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Determination of the Effect of Harmonics on the Performance of Single-Phase Low Voltage kWh Meters

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ABSTRACT

Low-voltage installation systems with 450 VA and 900 VA power are one of the most commonly used electricity distribution systems in Indonesia. In the previous study, adjustments to the load of household needs were clearly made, and measurements were made at the load of 450-900 VA because some users received payment subsidies. Two types of kWh meters in accordance with standards in Indonesia are used by testing the readings of analog and digital kWh meters, which are loaded according to the load pattern. The load used is varied based on the load pattern that has been described in Table IV. Installation evaluation in the form of installing filters and improving the cross-sectional area value is carried out. After the installation of the passive filter, the power quality at 450 VA and 900 VA full load conditions improved, with the power factor in the electrical system of the 450 VA home installation increasing from 0.916 to 1.

Keywords: harmonics, kWh meter, electrical energy, non-linear load, Home Installation

INTRODUCTION

Household burdens play an important role in the electricity sector, making a valuable contribution to energy generation, distribution, and consumption. It has been proven that the act of consumption has an important impact on various levels, as various sources point out. In today's era, the carbon footprint of households around the world is a topic of great concern to the academic community every year [1].

In Indonesia, electricity consumption exceeded a total of 250.4 Terawatt Hours (TWh) and grew by 6.61 percent annually. While this may be true, it is important to note that the rapid advancement of power electronics technology has resulted in significant developments in the field of electrical engineering. The segment of total energy utilization is related to non-linear household appliances. [2]

Referring to data from the Central Statistics Agency, 1-phase electricity users in 2021 reached 257,634.26, with details of social use as many as 8,665.99, households 115,370.05, businesses 44,440.85, industry 80,904.45, and the public 8,252.92. Single-phase systems are more susceptible to harmonic problems compared to three-phase systems. This is due to the absence of compensation between the different phases to compensate for the harmonic effect, as is the case in a three-phase system. Although the power of 450 VA is subsidized, this actually causes harmonic pollution [3].

Non-linear household appliances mostly exhibit non-linear characteristics [4]. This situation causes measurements on kWh meters to be affected because their power consumption is not proportional to the voltage applied [5].

This non-linearity can lead to unwanted effects such as harmonics, flickering lights, and reduced efficiency in the power grid. As a result, there is an increase in power loss and a decrease in power quality. Therefore, understanding and reducing this non-linearity is an important area of research and development in the field of electrical engineering [6].

In accordance with the Regulation of the Minister of Energy and Mineral Resources No. 31 of 2014 dated November 5, 2014, the adjusment tariff is a mechanism that changes and determines the fluctuation of the amount of electricity tariff following changes in microeconomic factors, so that the tariff charged to consumers is close to the Cost of Electricity Supply (BPP). To a certain extent, odd multiples harmonics can have a bad effect on household electronics

The monitored approach requires direct injection in the home system because every kWh meter is fitted with an MCB for protection [7].

Measurement errors by kWh meters can cause losses on both the customer and producer sides. As an illustration, in Indonesia alone, millions of electricity customers use kWh meters as a tool to measure electricity transactions [8]. This illustrates the amount of losses that must be experienced if there is a measurement error by the kWh meter due to harmonics.

Several previous researchers [9], [10] have done this, but until now there has been no research that specifically focuses on household burden and the effect of the amount of energy used. Therefore, in this paper, it will be presented how the influence of non-linear load on the performance of kWh meters and its improvement efforts by installing filters that work in segments for 24 hours

MATERIALS & METHODS

This research began by conducting a comprehensive literature review related to harmonic calculations in electrical systems and analytical methods. This stage is crucial to build a deep understanding of the context of the research. Primary data is collected from LED, LHE, and motor data sheets, which then becomes an important basis for system design and implementation.

The next stage involves the creation and development of the load pattern design using PSIM software, which allows for the specification and adjustment of the load pattern. Once the design is complete, the implementation is carried out according to the specifications that have been determined, including the configuration of the LED, LHE, and motor according to the specifications.

Harmonic analysis is performed by studying the linear and non-linear loading of the system, identifying the load current and voltage as well as potential disturbances. Simulations are performed under normal and load-bearing conditions to calculate the power flow, as well as the current, voltage, and frequency values on the line.

The next step is to analyze the effect of harmonics on the calculation of kWh meters. The results of this analysis are used to understand the harmonic disturbances generated by the system that has been designed and implemented.

In Table 1, the calculations focus on the peak factor, form factor, and distortion factor. The peak factor measures the ratio between the peak value and the effective value (RMS) of an electric wave, with a high value indicating a large surge in the electrical signal [11]. The form factor compares the RMS value of the wave to its absolute mean value, which typically results in a value of about 1.11 for pure sinusoidal waves.

The distortion factor measures the extent to which an electric wave deviates from a purely sinusoidal form due to harmonics produced by a non-linear load, such as an electronic device. A high distortion factor value indicates a significant level of harmonic distortion. Understanding and managing these factors is important for maintaining power quality and preventing damage or deterioration in the efficiency of household electronic equipment.

Prior to the installation of the filters, the analysis and testing of the system was carried out by simulating typical household loads with power ratings of 450 VA and 900 VA. Each power rating is subdivided into 5 load levels based on time period and load type, as described in Table 2. Single-tuned passive filters are used to reduce harmonics, where two single-tuned filters have similar characteristics to double-band-pass filters. These filters are commonly used at low voltages and follow the THD 43 standard based on SPLN D5.004-1-2012.

Testing after the installation of the filter is carried out exclusively at load levels marked with high harmonics, in particular at load levels 1, 4 and 5. In addition, the assessment only includes variations of LED and LHE lights, to determine the impact of the installation of filters on the system. [12]

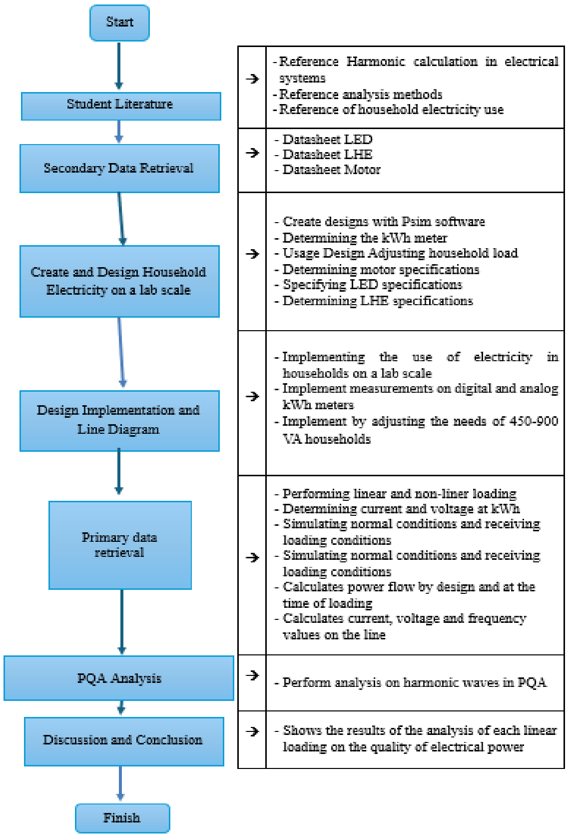

Figure 1. The working of Research Flow Chart

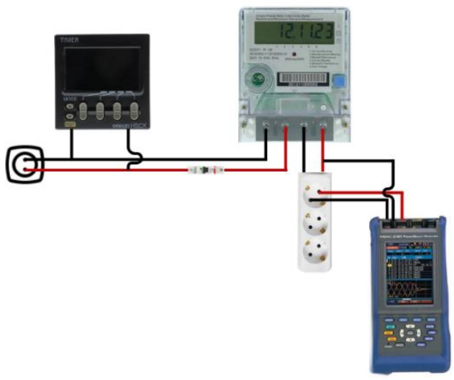

Figure 2. Non Filter kWh Digital

In accordance with Figure 2, the measurement is carried out using a digital kWh meter equipped with a timer. MCB (Miniature Circuit Breaker) is installed as a phase safety before the kWh meter to ensure safety. The PQA (Power Quality Analyzer) current probe is then connected to the output, and before the terminal is connected to the load, the energy meter's voltage probe is connected to the load.

The measurement implementation, similar to Figure 2, involves a digital kWh meter with a timer as well as a phase safety in the form of an MCB before input to the kWh meter. This arrangement connects the PQA current probe before the terminal is connected to the load.

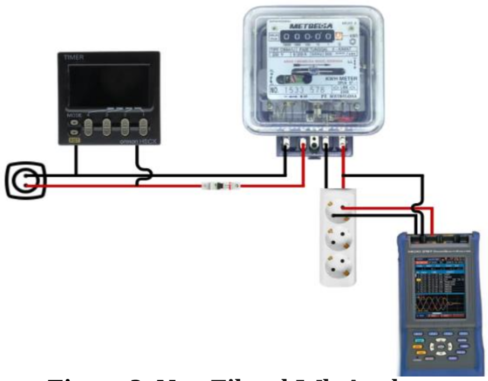

Figure 3. Non Filter kWh Analog

Two measurements were made due to differences in how kWh meters work. Analog KWh meters work using electromechanical mechanisms. The magnetic field generated by the electric current flowing through the conductor rotates the metal disc. The speed at which the disc rotates is proportional to the electrical power used. This disc is connected to a gear that turns a needle or a number wheel to indicate the total energy consumption in kWh.

In contrast, the method used by digital kWh meters is different. Electronic sensors used by digital meters measure the electrical current and voltage inside the conductor. The digital signals generated by these sensors are processed by microprocessors to determine power consumption. The results of these measurements are displayed on a digital screen as numerical values. Additionally, digital kWh meters are often equipped with additional capabilities such as reactive power measurement, power quality analysis, and the ability to communicate for remote readings.

As outlined in Table 1, the standards governing kWh meters are SPLN 57-1:1991 for electromechanical (analog) meters with accuracy classes 0.5, 1, and 2, and SPLN 57-4:1994 for static (digital) kWh meters with accuracy classes 1 and 2. Analog kWh meters are generally used in Indonesia homes with a power of 450 VA and 900 VA. This meter is used to measure the active power of the reverse current electrical energy with a nominal frequency of 50 Hz and a voltage that does not exceed 600 V.

Tool Specifications

TABLE 1 PRODUCT SPECIFICATION KWH METER

Type kWh Meter	kWh Meter			
	Brand	**Class**	**Current Voltage**	**Class**
Analog	Lipuvindo	2	220 V / 5(20) A	720/kWh
Digital	Huabang	1	220 V / 5(60) A	1000imp/kWh

The passive filter used in this study is a single-tuned filter, designed to handle specific harmonic frequencies [13].

TABLE 2 SPECIFICATIONS OF HARMONIC FILTERS

Filter Type	Frequency (Hz)	Quality Factor	Resistance (Ohms)	Capacitance (µF)
Single-tuned	50	30	0,5	10

Single-tuned passive filters work by targeting specific harmonic frequencies that cause disturbances in electrical systems. When this harmonic occurs, the filter absorbs and stores harmonic energy in its capacitive and inductive components, thereby removing harmonics from the system and improving the overall power quality.

TABLE *3* SPECIFICATIONS OF HARMONIC FILTERS

Brand	Power	Sum
Incandescent	200, 150, 100, 60, 40, 15	20
LED Light	3, 5, 7	16
LAMP	5, 13, 14, 15	22
Monitor	100	1
1 phase motor	100, 200	2
Charger	5, 18, 33, 45	5

This test is divided into several styles or models with a period of time and type of load that lights up on a home installation in 24 hours/1 day, as follows.

TABLE 4 FORMULA TABLE OF HARMONIC FILTER

Function	Items	Operation Expression
Electrical Signal Analysis	Crest Factor	$CC = \frac{V_{peak}}{V_{RMS}}$ (1)
	Form Factor	$FF = \frac{V_{RMS}}{V_{average}}$ (2)
	Distortion Factor	$DF = \frac{V_{Fundamental}}{V_{RMS}}$(3)
	Single tuned passive filter	$ZZ_f = R + j\left(\omega L - \frac{1}{\omega C}\right)$ (4)

Based on the findings presented in Table 4, it can be seen that the introduction of non-linear load filters into the system can lead to harmonic generation[14]. This harmonics then leads to a decrease in the power factor and an increase in reactive power in the system. In particular, the use of incandescent lamps results in a minimal decrease in power factor because the lamps are classified as linear loads that do not produce harmonics. As a result, the reactive power associated with harmonic components is also limited. For more detailed experiment data, see Table 5.

TABLE 5 LOAD IDOMS

It	Brand	Burden	Sum	Power
1.	05.00-10.00	Lamp*	2	200 W
2.	10.00-14.00	Led	3	7 W
		Fan	1	100 W
		Charger	1	16 W
3.	14.00-17.00	TELEVISION	1	100W
		Rice cooker	1	100 W
		Charger	1	63 W
4.	17.00-22.00	Lamp*	7	5 W
		TELEVISION	1	100 W
5.	22.00-05.00	Lamp	3	15 W

A. ELECTRICAL DATA

TABLE 6 ELECTRICAL DATA LOAD 450VA BEFORE FILTER

Idioms	Lamp	W	I_{peak}	I_{rms}	PF
05:00 - 10:00	LED	298	1,75	1,261	0,999
10:00 - 14:00	LED MTR	78	0,67	0,352	0,916
14:00 - 17:00	LES	167	1,86	1,273	0,527
17:00 - 22:00	LED	40	0,85	0,292	0,676
22:00 - 05:00	LED	13	0,23	0,79	0,729

Based on the existing findings, it is known that the current harmonic level has exceeded the set standard limits. Overcoming this problem requires the use of devices capable of reducing harmonic currents to within acceptable parameters. One effective method to reduce the impact of harmonics in electrical systems is to apply a single-tuned passive filter.

In the data presented, it is important to note that the prevailing values directly affect the effective power factor in the system[15]. This phenomenon arises as a result of the generation of harmonic components, which in turn introduces additional reactive force, thereby increasing the overall reactive force in the system. The substantial amount of reactive power serves to reduce the effective power factor in the electrical framework.

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TABLE 7 ELECTRICAL DATA LOAD 450VA AFTER FILTER

Idioms	Lamp	W	I_{peak}	I_{rms}	PF
05:00 - 10:00	LED	387	2,29	1,643	0,999
10:00 - 14:00	LED MTR	80	0,47	0,338	1
14:00 - 17:00	LES	237	2,03	1,436	0,687
17:00 - 22:00	LED	123	0,80	0,568	0,915
22:00 - 05:00	LED	87	0,54	0,38	0,988

RESULT

Calculation Analysis Before Filter

The following is the calculation of the power composition parameters and the diagram of the electric façade before the installation of the filter at a power load of 450 VA in peak load conditions, namely load 1 which turns on at 05:00 - 10:00.

The Crest Factor $CC = \frac{V_{peak}}{V_{RMS}} = \frac{1,75}{1,261} = 1,387$

1) Form Factor

$$V_{average} = \frac{V_{peak}}{\sqrt{2}} \rightarrow V_{average} = \frac{1,75}{\sqrt{2}} = 1,237$$

$$FF = \frac{V_{RMS}}{V_{average}} = \frac{1,261}{1,237436867} = 1,019$$

2) Distortion Factor *Calculation*

$$DF = \frac{V_{Fundamental}}{V_{RMS}} = \frac{1,261}{1,261} = 1$$

B. Calculation Analysis After Filter

1) Crest Factor

$$CC = \frac{V_{peak}}{V_{RMS}} = \frac{2,29}{1,643} = 1,393$$

2) From Factor

$$V_{average} = Arus \frac{Puncak}{\sqrt{2}V_{average}} = \frac{2,29}{\sqrt{2}} = 1,619274529$$

$$FF = \frac{V_{RMS}}{V_{average}} = \frac{1,643}{1,619} = 1,014$$

3) Distortion Factor

$$DF = \frac{V_{Fundamental}}{V_{RMS}} = 0{,}998$$

After taking measurements, it was found that the power factor increased significantly after the installation of the passive filter. Figure 3 illustrates the impact of a passive filter on the power factor of a 450 VA electrical installation, showing an increase from 0.916 to 1.

Harmonic distortion analysis focuses on the Total Harmonic Distortion (THD) level before and after the installation of the passive filter. The results showed a decrease in THD value, which indicates the effectiveness of the filter in reducing harmonic distortion.

CONCLUSION

This study shows that the application of passive filters can significantly improve power quality in household electrical installations. The results indicate improvements in the power factor and reduction of harmonic distortion, which contribute to more accurate kWh meter readings as well as overall system efficiency.

Declaration by Authors

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