Determination And Analysis Of Harmonic Contents In A Three-phase Installation

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***Abstract*— This paper summarizes a study of harmonic distortion for non-linear devices. The study of analysis held on Power System Laboratory at Level 6, UiTM Shah Alam. Large number of computers and fluorescent lamps were involved.**

The main objective and focus for this project is to measure total harmonic distortion of equipments. Therefore, in the purpose to find harmonic components, Psim Version 6.0 and Fluke RPM have been used. The circuit diagrams of equipments have been simulated by using Psim. Meanwhile by using Fluke RPM, the changes in harmonic distortions can be easily tracked.

***Keywords*— Total harmonic distortion, nonlinear devices.**

INTRODUCTION

In the early 1980's, the proliferation of personal computers and conversion to electronic lighting ballasts produced harmonic problems in commercial office buildings. Facility managers and designers soon discovered that single-phase electronic loads caused distribution transformers to overheat and 'shared' neutral conductors to become overloaded [1].

Harmonic distortion is divided into two classes, voltage distortion and current distortion. Harmonics are currents, usually in multiples of the supply fundamental frequency, produced by non-linear loads such as the AC to DC power conversion circuits. In mechanical terms, distortion refers to the changes an electrical current goes through as it passes from its source device into any type of receiver. Distortion can be caused by many things, but it travels mainly through the cables that connect electrical devices and can create problems in the systems that read and channel the current. Therefore, harmonic distortion is named because it creates disturbances at multiples of the fundamental power frequency being used by the voltage that 50Hz use as reference. The distortions vibrate up along the electrical system of a building or machine and can cause overheating problems, especially in sensitive electronics. Harmonic distortion is the production of harmonic frequencies by an electronic system when a signal is applied at the input. When an input signal goes through nonlinear electronic circuitry, the output signal will include some harmonic distortion (or unwanted frequencies)[2].

In the first electric power systems, harmonic distortion was mainly caused by saturation of transformers, industrial furnaces and other devices like large electric welders. The major concern was the effect that harmonic distortion could have on electric machines, telephone interference, and increased risk of faults from overvoltage conditions developed on power factor correction capacitors.

Thus, the total harmonic distortion (THD) created by an amplifier can be seen as an indirect measure of its transfer function linearity. The fundamental frequency's sinusoidal waveform, which is always predominant, becomes distorted by the additional of harmonic sinusoidal waveforms. The measure of distortion is given as Percent Total Harmonic Distortion of the Fundamental Waveform (%THDv [voltage] and %THDi [current]) [1].

The IEEE Standard 519-1992 specifies the maximum allowable voltage and current distortion apply to the amount of harmonic current to be supplied by the utility source to harmonic load. For most industrial power system, the maximum permitted voltage THD is 5% with the maximum permitted percentage at an individual of any one harmonic component equal to 3%.

i-NONLINEAR DEVICES

Harmonic waveform distortion is just one of many different disturbances that perturb the operation of electrical systems. It is also a unique problem in light of an increasing use of power electronics that basically operate through electronic switching.

There are basically two types of non-linear loads: single-phase and three-phase. Single-phase non-linear loads are prevalent in modern office buildings while three-phase non-linear loads are widespread in factories and industrial plants [3]. Different nonlinear loads produce different bur identifiable harmonics spectra. This makes the task of pinpointing possible culprits of harmonic distortion more tangible.

The most common cause of harmonic distortion is non-linear load. That is, load's current waveform is non-sinusoidal. Non-linear load include electronic devices such as rectifiers, current controllers, AC and DC devices also switched-mode power supplies such as computers, monitors, telephone systems, printers, scanners, and electronic lighting ballasts [1].

A non-linear load on a power system is typically a rectifier (such as used in a power supply), or some kind of arc discharge device such as a fluorescent lamp, electric welding machine, or arc furnace. Because current in these systems is interrupted by a switching action, the current contains frequency components that are multiples of the power system frequency [5].

Different nonlinear loads produce different bur identifiable harmonics spectra. This makes the task of pinpointing possible culprits of harmonic distortion more tangible. Additionally, the increasing use of nonlinear loads in industry is keeping harmonic distortion in distribution networks on the rise. The most used nonlinear device is perhaps the static power converter so widely used in industrial applications in the steel, paper, and textile industries. Nonlinear loads cause a number of disturbances like voltage waveform distortion, overheating in transformers and other power devices, telephone interference, and microprocessor control problems, among others.

Harmonic distortion is create most of often by computers as they change the incoming AC voltage into low-voltage DC current that can be used by digital systems. This is done by switched-mode power supply (SMPS) equipment, which takes in current in short bursts and with rated output power ranging from a few watts to more than 1 kW. Since the current moves through the cables to computer equipment continuously, being drawn out at intervals creates waves of harmonic distortion that can circulate through the entire system. Interference can also come from outside sources that affect computer circuits through the air [4].

The higher frequency of operation, the higher non-linearity in the circuit and the higher the distortion [6]. If the frequencies of the distortion are 2, 4, 6, etc., times the center frequency, it is even-order harmonics. If the frequencies of the distortion are 3, 5, 7, etc., times the center frequency, it is odd-order harmonics [2].

ii-SOURCES OF HARMONIC

In a normal AC power system, the voltage varies sinusoidal at a specific frequency, usually 50 or 60 Hertz. Harmonic distortion originates with non-linear devices on the power system. Such devices produce non-sinusoidal current waveforms when energized with a sinusoidal voltage.

Non-linear devices can be classified as traditional (Classical) type and Modern (power-electronic) type. Traditional types include transformer, rotating machine and arc furnace. Meanwhile, the modern type devices are fluorescent lamps, electronic control and switched-mode power supplies, and thyristor-controlled devices which include rectifiers and inverters.

When a non-linear load, such as a rectifier, is connected to the system, it draws a current that is not necessarily sinusoidal. The current waveform can become quite complex, depending on the type of load and its interaction with other components of the system.

iii-EFFECTS OF HARMONIC

The major effect of power system harmonics is to increase the current in the system. This is particularly the case for the third harmonic, which cause a sharp increase in the zero sequence current, and therefore increase the current in the neutral conductor.

This effect can require special consideration in the design of an electric system to serve non-linear loads. In addition to the increased line current, different pieces of electrical equipment can suffer effects from harmonics on the power system.

The main effect of voltage and current harmonics within the power system are reduction of efficiency of power generation, transmission, and utilization. Next that the overheating and failure of electric motors also excessive measurement errors in metering equipment are some effect of harmonics [7]. Then, the overstressing and overheating of insulation that are capacitive in nature hence could give rise to low impedance at high frequency. Beside that, harmonic generated in one part of a system may give rise to resonance effects in another part.

THEORITICAL BACKGROUND

This section presents the theoretical background related to the proposed approach. The Total Harmonic Distortion is the main purpose in this project that want to analyze it.

Total harmonic distortion, or THD, of signal is a measurement of the harmonic distortion present and is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency.

In most cases, the transfer function of a system is linear and time-invariant. When a signal passes through a non-linear device, additional content is added at the harmonics of the original frequencies. THD is a measurement of the extent of that distortion.

In this calculation, Vn means the RMS voltage of harmonic n, where n=1 is the fundamental harmonic. One can also calculate THD using all harmonic (n=∞) :

$$THD_v = \frac{V^2_{rms} - V^2_{1,rms}}{V^2_{1,rms}}$$

Other definitions may be used. Many authors define THD as an amplitude ratio than a power ratio [8]. This results in a definition of THD which is the square root of that given above. Vn means the RMS voltage of harmonic n, where n=1 is the fundamental harmonic. One can also calculate THD using all harmonic (n=∞). For example in term s of voltages the definition would be:

$$THDv = \frac{\sqrt{V_3^{\,2} + V_5^{\,2} + V_7^{\,2} .... + V_n^{\,2}}}{V_{rms}}$$

Meanwhile to calculate the Total Harmonic Distortion Current is as below:

$$\mathrm{THD}\,i = \frac{\sqrt{\left(I_3^{\,2} + I_5^{\,2} + I_7^{\,2} + ... + I_n^{\,2}\right)}}{I_{rms}}$$

A measurement must specify how it was measured. Measurements for calculating the THD are made at the output of a device under specified conditions. The THD is usually expressed in percent as distortion factor or in dB as distortion attenuation. A meaningful measurement must include the number of harmonics included.

METHODOLOGY

1-Psim Description

Psim is one of softwares used to simulate circuit. The Psim verse 6 has been used to complete this project in analysing harmonic distortions.

2- Fluke RPM Description

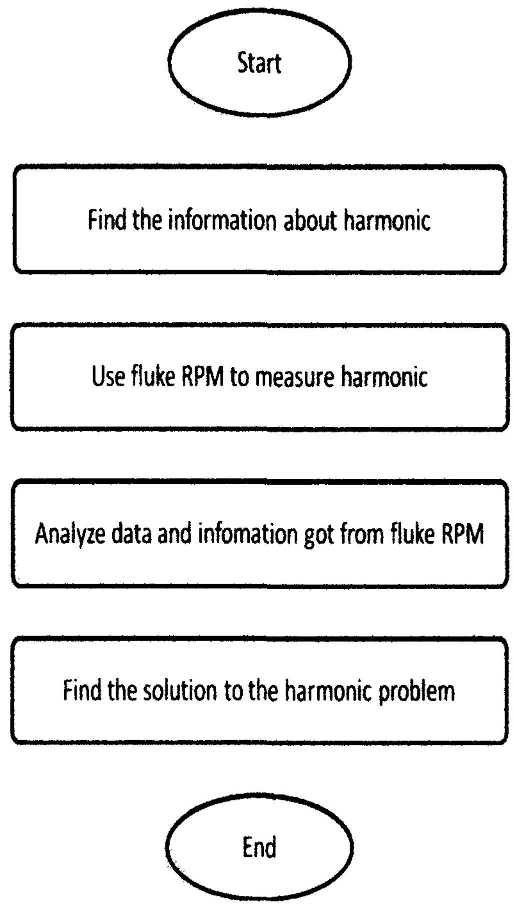
The Fluke 433/435 Three Phase Power Quality Analyzer is one of equipment that can use to measure harmonic distortion and many types of measurements like Fast Fourier Transform (FFT), voltage swing, power and so on. But, for this project I just take the measurement of total harmonic distortion, their waveform and FFT. This equipment is friendly to user because it can give the measurement value and waveform directly.

Firstly, the current at distribution board was checked by using test pen before set up the connection for 3-phase system using Fluke RPM. Next, make connection on conductors of phase A(L1), B(L2), C(L3), and N(Neutral) by put the current clamps around each of them. The clamps are marked with an arrow indicating the correct signal polarity. Then, the voltage connection was set up start with Ground and then in succession N,A(L1), B(L2), and C(L3). For correct measurement results, the Ground input always connected and double-checked the connections. Finally, make sure that current clamps are secured and completely closed around the conductors.

*A. **Experiment Overview***

The real measurement values for harmonic contents in the Power System Laboratory, Fluke RPM was setup. The measurement have been taken by connect the Fluke RPM from the distribution board to the computer to save the important data directly that have already installation software on it.

Below shows the flowchart for this project:



RESULTS & DISCUSSION

1-By using Psim

A-Fluorescent lamp

The lighting in Power System Laboratory installed that consist of two fluorescent lamps each at 36W and 230V connected in duo configuration. The duo configuration uses magnetic ballast. In this analysis, forty set of fluorescent lamps (2 x

36W) that installed in the Power System Laboratory involved. All the lamps are connected in parallel to each other. The fluorescent lamps were simulated as square-wave voltage sources behind an inductor (ballast). The model circuit diagram for fluorescent lamp shown in the Figure 1.

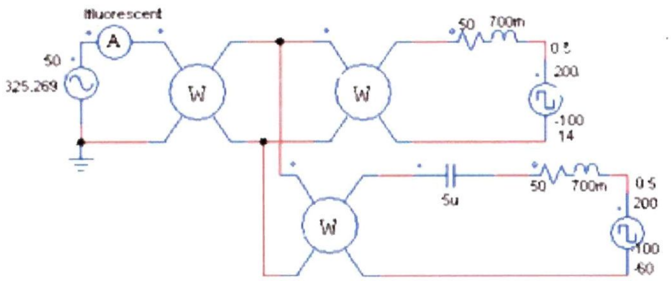


Figure 1: Circuit diagram of fluorescent lamp that contain 2x36W.

THE RESULT OF A SET OF FLUORESCENT LAMP

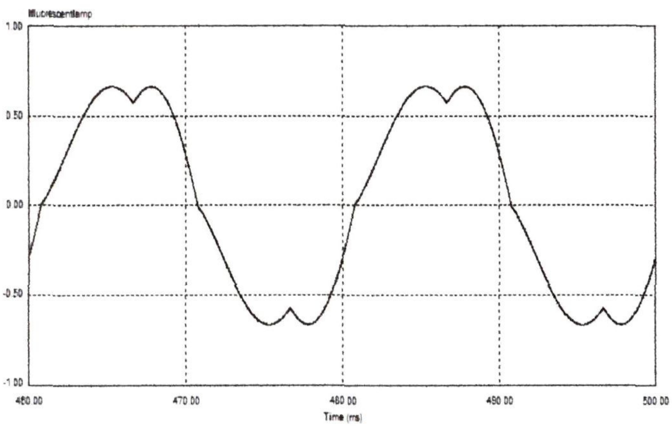


Figure 2 : The waveform of the harmonic distortion produce by two fluorescent lamps.

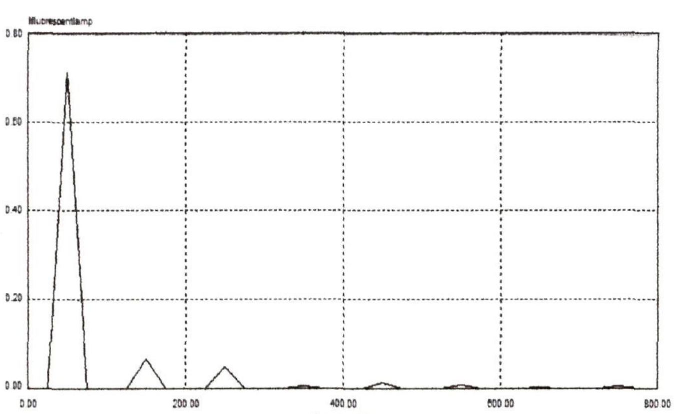


Figure 3: The spectrum diagram for one set fluorescent lamp.

Figure 2 shows the harmonic distortion current waveform that injects back to the ac source from the fluorescent lamps. The distortion on the waveform is more clearly compared to the waveform for a fluorescent lamp. Then, the magnitude of spectrum in the Figure 3 are also larger compared to the spectrum in Figure 3.

B-Computer

Computers are the second equipments where the harmonic distortion set of. In this analysis, there are 36 computers involved and have been simulated. All of computers are installed in the parallel connection. Beside that, the computer circuit was simulated as full wave diode bridges with a capacitor at the dc side and resistors as load. At the ac side, a RF filter was assumed to be between the ac terminals and the diode bridge. The computer model is shown in Figure 4.

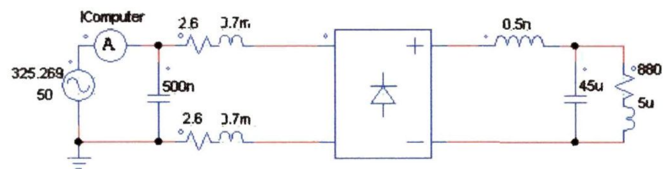


Figure 4 : Circuit diagram for a computer.

THE RESULT FOR A COMPUTER

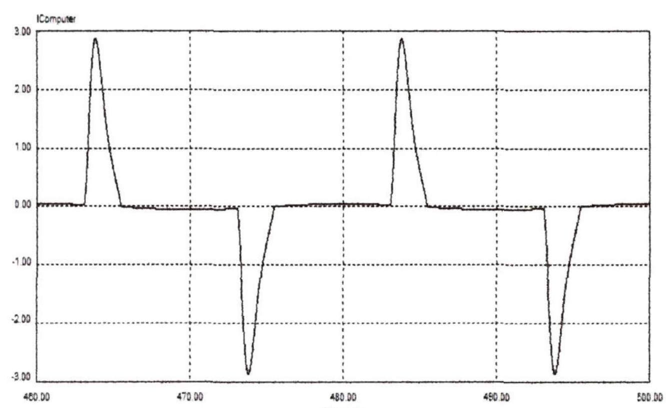


Figure 5 : The waveform of the harmonic distortion produce by a computer.

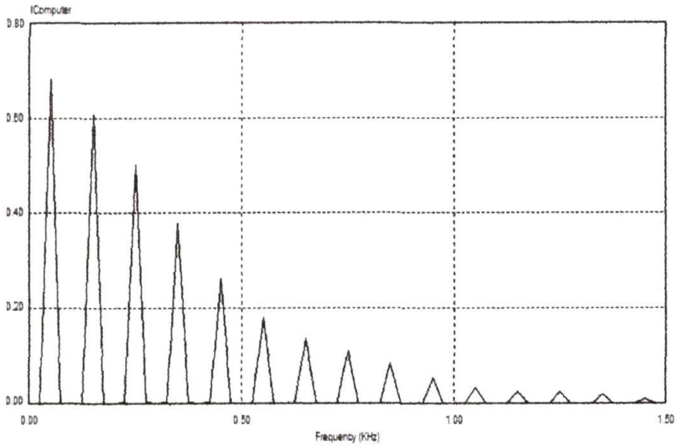


Figure 6: The spectrum diagram for a computer.

Figure 6 shows the waveform of current harmonic injects back to ac source produce by non-linear loads. This waveform is non-sinusoidal but cause by distortion produced by the combination of fundamental waveform and all harmonic waveforms.

2-By using Fluke RPM

From the distribution board, voltage rated that supply to the customers and socket was 230 V. The standard frequency that used as reference is 50Hz. The connection in distribution board is wye connection of three-phase. All the figures below are taken by using Fluke RPM. By using this equipment, many measurements can get such as percentages of harmonic distortion, voltage and current rms, waveform of harmonic and many more.

A. **Fluorescent Lamp Harmonics Measurement**

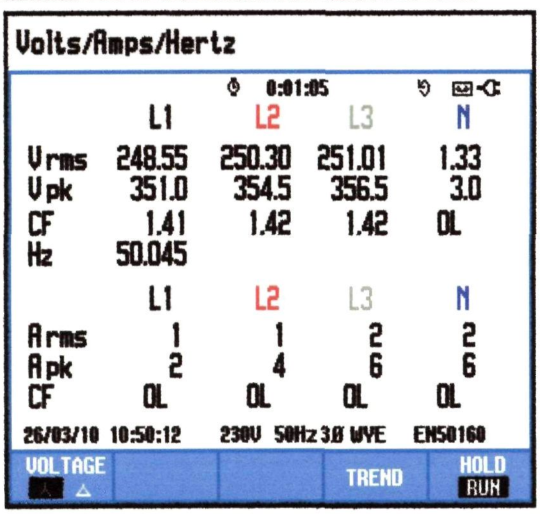


Figure 1 : Voltage, Current and Frequency of 3-phase Wye connection

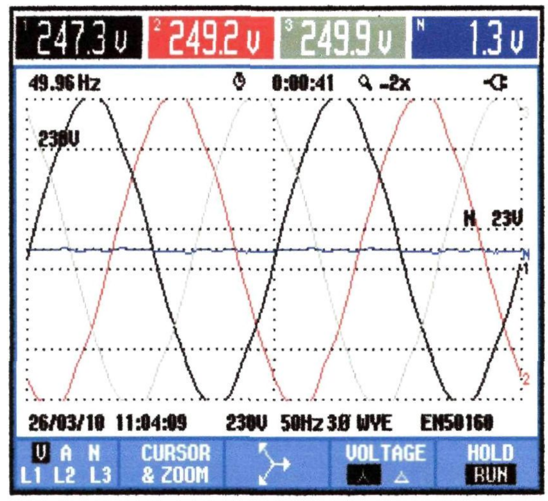


Figure 2: Voltage waveform and their values for all li

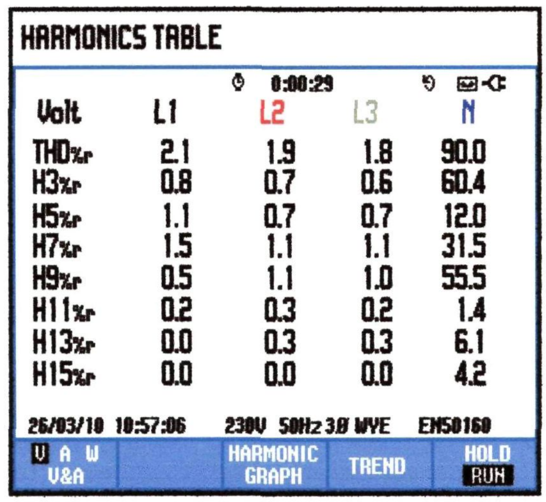


Figure 3: Harmonic table for voltage

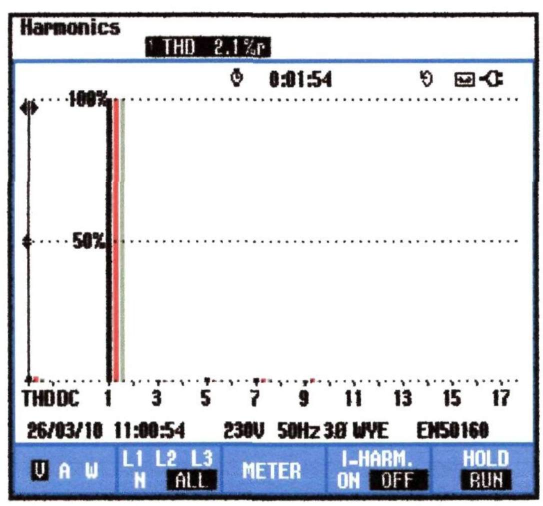
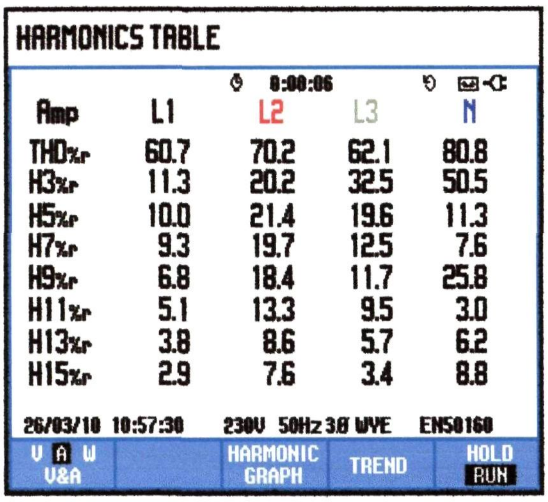


Figure 4: Magnitude of Voltage

Figure 1 until Figure 4 show the values and waveform of voltage for the fluorescent lamps in the power system laboratory. In Figure 1, the values of voltage RMS are higher at the distribution board than the value of voltage that supply to the sockets in the laboratory which is actually 230V. This is because have some losses in the cables from the distribution board. Figure 2 shows the waveform of voltage, the rms of the waveforms that displayed in the header and measured frequency.

Meanwhile harmonic distortion voltage obtained in the Figure 3. Observation from Figure 3 for live lines, harmonic distortion started from third harmonic and increases until seventh harmonic. After that, the harmonic decreases until fifteenth harmonic. For the neutral line, their harmonic distortions are bigger than live lines in each odd harmonic distortion. Figure 4 shows Total Harmonic Distortion (THD) of voltage is 2.1% and voltage magnitude for L1, L2 and L3 are 100% as the fundamental.


HARMONICS TABLE

Amp	L1	L2	L3	N
THD%r	60.7	70.2	62.1	80.8
H3%r	11.3	20.2	32.5	50.5
H5%r	10.0	21.4	19.6	11.3
H7%r	9.3	19.7	12.5	7.6
H9%r	6.8	18.4	11.7	25.8
H11%r	5.1	13.3	9.5	3.0
H13%r	3.8	8.6	5.7	6.2
H15%r	2.9	7.6	3.4	8.8

Figure 5: Harmonic table for current

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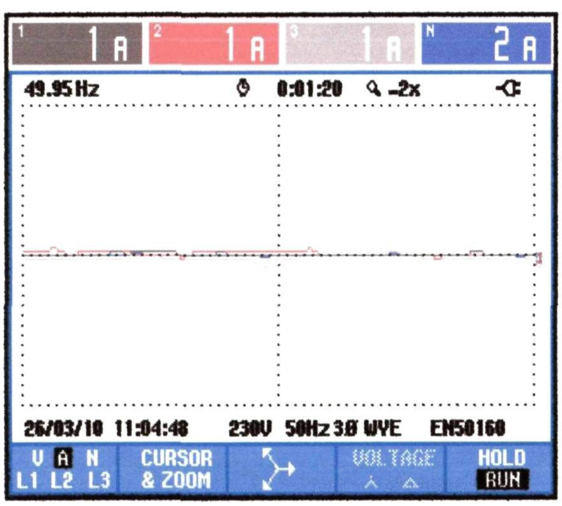


Figure 6: Harmonic waveform and values of current

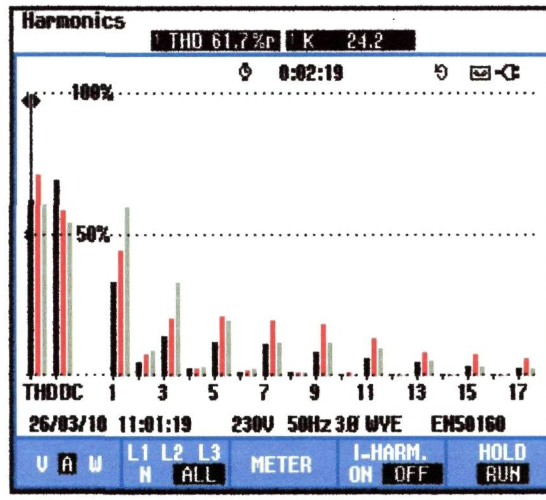
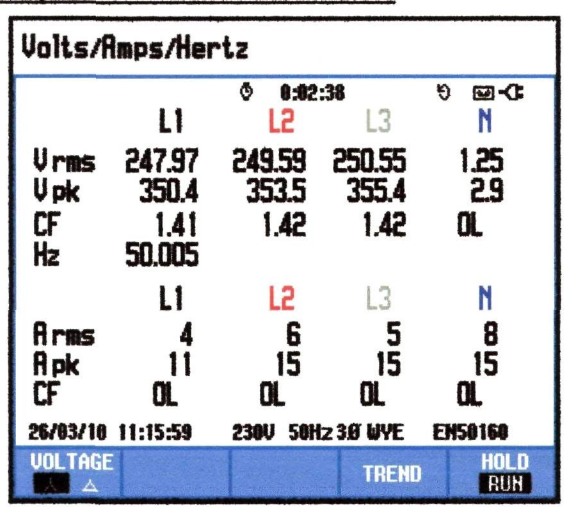


Figure 7: Total Harmonic Distortion and the magnitude Of current

Figure 5 shows the table of harmonic distortion for current of fluorescent lamps which gives 11.3% at the third harmonics for L1 and decreases until fifteenth harmonic distortion which is 2.9%. Percentages of harmonic distortion current for all live lines are bigger than the percentage of harmonics distortion for voltage in Figure 3. But the harmonic distortions neutral line for current almost less than the voltage harmonic distortion.

Figure 6 shows the harmonic waveform current and its values which have small value of current that is 1A for each live cable. Then, Figure 7 shows the Total Harmonic Distortion (THD) for current is 61.7%. Observation from this figure is the red line or L2 is almost higher in each integer of harmonic distortion. This happens because of more losses in red cable and this cable is used more to connect to equipments.

B. **Computer Harmonics Measurement**


Volts/Amps/Hertz

	L1	L2	L3	N
Vrms	247.97	249.59	250.55	1.25
Vpk	350.4	353.5	355.4	2.9
CF	1.41	1.42	1.42	OL
Hz	50.005			

	L1	L2	L3	N
Arms	4	6	5	8
Apk	11	15	15	15
CF	OL	OL	OL	OL

Figure 1 : Voltage, Current and Frequency of 3-phase Wye connection

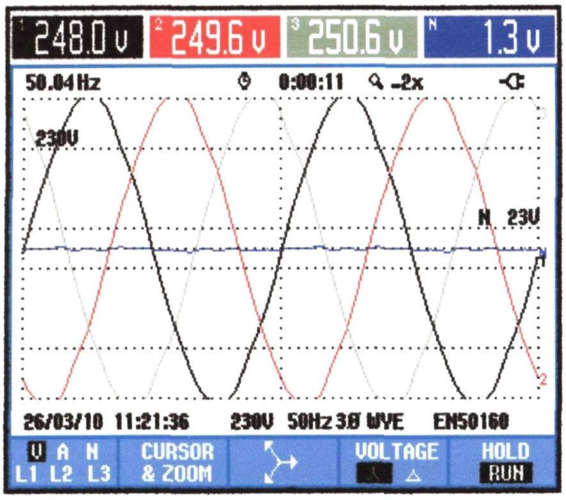
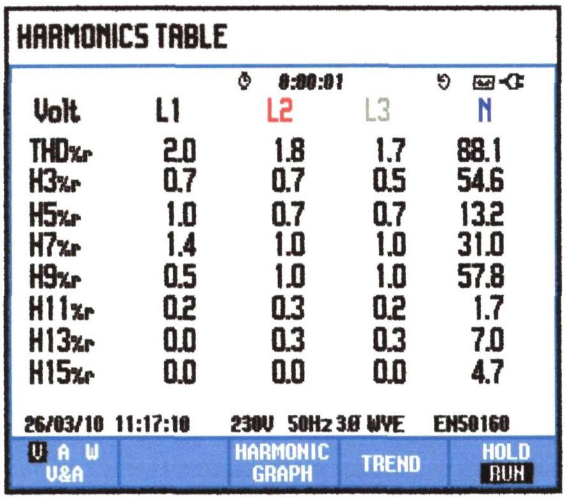


Figure 2: Voltage waveform and their values for all line



HARMONICS TABLE

0:00:01

Volt	L1	L2	L3	N
THD%r	2.0	1.8	1.7	88.1
H3%r	0.7	0.7	0.5	54.6
H5%r	1.0	0.7	0.7	13.2
H7%r	1.4	1.0	1.0	31.0
H9%r	0.5	1.0	1.0	57.8
H11%r	0.2	0.3	0.2	1.7
H13%r	0.0	0.3	0.3	7.0
H15%r	0.0	0.0	0.0	4.7

26/03/10 11:17:10 230V 50Hz 3Ø WYE EN50160

V A W V&A | HARMONIC GRAPH | TREND | HOLD RUN

Figure 3: Harmonic table for voltage

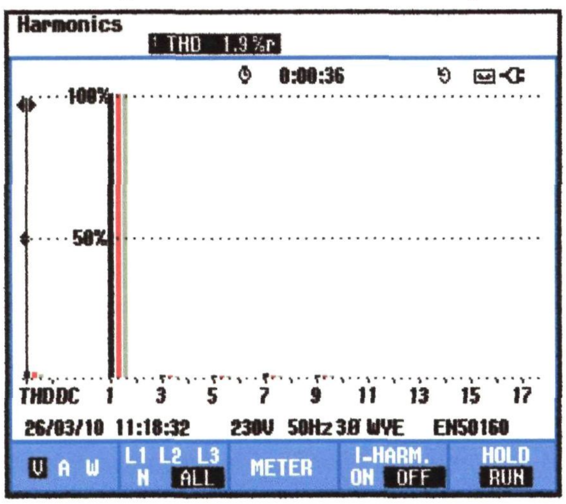
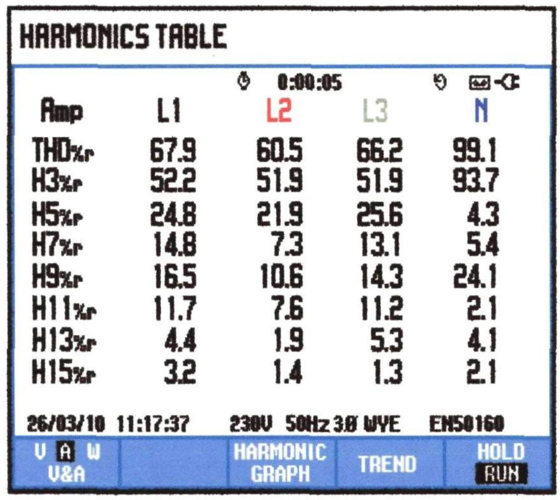


Figure 4: Magnitude of Voltage

Figure 1 until Figure 4 show the information about the voltage harmonic distortion for computers in Power System Laboratory. Figure 1 shows voltage rms for blue line or L3 indicate that this cable is used more for computer wiring installation. Current rms values of computers bigger current rms for fluorescent lamps. Inversely with voltage rms for computer which less than voltage rms values of fluorescent lamps for all line cables. In Figure 2, the actual voltages are displayed in the header.

Figure 3 shows the voltage harmonic distortion table. Observation from this figure is the percentage of harmonic distortion for all live line increase starting from third harmonic distortion until seventh harmonic distortion. Beside that, harmonic distortion for neutral line is very high compared to live lines. Figure 4 shows that the percentages of fundamental voltage are 100% and the Total Harmonic Distortion (THD) is 1.9%.



HARMONICS TABLE

0:00:05

Amp	L1	L2	L3	N
THD%r	67.9	60.5	66.2	99.1
H3%r	52.2	51.9	51.9	93.7
H5%r	24.8	21.9	25.6	4.3
H7%r	14.8	7.3	13.1	5.4
H9%r	16.5	10.6	14.3	24.1
H11%r	11.7	7.6	11.2	2.1
H13%r	4.4	1.9	5.3	4.1
H15%r	3.2	1.4	1.3	2.1

26/03/10 11:17:37 230V 50Hz 3Ø WYE EN50160

V A W V&A | HARMONIC GRAPH | TREND | HOLD RUN

Figure 5: Harmonic table for current

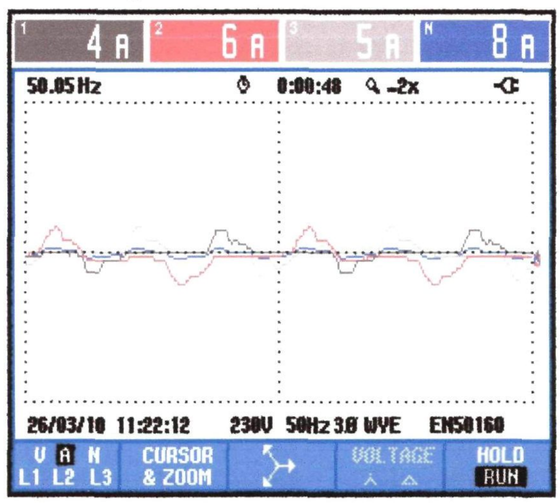


Figure 6: Harmonic waveform and values of current

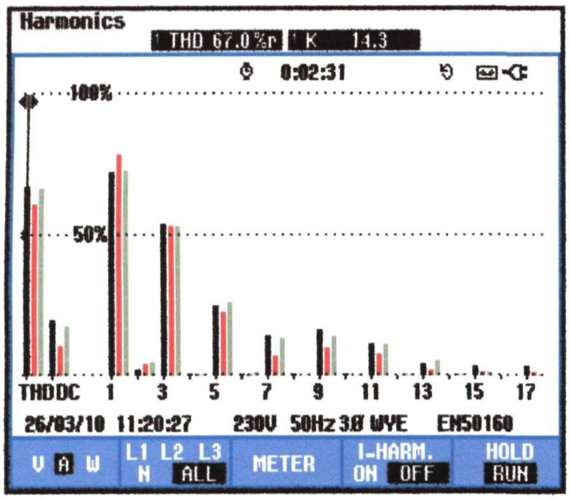


Figure 7: Total Harmonic Distortion and the magnitude Of current

Figure 5 shows the current harmonic table for the computers in Power System Laboratory. The harmonic distortion generally decreases starting from third harmonic until fifteenth harmonics. But at ninth harmonic distortion, the percentage of harmonic distortion for line cable slightly increases at this integer harmonic. The THD and third harmonic are over 90%. These values are very high because of exist of many nonlinear devices in the computer and all the live line currents gather at neutral point since voltage in wye-connection of three phase.

Figure 6 shows the harmonic waveform for current for all line and their values are bigger than the values of fluorescent lamp current. This is because the computers in this laboratory have many non-linear component likes rectifier. These current waveforms show greater than the current waveforms for fluorescent lamps. Meanwhile Figure 7 shows the Total Harmonic Distortion (THD) current for the computers are 67.0% which bigger than the THD of fluorescent lamps which is 61.7%.

C. **Power System Laboratory Harmonic Measurement**

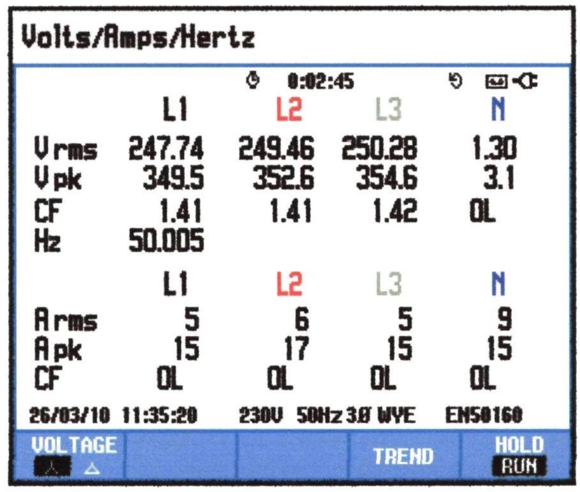


Figure 1 : Voltage, Current and Frequency of 3-phase Wye connection

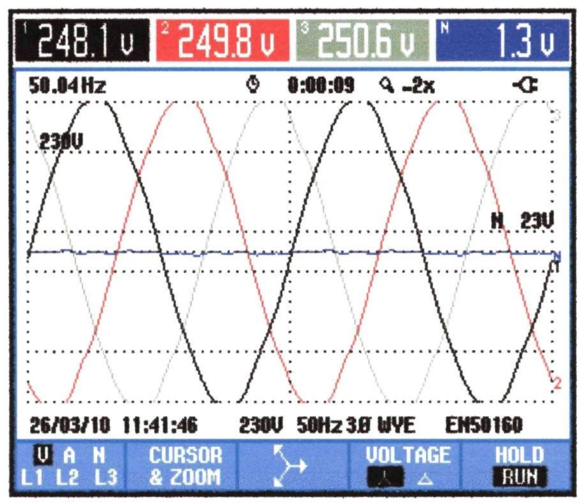
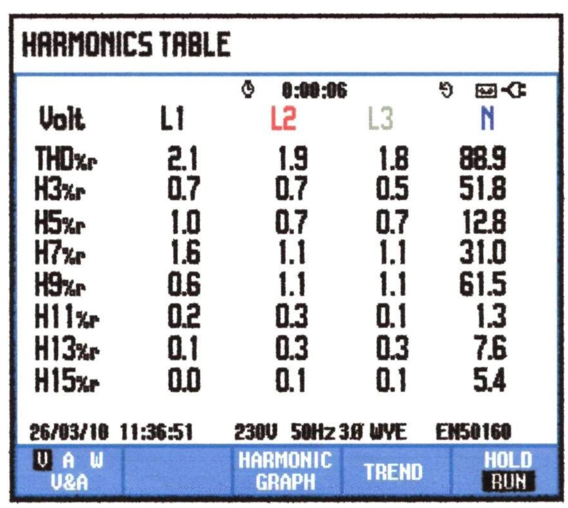


Figure 2: Voltage waveform and their values for all line


HARMONICS TABLE

0:00:06

Volt	L1	L2	L3	N
THD%r	2.1	1.9	1.8	88.9
H3%r	0.7	0.7	0.5	51.8
H5%r	1.0	0.7	0.7	12.8
H7%r	1.6	1.1	1.1	31.0
H9%r	0.6	1.1	1.1	61.5
H11%r	0.2	0.3	0.1	1.3
H13%r	0.1	0.3	0.3	7.6
H15%r	0.0	0.1	0.1	5.4

26/03/10 11:36:51 230V 50Hz 3Ø WYE EN50160

V A W V&A | HARMONIC GRAPH | TREND | HOLD RUN

Figure 3: Harmonic table for voltage

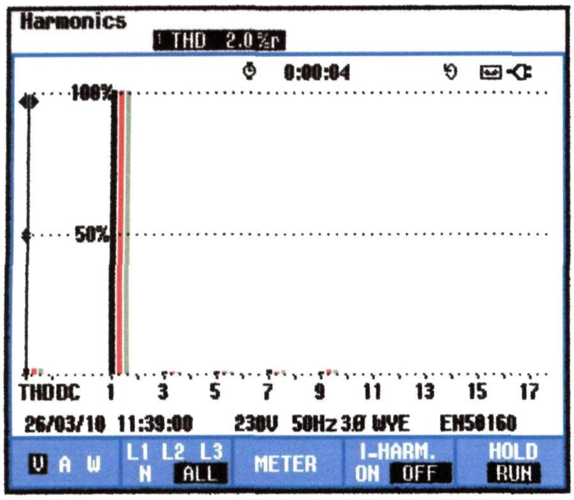
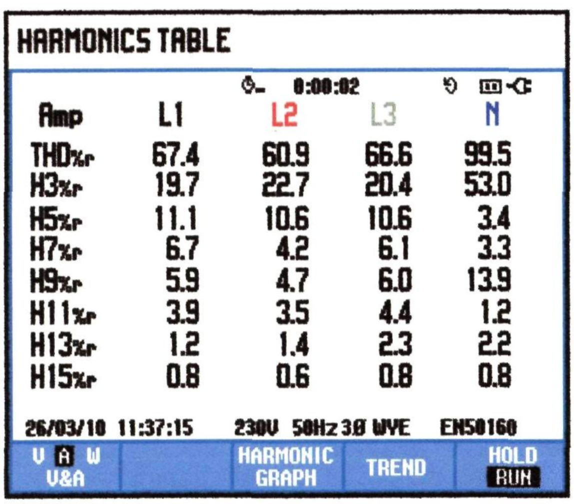


Figure 4: Magnitude of Voltage

From Figure 1 until Figure 4 display about measurement in voltage. Figure 1 shows the value of voltages and current for all lines in wye-connection and at 50Hz frequency. The rated voltage for the cable is 230V. Next, the Figure 2 displayed measurement of live lines and their values are greater than rated voltage.

Then, Figure 3 shows that third until ninth harmonic distortion values are greater than the eleventh until fifteenth harmonic distortion values. Beside that, total harmonic distortion for the voltage is 2.0% displayed in Figure 4. in this figure also shows the magnitude voltage for the fundamental of all live line.


HARMONICS TABLE

0:00:02

Amp	L1	L2	L3	N
THD%r	67.4	60.9	66.6	99.5
H3%r	19.7	22.7	20.4	53.0
H5%r	11.1	10.6	10.6	3.4
H7%r	6.7	4.2	6.1	3.3
H9%r	5.9	4.7	6.0	13.9
H11%r	3.9	3.5	4.4	1.2
H13%r	1.2	1.4	2.3	2.2
H15%r	0.8	0.6	0.8	0.8

26/03/10 11:37:15 230V 50Hz 3Ø WYE EN50160

V A W V&A | HARMONIC GRAPH | TREND | HOLD RUN

Figure 5: Harmonic table for current

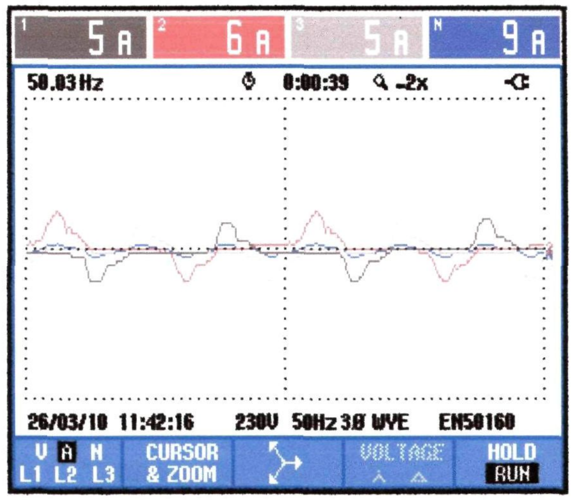


Figure 6: Harmonic waveform and values of current

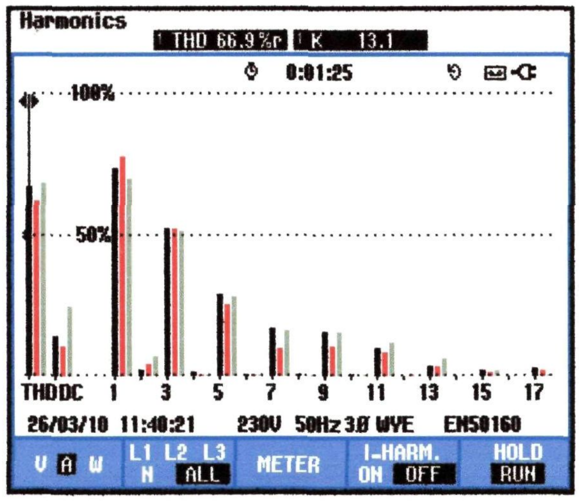


Figure 7: Total Harmonic Distortion and the magnitude Of current

Figure 5 shows the harmonics table of current for the whole Power System Laboratory. Indicate that the total harmonic distortion of current for neutral line is very high which is 99.5%. The measurement of harmonic in the Power System Laboratory is almost same when compared to the measurement of harmonic in the computers. This is because of the fluorescent lamps has less impedance.

Meanwhile in Figure 6, the waveform is no longer sinusoidal and become harmonics. The red line indicates harmonic current through the fluorescent lamps. The value is higher because of the fluorescent lamps have more non-linear component in it. Figure 7 shows the magnitude percentage of current for all live lines. From the observation, the black and grey colors are higher than red line. It is maybe because these two lines are used to connect to computers and their harmonics are higher.

CONCLUSSION

Harmonics content have been identified using Fluke rpm. *These occur because the equipments that involved were had* nonlinear devices include rectifier, current controllers also AC and DC drives.

From the overall figures, observed that the voltage harmonic distortion percentage for all equipment involved was less if compared to the current harmonic distortion percentage.

When distortion currents share a common neutral, most of these higher frequency sine waves cancel out just like what we expert from 50Hz sine waves. However, some harmonics do not cancel. In fact, they add in the neutral. These harmonics are called zero-sequence harmonics, and they are the reason that high neutral currents exists, even though the loads may be perfectly balanced.

FUTURE DEVELOPMENT

For the future development and to overcome the harmonic problem, active harmonic filter will use to monitor the distorted electrical signal, determine the frequency and magnitude of the harmonic content, and then cancel those harmonics with the dynamic injection of opposing current [9].

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