Correlation Analysis Between the Proportion of Prepaid kWh Meter Customers and the Rate of P2TL Violations at PT PLN (Persero) ULP Tebing Tinggi

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Abstract

Non-technical losses due to electricity usage violations are one of the main challenges faced by PT PLN (Persero) in maintaining energy distribution efficiency. A program to migrate from postpaid to prepaid kWh meters has been implemented as a control strategy; however, the relationship between the adoption rate of prepaid meters and the number of violations detected under the Electricity Usage Enforcement (P2TL) program has not yet been empirically examined using a correlational statistical approach. This study aims to analyze the correlation between the proportion of customers with prepaid kWh meters and the rate of P2TL violations at PT PLN (Persero)'s Tebing Tinggi ULP from January 2024 to December 2025. The method used is a quantitative correlational approach with monthly data comprising 24 observation points (n = 24). The Shapiro-Wilk normality test indicated that the prepaid proportion variable was normally distributed (W = 0.9505; p = 0.2773), whereas the total P2TL violation variable was not normally distributed (W = 0.8998; p = 0.0213); therefore, the analysis proceeded using Spearman's correlation test. The analysis results showed a correlation coefficient of $\rho = -0.1715$ with a p-value of 0.4230 and a calculated t-value of -0.817, which is smaller than the critical t-value of 2.074 (df = 22; $\alpha = 0.05$). These results indicate that there was no significant correlation between the proportion of prepaid kWh meter customers and the number of P2TL violations identified at the Tebing Tinggi ULP during the study period. Over the course of 24 months, P2TL operations successfully identified a total non-technical loss of 2,254,471 kWh, valued at Rp 1,110,779,065. These findings indicate that P2TL violations are influenced by factors other than the proportion of prepaid meter usage, thus requiring a more comprehensive control approach.

Keywords: Prepaid Meter, P2TL, Non-technical Loss, Spearman's Correlation, PLN ULP Tebing Tinggi

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Introduction

Electricity is one of the basic needs that supports economic, social, and industrial activities in Indonesia. PT PLN (Persero), as a state-owned enterprise responsible for the national supply and distribution of electricity, faces various operational challenges, one of which is energy losses. Energy losses are divided into two categories: technical losses caused by the physical characteristics of the grid, such as conductor resistance and transformers; and non-technical losses resulting from illegal energy use, low accuracy of metering equipment, meter reading errors, and illegal connections outside the metering system[1] . If non-technical losses are left unaddressed, the company's losses will continue to rise and impact the overall efficiency of electricity supply[2] .

Efforts to reduce non-technical losses are ongoing; PLN implements the Electricity Usage Enforcement Program (P2TL) as a mechanism for monitoring and taking action against electricity usage violations in the field. Based on PT PLN (Persero) Board of Directors Regulation No. 0028.P/DIR/2023, electricity usage violations are classified into four categories—Category I (P1) through Category IV (P4)—according to the type and severity of the irregularities found[3] . On the other hand, PLN is also encouraging customers to migrate from postpaid to prepaid meters as a strategy to control consumption and prevent meter tampering. The migration from postpaid to prepaid kWh meters has significantly reduced non-technical losses within the PLN ULP's service area, indicating that the adoption rate of prepaid meters may be correlated with a decrease in electricity usage violations[4][5] . Similar findings are supported by international research, which shows that replacing postpaid meters with prepaid meters increases recorded energy consumption by an average of 13.2%, indicating a reduction in non-technical losses by customers[5][6] . Nevertheless, the relationship between the proportion of prepaid meter customers and the number of P2TL violations has not yet been empirically examined through a statistical correlation analysis, particularly at the customer service unit level.

This study focuses on PT PLN (Persero)'s Tebing Tinggi Customer Service Unit (ULP), which is currently in a transition period for prepaid meter adoption, with approximately 55% of customers using prepaid meters and 45% using postpaid meters. The data used covers the period from January 2024 to December 2025, with two main variables: the monthly proportion of prepaid kWh meter customers as the independent variable (X) and the monthly total of P2TL violation findings (, P1–P4) as the dependent variable (Y). A correlational statistical approach was chosen to quantitatively measure the strength and direction of the relationship between the two variables, taking into account the results of the normality test to determine whether to use Pearson's or Spearman's correlation coefficient[7] .

Based on the background described above, this study aims to analyze the correlation between the proportion of prepaid kWh meter customers and the rate of P2TL violations at PT PLN (Persero) ULP Tebing Tinggi during the period from January 2024 to December 2025. The results of this study are expected to provide empirical evidence regarding the effectiveness of the prepaid meter migration program in reducing the number of electricity usage violations, while also serving as evaluation material for PLN management in making operational policy decisions.

Literature Review

Non-technical energy losses in the electricity distribution system are a problem that directly impacts the company's operational efficiency and revenue. Unlike technical losses, which are caused by the physical characteristics of network components, non-technical losses stem from illegal customer activities such as energy theft, tampering with kWh meters, and

unauthorized connections, resulting in distributed energy that goes unrecorded in the billing system[8][9] . Research at PT PLN (Persero) ULP Indarung shows that non-technical losses can reach 30.76% of total energy losses, and through the optimization of the P2TL program, these losses were successfully reduced to 4.03% over the course of one semester. Similarly, a study at the Panton Labu ULP noted that the implementation of the P2TL program contributed to savings of 14% of the initial total energy loss, with the value of losses successfully prevented reaching hundreds of millions of rupiah per semester[10] . These findings confirm that the P2TL program is an effective non-technical loss control tool; however, its success still depends on the intensity of implementation in the field and has not yet been systematically linked to structural factors such as the type of meter used by customers.

In addition to the implementation of P2TL, the migration of the kWh meter system from postpaid to prepaid has become one of PLN's strategic policies to reduce non-technical losses. Prepaid meters are considered more resistant to manipulation because the upfront payment system reduces the incentive for customers to commit meter fraud. The kWh meter migration at PT PLN (Persero) ULP Kota Fajar found that the transition from postpaid to prepaid meters had a significant impact on reducing non-technical losses, indicating a correlation between meter type and the rate of energy usage violations. This finding is supported by an international study in Ghana, which demonstrated that replacing postpaid meters with smart prepaid meters resulted in an average 13.2% increase in recorded energy consumption, reflecting a reduction in previously unreported non-technical losses[11] . On a more specific scale, an inspection of prepaid kWh meters with measurement anomalies at the Palopo City ULP was found to reduce the non-technical loss rate by 0.77% over a six-month observation period[12] . Although these studies indicate a relationship between prepaid meters and non-technical losses, no research has specifically examined the statistical correlation between the proportion of prepaid customers per time period and the number of monthly P2TL violation findings at the customer service unit level. This research gap forms the academic basis for the present study.

Based on the literature review above, there is a significant research gap: previous studies generally examined the effectiveness of P2TL descriptively or analyzed the impact of meter migration separately, without statistically testing whether month-to-month changes in the proportion of prepaid customers correlate with fluctuations in the number of detected P2TL violations. This situation is relevant for examination at PT PLN (Persero) ULP Tebing Tinggi, given that this unit is currently in a transitional phase with the proportion of prepaid customers gradually increasing from 49.67% in January 2024 to 54.04% in December 2025. Thus, the research question in this study is: Is there a significant correlation between the proportion of prepaid kWh meter customers and the rate of P2TL violations at PT PLN (Persero) ULP Tebing Tinggi from January 2024 to December 2025? The proposed hypotheses are: H_0 — there is no significant correlation between the two variables; H_1 — there is a significant negative correlation, such that the higher the proportion of prepaid customers, the lower the number of P2TL violations found.

Research Methodology

This study uses a quantitative approach with a correlational research design, a method aimed at determining whether a relationship exists between two variables and assessing the strength of that relationship without manipulating existing data[13] . The flowchart of the research analysis stages is presented in Figure 1.

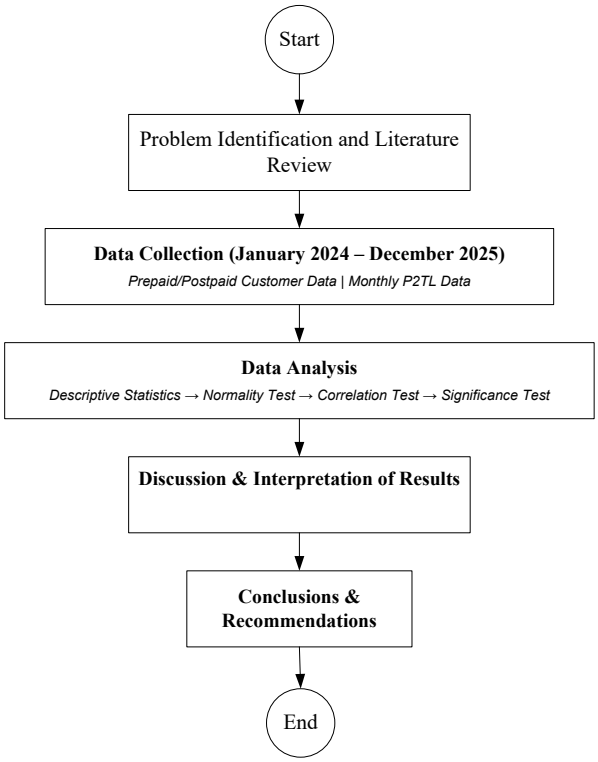

Figure 1. Research Analysis Flowchart

The data used consists of historical monthly secondary data collected through two methods. First, a documentary study of official documents from PT PLN (Persero) ULP Tebing Tinggi, specifically monthly customer data summaries from PLN's customer management system (variable X) and reports on P2TL operational results downloaded via the ap2t.pln.co.id system (variable Y). Second, unstructured interviews were conducted with supervisors and P2TL officers at the Tebing Tinggi ULP to obtain contextual information supporting the discussion of the research findings. The independent variable (X) is the proportion of prepaid kWh meter customers relative to the total number of active customers per month (%), while the dependent variable (Y) is the total number of P2TL violations found per month, covering Categories I through IV (P1–P4), measured in cases per month. Data were collected for the period from January 2024 to December 2025, with n = 24 months of observation using total sampling (census), meaning that all data within the specified time frame were used as the units of analysis for the study.

The data analysis stages were carried out sequentially as follows. First, descriptive statistics were calculated for each variable, including the mean, median, standard deviation, minimum value, and maximum value. Second, the Shapiro-Wilk normality test was applied to both variables at a significance level of $\alpha = 0.05$. The Shapiro-Wilk test was chosen because it has higher statistical power than the Kolmogorov-Smirnov test for small sample sizes ($n < 50$) [10]. Decision criteria: if $p > 0.05$, the data are normally distributed ; if $p \leq 0.05$, the data are not normally distributed. Third, the choice of correlation method was determined based on the results of the normality test. If both variables were normally distributed, the Pearson product-moment correlation was used; whereas if one or both were not normally distributed, the Spearman rank correlation was used—a nonparametric method that does not require the assumption of normality and is more robust to outliers [11]. Fourth, the significance test is performed using the t-test statistic with degrees of freedom $df = n - 2 = 22$ at a significance level of $\alpha = 0.05$, with the criterion for rejecting H_0 being |calculated t| > table t [11]. The strength of the correlation was interpreted using Guilford's

guidelines[14] , in which the absolute value of the correlation coefficient (|r| or |ρ|) is categorized into five levels, as shown in Table 1.

Table 1. Guidelines for interpreting correlation coefficients

Value of |r|	Interpretation
0.00 – 0.20	Very weak
0.21 – 0.40	Weak
0.41 – 0.60	Moderate
0.61–0.80	Strong
0.81–1.00	Very strong

In addition to the strength of the relationship, the direction of the correlation is also determined by the sign of the resulting coefficient. A positive value (+) indicates a positive relationship, meaning an increase in variable X is followed by an increase in variable Y, while a negative value (−) indicates an inverse relationship, meaning an increase in variable X is followed by a decrease in variable Y[15] . In the context of this study, the research hypothesis points to a negative correlation, where an increase in the proportion of prepaid meter customers (X) is expected to correlate with a decrease in the number of P2TL violations (Y). Additionally, the coefficient of determination (r^2) was calculated to determine what proportion of the variance in variable Y can be explained by variable X.

Results

4.1 Descriptive Statistics

A summary of the descriptive statistics for the two research variables during the period from January 2024 to December 2025 (n = 24) is presented in Table 2.

Table 2. Descriptive statistics for variables X and Y

Statistics	X Prepaid Proportion (%)	Y Total P2TL Violations (cases)
n	24	24
Average	51.97	48.88
Median	52.00	41.00
Standard Deviation	1.31	24.90
Minimum	49.67	16
Maximum	54.04	123
Range	4.37	107

Table 2 shows striking differences in the characteristics of the two variables. Variable X has a very small standard deviation (1.31%) with a range of only 4.37 percentage points over 24 months, indicating that the proportion of prepaid meters is changing gradually and consistently without significant fluctuations. This condition reflects an incremental transition at the Tebing Tinggi ULP, where the increase in prepaid customers occurs organically through new customers and voluntary migration. In contrast, variable Y exhibits much higher

variability with a standard deviation of 24.90 cases and a range of 107 cases, indicating that the number of P2TL violations fluctuates dynamically from month to month.

4.2 Analysis of Trends and Energy-Based Non-Technical Losses (kWh)

The monthly trend of variable Y during the study period shows a non-monotonic pattern. Violation findings peaked in August 2024 at 123 cases, then showed a downward trend in 2025. A complete summary of violations by category, kWh loss, and follow-up bills per month is presented in Table 3.

Table 3. Summary of P2TL violations by category, kWh loss, and follow-up bills

Period	Total	P1	P2	P3	P4	kWh Loss	Additional Bill (Rp)
January 2024	62	52	3	2	5	29,745	18,208,881
February 2024	34	2	4	4	24	116,496	58,890,996
March 2024	32	0	14	4	14	109,063	52,525,314
April 2024	16	0	5	2	9	44,618	21,472,182
May 2024	41	19	10	1	11	64,449	32,148,711
June 2024	79	52	11	5	11	106,307	58,298,850
July 2024	91	70	10	4	7	69,404	38,100,672
August 2024	123	109	3	6	5	37,182	24,801,903
September 2024	64	32	22	0	10	133,844	62,234,514
October 2024	31	11	3	1	16	52,055	24,195,726
November 2024	40	13	1	0	26	89,234	40,301,577
December 2024	53	5	0	1	47	183,146	90,489,459
January 2025	40	18	0	1	21	79,318	36,000,423
February 2025	41	3	0	1	37	148,717	65,335,518
March 2025	23	0	0	0	23	89,231	37,141,173
April 2025	48	30	2	1	15	71,880	33,924,636
May 2025	75	46	1	4	24	133,566	77,671,064
June 2025	66	47	0	3	16	88,954	68,982,904
July 2025	37	7	0	1	29	118,974	53,719,848
August 2025	22	0	0	1	21	79,318	36,646,938
September 2025	30	9	1	0	20	81,795	39,665,354
October 2025	57	34	1	0	22	94,187	41,914,574
November 2025	41	11	0	0	30	128,886	55,874,016
December 2025	27	1	0	0	26	104,102	42,233,832
TOTAL	**1,173**	**464**	**75**	**38**	**367**	**2,254,471**	**1,110,779,065**
Average/month	**48.88**	**—**	**—**	**—**	**—**	**93,936**	**46,282,461**

During the 24-month study period, the P2TL operation at the Tebing Tinggi ULP successfully identified a total of 2,254,471 kWh in non-technical losses, resulting in additional charges totaling Rp 1,110,779,065 successfully billed to non-compliant customers. On average per month, the energy saved through P2TL operations reached 93,936 kWh, valued at Rp 46,282,461. From a distribution engineering perspective, this figure is equivalent to the average monthly consumption of approximately 1,877 households with a 900 VA capacity, providing a concrete illustration of the magnitude of the technical impact of

violations on the distribution system at the Tebing Tinggi ULP. The composition of violations by category (P1–P4) per month is visualized in Figure 1 below.

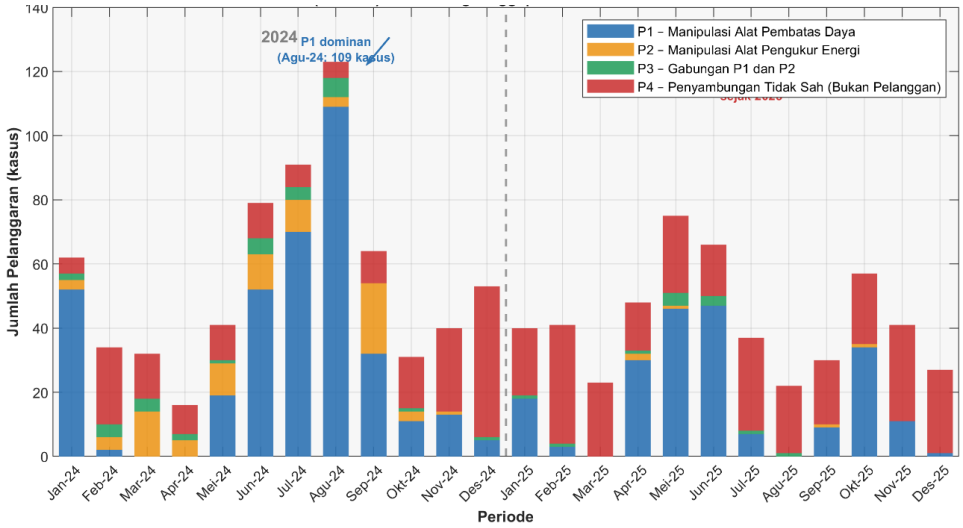

Figure 1. Composition of P2TL violations by category per month, PT PLN (Persero) Tebing Tinggi ULP, January 2024 – December 2025

Figure 1 shows a significant shift in the composition pattern between 2024 and 2025. In 2024, Category P1 violations (manipulation of power-limiting devices) dominated, peaking at 109 cases in August 2024. In 2025, the dominance shifted to Category P4—unauthorized connections by non-customers—which consistently became the most prevalent category. This shift indicates that as the proportion of prepaid meters—which are technically more difficult to tamper with—increases, violators tend to shift to more fundamental forms of misuse, although this causal claim cannot be directly confirmed from a correlation analysis alone. From a technical perspective, there is no consistent linear correlation between the number of violation cases and the identified kWh loss. August 2024 recorded the highest number of cases (123 cases) but had a relatively low kWh loss (37,182 kWh), whereas December 2024, which had only 53 cases, actually resulted in the highest kWh loss (183,146 kWh). This indicates that the amount of energy saved is more influenced by installed capacity and the estimated duration of each violation, as reflected in the formula for follow-up bills established in the regulations.

4.3 Shapiro-Wilk Normality Test

Before determining the correlation method to be used, a Shapiro-Wilk normality test was conducted on both variables with a significance level of $\alpha = 0.05$. The test results are presented in Table 4.

Table 4. Results of the Shapiro-Wilk normality test ($\alpha = 0.05$)

Variable	W	p-value	Decision
X — Proportion of prepaid	0.9505	0.2773	Normal ($p > 0.05$)
Y — Total P2TL violations	0.8998	0.0213	Non-normal ($p \leq 0.05$)

Based on Table 4, variable X is normally distributed ($W = 0.9505$; $p = 0.2773 > 0.05$), while variable Y is not normally distributed ($W = 0.8998$; $p = 0.0213 \leq 0.05$). The failure to

meet the assumption of normality for variable Y is likely due to an extreme value in August 2024 (123 cases) that far exceeds the mean.

4.4 Results of the Spearman Correlation Test and Significance Test

The guidelines for interpreting the strength of correlation coefficients used in this study refer to Guilford's criteria, as shown in Table 5.

Table 5. Guidelines for Interpreting Correlation Coefficients

Value of |ρ| or |r|	Interpretation of Correlation Strength
0.00 – 0.20	Very weak
0.21 – 0.40	Weak
0.41 – 0.60	Moderate
0.61–0.80	Strong
0.81–1.00	Very strong

The analysis results show a Spearman correlation coefficient of $\rho = -0.1715$ with a p-value of 0.4230. Since the value of |t-calculated| = 0.817 is smaller than the t-table value of 2.074 at a significance level of $\alpha = 0.05$ and df = 22, H_0 cannot be rejected. Thus, there is no statistically significant correlation between the proportion of prepaid kWh meter customers and the P2TL violation rate at PT PLN (Persero) ULP Tebing Tinggi for the period January 2024–December 2025. Referring to Table 5, the value $|\rho| = 0.1715$ falls into the "very weak" category. The coefficient of determination, $r^2 = 0.0294$, indicates that only 2.94% of the variance in the number of P2TL violations can be explained by the proportion of prepaid meters, while the remaining 97.06% is influenced by other factors outside the scope of the variables under study. The relationship between the two variables is visualized via a scatter plot in Figure 2 below:

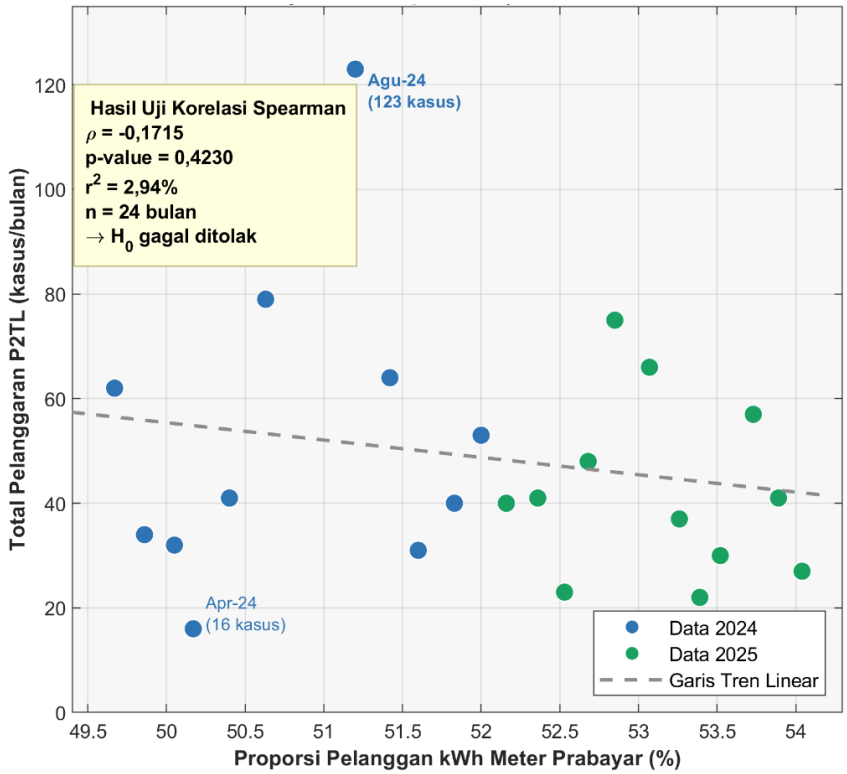

Figure 2. Relationship between the proportion of prepaid kWh meter customers and P2TL violations, Spearman's correlation test, n = 24 months

Figure 2 shows a distribution of data points that do not form a clear linear pattern, consistent with the non-significant correlation test results. The data points are randomly scattered around the trend line, confirming that changes in the proportion of prepaid meters within the range of 49.67%–54.04% are not accompanied by systematic changes in the number of P2TL violations.

4.5 Discussion

The results of this study differ from the initial hypothesis, which predicted a significant negative correlation between the two variables. Several methodological and contextual factors may explain these findings.

First, the range restriction of variable X. Variable X fluctuated only within a narrow range of 49.67%–54.04% over 24 months, with a standard deviation of just 1.31%. Statistically, a narrow range of variation in a variable is known to reduce the strength of the resulting correlation coefficient, even if a true relationship exists in the population.

Second, variable Y is influenced by uncontrolled operational factors. The number of P2TL violations detected per month not only reflects the actual prevalence of violations in the field but also depends on the intensity of P2TL operations conducted during that month. Months with intensive enforcement operations will naturally result in more findings without necessarily indicating an actual increase in violations. Factors such as the number of available officers, weather conditions, and target operational areas are confounding variables that were not controlled for in this study, as is commonly acknowledged as a limitation of correlational research in general.

Third, shifts in the composition of violation categories indicate behavioral adaptation. As shown in Figure 2 and Table 3, although the proportion of prepaid violations continued to rise, P4 violations actually became more dominant in 2025. This finding is consistent with the literature, which suggests that meter digitization can shift—rather than eliminate—violation behavior toward more fundamental forms.

Overall, the findings of this study underscore that the proportion of prepaid meters alone is not sufficient as a single predictor of P2TL violation rates. The total non-technical losses identified during the study period amounted to 2,254,471 kWh, indicating the significant potential for energy losses that still occur. Therefore, a more comprehensive approach is needed, including increased P2TL operational intensity, periodic monitoring of the low-voltage network (JTR), and customer education programs to sustainably reduce non-technical losses.

Conclusion

This study produced a correlation analysis between the proportion of prepaid kWh meter customers (X) and the P2TL violation rate (Y) at PT PLN (Persero) ULP Tebing Tinggi for the period January 2024–December 2025. Based on the Shapiro-Wilk normality test, variable X is normally distributed ($W = 0.9505$; $p = 0.2773$), whereas variable Y is not ($W = 0.8998$; $p = 0.0213$); therefore, Spearman's rank correlation was used. The results show $\rho = -0.1715$ with a p-value = 0.4230 and a calculated t-value = -0.817 < the critical t-value = 2.074 ($df = 22$; $\alpha = 0.05$), so H_0 cannot be rejected. Thus, there is no significant correlation between the proportion of prepaid meters and the number of P2TL violations found during the study period. The r^2 value of 2.94% indicates that 97.06% of the variance in violations is influenced by other factors.

From the electrical engineering perspective, the P2TL operation successfully identified a total non-technical loss of 2,254,471 kWh, valued at Rp 1,110,779,065, over 24 months—an average of 93,936 kWh per month. An analysis of the composition of violations reveals a shift in dominance

from P1 (2024) to P4 (2025), indicating that the adoption of prepaid meters has driven a shift in violation patterns toward a more fundamental form.

Based on these findings, this study recommends three technical measures. First, the implementation of an Automatic Meter Reading (AMR) system at priority distribution substations, which has been proven capable of detecting anomalies in current, voltage, and wiring errors at an early stage. Second, strengthening physical monitoring of the low-voltage network (JTR) to address the increase in P4 violations. Third, scheduling P2TL operations in a structured and evenly distributed manner throughout the year.

The limitations of this study include: a narrow range of variation in X, a correlational approach that does not establish cause and effect, and the lack of control over the P2TL operational variable. For future research, it is recommended to extend the study period until the proportion of prepaid customers reaches 70–80%, or to use multiple regression with P2TL operation intensity as a control variable.

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