EFFECT OF GENERATOR GROUNDING METHOD ON TRIPLEN HARMONICS PRODUCED BY SYNCHRONOUS GENERATOR

By

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FINAL PROJECT REPORT

Submitted to the Department of Electrical & Electronic Engineering
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronic Engineering)

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Department of Electrical & Electronic Engineering
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Approved:

Ir. Mohd Faris bin Abdullah
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

September 2012

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.

Muhammad Izzuddin bin Badrul Hisham

ABSTRACT

Salient pole synchronous generator is one of harmonic sources that cause various power system harmonic problems especially related to neutral. This paper is aim to study the characteristic of third harmonic voltage and current from generator when connected to balanced load, generator load connection with different generator neutral grounding resistor and generator load connection shunted by zig-zag transformer. Lab scale experiments have been conducted to vary all parameters related generator neutral grounding resistor and reactance earthing under various combined resistive and inductive load. The value for NER and reactance earthing is varied for each combined resistive and inductive load. Zig-zag transformer is connected to various combined resistive and inductive load. Generator neutral grounding resistor can effectively reduce the third harmonic in the phase and neutral. However care should be taken not to use very high generator neutral grounding resistor that can also restrict earth fault current that may pose problem to the sensitivity of earth fault protection system. Zig-zag transformer efficiently divert third harmonic current from generator to enter the load but high circulating third harmonic current between generator and zig-zag transformer may pose heating problem to the equipments. Reactance earthing can greatly reduce the third harmonic in the phase and neutral compared to both NER and zig-zag transformer.

ACKNOWLEDGEMENTS

I would like to express my appreciation to my project supervisor, Ir.Mohd Faris Bin Abdullah for his valuable input and guidance throughout the course of this project.

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Next, I would like to thank the Final Year Project (FYP) committee for their support and knowledge to assist the students. Thanks to all lecturers and technicians from UTP who had provided untiring guidance and help throughout the period of the project.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Gas District Cooling (GDC) is a power plant that supplies electricity and chill water to Universiti Teknologi PETRONAS (UTP). Two generating units of gas turbines are used to supply the electricity to the whole UTP. UTP power system is operating in island mode during normal operation whereas during emergency situation, the power system will be switched to parallel connection with utility grid of Tenaga Nasional Berhad (TNB). The grounding of each generator is equipped with neutral earthing resistor (NER). It has been a concern that the temperature of NER is high when the generator is operating in parallel with the utility grid [1]. The cause of the NER temperature increase is because of the increase in triplen harmonics current that flow continuously through NER. The NER used in GDC is manufactured to withstand temperature rise below 760 °C during specified short period of time. However, the NER is not designed to withstand any specified value of continuous current flow. This caused the damage of NER’s insulation. This paper studies the triplen harmonics characteristics under different generator grounding method. The project is feasible to conduct as all the equipments are ready in the lab and new equipment has arrived that will gives more accuracy to the readings and progress can be expedited. Thus, this project can be completed in two semesters. It is relevant to conduct this study as the study of triplen harmonic characteristics can help to solve this problems that caused by it such as the damage to equipment.

1.2 Problem Statement

The generator’s NER temperature increased when it is operating parallel with the grid. This project is to study the effect of generator grounding method and zig-zag transformer on triplen harmonics produced by synchronous generator.

1.3 Objective

1.3.1. To study the characteristics of triplen harmonics produced by synchronous generator under various generator neutral grounding methods.

1.3.2. To study the influence of grounding transformer on triplen harmonics produced by synchronous generator.

1.4 Scope of Study

1.4.1. Research and studies on triplen harmonic and grounding methods through past journal, thesis and books.
1.4.2. Conduct experiments on generator grounding methods in the lab
1.4.3. Conduct experiments on zig-zag transformer as grounding transformer in the lab.

CHAPTER 2

LITERATURE REVIEW

2.1 Fundamental of Triplen Harmonic

Triplen harmonics are the odd multiple of the third harmonic (h=3, 9, 15, 21…). For grounded-wye systems with current flowing through the neutral line of wye configuration, these harmonic orders become an important issue. Overloading of the neutral conductor and telephone interference are two typical problems that caused by triplen harmonics.

Fundamental neutral current components in the neutral are zero for a perfect balanced three phase nonsinusoidal loads system. In the case of third harmonic, neutral currents are three times the third harmonic phase currents because they coincide in phase or time.

Major component of triplen harmonic is the third harmonic. Third harmonic currents have zero displacement angles between them. This is called zero-sequence harmonics.

$$i_a^{(3)}(t) = I_a^{(3)} \cos(3\omega_0 t) \tag{1}$$

$$i_b^{(3)}(t) = I_b^{(3)} \cos 3(\omega_0 t - 120°) \tag{2}$$

$$= I_b^{(3)} \cos(3\omega_0 t - 360°) = I_b^{(3)} \cos(3\omega_0 t) \tag{3}$$

$$i_c^{(3)}(t) = I_c^{(3)} \cos 3(\omega_0 t - 240°) \tag{4}$$

$$= I_c^{(3)} \cos(3\omega_0 t - 720°) = I_c^{(3)} \cos(3\omega_0 t) \tag{5}$$

The three phases current will add up as they are in the same phase giving the neutral current three times the magnitude of phase current.

2.2 Generator neutral grounding methods

The two primary reasons for grounding are:

a. Protection and Safety
b. Reference Voltage

NESC (National Electrical Safety Code) provides the definition for an effectively grounded system as, "An effectively grounded system is intentionally connected to earth through a ground connection or connections of sufficiently low impedance and having sufficient current carrying capacity to limit the buildup of voltages to levels below that which may result in undue hazard to persons or to connected equipment [5]

Grounding methods that will be considered in this paper:

2.2.1. NER

The neutral is connected to earth through one resistor. The fault current, I_f, is limited to chosen value:

$$I_f = \frac{V}{R} \tag{6}$$

R= resistance value of resistor (Ω)
V= line to earth voltage (V)

A system is earthed to avoid destruction caused by transient over voltages.

Several reasons to limit the current using resistor are:

- To reduce burning and melting effect to the equipment during fault.
- To reduce fault current that can caused mechanical stresses in circuits and apparatus.
- To reduce electric shocks hazards that can cause harm to personnel.

Earthing resistor is divided to two classes based on its resistance value which are high value resistance that allow less than 10 A whereas the low resistance value allow 10 A to 3000 A of fault current to flow.

Both classes are designed to limit the earth fault current and and maintained to a safe level [6].

2.2.2. Reactance Earthing

Reactance earthing is used to reduce cost as it is cheaper than earthing resistor. The neutral is connected to earth through reactor. The ground fault that may flow is a function of the neutral reactance, the level of the fault current is often used as criteria for describing the degree of grounding. In this method the ground fault current should be at least 60% of the three phase fault current to prevent serious transient over voltages. This is considerably higher than the level of fault current desirable in the system using resistor, and therefore reactance grounding is usually not considered as an alternative to the system using resistor. [6]

2.2.3. Grounding Transformer

Zig-zag transformer is a special purpose transformer with a zig-zag or 'interconnected star winding connection [7]. The most common zig-zag transformer application is for the derivation of a neutral connection from an ungrounded 3-phase system and the grounding of that neutral to an earth reference point. Zig-zag transformers are also used to control of triplen harmonic currents [4], to supply 3-phase power as an autotransformer (serving as the primary and secondary with no isolated circuits), and to supply non-standard phase-shifted 3-phase power.

Zig-zag transformer is built with six windings, two for each phase. The windings are connected in a zig-zag connection. For each phase, the windings are divided to the outer winding and the inner winding which are on the same core but in opposite direction.

In balanced condition the magnetic fluxes from primary and secondary windings cancelled each other. Thus, no current will flow through the transformer. But in unbalanced condition, the magnetic fluxes might not be able to cancel out. Therefore, the current may flow.

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CHAPTER 3

METHODOLOGY

3.1.Flow chart

The project starts off with literature review and research on triplen harmonics. The basic understanding on the nature of triplen harmonics, how it affects the network and the causes of the phenomena is studied during this phase. The scope of this project is to study the effects of generator grounding method and grounding transformer on triplen harmonics. Research on several grounding methods is conducted. Methods that are in the consideration are NER, reactance earthing and zig-zag transformer. The project is conducted according to flow chart in Figure 1.

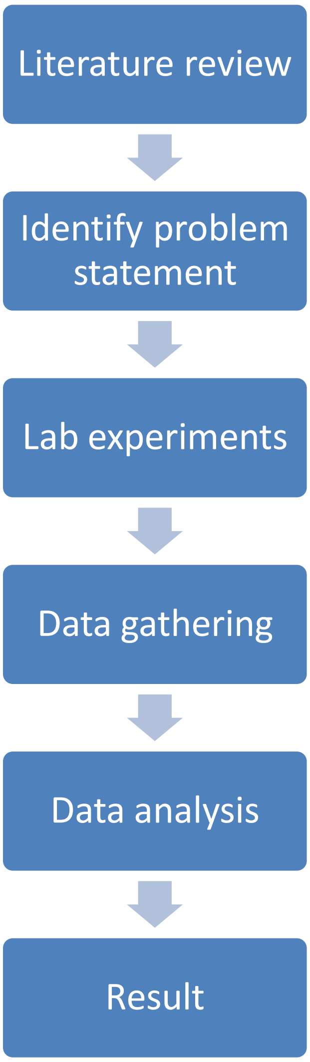


Figure 1: Flow chart

3.2.Methodology

To observe the effects of these grounding methods on triplen harmonics, lab experiments will be conducted. The experiment is set up such that it can simulate similar generation operation in GDC. Fluke power analyzer is used to analyze the existence and behaviour of triplen harmonics by attaching the device to the connection. From the result analysis, the effects of these grounding methods can be concluded.

Table 1 shows the laboratory equipment ratings for equipment use in experiment such as generator, transformer and load.

Table 1: Laboratory equipments ratings

Equipment	**Ratings**
Generator	415 V, 50 Hz, 0.2 kW
Transformer	415 V/240 V;250 VA
Resistive Load	415 V;1040 W
Inductive Load	415 V;1040 Var

There are two scenarios that will be conducted in the lab experiment:

1. Single generator
2. Parallel between grid and generator

3.2.2 Experiment plan:

a) First experiment is on single generator connected directly to the balanced load. Load spectrum is varied according to the values in Table 2.

Table 2: Value of balanced resistive & inductive load

Case	**Resistive & Inductive load (Ω)**	**Impedance angle (θ)**
Case 1	686+j686	45
Case 2	686+j1200	60
Case 3	686+j4800	82
Case 4	1200+j686	30
Case 5	4800+j686	8

For each of the case, current and voltage of harmonics are measured at the generator and load terminal. The result from this part will be used as a reference throughout the experiment.

b) Next, NER will be connected to the neutral wire of the generator as in Figure 2. The value of NER is varied according to the value in Table 3.

Table 3: Value NER in experiment for Case 1, Case 2, Case 3, Case 4, Case 5

NER (Ω)
0
80
120
240
480
960

The value for NER is varied whereas the value for the load is remained constant. Currents and voltage of harmonics are measured at the generator and load terminals. This part is repeated by changing the load value.

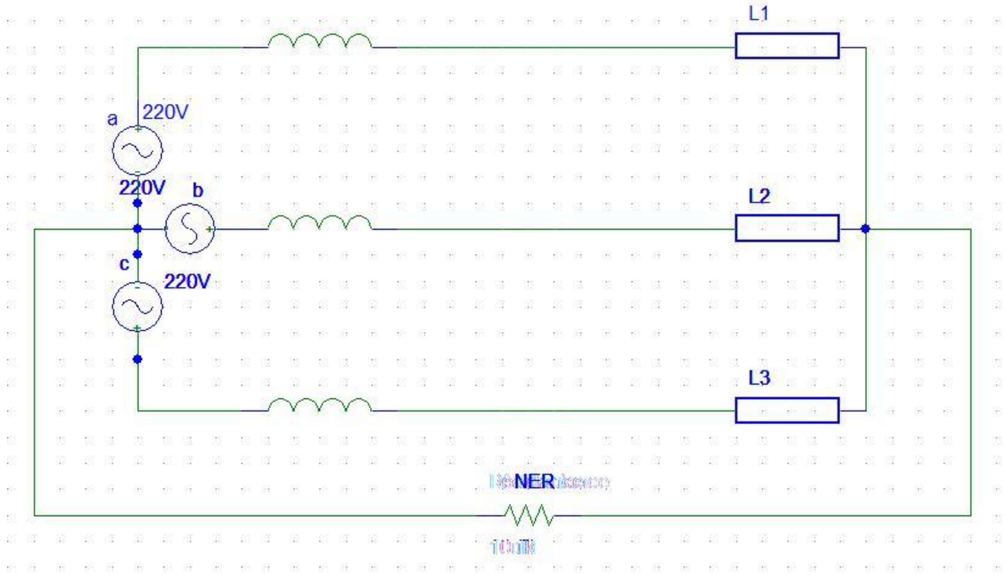


Figure 2: Single line diagram for NER

c) For reactance earthing, the value of reactance is approximately the same as in resistance earthing as in Table 4. Inductor is connected to the generator neutral wires in Figure 3. Current and voltage of harmonics at the generator and load terminals are measured.

Table 4: Value of Reactance Earthing for Case 1, Case 2, Case 3, Case 4, Case 5

Inductance (H)
0
0.25
0.38
0.76
1.52
3.05

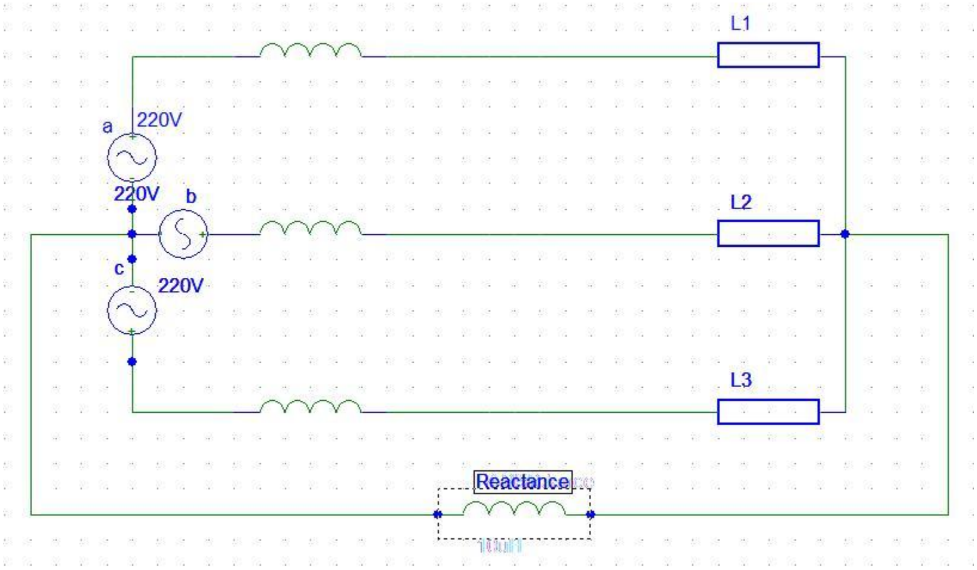


Figure 3: Single line diagram for Reactance earthing

d) Zig-zag transformer

Zig-zag transformer is added in between the generator and load as in Figure 4. Currents of harmonic are measured at the generator, transformer and load ends. Load is varied according to Case 1, Case 2, Case 3, Case 4 and Case 5.

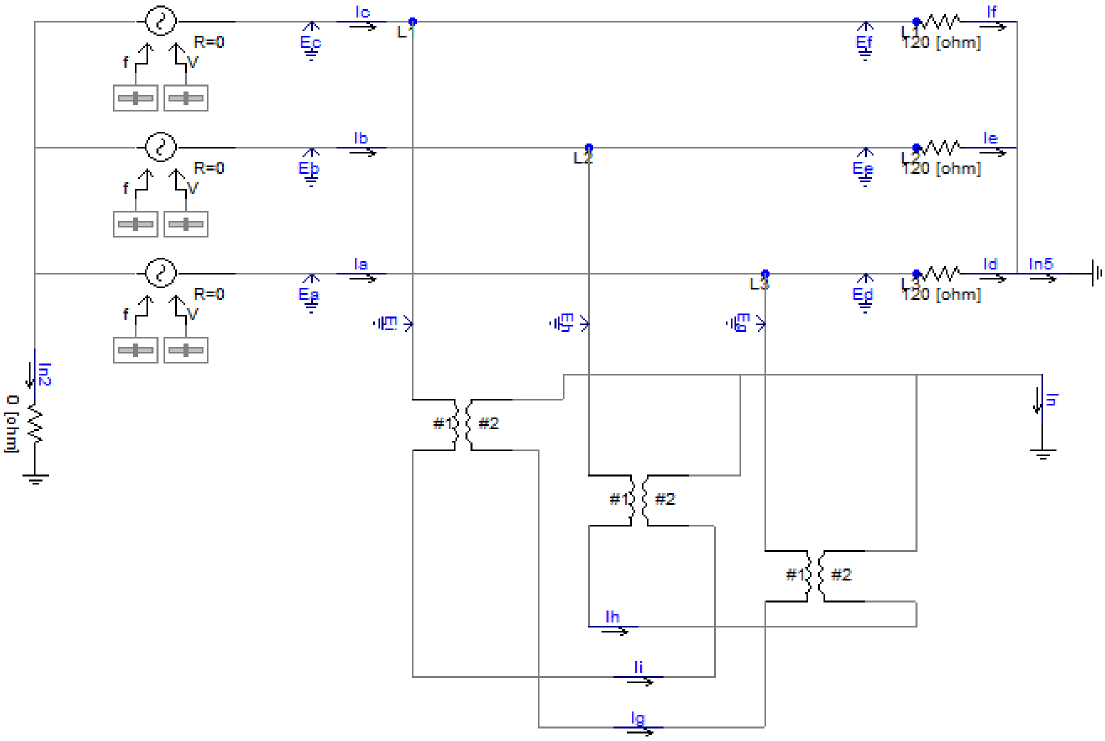


Figure 4: Single line diagram for Zig-zag transformer

3.2 Gantt Chart

Table 5 shows the gantt chart and key milestone of the project.

Table 5: Gantt chart

No.	**Details / Week**	**1**	**2**	**3**	**4**	**5**	**6**	**7**		**8**	**9**	**10**	**11**	**12**	**13**	**14**
	FYP 1								MID SEMESTER BREAK							
1	Selection of Project Title	🟩	🟩													
2	Preliminary Research Work		🟩	🟩	🟩	🟩	🟩									
3	Submission of Extended Proposal						🟦									
4	Modelling Work		🟩	🟩	🟩	🟩	🟩									
5	Simulation Work						🟩	🟩		🟩	🟩	🟩	🟩	🟩	🟩	🟩
6	Lab Experiment						🟩	🟩		🟩	🟩	🟩	🟩	🟩	🟩	🟩
7	Proposal Defend											🟦				
8	Submission of Draft Report														🟦	
9	Submission of Interim Final Report															🟦
	FYP 2															
1	Lab Experiment	🟩	🟩	🟩	🟩	🟩	🟩	🟩		🟩	🟩	🟩	🟩	🟩	🟩	🟩
2	Modelling Work	🟩	🟩	🟩	🟩	🟩	🟩	🟩		🟩	🟩	🟩	🟩	🟩	🟩	🟩
3	Submission of Progress Report									🟦						
4	Poster Presentation														🟦	
5	Submission of Draft Report														🟦	
6	Submission of Final Report															🟦

🟦 Key milestone

CHAPTER 4

RESULT AND DISCUSSION

4.0. Introduction

After analyzing the data for NER, zig-zag transformer and reactance, it has been a concerned that the data taken only at the load side is not enough. Thus, data at the generator side also need to be taken so that comparison of the behaviour of third harmonic at the load and generator side can be done.

Apart from that, there are some additions to the loads that have been used in the previous experiments. In the previous experiments, only R+L loads are used, but R load and L load are also required as base data. The new loads to be added in the experiments are as in Table 6 and Table 7.

Table 6: R load

R Load
686
800
1200
1600
2400

Table 7: L load

L load
j686
j800
j1200
j1600
j2400

4.1.1. NER

The generator neutral grounding resistor is varied for various combined resistive and inductive load. The third harmonic voltage at generator terminal is almost constant for all generator neutral grounding resistor values. However, at load terminal, the third harmonic voltage decrease as the neutral grounding resistor values increase as shown in Figure 5 for combined resistive and inductive load of 686+j686 Ω. This is due to voltage drop at neutral grounding resistor since the third harmonic current is present in the neutral. The magnitude reduction of third harmonic voltage is influenced by the neutral grounding resistance because the neutral third harmonic current is small.

The phase and neutral third harmonic current at generator and load terminals decrease as the neutral grounding resistor values increase as shown in Figure 6. Almost zero sequence in nature, the phase neutral current sum at neutral hence resulting neutral current almost three times phase current magnitude. The net series impedance of neutral grounding resistor value and combined resistive and inductive load value determine the phase/neutral third harmonic current magnitude.

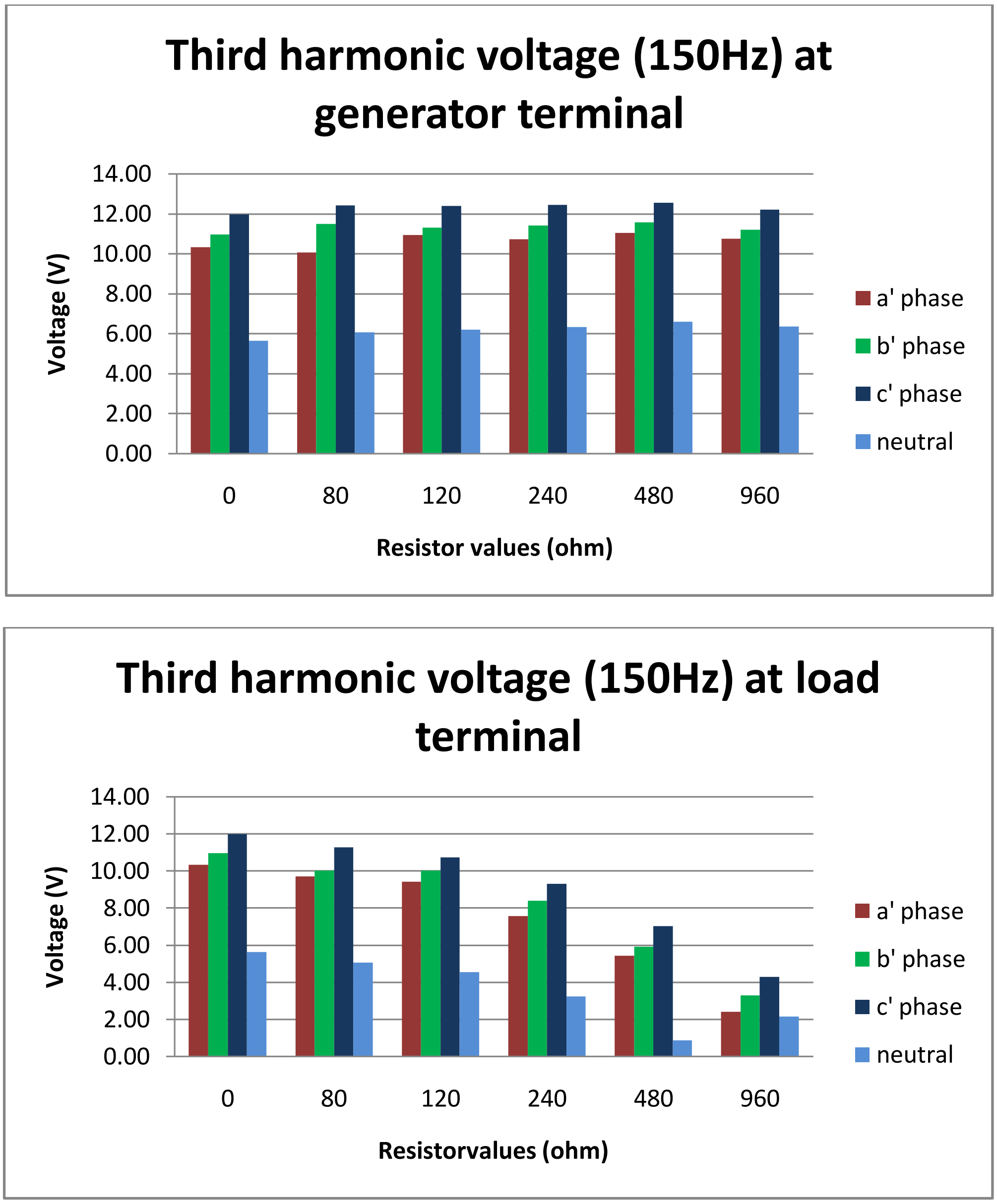
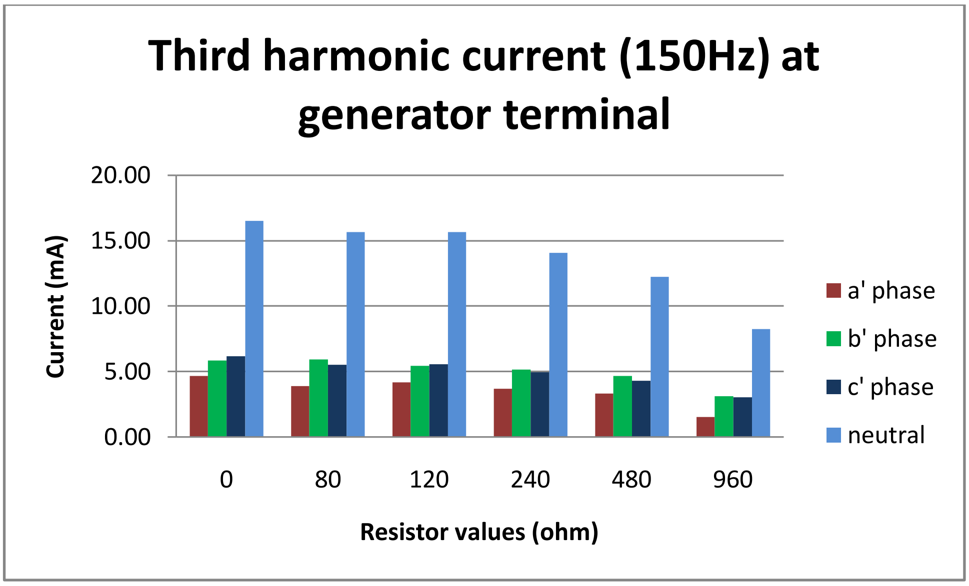


Figure 5: Third harmonic voltage with varied NER values



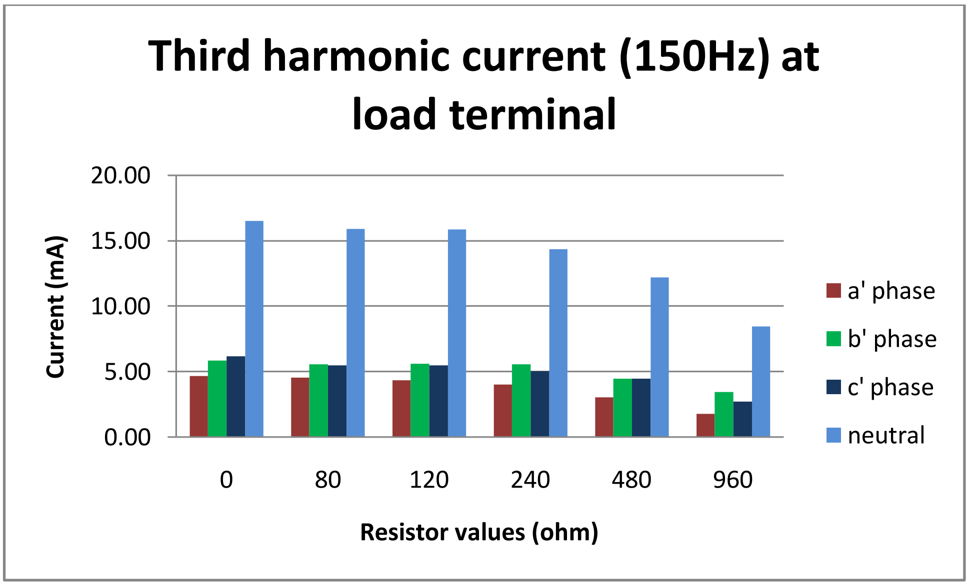
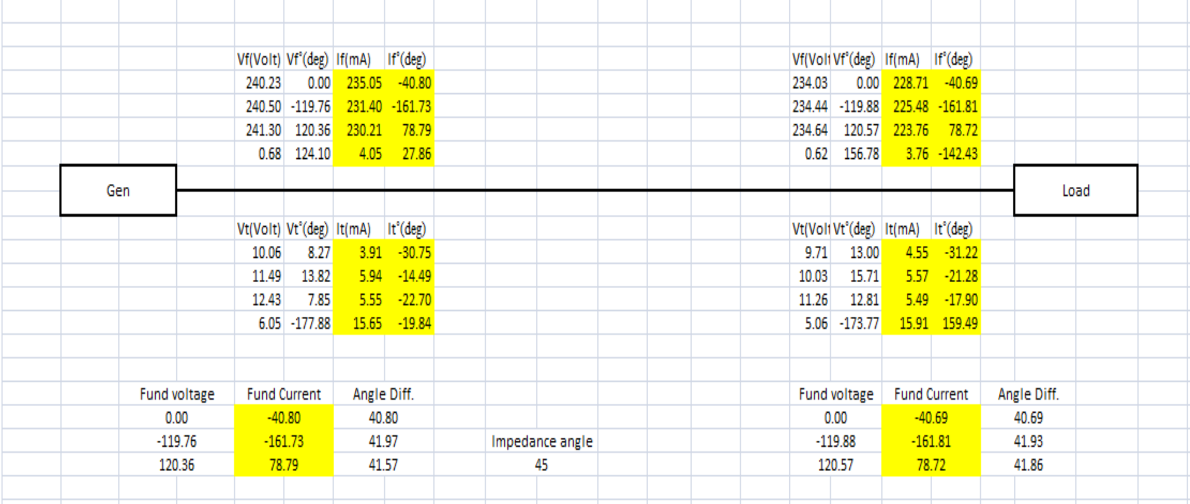


Figure 6: Third harmonic current with varied NER values

The phasor angle for fundamental of the three phase voltage and current are 120^0 apart. The current is lagging voltage by almost 45^0. In the third harmonic frequency, the three phase voltage and current are almost in phase as shown in Figure 7.



Vf(Volt)	Vf°(deg)	If(mA)	If°(deg)
240.23	0.00	235.05	-40.80
240.50	-119.76	231.40	-161.73
241.30	120.36	230.21	78.79
0.68	124.10	4.05	27.86

Vt(Volt)	Vt°(deg)	It(mA)	It°(deg)
10.06	8.27	3.91	-30.75
11.49	13.82	5.94	-14.49
12.43	7.85	5.55	-22.70
6.05	-177.88	15.65	-19.84

Fund voltage	Fund Current	Angle Diff.
0.00	-40.80	40.80
-119.76	-161.73	41.97
120.36	78.79	41.57

Impedance angle
45

Vf(Volt	Vf°(deg)	If(mA)	If°(deg)
234.03	0.00	228.71	-40.69
234.44	-119.88	225.48	-161.81
234.64	120.57	223.76	78.72
0.62	156.78	3.76	-142.43

Vt(Volt	Vt°(deg)	It(mA)	It°(deg)
9.71	13.00	4.55	-31.22
10.03	15.71	5.57	-21.28
11.26	12.81	5.49	-17.90
5.06	-173.77	15.91	159.49

Fund voltage	Fund Current	Angle Diff.
0.00	-40.69	40.69
-119.88	-161.81	41.93
120.57	78.72	41.86

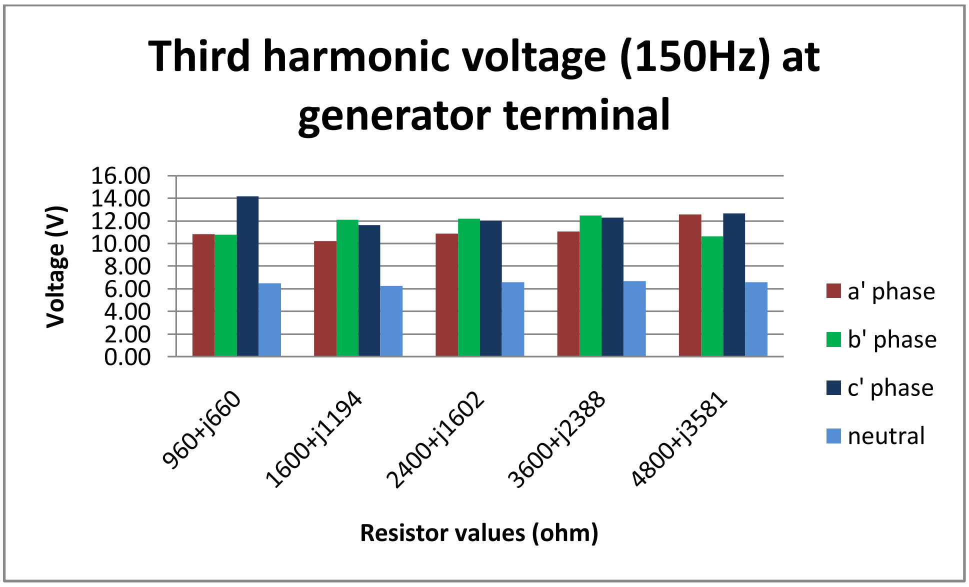
Figure 7: NER 80 ohm for 686+j686 load

4.1.2. Vary impedance magnitude for impedance angle 32^0 or between 32^0 - 37^0 correspond to 0.8 – 0.85 pf real case

The load is set to vary impedance magnitude for impedance angle 32^0 or between 32^0 - 37^0 correspond to 0.8 – 0.85 pf real case. The loads are as in Table 8. At the generator and load terminals, the neutral voltage is almost constant when the load impedance increased as in Figure 8. In Figure 9, as the load impedance increased, the neutral current decreased.

Table 8: New load with varied impedance and angle between 32^0 - 37^0

Load (ohm)
960+j660
1600+j1194
2400+j1602
3600+j2388
4800+j3581



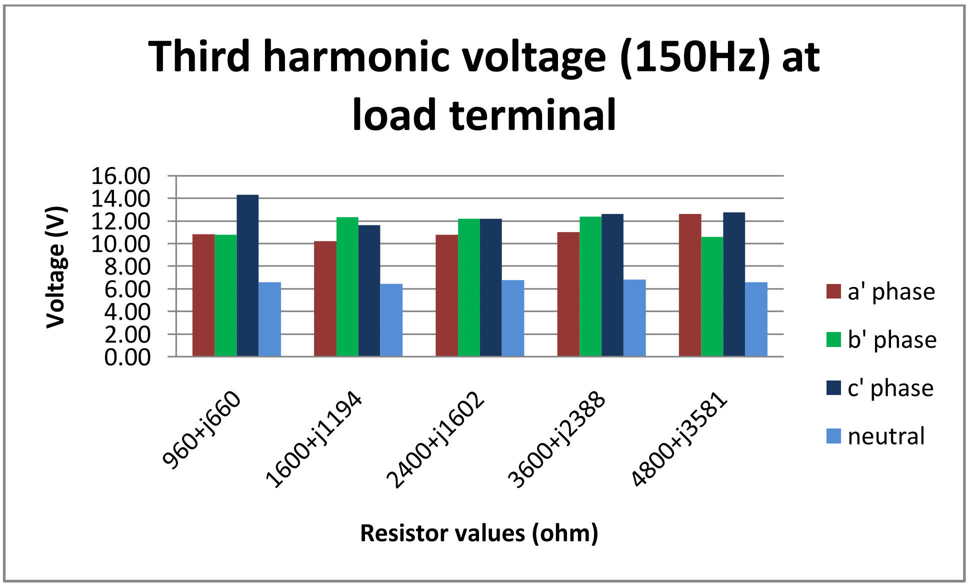


Figure 8: Third harmonic voltage for varied load magnitude

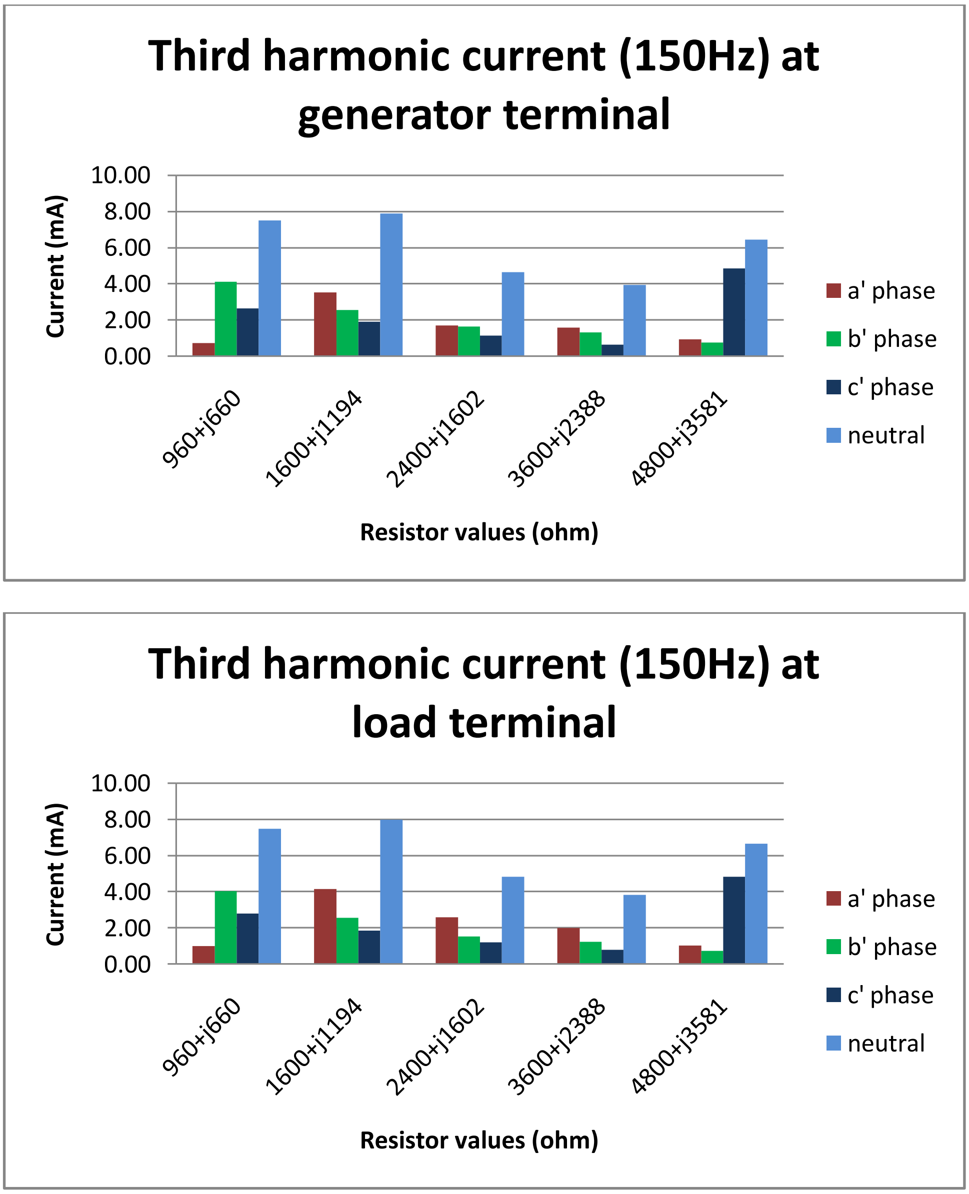
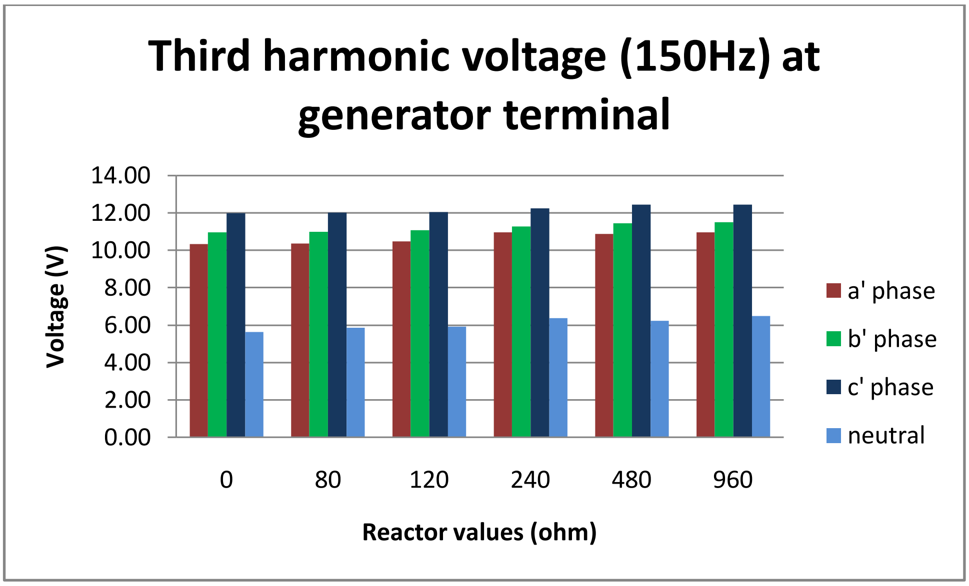


Figure 9: Third harmonic current for varied load magnitude

4.2.1. Reactance

The reactance is varied for various combined resistive and inductive load. The third harmonic voltage at generator terminal is almost constant for all reactance values. However, at load terminal, the third harmonic voltage decrease as the reactance values increase as shown in Fig. 10 for combined resistive and inductive load of 686+j686 Ω. This is due to voltage drop at reactance since the third harmonic current is present in the neutral. The magnitude reduction of third harmonic voltage is influenced by the reactance because the neutral third harmonic current is small.

The phase and neutral third harmonic current at generator and load terminals decrease as the reactance values increase as shown in Fig. 11. Almost zero sequence in nature, the phase neutral current sum at neutral hence resulting neutral current almost three times phase current magnitude. The net series impedance of reactance value and combined resistive and inductive load value determine the phase/neutral third harmonic current magnitude.



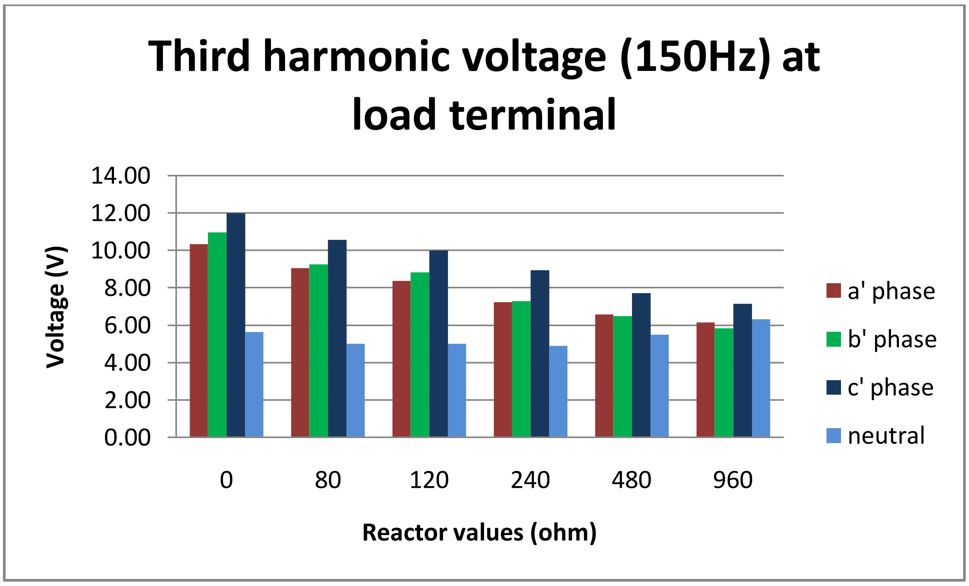
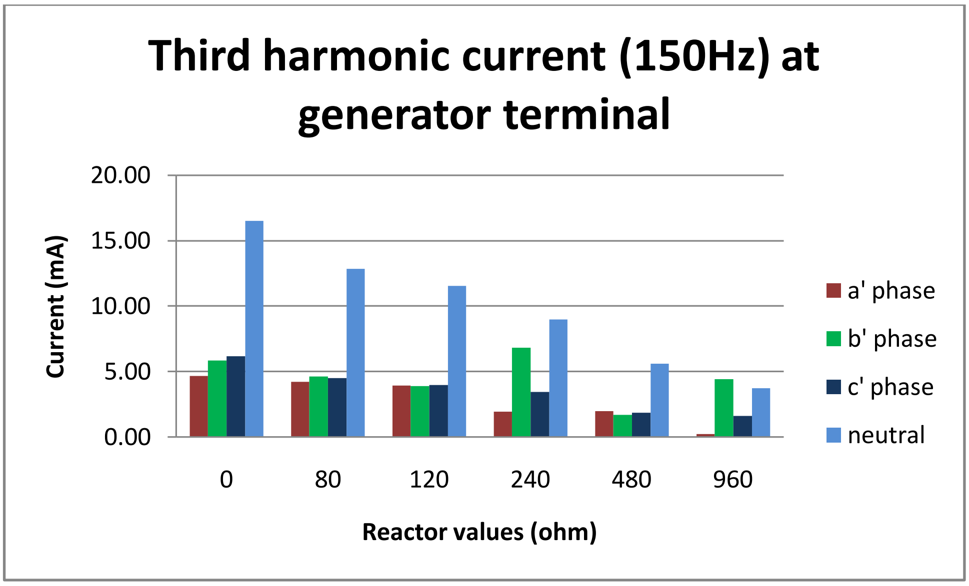


Figure 10: Third harmonic voltage with varied reactance value



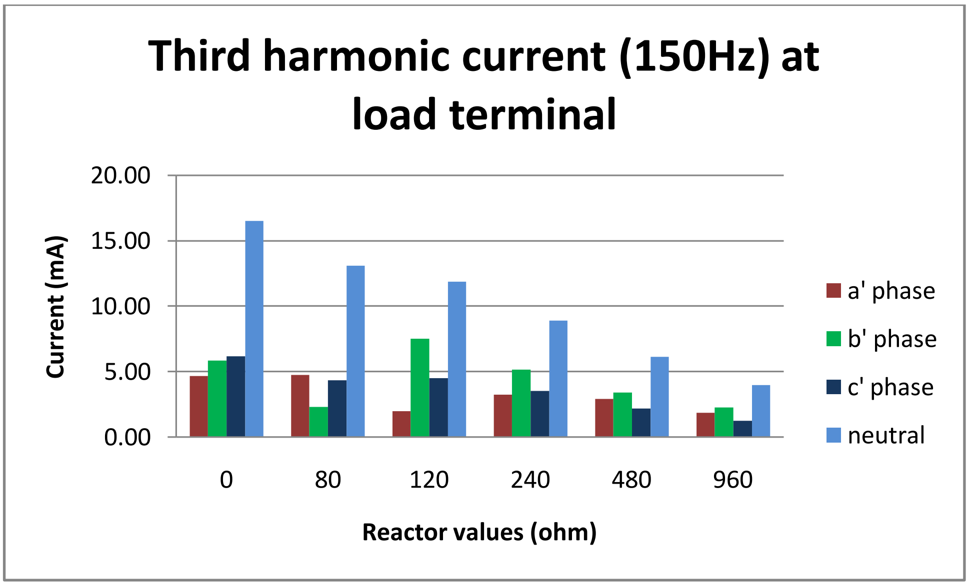
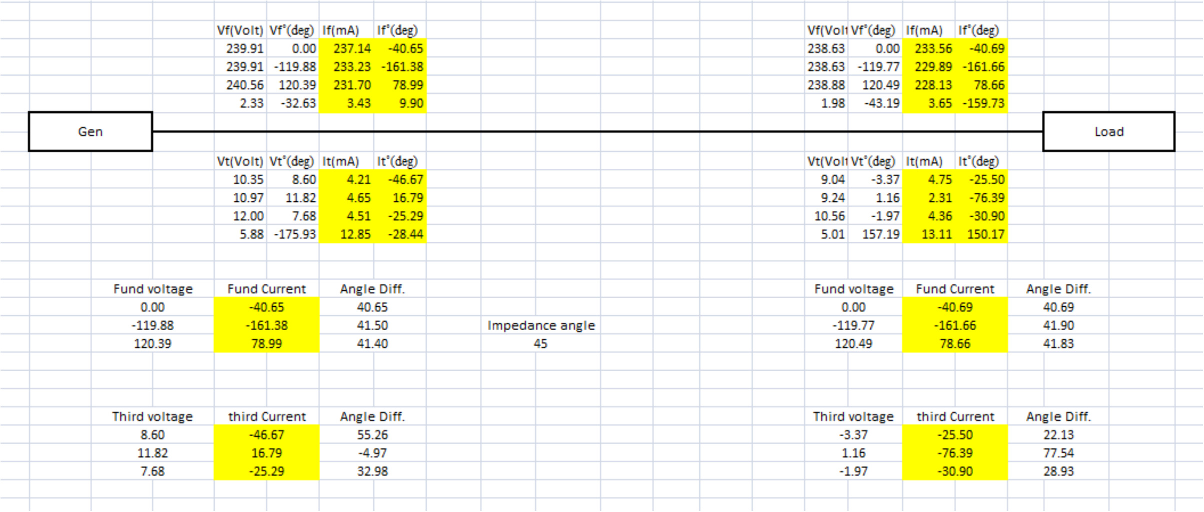


Figure 11: Third harmonic current with varied reactance value

The phasor angle for fundamental of the three phase voltage and current are 120^0 apart. The current is lagging voltage by almost 45^0. In the third harmonic frequency, the three phase voltage and current are almost in phase as shown in Figure 12.



Vf(Volt)	Vf°(deg)	If(mA)	If°(deg)
239.91	0.00	237.14	-40.65
239.91	-119.88	233.23	-161.38
240.56	120.39	231.70	78.99
2.33	-32.63	3.43	9.90

Vt(Volt)	Vt°(deg)	It(mA)	It°(deg)
10.35	8.60	4.21	-46.67
10.97	11.82	4.65	16.79
12.00	7.68	4.51	-25.29
5.88	-175.93	12.85	-28.44

Fund voltage	Fund Current	Angle Diff.
0.00	-40.65	40.65
-119.88	-161.38	41.50
120.39	78.99	41.40

Third voltage	third Current	Angle Diff.
8.60	-46.67	55.26
11.82	16.79	-4.97
7.68	-25.29	32.98

Impedance angle
45

Vf(Volt	Vf°(deg)	If(mA)	If°(deg)
238.63	0.00	233.56	-40.69
238.63	-119.77	229.89	-161.66
238.88	120.49	228.13	78.66
1.98	-43.19	3.65	-159.73

Vt(Volt	Vt°(deg)	It(mA)	It°(deg)
9.04	-3.37	4.75	-25.50
9.24	1.16	2.31	-76.39
10.56	-1.97	4.36	-30.90
5.01	157.19	13.11	150.17

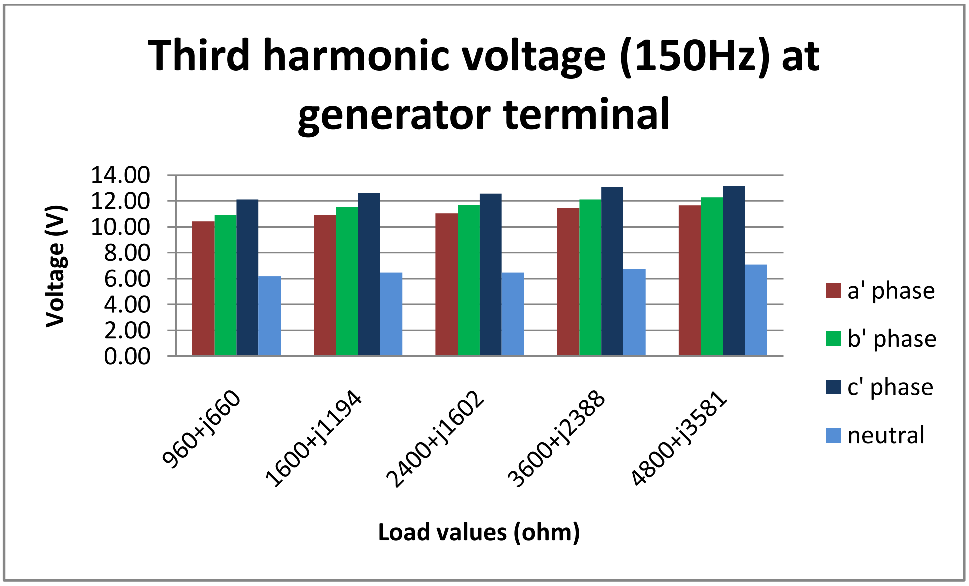
Fund voltage	Fund Current	Angle Diff.
0.00	-40.69	40.69
-119.77	-161.66	41.90
120.49	78.66	41.83

Third voltage	third Current	Angle Diff.
-3.37	-25.50	22.13
1.16	-76.39	77.54
-1.97	-30.90	28.93

Figure 12: Reactance 80 ohm for 686+j686 load

4.2.2. Vary impedance magnitude for impedance angle 32^0 or between 32^0 - 37^0 correspond to 0.8 – 0.85 pf real case

The load is set to vary impedance magnitude for impedance angle 32^0 or between 32^0 - 37^0 correspond to 0.8 – 0.85 pf real case. The loads are as in Table 8. At the generator and load terminals, the neutral voltage is almost constant when the load impedance increased as in Figure 13. In Figure 14, as the load impedance increased, the neutral current decreased.



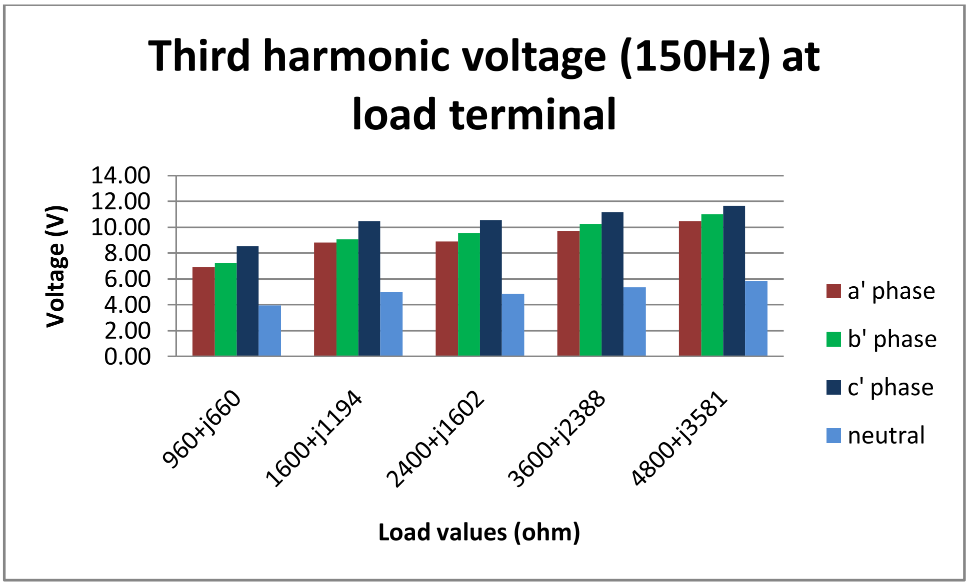
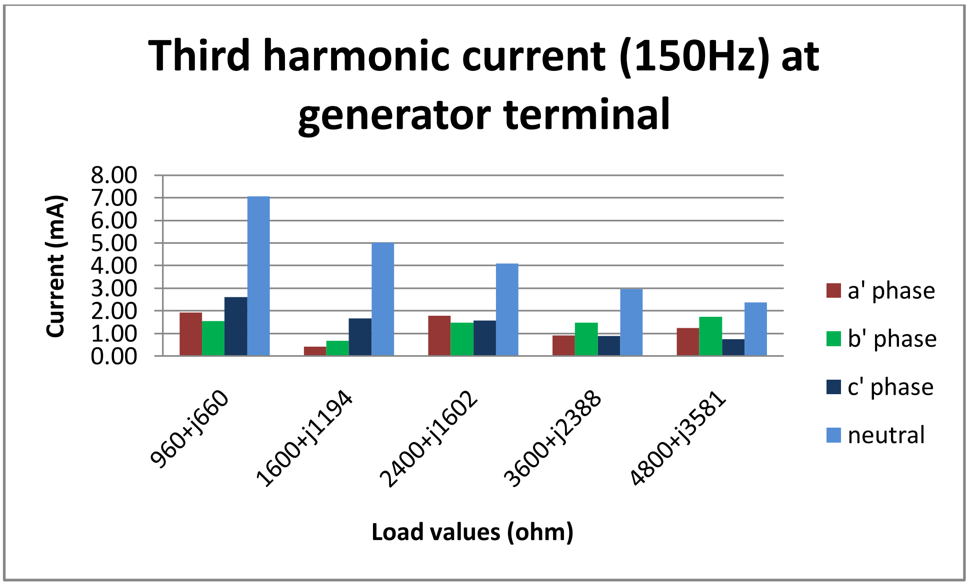


Figure 13: Third harmonic voltage for varied load magnitude



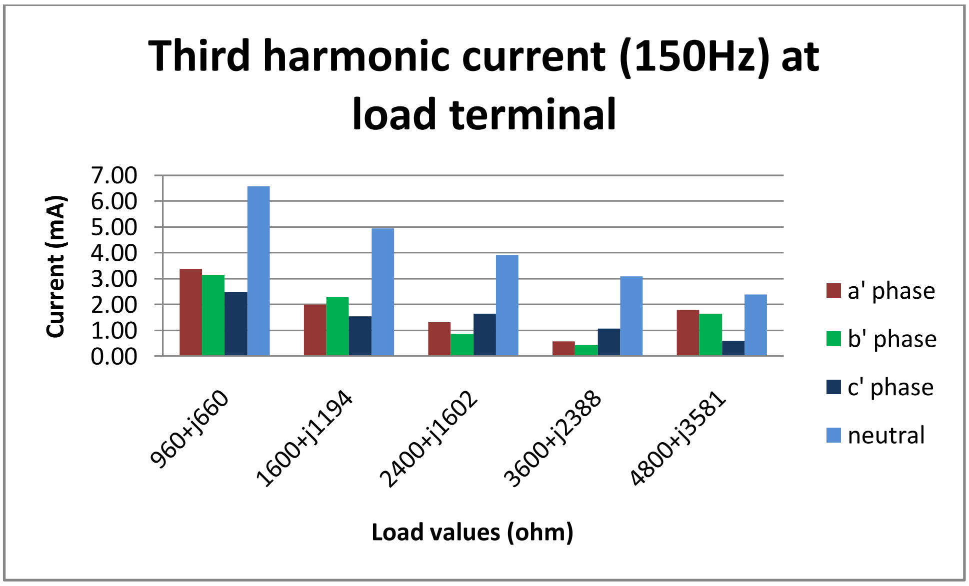


Figure 14: Third harmonic current for varied load magnitude

4.3.1. Zig-zag transformer

The third harmonic voltage at generator, zig-zag transformer and load terminals are quite constant for every combined resistive and inductive load as shown in Figure 15. Higher load impedance phase angle magnitude yield higher voltage magnitude at generator, zig-zag transformer and load terminals.

Almost zero sequence in nature, the phase neutral current sum at neutral hence resulting neutral current almost three times phase current magnitude. In Figure 16, almost all third harmonic current for phase and neutral from generator flow through zig-zag transformer and very small amount flow to the load for all combined resistive and inductive load. This is because zig-zag transformer provides the least impedance to ground as compared to combined resistive and inductive load for third harmonic current to flow.

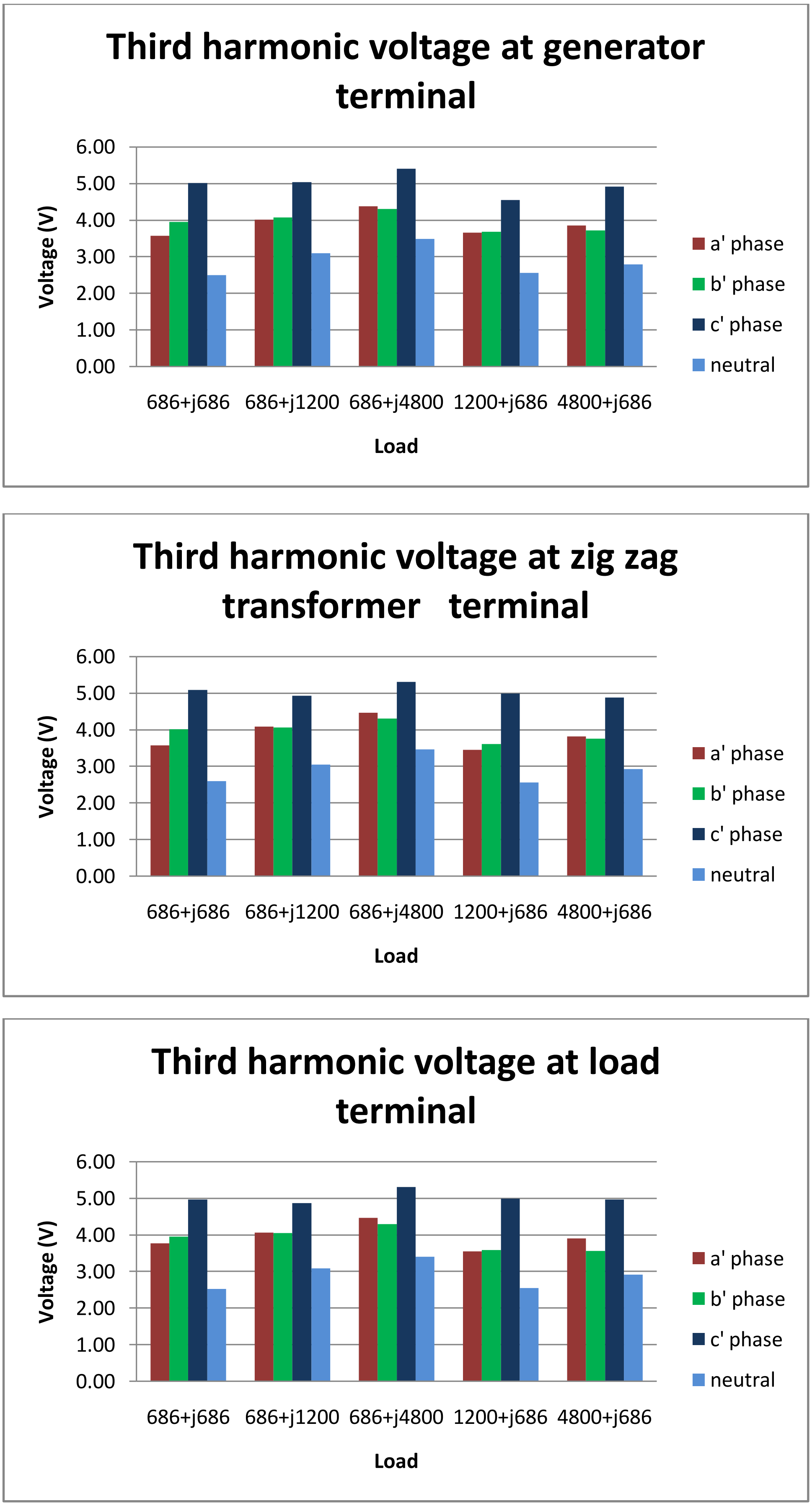
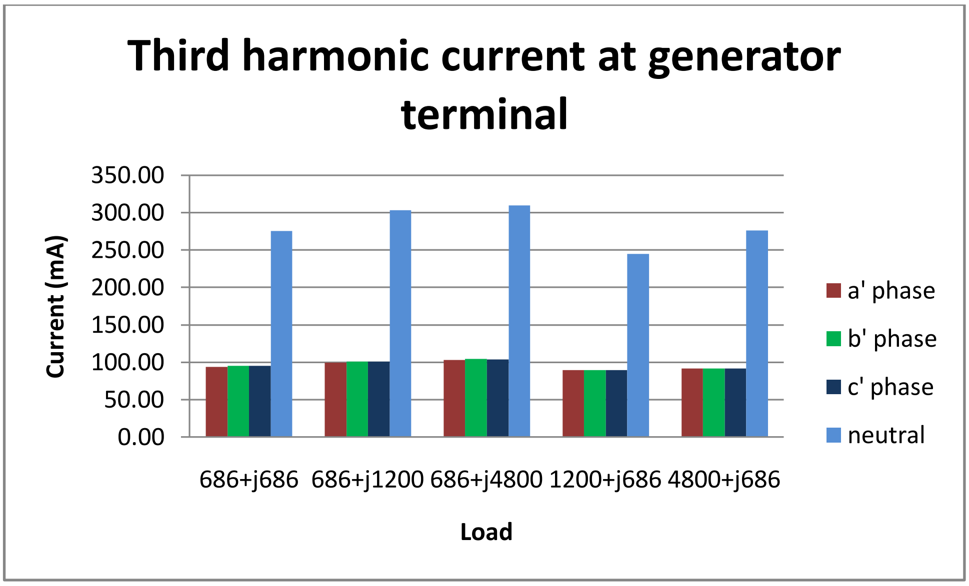
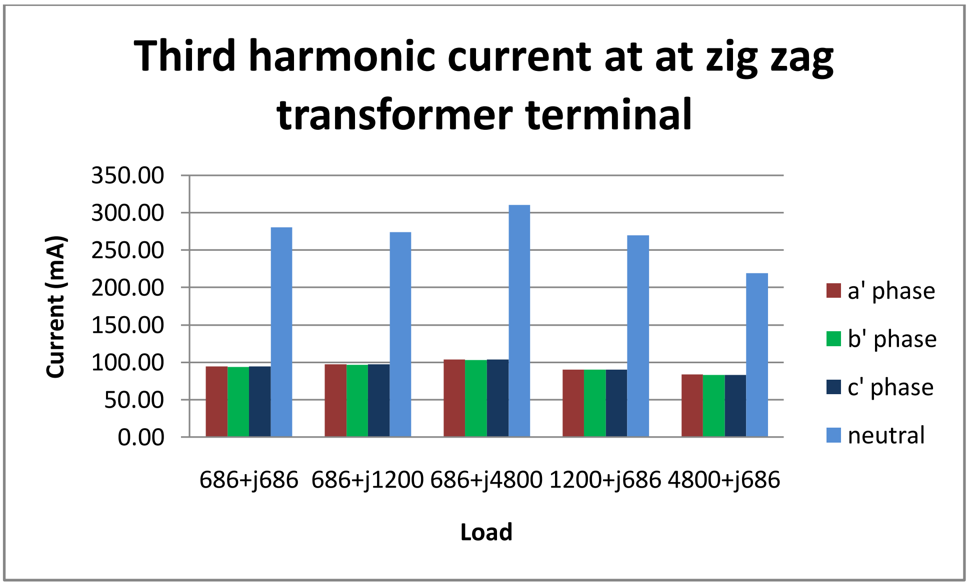


Figure 15: Third harmonic voltage with varied load





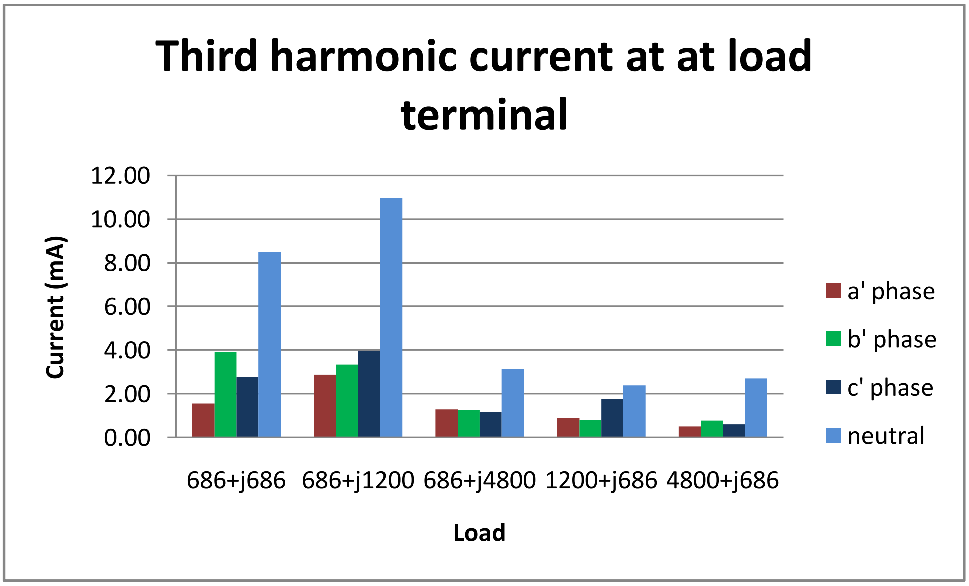
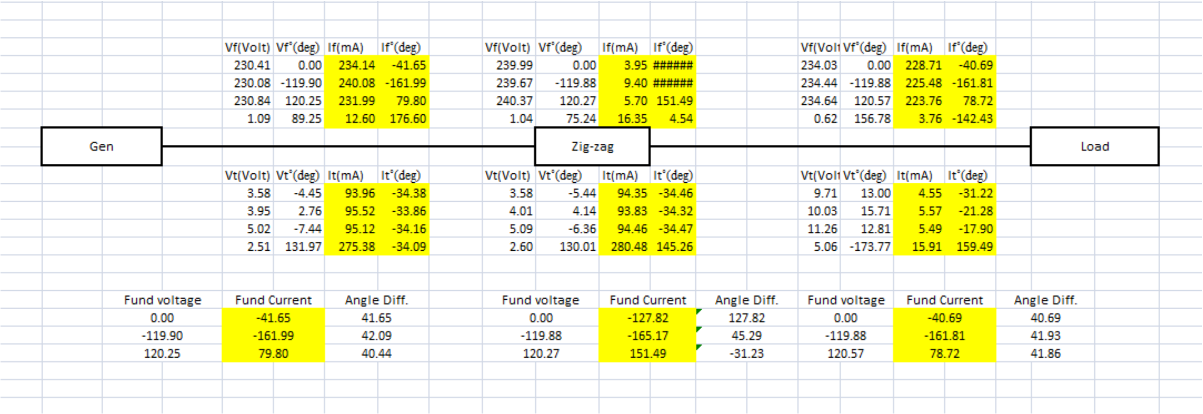


Figure 16: Third harmonic current with varied load

The phasor angle for fundamental of the three phase voltage and current are 120^0 apart. The current is lagging voltage by almost 45^0. In the third harmonic frequency, the three phase voltage and current are almost in phase as shown in Figure 17.



Vf(Volt)	Vf°(deg)	If(mA)	If°(deg)
230.41	0.00	234.14	-41.65
230.08	-119.90	240.08	-161.99
230.84	120.25	231.99	79.80
1.09	89.25	12.60	176.60

Vt(Volt)	Vt°(deg)	It(mA)	It°(deg)
3.58	-4.45	93.96	-34.38
3.95	2.76	95.52	-33.86
5.02	-7.44	95.12	-34.16
2.51	131.97	275.38	-34.09

Fund voltage	Fund Current	Angle Diff.
0.00	-41.65	41.65
-119.90	-161.99	42.09
120.25	79.80	40.44

Vf(Volt)	Vf°(deg)	If(mA)	If°(deg)
239.99	0.00	3.95	######
239.67	-119.88	9.40	######
240.37	120.27	5.70	151.49
1.04	75.24	16.35	4.54

Vt(Volt)	Vt°(deg)	It(mA)	It°(deg)
3.58	-5.44	94.35	-34.46
4.01	4.14	93.83	-34.32
5.09	-6.36	94.46	-34.47
2.60	130.01	280.48	145.26

Fund voltage	Fund Current	Angle Diff.
0.00	-127.82	127.82
-119.88	-165.17	45.29
120.27	151.49	-31.23

Vf(Volt	Vf°(deg)	If(mA)	If°(deg)
234.03	0.00	228.71	-40.69
234.44	-119.88	225.48	-161.81
234.64	120.57	223.76	78.72
0.62	156.78	3.76	-142.43

Vt(Volt	Vt°(deg)	It(mA)	It°(deg)
9.71	13.00	4.55	-31.22
10.03	15.71	5.57	-21.28
11.26	12.81	5.49	-17.90
5.06	-173.77	15.91	159.49

Fund voltage	Fund Current	Angle Diff.
0.00	-40.69	40.69
-119.88	-161.81	41.93
120.57	78.72	41.86

Figure 17: Result diagram for 686+j686 load

4.3.2. Vary impedance magnitude for impedance angle 32^0 or between 32^0 - 37^0 correspond to 0.8 – 0.85 pf real case

The load is set to vary impedance magnitude for impedance angle 32^0 or between 32^0 - 37^0 correspond to 0.8 – 0.85 pf real case. Refer to Table 8 for load values.

The third harmonic voltage at generator, zig-zag transformer and load terminals are quite constant for every combined resistive and inductive load as shown in Fig. 18. Higher load impedance phase angle magnitude yield higher voltage magnitude at generator, zig-zag transformer and load terminals.

Almost zero sequence in nature, the phase neutral current sum at neutral hence resulting neutral current almost three times phase current magnitude. In Fig. 19, almost all third harmonic current for phase and neutral from generator flow through zig-zag transformer and very small amount flow to the load for all combined resistive and inductive load. This is because zig-zag transformer provides the least impedance to ground as compared to combined resistive and inductive load for third harmonic current to flow.

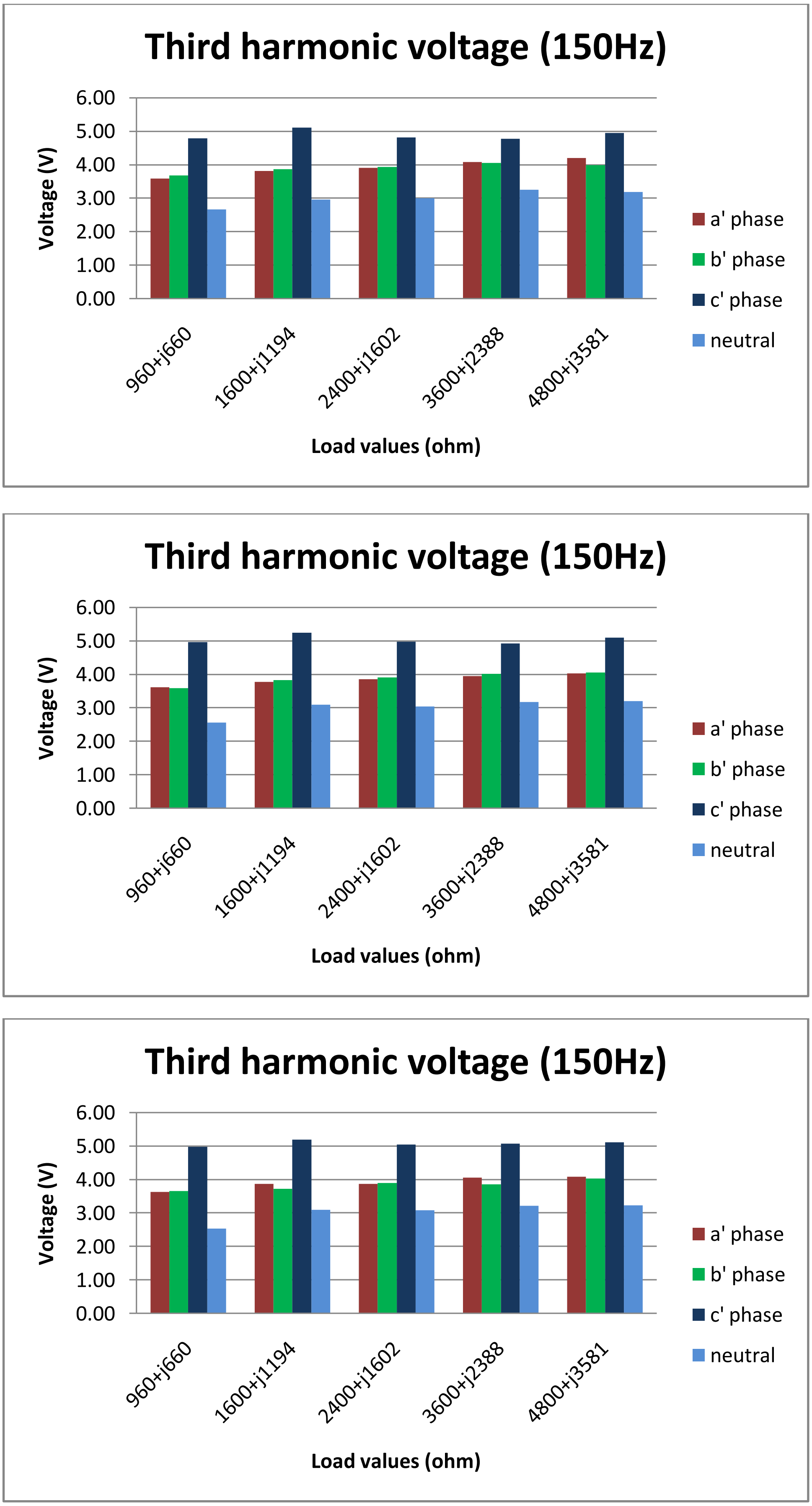
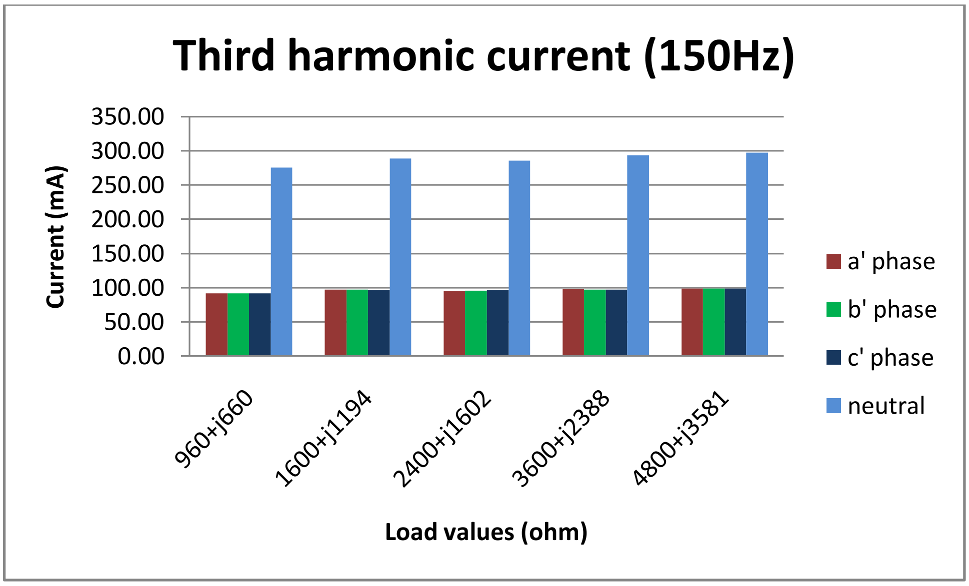
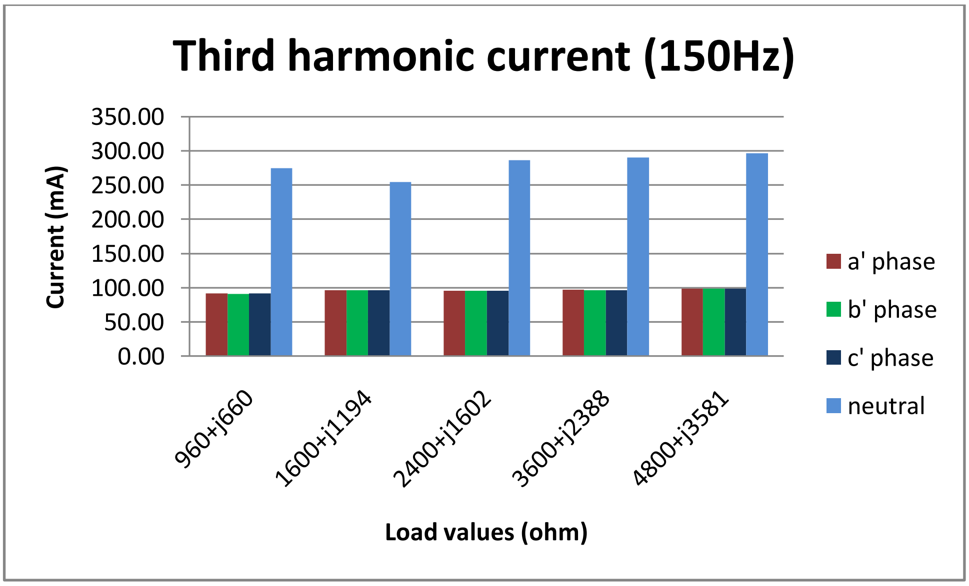


Figure 18: Third harmonic voltage for varied load magnitude





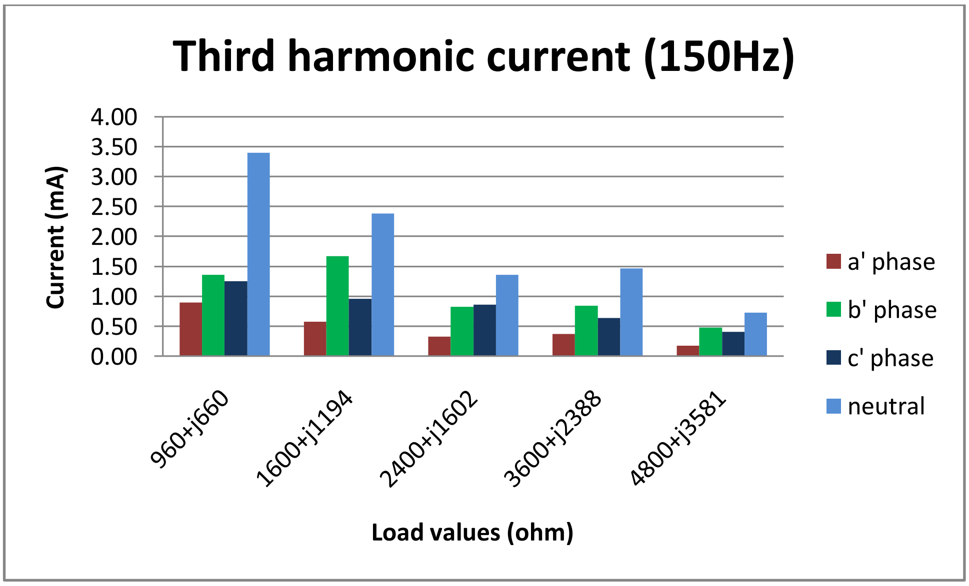


Figure 19: Third harmonic current for varied load magnitude

4.4. Comparison of third harmonic current between NER and Reactance with load 686+j686 at generator terminal

Table 9 shows the comparison of third harmonic current between NER and Reactance with load 686+j686 with varied neutral grounding impedance. As the neutral impedance is increased, the neutral current decreased. This applies to both NER and reactance earthing. The reduction of reactance earthing is higher when the value of neutral impedance increased compared to NER.

Table 9: Comparison of third harmonic current between NER and Reactance with load 686+j686

	NER		Reactance	
Neutral Grounding Impedance (ohm)	Neutral current (mA)	Percentage reduced (%)	Neutral current (mA)	Percentage reduced (%)
0	16.50	0	16.50	0
80	15.65	5.15	12.85	22.12
120	15.67	5.03	11.55	30
240	14.08	14.67	8.98	45.58
480	12.24	25.82	5.62	65.94
960	8.23	50.12	3.74	77.33

4.5. Comparison of third harmonic current between NER, Reactance and Zig-zag transformer with varied impedance magnitude for impedance angle 32^0 or between 32^0 - 37^0 correspond to 0.8 – 0.85 pf real case at generator terminal.

Table 10 shows comparison of third harmonic current at neutral between NER, Reactance and Zig-zag transformer with varied impedance magnitude for impedance angle 32^0 or between 32^0 - 37^0 correspond to 0.8 – 0.85 pf real case at generator terminal. The neutral current is decreased as the load values increased for NER and reactance earthing. The reduction for reactance earthing is higher. For zig-zig transformer, the neutral current is almost constant for all load values, but there are slight increased in neutral current as the load values increased.

Table 10: Comparison of grounding method with varied impedance magnitude

	NER		Reactance		Zig-zag transformer	
Load values (ohm)	Neutral current (mA)	Percentage reduced (%)	Neutral current (mA)	Percentage reduced (%)	Neutral current (mA)	Percentage reduced (%)
960+j660	7.50	0	7.06	0	275.71	0
1600+j1194	7.89	-5.20	5.00	29.18	288.37	-4.59
2400+j1602	4.64	38.13	4.10	41.93	285.64	-3.60
3600+j2388	3.94	47.47	2.96	58.07	292.88	-6.23
4800+j3581	6.43	14.27	2.38	66.29	297.21	-7.80

CHAPTER 5

CONCLUSION

Generator neutral grounding resistor provides additional impedance in the neutral and their resultant impedance with combined resistive and inductive load determines the magnitude of third harmonic current. Practically, generator neutral grounding resistor can be used to reduce third harmonic current from generator.

Reactance earthing also provides additional impedance in the neutral and their resultant impedance with combined resistive and inductive load determines the magnitude of third harmonic current. Practically, generator neutral grounding reactance can also be used to reduce third harmonic current from generator.

Zig-zag transformer exhibit low impedance earth path for third harmonic current to return to generator neutral. It diverts the generator third harmonic current from flowing to the load but very high third harmonic current circulating between generator and zig-zag transformer. This may pose heating problem to generator, zig-zag transformer and generator neutral grounding resistor.

The two generator grounding which are the NER and reactance earthing and grounding transformer which is the zig-zag transformer are compared when the impedance magnitude are varied. It has been demonstrated that the neutral current is decreased as the load values increased for NER and reactance earthing. The reduction for reactance earthing is higher. For zig-zig transformer, the neutral current is almost constant for all load values, but there are slight increased in neutral current as the load values increased.

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