Error comparison between postpaid and prepaid kWh meter readings under load variations

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ABSTRACT

Load variations found in PT PLN Persero customers, such as resistive, inductive, or capacitive loads, can potentially affect the error rate in kWh meter readings. To determine the error rate of kWh meter readings, it is necessary to compare the reading data from each kWh meter with the measurement data from a 6-in-1 multimeter display. This involves comparing the prepaid digital kWh meter, the postpaid semi-digital kWh meter, and the postpaid analog kWh meter, all assembled in series. Based on the test results, the average reading error rate for resistive loads was found to be 0,11% for the prepaid digital kWh meter, 6,91% for the postpaid semi-digital kWh meter, and 0,36% for the postpaid analog kWh meter. For inductive loads, the average reading error rate was 0,36% for the prepaid digital kWh meter, 7,00% for the postpaid semi-digital kWh meter, and 0,27% for the postpaid analog kWh meter. For capacitive loads, the average reading error rate was 0,09% for the prepaid digital kWh meter, 7,52% for the postpaid semi-digital kWh meter, and 0,62% for the postpaid analog kWh meter. This research is important for the electricity supply industry because the accuracy of electrical energy measurement is a key factor in maintaining operational efficiency and improving tariff fairness for customers.

Keywords: kWh Meter, reading error, load variations, 6in1 Multimeter Display

ABSTRAK

Variasi beban yang terdapat pada pelanggan PT PLN Persero, seperti beban resistif, induktif, atau kapasitif, dapat berpotensi mempengaruhi tingkat *error* pada pembacaan kWh meter. Untuk mencari tingkat *error* pembacaan kWh meter, dibutuhkan data hasil pembacaan pada masing-masing stand kWh meter dan data hasil pengukuran dengan alat *multimeter display 6in1*. Kemudian membandingkan kWh meter digital prabayar, kWh meter semi digital pascabayar, dan kWh meter analog pascabayar yang telah dirangkai secara seri. Berdasarkan hasil pengujian diperoleh bahwa, pada pengujian terhadap beban resistif, rata-rata tingkat *error* pembacaan pada kWh meter digital prabayar sebesar 0,11%, pada kWh meter semi digital pascabayar sebesar 6,91%, dan pada kWh meter analog pascabayar sebesar 0,36%. Pada pengujian terhadap beban induktif, rata-rata tingkat *error* pembacaan pada kWh meter digital prabayar sebesar 0,36%, pada kWh meter semi digital pascabayar sebesar 7,00%, dan pada kWh meter analog pascabayar sebesar 0,27%. Pada pengujian terhadap beban kapasitif, rata-rata tingkat *error* pembacaan pada kWh meter digital prabayar sebesar 0,09%, pada kWh meter semi digital pascabayar sebesar 7,52%, dan pada kWh meter analog pascabayar sebesar 0,62%. Penelitian ini penting untuk industri penyediaan listrik karena keakuratan pengukuran energi listrik merupakan faktor kunci dalam menjaga efisiensi operasional dan meningkatkan keadilan tarif bagi pelanggan.

Kata kunci: kWh Meter, *error* pembacaan, variasi beban, 6in1 Multimeter Display

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1. INTRODUCTION

The advancement of technology in the electricity industry has enhanced the ability to measure energy consumption accurately [1]. However, there is still the possibility of errors in kWh meter readings, which can affect the accuracy of measurements and the calculation of electricity costs payable by customers [2]. Common load variations found in the electrical installations of PT PLN Persero customers, such as resistive, inductive, and capacitive loads, have the potential to influence the error rate in kWh meter readings.

Resistive loads, such as incandescent lamps, electric irons, and water heaters, have a characteristic where the voltage aligns with the current, so the power consumed by resistive loads is purely active power [3]. Inductive loads, found in appliances like blenders, vacuum cleaners, and electric drills, exhibit a characteristic where the current lags behind the voltage. Consequently, inductive loads consume both active and reactive power. The phase shift in inductive loads occurs due to the magnetic field energy of the coils, causing the current phase to lag behind the voltage. This condition, known as lagging, means that inductive loads absorb both active and reactive power [4]. Capacitive loads, such as LED spotlights, charging laptops, and fluorescent lamps, have the ability to store energy through electric charge in a circuit, leading to a condition where the current leads the voltage (leading). Therefore, capacitive loads absorb active power and release reactive power [5]. From these three load characteristics, these variations will be considered as factors influencing the error rate of kWh meter readings.

The objective of this research is to compare the error rates of postpaid kWh meters and prepaid kWh meters under different load variations. Another objective is to understand the impact of resistive, inductive, and capacitive load characteristics on the error rates of postpaid and prepaid kWh meters.

This research holds significant benefits for the community. By understanding which type of kWh meter offers higher accuracy, recommendations and strategies can be provided to optimize kWh meter performance based on the findings. This can help reduce losses due to measurement errors and enhance tariff fairness for customers.

2. RESEARCH METHOD

2.1. Collection of Primary Data

Primary data refers to the data collected directly to address the objectives of the research. To determine the error rate of kWh meter readings, it is necessary to obtain the initial and final reading results from each kWh meter stand. From these kWh meter readings, the energy consumption value for each tested load can be determined. This value will serve as P1 in equation (1) to find the kWh meter reading error rate. Additionally, measurements using the 6-in-1 Multimeter Display tool will be recorded as reference values to determine the error rate of each kWh meter reading. The results obtained from the 6-in-1 Multimeter Display tool will be entered into equation (2) to find the energy used (kWh), which will then become P2 in equation (1) to determine the kWh meter reading error rate.

To calculate the percentage error rate based on the energy calculation results, the following equation is used [7] :

$$Error = \left|\frac{P1 - P2}{P2} \times 100\%\right| \quad (1)$$

Definition:

-P1 is the energy read on the kWh meter stand

-P2 is the energy measured using the 6-in-1 Multimeter Display tool or calculated using the equation:

$$P2 = \frac{\text{V x I x Cos } \varphi \text{ x t}}{1000} \quad (2)$$

According to IEC Standard No. 13B-23, electrical measuring instruments are classified into eight accuracy classes, which are: 0.05; 0.1; 0.2; 0.5; 1.0; 1.5; 2.0; and 5. These classes indicate the measurement error margin of ±0.05%, ±0.1%, ±0.2%, ±0.5, ±1.0%, ±1.5%, ±2.0%, and ±5% [8].

2.2. Collection of Secondary Data

The collection of secondary data involves gathering data that already exists and has been collected by other parties. Secondary data typically comes from sources such as previous research reports, journal articles, government databases, and other online resources. The collection of secondary data is a crucial procedure that allows researchers to utilize existing information, thereby saving time and resources. In this study, the secondary data collected includes the preparation of tools and materials, determination of the load variations to be used for testing, and the planning of the installation circuit.

1. Preparation of Tools and Materials

The tools and materials used in this research are as follows:

- **Postpaid kWh Meter**

  The postpaid kWh meter includes both analog and semi-digital types [2]. The mechanical kWh meter operates based on the principle of induction, which involves the interaction between the induction of the driving element and the current generated on the disk [9]. The resulting rotational force on the disk is transferred via an axis attached to its center. Permanent magnets are used to regulate and maintain the speed of the disk. The displacement gear and counter record the rotations produced by the shaft, which are then used to measure the energy consumed. [10].

Figure 2. Postpaid kWh Meter

Below is a table specification of Melcoinda Analog kWh Meter:

Table 1. Specification of Melcoinda Analog kWh Meter

Type of kWh Meter	MF-97 E
Wiring	Single phase 2 wire
Voltage	230 Volt
Frequency	50 Hz
Constant	300 rev/kWh
Accuracy Class	Class 2
Measurement Limits	20(60) A
Production Year	2011

A semi-digital kWh meter is a type of meter that closely resembles a digital kWh meter, but its design still includes a register, with the constant displayed in blinking form. The average electrical energy consumption is calculated by multiplying binary numbers representing current and voltage. The electrical energy consumption is then determined by accumulating the energy over each time interval [11]. One of the distinctive features of the semi-digital kWh meter is its display, which combines both analog and digital elements [12].

Figure 3. Postpaid semi-digital kWh meter

Below is a table specification of Smart Meter semi digital kWh Meter:

Table 2. Specification of Smart Meter semi digital kWh Meter

Type of kWh Meter	SMI-200S
Wiring	Single phase 2 wire
Voltage	230 Volt
Frequency	50 Hz
Constant	3200 imp/kWh
Accuracy Class	Class 1
Measurement Limits	5(40) A
Production Year	2015

- **Prepaid kWh Meter**

The prepaid kWh meter consists solely of a digital kWh meter [13]. The working principle of the digital kWh meter begins with detecting the current passing through the sensor and the voltage supplied from the power source. The current and voltage sensor outputs are then processed, generating a phase shift within the circuit. This signal is subsequently converted into DC voltage, which is fed into the ADC (Analog-to-Digital Converter) to be transformed into a digital signal [14]. The processed signal is then displayed on the LCD, showing the accumulated electrical energy usage along with the corresponding cost in rupiah [2].

Figure 4. Digital kWh Meter

Below is a table specification of Itron digital kWh Meter:

Table 3. Specification of Itron digital kWh Meter

Type of kWh Meter	700 JAVA VI
Wiring	Single phase 2 wire
Voltage	230 Volt
Frequency	50 Hz
Constant	1000 imp/kWh
Accuracy Class	Class 1
Measurement Limits	5(60) A
Production Year	2021

- **Determining Load Variations**
  In this study, the error rate of kWh meter readings will be analyzed in relation to load variations. To determine the characteristics of each load variation, a literature review of previous research and journal articles was conducted. This allows for the classification of loads based on their specific characteristics, such as identifying which loads fall under resistive, inductive, and capacitive categories. The following are the results of the load variation classification that will be used in this study:

Table 4. Variation of Loads [15]

Resistive Loads	Inductive Loads	Capacitive Loads
Glue Gun	Mixer	LED Spotlight
Electric Iron	Vacum Cleaner	Laptop (while charging)
Water Heater	Electric Drill	Smart Watch
Incandescent Lamps	Blender	Printer
Solder	Fan	Emergency Lights
Energy Saving Lamps	Hair Dryer	Portable Vacuum (while charging)
Rice Cooker	Portable Fan	Mobile Phone (while charging)
Toaster	Vacum Portable (at operate)	Fluorescent Lamps

- **Multimeter Display 6in1**
  The 6-in-1 Multimeter Display is a tool used to measure electrical values, i.e., current, voltage, power, frequency, and power factor. This tool also serves as a reference for calculating the error reading rate for each kWh meter.

Figure 5. Multimeter Display 6in1

The following is the specification table of the 6in1 display multimeter :

Table 5. Specification of Multimeter Display 6in1

Type of tool	P065-100
Power	22.000 Watt
Current	100 A
Accuracy Class	Level 1
Voltage	110 Volt – 250 Volt

2. Installation of Circuit Installation

The testing procedure involves connecting the three types of kWh meters in series with each load to be tested [16]. The following diagram illustrates the circuit configuration of the three kWh meters:

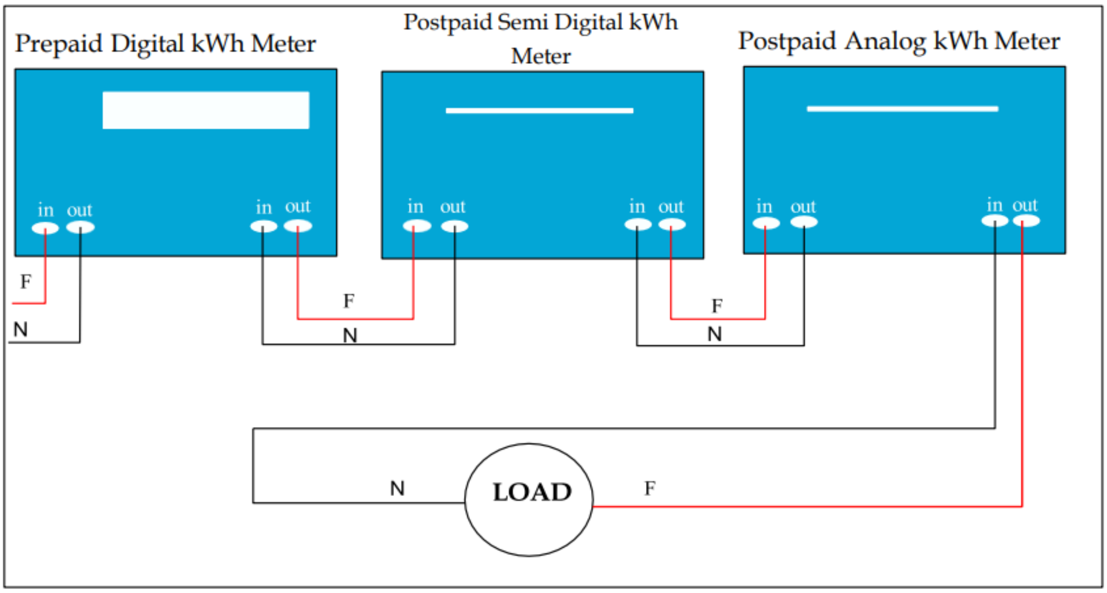

Figure 6. A series of kWh Meter tests on load variations

The comparison will be made between prepaid digital kWh meters, postpaid semi-digital kWh meters, and postpaid analog kWh meters. Where the three kWh meters have different levels of accuracy, which affects the percentage of error in the kWh meter.

3. RESULTS AND DISCUSSION

The three types of kWh meters, namely the postpaid analog kWh meter, the postpaid semi-digital kWh meter, and the prepaid digital kWh meter, were assembled in series for each load to be tested. The following image shows the series arrangement compiled on a test board:

Figure 7. Circuit installation

3.1. Data of kWh Meter Reading Result

To determine the error rate of kWh meter readings, it is necessary to obtain data from the stand reading results of each kWh meter as well as measurements from the 6-in-1 Multimeter Displaytool. The following table presents the stand reading results of the three kWh meters tested under load variations:

Table 6. Data of kWh Meter Reading Result

No	Load	Stand Value kWh Meter						Amount of Electrical Energy Consumption (kWh)		
		Digital Prepaid		Semi Digital Postpaid		Analog Postpaid		Digital Prepaid	Semi Digital Postpaid	Analog Postpaid
		Start	End	Start	End	Start	End			
Resistive Load										
1	Glue Gun	4,96	4,96	25983,74	25983,78	3,36	3,37	0	0,04	0,01
2	Electric Iron	4,95	4,92	25983,8	25984,1	3,37	3,4	0,03	0,3	0,03
3	Water Heater	4,84	4,8	25984,79	25985,21	3,46	3,51	0,04	0,42	0,05
4	Incandescent Lamps	4,97	4,96	25983,73	25983,74	3,35	3,36	0,01	0,01	0,01
5	Solder	4,79	4,78	25985,25	25985,37	3,52	3,53	0,01	0,12	0,01
6	Energy Saving Lamps	4,7	4,69	25985,94	25985,96	3,6	3,61	0,01	0,02	0,01
7	Rice Cooker	4,71	4,7	25985,77	25985,86	3,595	3,6	0,01	0,09	0,005
8	Toaster	4,75	4,73	25985,43	25985,65	3,55	3,57	0,02	0,22	0,02
Inductive Load										
1	Mixer	4,92	4,91	25984,13	25984,17	3,4	3,41	0,01	0,04	0,01
2	Vacum Cleaner	4,91	4,87	25984,17	25984,53	3,41	3,44	0,04	0,36	0,03
3	Electric Drill	4,87	4,86	25984,53	25984,65	3,44	3,45	0,01	0,12	0,01
4	Blender	4,8	4,79	25985,21	25985,25	3,51	3,52	0,01	0,04	0,01
5	Fan	4,7	4,7	25985,87	25985,92	3,6	3,6	0	0,05	0
6	Hair Dryer	4,78	4,75	25985,37	25985,43	3,53	3,55	0,03	0,06	0,02
7	Portable Fan	4,73	4,72	25985,65	25985,67	3,57	3,58	0,01	0,02	0,01
8	Vacum Portable (at operate)	4,7	4,7	25985,86	25985,87	3,6	3,6	0	0,01	0
Capacitive Load										
1	LED Spotlight	4,71	4,71	25985,68	25985,77	3,59	3,595	0	0,09	0,005
2	Laptop (while charging)	4,86	4,85	25984,65	25984,76	3,45	3,46	0,01	0,11	0,01
3	Smart Watch	4,7	4,7	25985,93	25985,94	3,6	3,6	0	0,01	0
4	Printer	4,69	4,69	25985,96	25985,97	3,61	3,61	0	0,01	0
5	Emergency Lights	4,92	4,91	25984,1	25984,13	3,39	3,4	0,01	0,03	0,01
6	Portable Vacuum (while charging)	4,72	4,72	25985,67	25985,68	3,58	3,59	0	0,01	0,01
7	Mobile Phone (while charging)	4,85	4,84	25984,76	25984,8	3,46	3,47	0,01	0,04	0,01
8	Fluorescent Lamps	4,7	4,7	25985,92	25985,93	3,6	3,6	0	0,01	0

After that, the difference between the final value on the subtracted stand and the initial value on the kWh meter stand was calculated. This process yields the value of electrical energy consumption (kWh) for each kWh meter, which will later be referred to as P1 in equation (1) to determine the error rate of the kWh meter reading.

3.2. Measurement Result Data with Multimeter Display 6in1

The next required data consists of the measurement results obtained using the 6-in-1 Multimeter Display tool. Several parameters are noted to determine the amount of electrical energy consumption in kWh units, including current value, voltage, power factor, and power consumed by each load. These measurements serve as accurate reference values for calculating the error rate of readings from both prepaid and postpaid kWh meters. The results from the 6-in-1 Multimeter Display will be incorporated into equation (2) to find the energy value used (kWh), which will subsequently be referred to as P2 in equation (1) for determining the kWh meter reading error rate. The measurement data obtained with the 6-in-1 Multimeter Display tool is presented in Table 2 below:

Table 7. Measurement result data with multimeter display 6in1

No	Load	Voltage (V)	Current (A)	Cos φ	Time (hour)	Power (W)	Energy Used (kWh)
	Resistive Load						
1	Glue Gun	221	0,04	0,95	0,5	7,39	0,00420
2	Electric Iron	226	2,18	0,99	0,25	493,6	0,12194
3	Water Heater	221	4,21	0,99	0,05	928,3	0,04606
4	Incandescent Lamps	221	0,43	0,99	1	96,4	0,09408
5	Solder	225	0,13	0,99	0,25	28,21	0,00724
6	Energy Saving Lamps	217	0,2	0,61	0,083	25,34	0,00220
7	Rice Cooker	218	0,17	0,99	0,25	35,27	0,00917
8	Toaster	210	3,2	0,99	0,05	670	0,03326
	Inductive Load						
1	Mixer	236	0,25	0,94	0,083	55,7	0,00460
2	Vacum Cleaner	233	1,99	0,97	0,083	454,2	0,03733
3	Electric Drill	236	0,57	0,89	0,166	121,7	0,01987
4	Blender	223	0,65	0,82	0,05	119,6	0,00594
5	Fan	219	0,16	0,93	0,166	36,4	0,00541
6	Hair Dryer	219	1,55	0,75	0,083	314	0,02113
7	Portable Fan	223	0,07	0,38	0,416	1,52	0,00247
8	Vacum Portable (at operate)	219	0,09	0,48	0,083	7,02	0,00079
	Capacitive Load						
1	LED Spotlight	218	0,14	0,9	0,5	25,7	0,01373
2	Laptop (while charging)	230	0,34	0,48	0,25	37,62	0,00938
3	Smart Watch	217	0,07	0,48	0,166	1,64	0,00121
4	Printer	218	0,08	0,38	0,333	2,75	0,00221
5	Emergency Lights	229	0,09	0,23	0,583	4,61	0,00276
6	Portable Vacuum (while charging)	224	0,07	0,49	0,333	3,79	0,00256
7	Mobile Phone (while charging)	230	0,09	0,48	0,25	9,43	0,00248
8	Fluorescent Lamps	217	0,08	0,56	0,166	4,52	0,00161

3.3. Calculating of Error Rate Reading kWh Meter

After obtaining the reading result data from each kWh meter and the measurement results from the 6-in-1 Multimeter Display tool. The next step is to determine the error reading rate for prepaid digital kWh meters, postpaid digital kWh meters, and postpaid analog kWh meters.

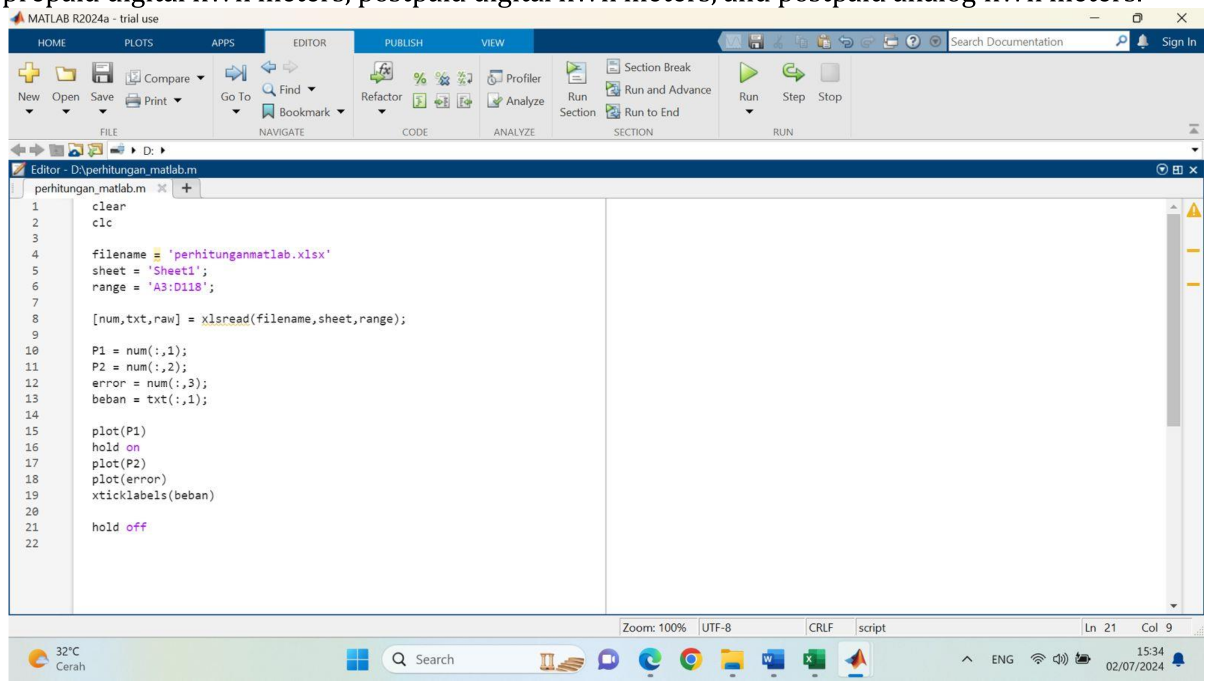

Figure 8. Analyze with Matlab

The data obtained will be entered into equation (1), where P1 represents the electrical energy value from the reading of each kWh meter, and P2 represents the electrical energy value from the measurement results obtained using the 6-in-1 Multimeter Display. The reading results from each kWh meter will be compared with the measurement results from the 6-in-1 Multimeter Display tool, which serves as a stable and accurate reference. The following table presents the results of the calculation of the postpaid kWh meter reading error rate and the prepaid kWh meter under load variations:

Table 8. Calculating of Error Rate Reading kWh Meter

No	Load	Prepaid Digital kWh Meter			Postpaid Semi Digital kWh Meter			Postpaid Analog kWh Meter		
		P1	P2	*Error* (%)	P1	P2	*Error* (%)	P1	P2	*Error* (%)
Resistive Load										
1	Glue Gun	0	0,00420	-1,00%	0,04	0,00420	8,53%	0,01	0,00420	1,38%
2	Electric Iron	0,03	0,12194	-0,75%	0,3	0,12194	1,46%	0,03	0,12194	-0,75%
3	Water Heater	0,04	0,04606	-0,13%	0,42	0,04606	8,12%	0,05	0,04606	0,09%
4	Incandescent Lamps	0,01	0,09408	-0,89%	0,01	0,09408	-0,89%	0,01	0,09408	-0,89%
5	Solder	0,01	0,00724	0,38%	0,12	0,00724	15,58%	0,01	0,00724	0,38%
6	Energy Saving Lamps	0,01	0,00220	3,55%	0,02	0,00220	8,10%	0,01	0,00220	3,55%
7	Rice Cooker	0,01	0,00917	0,09%	0,09	0,00917	8,81%	0,005	0,00917	-0,45%
8	Toaster	0,02	0,03326	-0,40%	0,22	0,03326	5,61%	0,02	0,03326	-0,40%
Inductive Load										
1	Mixer	0,01	0,00460	1,17%	0,04	0,00460	7,69%	0,01	0,00460	1,17%
2	Vacum Cleaner	0,04	0,03733	0,07%	0,36	0,03733	8,64%	0,03	0,03733	-0,20%
3	Electric Drill	0,01	0,01987	-0,50%	0,12	0,01987	5,04%	0,01	0,01987	-0,50%
4	Blender	0,01	0,00594	0,68%	0,04	0,00594	5,73%	0,01	0,00594	0,68%
5	Fan	0	0,00541	-1,00%	0,05	0,00541	8,24%	0	0,00541	-1,00%
6	Hair Dryer	0,03	0,02113	0,42%	0,06	0,02113	1,84%	0,02	0,02113	-0,05%
7	Portable Fan	0,01	0,00247	3,05%	0,02	0,00247	7,10%	0,01	0,00247	3,05%
8	Vacum Portable (at operate)	0	0,00079	-1,00%	0,01	0,00079	11,73%	0	0,00079	-1,00%
Capacitive Load										
1	LED Spotlight	0	0,01373	-1,00%	0,09	0,01373	5,55%	0,005	0,01373	-0,64%
2	Laptop (while charging)	0,01	0,00938	0,07%	0,11	0,00938	10,72%	0,01	0,00938	0,07%
3	Smart Watch	0	0,00121	-1,00%	0,01	0,00121	7,26%	0	0,00121	-1,00%
4	Printer	0	0,00221	-1,00%	0,01	0,00221	3,53%	0	0,00221	-1,00%
5	Emergency Lights	0,01	0,00276	2,62%	0,03	0,00276	9,86%	0,01	0,00276	2,62%
6	Portable Vacuum (while charging)	0	0,00256	-1,00%	0,01	0,00256	2,91%	0,01	0,00256	2,91%
7	Mobile Phone (while charging)	0,01	0,00248	3,03%	0,04	0,00248	15,10%	0,01	0,00248	3,03%
8	Fluorescent Lamps	0	0,00161	-1,00%	0,01	0,00161	5,20%	0	0,00161	-1,00%

In Table 8, it can be observed that the percentage of the resulting reading error values includes both negative and positive values. A negative error reading percentage indicates that the energy measured by the kWh meter is less than the actual energy consumed by the customer, resulting in a loss for PLN. Conversely, a positive error reading percentage indicates that the energy measured by the kWh meter exceeds the actual energy consumed by the customer, leading to losses for the customer.

3.4. Error Rate of kWh Meter Reading Under Load Variation

The load variations tested include resistive, inductive, and capacitive loads, with several types of each load variation being evaluated.

- Error Rate of kWh Meter Readings Under Resistive Loads
  In testing against resistive loads, the following appliances were used: glue guns, electric irons, water heaters, incandescent lamps, soldering irons, energy-efficient lamps, rice cookers, and toasters. Each load tested exhibited a different level of reading error. The following presents a comparison of the error rates of reading the postpaid kWh meter versus the prepaid kWh meter under resistive load conditions:

Table 9. Error Rate of kWh Meter Readings Under Resistive Loads

No	Resistive Load	Prepaid Digital kWh Meter	Postpaid Semi Digital kWh Meter	Postpaid Analog kWh Meter
1	Glue Gun	-1,00%	8,53%	1,38%
2	Electric Iron	-0,75%	1,46%	-0,75%
3	Water Heater	-0,13%	8,12%	0,09%
4	Incandescent Lamps	-0,89%	-0,89%	-0,89%
5	Solder	0,38%	15,58%	0,38%
6	Energy Saving Lamps	3,55%	8,10%	3,55%
7	Rice Cooker	0,09%	8,81%	-0,45%
8	Toaster	-0,40%	5,61%	-0,40%
	Average	0,11%	6,91%	0,36%

To present the data visually, the information in Table 9 will be represented in graphical form. Below is a graph illustrating the error rate of kWh meter readings under resistive loads:

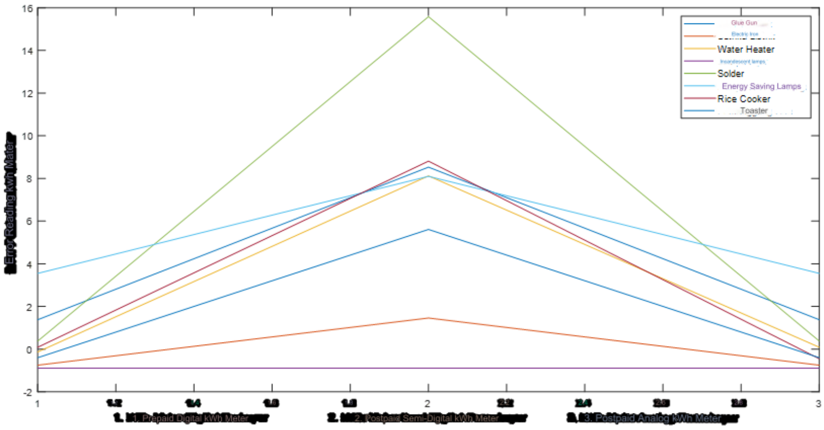

Figure 9. Graph of the kWh meter reading error under resistive loads

The graph above indicates that the error rate of the prepaid digital kWh meter is comparable to that of the postpaid analog kWh meter. In contrast, the postpaid semi-digital kWh meter showed a higher error rate compared to the other types of kWh meters, with the highest error rate observed at 15,58% during the solder load testing.

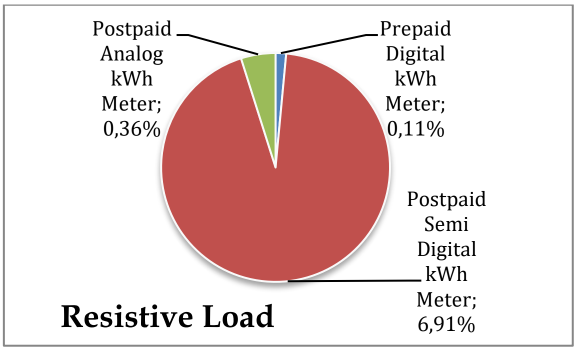

Figure 10. Average kWh meter reading error under resistive load

In testing resistive loads, the average error rate for the prepaid digital kWh meter is 0,11%, the postpaid digital kWh meter also shows an average error rate of 6,91%, and the analog kWh meter demonstrates an average error rate of 0,36%. This error rate is not as significant as the average error rate for inductive loads but is slightly higher than that for capacitive loads. This discrepancy is attributed to the characteristic of resistive loads, where the current is in phase with the voltage. Since resistive loads only consume active power, the error rate in reading these loads is not as high as that for inductive loads.

- Error Rate of kWh Meter Readings Under Inductive Loads

In testing the inductive load, various devices were used, including mixers, vacuum cleaners, electric drills, blenders, fans, hair dryers, portable fans, and portable vacuums (while in use). Each load tested showed a different level of reading error. The following is a comparison of the error rates between the postpaid and prepaid kWh meters under inductive loads:

Table 10. Error Rate of kWh Meter Readings Under Inductive Loads

No	Inductive Load	Prepaid Digital kWh Meter	Postpaid Semi Digital kWh Meter	Postpaid Analog kWh Meter
1	Mixer	1,17%	7,69%	1,17%
2	Vacum Cleaner	0,07%	8,64%	-0,20%
3	Electric Drill	-0,50%	5,04%	-0,50%
4	Blender	0,68%	5,73%	0,68%
5	Fan	-1,00%	8,24%	-1,00%
6	Hair Dryer	0,42%	1,84%	-0,05%
7	Portable Fan	3,05%	7,10%	3,05%
8	Vacum Portable (at operate)	-1,00%	11,73%	-1,00%
	Average	0,36%	7,00%	0,27%

To present the data visually, the information in Table 10 will be represented in graphical form. Below is a graph illustrating the error rate of kWh meter readings under inductive load:

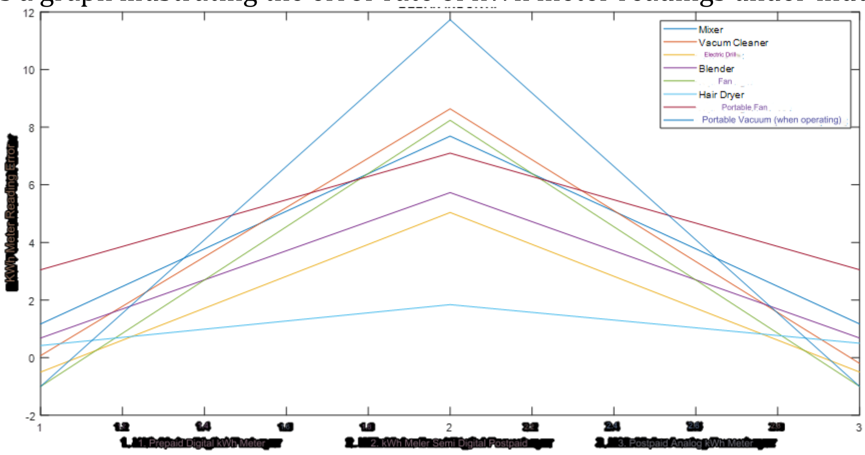

Figure 11. Graph of the kWh meter reading error under inductive loads

As shown in the graph above, the error rate of the prepaid digital kWh meter is almost the same as that of the postpaid analog kWh meter. However, the postpaid semi-digital kWh meter showed a higher error rate than the other types. The highest error rate, 11,73%, is observed during testing with the portable vacuum load (while in use).

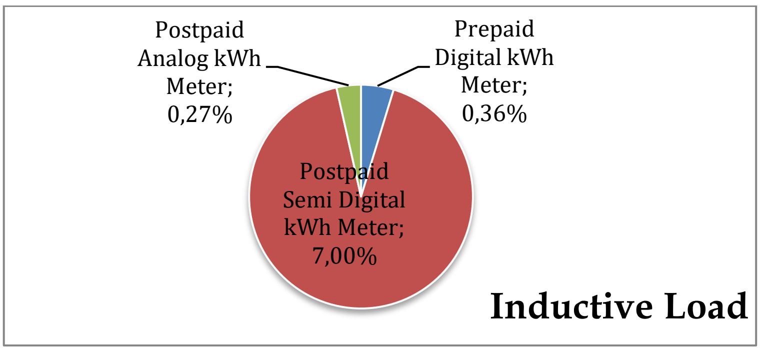

Figure 12. Average kWh meter reading error under inductive load

In the inductive load test, the average reading error rate for the digital kWh meter is 0,36%, for the postpaid semi-digital kWh meter is 7,00%, and for the analog kWh meter is 0,27%.

The error rate for kWh meter readings is higher compared to resistive load readings but lower than the error rate for capacitive loads. This is due to the nature of inductive loads, where the current lags behind the voltage due to the energy stored in the magnetic field of the coil. As a result, there is a phase shift, causing the current to be out of phase with the voltage. Inductive loads consume both active and reactive power. Since the semi-digital postpaid kWh meter and the postpaid analog kWh meter cannot measure reactive power, the reading error rate for these meters is higher than that of the prepaid digital kWh meter.

- Error Rate of kWh Meter Readings Under Capacitive Load
  In testing the capacitive load, researchers used loads in the form of LED spotlights, laptops (when charged), Smart Watches, printers, emergency lights, portable vacum (when charged), HandPhones (when charged), and fluorescent lights. Each of the loads tested has a different level of reading error. The following is a comparison of the error rate of reading the postpaid kWh meter with the prepaid kWh meter against the capacitive load:

Table 11. Error Rate of kWh Meter Reading Against Capacitive Load

No	Capacitive Load	Prepaid Digital kWh Meter	Postpaid Semi Digital kWh Meter	Postpaid Analog kWh Meter
1	LED Spotlight	-1,00%	5,55%	-0,64%
2	Laptop (while charging)	0,07%	10,72%	0,07%
3	Smart Watch	-1,00%	7,26%	-1,00%
4	Printer	-1,00%	3,53%	-1,00%
5	Emergency Lights	2,62%	9,86%	2,62%
6	Portable Vacuum (while charging)	-1,00%	2,91%	2,91%
7	Mobile Phone (while charging)	3,03%	15,10%	3,03%
8	Fluorescent Lamps	-1,00%	5,20%	-1,00%
Average		0,09%	7,52%	0,62%

To present the data visually, the information in Table 11 will be represented in graphical form. Below is a graph illustrating the error rate of kWh meter readings under capacitive load:

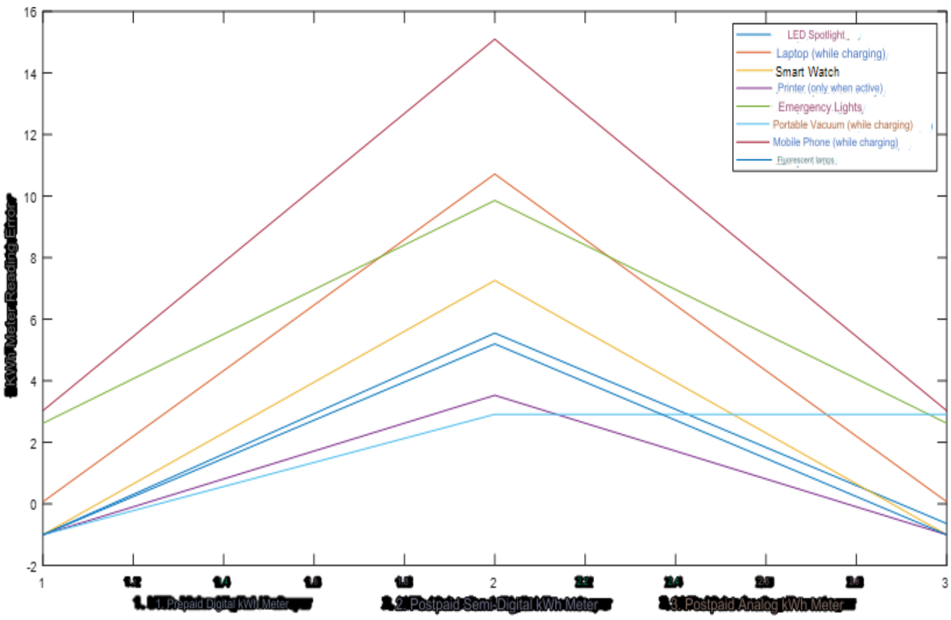

Figure 13. Graph of the kWh meter reading error under capacitive loads

It can be seen in the graph image above, that the error rate on the prepaid digital kWh meter is almost the same as the postpaid analog kWh meter. While the postpaid digital semi kWh meter has a higher error rate than other types of kWh meters, the highest error rate in the HandPhone load test when charged is 15.10%.

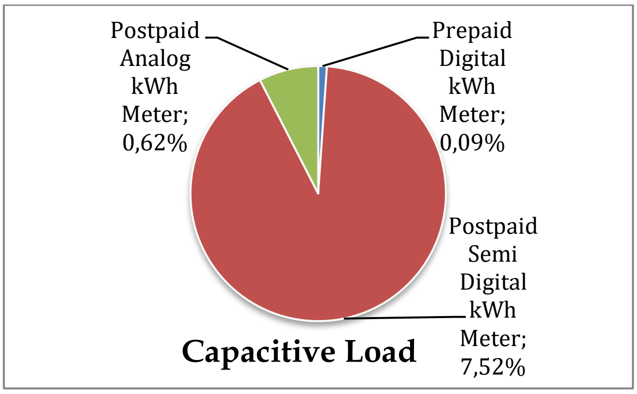

Figure 14. Average kWh meter reading error under capacitive load

In the capacitive load testing, the average error rate for the digital kWh meter reading is 0,09%, the postpaid semi-digital kWh meter shows an average error rate of 7,52%, and the analog kWh meter exhibits an average error rate of 0,62%. The error rate for kWh meter readings under capacitive loads is higher than those for resistive and inductive loads. This is attributed to the characteristics of capacitive loads, which possess the ability to store energy through electrical discharge within a circuit. As a result, the current leads the voltage. Capacitive loads absorb active power while releasing reactive power, which contributes to the higher error rate observed in capacitive load readings compared to other load types.

4. CONCLUSION

Based on the test results of the three types of kWh meters, namely prepaid digital kWh meters, postpaid digital kWh meters, and postpaid analog kWh meters, it was found that the reading error value for the postpaid semi-digital kWh meter has a higher average error rate of 7,14%, compared to an average error rate of only 0,19% for the prepaid digital kWh meter and 0,42% for the postpaid analog kWh meter. The average reading error for the semi-digital kWh meter is significantly higher than the standard set by the International Electrotechnical Commission (IEC) No. 13B-23, which allows a permissible error limit of only 1.0% for class 1 kWh meters.

Based on the test results, for resistive loads, the average reading error rate for the prepaid digital kWh meter is 0,11%, for the postpaid semi-digital kWh meter is 6,91%, and for the postpaid analog kWh meter is 0,36%. For inductive loads, the average reading error rate for the prepaid digital kWh meter is 0,36%, for the postpaid semi-digital kWh meter is 7,00%, and for the postpaid analog kWh meter is 0,27%. For capacitive loads, the average reading error rate for the prepaid digital kWh meter is 0,09%, for the postpaid semi-digital kWh meter is 7,52%, and for the postpaid analog kWh meter is 0,62%.

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