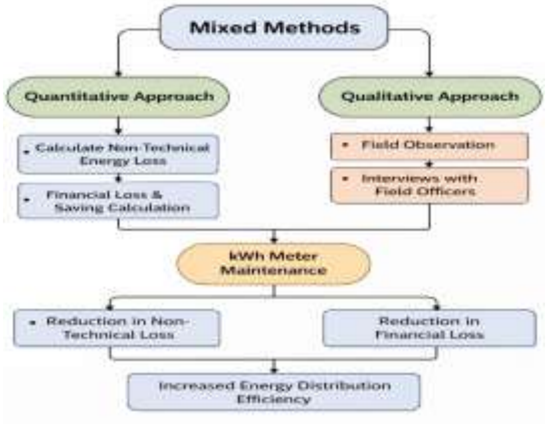
quantitative analysis through field observations and interviews related to kWh meter conditions and maintenance implementation.



Source: Processed Data

Figure 1. Research Design

The figure shows a mixed-methods research design that combines quantitative and qualitative methods. In the initial stages, the research was divided into two main approaches: a quantitative approach and a qualitative approach. The quantitative approach was used to calculate the amount of non-technical electrical energy loss and analyze the resulting losses and savings. Meanwhile, the qualitative approach was conducted through field observations and interviews with staff to obtain an overview of the kWh meter condition and maintenance implementation.

The results of these two approaches are then used as the basis for implementing kWh meter maintenance. This maintenance is expected to improve the accuracy of customer electricity recording. The impact of kWh meter maintenance is demonstrated through reduced non-technical losses and financial losses. Ultimately, the entire research process culminates in improved efficiency of the electricity distribution system.

The research population was all single-phase low-voltage customers in the working area of PT. PLN (Persero) ULP Panarukan. The research sample was determined using a purposive sampling technique, namely customers who have potential non-technical losses, such as old kWh meters, jammed kWh meters, and anomalies in electricity usage based on the company's operational data.

Data collection techniques include observation, interviews, and documentation. Observations were conducted to identify the physical condition and performance of kWh meters in the field. Semi-structured interviews were conducted with relevant officers as supporting data. Documentation was used to collect quantitative data sourced from PT. PLN (Persero)'s internal system, including electrical energy reading data from the ACMT application, customer data from AP2T, and electrical energy loss data from EIS. The research instruments were observation sheets, interview guidelines, and system data reports.

Quantitative data analysis was performed by calculating non-technical losses based on the difference between the electrical energy supplied and the recorded electrical energy before and after kWh meter maintenance. Unrecorded electrical energy was converted into rupiah to determine the extent of losses and savings. Qualitative data analysis was performed by describing the results of observations and interviews to strengthen the interpretation of the quantitative results. The research model describes the relationship between kWh meter maintenance as an action variable and a reduction in non-technical losses and financial losses as outcome variables. Quantitative and qualitative approaches are used in an integrated manner to provide a comprehensive picture of the effectiveness of kWh meter maintenance in improving the efficiency of the electricity distribution system.

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4. Results and Discussion

Electrical Energy Loss Analysis

Electrical energy loss is the difference between the electrical energy distributed and the electrical energy recorded in the measurement system. The loss value is used as an indicator of the efficiency of the electrical power distribution system. In this study, the analysis focuses on non-technical losses caused by inaccuracies in measuring and recording electrical energy. The amount of loss is calculated by comparing the electrical energy distributed and recorded electrical energy, then expressed in kWh units and a percentage as the basis for evaluating system efficiency. The calculation of electrical energy loss is then carried out using the equation presented below.

a. Calculating Total Technical and Non-Technical Loss

After obtaining the data as in the tables above, it is calculated using the equation. Calculating total shrinkage:

Eterima = 13,688,635 kWh
III-09 = 7,982,509 kWh
Send = 4,360,221 kWh
PS = 81,462 kWh

So we get:

Eterima = E – (III-09) – E – PS
= 13,688,635 – 7,982,509 – 4,360,221 – 81,462
= 1,264,443 kWh
Total (%) = (1,264,443/13,688,635) x 100%
= 9.24%

b. Calculating Technical Loss

To find out how much this technical loss is, we first calculate the loss in the medium voltage network (JTM), transformer, low voltage network (JTR) and house connection (SR). Calculating the loss in JTM, where:

∑f = 5
Lbp/f = 359.984 kW
LLF = 1,264,443 kWh
T = 720 h

So we get:

Ljtm = ∑fx Lbp/fx LLF x T)
= 5 x 359.984 x 0.3 x 720
= 388,782.72 kWh
Ljtm(%) = (388,782.72/13,688.635) x 100%
= 2.84%

c. Calculating Non-Technical Loss

Once we know the total shrinkage and technical shrinkage, we can calculate how much non-technical shrinkage there is.

Ltot = 1,264,443 kWh
Technical = 1,025,902 kWh

So we get:

Lnontek = Ltot - Lteknis

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	= 1,264,443 – 1,025,902
	= 238,541 kWh
Non-tech (%)	= Total (%) – Technical (%)
	= 9.24 – 7.49
	= 1.75%

The level of electrical energy loss in the distribution system can be analyzed based on network components, including the medium-voltage network (MV), distribution transformers, low-voltage network (LV), and household connections (SR). This analysis is conducted to determine the contribution of each component to the total technical losses. A summary of electrical energy losses by network component for the period from July to September is presented in Table 1.

Table 1. ShrinkageJTM, Transformer, JTR, SR and Technical

Shrinkage		**Month**		
		July	**August**	**September**
LJTM	kWh	388,782	384,887	350,848
	%	2.48	2.87	2.62
Transformer	kWh	155,520	150,336	150,336
	%	1.13	1.12	1.12
LJTR	kWh	231,465	227,404	206,085
	%	1.69	1.70	1.54
LSR	kWh	250,135	243,002	223,532
	%	1.82	1.81	1.67
Technical	kWh	1,025,902	1,005,629	930,801
	%	7.49	7.51	6.95

Based on Table 1, total technical losses showed a downward trend from July to September. In July, total technical losses were recorded at 1,025,902 kWh, or 7.49%, then decreased to 1,005,629 kWh, or 7.51%, in August, and again to 930,801 kWh, or 6.95%, in September. This decrease indicates an improvement in the performance of the electricity distribution system.

When viewed individually, losses in the medium voltage (MV) network fluctuated, with the highest value occurring in August, while losses in transformers remained relatively stable across the three months of observation. Losses in the low voltage (LV) network and home connections (SR) tended to decrease, indicating improvements in the distribution and customer side. Overall, the data demonstrates that technical loss control, particularly in the distribution network and home connections, contributed to the reduction in total electricity losses.

Graphs are presented to visualize the trend of electrical energy losses based on network components, namely JTM, transformers, JTR, and house connections (SR), from July to September. The graphical presentation aims to facilitate the analysis of changes in electrical energy losses over time and to compare the contribution of each component to the total technical losses. Graphs of electrical energy losses based on network components are shown in Figures 2 and 3.

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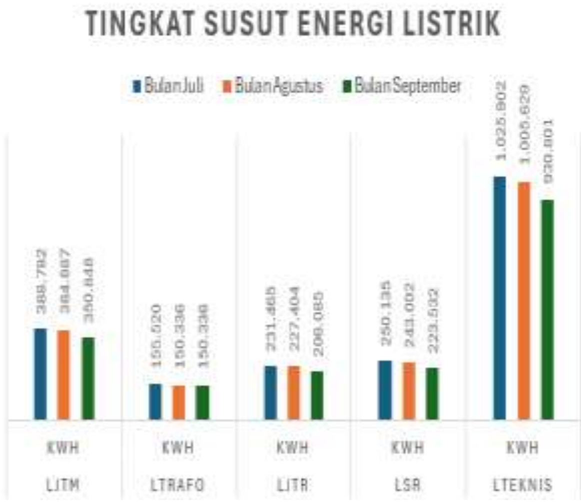

Source: Processed Data

Figure 2. Electrical Energy Loss Rate

Source: Processed Data

Figure 3. Percentage of Electrical Energy Loss Level

Based on Figures 2 and 3, electrical energy losses in most network components showed a downward trend from July to September. The most visible decline occurred in the low-voltage (LV) and home connections (SR) networks, indicating improvements in the final distribution network. Losses in the medium-voltage (MV) network fluctuated, with the highest value occurring in August, while losses in transformers remained relatively stable throughout the observation period.

Overall, the graph shows a decrease in total technical losses in September compared to the previous month. This indicates improved power distribution system performance and the effectiveness of loss control efforts in distribution network components.

Non-Technical Losses and Savings

A loss and savings analysis was conducted to determine the financial impact of non-technical losses and the effectiveness of kWh meter maintenance. Losses were calculated based on unrecorded electrical energy and converted to rupiah using applicable electricity tariffs. The difference in loss values before and after kWh meter maintenance indicates the amount of savings achieved. A summary of losses and savings is presented in Table 2.

Calculation assumptions

d. Average electricity rate: Rp 1,467/kWh
e. Losses/savings are calculated from unrecorded energy (kWh)
f. Loss = Unrecorded Energy (kWh) × Tariff (Rp/kWh)
g. Saving = Loss Before - Loss After

Table 2. Losses and Savings Due to Non-Technical Shrinkage

Condition	Unrecorded Energy (kWh)	Tariff (Rp/kWh)	Loss / Saving (Rp)
Before Maintenance	12,372	1,467	18,149,724
After Maintenance	7,128	1,467	10,456,776
Savings Obtained	**5,244**	**1,467**	**7,692,948**

Based on Table 2, unrecorded electrical energy decreased from 12,372 kWh before maintenance to 7,128 kWh after kWh meter maintenance. This decrease resulted in a reduction in financial losses from Rp18,149,724 to Rp10,456,776. The difference in unrecorded energy of 5,244 kWh resulted in savings of Rp7,692,948, which indicates that kWh meter maintenance is effective in reducing non-technical losses and securing PT. PLN (Persero)'s income.

Old Meter Operation Target

The Operational Target (TO) for replacing old meters is determined based on the meter's kWh age as an indicator of potential measurement inaccuracy. Meters with a longer operational age are prioritized due to their greater risk of non-technical losses, while meters with a shorter age are monitored. The mapping of meter replacement TO based on age is presented in Table 3.

Table 3. Opera Targetsi (TO) Replacement of Old Meters Based on Age

Meter Age (Years)	General Condition of Meter	Non-Technical Shrinkage Risk	Replacement Priority	Operational Target (TO)
9 – 10	Low accuracy, often jams/breaks	Very high	1 (High Priority)	Will be replaced soon
7 – 8	Significant decrease in accuracy	Tall	2 (Top Priority)	Replaced gradually
5 – 6	Starting to decrease, potential for reading errors	Currently	3 (Medium Priority)	Evaluation & selective
3 – 4	Relatively good condition	Low	4	Routine monitoring
1 – 2	Accuracy is still good	Very low	5	Not replaced
0 – <1	Just installed	Minimum	6	Not replaced

Replacement of old meters is prioritized based on their age and risk of non-technical losses. Meters over 7 years old have the potential for significant reductions in measurement accuracy and are therefore a top priority in the Operational Target (TO) for replacement. Meters under 5 years old are not a priority for replacement and require regular monitoring to ensure optimal performance.

5. Conclusion

Based on the analysis results, electrical energy losses in the distribution system remain a problem that affects the efficiency and revenue of PT. PLN (Persero). The loss analysis shows that non-technical losses are influenced by the inaccuracy of electrical energy measuring instruments, particularly old or faulty kWh meters, resulting in the electrical energy consumed by customers not being recorded optimally. Implementing kWh meter maintenance and replacement has been proven to contribute to improving the

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accuracy of electricity recording and reducing non-technical losses. This reduction in losses has a direct impact on financial losses and generates savings, indicating increased distribution system efficiency. Furthermore, mapping the Operational Target (TO) for meter replacement based on meter age is an effective strategy for determining replacement priorities in a planned and sustainable manner. Overall, the research results indicate that optimizing the kWh meter maintenance program, especially for meters with a long operational life, can be a strategic step in controlling non-technical losses and securing PT. PLN (Persero)'s revenue.

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