Prediction of Harmonic Distortion in a Distribution System Caused by Housing Loads
(Case Study in Surabaya, Indonesia)

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Abstract*: This paper will discuss about impact of nonlinear load in residential costumer to harmonic distortion. Electricity consumer behaviour particularly in the household sector with the development of technology will evolve. Equipment used for everyday purposes continues to grow and has become a lifestyle**. The modern life is becoming fabulous with the invention of new technology, so that many more electricity utilities are used by people and their houses in daily life. Nowadays, loads in the housing electricity utility do not only contain of linier loads, but also non-linier loads such as television, computer, microwave, fluorescent lamp and so on. The problem uses nonlinear load is create harmonic distortion. The harmonic distortion will reduce the life time of electrical equipment and inefficiency. The purpose of this research is to do modelling and prediction of harmonics level on housing electricity utility. The modelling and prediction of this research was using harmonic analysis with ETAP PowerStation version 4.0.0 C. This experiment was done in five houses as sample. The measurement was done on non-linier load and Kwh-meter in every house using Fluke 41B. The result of measurement on Kwh-meter on houses was compared in order to get the analysis result for VTHD, ITHD, power factor and frequency. The results research showed that VTHD, power factor (PF) and frequency on house are comply to the normal standard. VTHD result (maximum 5%) is 1.1 % – 3.6%. Beside those, ITHD on house also comfortable to due standard, but there are houses that did not comply into the appointed standard. The analysis result showed that energy saving lamp cause the biggest harmonics level. The level of harmonics in every house depends on how many electricity equipment used in it.*

***Keywords****: Power Quality, Harmonics, Housing Electricity Utility.*

I.   Introduction

Power quality is a major concern in the world of electricity in this decade. It is the electrical power used by consumers and not damage or reduce the life time of the equipment and the power can be used efficiently [1][2]. Power quality means the quality of voltage and current. Quality the voltage and currents is the value what used does not exceed limits of tolerance from equipment that used. In addition, a wave of currents and voltages are sinusoidal waves are normal. One of the problems that resulted in the current and voltage waveforms will not be sinusoidal or defect is caused by the resulting harmonics in the power system. Terms of quality power to a building and housing is power and voltage shall be in accordance with specified standards and Harmonics harmonic currents and voltages that occur must be small.

Harmonics is a phenomenon arising from the operation of the electrical load that is mainly caused from the non-linear load, which will form a high-frequency waves (100 Hz, 150 Hz, 200 Hz and so on) and can interfere with the electrical power system fundamental frequency is 50 Hz or 60 Hz, so that the current and voltage waveforms are purely sinusoidal ideally would be disabled as a result of harmonic distortion that occurs. The ideal form of the provision of electric power systems both voltage and current must be contained on a single frequency sinusoidal and constant value that is 50 Hz. In the power system voltage and current harmonics always contain, because the harmonics have a frequency which is an integer multiple of the fundamental wave component [3].

The third harmonic wave formation of a 3 wave periods are repeated when the fundamental wave is still going on in one period. This also applies to other waves, like the waves of the fifth harmonic is also formed into 5 periods of smaller waves again when the wave amplitude of the fundamental harmonic wave is still ongoing in the period as shown in figure 1.The pattern of harmonic distortion on the basic wave.

Figure 1 Fundamental and Sinusoidal Signal Distorted
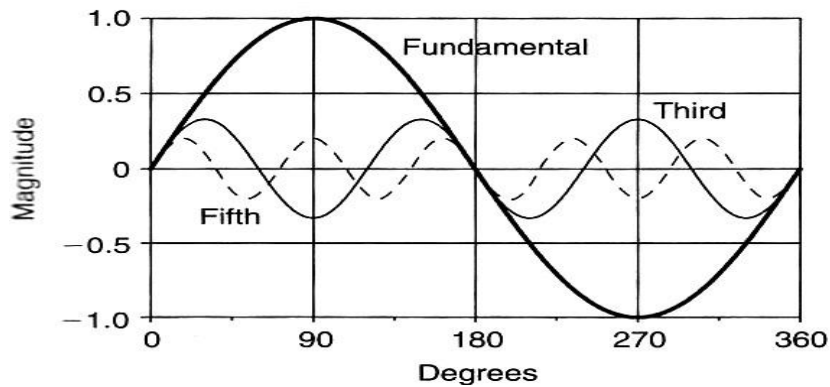
Fundamental frequency (first harmonic) is f, the harmonics have frequencies 2f second, third harmonics have frequencies 3f and n-th harmonic has a frequency nf. If the fundamental frequency is 50 Hz, the second harmonic has a frequency of 100 Hz, the third harmonic has a frequency of 150 Hz, and so on.

Harmonic distortion can be understood through some major parameters. The important parameters to describe the effects of harmonics on power system components. The first parameter is the THD (Total Harmonic Distortion) Total harmonic distortion is the ratio of the rms value of the harmonic components to the rms value of the fundamental component is usually expressed in percent (%). The index is used to measure the deviation of a periodic waveform containing harmonics from a perfect sine wave [4]. For a perfect sine wave THD is zero percent. Here is the formula for the voltage and current THD, namely:

$$VTHD = \frac{\sqrt{\sum_{n=2}^{\infty} V_n^{\,2}}}{V_1} \qquad (1)$$

Where: V_n = Rated voltage harmonics, V1 = Fundamental value and n = maximum harmonic component is observed

$$ITHD = \frac{\sqrt{\sum_{n=2}^{\infty} I_n^{\,2}}}{I_1} \qquad (2)$$

Where: V_n= Value of harmonic currents, I_1= Fundamental value and n = maximum harmonic component is observed

The second parameter is the IHD (Individual Harmonic Distortion). Individual harmonic distortion is the ratio of the rms value of the individual harmonics to the rms value of the fundamental [3]. The third parameter is TDD (Total Demand Distortion) Total demand distortion (TDD) are total harmonic current distortion is defined as:

$$TDD = \frac{\sqrt{\sum_{n=2}^{N} I_n^{\,2}}}{I_R} \qquad (3)$$

Where : I_R = the maximum demand load current (selama15 or 30 minutes) on the basis of the frequency of Point of Common Coupling / PCC (point of common expenses), calculated as the average current of the maximum demand for the previous 12 months. Harmonics standard is used to evaluate the standard IEEE-519 "IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems" [5]. There are two types of criteria are used to evaluate the harmonic distortion is the harmonic current limits and limits for voltage harmonics.

Table 1 Standard of Maximum Harmonic Current Distortion

I_{sc}/I_L	Maximum Harmonic Current Distortion (in % of fundamental)					Total Harmonic Distortion
	Harmonic Order (Odd Harmonics)					
	<11	11≤ h17	17≤ h <23	23≤ h <35	35 ≤h	
< 0	4.0	2.0	1.5	0.6	0.3	5.0
20-50	7.0	3.5	2.5	1.0	0.5	8.0
50-100	10.0	4.5	4.0	1.5	0.7	12.0
100-1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

Percentage of the amount of harmonic current distortion (% I_{THD}) is the percentage of the total amount of current is distorted by harmonics of the fundamental frequency. To determine (% I_{THD}) is depending on the ratio of Isc / I_L. Percentage of the number of harmonic voltage distortion (% V_{THD}) is the percentage of the total voltage is distorted by harmonics of the fundamental frequency. % V_{THD} system is determined by the voltage used. Detailed information on the standard harmonic current and voltage allowed is as shown in table 1 and table 2 [6].

Electrical load which is the source of harmonics can be grouped into two kinds, namely [7]: First Load linear, linear load is a load that gives a linear output waveform means the current flowing is proportional to the impedance and voltage changes. Non-linear load waveform output is not proportional to the voltage in each half cycle so that the current waveform and output voltage waveform is not the same as the input (distorted).

Table 2 Standard of Maximum Harmonic Voltage Distortion

| Maximum Distortion	System Voltage		
	< 69 kV	69 - 38 kV	> 138 kV
Individual Harmonic	3.0	1.5	1.0
Total Harmonic	5.0	2.5	1.5

The non-linear load is dominant create harmonics in comparison with linear load. This is due to the semiconductor component in which the process works act as a switch that works on every cycle of the source voltage waveform. In addition, the harmonics are also often caused by equipment especially equipment that uses a rectifier diode and thyristor rectifier. Function of the rectifier is to convert alternating current into direct current. In the use of the converter as a direct resource to take a loss on the destructive power grid voltage waveform and alternating current so it is not a pure sinusoidal wave.

The main effect of voltage and current harmonics on power systems, namely: Addition of harmonics due to the level of the series and parallel resonant relationship and decrease the efficiency of power generators, transmission and load equipment. Broadly speaking, the effects of harmonics that arise in the power system depends on the location of the source harmonics and harmonics. In addition to the harmonics of the power system can cause undesirable effects such as equipment becomes heat, equipment not working properly, the life time of the equipment is reduced, equipment damage, signal interference or noise on the phone line. This is because the series is zero, the resonance between the capacitance and the transformer reactance resulting in excessive voltage and current. Economic and environmental losses caused by harmonic distortion is very serious, it becomes imperative to conduct routine of monitoring and evaluation of the distribution system and the identification of load used by electricity consumers [2]. Consumer household sector is one segment of consumers who use non-linear devices in large numbers. This research was conducted with the aim to identify the use of non-linear load in the household sector and its impact on the increase of harmonic distortion. This study is used five samples of household with loads 2200 VA < loads ≤ 6600 VA.

II.   MATERIAL AND METHODS

Measurements taken are to measure each nonlinear load in every house. In addition measurements were also carried out in power-meter (through MCB grouping in each house). The scheme and real condition of measurement as shown in figure 4. A measurement on power-meter in every house was at the peak load time. This is done because at the time of peak load, all the electronic equipment that is in every house is up and also during peak load voltage drop occurs. Measurements were performed using special equipment is power harmonics analyzer fluke 41B. After retrieval of data, then the data stored in the memory fluke 41B and then the data is transferred to a computer for analysis and in the print-out results. The specification of power harmonics analyzer fluke 41B as describe in table 3.

**Figure 2 Measurement Scheme for Load one Phase**
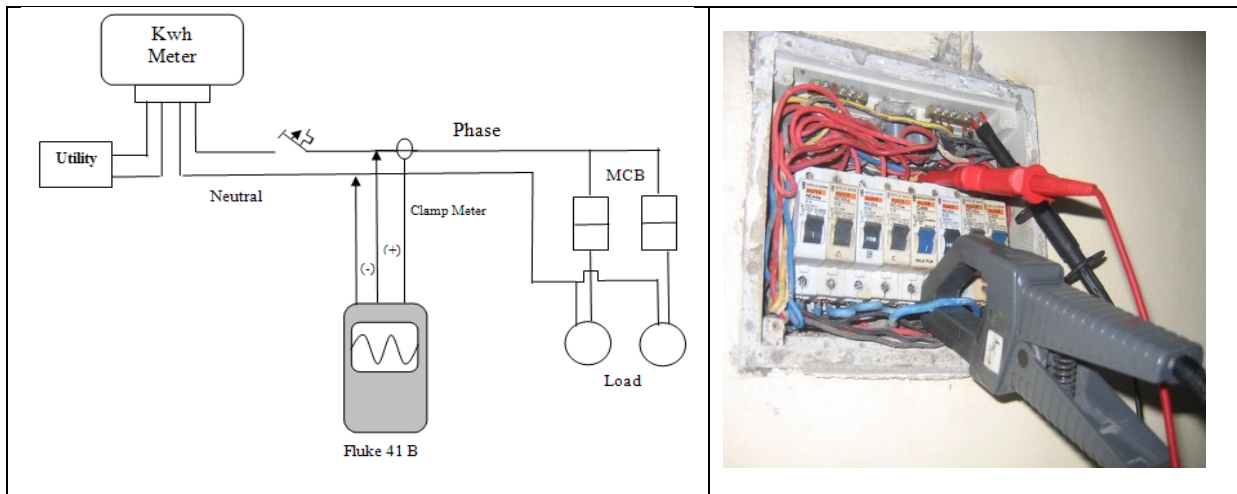
Evaluation and calculation in this study uses of the IEEE 519-1992 standard. Current THD is evaluated by first calculating the value of the comparison between the I_{SC} with I_L. From the comparison of these values can be evaluated from the value of THD that has been obtained from the measurement exceeds the standard or not. Short circuit current (I_{SC}) is obtained by determining the upper side of the point as a benchmark, the position where the short circuit current will be calculated. The first count is a short circuit in the transformer, which is connected to each Kwh-meter house. While the value of I_L is the rms value of current generated from measurement.

III. RESULT AND DISCUSSION

The value obtained from the I_{SC} / I_L will be compared with the standard current THD. One was selected as an example for the calculation of current THD. The data is used to calculate are the length of cable from the transformer to the power pole closest to the 180 m with a cable cross-sectional area of 35 mm^2. According to the data obtained cable short circuit current (I_{SC}) of 1.6 kA. Cable length from power lines to Kwh-meter house with a 15 m cross-sectional area of 6 mm^2. Base on the data obtained short-circuit current (I_{SC}) 1.1 kA.

Figure 3 Spectrum of harmonic distortions
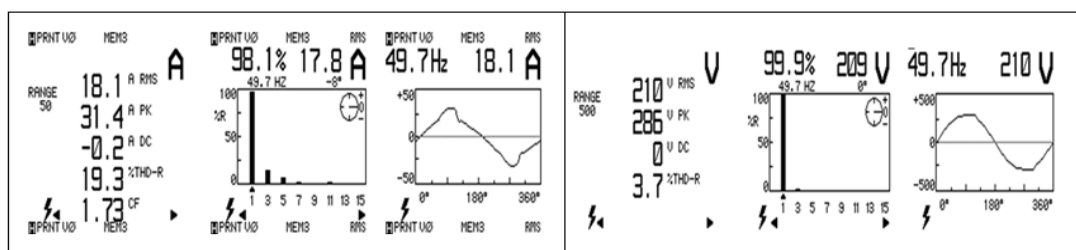
Calculation ISC / IL and ITHD by looking at the results of measurements obtained results are as follows: 1st Harmonic (fundamental rms current) is 99.26%., 3rd Harmonics is 6.92%, ie 5th Harmonics 5, 63%., Harmonics 7th namely 4.9%, 9th Harmonics, namely 2.98%, Harmonics 11th is 2.11% and Harmonic to-31 is 0.14%. ISC calculation results obtained at 6:08 kA and measurement results obtained from the value of I_L = 13.65 A. From the above calculation THD current is generated that is equal to 10.967% and these results do not exceed the prescribed standards. More an calculations measurement results contained in Table 3. This condition shows that 20% of houses do not meet standard evaluated from the aspect ITDH. The results of calculations and measurements for house IV are very small difference that is 0.3. So there is a specific between calculations and measurements. Differences between the measurements and standards reached 52.5%. The use of non-linear devices in the home will increase the electric current harmonic distortion wave, when connected to the distribution system [8] The Calculations for V_{TDH} is used of standard IEEE 519-1992. In calculating the value of voltage THD is a standard used for voltages below 69 kV. Furthermore, from the results of measurements that has been obtained by a comparison with appropriate standards for voltages below 69 kV. From the results of this comparison can be seen the value of measurement results that have been conducted over the allowable limit or

not. Obtained from the calculation of the resulting voltage THD is equal to 2.86% and the result does not exceed the predetermined voltage standards.

Table 4 Evaluation of Total Harmonic Distortion of Current (I_{THD})

Houses	Measurement Fluke 41B (%)	Calculation (%)	I_{SC} / I_L	Standards I_{THD} (%)	Evaluation
I	11.4	10.96	80.58	12	according to Standard
II	12	5.18	295.98	15	according to Standard
III	10.3	6,78	164.89	15	according to Standard
IV	19.3	19.6	77.30	12	out of standards
V	10.8	8.9	182.29	15	according to Standard

Table 5 Evaluation of V_{THD}

Houses	Fluke 41B (%)	ETAP (%)	Calculation (%)	Standard V_{THD} (%)	Evaluations
I.	3.0	3.25	2.98	5	According to standard
II.	1.1	3.22	1.09	5	According to standard
III.	2.3	3.20	2.32	5	According to standard
IV.	3.7	3.27	3.73	5	According to standard
V.	2.7	3.19	2.68	5	According to standard

Other electrical parameters were measured as in Table 6. Measurement result shows that the power factor (PF) has been produced in accordance with the standards set by the standard Indonesia Electric Company PLN (0.85 minimum). The resulting frequencies are also in accordance with the standard 49.8 to 50 Hz. These data prove that, distortion harmonics can be seen from the electrical parameters. If the electrical parameters have been determined to meet the standards, means harmonics in conditions that are safe or in accordance with established standards.

Table 6 Evaluation of Electric Paremeter

Electric Parameter	Houses					Eveluations
	I	II	III	IV	V	
Frekuensi (49,5-50,5)	49.8-50	50	49.8-50	49.8-50	49.7-50	According to standard
Power	3080-3780	2800-3300	1830-2500	3400-3700	1290-1500	N/A
Vrms (198-231)	389-391	210-217	225-226	210	199-201	According to standard
Irms	4.73-5.59	13.6-16.6	8.49-11.20	16,5-18,1	6.66-7.68	N/A
PF (min 0.85)	0.95-0.96	0.95-0.96	0.95-0.99	0.97-0.98	0.97-0.98	According to standard

IV. CONCLUSION

The results of the simulation, calculation and measurement showed that V_{THD} range at 1.1% - 3.6% already meet the IEEE standard is 5% and showed results ranging I_{THD}-10.3% -19.3%. At I_{THD} there are 20% of households that do not meet the standards. Between simulation, calculation and measurement is not a significant difference. Energy-efficient lighting is one of the electronic devices that pose the greatest harmonic on residential electric utility compared with other electronic equipment and the amount of harmonics that may arise depending on the electronics used. If more and more electronic equipment, the greater the harmonics produced in the home.

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