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Analysis of the Effect of the Age of Postpaid Single-Phase kWh-meters on Measurement Accuracy

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Abstract

The background of this research stems from the need to ensure that the age of single-phase post-paid kWh meters significantly influences consumer electricity consumption. The accuracy of kWh meter measurements in recording electrical energy usage is a critical factor for PT. PLN (Perusahaan Listrik Negara) is to provide satisfactory service to customers in Indonesia while ensuring no party is disadvantaged. To achieve this objective, routine inspections are conducted on customer kWh meters, particularly those installed beyond the standard limit of 10 years or that exhibit an error deviation exceeding 5%. Testing results from 10 selected customers revealed that 6 customers fell into the normal category with inspection results below 5%, while 4 customers fell into the normal category with results exceeding 5%. The impact of a kWh meter age exceeding the standard limit is a loss for PLN and a gain for the customer if the deviation is "Negative (-)"; in such cases, the customer effectively pays less than the energy consumed. Conversely, it results in a loss for the customer and a gain for PLN if the error deviation is "Positive (+)", requiring PLN to compensate for the energy surplus paid for but not consumed. Therefore, consistent monitoring by PT. PLN as the producer and customer awareness as consumers are essential for maintaining kWh meters to minimise measurement inaccuracies.

1. Introduction

Electrical energy is a primary necessity of modern society, utilised in various aspects of life, ranging from households to industrial sectors [1]-[5]. To ensure that electrical energy consumption is accurately measured, reliable and precise measurement devices are essential [4], [6], [7].

One of the main devices in the electrical energy measurement system is the kWh meter, which records the amount of electrical energy consumed by the customer [2], [8]. The accuracy of a kWh meter is crucial as it forms the basis for determining the electricity costs that consumers must pay [1][4]. There are two commonly used types of kWh meters: post-paid and pre-paid. In the post-paid system, customers pay based on the total amount of electrical energy recorded by the meter. Single-phase post-paid kWh meters are widely used in households because they are suitable for small to medium-scale power requirements [2]-[4], [6].

Over time, the age of a kWh meter can affect its measurement accuracy due to factors such as component wear and tear, performance degradation, and technical disturbances [1],[8]. Measurement inaccuracies can lead to financial losses for both the consumer and the electricity provider [4],[9]. Therefore, this study aims to analyse the influence of the age of single-phase post-paid kWh meters on measurement accuracy, thereby providing an overview of the reliability of the measuring device over a specific period of use [6].

2. Methodology

2.1 Research Design

Research Location: The study was conducted at PT. PLN (Persero) UP3 Gunung Putri, Bogor. This location was selected to represent the characteristics of residential electricity loads in an urban-industrial area. Fig. 1 shows the Analogue Meter Construction.

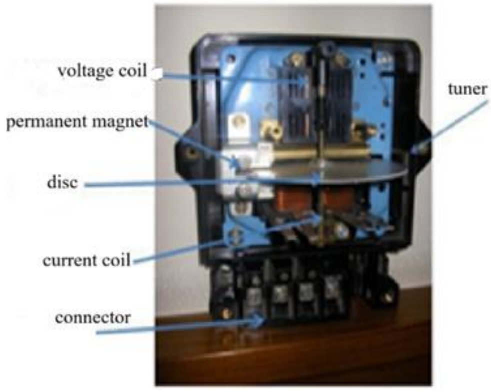

Fig. 1 *Analogue meter construction [6]*

Data Collection Techniques Research data were obtained through two primary sources:

- Secondary Data: Information regarding the age of kWh meters was extracted from PT. PLN's centralised system applications (such as AP2T or asset management systems). This data served to identify customers utilising measuring instruments with a service life exceeding 10 years.
- Primary Data: Field testing was performed using a standard Energy Meter Tester to obtain direct error deviation values at the customer sites. Tables 1 and 2 summarise customer data over 10 years.

- **Table 1** *Summary of customer data over >10 years with meter reading codes*

Meter Reading Code	Year kWh Meter			Total	(%)
	2011	2012	2013		
more kWh billed	2	0	1	3	3,75
kWh meter blurry/cracked	0	1	1	2	2,50
high-position kWh meter	0	1	0	1	1,25
The gate is locked	0	1	1	2	2,50
Empty House	1	3	3	7	8,75
Normal	18	16	31	65	81,25
TOTAL	21	22	37	80	100

Table 2 *Summary of normal customer data based on contract power*

No.	Installed power (VA)	Year kWh Meter			Number of Customers
		2011	2012	2013	
1	450	14	12	0	26
2	900	2	1	17	20
3	1300	1	2	10	13
4	2200	1	1	2	4
5	3500	0	0	1	1
6	4400	0	0	0	0
7	5500	0	0	1	1
TOTAL		18	16	31	65

2.2 Population and Sample

This study has a major limitation in the sample size tested, which is limited to only 10 kWh meters. While this finding successfully provides a crucial initial snapshot of accuracy degradation in ageing metering infrastructure, the sample size cannot represent the entire statistical variance of the thousands of meters installed in the PT. PLN UP3 Gunung Putri area. Therefore, the percentage results in this study are indicative, and further research with a larger sample size is highly recommended for data generalisation purposes. Table 3 tabulated the sampling data of kWh by measurement.

Table 3 *Sampling Data of kWh Meter Measurement Results*

No	power	Customer	Measurement Results				
			I (Ampere)	V (Volt)	Cos ρ (pf)	n (turn)	t (Time)
1	450	538670308***	1,29	219	0,90	1	17,54
2		538670309***	1,26	231	0,90	1	15,09
3		538670301***	1,07	230	0,90	1	21,16
4	900	538656413***	2,57	220	0,90	1	7,93
5		538656385***	2,01	228	0,90	1	9,55
6	1300	538610277***	3,58	222	0,90	1	6,22
7		538656114***	2,98	221	0,90	1	6,65
8	2200	538650959***	4,90	226	0,90	1	4,44
9	3500	538613937***	6,52	220	0,90	1	3,11
10	5500	538656409***	8,23	220	0,90	1	2,44

Note:
- Single-phase post-paid kWh meters.
- Operational age exceeding the technical standard limit of more than 10 years (>10 years).
- A total of 10 customers in the Gunung Putri area were selected through purposive sampling based on the aforementioned meter age criteria.

2.3 Analysis Procedure

The deviation data obtained from the 10 samples were compared against established accuracy class standards (a tolerance limit of ±5% according to prevailing regulations). The analysis was conducted to examine the correlation between the duration of service life and the magnitude of the error value (positive or negative).

Calculating kWh meter error is carried out in order to determine the accuracy of measurements on the kWh meter in the form of a percentage. If the error calculation results exceed the standard, it can affect the measurement accuracy of the kWh meter, which can cause losses for both the customers and the company. The kWh meter error calculation is expressed with the following formula: equation (1) is the measured power passing through the kWh meter, equation (2) is the active power measured through other measuring instruments, and equation (3) is the active error kWh Meter (Error %).

$$P_1 = \frac{3600\ x\ n}{t\ x\ c} \tag{1}$$

where:

ŋ = Many Rounds
t = time (Detik)
c = Konstanta kWh Meter

$$P_2 = V\ x\ I\ x\ \text{Cos}\ \varphi \tag{2}$$

where

V = Voltage (Volt)
I = Load Current (Ampere)
Cos φ = fowerfactor

$$Error\ \% = \frac{P_1 - P_2}{P_2}\ x\ 100\% \tag{3}$$

3. Result

3.1 Measurement Error Distribution in kWh Meter Samples

Based on field data collection conducted on 10 sample customers using single-phase postpaid kWh meters, significant variations in energy measurement accuracy were identified. Testing was performed by comparing the kWh meter readings against a standard calibration device to determine the percentage error.

In accordance with SPLN (State Electricity Company) standards and applicable legal metrology regulations, the allowable error tolerance for Class 2.0 kWh meters is ±5%. If the error value falls outside this range, the measuring device is declared unfit for operation or is experiencing performance degradation. The error deviation results for these 10 samples are presented in Table 4.

Table 4 *Measurement Calculation Data on the kWh Meter*

No	Customer	Error Calculation		
		P_1 (kWh) KW	P_2 (Burden) KW	Deviation Error
1	538670308***	0,228	0,254	-10,23%
2	538670309***	0,265	0,262	1,14%
3	538670301***	0,189	0,221	-14,48%
4	538656413***	0,504	0,509	-0,98%
5	538656385***	0,419	0,412	1,70%
6	538610277***	0,643	0,715	-10,07%
7	538656114***	0,602	0,593	1,52%
8	538650959***	0,901	0,997	-9,63%
9	538613937***	1,286	1,291	-0,39%
10	538656409***	1,639	1,630	0,55%

3.2 Analysis of The Impact of Age on Error Deviation

The data indicates a correlation between the service life of the kWh meter and a decline in measurement accuracy. From the total of 10 samples tested. 60% (6 customers) utilise kWh meters with performance remaining within the tolerance threshold (≤5%). 40% (4 customers) utilise kWh meters with extreme error deviations exceeding standard limits (>5%). Significant findings were observed in 4 samples categorised as "Fail". All failed samples exhibited large negative error values, specifically −9.63%, −10.07%, −10.23%, and −14.48%. Technically, a negative error value indicates that the rotating disc or digital counting system of the kWh meter operates more slowly than the actual energy consumption by the customer (underegistering).

3.3 Implication of Accuracy Abnormalities

This phenomenon confirms the hypothesis that the service life of a kWh meter affects its internal mechanical and electrical components, such as weakening of the magnetic field in the braking magnet and increased friction in the bearing friction due to wear or dust, which causes the rotation to become sluggish. Extreme deviations of up to −14.48% represent significant non-technical losses for the electricity service provider, as the consumed energy is not fully recorded. Conversely, this also shows that the reliability of measuring instruments decreases drastically with age, necessitating stricter rejuvenation or recalibration programs.

4. Discussion

4.1 Evaluation of Accuracy Degradation Due to Ageing

This study provides empirical evidence that the lifetime of a single-phase postpaid kWh meter has a negative correlation with energy measurement accuracy[8]. Based on sampling data, it was found that 40% of the sample population (4 kWh meters) experienced significant performance degradation, exceeding the ±5% error tolerance threshold set in SPLN D3.009-1:2010 and legal metrology standards[9]. These findings indicate that the longer a kWh meter operates in the field, the higher the probability of drifting error values[5], [6], [9]. The 6 customers categorised as normal likely represent kWh meters with younger installation ages or better-maintained environmental conditions.

4.2 Technical Analysis of Negative Error (Underegistering)

The most critical point of this research is the deviation characteristics in the 4 kWh meters that are abnormal. All error data exceeding the standard limit showed negative values, namely: −9.63%, −10.07%, −10.23%, and −14.48%. Technically, a negative error indicates that the kWh meter records lower energy consumption than the actual usage (underregistering). In electromechanical (analogue) kWh meters, this phenomenon is generally caused by mechanical wear due to ageing, including the following.

- Increased Friction: As the meter ages, the bearings of the induction disk become worn, or the lubricant dries out. This increases the frictional torque (Tf) that opposes the driving torque (Td). The working principle of an analogue kWh meter is illustrated in Fig. 2.
- Accumulation of Dust and Corrosion: Dust entering the meter case can hinder the rotation of the aluminium disc. Degradation of Electrical Components. The deterioration of insulation quality in the voltage coil and current coil affects the magnetic flux generated.

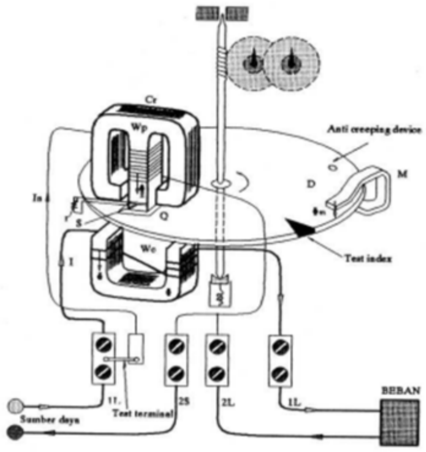

Fig. 2 *Part analogue meter[6]*

Fig. 2 illustrates the internal components of the electricity meter. In cases of deviation of up to −14.48%, the mechanical resistance on the disc shaft is already significant enough that the disc rotates much more slowly than it should, even though the electrical load used by the customer remains high.

4.3 Financial and Operational Implications

Error deviations reaching extreme figures (up to nearly -15%) have serious implications for Non-Technical Losses (NTL) for the service provider (PLN). With an error of −14.48%, for every 100 kWh of energy delivered and consumed, only 85.52 kWh is recorded and billed. Accumulated over the years, this results in massive revenue losses. Furthermore, while a negative error may financially benefit the customer, it violates the principle of fair energy transactions and measuring instrument validity guaranteed by metrology laws.

For household electricity tariffs in 2023 with a power of 450 VA, the cost is IDR 415 per kWh, so consumers suffer a loss of IDR 6,0092 for every 100 kWh.

4.4 Urgency of Replacement and Recalibration

The data, particularly deviations of −10.07% and −10.23%, confirms that the replacement deadline for kWh meters should not rely solely on total failure reports (stuck meters) but must be based on Time-Based Maintenance (TBM). kWh meters exceeding a certain service life (e.g., >15 years) show a strong tendency for negative errors, making revitalisation or replacement of old meters an absolute solution to minimise losses [10].

5. Conclusion

After examining and calculating the error deviation for 10 sampled customers, it is evident that age significantly influences kWh meter accuracy, leading to abnormalities where a portion of the samples exceeded the 5% error standard. Out of these 10 customers, 6 kWh meters were categorised as normal (error <5%), while 4 kWh meters were abnormal with negative readings of −10.23%, −14.48%, −10.07%, and −9.63%.

For kWh meters of customers that have exceeded the standard age limit, follow-up actions such as replacement or refurbishment of the kWh meters must be carried out, especially for those whose error deviation inspection results are above 5%.

Immediate follow-up, specifically replacement or rejuvenation, is required for kWh meters exceeding the service life standards, particularly those with deviations above 5%. The impact of ageing kWh meters manifests as a loss for the provider and a gain for the customer when the deviation is "Minus (-)". Conversely, a "Plus (+)" error deviation results in a loss for the customer and a gain for the provider. Therefore, meter revitalisation is essential to ensure transactional fairness and operational efficiency.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The first author is responsible for the revision and content of the research, the second author is responsible for the testing data, and the third author is responsible for the research funding proposal at Krisnadwipayana University.

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