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Impact of the Advanced Metering Infrastructure (AMI) Program on Non-Technical Losses at Distribution System

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Abstract— *Advanced Metering Infrastructure (AMI) is a key component in the development of Smart Grid systems and plays a vital role in reducing non-technical losses in electricity distribution. However, empirical studies on its effectiveness in real operational contexts, especially in Indonesia, remain limited. This study aims to evaluate the impact of AMI implementation on reducing meter reading errors, customer arrears, and unauthorized electricity usage at PT PLN (Persero) UP3 Bandengan. The research employs a mixed-methods approach by combining quantitative data analysis and qualitative interviews with field officers. Quantitative data shows that average monthly meter reading failures decreased by 97% after AMI implementation, with a financial saving of approximately IDR 245,792,276 per month. Disconnection operations due to arrears also decreased by 29,29%, resulting in operational cost savings of IDR 7,807,696,000 per month. Additionally, the detection of electricity theft was improved using phase-neutral current gap analysis based on MDMS data, enabling better targeting of inspection operations. This study contributes to the literature by providing operational-level insights into AMI's effectiveness and supports smart grid strategies in Indonesia. Future research is encouraged to incorporate multi-location comparisons and inferential statistical analysis to enhance generalizability.*

Keywords : *Advanced Metering Infrastructure (AMI), Non-Technical Electricity Losses, PT PLN (Persero).*

I. INTRODUCTION

In this era of digitalization, electricity has become an essential part of daily life. From households to industries, the demand for energy continues to increase, making it crucial to ensure its efficient and sustainable use. One of the technological advancements that supports energy efficiency and the development of smart infrastructure is the Advanced Metering Infrastructure (AMI). This technology enables both electricity providers and consumers to monitor and control energy consumption in real time, helping to prevent excessive usage and improve efficiency by reducing energy losses commonly occurring during power distribution.

In support of the Sustainable Development Goals (SDG), particularly Goal 9 which focuses on building resilient infrastructure, fostering innovation, and promoting sustainable industrialization, the application of digital technology such as AMI contributes to creating a more efficient power system and accelerating digital transformation within the energy sector. Aligned with this objective, PT PLN (Persero) has implemented AMI in several pilot projects, including in Jakarta, Bali, and Bogor. PT PLN (Persero) UP3 Bandengan is one of the pilot projects located in Jakarta, which began implementing the AMI system in 2024. This implementation includes various features designed to enhance service performance. As of May 5, 2024, the system has successfully monitored 141,168 single-phase customers and 10,237 three-phase customers through the Meter Data Management System (MDMS). In 2023, the total billing arrears at UP3 Bandengan amounted to IDR 181,924,782,016 across 286,757 overdue bills. Meanwhile, electricity usage violation findings (P2TL) reached 5,212 cases in 2023 and increased to 6,058 cases in 2024. Additionally, there were 77,763 recorded cases of meter reading disturbances.

Energy loss, particularly non-technical losses, remains a critical issue for electricity providers in many developing countries. In Indonesia, PT PLN (Persero) faces similar challenges, with distribution losses often exceeding the national target of 6% [1]. The main causes of non-technical losses include electricity theft, inaccurate meter readings, and recording errors [2]. The implementation of AMI has been proven to significantly reduce non-technical losses. This system establishes two-way communication between smart meters and PLN's data center, enabling theft detection, real-time monitoring, and accurate automatic readings [3][4].

However, despite various pilot implementations of AMI in Indonesia, there remains a lack of empirical studies quantifying its direct impact on operational performance, particularly in urban distribution networks such as UP3 Bandengan [3][4][19]. This study seeks to answer the question: To what extent does AMI implementation reduce non-technical losses and operational inefficiencies in meter reading, customer arrears, and energy misuse detection.

The use of AMI systems requires post-implementation evaluation to assess the impact and efficiency gained from the implementation at UP3 Bandengan in particular. Such evaluation can also offer insights for further system development to maximize the benefits of AMI in the future.

II. RESEARCH METHODS

2.1. Advanced Metering Infrastructure (AMI)

Advanced Metering Infrastructure (AMI) is a modern electrical energy metering system that enables two-way communication between customer metering devices and the utility's central data system. The system consists of several key components, including smart meters, two-way communication modules such as Power Line Communication (PLC), Radio Frequency (RF), or Fiber Optic (FO), a Data Concentrator Unit (DCU), a Head End System (HES), and a Meter Data Management System (MDMS) [3][5].

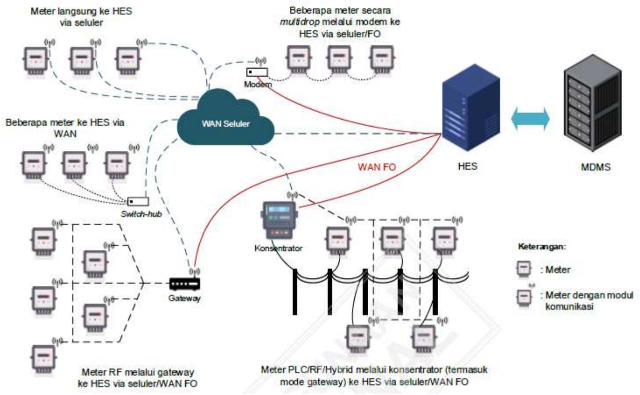


Figure 1. AMI System Configuration [1]

AMI not only enables remote energy reading but also provides capabilities for load control, power quality monitoring, and anomaly detection such as disturbances or energy theft [1].

Figure 1 illustrates two types of AMI system configurations based on the communication pattern between the meter and the Head End System (HES):

1. Single AMI Configuration
   In this setup, meters communicate directly with the HES without using a data concentrator or collector. Communication media include cellular networks and/or wide area networks (WAN) using fiber optics. Examples in Figure 1 include direct meter-to-HES communication, multiple meters connecting via WAN, and multi-drop connections through modems.
2. Cluster AMI Configuration
   In this setup, multiple meters share a communication medium through a gateway or concentrator to reach the HES. Figure 1 includes configurations such as RF meters communicating through a gateway, and RF/PLC/hybrid meters connecting via a concentrator to the HES.

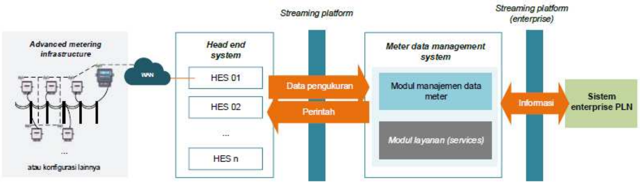


Figure 2. AMI Architecture Diagram [1]

The AMI system architecture integrates both software and hardware components to ensure interoperability and reliable communication between field devices and the central control system. It supports both downlink (from the control center to devices) and uplink (from devices to the center) communication channels, utilizing various media such as Power Line Communication (PLC), Radio Frequency (RF), and cellular networks (GPRS/4G) [5][6]. The communication protocol employed in this system is DLMS/COSEM, an international standard for data exchange between metering devices and central systems [5].]. In SPLN D3.007:2021, single-phase postpaid meters used in the AMI system must meet the following criteria [7]:

- Measure active energy (accuracy class 1) and reactive energy (class 2);
- Support two-way communication with an optical communication port and a local port;
- Feature a display screen, navigation buttons, LED indicators, and a tampering detection system;
- Support load profiling, historical data, and instant profiles;
- Capable of operating in export-import power mode (four-quadrant metering).

Figure 3. AMI enabled kWh meter

2.1.1. Data Concentrator Unit (DCU)

The Data Concentrator Unit (DCU) is a key component within the Advanced Metering Infrastructure (AMI) system, responsible for aggregating data from multiple customer smart meters and transmitting it to the Head End System (HES) via a communication network. In accordance with the specifications outlined in SPLN D3.036:2021, the DCU is equipped with several essential features that support its effective operation within the AMI framework. The DCU enables two-way communication: downlink communication from smart meters to the DCU typically occurs over Power Line Communication (PLC) or Radio Frequency (RF), while uplink communication from the DCU to the HES utilizes Ethernet or cellular networks.

Figure 4. Data Concentrator Unit (DCU)

In addition to serving as a data aggregator, the DCU also functions as a gateway, facilitating seamless communication between field meters and central systems. Moreover, the DCU is capable of measuring energy at the distribution level, enabling energy consumption to be recorded at the network segment level. It is also designed to support temporary data storage, event logging, system alarms, and time synchronization, all of which are critical for anomaly detection and maintaining power system reliability [6]. According to Supplement SPLN D3.036:2021/SUP-1:2023, the DCU is further enhanced with additional features to ensure optimal reliability and performance. These include an auxiliary I/O port that serves as an interface for external control—such as the automated operation of devices like Molded Case Circuit Breakers (MCCBs)—and a backup battery designed to maintain system functionality for at least 60 minutes during power outages, ensuring uninterrupted data acquisition. For ease of monitoring, the DCU is also equipped with LED indicators that visually display the measurement status of both active and reactive energy, providing clear real-time information to field operators [9].

2.1.2. Head End System (HES) dan Meter Data Management System (MDMS)

The Head End System (HES) is responsible for managing communication with smart meters and data concentrators. Its functions include data acquisition, executing commands issued by the MDMS, and performing firmware updates on metering devices [5]. In contrast, the Meter Data Management System (MDMS) is tasked with managing and validating measurement data, supporting billing processes, and providing data for system performance analysis and customer usage insights.

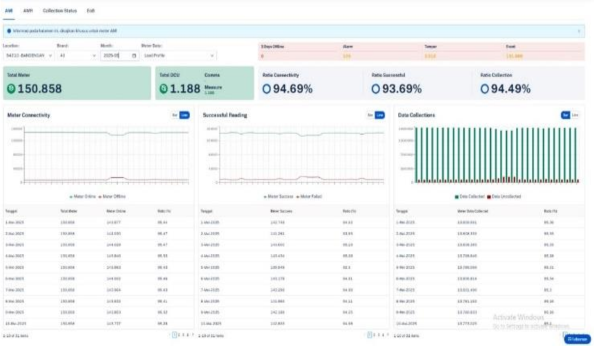


Figure 5. Dashboard MDMS

2.2. Losses

Energy losses refer to the difference between the amount of electricity purchased by the utility and the amount successfully sold to customers. These losses serve as a key indicator of distribution system efficiency and are categorized into two main types: technical losses and non-technical losses (NTL) [9]. Technical losses occur naturally due to physical factors in the transmission and distribution process, such as conductor resistance, transformer losses, and equipment inefficiencies. Although unavoidable, they can be minimized through network optimization, the use of low-resistance conductors, and routine infrastructure maintenance. Technical losses are predictable and can be estimated using mathematical models or simulation methods such as backward/forward sweep algorithms [2]. In contrast, non-technical losses arise from administrative weaknesses, customer misconduct, and inadequate monitoring systems. Common causes include electricity theft (e.g., meter bypassing, illegal connections), inaccurate meter readings due to human error or damaged devices, and unregistered public street lighting (PJU) [2][9][10]. In developing countries, NTL can exceed 50% of total losses [2]. For instance, a study in ULP Palopo Kota recorded a reduction in NTL from 1.45% in 2022 to 0.68% in early 2023 through prepaid meter inspections, back billing (Tagsus), and meter replacement programs [9]. Similarly, in PLN Disjaya and Tangerang, the gradual deployment of AMR systems reduced losses from 8.52% in 2013 to 6.61% in 2014, identifying energy losses totaling 4.55 million kWh or IDR 4.17 billion [9]. According to PT PLN (Persero) Director's Decree No. 217-1.JK/DIR/2005, controlling both technical and non-technical losses is a strategic effort to improve distribution efficiency and corporate profitability [9]. To support this, PLN has adopted smart metering technologies such as AMI (Advanced Metering Infrastructure), which enable real-time monitoring, anomaly detection (e.g., zero current or unmeasurable voltage), and automated meter reading without human intervention [2][9]. In summary, addressing energy losses—particularly NTL—is not merely a technical issue, but also involves policy, supervision, data integrity, and customer education. Reducing these losses contributes directly to improving national energy efficiency and the financial sustainability of power utilities. PLN has established official guidelines for calculating technical and non-technical losses, as stipulated in Director Regulation No. 0021.P/DIR/2018 [10], using the following standard formula-based approach:

Losses (%)=((Purchased kWh-Billed kWh)/Purchased kWh)×100% ……………………………………(1)
Purchased kWh = kWh delivered to customers
Billed kWh = kWh received by customers

This study employs a mixed methods approach, combining quantitative and qualitative analysis within a case study design at PT PLN (Persero) UP3 Bandengan. The quantitative approach is used to analyze numerical data before (2023) and after (2024) the implementation of AMI. The data includes the number of meter reading disturbances, Target Operation (TO) P2TL data, delinquent billing data (both in number of bills and monetary value), as well as calculations of operational cost efficiency.

Quantitative data was analyzed using comparative trend analysis to assess the percentage change before and after AMI implementation. Furthermore, percentage reductions were calculated to quantify the AMI's impact, while qualitative interview data was thematically coded to triangulate operational challenges and validate performance improvements [21], [22]. Future work may incorporate inferential statistics or regression modeling for broader generalization [2].

The qualitative approach is employed to identify the root causes of non-technical losses and to validate findings derived from the quantitative data. This is achieved through in-depth interviews with key informants who have the relevant expertise and direct roles in managing non-technical losses at PT PLN (Persero) UP3 Bandengan.

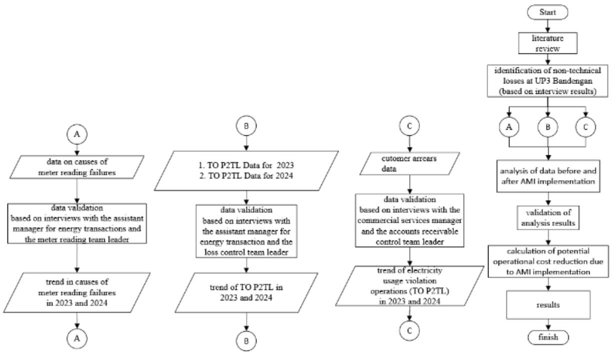


Figure 6. Flowchart Research Method

The initial stage of this research involved a literature review to establish a solid theoretical foundation. This review covered topics such as Advanced Metering Infrastructure (AMI) systems, energy loss calculations, causes of non-technical losses, and findings from previous AMI implementation studies. A key limitation identified in earlier research is the lack of quantitative comparisons before and after AMI deployment—particularly in the Jakarta region—which makes it difficult to assess the actual impact on loss reduction, system efficiency, or distribution reliability. As a result, many evaluations remain qualitative and do not present measurable outcomes over a defined period.

Problem identification was conducted to understand the dominant factors contributing to non-technical losses at PT PLN (Persero) UP3 Bandengan. In-depth interviews with key stakeholders—including the Assistant Manager of Energy Transactions, Assistant Manager of Commercial Services, and Team Leaders for Loss Control and Accounts Receivable—revealed three primary causes: inaccurate meter reading, electricity theft, and bill payment delinquency.

The first factor is meter reading inaccuracy, largely due to manual processes that are prone to human error and technical constraints, such as inaccessible meters or damaged devices. These inaccuracies result in unrecorded consumption, revenue losses for PLN, and unfair billing for customers.

The second factor is unauthorized electricity usage. P2TL team findings indicate that some customers manipulate electrical installations to bypass official metering, leading to unbilled consumption and elevated non-technical losses. These illegal practices also pose safety risks.

The third factor is delayed bill payments. Interviews indicate a lack of customer awareness regarding billing deadlines, causing frequent late payments, temporary disconnections, and increased administrative burdens.

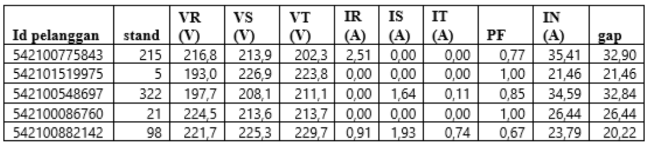
These issues highlight the need for a system that minimizes manual intervention, enhances data accuracy, and provides automated monitoring and alerts. The implementation of Advanced Metering Infrastructure (AMI), with its automated reading, real-time data integration, and anomaly detection capabilities, offers a strategic solution to significantly reduce non-technical losses and improve service efficiency at UP3 Bandengan.

Table 1. Data Sources, Data Collection Techniques and Types of Research Data

Types of data	Data Sources	Methods of Data Collection
Primary	Key personal at PT PLN (Persero) UP3 Bandengan (Assistant Manager, Team Leaders and Field Officers)	In-depth Interview
Secondary	Internal reports from PT PLN (Persero) UP3 Bandengan (arrears data, meter reading failure records, TO P2TL data, and operational cost data)	Documentaion and archival study

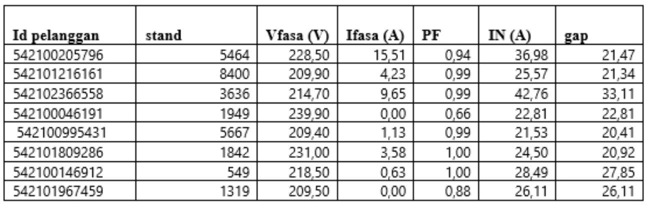
A qualitative descriptive analysis was used to interpret interview results for identifying key issues and validating findings. A quantitative comparative analysis was applied to evaluate data trends between 2023 (pre-AMI) and 2024 (post-AMI), measuring the impact of implementation. Cost-efficiency analysis was conducted by estimating potential operational savings based on the volume of manual tasks replaced by AMI, multiplied by the unit cost per activity. Additionally, P2TL target analysis was based on anomaly detection from the Meter Data Management System (MDMS), focusing on significant discrepancies between phase currents (IR, IS, IT) and neutral current (IN).

Table 2. Sample Data Analysis of 3 Phase AMI Customer Electricity Consumption



Id pelanggan	stand	VR (V)	VS (V)	VT (V)	IR (A)	IS (A)	IT (A)	PF	IN (A)	gap
542100775843	215	216,8	213,9	202,3	2,51	0,00	0,00	0,77	35,41	32,90
542101519975	5	193,0	226,9	223,8	0,00	0,00	0,00	1,00	21,46	21,46
542100548697	322	197,7	208,1	211,1	0,00	1,64	0,11	0,85	34,59	32,84
542100086760	21	224,5	213,6	213,7	0,00	0,00	0,00	1,00	26,44	26,44
542100882142	98	221,7	225,3	229,7	0,91	1,93	0,74	0,67	23,79	20,22

Table 3. Sample Data Analysis of 1 Phase AMI Customer Electricity Consumption



Id pelanggan	stand	Vfasa (V)	Ifasa (A)	PF	IN (A)	gap
542100205796	5464	228,50	15,51	0,94	36,98	21,47
542101216161	8400	209,90	4,23	0,99	25,57	21,34
542102366558	3636	214,70	9,65	0,99	42,76	33,11
542100046191	1949	239,90	0,00	0,66	22,81	22,81
542100995431	5667	209,40	1,13	0,99	21,53	20,41
542101809286	1842	231,00	3,58	1,00	24,50	20,92
542100146912	549	218,50	0,63	1,00	28,49	27,85
542101967459	1319	209,50	0,00	0,88	26,11	26,11

In this study, the determination of electricity theft targets was based on anomaly data from AMI-based customer meters by analyzing the current gap between phase input and neutral current, as shown in Table 2, along with stop metering indicators retrieved from the MDMS. Customers showing significant current discrepancies were inspected by the P2TL team to verify potential violations or anomalies. Interviews with field personnel revealed that unauthorized electricity use is often economically motivated. Additionally, the loss control team at UP3 Bandengan noted some anomalies were due to installation errors, such as phase current being connected to the neutral line, resulting in unusually high neutral current readings.

III. RESULT AND ANALYSIS

3.1 Analysis of Meter Reading Disruption Trends Before and After AMI Implementation

An analysis was conducted on the meter reading failures recorded at UP3 Bandengan, focusing on four major causes: inaccessible customer homes/staff unable to access kWh meters, kWh meter removed (disassembled) kWh meters, stagnant kWh meter status, and Inaccesible kWh meters. The comparison between 2023 (before the implementation of AMI) and 2024 (after AMI implementation) highlights significant improvements in meter accessibility and reading accuracy.

3.1.1. Inaccessible Customer Homes / Staff Unable to Access kWh Meters

Based on Table 4, there is a significant difference in the number of meter reading disruptions between the years 2023 and 2024. In 2023, the disruptions for inaccessible residential meters were still very high, particularly in May and October, which recorded 7,576 and 7,734 cases, respectively. This indicates that the manual meter reading process remains highly dependent on field conditions and the accessibility of customers' locations by the staff. The unreliability of this method results in low accuracy in recording customers' energy consumption and is a primary source of non-technical losses.

Table 4. Percentage of Decrease in Meter Reading Disruptions for Inaccessible Customer Homes

Month	Number of cases		"Percentage of disruption reduction"
	2023	2024	
Jan	4,154	1,511	63.63%
Feb	5,381	1,301	75.82%
Mar	5,393	405	92.49%
Apr	6,453	140	97.83%
May	7,576	149	98.03%
Jun	5,221	212	95.94%
Jul	5,928	205	96.54%
Aug	6,999	255	96.36%
Sep	6,118	360	94.12%
Oct	7,734	1,132	85.36%
Nov	7,351	1,093	85.13%
Dec	1,113	876	21.29%

Conversely, in 2024, there was a significant and consistent decrease in meter reading disruptions. The number of disruptions drastically declined from March to November, averaging below 400 cases per month. This suggests that the Advanced Metering Infrastructure (AMI) system has begun to be active and function effectively since late 2023, particularly highlighted by a sharp decrease in December 2023 (dropping from 7,351 to 876 cases).

This decrease illustrates that the integration of smart meters with the Meter Data Management System (MDMS) application has a positive impact on the previously manual meter reading process. However, as shown in Table 4.3, there are still challenges in the implementation of the automated AMI meter reading system, specifically due to meter reading failures during the End of Billing (EOB) process by the MDMS/HES. The average failure percentage for EOB readings ranges from 1.62% to 2.97% of the total AMI meter customers. While this value is relatively small, it still indicates that the communication system between devices is not yet fully stable.

This information is further corroborated by interviews with the meter reading team leader, who mentioned that EOB failures are typically addressed immediately through field staff intervention. Thus, although AMI is designed to automate the energy recording process, in practice, this system has not completely removed human involvement, as it still requires personnel to verify or complete data collection for instances where readings could not be automatically retrieved.

Table 5. Percentage End of Billing (EOB) Failure per Month on the Same Date

Month	Number of Meter EOB	Number of AMI Customers in 2025	Percentage of AMI Meter Reading Failures
Sep-24	147,722	150,148	1.62%
Oct-24	147,467	150,148	1.79%
Nov-24	147,068	150,148	2.05%
Dec-24	146,859	150,148	2.19%
Jan-25	146,421	150,148	2.48%
Feb-25	146,014	150,148	2.75%
Mar-25	145,695	150,148	2.97%

As a result, in cases of EOB failures, customer consumption is determined based on historical data from the last three months, which can lead to inaccuracies if customers have dynamic or unstable consumption patterns. This condition has the potential to generate customer complaints and contribute to undetected non-technical losses. Nevertheless, from a macro perspective, the data presented demonstrates that the implementation of AMI has had a significant impact on reducing meter reading disruptions, thus enhancing operational efficiency in distribution and minimizing potential energy losses due to recording errors.

Quantitatively, the decrease in average meter reading disruptions from thousands of cases per month to hundreds or even dozens serves as an evidence of initial success for the AMI system. If the communication systems and coverage of AMI meter installations continue to improve, the EOB failure rate could also be reduced to near zero in the future. The sharp contrast between 2023 and 2024, particularly in the percentage reduction of disruptions reaching 98% in April and May, indicates that the reliability of the AMI system at optimal conditions can effectively replace manual systems with much higher accuracy and continuity. Thus, the AMI system functions not only as a tool for recording energy consumption but also as a direct controller of non-technical losses, through improved data accuracy, early anomaly detection, and a reduction in reliance on error-prone manual processes.

3.1.2. kWh Meter Removed

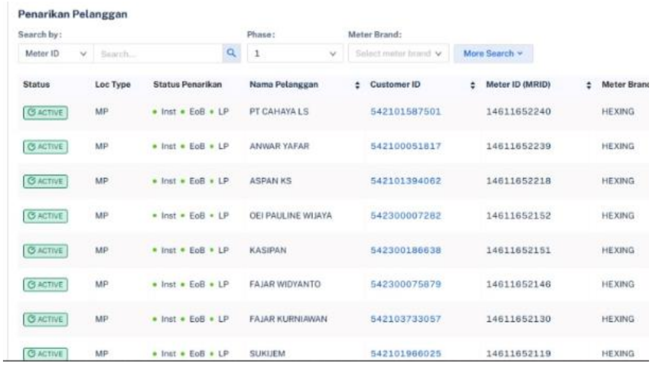
In Table 6, it is evident that during 2023, the number of meter reading disruptions caused by removed kWh meters was relatively high and fluctuating. The peak occurred in June with a total of 311 cases. The primary cause of this high number was weak coordination among internal work units at UP3 Bandengan, particularly between network disruption personnel, meter readers, and temporary disconnection officers (for customers overdue by more than three months). These three activities were conducted separately and not integrated into a unified monitoring system, often resulting in delays in updating the status of removed or inactive kWh meters.

Table 6. Percentage of Decrease in Disruptions for Removed kWh Meters

Month	Number of cases		Percentage of disruption reduction
	2023	2024	
Jan	204	137	32.84%
Feb	264	117	55.68%
Mar	254	73	71.26%
Apr	265	58	78.11%
Mei	179	46	74.30%
Jun	311	100	67.85%
Jul	222	107	51.80%
Agu	239	100	58.16%
Sep	268	81	69.78%
Okt	260	125	51.92%
Nov	235	111	52.77%
Des	185	101	45.41%

This situation was validated through interviews with the meter reading team leader and senior officer for electricity transaction performance, who reported that the lack of a centralized control system in 2023 made it impossible to detect inactive meters or anomalies directly. Consequently, readings continued to be taken for customers who were no longer using meters, which were recorded as meter reading disruptions. However, in 2024, there was a significant decrease in meter reading disruptions due to removed meters, with average numbers dropping to below 100 cases per month. Although there was a surge in cases during the period of May to July, the overall trend still indicated a more stable and consistent improvement compared to the previous year.

This decrease aligns with the implementation of the Advanced Metering Infrastructure (AMI) system, which became active at the beginning of 2024 and plays a crucial role in improving the quality of information and the speed of anomaly detection in customer meter devices. The role of the Meter Data Management System (MDMS) and Head End System (HES) in reducing these disruptions can be seen in Figure 6, which displays the status of customer kWh meters directly on the MDMS dashboard. In this view, there are status indicators for kWh meters, with several meter units marked as "online" or active (in red boxes), indicating that the AMI kWh meters are actively measuring energy consumption.



Status	Loc Type	Status Penarikan	Nama Pelanggan	Customer ID	Meter ID (MRID)	Meter Bran
ACTIVE	MP	• Inst • EoB • LP	PT CAHAYA LS	542101587501	14611652240	HEXING
ACTIVE	MP	• Inst • EoB • LP	ANWAR YAFAR	542100051817	14611652239	HEXING
ACTIVE	MP	• Inst • EoB • LP	ASPAN KS	542101394062	14611652218	HEXING
ACTIVE	MP	• Inst • EoB • LP	OEI PAULINE WIJAYA	542300007282	14611652152	HEXING
ACTIVE	MP	• Inst • EoB • LP	KASIPAN	542300186638	14611652151	HEXING
ACTIVE	MP	• Inst • EoB • LP	FAJAR WIDYANTO	542300075879	14611652146	HEXING
ACTIVE	MP	• Inst • EoB • LP	FAJAR KURNIAWAN	542103733057	14611652130	HEXING
ACTIVE	MP	• Inst • EoB • LP	SUKIJEM	542101966025	14611652119	HEXING

Figure 7. MDMS Dashboard Status of AMI-Based kWh Meters

Through this feature, staff can quickly identify meters experiencing issues such as stop metering or being offline and can promptly carry out verification or field actions without needing to wait for manual reading results. The AMI system is also equipped with automatic alarms and stop metering notification features that can be viewed on the MDMS dashboard. When a meter is not measuring energy, the system will immediately log the incident, which not only enhances data accuracy but also accelerates the resolution of disruptions before they impact the billing process.

The direct effect of this rapid detection is a reduction in non-technical losses, which previously stemmed from delays in detecting and recording consumption for customers whose meters were no longer active. Overall, the AMI system provides tangible benefits in reducing meter reading disruptions caused by discrepancies in device status in the field, while strengthening operational efficiency and reliability of electricity consumption data. The decrease in disruptions from an average of 250–300 cases per month in 2023 to around 100 cases per month in 2024 is concrete evidence that the integration of digital technology in the electricity distribution system can mitigate administrative and technical weaknesses that were previously the root causes of high non-technical losses.

3.1.3. Stagnant kWh Meter Status

The year 2023 represents the condition before the implementation of the AMI system. During this year, the meter reading process was still conducted manually or using conventional methods. The graph shows significant fluctuations, with the highest disruptions occurring in July, totaling 73 cases. Other months also experienced relatively high numbers of disruptions, such as February (38 cases), April (36 cases), May (31 cases), and June (48 cases).

Table 7. Percentage of Meter Reading Disruptions for Stagnant kWh Meters

Month	Number of cases		Percentage of disruption reduction
	2023	2024	
Jan	25	12	52.00%
Feb	38	5	86.84%
Mar	16	3	81.25%
Apr	36	1	97.22%
Mei	31	1	96.77%
Jun	48	4	91.67%
Jul	73	0	100%
Agu	49	0	100%
Sep	24	0	100%
Okt	18	1	94.44%
Nov	16	3	81.25%
Des	18	0	100%

This fluctuation highlights the limitations of manual systems in addressing technical problems quickly and accurately. Several factors contributing to the high disruptions include: physical damage to kWh meters that went undetected in real-time, delayed responses to anomalies in kWh meter measurements indicated by the recorded readings showing the same numbers or experiencing very slight increases compared to the previous month, and limitations in data-based monitoring and reporting when kWh meters were temporarily connected by disruption personnel for follow-up by meter replacement staff for faulty or aging meters. The year 2024 marks the beginning of the implementation of the AMI system in the process of reading and monitoring kWh meters.

The results indicate a significant positive impact on the reduction of disruptions. The highest number of disruptions recorded was only 12 cases in January, and this number continued to decline, reaching 0 cases for the majority of the months. When comparing the total disruptions in 2023, which amounted to 389 cases, to the 31 cases in 2024, the implementation of the AMI system proved to be very effective, resulting in a nearly 92% decrease in disruptions from the previous year. Early detection and reduced response time in addressing meter reading disruptions caused by stagnant or faulty kWh meters contribute to lowering non-technical losses at UP3 Bandengan through improved accuracy in meter readings.

3.1.4. Inaccessible kWh Meters

In 2023, the trend of meter reading disturbances showed fluctuations that tended to increase throughout the year. Starting with 236 disturbances in January, the number continued to rise, peaking in October with 713 disturbances. Afterward, there was a decline until December, reaching 111 disturbances. In 2024, the disturbance trend showed a very significant improvement. The number of disturbances in January was 250, relatively similar to January 2023.

However, starting in March, there was a drastic and consistent decrease, with the number of disturbances dropping to its lowest point in May (20 disturbances). A comparison of the trends between 2023 and 2024 indicates that the implementation of AMI has positively impacted the reduction of meter reading disturbances caused by difficult kWh meter positions. The average number of meter reading disturbances in 2023 was 427 disturbances per month, while in 2024 it decreased to 80 disturbances per month.

Table 8. Percentage of Meter Reading Disruptions for Inaccessible kWh Meters

Month	Number of cases		Percentage of disruption reduction
	2023	2024	
Jan	235	236	0.43%
Feb	320	250	21.88%
Mar	364	71	80.49%
Apr	427	33	92.27%
Mei	212	20	90.57%
Jun	388	53	86.34%
Jul	429	48	88.81%
Agu	491	35	92.87%
Sep	604	53	91.23%
Okt	713	104	85.41%
Nov	670	175	73.88%
Des	211	112	46.92%

The implementation of AMI can reduce the number of cases of manual kWh meter readings that are hindered by difficult-to-reach positions by utilizing an automated and real-time meter reading system. The implementation of AMI also assists UP3 Bandengan in operational cost efficiency for meter reading personnel and can reduce the operational time required for staff to read meters in challenging positions.

3.2 Data Analysis of P2TL Operational Target Trends Before and After AMI Implementation

Based on Table 9, there is a declining trend in the number of findings in the Operational Target (TO) activities of P2TL between the years 2023 and 2024. This decline is very significant, with an average decrease in findings reaching almost 90%. This condition highlights the crucial role of the implementation of Advanced Metering Infrastructure (AMI) in detecting and reducing instances of electricity usage violations. At the beginning of 2024, the number of findings was still relatively high, particularly in January and February, as it coincided with the initial implementation process of AMI. This was confirmed by an interview with the Team Leader of Loss Control, who explained that during the early phase, many customers were not yet fully monitored due to infrastructure limitations and the ongoing transition from manual systems. However, as time progressed, the AMI system began to show significant effects.

Table 9. Percentage Change of TO P2TL

Month	Number of cases		Percentage of disruption reduction
	2023	2024	
Jan	953	913	4.20%
Feb	436	897	105.73%
Mar	512	598	16.80%
Apr	223	498	123.32%
May	384	586	52.60%
Jun	322	550	70.81%
Jul	353	395	11.90%
Aug	389	414	6.43%
Sep	388	250	35.57%
Oct	351	329	6.27%
Nov	524	333	36.45%
Dec	377	295	21.75%

The decrease in the number of findings started to be evident from the middle of the year and continued until the end of the year. This improvement can be attributed to AMI's capability to provide real-time monitoring of electricity consumption through the integration of smart meters with the Meter Data Management System (MDMS) application. This monitoring enables the back office team to directly detect irregularities in electricity usage by customers, such as current anomalies between phase and neutral, stop metering, or unusual zero consumption. Such irregularities are then promptly followed up by field officers assigned to conduct direct inspections at the locations.

Table 10. Revenue from P2TL P1,P2 and P3 AMI in 2024

Month	Saving kWh	Rupiah
Jan	273,745	327,673,122.00
Feb	92,258	113,368,847.00
Mar	93,914	120,803,053.00
Apr	119,528	139,356,972.00
Mei	350,313	500,018,037.00
Jun	104,376	159,473,144.00
Jul	177,906	242,375,444.00
Ags	60,589	94,536,590.00
Sep	31,671	40,991,468.00
Okt	187,270	281,716,532.00
Nov	74,081	100,396,868.00
Des	152,570	241,298,767.00
Total	1,718,221	2,362,008,844.00

The effectiveness of AMI is also reflected in the energy savings recorded in Table 4.8. Throughout 2024, a total of 1,718,221 kWh of energy was successfully secured through AMI-based customer enforcement, with a total follow-up billing amounting to Rp 2,362,008,844. This amount directly represents the success of AMI in detecting and reconstructing energy that was previously unmeasured or unpaid by customers. The largest findings were recorded in May, totaling 350,313 kWh, indicating that in the early months, many violations that were previously undetected have now been uncovered. However, in the following months, such as August and September, the number of findings began to decline drastically. This suggests that customers have started to become aware of the strict monitoring systems implemented and that abuse is becoming increasingly difficult to carry out without being detected.

The implementation of AMI has also had a positive impact in reducing the involvement of manual meter reading officers, which has previously been a vulnerable point for irregularities. With automatic and centralized readings, the potential for violations by certain staff members can be significantly minimized. Additionally, the entire process from detection to enforcement has become faster and more efficient.

Thus, the implementation of AMI at PT PLN (Persero) UP3 Bandengan has proven to be effective in reducing the number of violations in electricity usage, enhancing the transparency of the distribution system, and generating operational efficiencies and recovery of previously lost energy. These findings reinforce the strategic role of AMI in supporting digital transformation and efficiency in the national electricity system.

3.3 Analysis of Arrears Trend Data Before and After AMI Implementation

In 2023, the number of overdue bills was relatively high. The highest number occurred in January (29,187 bills) and gradually decreased until December (17,779 bills). This trend indicates a potential accumulation of arrears due to limitations in monitoring and manual billing processes. Fluctuations in arrears were also observed in months like May and June, which showed an increase in the number of overdue bills compared to the previous month. This pattern suggests that the manual system still heavily relies on the effectiveness of personnel and customer responsiveness to the billing process.

In 2024, a more consistent and earlier declining trend was observed compared to the previous year. Starting from 21,269 bills in January, it reached 14,717 bills in December. The most significant decrease occurred in June, dropping from 26,924 bills in 2023 to 14,689 bills in 2024, a reduction of 45.44%, as shown in Table 3.7.

The implementation of AMI in 2024 allows for more accurate and timely billing, enabling customers to pay their bills well before the specified deadlines. The automated disconnection and reconnection system also helps reduce customer interventions that obstruct personnel from manually disconnecting electricity services. This system also minimizes potential conflicts of interest between field personnel and customers.

Additionally, Table 11 shows a significant decrease in the nominal value of arrears after the implementation of AMI. The highest nominal arrears in 2023 occurred in January, amounting to Rp 27,708,928,969.00, which exhibited inconsistent declines throughout the year. On the other hand, in 2024, the nominal arrears generally decreased more steadily. The highest nominal decrease occurred in September, from Rp 11,760,059,932.00 in 2023 to only Rp 1,072,223,932.00 in 2024, representing a reduction of 90.88%, as shown in Table 12. This indicates that the AMI system not only reduced the number of overdue bills but also directly increased the company's revenue potential by decreasing outstanding receivables.

The AMI system helps improve the revenue of UP3 Bandengan by encouraging customers to pay their bills more diligently through notifications and real-time meter readings. There are still overdue bills arising because not all customers receive income before the electricity payment deadline. In practice, some customers still refrain from using electricity until they can pay their electric bills. The implementation of AMI also reduces the operational costs associated with personnel for disconnecting and reconnecting customer electricity services, as this can now be done automatically. In other words, the graphs and tables presented indicate that the AMI system is capable of optimizing the billing process, improving customer compliance in payments, and significantly reducing the number of overdue bills both in terms of quantity and nominal value.

Tabel 11. Precentage Decrease of Overdue Bills

Month	Number of overdue bills		Percentage decrease
	2023	2024	
Jan	29,187	21,269	27.13%
Feb	27,198	18,726	31.15%
Mar	27,186	17,264	36.50%
Apr	24,480	18,763	23.35%
May	27,286	14,852	45.57%
Jun	26,924	14,689	45.44%
Jul	26,147	15,260	41.64%
Aug	24,179	14,456	40.21%
Sep	18,579	15,067	18.90%
Oct	18,941	17,428	7.99%
Nov	18,871	15,775	16.41%
Dec	17,779	14,717	17.22%

Tabel 12. Percentage Decrease of Nominal Arrears

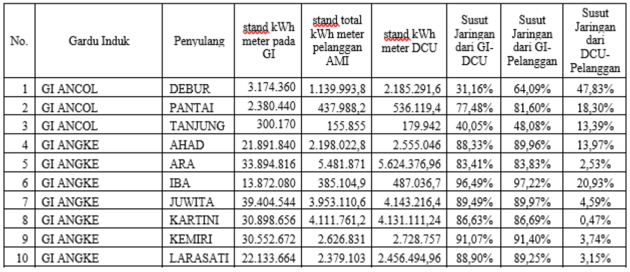
Month	Number of overdua bills		Percentage decrease
	2023 (IDR)	2024 (IDR)	
Jan	27,708,928,969.00	18,738,355,012.00	32.37%
Feb	15,338,111,758.00	19,119,458,974.00	24.65%
Mar	13,359,208,501.00	14,148,822,495.00	5.91%
Apr	20,005,014,824.00	14,231,086,784.00	28.86%
May	15,738,780,504.00	9,508,469,681.00	39.59%
Jun	16,258,910,081.00	9,935,467,208.00	38.89%
Jul	19,416,196,478.00	11,670,807,845.00	39.89%
Aug	15,782,446,489.00	10,380,859,175.00	34.23%
Sept	11,760,059,932.00	1,072,223,932.00	90.88%
Oct	1,184,181,834.00	1,486,674,094.00	25.54%
Nov	13,664,328,245.00	12,640,813,256.00	7.49%
Dec	11,708,614,401.00	10,036,166,749.00	14.28%

3.4 Analysis of Technical Losses Using AMI Implementation Data

The analysis of technical losses in the distribution system of PT PLN (Persero) UP3 Bandengan is conducted by comparing energy meter reading data at three main points: the Substation (GI), the Data Concentrator Unit (DCU), and customers based on AMI meters. The kWh meter at the Substation reflects the total energy purchased (kWh purchased), while the kWh meter for AMI customers reflects the energy sold to customers (kWh sold). The kWh meter at the DCU serves as a connector and comparator of energy from the Substation to the customers. Thus, these three data points allow for the calculation of technical losses in stages: from the Substation to customers, from the Substation to the DCU, and from the DCU to the customers.

However, it should be noted that the results of this analysis do not fully reflect the actual technical losses in the entire distribution system, as the implementation of AMI in the UP3 Bandengan area is still in the pilot project phase and does not yet cover all substations or customers. In one substation (DCU), the majority of customers still use conventional kWh meters, so the recorded data is not entirely representative. Additionally, the DCU is only installed at the Low Voltage Rack (TR) and does not yet include Medium Voltage (TM) substations, making the measurement of losses from the Substation to the DCU inaccurate; losses occurring at the Medium Voltage substations are automatically considered losses in Table 13.

Tabel 13 Estimated Technical Losses in the GI Network – AMI Customers for April 2025



No.	Gardu Induk	Penyulang	stand kWh meter pada GI	stand total kWh meter pelanggan AMI	stand kWh meter DCU	Susut Jaringan dari GI-DCU	Susut Jaringan dari GI-Pelanggan	Susut Jaringan dari DCU-Pelanggan
1	GI ANCOL	DEBUR	3.174.360	1.139.993,8	2.185.291,6	31,16%	64,09%	47,83%
2	GI ANCOL	PANTAI	2.380.440	437.988,2	536.119,4	77,48%	81,60%	18,30%
3	GI ANCOL	TANJUNG	300.170	155.855	179.942	40,05%	48,08%	13,39%
4	GI ANGKE	AHAD	21.891.840	2.198.022,8	2.555.046	88,33%	89,96%	13,97%
5	GI ANGKE	ARA	33.894.816	5.481.871	5.624.376,96	83,41%	83,83%	2,53%
6	GI ANGKE	IBA	13.872.080	385.104,9	487.036,7	96,49%	97,22%	20,93%
7	GI ANGKE	JUWITA	39.404.544	3.953.110,6	4.143.216,4	89,49%	89,97%	4,59%
8	GI ANGKE	KARTINI	30.898.656	4.111.761,2	4.131.111,24	86,63%	86,69%	0,47%
9	GI ANGKE	KEMIRI	30.552.672	2.626.831	2.728.757	91,07%	91,40%	3,74%
10	GI ANGKE	LARASATI	22.133.664	2.379.103	2.456.494,96	88,90%	89,25%	3,15%

Analysis of the Segment from substations to Customers shows high loss values on several feeders. The Pantai feeder (GI Ancol) shows a loss value of 81.60%, Debur at 64.09%, Ngetop (GI Kemayoran) at 54.90%, and Pinang (GI Gunung Sahari) even reaches 87.03%. These values are far above the reasonable threshold for technical losses in a distribution network, which ideally should be below 10%. The primary causes are likely related to inaccurate manual readings at the GI side, suboptimal installation of AMI, and the potential for electricity misuse.

Based on interview results, in several locations, limitations in DCU installation lead to customers not being integrated into the AMI system, making it impossible to track lost energy accurately. In the segment from GI to DCU, high loss values are also evident in several feeders, such as Pantai (53.56%), Debur (59.87%), and Ngetop (55.68%). This indicates that the energy readings from the GI have not been fully captured by the DCU, as not all customer substations are equipped with a DCU, particularly in the medium voltage substations. This aligns with statements from the distribution network performance officer, confirming that the TM substations are not connected to the AMI system due to the DCU's position only being on the low voltage side.

Furthermore, the segment from DCU to Customers depicts a gap between the energy data recorded by the DCU and the total consumption of connected AMI customers. The high losses in this segment indicate that many customers within a feeder have not yet adopted AMI meters. For example, in the Pinang feeder (GI Gunung Sahari), the loss from DCU to customers reaches 30.07%, Dingin (GI Kemayoran) at 11.84%, and Tripang (GI MK Baru) at 7.5%. This shows that only a small portion of customers within a single feeder are using AMI meters.

Based on interviews with the meter reading team leader, in several locations, only about 30–50% of customers in a single DCU have adopted AMI meters. This impacts the representativeness of readings, as the total energy recorded in the DCU has not been fully allocated to AMI customers. Conversely, in feeders with low DCU-to-customer loss values, the majority of customers have fully adopted AMI meters, resulting in loss values that are closer to the actual technical conditions.
The results of this analysis provide an initial overview of the potential reduction in technical losses through comprehensive AMI implementation. With the integration of all customers and substations into the AMI system and the installation of DCUs in both TM (medium voltage) and TR (transformer) substations, energy readings will become more accurate. This allows for more targeted setting of goals to reduce technical losses closer to the ideal threshold.

3.5 Potential Reduction of Operational Costs due to the Impact of AMI Implementation

The implementation of Advanced Metering Infrastructure (AMI) at PT PLN (Persero) UP3 Bandengan has shown significant potential in reducing operational costs across several key activities. These include meter reading, field inspections related to electricity usage violations

(P2TL), and the management of customer arrears. The following sections present cost efficiency calculations derived from the transition from manual processes to automated, AMI-based systems.

3.5.1. Calculation of Cost Efficiency in AMI

In manual meter reading, UP3 Bandengan incurs operational costs for meter readers at a unit price of Rp 1,637 per customer, according to the meter reading team leader. UP3 Bandengan has 150,148 AMI customers. The following is a table showing the cost calculations that can be reduced after AMI implementation at UP3 Bandengan:

Tabel 14. Potential Savings in Operational Costs for Meter Reading

Unit Price	Operational cost based on the number of AMI Meter sat UP3 Bandengan	Operational cost based on the actual monthly average EOB
Rp 1.637,- /customer*	Rp 245.792.276,00	Rp 7.373.768,28

*Price validated by the Meter Reading Team Leader of PT PLN (Persero) UP3 Bandengan.

C = HS x M_AMI.................................... (2)
Akt = HS x 3% x M_AMI…………….. (3)
C = Potential Cost Savings from AMI Meter Implementation at UP3 Bandengan
HS = Unit Cost of Meter Reading Personnel
M_{AMI} = Number of AMI Customers
Akt = Actual Monthly Average of EOB (End of Billing) Cases at UP3 Bandengan

If there are no AMI customers with failed automatic meter readings (successful EOB) each month, the potential cost savings would be Rp 245,792,276. However, according to the actual EOB success rate in Table 5, an average of 3% of meter readings fail each month, requiring UP3 Bandengan to continue employing personnel for manual meter readings at a cost of Rp 7,373,768 per month, in addition to the operational costs for non-AMI customers. The implementation of AMI can reduce the operational burden on meter readers by approximately 97% based on the number of AMI customers each month.

3.5.2. Calculation of Cost Efficiency in AMI Implementation for P2TL Operational Targets

According to the team leader for loss control at UP3 Bandengan, the unit price for customer inspections for P2TL is Rp 43,687 per customer. UP3 Bandengan has 150,148 customers using AMI. The determination of P2TL operational targets for AMI customers is based on the gap indicated in Table 2 and 3, which reflects the difference between incoming current in the kWh meter and neutral current. The following is a calculation of the costs that can be reduced after the implementation of AMI at UP3 Bandengan.

Table 15. Potential Savings in Operational Costs for P2TL Inspections

Unit price	Cost Savings from AMI implementations at UP3 Bandengan	Operational Costs Based on the Actual Average of AMI Violation Findings at UP3 Bandengan At UP3 Bandengan
Rp 43.687,- /customer*	Rp 6.559.515.676,00	Rp 1.967.854,70

*Price validated by the Loss Control Team Leader of UP3 Bandengan.

P= HS x M_AMI................................. (4)
Akt= HS x 0,03% x M_AMI…………….. (5)
P = Potential Cost Savings from AMI Implementation at UP3 Bandengan
HS = Unit Cost of P2TL Inspection Personnel
Akt = Actual Average Number of AMI Customer Violations at UP3 Bandengan
M_{AMI} = Number of AMI Customers at UP3 Bandengan

Based on the 2024 TO P2TL data, UP3 Bandengan found an average of 41 AMI customers per month classified as P1, P2, and P3, which is 0.03% of the total AMI customers. The potential cost for UP3 Bandengan to inspect customers without AMI was Rp 6,559,515,675. However, the average cost for inspecting the AMI customers identified in P2TL was only around Rp 1,967,854. The implementation of AMI can reduce operational burdens for P2TL inspections by approximately 99.97% and provide a measurable inspection timeframe for identifying P2TL targets.

3.5.3. Calculation of Cost Efficiency in AMI Implementation for Reducing Arrears

According to information from the Assistant Manager of Sales, the unit price for temporary disconnection at UP3 Bandengan is based on GM Decree No. 0005.K/GM/2020 regarding Temporary Disconnection, Reconnection, and Final Disconnection of Prepaid and Postpaid Customers, set at Rp 52,000 per customer, with Rp 26,000 for disconnection and Rp 26,000 for reconnection after payment of the bill. The following are the calculations of costs that can be reduced after implementing AMI at UP3 Bandengan:

Table 16. Potential Savings from Temporary Disconnection

Unit price	Operational Costs Based on the Number of AMI Meters at UP3 Bandengan	Operational Costs Based on Disconnection Target
Rp 52.000,- /pelanggan*	Rp 7.807.696.000,00	Rp 17.160.000,00

*[11]

PS = HS x M_AMI.................... (6)
T= HS x 330.............................. (7)
PS = Potential Cost Savings from Temporary Disconnection through AMI Implementation at UP3 Bandengan
HS = Unit Cost of Temporary Disconnection Personnel

MAMI = Number of AMI Meter Customers at UP3 Bandengan
T = Disconnection target of 330 customers per month

The potential savings in operational costs for temporary disconnection by personnel at UP3 Bandengan, due to AMI-based meters, amounts to Rp 7,807,696,000. Meanwhile, for the predetermined monthly target of 330 customers, the operational cost reduction is Rp 17,160,000 per month.

3.5.4. Potential Reduction of Operational Costs Due to AMI Implementation

The implementation of AMI at UP3 Bandengan has significantly reduced operational costs across various aspects of customer service, as shown in Figure 6. In the meter reading process, the use of AMI has reduced costs by up to 97%, with monthly savings potential exceeding Rp 245,792,276, although there is still an average of 3% of customers requiring manual readings. For P2TL customer inspections, AMI has drastically decreased the need for field checks, achieving a cost efficiency of 99.97%, reducing potential costs from Rp 6,559,515,676 to approximately Rp 1,967,854.

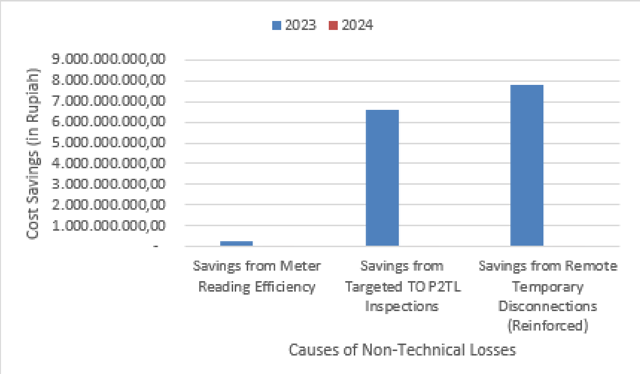


Figure 8. Potential Savings from Temporary Disconnection

IV. CONCLUSION

Based on research conducted on the implementation of the Advanced Metering Infrastructure (AMI) system at PT PLN (Persero) UP3 Bandengan, several significant conclusions have been drawn. The implementation of AMI has led to a notable reduction in meter reading interruptions, achieving a decrease of over 90% in various categories compared to the previous year. This decline is attributed to factors such as more accurate automatic meter readings through the MDMS system, with fewer issues arising from inaccessible customer premises, tampered meters, stuck readings, and difficult locations. Furthermore, the AMI system has greatly enhanced the efficiency of controlling arrears; the introduction of remote disconnection and reconnection features has resulted in a decrease in overdue bills from 286,757 in 2023 to 198,266 in 2024, and the total nominal value of arrears has dropped from Rp 181,924,782,016 to Rp 132,969,205,205. This illustrates the effectiveness of digital technology in supporting cash flow efficiency and company billing. Additionally, the AMI system has improved the operational targets for P2TL by enabling early detection of current anomalies, which serve as indicators of electricity misuse. Consequently, the determination of P2TL operational targets has become more data-driven, precise, and effective, resulting in an increase in the number of detected customer violations in 2024. The AMI implementation has also resulted in substantial operational cost efficiencies. Costs associated with manual meter reading, P2TL inspections, and temporary disconnections have all decreased due to the automation offered by AMI features. Estimated total savings have reached more than Rp 8 billion per month, with detailed savings of Rp 245,792,276 from meter reading costs, Rp 7,807,696,000 from disconnections of delinquent customers, and Rp 3,047,406,000 from reduced P2TL inspection costs based on the effectiveness of anomaly detection.

Lastly, the use of AMI has significantly improved the quality of real-time monitoring of customer consumption, fostering a more transparent, efficient, and reliable electricity distribution system. This aligns with the Sustainable Development Goal (SDG 9), which emphasizes the development of smart infrastructure and energy efficiency.

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