**Characteristic of Triplen Harmonics**

**in Low Voltage Network**

By

Mohamad Hisham B Mohamad Nasir

A project dissertation

submitted in partial fulfillment of

the requirements for the

Bachelor of Engineering (Hons)

(Electrical & Electronics Engineering)

May 2011

Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

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# CERTIFICATION OF APPROVAL

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Approved:

Ir. Mohd Faris B Abdullah 12/5/11
Project Supervisor

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## CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

________________________________________

MOHAMAD HISHAM B MOHAMAD NASIR

# ABSTRACT

Triplen harmonics study for harmonics produced by non-linear loads and salient pole synchronous generator is very important because their presence have caused communication line interference, damage to neutral earthing resistor etc. The purpose of this project is to study the characteristics of triplen harmonics under balanced/unbalanced resistive/inductive/capacitive loads, different generator neutral earthing resistor values and various transformer winding configurations. Lab scale non-linear load and salient pole synchronous generator is used for the experiment and third harmonic currents are recorded for analysis to represent triplen harmonics currents characteristics. Results from the under balanced load experiment shows that third harmonic current is inversely proportional to load impedance and neutral current is three times the phase current. During unbalanced load condition, the magnitude current is different for each phase and the neutral current is lower than arithmetic sum of phase current due to different phase current magnitude and angle. The phase and neutral third harmonic currents magnitude is inversely proportional to generator NER resistance under balanced load. Transformer winding configurations under balanced load permit third harmonic current flowing through them in accordance to zero sequence network for the transformer apart from higher transformer reactive impedance at third harmonic.

# ACKNOWLEDGEMENT

First of all, I would like to express my gratitude to God for giving me the strength and health to complete this project. Not forgotten to my parents and my family members for providing advises.

I would like to thank my supervisor, Ir. Mohd Faris B Abdullah for sharing his knowledge and giving me the support and guidance throughout the project. I also would like to thank to my laboratory technician, Mr. Zuraimi and Mr. Yasin for assisting me to do some electrical wire connection.

My appreciation to Universiti Teknologi PETRONAS especially Electrical and Electronics Engineering Department, by providing me the necessary assets and resources, not only to accomplish my task, but also to enrich my knowledge further.

Finally, I offer my regards to those who support me especially all my friends and technicians in Electrical and Electronics Department for contributing their assistance and ideas for this project.

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background study

Harmonics have existed in power systems for many years. In the past, harmonics represented less of a problem due to a conservative design of power equipment. However, they have magnified nowadays with the increased use of non-linear devices and produces non-sinusoidal current when supplied with a sinusoidal voltage, and vice-versa [1]. This keeping harmonic distortion in distribution networks on the rise.

Harmonics get more complicated in three phase applications where in these applications the industry need to deal with phase conductors, neutral conductor, sequence harmonics and triplen harmonics.

## 1.2 Problem statement

Synchronous generator and non-linear loads in the electrical system are source of harmonic distortion of both the voltage and current signals. This is one of the major quality concerns in electric power industry. This harmonics have the ability to cause the voltage and current waveforms become distorted.

The magnitude of the triplen harmonics current produced three times the phase current at the neutral conductor [2] [3]. The excessive current in the neutral conductor can cause higher-than-normal voltage drops between the neutral conductor and ground.

When the linear loads are subjected to harmonics voltage distortion, they will draw a non-linear harmonic current. For example in distribution transformers, harmonics currents can cause increased heating, due to iron and copper losses, in motor and generators. This increased heating can reduce the life of the electrical device as well as the electrical device efficiency.

The other bad impact that causes by the triplen harmonics are increased cooling load on buildings, increased heating in cables, nuisance tripping of breakers and malfunction of communications and data processing equipment. More details information already has been discuss in [4] and [5].

## 1.3 Objective and Scopes of study

There are four main objectives of this project which are stated as below:

1. To study the behaviour of the triplen harmonics in the non-linear loads
2. To study the behaviour of the triplen harmonics under balanced and unbalanced loads
3. To study the influence of neutral earthing resistor (NER) to the triplen harmonics
4. To study the influence of different transformer configuration winding to the triplen harmonics

The scopes of study in this project are:

### *1.3.1 Lab modeling and measurement*

The scope of research is confine to perform the lab modeling using the Lab-Volt device such as generator, load impedances, record and measure the voltage and current harmonics waveform.

### *1.3.2 Data analysis*

Data analysis is to understand the behavior of the triplen harmonic in the power system.

# CHAPTER 2
# LITERATURE REVIEW

## 2.1 Triplen Harmonics

One of the major power quality concerns in electric power industry is the distortion of sinusoidal voltage and current waveforms that caused by harmonics. The harmonics generated by the proliferation of non-linear loads have been dividing into three types that are positive-sequence harmonics, negative-sequence harmonics and zero-sequence harmonics.

Zero sequence harmonics also is known as triplen harmonics. Triplen harmonics are sinusoidal voltages or currents that are multiple odd numbers of third order harmonics. Triplen harmonics is the third order harmonics, nine order harmonics, fifteen order harmonics and so on [6].

In three phase AC circuits which contain balanced linear loads, the sinusoidal waveforms for voltage, current and power remain proportionally related as well, and there is no net current flowing in the neutral. The situation changes when non-linear loads are imposed on one or more phases.

Most of the three phase branch circuits contain a single neutral conductor for all three phase conductors. This is a safe arrangement when the neutral current is zero, or at worst, equal to the current in any single phase. Even numbered harmonic currents cancel out on the neutral; whereas triplen harmonics do not. Instead, they add up algebraically in the neutral conductor. When the neutral current is higher than the phase current, the solitary neutral conductor is in danger of overheating [7].

Figure 1 below show a normal 60-cycle power line voltage appears on the oscilloscope as near sine wave. When harmonics are present, the distorted waveform is produce as shown in Figure 2 below [8].

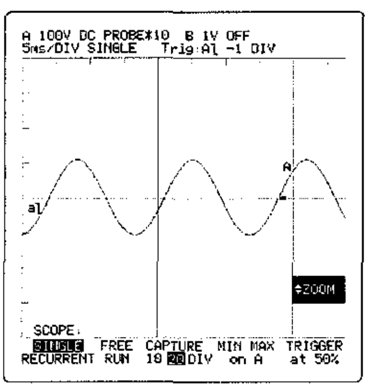


Figure 1: Near sine wave

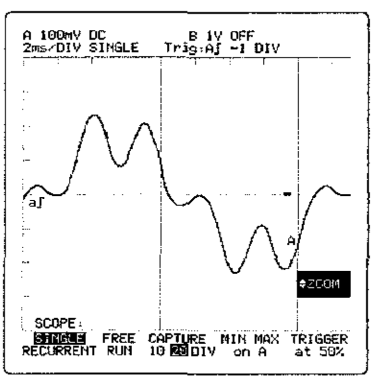


Figure 2: Distorted current waveform

## 2.2 Total harmonic distortion

Harmonics work together in distorting the fundamental waveform. The representation of the harmonic current with respect to the fundamental waveform is called total harmonic distortion (THD).

Total harmonic distortion (THD) is use as the harmonic index to study the effect of these non-linear loads. It considers the contribution of every individual harmonic component on the signal. A commonly cited value of 5% is often use as a dividing line between a high and low distortion level [9].

The THD of a waveform is calculated by taking the square root of the addition of the squares of the harmonic currents, and dividing them by the fundamental current. As a formula:

$$I_{THD} = \frac{\sqrt{\left(I_3 2 + I_5 2 + I_7 2 + I_9 2 + \ldots\right)}}{I1} \qquad (1)$$

Where $I_1$, $I_3$, $I_5$, $I_7$, $I_9$ ... are the currents at their respective harmonics.

Linear loads have very low values of THD because they have little to no harmonic current. Non-linear loads have large values of THD, and cause considerable distortion to the normal sine wave.

## 2.3 Low voltage networks

A low voltage network usually have a voltage level less than 1000 volts or 1 kV and consists of three phase four wire system. The phase is referred to red, yellow and blue phase while the four wires consist of the three phase wire plus one neutral wire.

The low voltage networks have neutral point solidly earthed mixture of overhead lines, underground cables and aerial insulated cables [10]. In low voltage network, it has three types of supply voltage option. The supply voltage options are:

- Single-phase, two-wire, 240V, up to 12 kVA maximum demand
- Three-phase, four-wire, 415V, up to 45 kVA maximum demand
- Three-phase, four-wire, C.T. metered, 415V, up to 1,000 kVA maximum demand

## 2.4 Non-linear load

Most of the electronic equipment requires dc voltage to operate. The ac power supply need to convert to dc voltage via the rectifier and capacitors that within the equipment. Today electronics device mostly come together with the switched electronic device. As the capacitors charge and discharge during this conversion, the capacitor draws current in pulses, not at a continuous rate as explain in details in [11]. This irregular current demand, distorts the linear sine wave. As a result, these types of loads are commonly referred to as non-sinusoidal or non-linear loads.

## 2.5 Salient pole synchronous generator

Synchronous generator also produced triplen harmonics depending on its winding design in terms of pitch factor, distribution factor and slot skew. Salient pole shape and concentrated field winding of synchronous generator have caused third harmonic voltage at no-load.

Salient pole shape and concentrated field winding, direct-axis armature reactance and quadrature-axis armature reactance contribute to third harmonic voltage at balanced load. Resultant of addition the effect of backward field mmf to salient pole shape and concentrated field winding, direct-axis armature reactance and quadrature-axis armature reactance yield third harmonic voltage at unbalanced load [12].

Triplen harmonics currents are continuously flow through neutral earthing resistor (NER) that cause high temperature for generator. The high NER temperature is caused by increase in triplen harmonics currents that flow through it [13].

# CHAPTER 3

# METHODOLOGY

## 3.1 Procedure identification

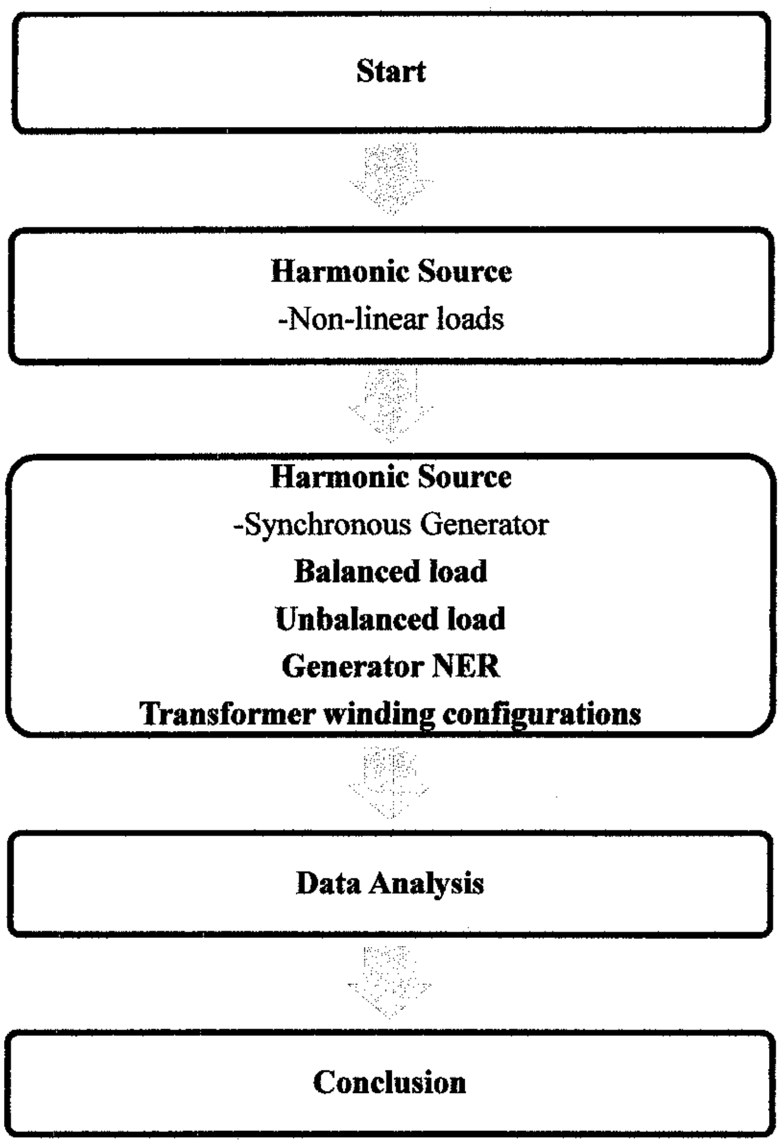


Figure 3: Work Flow chart

## 3.2 Research methodology

Triplen harmonics voltages are present at the output terminals of generator even when connected to a load. However, triplen harmonics currents only exist when generator begin to supply a load.

The focus for this project is to study the characteristic of the triplen harmonics and parameters that influent the triplen harmonics in the low voltage network. There are many factors that influenced triplen harmonics currents produced by generator as simulated in [14].

In order to study the triplen harmonics characteristic, a low voltage generator is use for laboratory scale experiment. This project is dividing into two phases where the first phase of this project is to study the characteristics of triplen harmonic produced by non-linear loads. The second phase involves study of triplen harmonic produced by synchronous generator. Please refer to appendix A.

## 3.3 Project activities

### *3.3.1 First phase experiment*

The first phase experiment of the project is on the non-linear loads as listed in Table 1. 230V, 50 Hz AC system is being supply to the loads. Harmonic spectrum and THDs for each load is record for analyzing the effect of harmonics introduced by these loads.

Table 1: Non-linear loads rating

| No. | Domestic Load | Rating |
|---|---|---|
| 1 | Battery Charger | 4.9V; 700mA |
| 2 | Laptop | 65W |
| 3 | Printer | 16V; 500mA |
| 4 | Radio | 6W |
| 5 | Television | 120W |
| 6 | Fan | 10W |

Figure 4 below show a line diagram for the measurement of the non-linear loads:

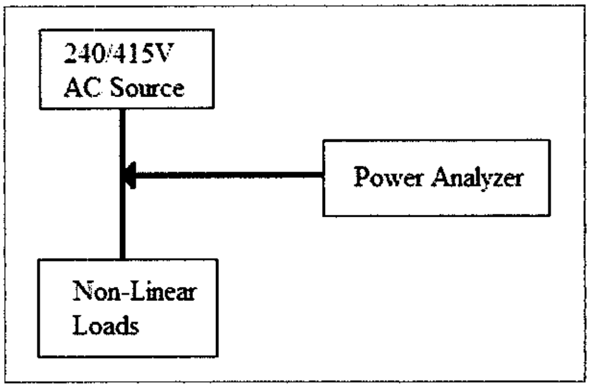

Figure 4: One line diagram indicating measuring point

### *3.3.2 Second phase experiment*

The second phase of the project is on the triplen harmonic produced by synchronous generator for balanced, unbalanced load, generator NER and different transformer winding configurations. The 240 VAC power supply is being supply to this generator. The laboratory equipment rating for the second phase experiment is show in Table 2 below while figure 5 shows the connection in the second phase experiment.

Table 2: Laboratory equipment rating

| No. | Equipment | Ratings |
|---|---|---|
| 1 | Generator | 415V; 0.35A; 175W |
| 2 | Resistive load | 240V; 252W |
| 3 | Inductive load | 240V; 252Var |
| 4 | Capacitive load | 240V; 252Var |

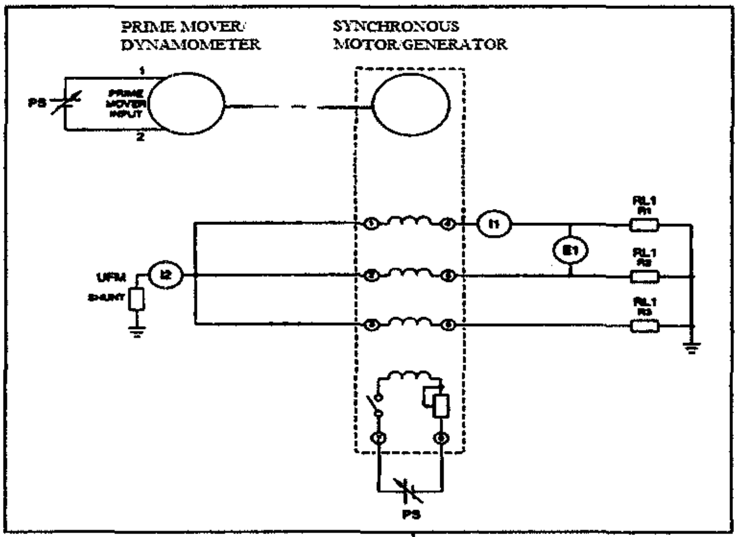


Figure 5: Diagram for 2nd phase experiment

### *3.3.2.1 Load Variation (Resistive/Inductive/Capacitive)*

Table 3 to Table 11 shows the load value for each phase under balanced, unbalanced and their combination load impedances. The loads is in wye connection with neutral wire connected directly to the generator neutral and the harmonics current are measured at the load terminals.

Table 3: Balanced Resistive load

| Case study | Phase 'a' (Ω) | Phase 'b' (Ω) | Phase 'c' (Ω) |
|---|---|---|---|
| 1 | 686 | 686 | 686 |
| 2 | 800 | 800 | 800 |
| 3 | 1200 | 1200 | 1200 |
| 4 | 1600 | 1600 | 1600 |
| 5 | 2400 | 2400 | 2400 |
| 6 | 3600 | 3600 | 3600 |
| 7 | 4800 | 4800 | 4800 |
| 8 | 6000 | 6000 | 6000 |
| 9 | 7200 | 7200 | 7200 |
| 10 | 9600 | 9600 | 9600 |

Table 4: Balanced Inductive load

| Case study | Phase 'a' (H) | Phase 'b' (H) | Phase 'c' (H) |
|---|---|---|---|
| 1 | 2.1 | 2.1 | 2.1 |
| 2 | 2.5 | 2.5 | 2.5 |
| 3 | 3.8 | 3.8 | 3.8 |
| 4 | 4.3 | 4.3 | 4.3 |
| 5 | 5.1 | 5.1 | 5.1 |
| 6 | 7.6 | 7.6 | 7.6 |
| 7 | 10.1 | 10.1 | 10.1 |
| 8 | 11.4 | 11.4 | 11.4 |
| 9 | 15.3 | 15.3 | 15.3 |
| 10 | 19.1 | 19.1 | 19.1 |

Table 5: Balanced Capacitive load

| Case study | Phase 'a' (μF) | Phase 'b' (μF) | Phase 'c' (μF) |
|---|---|---|---|
| 1 | 0.44 | 0.44 | 0.44 |
| 2 | 0.53 | 0.53 | 0.53 |
| 3 | 0.66 | 0.66 | 0.66 |
| 4 | 0.89 | 0.89 | 0.89 |
| 5 | 1.33 | 1.33 | 1.33 |
| 6 | 1.99 | 1.99 | 1.99 |
| 7 | 2.65 | 2.65 | 2.65 |
| 8 | 3.31 | 3.31 | 3.31 |
| 9 | 3.68 | 3.68 | 3.68 |

Table 6: Unbalanced Resistive load

| Case study | Phase 'a' (Ω) | Phase 'b' (Ω) | Phase 'c' (Ω) |
|---|---|---|---|
| 1 | 686 | 800 | 1200 |
| 2 | 1600 | 2400 | 4800 |
| 3 | 800 | 1600 | 2400 |
| 4 | 1200 | 2400 | 4800 |
| 5 | 800 | 1200 | 1600 |
| 6 | 1600 | 2400 | 4800 |
| 7 | 686 | 1600 | 2400 |
| 8 | 2400 | 3600 | 4800 |
| 9 | 3600 | 4800 | 6000 |
| 10 | 6000 | 7200 | 9600 |

Table 7: Unbalanced Inductive load

| Case study | Phase 'a' (H) | Phase 'b' (H) | Phase 'c' (H) |
|---|---|---|---|
| 1 | 2.5 | 3.8 | 5.1 |
| 2 | 3.8 | 5.1 | 7.6 |
| 3 | 5.1 | 7.6 | 2.1 |
| 4 | 10.1 | 11.4 | 15.2 |
| 5 | 2.5 | 3.8 | 7.6 |
| 6 | 2.1 | 2.5 | 3.8 |
| 7 | 11.4 | 15.2 | 19.1 |
| 8 | 4.3 | 15.2 | 19.1 |
| 9 | 7.6 | 5.1 | 15.3 |
| 10 | 4.3 | 19.1 | 11.4 |

Table 8: Unbalanced Capacitive load

| Case study | Phase 'a' (μF) | Phase 'b' (μF) | Phase 'c' (μF) |
|---|---|---|---|
| 1 | 0.66 | 1.33 | 2.65 |
| 2 | 1.99 | 3.68 | 3.31 |
| 3 | 0.44 | 0.89 | 0.53 |
| 4 | 0.66 | 1.33 | 1.99 |
| 5 | 1.33 | 2.65 | 3.68 |
| 6 | 2.65 | 3.31 | 3.68 |
| 7 | 1.33 | 1.99 | 2.65 |
| 8 | 0.66 | 2.65 | 1.99 |

Table 9: Combination Unbalanced Resistive Inductive load

| Case study | Phase 'a' (Ω+H) | Phase 'b' (Ω+H) | Phase 'c' (Ω+H) |
|---|---|---|---|
| 1 | 686+2.5 | 800+3.8 | 1200+5.1 |
| 2 | 1600+3.8 | 2400+5.1 | 4800+7.6 |
| 3 | 800+5.1 | 1600+7.6 | 2400+2.1 |
| 4 | 1200+2.5 | 2400+3.8 | 4800+5.1 |
| 5 | 800+2.5 | 1200+3.8 | 1600+7.6 |
| 6 | 1600+2.1 | 2400+2.5 | 4800+3.8 |
| 7 | 686+11.4 | 1600+15.2 | 2400+19.1 |
| 8 | 2400+4.3 | 1200+11.4 | 4800+10.1 |
| 9 | 3600+7.6 | 4800+3.8 | 6000+15.3 |
| 10 | 6000+2.1 | 7200+7.6 | 9600+3.8 |

Table 10: Combination Unbalanced Resistive Inductive and Capacitive load

| Case study | Phase 'a' (Ω+H+ μF) | Phase 'b' (Ω+H+ μF) | Phase 'c' (Ω+H+ μF) |
|---|---|---|---|
| 1 | 686+2.5+0.44 | 800+3.8+0.53 | 1200+5.1+0.89 |
| 2 | 1600+3.8+0.44 | 2400+5.1+0.53 | 4800+7.6+0.89 |
| 3 | 800+5.1+0.44 | 1600+7.6+0.53 | 2400+2.1+0.89 |
| 4 | 1200+2.5+0.44 | 2400+3.8+0.53 | 4800+5.1+0.89 |
| 5 | 800+2.5+0.44 | 1200+3.8+0.53 | 1600+7.6+0.89 |
| 6 | 1600+2.1+0.44 | 2400+2.5+0.53 | 4800+3.8+0.89 |
| 7 | 686+11.4+0.44 | 1600+15.2+0.53 | 2400+19.1+0.89 |
| 8 | 2400+4.3+0.44 | 1200+11.4+0.53 | 4800+10.1+0.89 |
| 9 | 3600+7.6+0.44 | 4800+3.8+0.53 | 6000+15.3+0.89 |
| 10 | 6000+2.1+0.44 | 7200+7.6+0.53 | 9600+3.8+0.89 |

Table 11: Generator NER

| Case study | Phase 'a' (Ω) | Phase 'b' (Ω) | Phase 'c' (Ω) |
|---|---|---|---|
| 1 | 0 | 0 | 0 |
| 2 | 80 | 80 | 80 |
| 3 | 120 | 120 | 120 |
| 4 | 160 | 160 | 160 |
| 5 | 240 | 240 | 240 |
| 6 | 480 | 480 | 480 |
| 7 | 960 | 960 | 960 |

#### *3.3.2.2 Generator Neutral Earth Resistor (NER)*

The NER value for the generator is varied and is connect with the balanced resistive load. Loads are connecting in wye with neutral wire connected to generator neutral. The harmonics currents are measure at the generator terminals. The generator NER value is varying from 0 ohm to 960 ohm.

#### *3.3.2.3 Transformer winding configurations*

The connection of the transformers is use with four different winding configurations, which are delta-delta, delta-wye, wye-delta and wye-wye. The primary winding of the transformer is connecting to the terminal voltage of the generator and the step-down secondary winding is directly connecting to balanced resistive load. Loads are connecting in wye with neutral wire connected to the wye transformer winding (where applicable) and generator neutral points.

# CHAPTER 4

# RESULTS AND DISCUSSIONS

## 4.1 Non-linear load

Figure 6 shows the third harmonic current produce at neutral conductor for each non-linear load. This figure shows that television contains highest third harmonic neutral current (199.62 mA) follows with laptop (77.14 mA), radio (17.21 mA), printer (15.46 mA), battery charger (15.37 mA) and finally fan (3 mA).

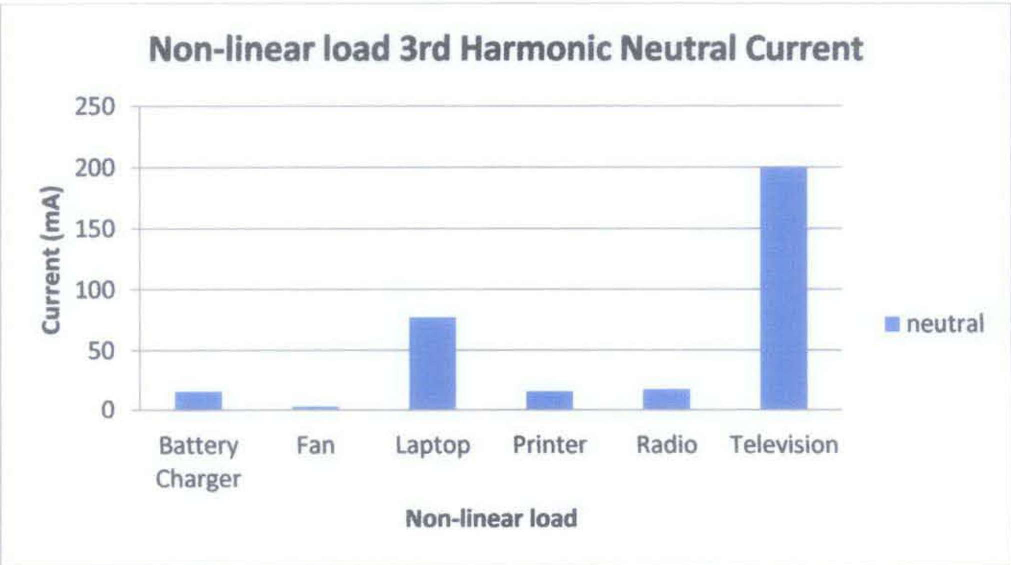


Figure 6: Third Harmonic Current vs. nonlinear load

Figure 7 to Figure 18 shows the current harmonic waveform and spectrum for respective domestic non-linear load. The voltage waveform in each domestic non-linear load still in sinusoidal waveform but produce the distorted current waveforms in all domestic loads.

### *4.1.1 Battery Charger*

Figure 7 show that the current waveform is distorted while the voltage waveform is remaining in sinusoidal waveform. The current is 292.8 mA while voltage is 246.6V.

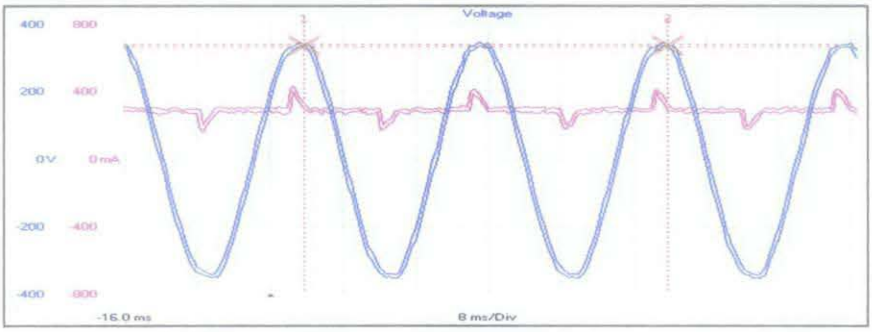


Figure 7: Battery Charger Voltage and Current waveform

Figure 8 show the triplen harmonic spectrum for battery charger from fundamental to fifty first order harmonics. As the order of triplen harmonic is increase the current become lower.

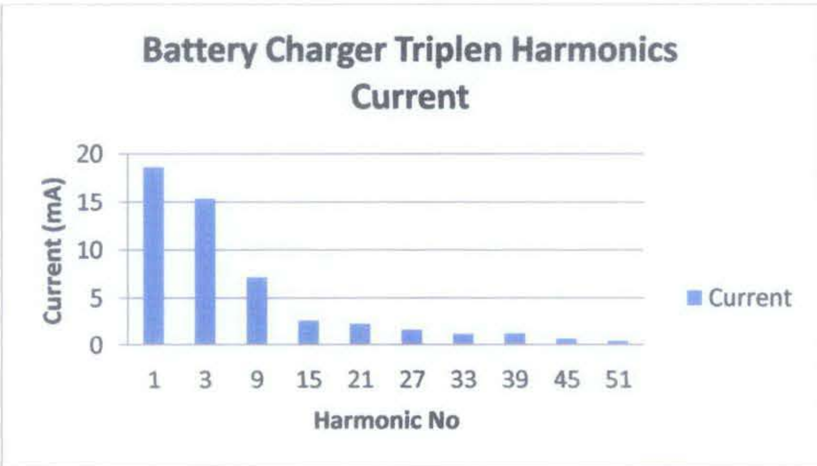


Figure 8: Battery charger triplen harmonics current

### *4.1.2 Laptop*

Figure 9 show that the current waveform is distorted while the voltage waveform is remaining in sinusoidal waveform. The current is 489 mA while voltage is 255.2 V.

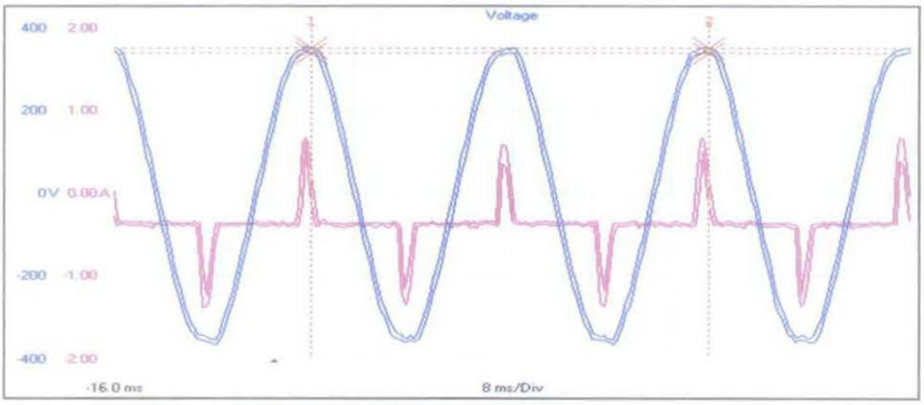


Figure 9: Laptop Voltage and Current waveform

Figure 10 show the triplen harmonic spectrum for laptop from fundamental to fifty first order harmonics. As the order of triplen harmonic is increase the current become lower.

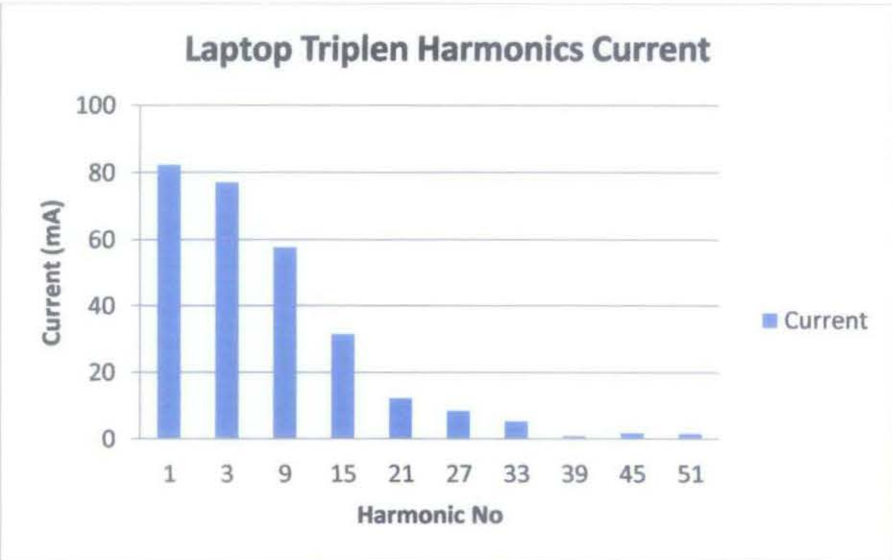


Figure 10: Laptop triplen harmonics current

### *4.1.3 Printer*

Figure 11 show that the current waveform is distorted while the voltage waveform is remaining in sinusoidal waveform. The current is 244.9 mA while voltage is 251.6 V.

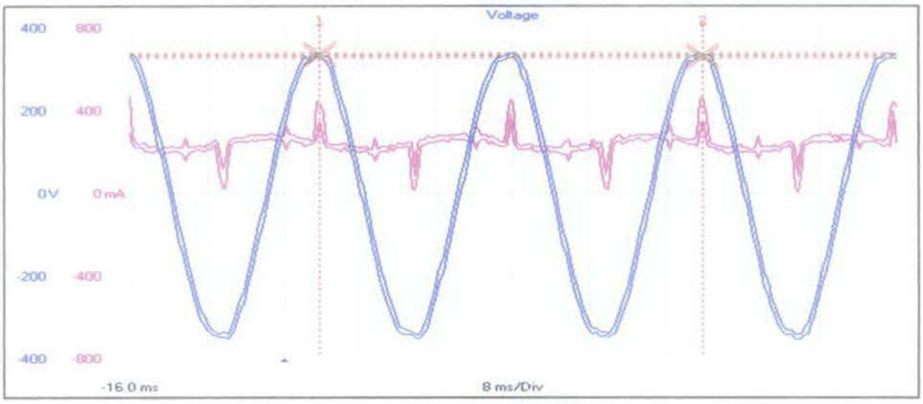

Figure 11: Printer Voltage and Current waveform

Figure 12 show the triplen harmonic spectrum for printer from fundamental to fifty first order harmonics. As the order of triplen harmonic is increase the current become lower.

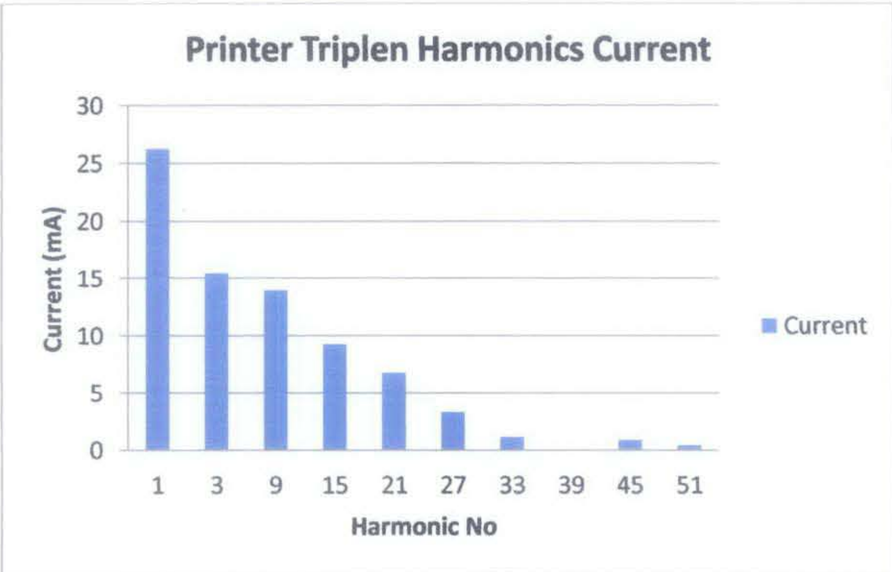

Figure 12: Printer triplen harmonics current

### *4.1.4 Radio*

Figure 13 show that the current waveform is distorted while the voltage waveform is remaining in sinusoidal waveform. The current is 245.4 mA while voltage is 246.1 V.

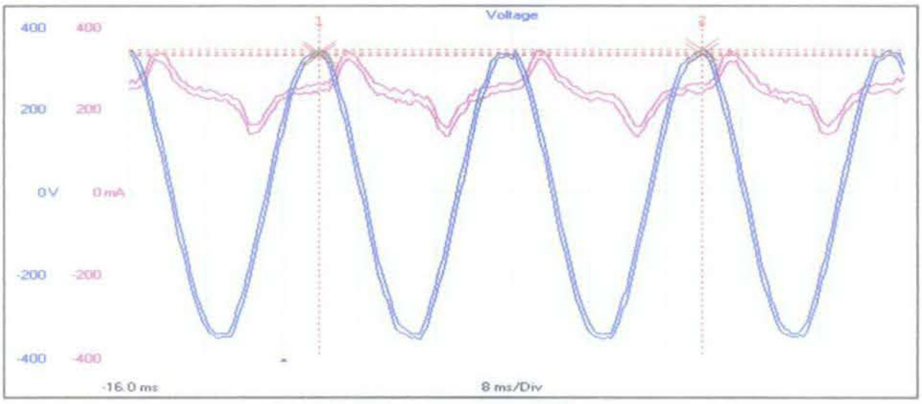

Figure 13: Radio Voltage and Current waveform

Figure 14 show the triplen harmonic spectrum for radio from fundamental to fifty first order harmonics. The fundamental and third order produces more than 15 mA current while the remaining order harmonics produce very small current.

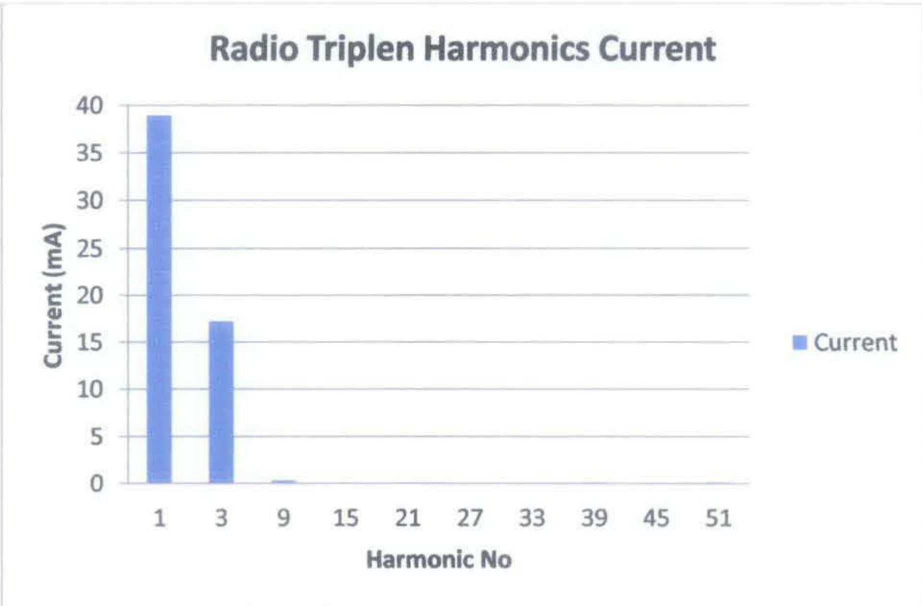

Figure 14: Radio triplen harmonics current

### *4.1.5 Television*

Figure 15 show that the current waveform is distorted while the voltage waveform is remaining in sinusoidal waveform. The current is 1 A while voltage is 354 V.

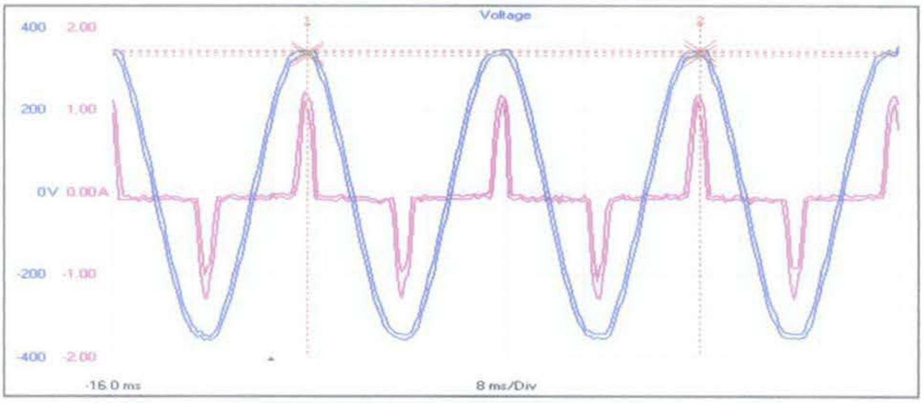


Figure 15: Television Voltage and Current waveform

Figure 16 show the triplen harmonic spectrum for television from fundamental to fifty first order harmonics. As the order of triplen harmonic is increase the current become lower.

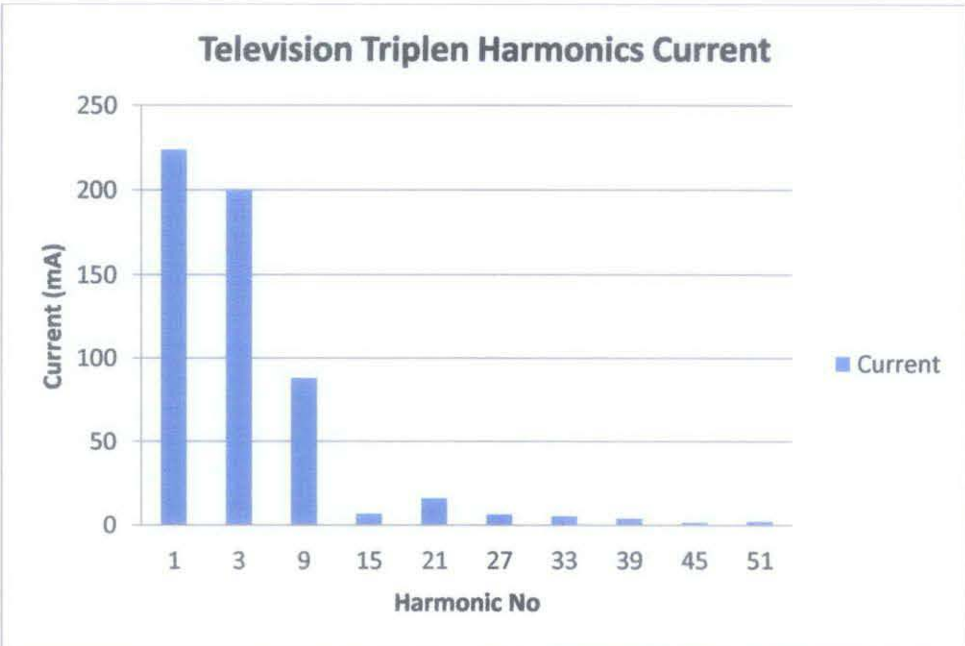


Figure 16: Television triplen harmonics current

### *4.1.6 Fan*

Figure 17 show that the current waveform is distorted while the voltage waveform is remaining in sinusoidal waveform. The current is 229.7 mA while voltage is 251.5 V.

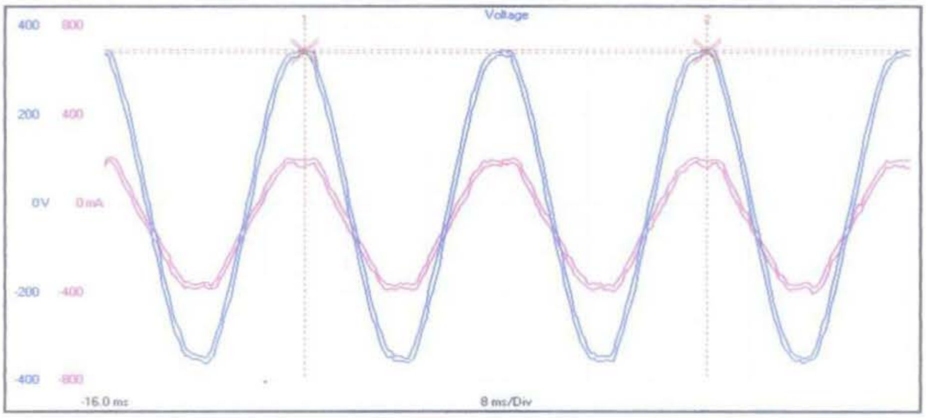


Figure 17: Fan Voltage and Current waveform

Figure 18 show the triplen harmonic spectrum for fan from fundamental to fifty first order harmonics. The fundamental produce more than 200 mA while the third order is very small.

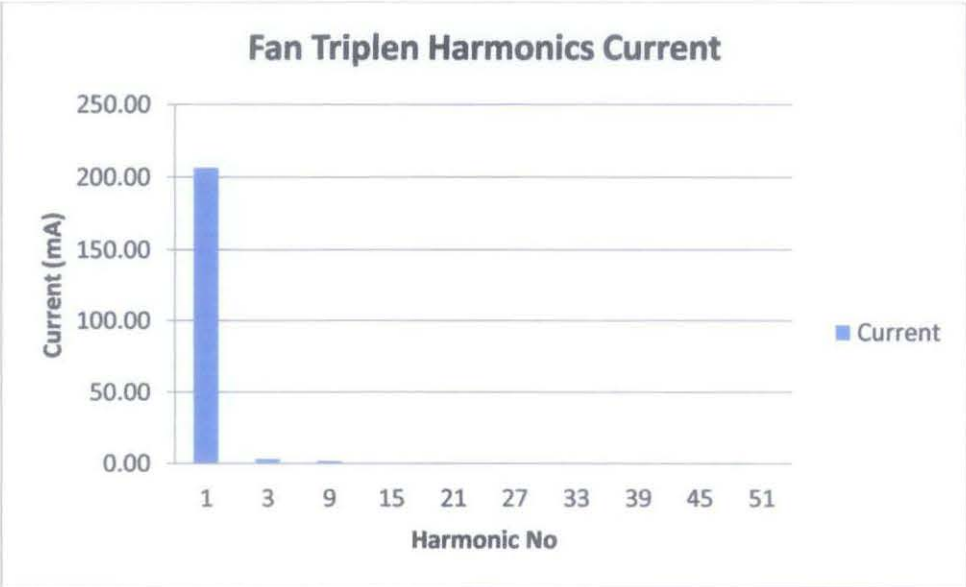


Figure 18: Fan triplen harmonics current

## 4.2 Synchronous Generator

The third harmonic current for balanced resistive, inductive, capacitive, combination of resistive and inductive and combination of resistive, inductive and capacitive load are show in Figure 19 to Figure 23, correspondingly.

### *4.2.1 Load variation*

#### *4.2.1.1 Balanced load*

##### *4.2.1.1.1 Balanced Resistive load*

Figure 19 show the third harmonic current versus balanced resistive load. Under balanced load condition, the magnitude of current in each phase is almost same. The phase and neutral third harmonic currents are inversely proportional to balanced resistive.

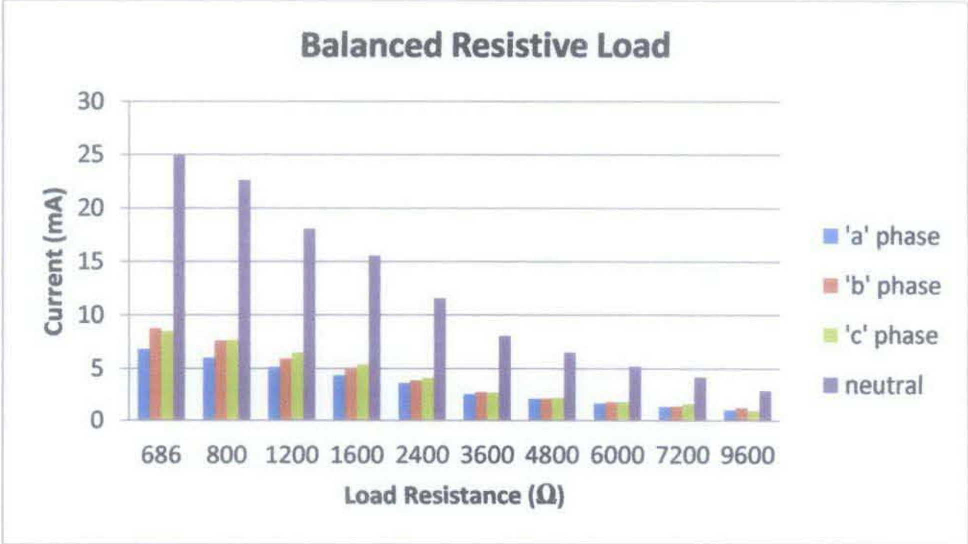


Figure 19: Third harmonic current vs. balanced resistive load

#### *4.2.1.1.2 Balanced Inductive load*

Figure 20 show the third harmonic current versus balanced inductive load. The neutral third harmonic currents are inversely proportional to balanced inductive load. The magnitude of current in each phase is same.

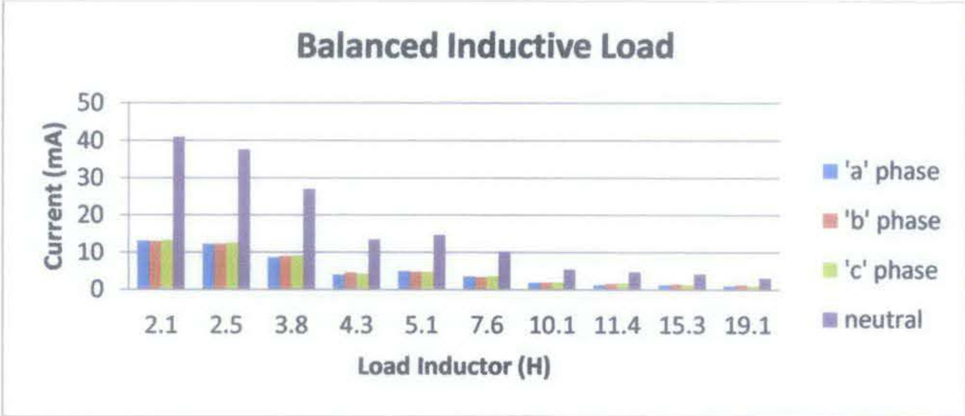


Figure 20: Third harmonic current vs. balanced inductive load

#### *4.2.1.1.3 Balanced Capacitive load*

Figure 21 show the third harmonic current versus balanced capacitive load. Under balanced load condition, the magnitude of current in each phase is same. The phase and neutral third harmonic currents are proportional to balanced capacitive. The neutral third harmonic currents produce is much higher if compare with the balanced resistive and inductive loads.

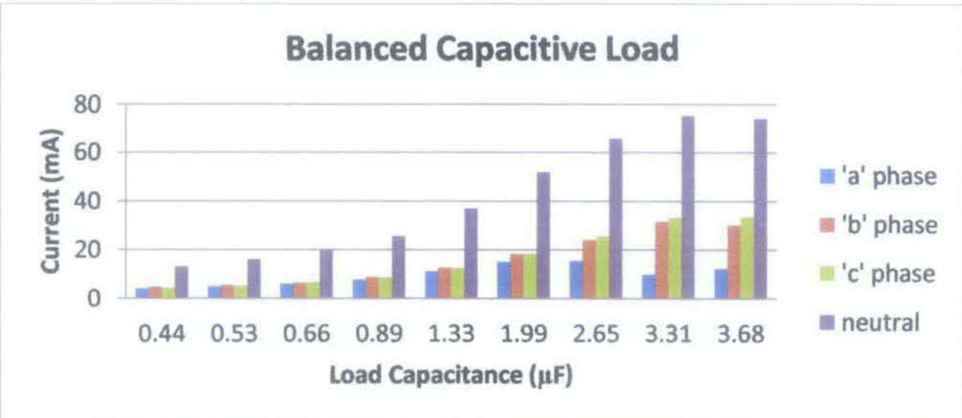


Figure 21: Third harmonic current vs. balanced capacitive load

#### *4.2.1.1.4 Balanced Resistive and Inductive load*

Figure 22 show the third harmonic current versus balanced resistive plus inductive load. The first five experiment show that the neutral third harmonic currents are inversely proportional to the loads. Start at the six experiment until ten experiment, the neutral third harmonic currents start to increase and decrease slowly. This is probably due to value of impedance in six experiment is slightly higher than in seven experiment.

The magnitude of the phase current in each phase is same for the ten experiments.

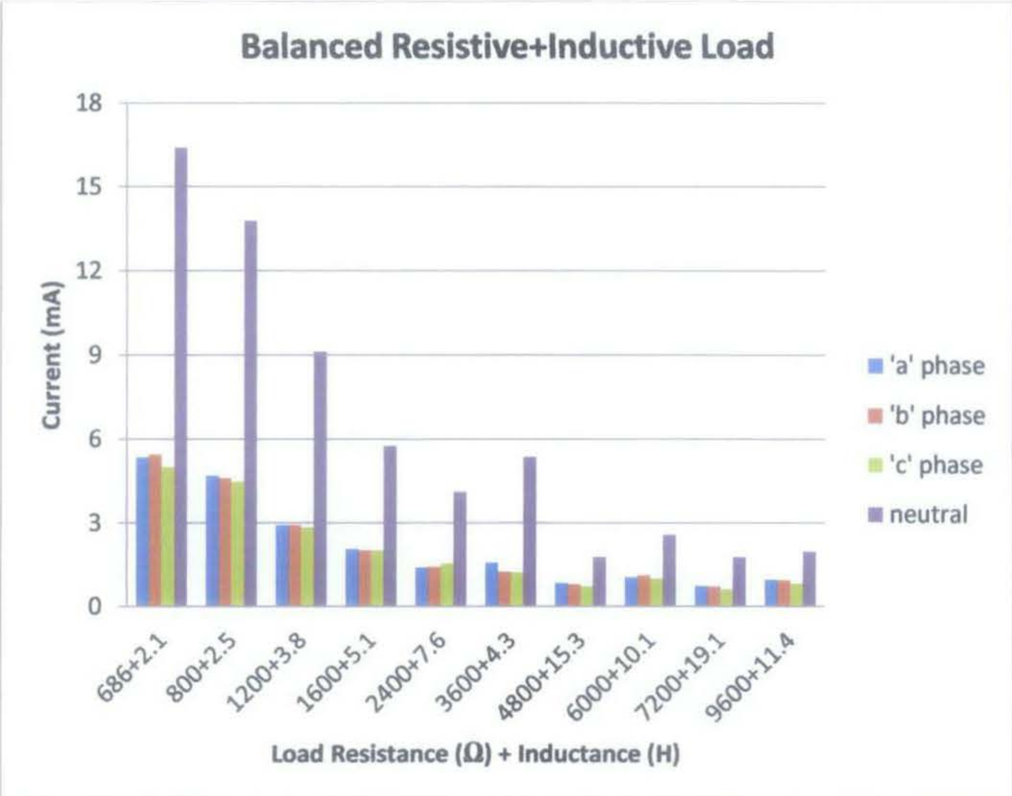


Figure 22: Third harmonic current vs. balanced resistive + inductive load

*4.2.1.1.5 Balanced Resistive, Inductive and Capacitive load*

Results from the combination of the balanced resistive, Inductive and capacitive load is shown in Figure 23. Generally, this combination shows that the neutral third harmonic currents are inversely proportional to the load.

The first six experiments shows the third harmonic currents are inversely proportional to the loads. The seven experiments have high neutral third harmonics current than six experiments due to the total value of impedance in the seven experiments are higher than six experiments.

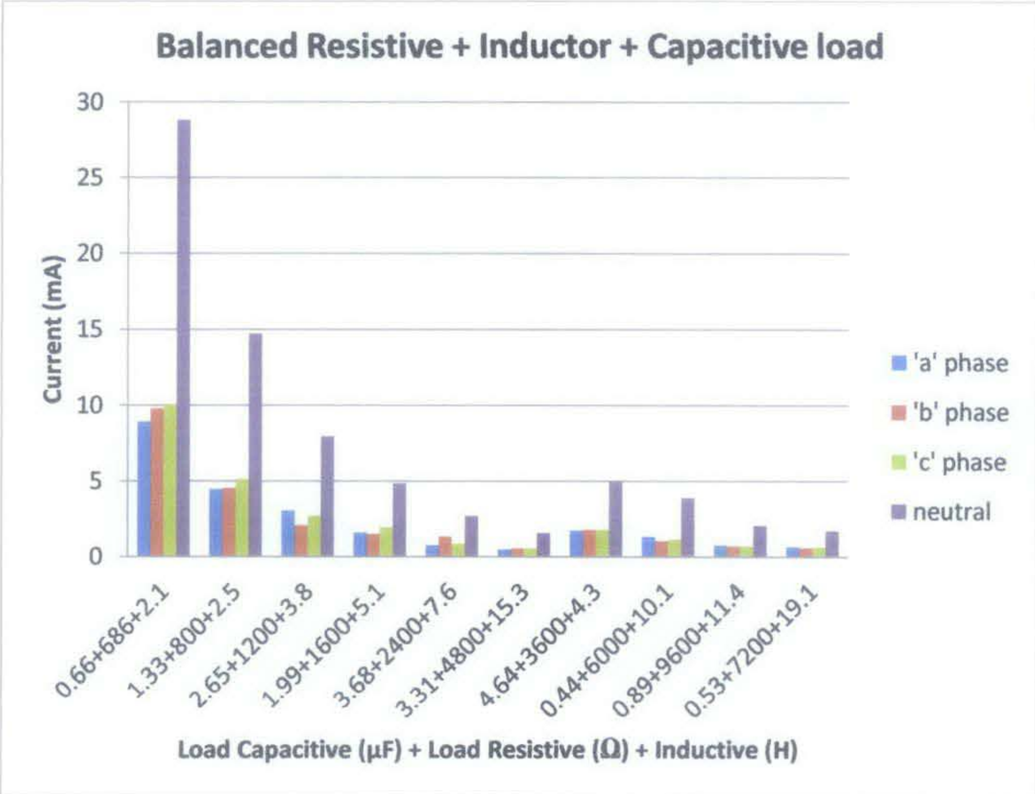


Figure 23: Third harmonic current vs. balanced resistive + Inductive + capacitive load

The third harmonic current for unbalanced resistive, inductive, capacitive, combination of resistive and inductive and combination of resistive, inductive and capacitive load are show in Figure 24 to Figure 28, correspondingly.

#### *4.2.1.2 Unbalanced load*

In Figure 24 to Figure 28 below, the current magnitudes in each phase in the unbalanced load condition are different. This is due to the load in each phase is connected in different value thus cause the system become unbalanced. In unbalanced condition, the third harmonic current phase angle is different with each other. The result from this different phase angle, cause the third harmonic current in the neutral is slightly lower than the arithmetic sum of all phase currents.

##### *4.2.1.2.1 Unbalanced Resistive load*

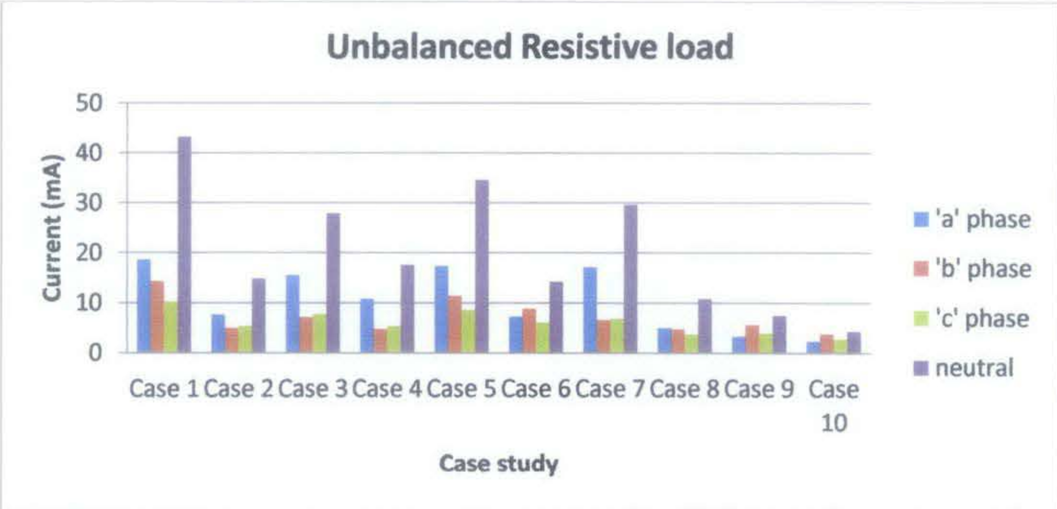


Figure 24: Third harmonic current vs. unbalanced resistive load

*4.2.1.2.2 Unbalanced Inductive load*

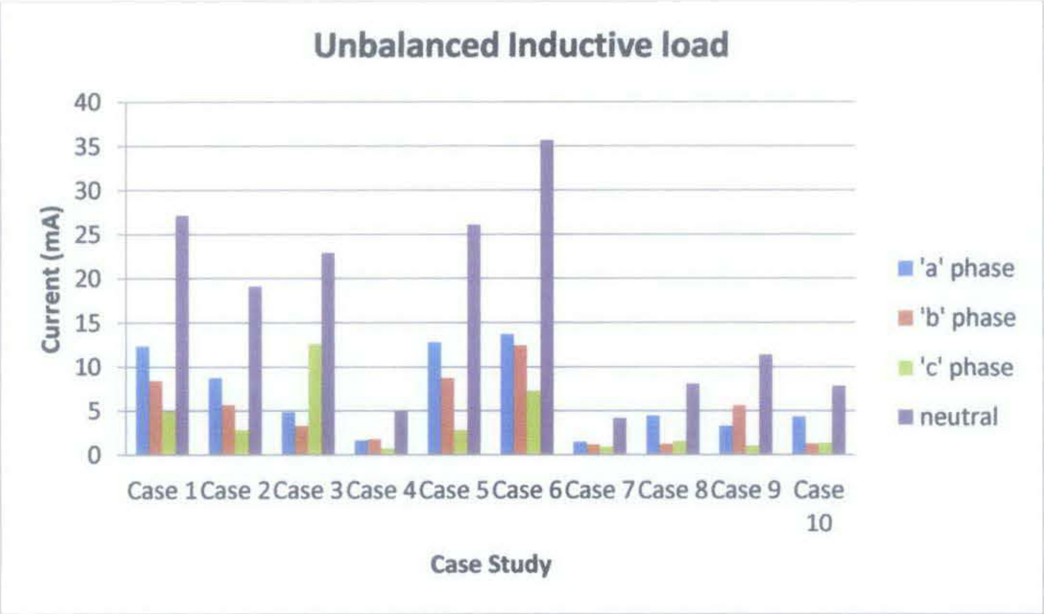


Figure 25: Third harmonic current vs. unbalanced inductive load

*4.2.1.2.3 Unbalanced Capacitive load*

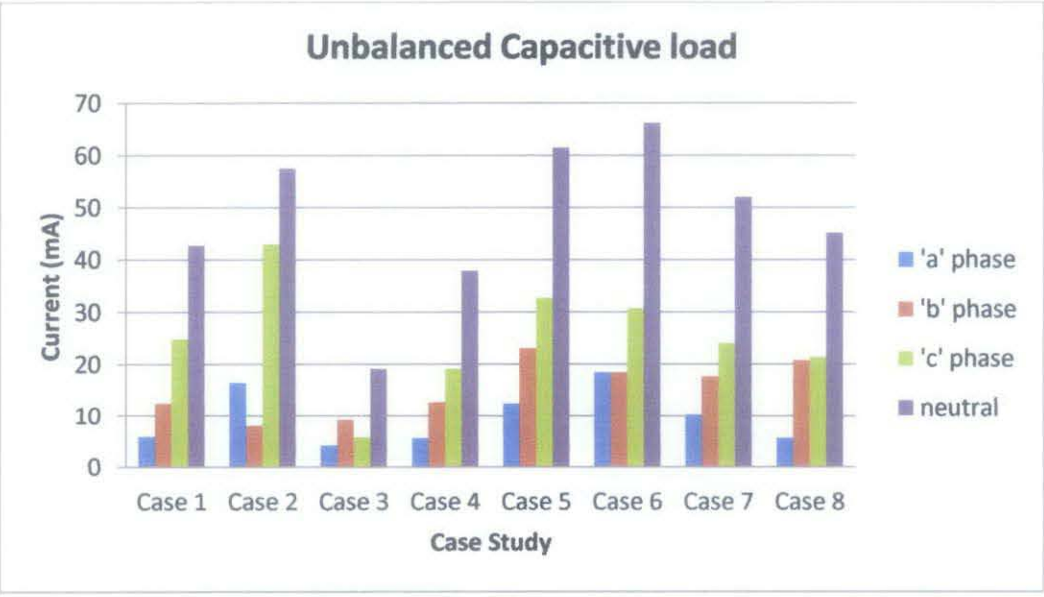


Figure 26: Third harmonic current vs. unbalanced capacitive load

*4.2.1.2.4 Unbalanced Resistive and Inductive load*

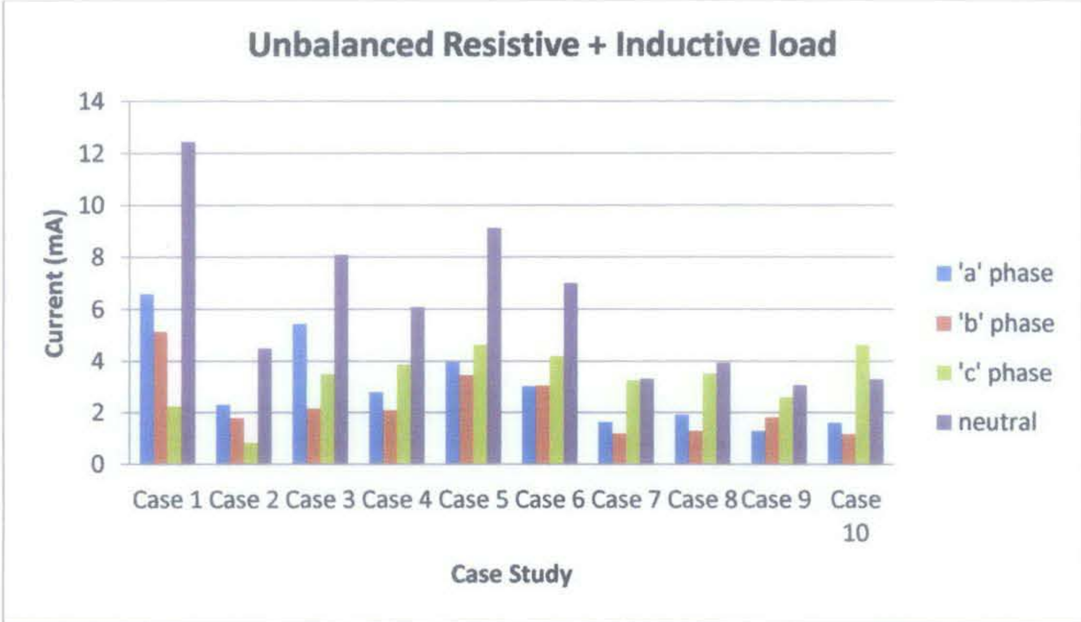


Figure 27: Third harmonic current vs. unbalanced resistive + inductive load

*4.2.1.2.5 Unbalanced Resistive, Inductive and Capacitive load*

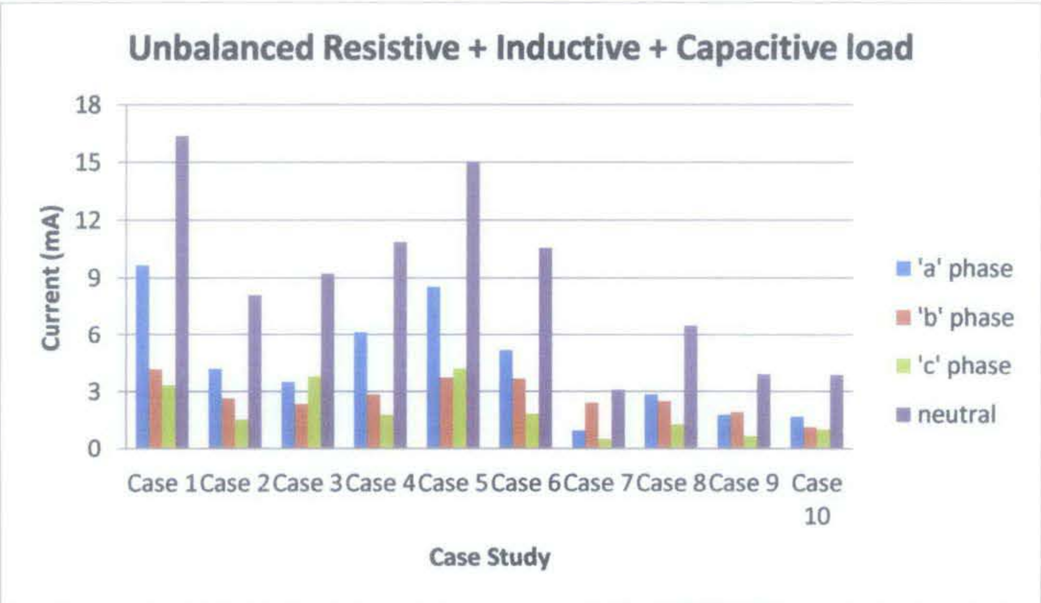


Figure 28: Third harmonic current vs. unbalanced resistive + inductive + Capacitive load

### *4.2.2 Generator Neutral Earth Resistor (NER)*

Figure 29 show the relationship between the generator NER values and third harmonic current. The phase and neutral third harmonic currents are inversely proportional to the generator NER value. On average the reduction are 32% against 100% increase in NER resistance for the phase and neutral third harmonic currents.

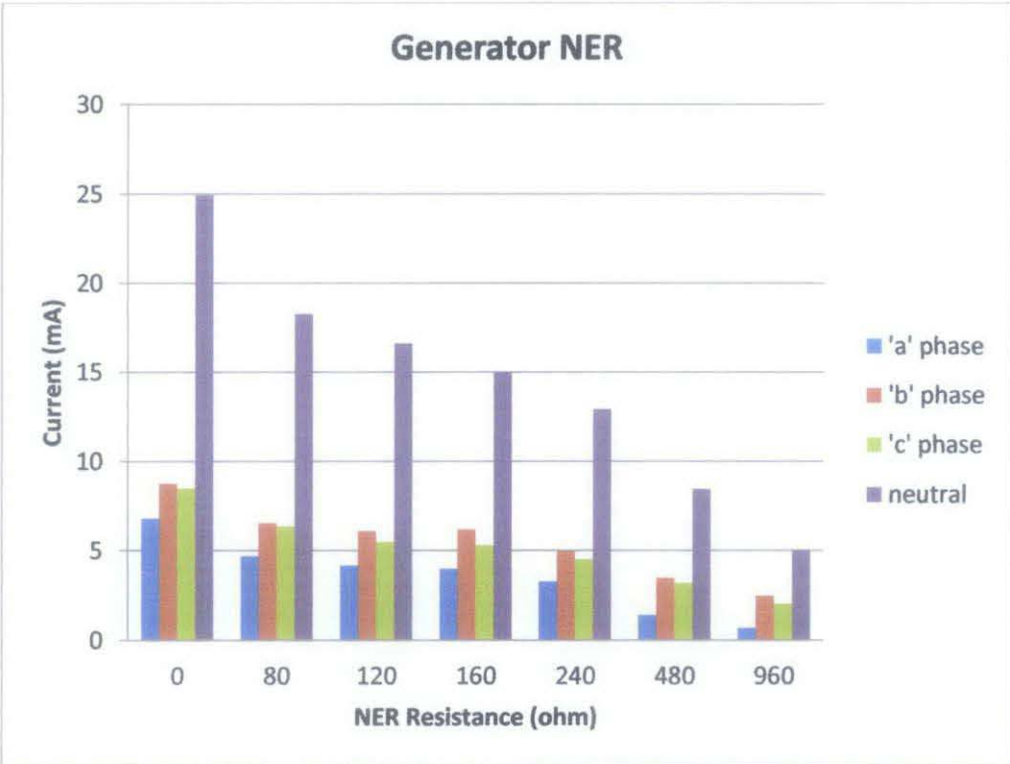


Figure 29: Third harmonic current vs. generator NER value

### *4.2.3 Transformer Winding configurations*

Figure 30 to Figure 33 shows the phase and neutral third harmonic currents at the generator terminal, primary winding, secondary winding and load end for four different winding configurations.

#### *4.2.3.1 Delta-Delta Transformer Configuration*

Figure 30 show the third harmonic current for delta-delta transformer configuration. In delta-delta transformer configuration, the circulating third harmonic current in the delta primary is lower than the circulating third harmonic currents in the delta secondary. No third harmonic current flows in the load because the current circulates in the delta primary and secondary windings.

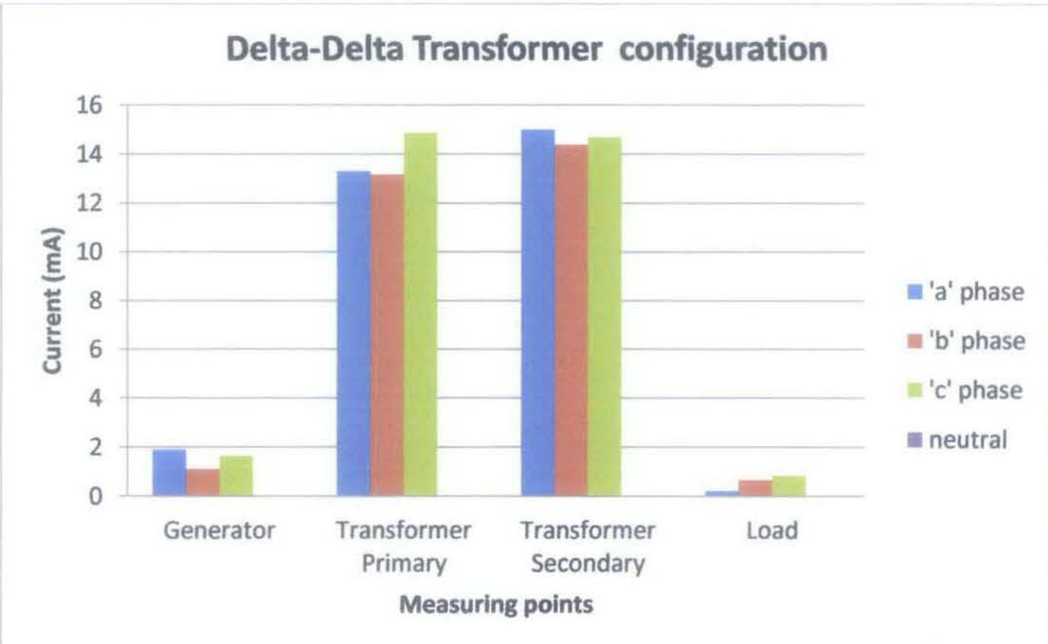


Figure 30: Third harmonic current for delta-delta transformer configuration

*4.2.3.2 Delta-Wye Transformer Configuration*

Figure 31 show the third harmonic current for delta-wye transformer configuration. There is almost no third harmonic currents flow in the transformers secondary winding and in the loads. This is because the third harmonic currents are being trap in the delta primary windings it just circulates in there.

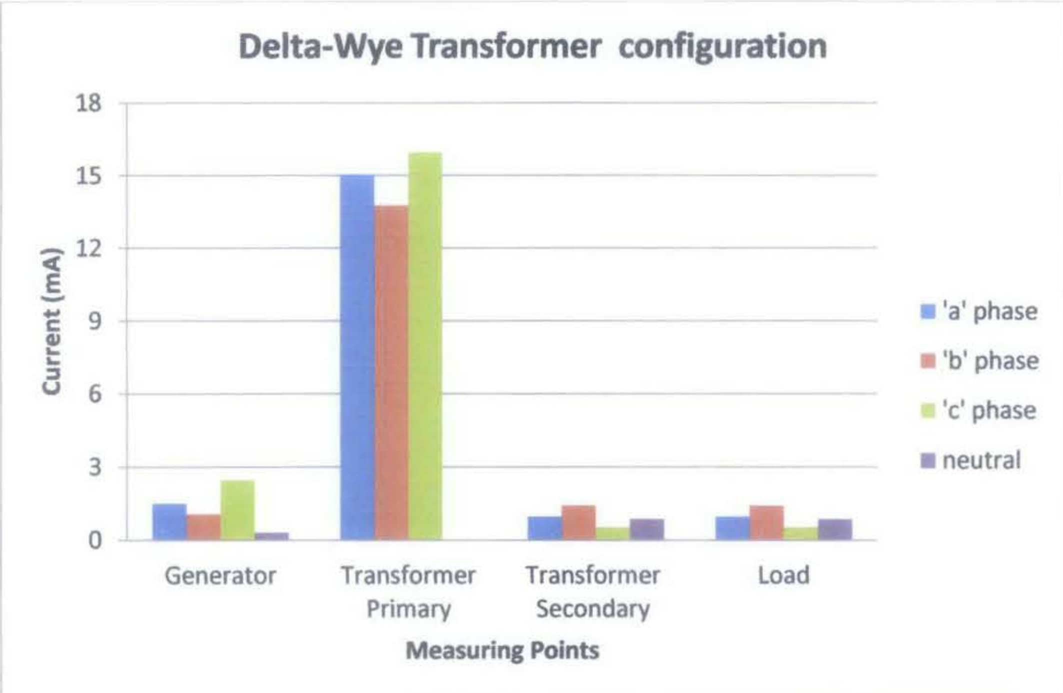


Figure 31: Third harmonic current for delta-wye transformer configuration

#### *4.2.3.3 Wye-Delta Transformer Configuration*

Figure 32 show the wye-delta transformer winding configuration. Since wye primary windings provide the lowest zero sequence impedance to the neutral, in wye-delta transformer configuration it produce the highest phase and neutral third harmonic currents. The current is about 80 mA in each phase while the neutral current is 237.85 mA. There is no third harmonic currents circulate in the secondary winding.

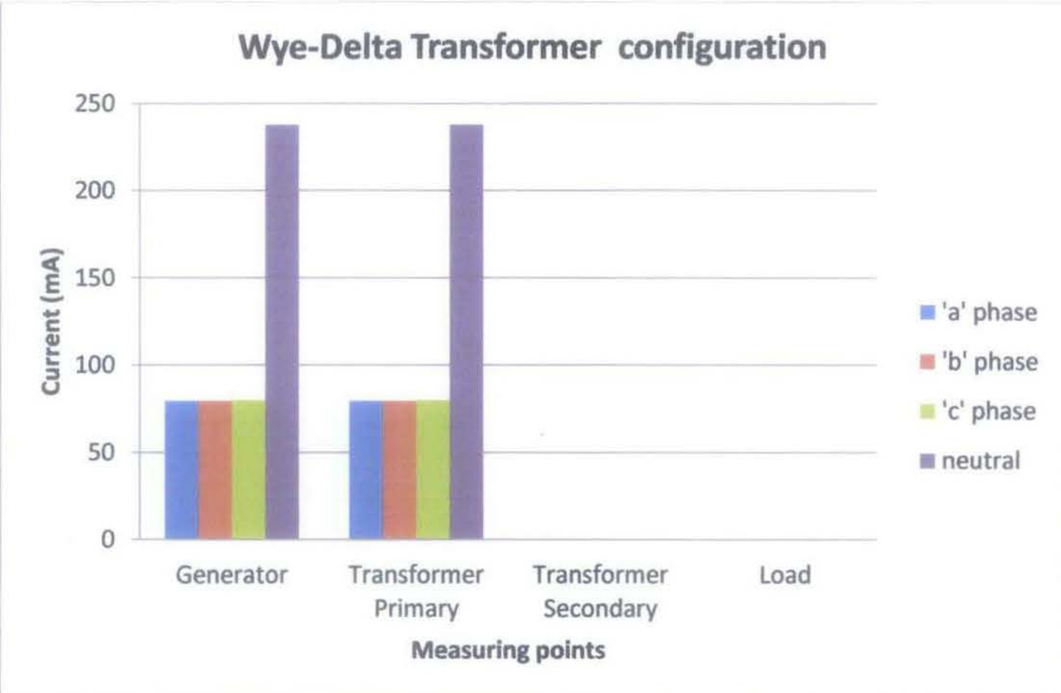


Figure 32: Third harmonic current for wye-delta transformer configuration

#### *4.2.3.4 Wye-Wye Transformer Configuration*

In wye-wye transformer configuration as shown in Figure 33 below, the third harmonic currents flow through the transformer windings and it contain high neutral third harmonic current in the secondary transformer winding (23.77 mA) and in the end load (23.77 mA) as this transformer type of configuration provide the lowest zero impedance that allowed the neutral current to flow at the neutral conductor.

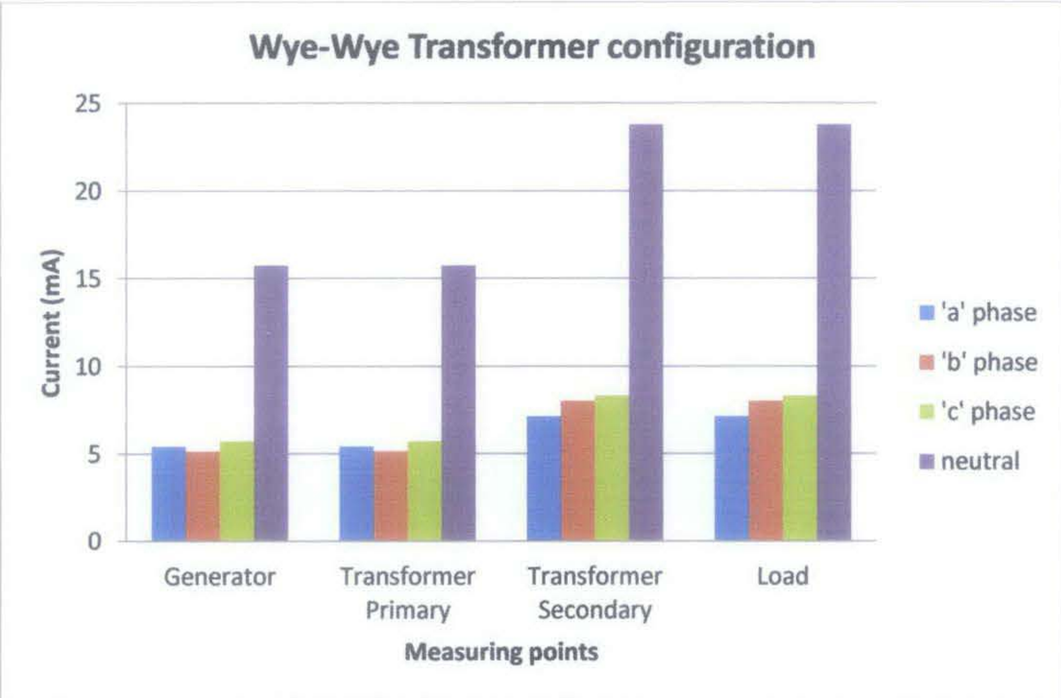


Figure 33: Third harmonic current for wye-wye transformer configuration

# CHAPTER 5

# CONCLUSIONS AND RECOMMENDATION

## 5.1 Conclusions

Non-linear load such as television and laptop produce triplen harmonics. The non-linear loads with higher technology produce highest third harmonic currents.

The load impedance such as resistive, inductive and capacitive, generator NER values and transformer winding configurations influences third harmonic currents.

Highest load impedance can reduce the magnitude of the neutral third harmonic currents while the unbalanced load can cause the system become unbalanced thus produce different current magnitude and phase angle in each phase.

The existing of generator NER helps to reduce the magnitude of triplen harmonic currents in the system. Triplen harmonic currents are zero sequence in balanced load condition.

Zero sequence networks would determine the triplen harmonic currents flow in different transformer winding configurations. Third harmonics currents do not flow through wye-delta transformers and the amount that flows depends on the phase angle and magnitude of the currents in each of the three phases.

## 5.2 Recommendation

The outcome of this project can be used to further research on method to reduce the triplen harmonic currents flowing in the network. The research to reduce the triplen harmonics can be conducted in terms of using the characteristics of triplen harmonics in balanced load, the existing of generator NER and also the transformers winding configuration.

Special attention must be given to address unbalanced triplen harmonics currents due to unbalanced network impedance. This is due to in unbalanced load, the triplen harmonics in neutral conductor can't be estimate.

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## APPENDIX

# APPENDIX A

## Gantt chart

| No. | Detail/ Week | 1 | 2 | 3 | 4 | 5 | 6 | 7 | MID SEMESTER BREAK | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Selection of Project Title | | | | | | | | | | | | | | | |
| 2 | Preliminary Research Work / Journal study | | | | | | | | | | | | | | | |
| 3 | Submission of Prelim Report | | | | | | | | | | | | | | | |
| 4 | Harmonic Source – Non-linear load | | | | | | | | | | | | | | | |
| 5 | Harmonic Source – Synchronous Generator | | | | | | | | | | | | | | | |
| 6 | Transformer Winding Configuration | | | | | | | | | | | | | | | |
| 7 | Submission of Progress Report | | | | | | | | | | | | | | | |
| 8 | Report/Poster/Technical Paper | | | | | | | | | | | | | | | |
| 9 | Submission of Final Report | | | | | | | | | | | | | | | |

Process