

G201

# Analysis of Harmonic Distortion Effect on Diviation Measurement of Electrical Energy in kWh Meter

**Amien Rahardjo**  
Electrical Engineering  
Faculty of Engineering UI  
Depok, Indonesia 16424  
Email: amien@eng.ui.ac.id

**Iwa Garniwa MK**  
Electrical Engineering  
Faculty of Engineering UI  
Depok, Indonesia 16424  
Email: iwa@eng.ui.ac.id

**Faiz Husnayain**  
Electrical Engineering  
Faculty of Engineering UI  
Depok, Indonesia 16424  
Email: faiz.h@ui.ac.id

**Abstract**— *The measurement of electrical energy in kWh meter becomes very important because it involves the energy transaction process. When an error occurs in it then it will cause disserve to the consumer and / or producer. This study aims to look at the characteristics of the measurement by the kWh meter, both analog and digital types, which are affected by harmonic distortion which is mounted kWh meters. The results showed that the greater the value of the harmonics on the load it will be more damaging current and voltage waveforms (distorted). As the wave distorted by the kWh meter, the measurement process will be far from the actual values used. In this study, the different in measurement results between Analog kWh-meter and PQA is up to 15% and Total Harmonics Distortion THD-Fi on 2200VA household consumer is 40.86%. For 3500VA the difference is 9.8% with THD-Fi = 12.29%, and for 7700VA 12.8% with THD-Fi = 15.4%. On the other hand, with Digital kWh in 3500VA household consumer, the different measurement results with PQA is equal 4% with THD-Fi = 10.74%. Thus the effect on deviation measurement of electrical energy in Analog kWh-meter is larger than in Digital kWh-meter.*

**Keywords:** *Measurement of Electrical Energy; Power Quality; Harmonic Distortion; Analog & Digital kWh Meters, THD*

## IV. INTRODUCTION

Harmonics is a phenomenon that arises as a result of the use of non-linear load on the power system. This phenomenon can cause problems in terms of quality of power that would eventually lead to a variety of loss and even damage to some of the electrical equipment. Harmonics become a very important issue to be learned and studied because if not treated correctly and immediately, then its impacts will be greater and adversely affect the performance of electrical equipment.

KWh meter is a device used to measure electric power transaction also includes electrical equipment that cannot be separated from the bad influence caused by harmonics. In general, the tool is designed to measure and calculate the power used by the load in the form of current and voltage in pure sinusoidal waveform, so the presence of the ideal waveform (pure sinusoidal) will improve the accuracy of the measurement results by the kWh meter. In other words, if the input waveform is no longer in form of pure sinusoidal because

of harmonic distortion effect, then error measurement would be taken place in the kWh meter device. This paper was made to fulfill the author's curiosity about the effects of harmonic distortion on the performance of kWh meters and the possibilities of losses that will occur in the power system when the phenomenon of harmonics present in power system.

## V. LITERATURE REVIEW

### A. Harmonics

According to IEC 555 - 1982: "Harmonics is sinusoidal voltages or currents having frequencies that are integer multiples of the frequency at the which the supply system is designed to operate-(50Hz or 60 Hz)" which is more or less clear that the harmonics are periodic distortion of the wave sine current, voltage, with a waveform whose frequency is a multiple of the number beyond which the fundamental frequency in the supply system is designed to operate at 50 Hz/60 Hz 11.

While the definition of harmonic distortion that any change in the form of signals generally unintentional and unwanted presence on the system. Harmonics is one of the things that can cause distortion on the voltage waveform and the current fundamentals. This phenomenon arises due to the influence of non-linear load characteristics are modeled as a current source that injects harmonic currents into the power system.

Fundamental frequency of a power system is 50 Hz (in Indonesian). If there is a 2nd harmonic then the wave has a frequency of 100 Hz, the 3rd harmonic has a frequency of 150 Hz and so on so that it can be made a general equation as follows:

$$f_h = f_1 \times n \quad (2.1)$$

Where:  $f_h$  = harmonics frequency;  $f_1$  = fundamental frequency,  $n$  = positive integer.

Summation of harmonic wave and distorted wave is a wave that is continuous and periodic (the wave has a period T if  $f(t)=$

$f(t + T)$  for all  $t$ ). If  $f(t)$  is periodic, then the characteristic harmonics can be represented using Fourier series as follows:

$$f(t) = \frac{a_0}{2} + \sum_{h=1}^{\infty} \{a_h \cdot \cos(h\omega_0 t) + b_h \cdot \sin(h\omega_0 t)\} \quad (2.2)$$

where:

$$a_0 = \frac{1}{T} \int_0^T f(t) dt \quad (2.3)$$

$$a_h = \frac{2}{T} \int_0^T f(t) \cdot \cos(h\omega_0 t) dt \quad (2.4)$$

$$b_h = \frac{2}{T} \int_0^T f(t) \cdot \sin(h\omega_0 t) dt \quad (2.5)$$

In addition, to determine the value of the amplitude of a harmonic wave can be found by the equation:

$$C_h = \sqrt{a_h^2 + b_h^2} \quad \text{whereas } h \geq 1 \quad (2.6)$$

the value of  $C$  as a function of  $h$  are often portrayed in a bar chart called "harmonic spectrum"

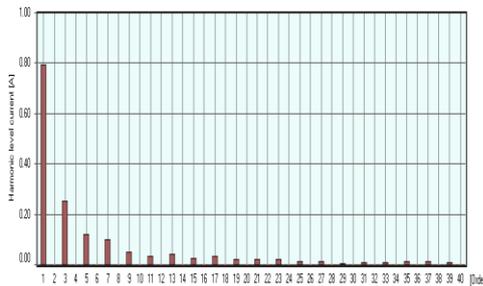


Fig. 1 Harmonic Spectrum

Source of harmonic distortion can be divided into 3 categories:

1. Industrial machines

The machines that are in the industry generally have a converter which is a non-linear load that induces continuous harmonics with arbitrary values. Generally, large-scale industry connected directly to the high voltage network. So the harmonic distortion effect can be fatal to the electrical system.

2. Converter connected to the grid

Converters are connected to the electricity grid can induce large harmonics to the network. Attendance of High Voltage Direct Current (HVDC) system and converter in the battery storage system in the solar power generation system should raise awareness of the influence of the harmonics to the network.

3. Power tools Household

Household appliance such as computers, televisions, and etc is a source of harmonics. This burdens a current source or a

DC voltage source. If there are large amounts, it can damage the stability of the system

B. kWh Meters

KWh meter is a common tool used to measure electrical energy. This tool is used by the electricity company to record and analyze the use of electrical energy used by the consumer. In addition, also at the same kWh meter is used as a tool of power transactions because this tool can record how much electrical energy is used up. Electrical energy consumption by consumers, both industrial and domestic use kilowatt unit - hour (kWh) where 1 kWh is equivalent to 3.6 MJ. Thus kWh meter is an appropriate tool used to measure the electrical energy used.

In kWh meter power measurement, components that are comprised of components measuring current and voltage measuring components. KWh meter is widely known in the community is a conventional kWh meter has limited features. KWh meter of this type is referred to as analogue kWh meter. This species is still quite able to read the number of active power consumption well, but are less able to read well so that reactive power kWh meters were created digitally.

KWh meter can read the digital has the advantage of active power and reactive power is unused. In addition, it has the level of accuracy that is better than any analogue kWh meter so that now over PLN encourage consumers to switch to using digital kWh meter.

KWh meter based on its type is divided into two categories, namely:

- Analog KWh Meter

As mentioned before analog kWh meter is already commonly used and the most widely used prior to the creation of digital kWh meter. The main parts of an analogue kWh meter is the coil voltage, coil current, an aluminum disc, permanent magnets, and a mechanical gear that records the number of the rotation is on the device.

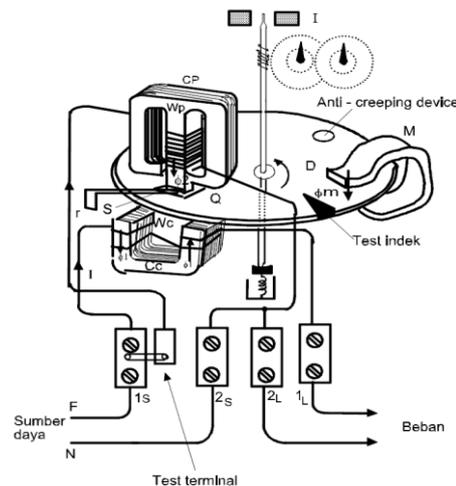


Fig. 2 Analog kWh Meter [1]

From the fig. 2 can be explained on the working principle of an analog meter kWh. At the time of the load current flowing in the coil current  $I$  (WC), this current will cause the magnetic flux  $\Phi_1$ . On the other hand because the voltage is the inductor coil, the coil voltage occurs on the phase difference between current and voltage by  $90^\circ$ . Current through the coil voltage will also cause magnet flux  $\Phi_2$  with different conditions with a  $90^\circ$  phase  $\Phi_1$ .

Phase difference between  $\Phi_1$  and  $\Phi_2$  will cause motion moments on aluminum plate (D) so that the plate rotates in such a way. Round aluminum plates will be forwarded to the registrar wheels / gear mechanical (J) which in turn will run the counter.

The magnitude of the moment of motion / torque that of the aluminum plate is proportional to the magnitude of current  $I$  and voltage  $V$ , by the equation:

$$T = k \cdot V \cdot I \cdot \cos \varphi \text{ (Nm)} \quad (2.7)$$

Where:  $k$  = constant (s/rad),  $V$  = voltage (volts),  $I$  = Current (Amperes), and  $\cos \varphi$  = angle between  $V$  and  $I$

From the equation (2.7) it can be seen that the aluminum plate rotation torque ( $T$ ) will be proportional to the active power ( $V \cdot I \cdot \cos \varphi$ ) supplied to the load, so the larger the active power used in the load side round aluminum plate will be faster and vice versa.

- Digital kWh Meter

Digital kWh meter is a measurement tool that has the same function as the analog kWh meter, which measures the amount of electrical energy consumption in units of time. If the analogue kWh meter works on the principle of induction, digital kWh meter works based program designed to microprocessor contained in the digital kWh meter devices.



Fig. 3 Digital kWh Meter [2]

The working principle of a digital kWh meter voltage and current is received by the digital kWh meter will be read separately. Incoming voltage will be read and then passed to a microcontroller. Read currents will also be forwarded to the microcontroller. Inside the microcontroller there is a program that is set up such that the voltage and current will be processed and calculated by the amount of output in the form of electrical energy. The amount in question is active power and energy. So

with the digital kWh meter will be able to read electrical energy consumption used by consumers. The instrument used to measure the power used by consumers is kWh meters. This tool has the general form of the input current and voltage measured in a sinusoidal waveform and is used to calculate the power used. If the input waveform is not ideal, it can affect the results of measurements with kWh meter used. Expenses for use in both households and industry have so harmonic distortion measurements using kWh meters are less accurate.

When a measurement error occurs using kWh meter, both customers and producers will lose. Previous research has been conducted to analyze the effect of harmonics on electric energy measurement deviation using analog and digital kWh meter [3]. The type of load used for testing a non- standard energy-saving lamps. However, the results of these measurements have not been compared to estimated system [4]. The system is able to generate estimates of the value of the voltage and current at the fundamental frequency.

With good research and development, the expected estimation system can be used to provide power estimates with more accurate values in the condition of harmonic distortion. If proven to provide a more accurate measurement results, the estimation system can be further developed to be used as the software for kWh meters. These devices are generally having an input in the form of currents and voltages measured in the form of a sinusoidal wave and used to calculate the power used. If the input waveform is not ideal, it can affect the results of measurements with kWh meter used. Expenses for use in both households and industry have so harmonic distortion measurements using kWh meters are less accurate.

## VI. METHODOLOGY

To determine the effect of harmonic distortion characteristics caused by the burden of household electrical appliances, testing is carried out in the Laboratory of High Voltage and Electrical Measurements, Department of Electrical Engineering, Faculty of Engineering-University of Indonesia, while for performance testing kWh-meter (Analog and Digital) performed direct on consumer / Household electric customers with a series of tests as follows:

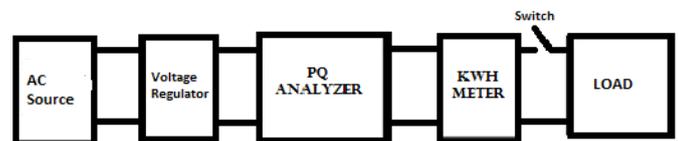


Fig. 4 Schematic testing circuit

## VII. RESULTS AND ANALYSIS

In research focused on the problem of harmonic distortion of the load on the network in the form of electrical installation of non-linear loads in particular contained in the household burden. Although the problem of harmonic distortion on household is not great, but the burden of housing in Indonesia is very much the problem of harmonic distortion will

accumulate and have a significant impact on the power system and the readings on the gauges of energy (kWh-meter) PLN.

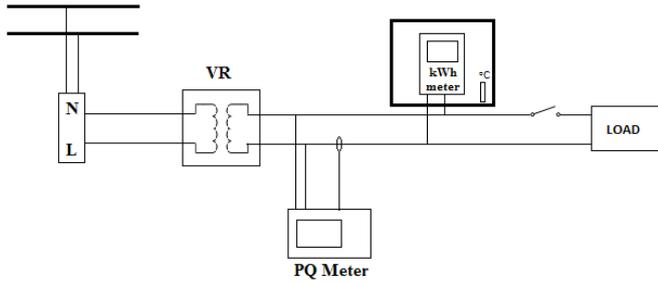


Fig. 5 Layout testing circuit

The cause of the harmonics due to the burdens of non-linear. Non-linear load is derived from electrical equipment that has a saturation value or which have the power electronics components. Identify the type of load carried by recognizing the electrical appliances that have components such as coils, rotating machines (motors), power supply, diode, thyristor, converters, ballasts, and equipment made from semiconductors.

After identification of the load, obtained electrical equipment is a source of harmonics. The equipment is then tested (measured) to investigate the characteristics of voltage and current harmonic distortion, power.

The following are the specifications of electrical equipment, as object measurement:

TABLE I. SPECIFICATIONS LOAD MEASUREMENT OBJECTS

No	Home Appliance Specification <sup>a</sup>		
	Home appliance	Power (W)	Voltage (V)
1	Compact lamp A	8	170-250
	Compact lamp B	18	170-250
	Compact lamp C	20	170-250
2	Television	65	180-270
3	Air Conditioner	750	220
	CPU	350	110/220
4	Monitor	240	100-240
	Refrigerator	77	220
5	Refrigerator	77	220
6	Dispenser	300	220

<sup>a</sup> All the home appliance has working frequency of 50Hz

As it is known that the true kWh meter is designed to calculate the power (through the current and voltage waveforms that go to the kWh) with the ideal waveform or a pure sinusoidal waveform so that if they are no longer purely sinusoidal then the tool will not be able to work accurately. One thing that can ruin the flow waveform and / or the voltage is harmonic

In general, the more harmonics are generated, the greater the value of %-THD which will then impact on the worsening

waveform generated. With poor waveform current / voltage harmonic distortion due to the strong likelihood of error in the measurement. That way, if the tools do not work accurately measuring the possibility of one of the parties will be harmed.

Value of a number of graphs kWh in Fig 6 the harmonic distortion can be seen that in general with increasing harmonic distortion will result in an increase in the value of the measured kWh. This is especially true in kWh analog type, because this type there kWh moving parts / mechanic who is most likely to be influenced by harmonic distortion factor of the kWh. In contrast, the kWh meter digital type is not too affected by harmonic distortion because physically the kWh meter of this type there is no electromechanical parts as well as on the type of analogue kWh meter.

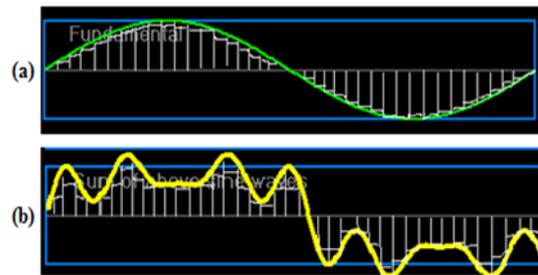


Fig. 6 (a) Illustration Digitally on Ideal Wave Measurements and (b) the Distorted Wave Harmonics [3]

A. The end result of harmonic distortion measurement of household electric appliance in the Laboratory:

TABLE II. MEASUREMENT RESULTS

No	Total Harmonics Distortion (THD) <sup>b</sup>		
	Home appliance	Voltage (%)	Current (%)
1	Compact lamp	1.66	90.4
2	Television	1.96	126.3
3	Air Conditioner	1.925	111.2
4	Computer	1.388	114.7
5	Refrigerator	1.82	104.5
6	Dispenser	2.00	105.1

<sup>b</sup> All the home appliance measured shared common dominant harmonics distortion in 5<sup>th</sup> order (250Hz) for voltage and 3<sup>rd</sup> (150Hz) for current

B. Based on the results of measurements of the energy consumption for 1 (one) week in Household PLN customers.

From the real measurement results in customers Household PLN, indicated that the difference in energy consumption in kWh-meter recorded PLN with the PQA

C. kWh-meter accuracy against PQA:

The higher the current harmonic distortion, the higher the potential deviation kWh-meter readings will be. Based on measurement result, the distortion in measurement result of analog is 2.45 higher than the digital.

TABLE III. MEASUREMENT RESULTS

Customer (VA)	THD-i (%)	THD-v (%)	Difference PQA and PLN Meter <sup>c</sup>	
			kWh	%
2200 with kWh-Analog	40.86	3.78	7.23	15
3500 with kWh-Digital	10.74	3.57	8.84	4
3500 with kWh-Analog	12.29	1.57	15.45	9.8
7700 with kWh-Analog	15.4	2.02	142	12.8

<sup>c</sup>. All PLN Meter measurement results are higher compare with PQA results

### VIII. CONCLUSION AND DISCUSSION

Study results show the effect of harmonics distortion on kWh meter are:

- 1) The magnitude of the deviation of error measurement in the form of energy by the analog and digital kWh meter is affected by the harmonic components in the system. Based on testing, the greater the THD, the larger value of error measurement would be. Irregularities in previous research, the value of the deviation in the measurement due to harmonics can reach 15% (kWh-Analog)
- 2) The total harmonic distortion factors have more influences on the performance of analog kWh meter compare with the digital kWh meter, with factor 2.45 in 3500VA household consumer.
- 3) Harmonic filter could be used either on the household electrical installation or in each electrical appliances in order to reduce the harmonics effect in the deviation measurement of energy consumption by analog kWh-meter.

### REFERENCES

- [1]. Alam, Reza Mighty, "Harmonic Load Effect Analysis (Energy Saving Lamp) The Conductor", Thesis UI
- [2]. Amirudin, Arief, "System Hardware kWh Meter Prepaid", KP Reports, Digital London 2009
- [3]. Dugan, Roger C., et al., "Electrical Power Systems Quality, Second Edition", McGraw-Hill, 2004.
- [4]. Koswara, Firman Indra, "Analysis of the Effect of Harmonics in Power Transformer in the Cement Industry", Thesis, Department of Electrical Engineering-Faculty of Engineering University of Indonesia
- [5]. Boromeus SW, "Comparative Analysis of Reading kWh Meter with Analog Digital Meter on Imbalance Charges", the UI Thesis 2008
- [6]. Kurnaen, Jemjem, et al ., "Effects of Harmonics on Power Loss and Loss of Electric Power Systems", PT. PLN P3B Jawa Bali
- [7]. Kurniawan, Irfan, "Study of the Effect of harmonic performance measurement tool kWh meters as Power Transactions", Depok: DTE FT UI Thesis Book 2011
- [8]. Measurement Module: Electrical Measurement Operation
- [9]. Nurhidayat, Eka, "Occupational and Environmental Effect of Temperature on Performance Transformer Harmonic Flow", Thesis UI 2010
- [10]. Sujatmiko, the Great, "The Effect on Performance Transformer Harmonic Flow", DTE UI 2010
- [11]. Tobing, Cristof NH, "The Effect of Harmonics In Distribution Transformer", Universitas Indonesia in 2008
- [12]. Sudiarto, Budi, "Analysis of Loss and Loss on Low voltage networks Harmonic Effect Effect On Energy Saving Lamps" UI Thesis 2004
- [13]. Falcon, Rafael, "Analysis of Thermal Characteristics and Resistance Dual Core Cable Conductor at NYM 2 x 1.5 mm<sup>2</sup> ", Thesis UI 2008
- [14]. Sitompul, Andigan D., "Study of the Effect of Temperature Ambient Temperature Characteristics Hotspot on Transformer ", Thesis UI 2011
- [15]. Rajani, Ahmad, "Correlation Analysis of Energy Efficient Lamps Against Imposition and Amount of Harmonic Wave Forms", Thesis UI 2012.