FINAL YEAR PROJECT 2

FINAL REPORT

The Study of Third Harmonic Current Contribution during Ground Fault

PREPARED BY:

AARON SCOTT G. YUNSAI

12996

BACHELOR OF ENGINEERING (HONS) ELECTRICAL AND ELECTRONIC

SUPERVISED BY:

IR MOHD FARIS BIN ABDULLAH

CERTIFICATION OF APPROVAL

THE STUDY OF THIRD HARMONIC CURRENT CONTRIBUTION DURING GROUND FAULT

By

AARON SCOTT G. YUNSAI

A project dissertation submitted to the
Department of Electrical & Electronic Engineering
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(Electrical & Electronic Engineering)

Approved:

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Ir. Mohd Faris bin Abdullah
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

September 2013

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 reference and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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AARON SCOTT G. YUNSAI

ABSTRACT

Third harmonic current exist in the electrical power system due to non-linear loads and from the salient pole synchronous generator. In Universiti Teknologi PETRONAS (UTP), the campus has its own power plant which is the Gas District Cooling (GDC) plant and studies show the plant produces third harmonic current. Third harmonic current magnitude tripled at the neutral, when it flows back, has caused damages to the Neutral Earth Resistor (NER) at the GDC generator. Studies need to be conducted to see whether the third harmonic current will have the same characteristic when it is in steady-state conditions and also during ground fault. The objective of this project is to study the characteristic of third harmonic current and voltage during steady-state and ground fault. Data and information about third harmonic current will firstly be gathered and studied to have a strong basic about harmonics current and voltages. A lab-scale experiment with two types of connection which is generator-load and generator-transformer-load connection will be conducted. A fault is intentionally occurred at Phase A in each experiment to simulate a single-phase-to-ground fault. During each experiment, measurement for third harmonic current and voltage will be taken at the generator and load terminal for generator-load connection and generator, load and transformer terminal for generator-transformer-load connection. During steady-state condition, third harmonic current will tripled of phase magnitude at the neutral at the generator and load terminal for generator-load connection. When Delta-Wye transformer is added, third harmonic current will only circulate at the Delta transformer and will not flow through the load and travel back to generator through the neutral. When single-phase-to-ground fault occurred at Phase A, all the current carrying third harmonic current will flow through the fault back to the neutral of the generator for both of the experiment connection. When ground fault occur, third harmonic current flowing back to generator is higher than third harmonic current during steady-state.

ACKNOWLEDGEMENTS

First and foremost my deepest gratitude to God for with His help I manage to finish my Final Year Project (FYP) on time.

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

I would also like to express my gratitude to Electrical and Electronic Engineering (EE) Department of Universiti Teknologi PETRONAS (UTP) for providing this chance to undertake this Final Year Project in my final year of EE student.

Next, I would like to thank the FYP committee for their support and knowledge to assist the students. Thank you to all the lecturers and lab technicians from UTP who has provided efficient guidance and help throughout the course of the project.

Finally, I would like to apologize if any party was inadvertently excluded from being mentioned above and I would like to thank all the parties that were involved in making this project a success. Thank you.

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INTRODUCTION

1.1 PROJECT BACKGROUND

The presence of the third harmonic components is caused by non-linear loads and from synchronous generator. The order of the triplen harmonics current is currents of 3^{rd}, 9^{th}, 15^{th} and etc. They have the same magnitude and also their phase angle in balanced triplen harmonics causing the magnitude of current in neutral is three time the phase triplen harmonics current. The triplen harmonics current that return to neutral are zero sequence harmonics current.

In early design of electrical power system, engineers at that time did not know the existence of the third harmonic current because the effect of the third harmonic current have little effect on the electrical power system. It was when the system has become more advanced and the effect of the third harmonic current begins to show its marks on the system. Hence, more research is done to reduce the third harmonic components as much as possible to reduce the damage done to the system.

When there is any presence of abnormal electric current, it is called a fault. There are several types of faults in electrical power system. This project will focus more on the ground fault since third harmonic current flows to ground.

The contribution of the third harmonic current during ground fault will be studied. The third harmonic current will be observed whether it has the same characteristics as in the steady-state condition. Lab experiments will be conducted to observe the characteristic and its contribution.

1.2 PROBLEM STATEMENT

Third harmonic current flows back into the GDC neutral, has causes the GDC NER to become very hot. When a ground fault occurred, the fault causes the fundamental current to flow back into the neutral. Hence, a research will be conducted to observe the contribution of the third harmonic current and its effect during ground fault.

1.3 OBJECTIVES

The objectives of this project are:

- To study the characteristics of third harmonic current and voltage during steady-state condition
- To study the characteristics of third harmonic current and voltage during ground fault

1.4 SCOPE OF STUDY

Studies and research on third harmonic current and voltage characteristics and ground fault is done to understand the fundamentals. Then rigorous lab experiment will be conducted to investigate the characteristic of third harmonic current and its contribution during ground fault.

1.5 RELEVANCY OF PROJECT

The project is relevant to be conducted as currently less studies and emphasis to the contribution of the third harmonic current during ground fault. This project may help to a better understanding of the characteristic of third harmonic current as it will helps to provide a solution in tackling this problem in power system.

1.6 FEASIBILITY OF THE PROJECT WITHIN THE SCOPE AND TIME FRAME

This project can be completed within the allocated time frame of the Final Year Project for the final year student in UTP as the materials can be gathered easily and the experiments are easy to be conducted inside the Power System lab. Previous final year projects with the same basic foundation of this project can be used as a reference for this project making this project is not impossible to be achieved.

CHAPTER 2

2.1 LITERATURE REVIEW

In understanding more about the project on third harmonic current characteristic and ground faults, it is essential to go through and review several research papers that has discussed about these two topics.

2.1.1 Third Harmonic Current

Triplen harmonics current is a current in the order of the 3^{rd}, 9^{th}, 15^{th}, and so on. During the balanced condition triplen harmonics current will have the same phase angle and also their magnitude is the same. They will add up at the neutral making their magnitude three times larger than phase triplen harmonics currents [1].

In research conducted in [2] and [3], the measurement for the third harmonic current and voltage are recorded in their phase values. The three phase harmonic voltages are produced by salient pole synchronous generator as stated in [4] and it is symmetrical and balanced. In mathematical form, the harmonic voltages are represented as:

$$V_a = V_1e^{jwt} + V_2e^{j2wt} + V_3e^{j3wt} + \ldots\ldots \quad (1)$$

$$V_b = a^2V_1e^{jwt} + aV_2e^{j2wt} + V_3e^{j3wt} + \ldots\ldots \quad (2)$$

$$V_c = aV_1e^{jwt} + a^2V_2e^{j2wt} + V_3e^{j3wt} + \ldots\ldots \quad (3)$$

where, $a=e^{j\frac{2\pi}{3}}$

Therefore, three phase third harmonic voltage:

$$V_a = V_3e^{j3wt} \quad (4)$$

$$V_b = V_3e^{j3wt} \quad (5)$$

$$V_c = V_3e^{j3wt} \quad (6)$$

In [1], research conducted in UTP to investigate the effect of third harmonic current on the temperature of the NER. It shows that the triplen harmonics current causes the temperature of the NER to become very hot. The temperature also raises more when the GDC plant is connected in parallel with the Tenaga Nasional Berhad (TNB) grid.

Third harmonic current is caused when the electrical power system is connected to non-linear loads. This is discussed in [5] where non-linear loads from commercial fluorescent lightning and arc furnaces have always caused harmonic distortion on the current waveform

as shown in Figure 1. Because of little effect on the harmonic distortion occurred in the older days, less literature on the effect of the harmonic distortion is still insufficient to provide information regarding the distortion. It only in the recent times when non-linear loads has become more common and the effects of the triplen harmonics current began to rise.

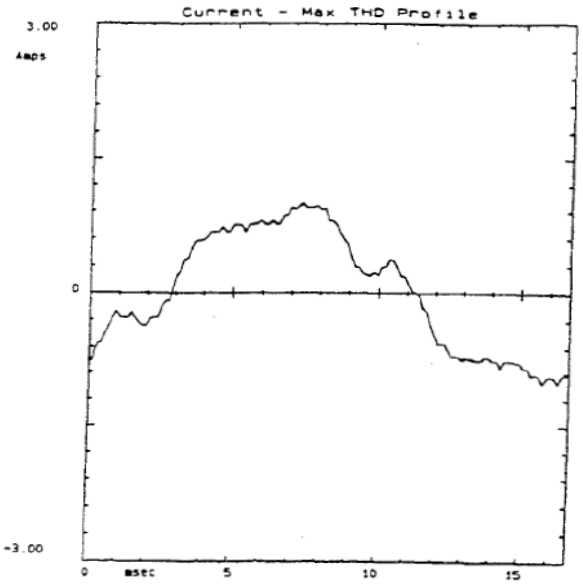


Figure 1: An example of a harmonic distortion on a current waveform caused by non-linear loads. [5]

Besides non-linear loads, it is also having been discussed that the triplen harmonics currents also come from salient pole synchronous generator [4]. This generator produced triplen harmonics current that depends on the winding design which takes into account the pitch factor, distribution factor and also slot skew [6]. But the amount of triplen harmonics current produced is affected by the design of transformer winding configurations, generator NER value and load impedance. Transformers that have a configuration with ground connection will surely have third harmonic currents to flow through them [4].

2.1.2 **Ground Fault**

A ground fault occurs when electricity travels outside an intended path and tries to get to the ground by the shortest route. It can further be divided into two type of fault which is:

1) Single line to ground fault
2) Double line to line fault

In power system, these types of fault are categorized as unsymmetrical or unbalanced fault. This is in contrast to symmetrical fault, where the three phases are affected equally. Unsymmetrical fault does not affect each of the three phases equally. There is also another type of fault in this category which is line-to-line fault. Since this project focuses more on ground fault, this type of fault will not be discussed.

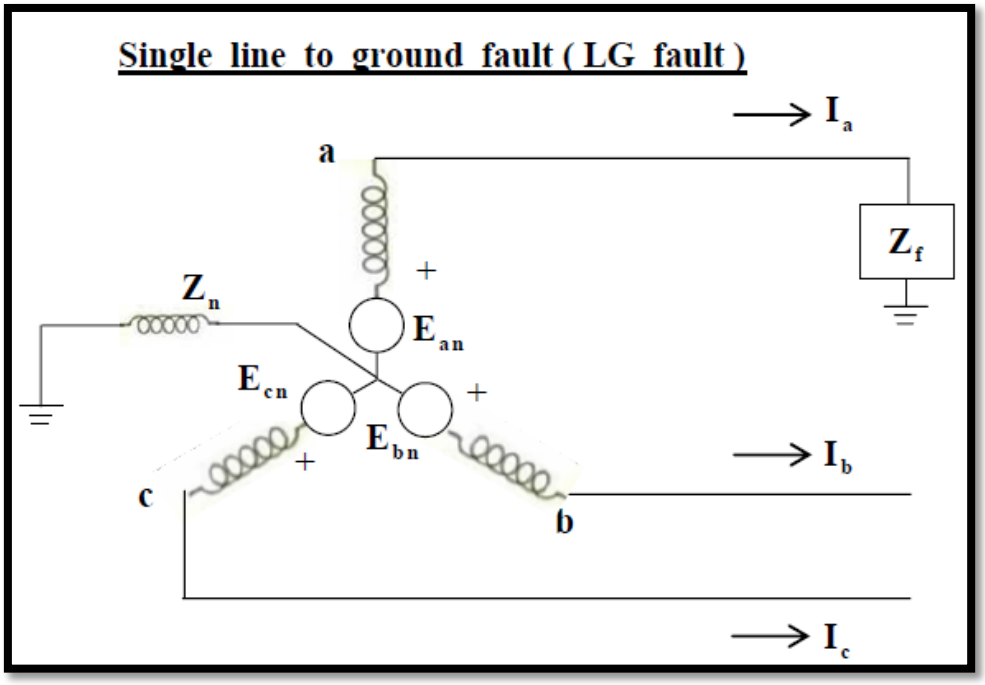


Figure 2: Single line to ground fault. The fault is at Phase A. [7]

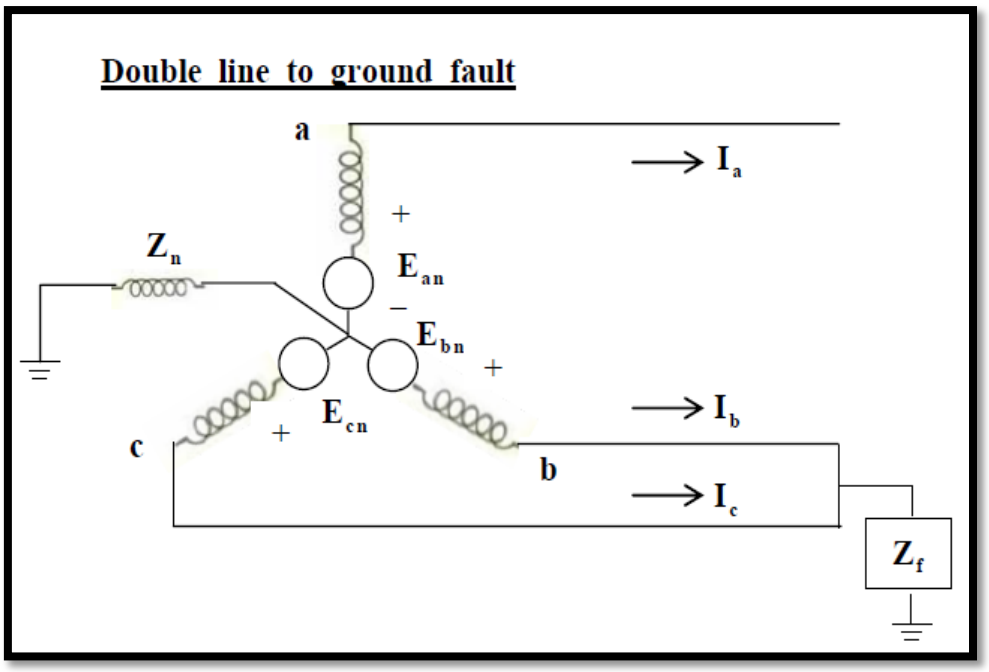


Figure 3: Double line to ground fault. The fault is at Phase B and Phase C combined. [7]

During ground fault, fundamental current flows back into the neutral of the source. In this case, the source is the generator. The fundamental current that flows back can be significantly large. Due to the large current flowing back, it can cause devastating damages to the generators that would require long and costly repairs. Hence, it became a priority for generator protection engineers to limit and monitor ground fault currents [8].

Currently, in research conducted by [9], it stated that when a ground fault occurred near the neutral of a generator, the third harmonic voltages at the neutral will decrease and that at line neutral increase. By utilizing the third harmonic voltages phase amplitude, it can serve as a ground fault protection for generator [10]. But more research need to be conducted for a more reliable third harmonic ground fault protection as the third harmonic voltages and current are influenced in many factors that leads to its unreliability [11].

CHAPTER 3

METHODOLOGY

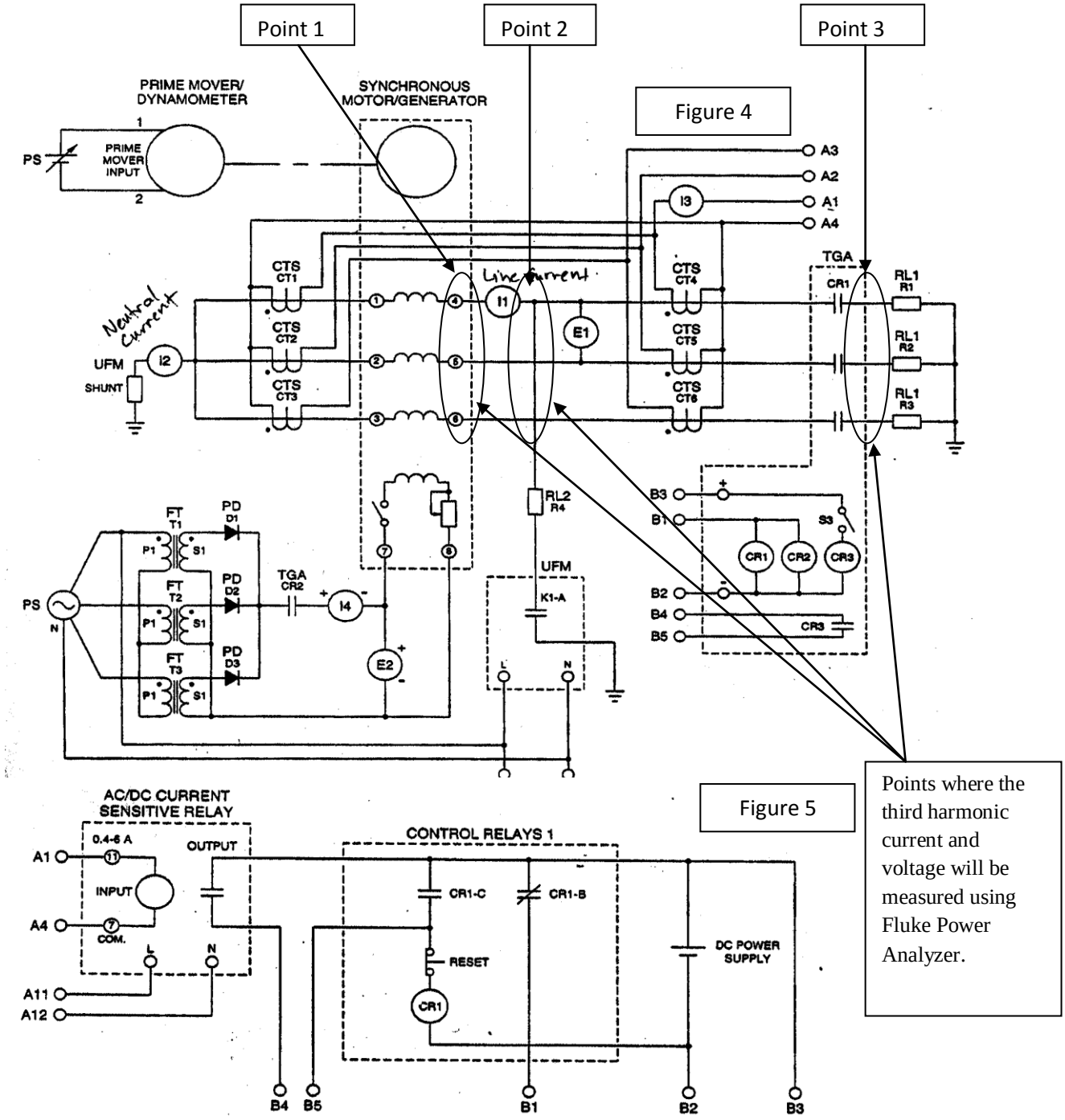
3.1 RESEARCH METHODOLOGY

In this project, the fundamental thing is to understand the three main points inside the project itself which is the third harmonic current in electrical power system analysis, the ground fault in electric power system, and the contribution of the third harmonic current during ground fault to the electrical power system. Hence, the first step is to go through and study several research papers, journal and books.

Rigorous lab experiment will be conducted to observe third harmonic current and voltage characteristic during steady-state and single-phase-to-ground fault.

Fluke 434/435 Three Phase Power Quality Analyzer will be used as the measuring tools to measure the third harmonic voltage and current in the electrical power system during steady state and ground fault. Figure 4 and Figure 5 is the schematic diagram of the Electromechanical System (EMS) workstation and also Protective Relaying Control Station (PRCS).

The data then will be further analyzed to see and understand the characteristic of third harmonic current contribution during ground fault.



PS	Power Supply	FT	Faultable Transformers	PD	Power Diodes
CTS	Current Transformer	UFM	Universal Fault Module	TGA	Transmission Grid "A"
RL1	Resistive Load 1	RL2	Resistive Load 2	R1, R2, R3, R4 = 1600 OHM	

Figure 4: Connection diagram of the equipment in the EMS Workstation
Figure 5: Connection diagram of the equipment in the Protective Relaying Control Station.

For this lab-scale experiment, the generator rating that will be used is 120 VA. It will be tested with 5 different set of loads impedance. The first step is to record the base data of the experiment. This data will be the base value for the whole experiment to see the changes in characteristics of the third harmonic voltage and current.

The ratings of the generator are:

Table 1: Ratings of the generator

Power (VA)	Voltage (V)	Full-load Current (A)
120	240	0.17

The 5 set of load impedance for the generator is set vary impedance magnitude angle from 32° to 37° which is corresponds to 0.8 to 0.85 of power factor in the real case. The loads for the generator are shown in Table 2.

Table 2: Load impedance

Resistance (Ω)	Impedance (Ω)	Inductor (H)
960	660	2.1
1600	1194	3.8
2400	1602	5.1
3600	2388	7.6
4800	3581	11.4

The calculation for the load impedance variation for the generator is calculated using this formula:

$$P = 3\ V\ I \cos\theta \text{ (phase line)}$$

The rating of the generator is:
Current = 0.17 A

Power = 120 VA

$$120\ VA = 3\ (240)\ (0.17)\ (\cos\theta)$$

$$120\ VA/\ (240)\ (3)\ (0.17) = \cos\theta$$

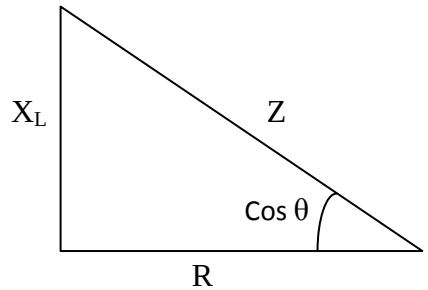
$$\cos\theta = 0.9804 \text{ (Generator pF)}$$

The values are then calculated using the power factor triangle formula to find the resistance and impedance:

The 36°= Cos 0.8 of power factor

Cos 36° = R / Z

Sin 36° = X_L / Z



In direct load connection, for the base data experiment and fault experiment, the generator is connected straight to the load. To take the measurement of the third harmonic current, the measurement will take place at two points of the circuit which is after the generator and before the load.

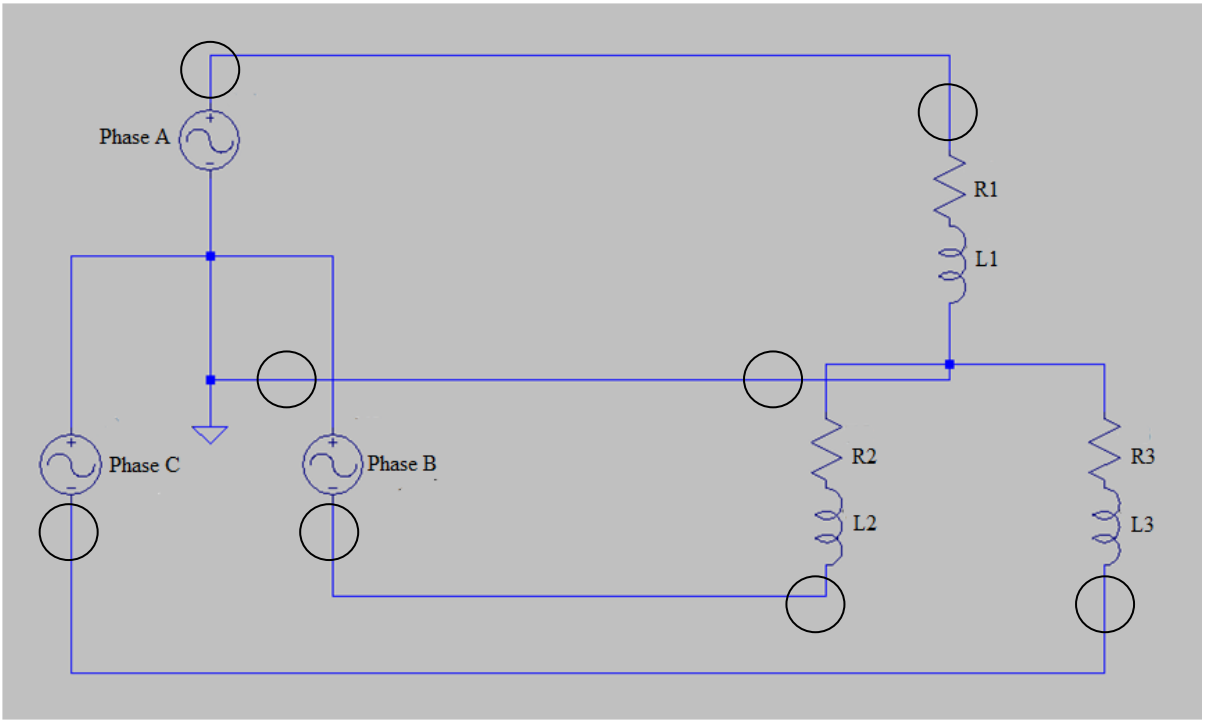


Figure 6: The connection of the direct load to generator connection.

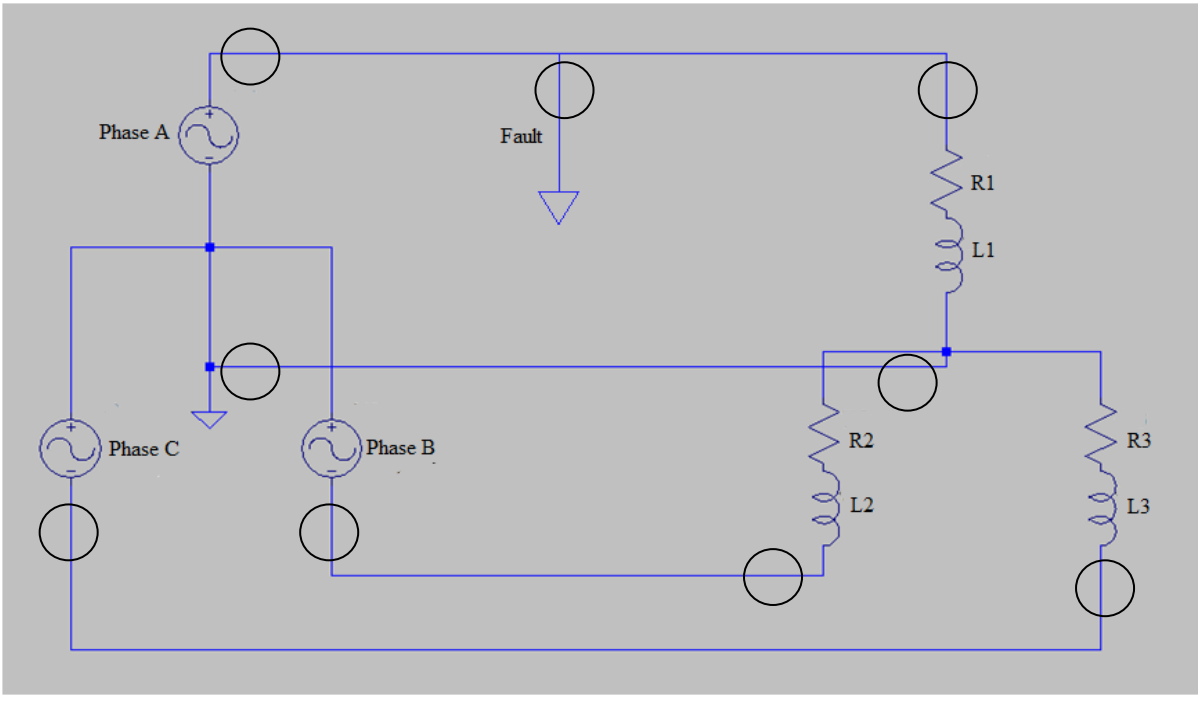


Figure 7: The connection of the direct load to generator connection with fault at Phase A.

In transformer-load connection, for the base data experiment and fault experiment, the generator is connected to a Delta-Wye transformer connection and then to the load. To take the measurement of the third harmonic current, the measurement will take place at four points of the circuit which is after the generator, inside the Delta connection, after the Wye connection, and before the load.

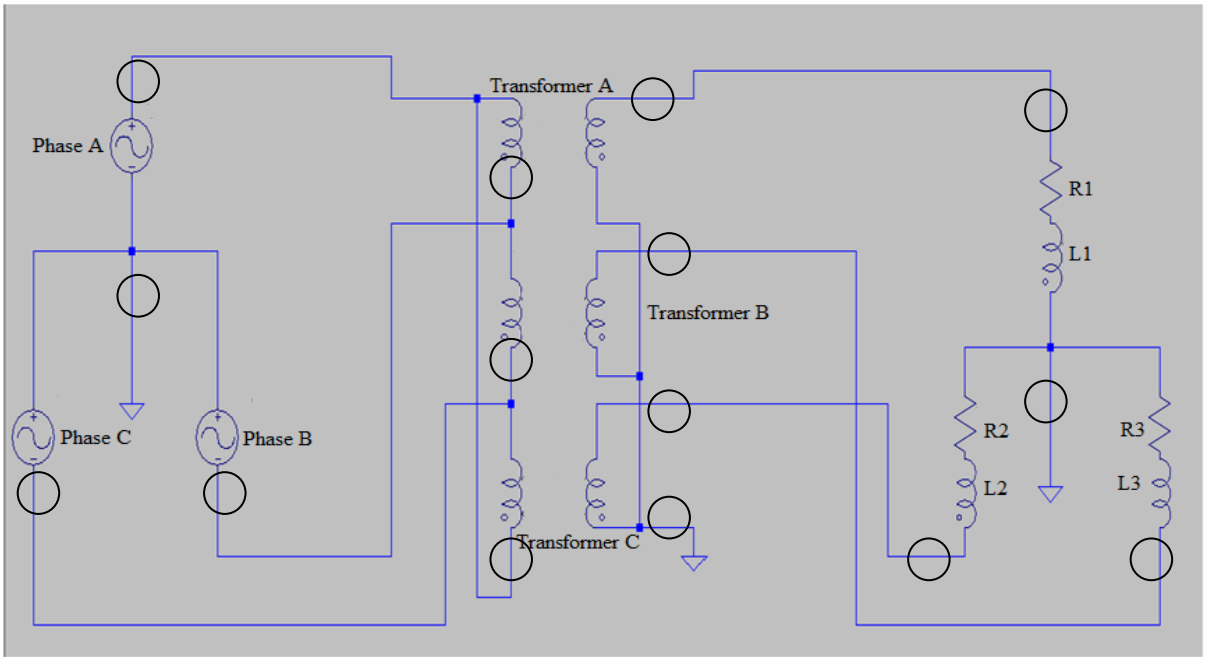


Figure 8: The connection of generator-transformer-load connection.

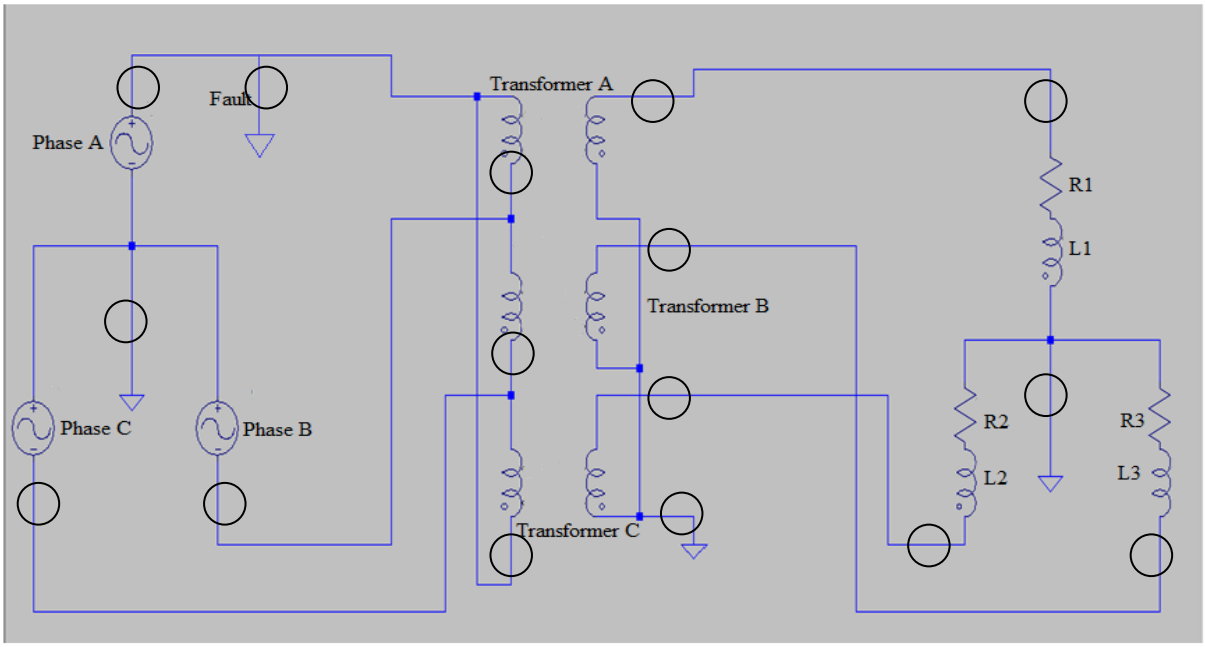


Figure 9: The connection of the generator-transformer-load connection with fault at Phase A.

The black circle on the schematic diagram indicates the point of measurement that will be taken there. Fluke 435 Power Quality Analyzer will be the tool for measuring the third harmonic voltage and current at each point. Fluke 435 has a current clamp that easily clamps on to the wire cable and measure the current that flows through it.

Figure 10: Fluke 435 Power Quality Analyzer with i5s Current clamp.

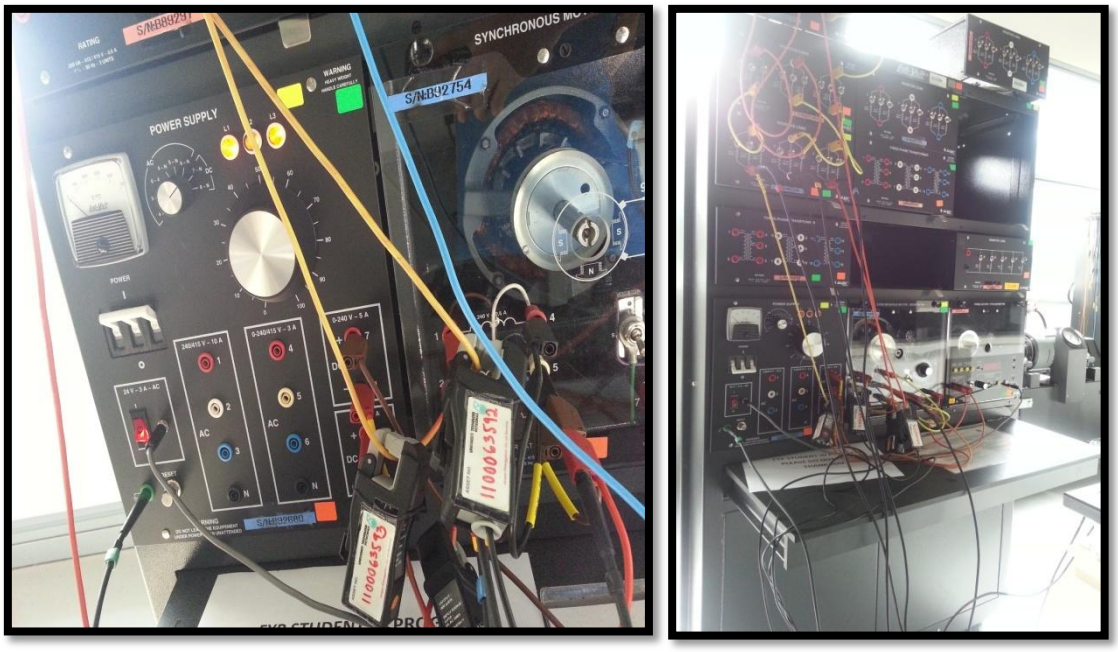
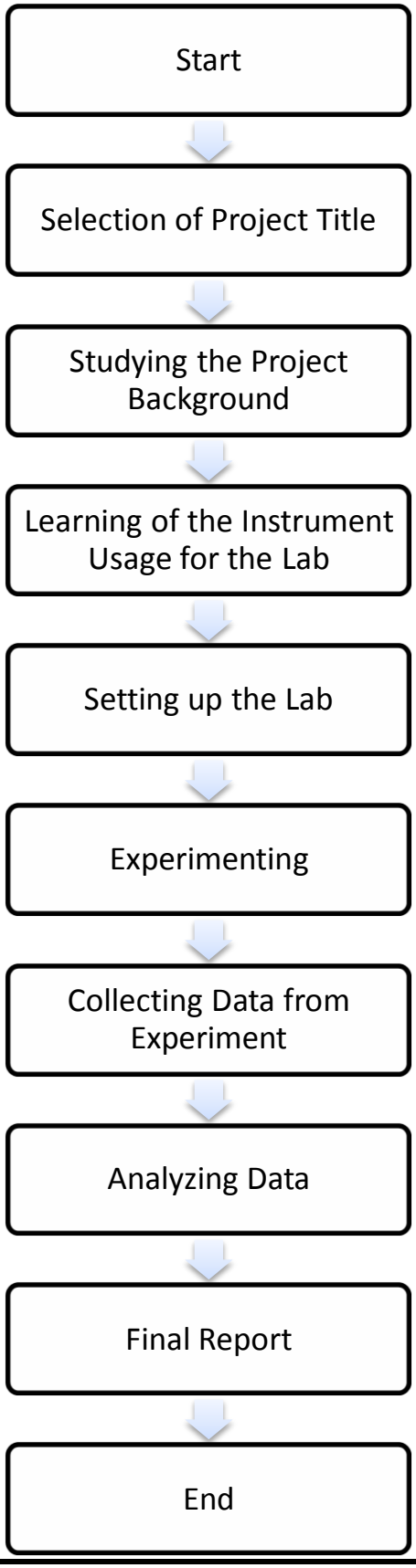


Figure 11: Experiment setting with the current clamp on the wire cable.

3.2 PROJECT ACTIVITIES



3.3 KEY MILESTONE AND GANTT CHART

Table 3: Key milestone and Gantt chart FYP 1

NO	Activities/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Title														
2	Research on the Third Harmonic Current and Ground Fault														
3	Extended Proposal Submission														
4	Proposal Defence														
5	Familiarizing with the Lab Equipment and Fluke Power Quality Software														
6	Conducting Lab Experiments														
7	Draft Report Submission														
8	Interim Report Submission														

Table 4: Key milestone and Gantt chart FYP 2

NO	Activities/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Continuation of Progress from FYP 1																
2	Progress Report Submission																
3	ELECTREX																
4	Draft Report Submission																
5	Final Report																
6	Technical Paper																
7	Viva																
8	Final Report (Hard Cover)																

3.4 TOOLS

HARDWARE:

- Electromechanical System (EMS) Workstation
- Protective Relaying Control Station (PRCS)
- Fluke 434/435 Three Phase Power Quality Analyzer
- Resistor
- Inductor
- Wire cable
- Multi meter
- Laptop

SOFTWARE:

- FlukeView Power Quality Analyzer Software
- Microsoft Excel

Figures below shows the main component used in the EMS workstation.

Figure 12: Current Transformer

Figure 13: Power Supply

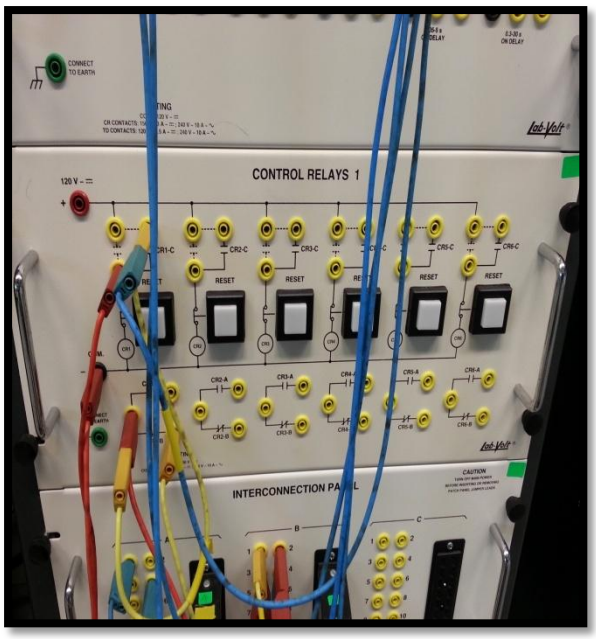


Figure 14: Control Relays

Figure 15: AC/DC Current Sensitive Relay

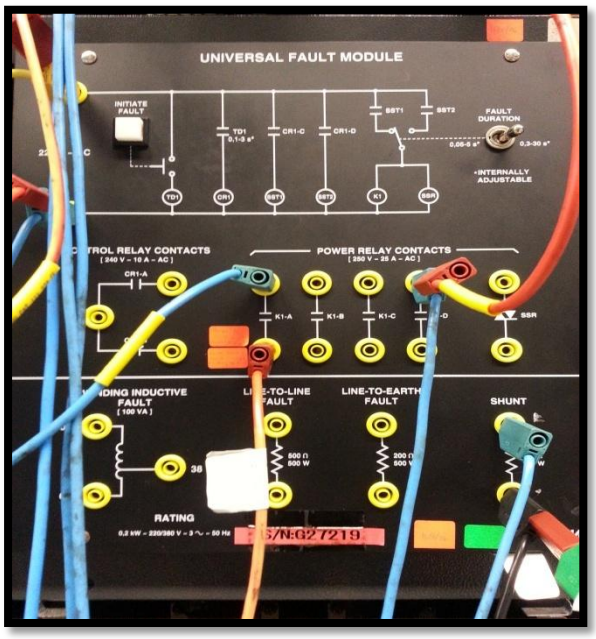


Figure 16: Universal Fault Module

Figure 17: Synchronous Generator

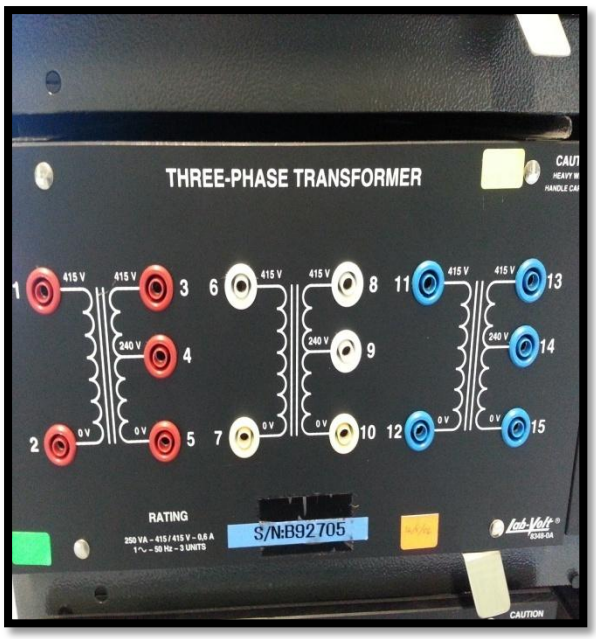


Figure 18: Three-Phase Transformer

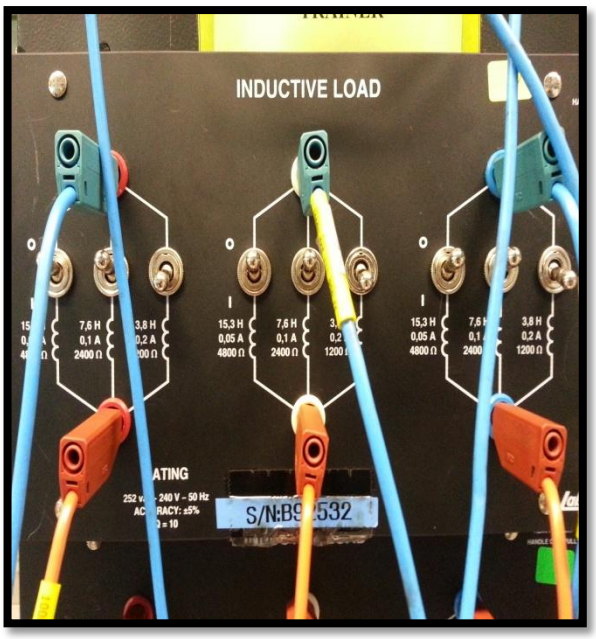


Figure 19: Inductive Load

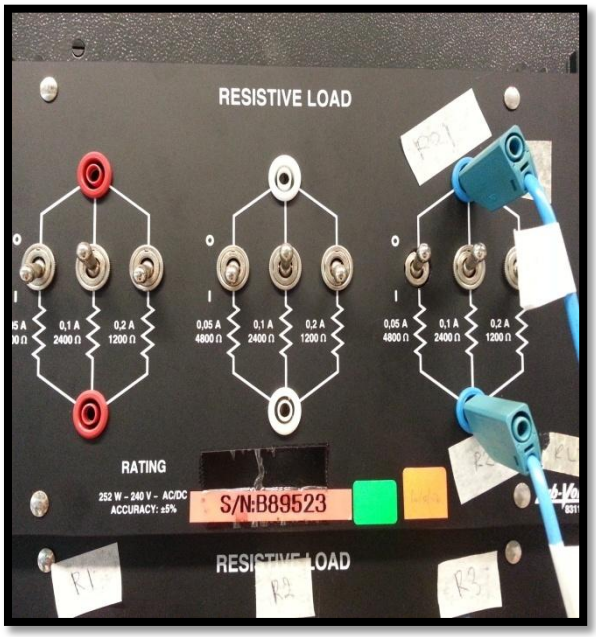


Figure 20: Resistive Load

CHAPTER 4

RESULTS

4.1 BASE EXPERIMENT (BEFORE FAULT)

This experiment is different from base experiment because of the presence of current transformer and universal fault module which will cause the neutral voltage flowing back to neutral of generator is very small whereas base experiment does not involve other equipment. Refer to Appendices for more details on third harmonic voltages and currents phase magnitude and phase angle

4.1.1 Generator – Load

Figure 21, 22, 23 and 24 shows the third harmonic voltage and current measurement taken at generator and load terminal. The data shows that third harmonic current magnitude is tripled at the neutral. As the load impedance increase, the third harmonic current shows decrease of magnitude value. For the voltage value, it is almost the same for all the load variation. The phase angle between each phase for the fundamental voltage is 120° apart and the current is almost 30° lagging for each phase current.

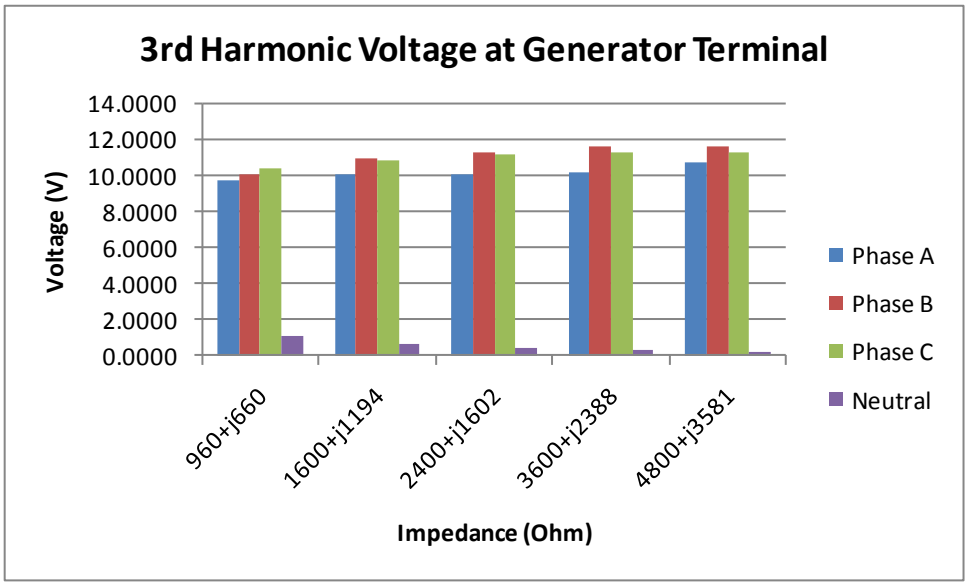


Figure 21: 3rd harmonic voltage for varied load magnitude

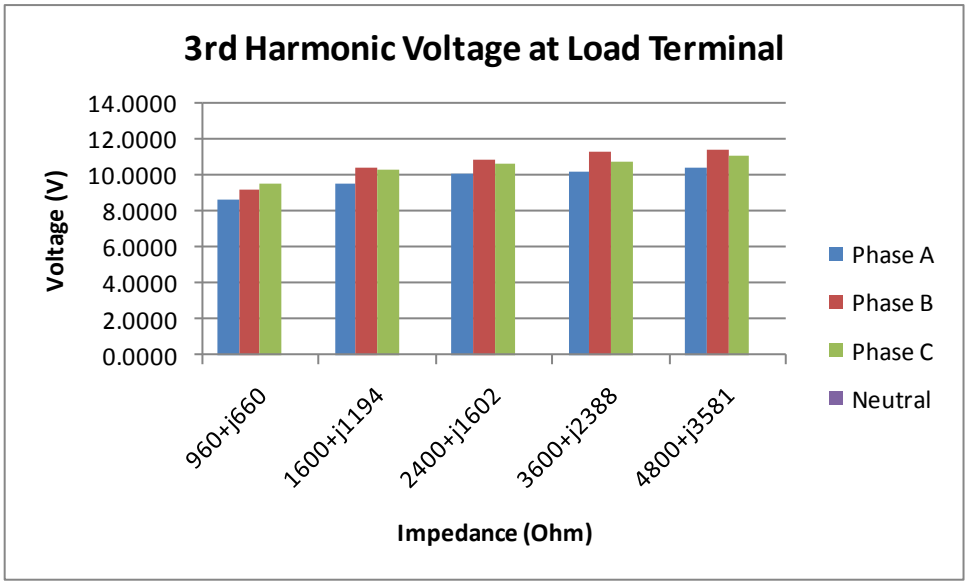


Figure 22: 3rd harmonic voltage for varied load magnitude

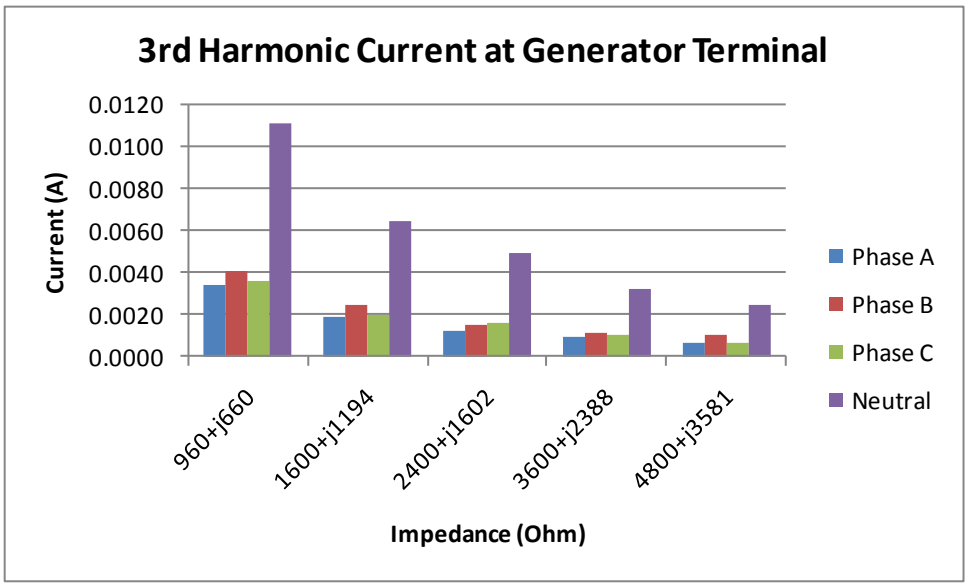


Figure 23: 3rd harmonic current for varied load magnitude

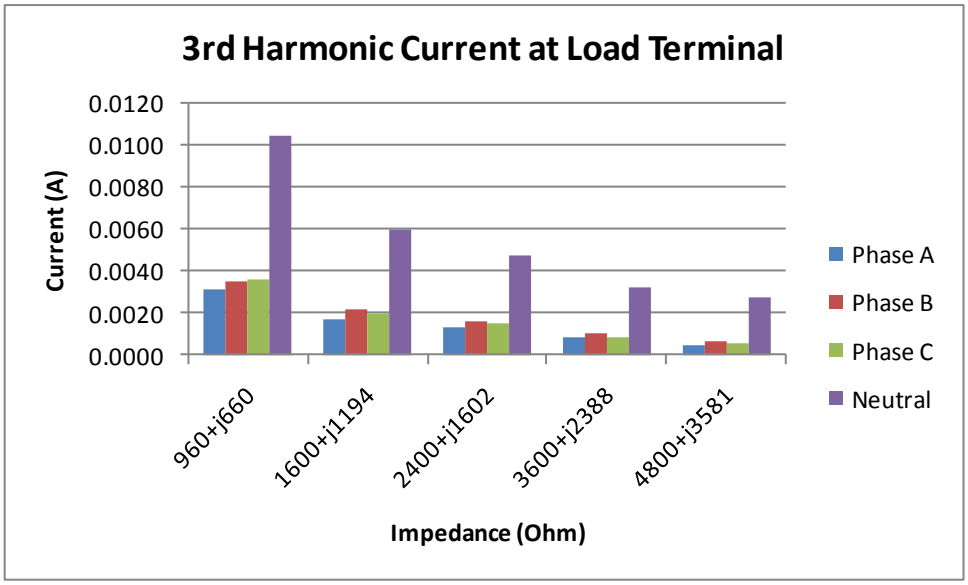


Figure 24: 3rd harmonic current for varied load magnitude

4.1.2 Generator – Transformer – Load

Figure 25 to 32 shows the third harmonic voltage and current measurement taken at generator, transformer Delta and Wye, and load terminal. From the results of the experiment, the third harmonic voltage is the highest at the generator point than any other point. The third harmonic current is the highest at the Delta point because Delta connection has no neutral connection. Hence, the third harmonic current circulates at Delta. The third harmonic current cannot travel through the secondary transformer because of the Delta-Wye connection causing small third harmonic current presence at the secondary transformer and at the load.

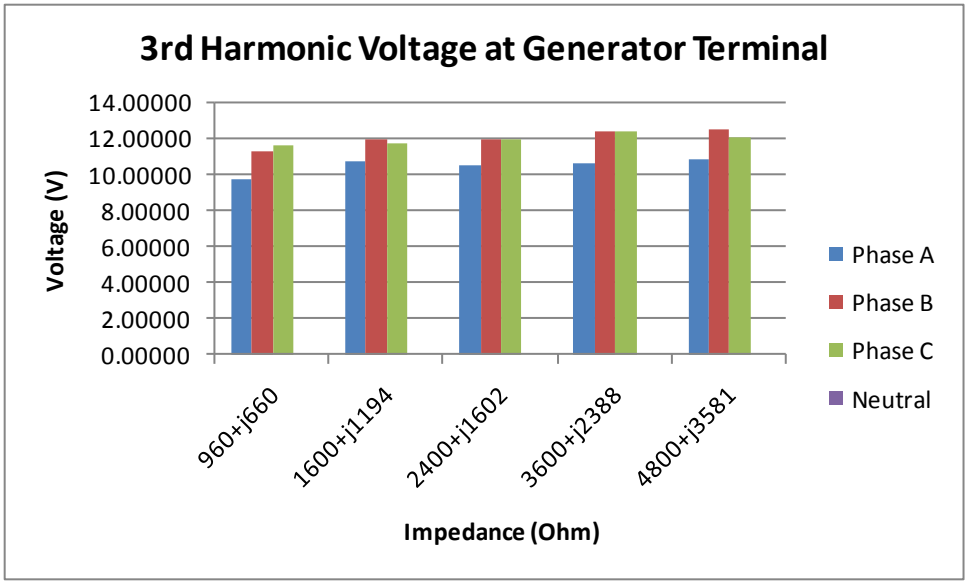


Figure 25: 3rd harmonic voltage for varied load magnitude

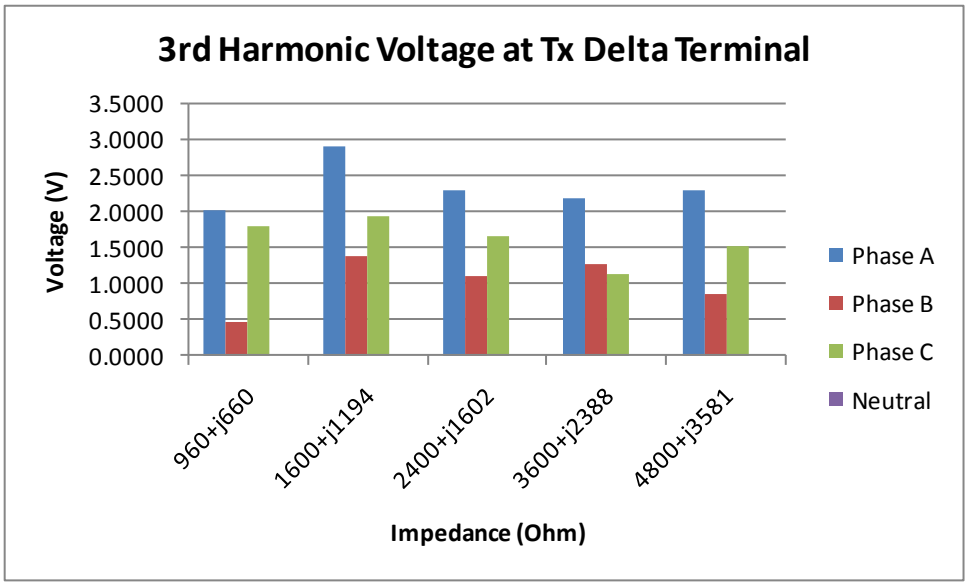


Figure 26: 3rd harmonic voltage for varied load magnitude

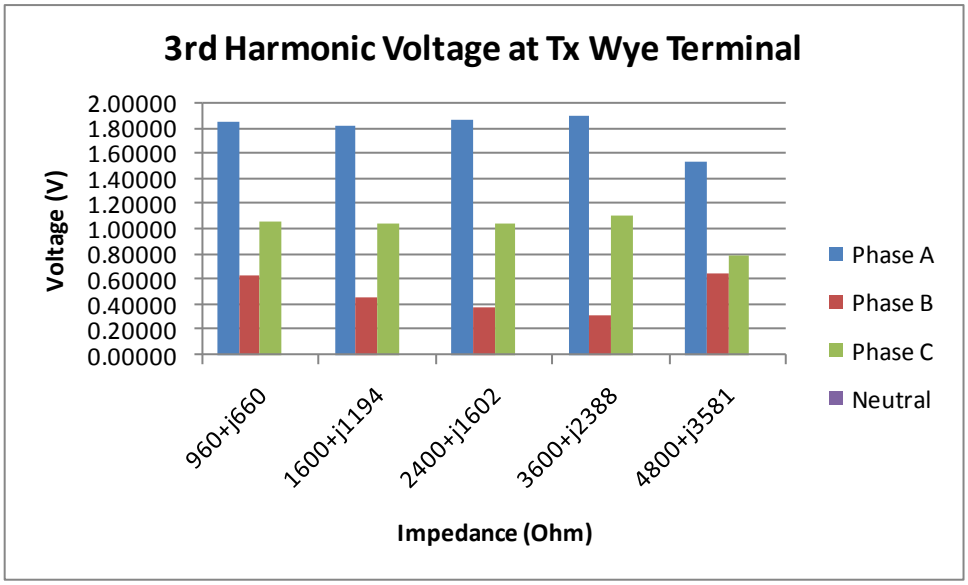


Figure 27: 3rd harmonic voltage for varied load magnitude

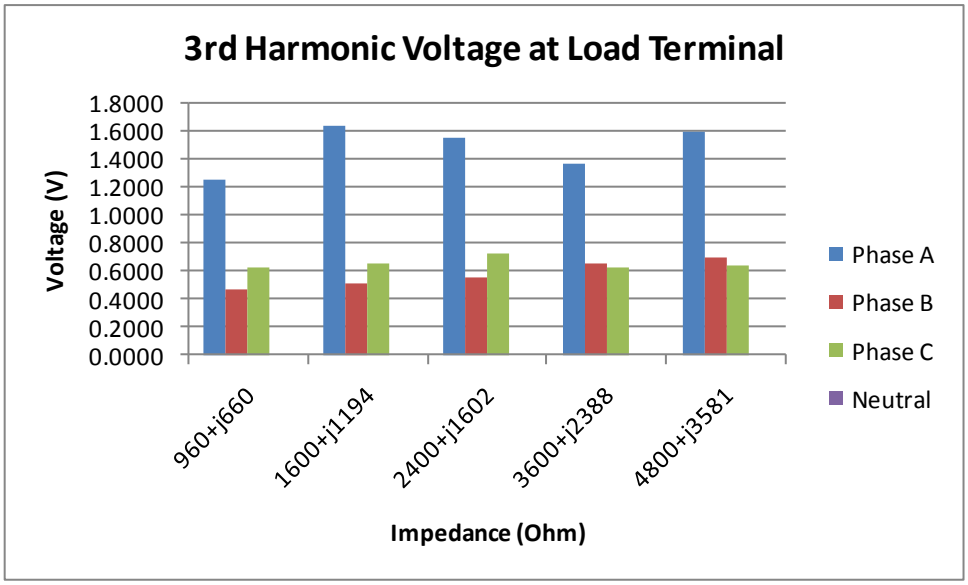


Figure 28: 3rd harmonic voltage for varied load magnitude

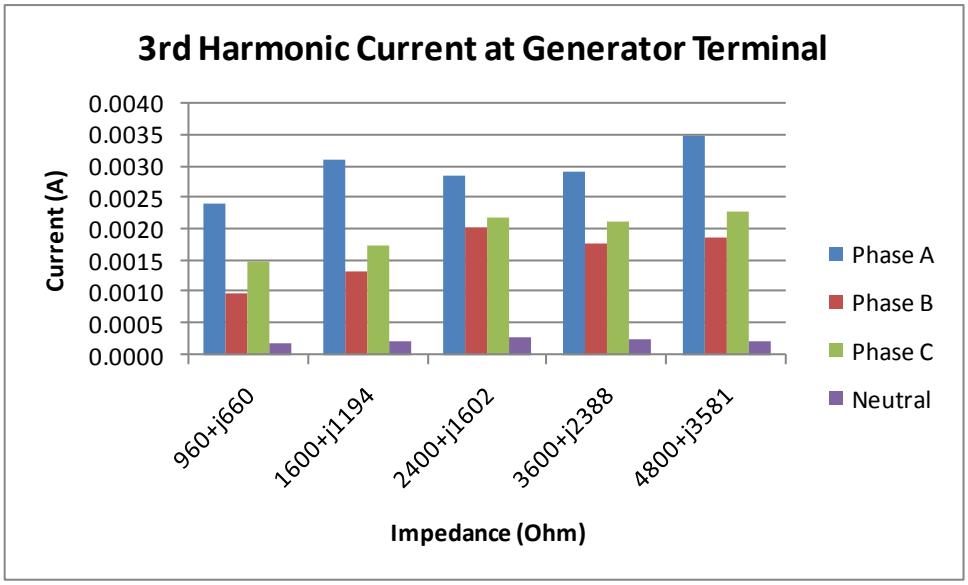


Figure 29: 3rd harmonic current for varied load magnitude

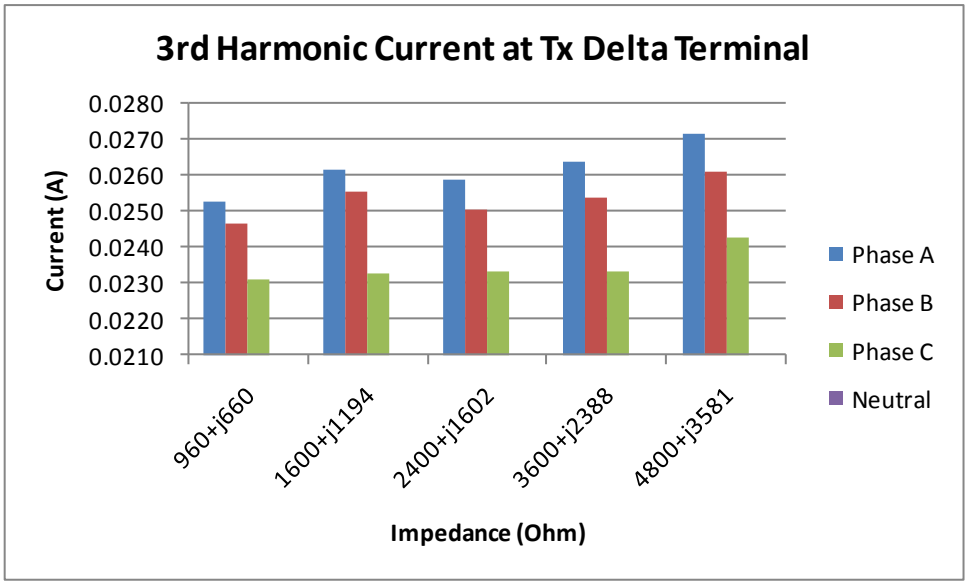


Figure 30: 3rd harmonic current for varied load magnitude

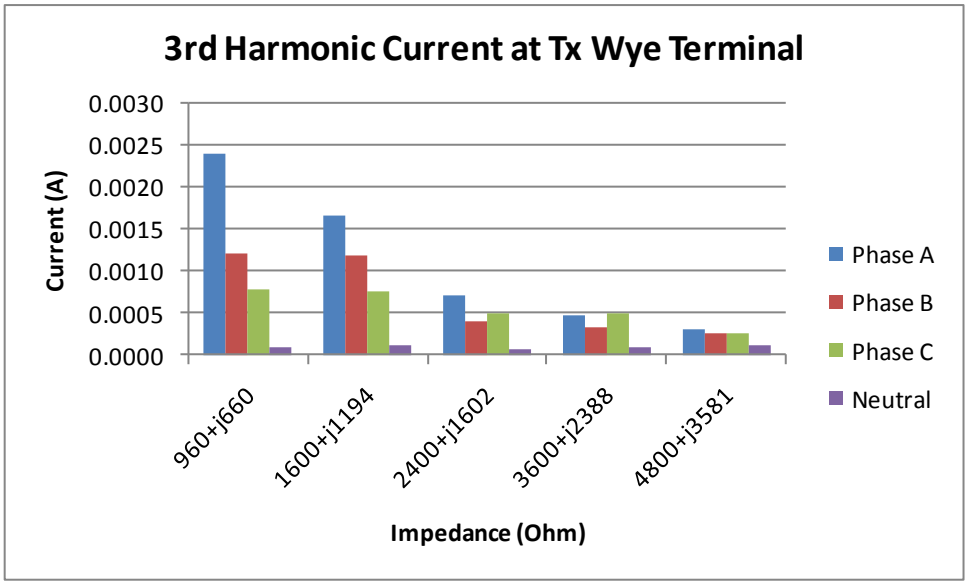


Figure 31: 3rd harmonic current for varied load magnitude

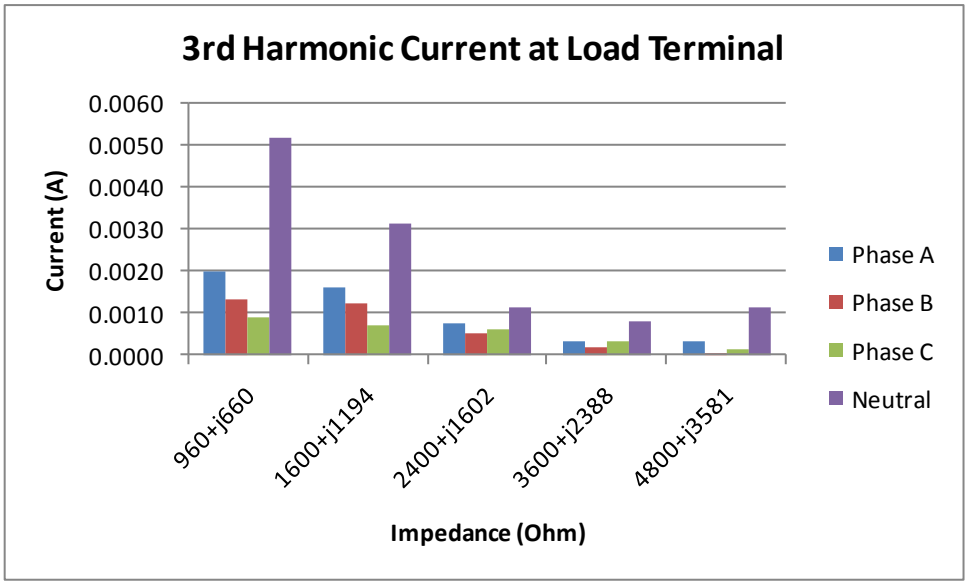


Figure 32: 3rd harmonic current for varied load magnitude

4.2 UNBALANCED LOAD EXPERIMENT

For this experiment, new load is introduced to simulate the unbalanced load during the occurrence of ground fault. This data is to compare the third harmonic voltage and current data during ground fault. The new load is:

Table 5: New Unbalanced Load

New Load	Phase A	Phase B & Phase C
Load 1	960+j660	1600+j1194
Load 2	960+j660	2400+j1602
Load 3	960+j660	3600+j2388
Load 4	960+j660	4800+j3581
Load 5	1600+j1194	2400+j1602

Basically, the load at Phase A is maintained at constant load and the load at Phase B and C is varied. Refer to Appendices 31 to 40 for more details on third harmonic voltages and current magnitude and phase angle.

4.2.1 Generator – Load

With the same configuration as the previous generator-load connection, the experiment is repeated with new load being used in this experiment. Difference in this experiment and fault experiment is that the phase angle of Phase A is not affected by any resistance angle as it maintain in negative angle whereas in fault experiment Phase A angle changes from negative angle to positive angle. This is because there is a presence of resistor in fault experiment to minimize the current flowing back to generator. For more details refer to Appendices.

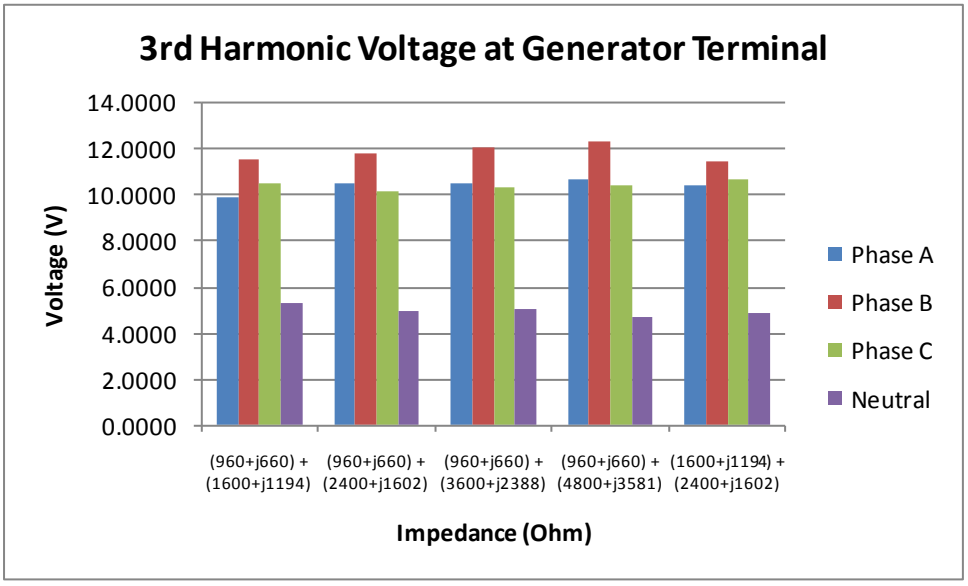


Figure 33: 3rd harmonic voltage for varied load magnitude

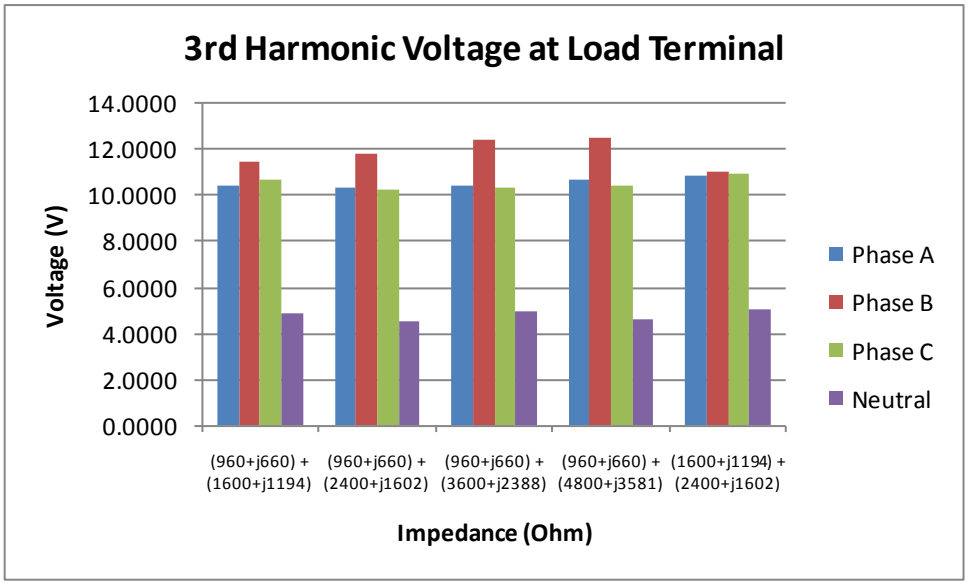


Figure 34: 3rd harmonic voltage for varied load magnitude

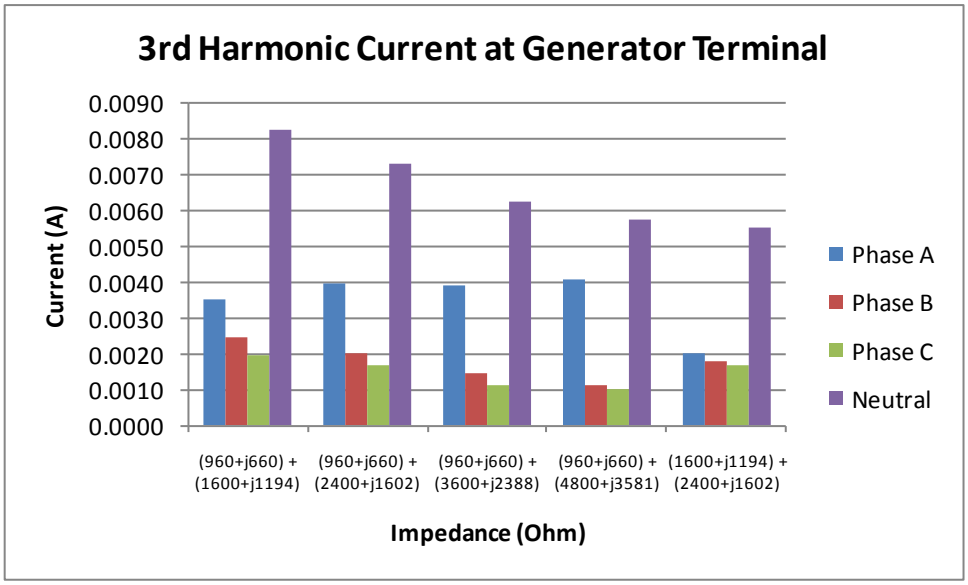


Figure 35: 3rd harmonic current for varied load magnitude

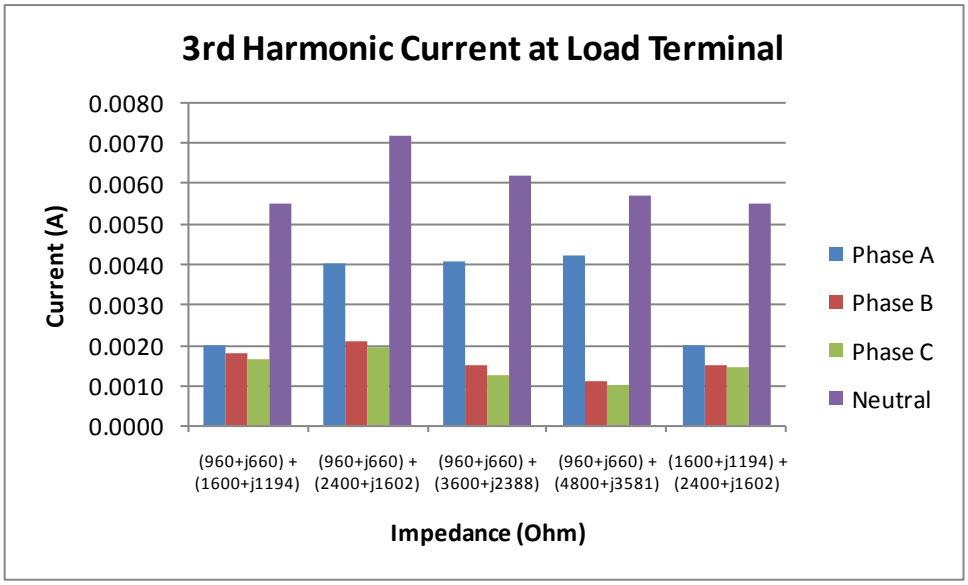


Figure 36: 3rd harmonic current for varied load magnitude

4.2.2 Generator – Transformer – Load

With the same configuration as the previous generator-transformer-load connection, the experiment is repeated with new load being used in this experiment. Difference in this experiment and fault experiment is that the phase angle of Phase A is not affected by any resistance angle as it maintain in negative angle whereas in fault experiment Phase A angle changes from negative angle to positive angle. This is because there is a presence of resistor in fault experiment to minimize the current flowing back to generator. For more details refer to Appendices.

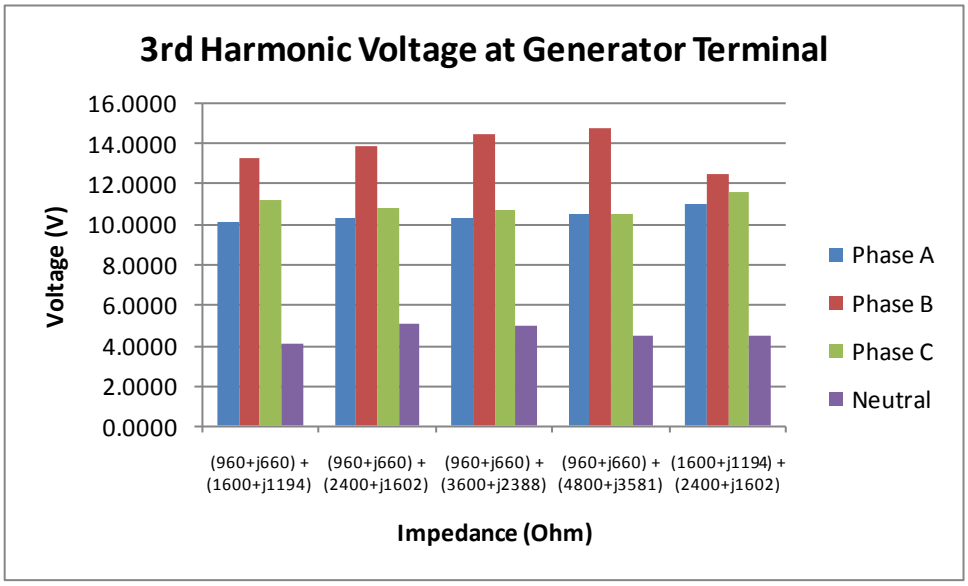


Figure 37: 3rd harmonic voltage for varied load magnitude

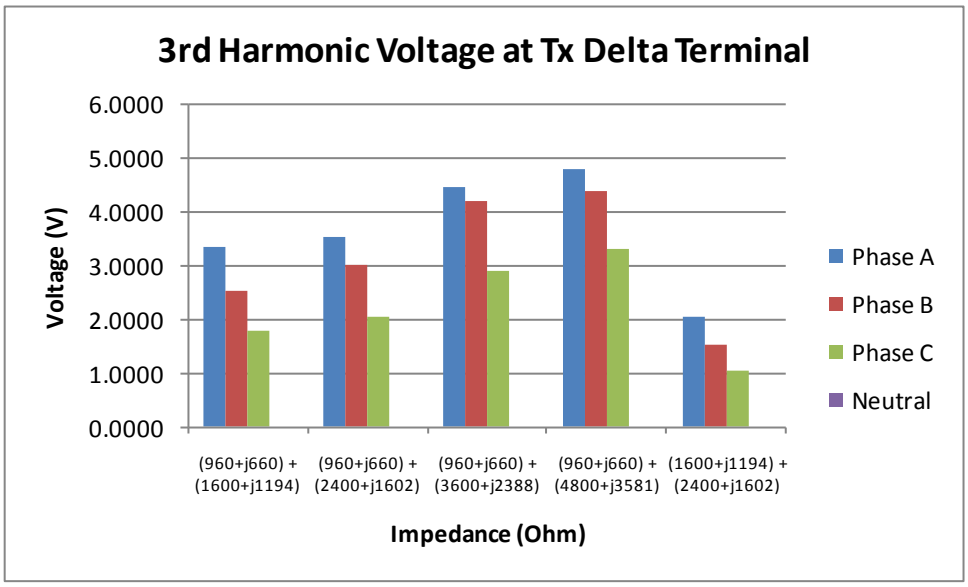


Figure 38: 3rd harmonic voltage for varied load magnitude

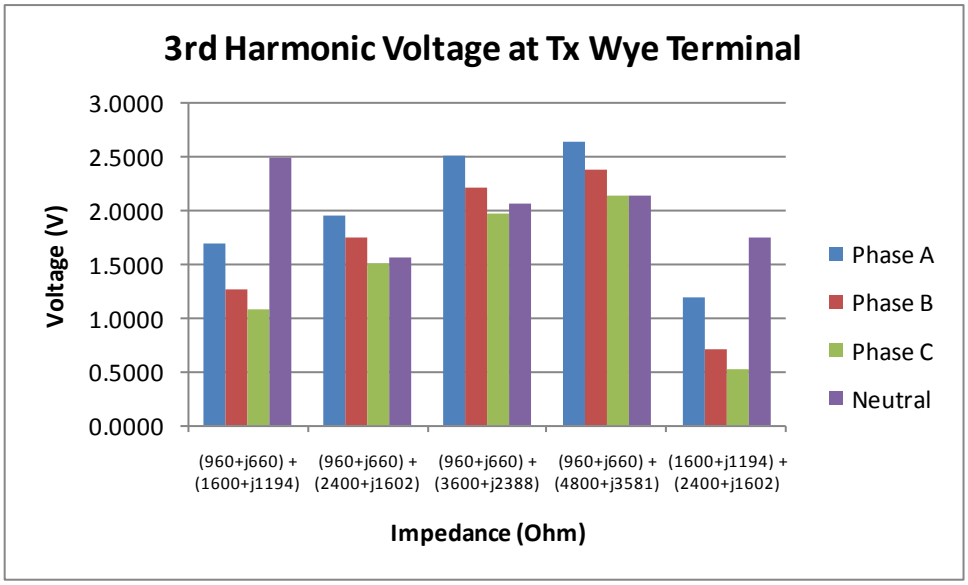


Figure 39: 3rd harmonic voltage for varied load magnitude

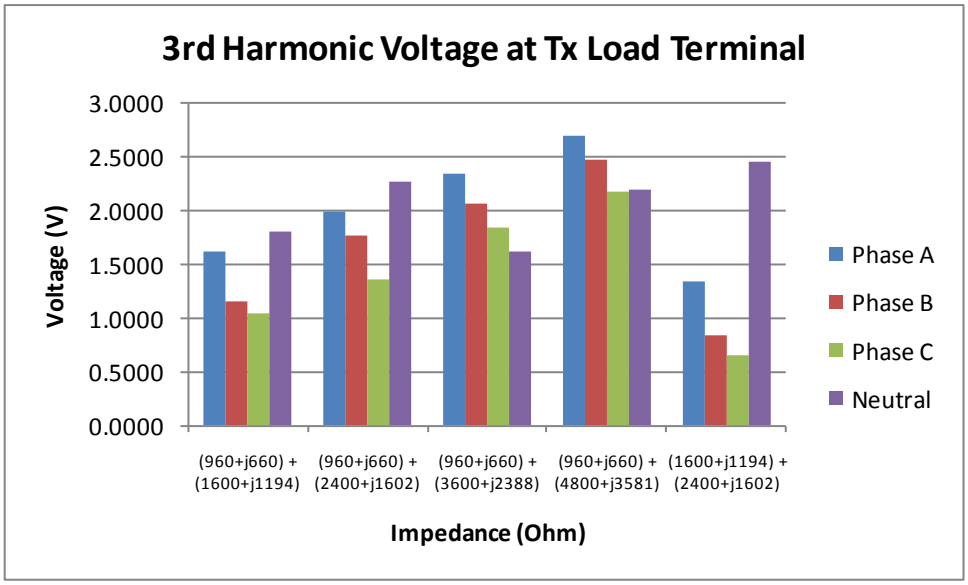


Figure 40: 3rd harmonic voltage for varied load magnitude

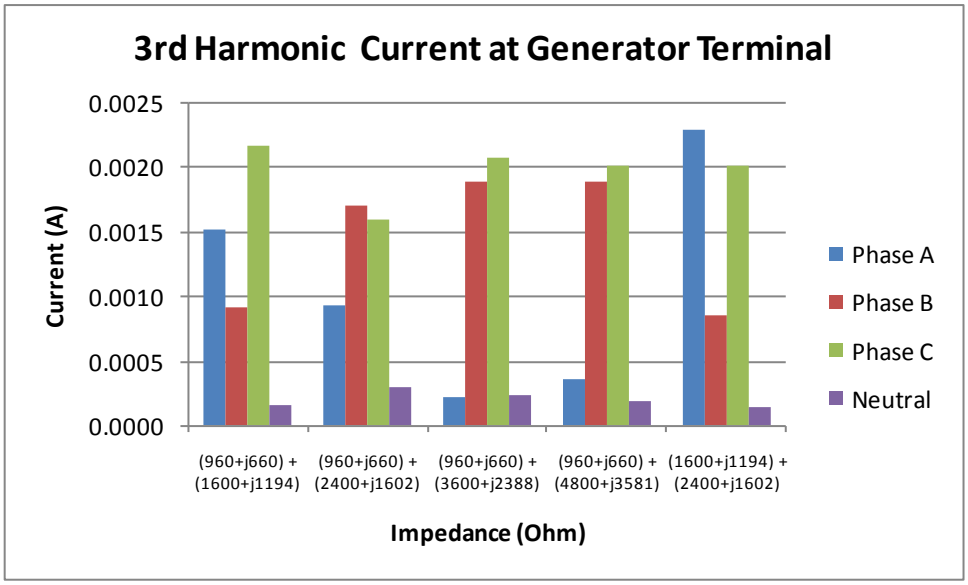


Figure 41: 3rd harmonic current for varied load magnitude

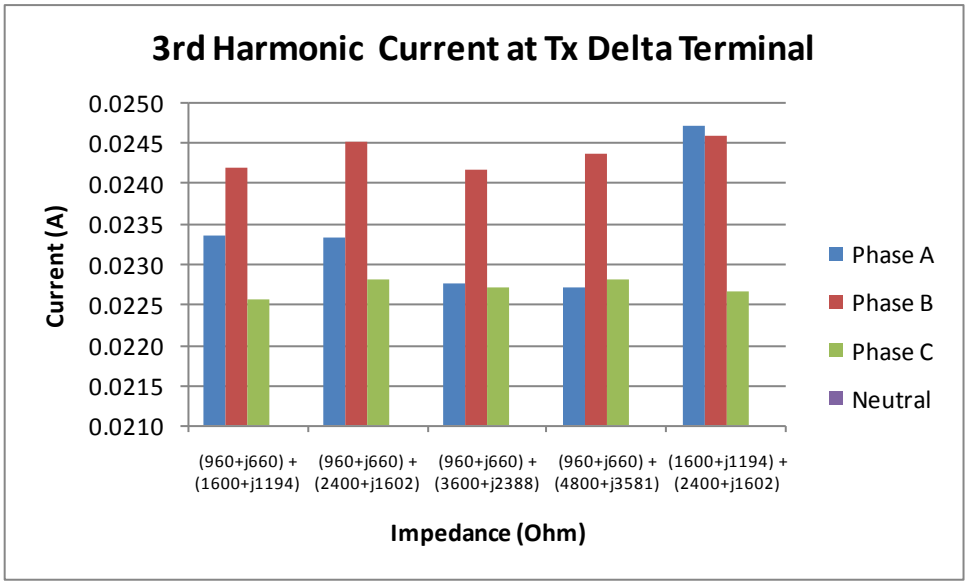


Figure 42: 3rd harmonic current for varied load magnitude

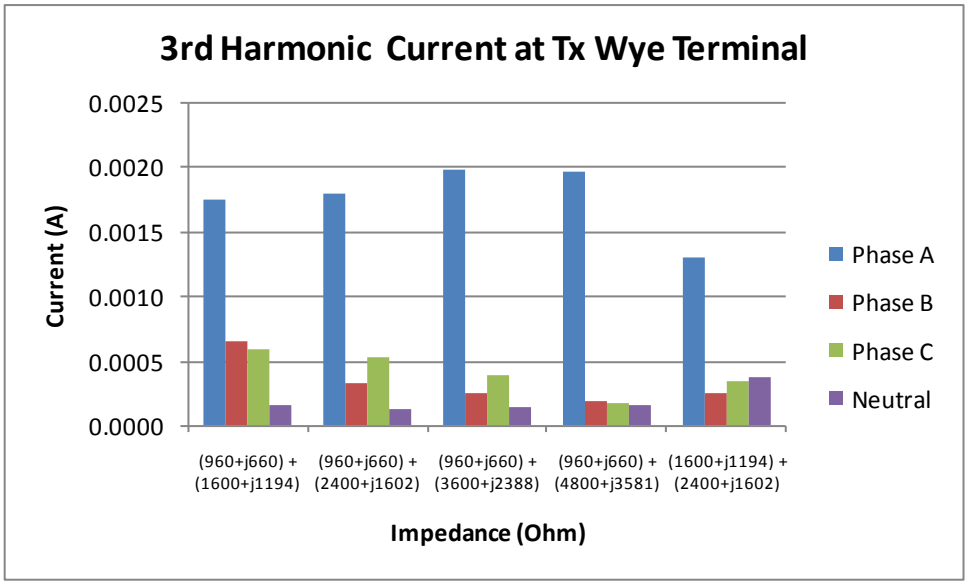


Figure 43: 3rd harmonic current for varied load magnitude

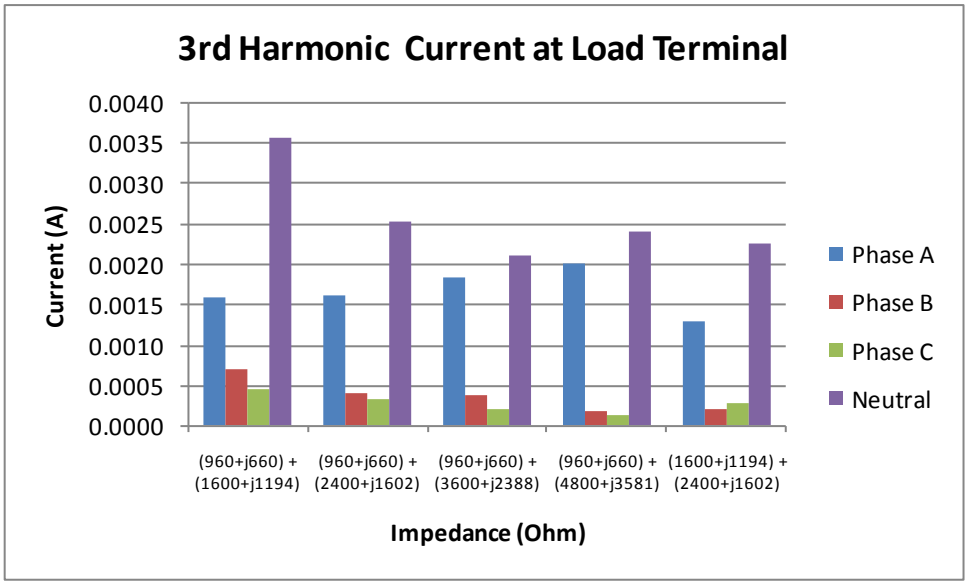


Figure 44: 3rd harmonic current for varied load magnitude

4.3 FAULT EXPERIMENT

The experiment is conducted with the same configuration with the base experiment which is direct-load connection and generator-transformer-load connection but in this experiment a fault is intentionally created at Phase A to simulate a single line to ground fault. The circuit diagram is shown in Figure 7 and 9. Refer to Appendices for more details on third harmonic voltage and current magnitude and phase angle.

4.3.1 Generator – Load

Figure 33 to 36 shows the third harmonic voltage and current measurement taken at generator and load terminal during fault. The magnitude of third harmonic voltage and current fault for each load variation is:

Table 6: Voltage and current magnitude and degrees for each load

Load	Voltage Magnitude (V)	Voltage Phase Angle (°deg)	Current Magnitude (A)	Current Phase Angle (°deg)
960+j660	0.0012	-82.3150	0.0002	35.6268
1600+j1194	0.0035	74.3195	0.0002	25.4995
2400+j1602	0.0028	143.1625	0.0002	28.7557
3600+j2388	0.0015	-36.1022	0.0002	30.0926
4800+j3581	0.0032	-22.8142	0.0002	35.1074

From the data collected, the third harmonic current difference at the highest impedance is the highest than all the other impedance. During fault, the voltage at Phase A drops in about 16% of the fundamental voltage for all load variation. Before fault, the third harmonic current in the neutral is tripled but during fault occurred, the third harmonic current at Phase A tripled and at the neutral it decreases. The fundamental current at Phase A increases in about 70% increment during ground fault.

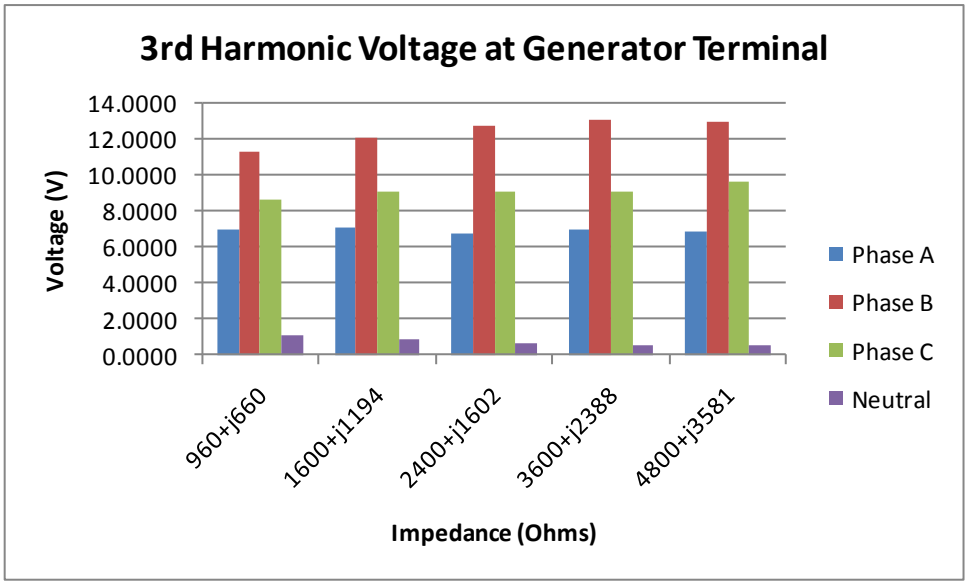


Figure 45: 3rd harmonic voltage for varied load magnitude

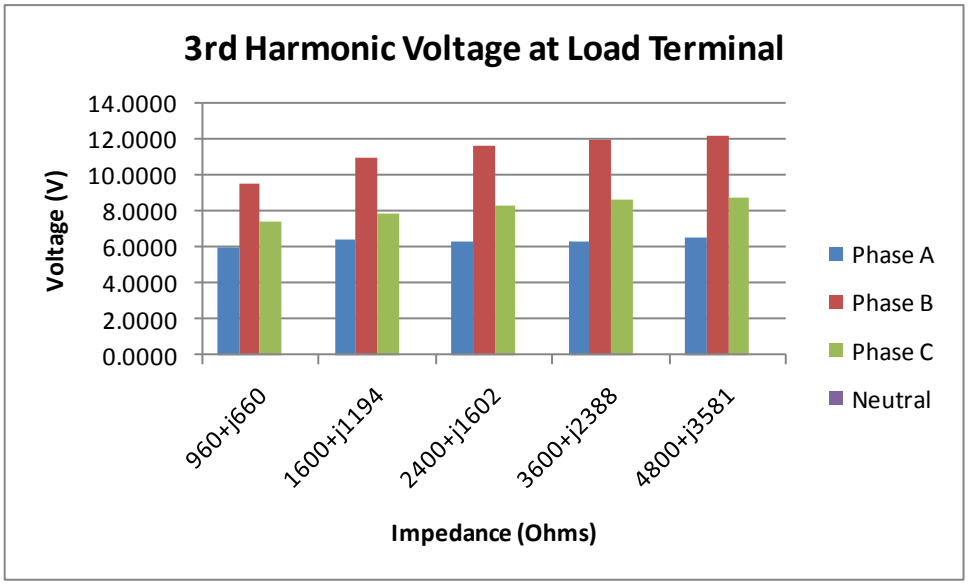


Figure 46: 3rd harmonic voltage for varied load magnitude

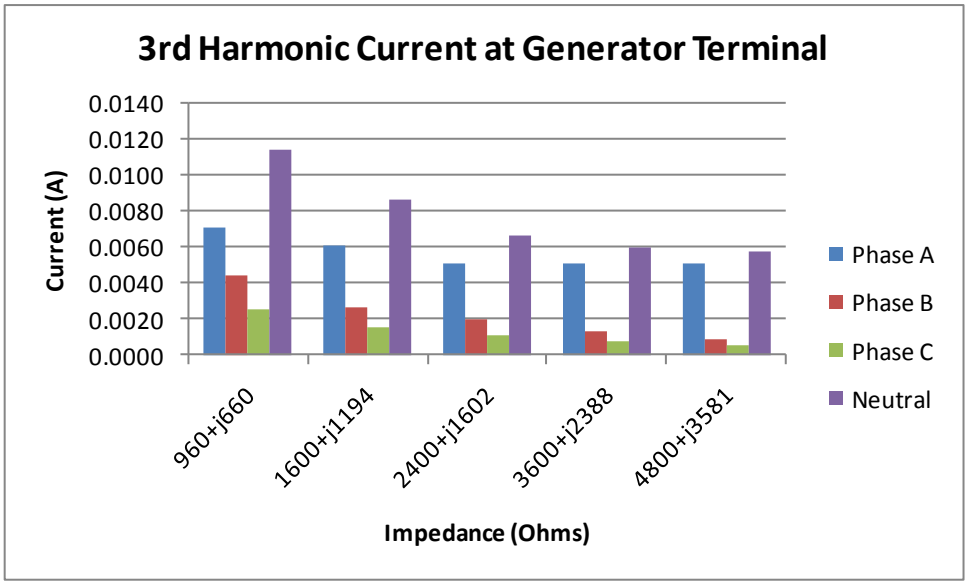


Figure 47: 3rd harmonic current for varied load magnitude

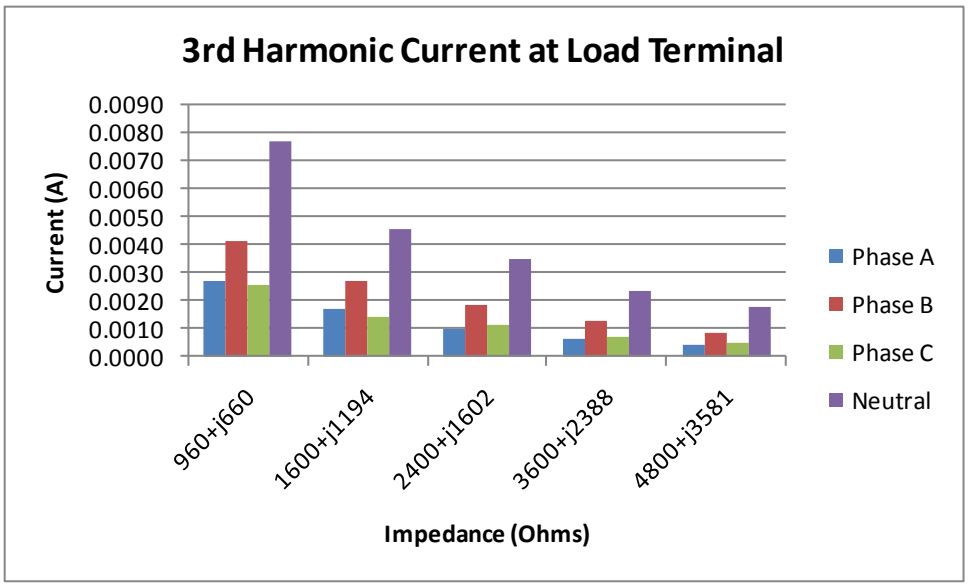


Figure 48: 3rd harmonic current for varied load magnitude

The percentage of difference in magnitude of third harmonic current travelling to neutral of generator before and during fault is:

Table 7: Percentage difference of current for each load

Load	Before Fault Current (A)	During Fault Current (A)	Percentage Difference % (+ increase, - decrease)
960+j660	0.0111	0.0114	+2.70
1600+j1194	0.0065	0.0086	+32.31
2400+j1602	0.0050	0.0066	+32.00
3600+j2388	0.0032	0.0060	+87.50
4800+j3581	0.0025	0.0058	+132.00

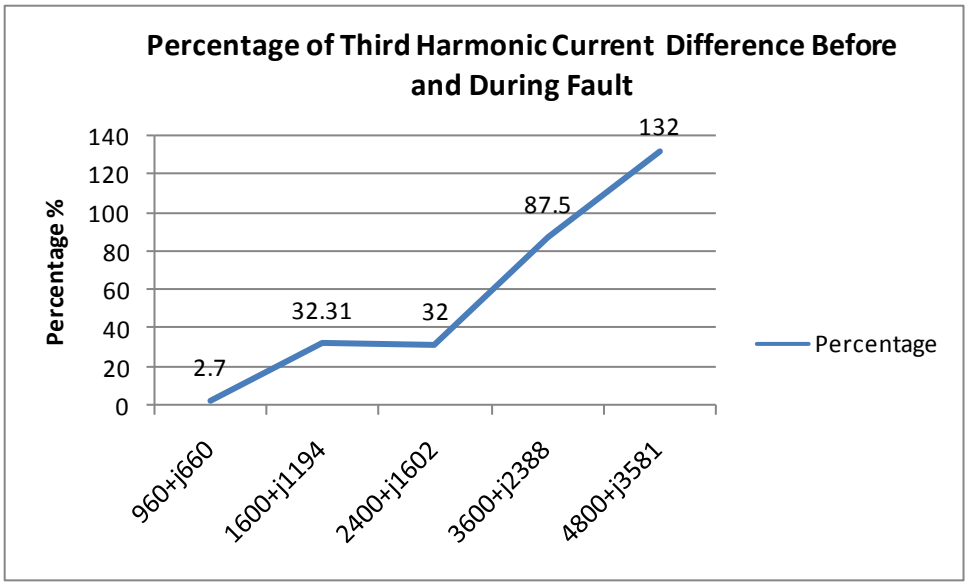


Figure 49: Third harmonic current percentage difference between before and during fault current

4.3.2 Generator – Transformer – Load

Figure 38 to 45 shows the third harmonic voltage and current reading taken at generator, transformer Delta and Wye, and load terminal during fault. The magnitude of third harmonic voltage and current fault for each load variation is:

Table 8: Voltage and current magnitude and degrees for each load

Load	Voltage Magnitude (V)	Voltage Phase Angle (°deg)	Current Magnitude (A)	Current Phase Angle (°deg)
960+j660	0.00052	163.87250	0.00577	34.49155
1600+j1194	0.0007	44.2407	0.0057	24.4655
2400+j1602	0.0004	66.5461	0.0055	22.5885
3600+j2388	0.0006	-137.6443	0.0058	20.4979
4800+j3581	0.0004	65.3878	0.0058	17.2932

From the data collected, it shows huge increase of third harmonic current that flows back to the neutral of generator during fault. The third harmonic current at the generator increase during the occurrence of fault because of the fault provided a zero sequence path for the third harmonic current to flow back to the neutral of the generator. The third harmonic current that circulates at Delta only shows small decrease of current at Phase A when fault occurred and no differences between the other two phase.

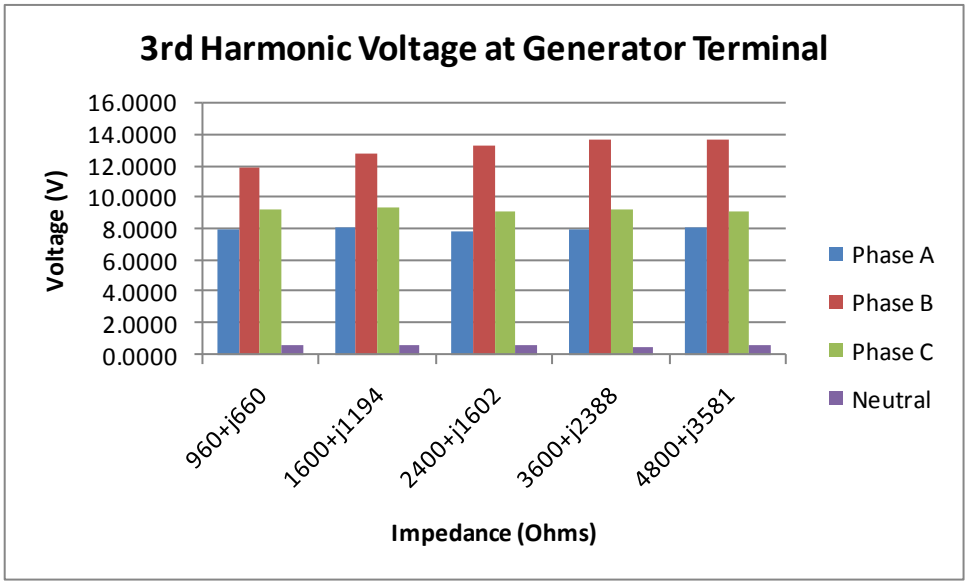


Figure 50: 3rd harmonic voltage for varied load magnitude

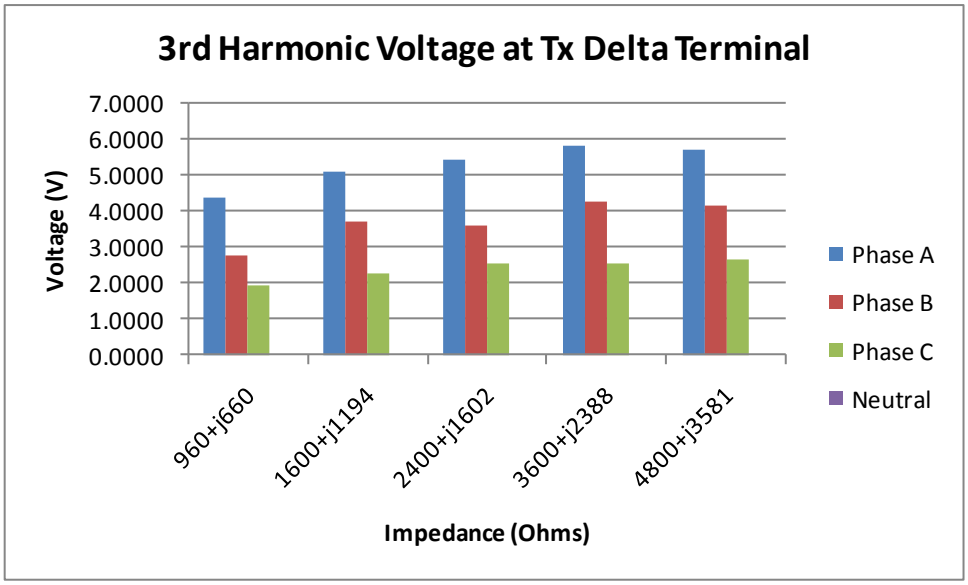


Figure 51: 3rd harmonic voltage for varied load magnitude

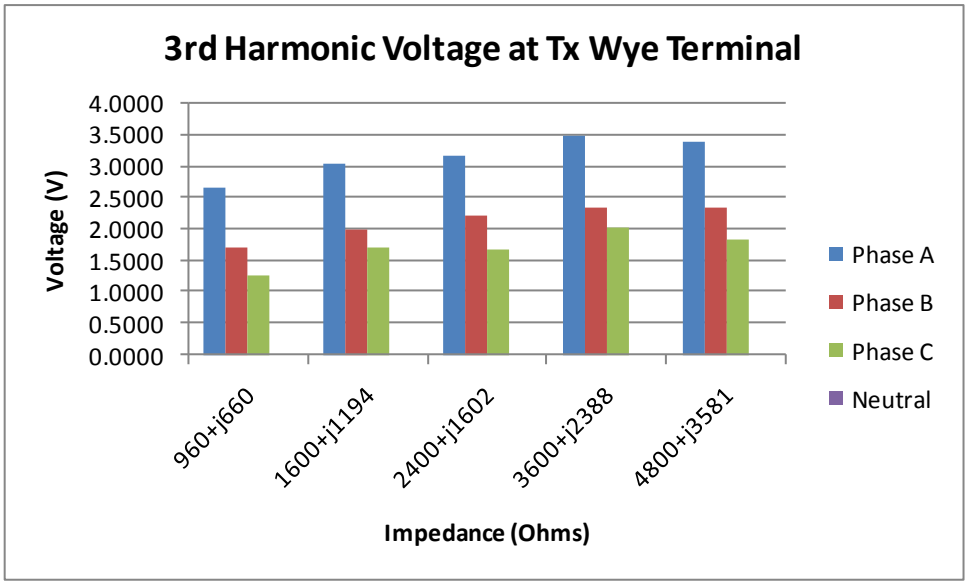


Figure 52: 3rd harmonic voltage for varied load magnitude

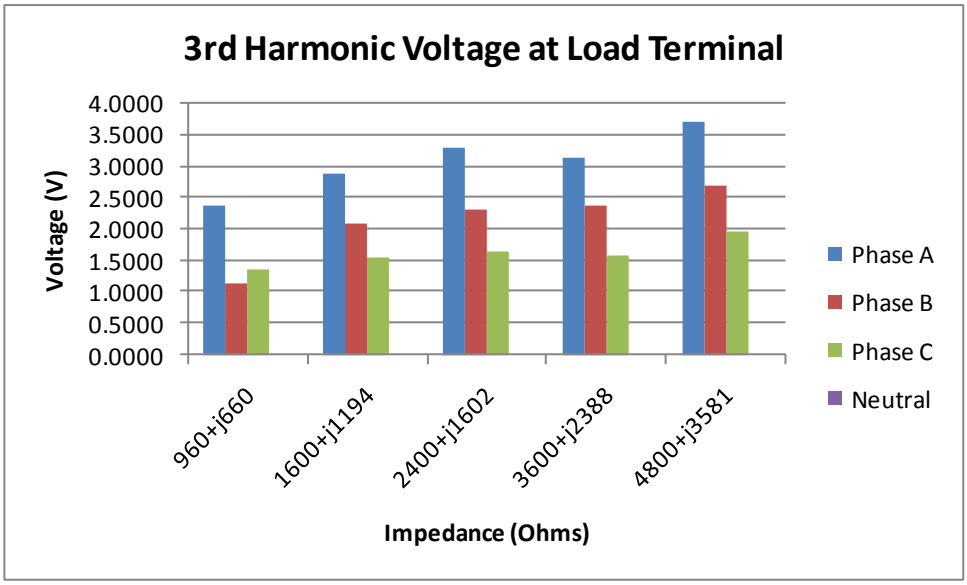


Figure 53: 3rd harmonic voltage for varied load magnitude

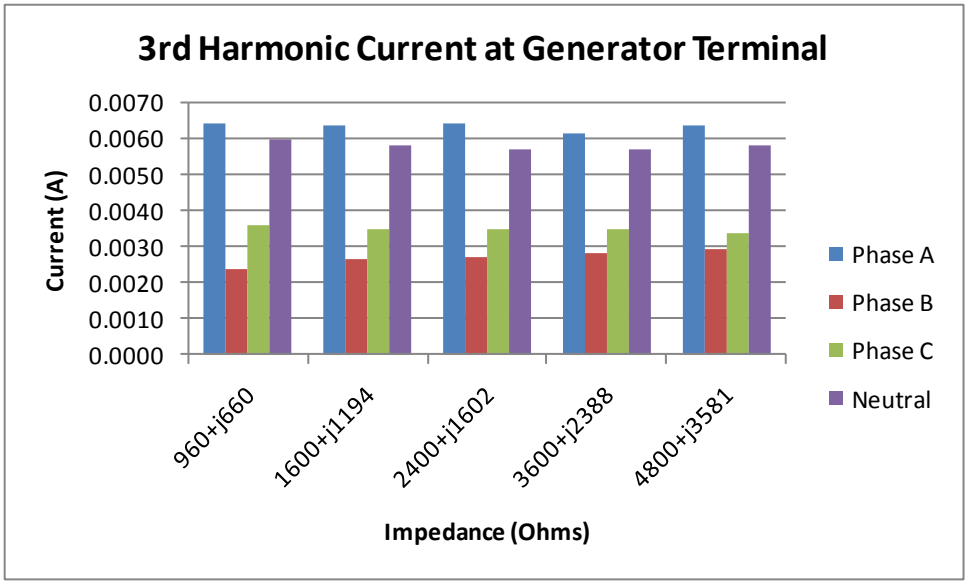


Figure 54: 3rd harmonic current for varied load magnitude

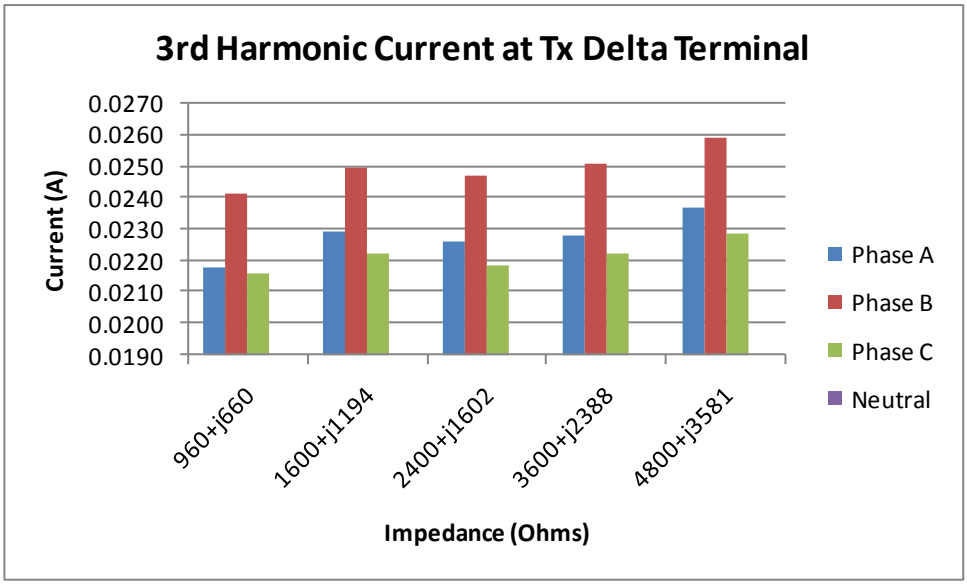


Figure 55: 3rd harmonic current for varied load magnitude

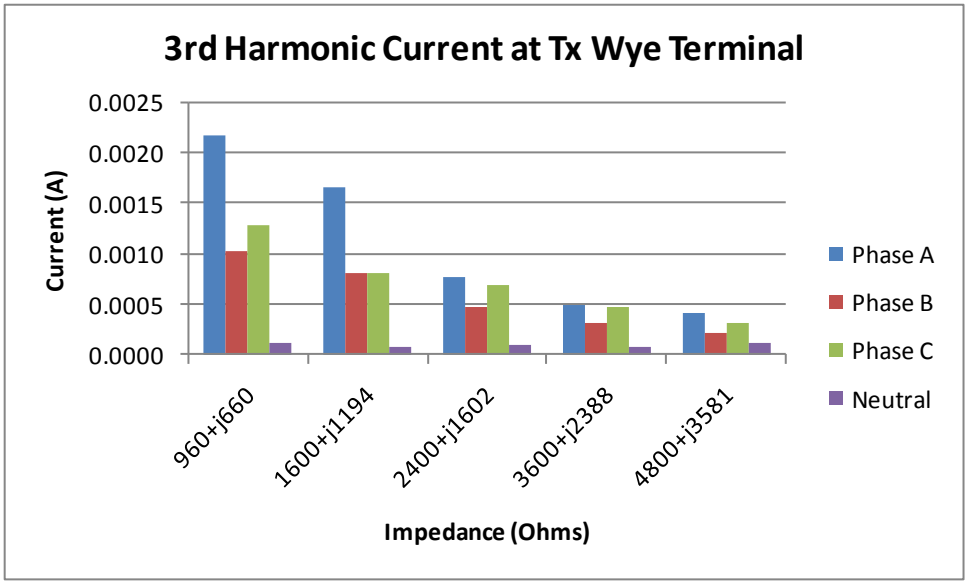


Figure 56: 3rd harmonic current for varied load magnitude

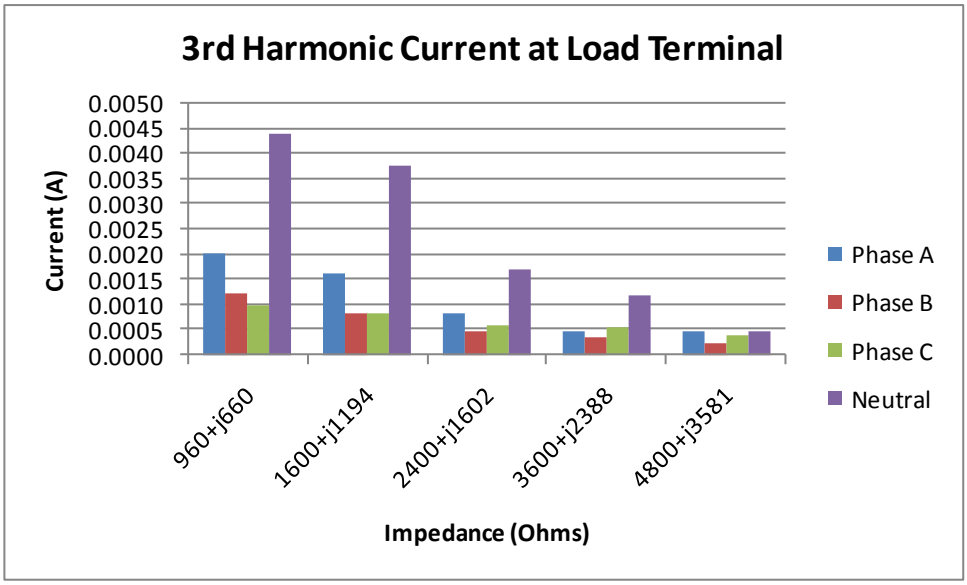


Figure 57: 3rd harmonic current for varied load magnitude

The percentage of difference in magnitude of third harmonic current travelling to neutral of generator before and during fault is:

Table 9: Percentage difference of current for each load

Load	Before Fault Current (A)	During Fault Current (A)	Percentage Difference % (+ increase, - decrease)
960+j660	0.0002	0.0060	+2900
1600+j1194	0.0002	0.0059	+2850
2400+j1602	0.0003	0.0057	+1800
3600+j2388	0.0003	0.0057	+1800
4800+j3581	0.0002	0.0058	+2800

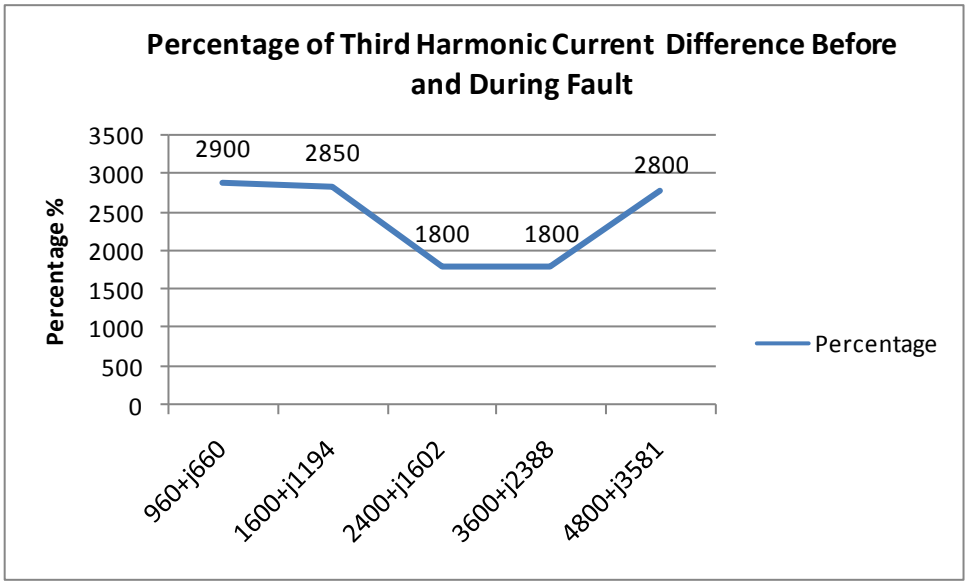


Figure 58: Third harmonic current percentage difference between before and during fault current

CONCLUSION

In the base experiment, it is proven that third harmonic current is tripled at the neutral. The third harmonic current travels through the neutral because the neutral serves as zero sequence pathway for the current. Each of the line phase angle will be almost the same phase angle. Hence, the phase angle magnitude at the neutral will be the summation of the phase magnitude for each line, making it tripled at the neutral.

During ground fault, third harmonic current at the neutral is higher than before fault occurred. When fault occurred, the current flows through a resistor with 1200 Ω and this causes the phase angle to change from negative to positive phase angle. This makes the load becomes unbalanced and third harmonic current no longer tripled at the neutral. This is the same for generator-load connection and generator-transformer-load connection.

Third harmonic current contribute to ground fault. Because ground fault serves as zero sequence pathway for the current to flow to ground and back to neutral of generator. The third harmonic current becomes an additional current during ground fault. Generator-load connection has a lower third harmonic current returning to neutral of generator than generator-transformer-load connection because Delta connection transformer stores all the third harmonic current in steady-state condition. When ground fault occurs, it releases all the third harmonic current to flow back to generator.

Since the fault occurred at Phase A, the third harmonic current at Phase A increase during fault. This shows that Phase A provides zero sequence path for the triplen harmonics currents to flow back to the generator.

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APPENDICES

Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)
240.1274	0.0000	0.1910	-33.1364	239.4143	0.0000	0.1913	-32.8649
239.4475	-119.6448	0.1914	-153.2992	238.8834	-119.7598	0.1912	-152.9309
240.8458	120.4415	0.1905	87.6273	240.1581	120.3910	0.1895	87.8260
6.7003	-90.7793	0.0029	-160.8678	5.8009	-101.7942	0.0027	-160.5861

Gen — Load

Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
9.6027	10.5710	0.0032	-29.6025	9.7923	12.5983	0.0036	-30.9767
10.6519	18.1890	0.0039	-19.5660	10.4678	14.6956	0.0040	-27.6304
10.8706	10.9040	0.0038	-38.7657	10.4722	11.1299	0.0039	-33.0857
5.6489	-174.8576	0.0116	-30.3420	5.5264	-168.0075	0.0125	-31.2252

Appendix 1: 960+j660 base data value generator-load connection

Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(mAmps)	If°(deg)
239.5072	0.0000	0.1920	-32.9021	239.6982	0.0000	0.1941	-33.5212
239.2060	-119.8529	0.1920	-152.8766	238.3792	-119.6703	0.1943	-153.1518
240.3219	120.3468	0.1919	87.3454	239.8313	120.3677	0.1930	87.2961
0.3052	13.8380	0.0026	167.7797	0.0071	122.1751	0.0032	-169.9519

Gen — Load

Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
9.7326	10.4837	0.0034	-19.9951	8.6127	12.0436	0.0031	-23.7216
10.1642	13.2399	0.0041	-23.4185	9.2137	15.9060	0.0036	-20.9676
10.4479	9.6187	0.0036	-31.9134	9.5195	11.8083	0.0036	-33.6746
1.0672	155.1255	0.0111	-24.2504	0.0013	-3.2017	0.0105	-27.2932

Vfault(Volt)	Vfault°(deg)	Ifault(Amps)	Ifault°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
239.8266	0.0006	0.0014	133.5568	8.8559	14.5804	0.0001	42.2155
0.0000	59.8600	0.0031	-114.7928	0.0006	-103.1145	0.0003	44.1088

Fault

Appendix 2: 960+j660 before fault data value generator-load connection

Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)
218.3308	0.0000	0.3060	-15.9492	212.1625	0.0000	0.1731	-32.3712
228.4420	-117.3325	0.1908	-152.0714	234.1734	-119.5283	0.1931	-151.9057
234.0024	121.9668	0.1933	92.7882	238.4119	125.2259	0.1937	93.0413
11.3357	-174.0972	0.1157	6.8917	0.0091	135.0154	0.0348	159.7466

Gen — Load

Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
7.0075	38.1235	0.0071	29.9564	6.0358	42.8662	0.0027	5.1908
11.2801	27.1853	0.0044	-10.7561	9.5237	27.7787	0.0041	-11.2728
8.7099	17.4662	0.0025	-25.5652	7.3988	20.1263	0.0026	-18.2078
1.1408	-170.8336	0.0114	9.0717	0.0011	17.5050	0.0077	-7.7080

Vfault(Volt)	Vfault°(deg)	Ifault(Amps)	Ifault°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
206.9470	0.0000	0.1472	0.9206	5.9652	46.4117	0.0043	46.9656
0.0026	101.9940	0.0047	-33.0115	0.0012	-82.3150	0.0002	35.6268

Fault

Appendix 3: 960+j660 during fault data value generator-load connection

Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)
239.8643	0.0000	0.1118	-34.4408	240.3656	0.0000	0.1122	-34.3684
239.1807	-119.7444	0.1120	-154.9286	239.6340	-119.6463	0.1121	-154.6518
240.5252	120.4344	0.1115	85.6732	241.1041	120.4672	0.1108	86.1284
4.9606	-77.4127	0.0013	179.7205	3.6813	-89.2097	0.0011	178.5684

Gen — Load

Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
10.4647	0.4016	0.0018	-37.9112	10.3386	-0.9160	0.0021	-36.3953
11.1540	3.6018	0.0023	-37.2914	11.1761	4.8500	0.0024	-31.0809
11.1249	0.0000	0.0022	-55.2023	11.3173	0.0000	0.0023	-43.5808
5.3297	172.5367	0.0070	-40.1973	4.9356	174.6862	0.0065	-39.5751

Appendix 4: 1600+j1194 base data value generator-load connection

Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)
240.6512	0.0000	0.1121	-33.8086	240.1908	0.0000	0.1127	-34.2882
240.1919	-119.8146	0.1118	-154.1181	239.3161	-119.7095	0.1127	-154.2020
241.3579	120.4171	0.1123	86.0118	240.4864	120.4877	0.1125	85.9557
0.0946	-14.5920	0.0015	110.3150	0.0071	122.8265	0.0011	162.4321

Gen — Load

Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
10.0567	0.6884	0.0019	-20.5413	9.5987	0.0000	0.0017	-25.8746
11.0433	1.2072	0.0025	-24.8683	10.4985	3.5622	0.0022	-29.1300
10.9233	-2.5732	0.0020	-45.3181	10.3807	0.0000	0.0020	-43.8661
0.6420	145.0850	0.0065	-33.8689	0.0013	-7.1530	0.0060	-37.3611

Vfault(Volt)	Vfault°(deg)	Ifault(Amps)	Ifault°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
239.8419	0.0000	0.0010	118.1341	9.8959	1.2698	0.0001	128.3762
0.0007	-162.5921	0.0023	-105.8599	0.0007	4.6094	0.0002	-16.2140

Fault

Appendix 5: 1600+j1194 before fault data value generator-load connection

Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)
216.6651	0.0000	0.2362	-11.6166	209.6414	0.0000	0.0994	-33.2484
227.0844	-117.2388	0.1106	-153.1273	233.0208	-119.8768	0.1112	-152.9845
233.0988	122.1774	0.1131	92.0648	237.9859	125.5061	0.1127	92.3394
12.5385	-175.8653	0.1281	5.0301	0.0081	129.1959	0.0210	154.4382

Gen — Load

Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
7.0795	31.0966	0.0061	26.2171	6.4315	31.9510	0.0017	4.4294
12.1076	15.4958	0.0027	-20.7932	11.0385	17.9021	0.0027	-16.0385
9.0824	5.3747	0.0015	-36.0630	7.8630	6.3381	0.0014	-37.0072
0.8559	-173.0530	0.0086	7.0057	0.0008	9.5107	0.0046	-16.9369

Vfault(Volt)	Vfault°(deg)	Ifault(Amps)	Ifault°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
206.2808	0.0000	0.1359	0.9650	6.4025	35.4075	0.0043	35.3123
0.0027	-170.6071	0.0050	-17.7068	0.0035	74.3195	0.0002	25.4995

Fault

Appendix 6: 1600+j1194 during fault data value generator-load connection

Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)
240.1377	0.0000	0.0786	-30.3328	239.8727	0.0000	0.0783	-30.3064
239.4809	-119.7489	0.0788	-150.1800	239.2656	-119.8114	0.0783	-150.0680
240.7767	120.4360	0.0784	90.6438	240.4084	120.4669	0.0776	90.6922
3.3329	-99.3331	0.0017	-162.9688	2.5541	-123.5892	0.0016	-166.3938

Gen — Load

Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
10.4572	-2.3550	0.0013	-40.9744	10.6556	-1.6840	0.0016	-47.7665
11.3135	-1.0784	0.0016	-45.6248	11.5553	-1.8940	0.0018	-53.5355
11.0293	-4.3912	0.0014	-46.0409	11.0331	-2.8418	0.0014	-54.5688
5.5584	161.5295	0.0048	-54.1243	4.7904	167.9461	0.0055	-52.7110

Appendix 7: 2400+j1602 base data value generator-load connection

Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)
239.9672	0.0000	0.0778	-29.4507	240.1020	0.0000	0.0784	-30.2963
239.5749	-119.7669	0.0780	-149.6975	239.1945	-119.6981	0.0788	-149.7584
240.7832	120.4153	0.0789	90.4586	240.3651	120.4537	0.0794	90.6475
0.1229	-11.6965	0.0016	117.8699	0.0071	122.9525	0.0014	161.6539

Gen — Load

Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
10.0819	-2.4268	0.0012	-44.6657	10.1415	-2.6547	0.0014	-49.5812
11.3326	-1.6297	0.0015	-39.5495	10.8562	0.2472	0.0016	-46.9270
11.2530	-5.3297	0.0016	-52.4033	10.6345	-2.3891	0.0016	-46.3480
0.4861	129.0871	0.0050	-50.6722	0.0009	-16.1364	0.0047	-50.9755

Vfault(Volt)	Vfault°(deg)	Ifault(Amps)	Ifault°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
240.1061	0.0000	0.0010	98.4227	9.7681	-1.4230	0.0002	67.1478
0.0007	140.3615	0.0016	-93.5938	0.0006	69.1942	0.0001	158.4165

Fault

Appendix 8: 2400+j1602 before fault data value generator-load connection

Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)
215.4973	0.0000	0.2032	-7.6310	205.9920	0.0000	0.0682	-28.8813
225.5138	-117.1322	0.0767	-148.7686	231.3046	-120.0522	0.0774	-148.5937
231.6593	122.2177	0.0791	96.7842	237.3585	125.5463	0.0793	97.1770
12.3846	-177.4133	0.1265	3.4542	0.0080	130.3690	0.0164	157.3204

Gen — Load

Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
6.7505	29.1271	0.0052	26.5297	6.3255	31.4645	0.0010	-1.8255
12.8150	14.5601	0.0021	-30.1122	11.6680	14.7617	0.0019	-30.2187
9.1651	1.7060	0.0011	-47.0375	8.3807	4.1135	0.0011	-42.6022
0.6559	-176.2581	0.0066	4.1717	0.0007	3.0356	0.0035	-31.2350

Vfault(Volt)	Vfault°(deg)	Ifault(Amps)	Ifault°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
205.5289	0.0000	0.1304	1.1937	6.5427	32.0526	0.0042	32.6475
0.0024	157.2971	0.0048	-6.8881	0.0028	143.1625	0.0002	28.7557

Fault

Appendix 9: 2400+j1602 during fault data value generator-load connection

Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)
239.9873	0.0000	0.0525	-30.1232	240.1787	0.0000	0.0525	-29.6540
239.4977	-119.7733	0.0529	-150.4765	239.6520	-119.7216	0.0526	-149.7407
240.7479	120.4081	0.0525	89.9377	241.0565	120.4091	0.0525	90.2418
3.5866	-94.0459	0.0010	-164.7338	2.3076	-104.3322	0.0009	-153.5467

Gen — Load

Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
10.6631	-6.8472	0.0008	-73.0438	10.5820	-6.6752	0.0009	-60.2292
11.5678	-5.3389	0.0011	-66.8092	11.7187	-5.3906	0.0012	-56.2885
11.2274	-9.4044	0.0009	-75.3483	11.3457	-8.9499	0.0013	-43.9506
5.6452	164.8373	0.0035	-63.5265	5.4841	162.5224	0.0034	-63.0025

Appendix 10: 3600+2388 base data value generator-load connection

Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)
239.6106	0.0000	0.0517	-28.8007	239.7716	0.0000	0.0520	-29.5193
239.2605	-119.7831	0.0520	-149.5836	239.1324	-119.7389	0.0527	-149.1563
240.4295	120.3610	0.0526	90.4358	240.3678	120.4250	0.0535	90.6419
0.0527	-23.9166	0.0014	89.5682	0.0071	121.7507	0.0006	148.5869

Gen — Load

Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
10.2292	-7.2350	0.0009	-55.1473	10.2765	-5.9156	0.0009	-51.0601
11.6961	-5.4655	0.0011	-68.9888	11.3007	-4.9160	0.0010	-53.4898
11.3397	-9.9070	0.0010	-58.0275	10.7367	-9.1535	0.0008	-51.0075
0.3195	121.4792	0.0032	-57.7078	0.0009	-26.3875	0.0033	-58.8295

Vfault(Volt)	Vfault°(deg)	Ifault(Amps)	Ifault°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
240.1286	0.0000	0.0007	100.4223	10.3762	-7.1101	0.0004	43.8968
0.0007	125.6317	0.0013	-112.5108	0.0006	-166.5313	0.0001	102.3857

Fault

Appendix 11: 3600+2388 before fault data value generator-load connection

Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)
214.2560	0.0000	0.1825	-5.2325	205.7475	0.0000	0.0455	-28.3380
224.4192	-117.0988	0.0510	-148.7229	231.0761	-120.2121	0.0519	-148.3069
230.7907	122.3299	0.0527	97.0172	237.5030	125.5685	0.0532	97.5334
12.8790	-178.1943	0.1316	2.6945	0.0079	128.9793	0.0109	155.5714

Gen — Load

Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
6.9985	24.9152	0.0051	22.5895	6.3391	27.3367	0.0006	-6.0662
13.0681	10.5975	0.0013	-40.8024	11.9490	10.5393	0.0013	-35.8169
9.1654	-2.2619	0.0007	-53.1438	8.7208	-3.0710	0.0007	-49.4988
0.5901	-174.8244	0.0060	5.3527	0.0006	33.0438	0.0024	-38.5286

Vfault(Volt)	Vfault°(deg)	Ifault(Amps)	Ifault°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
201.4163	0.0000	0.1406	1.2220	6.3584	26.2805	0.0045	26.5710
0.0025	-159.0616	0.0050	-0.8402	0.0015	-36.1022	0.0002	30.0926

Fault

Appendix 12: 3600+2388 during fault data value generator-load connection

Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)
240.2975	0.0000	0.0394	-30.0528	239.5956	0.0000	0.0394	-29.0042
239.6677	-119.6774	0.0379	-152.9107	239.0236	-119.6117	0.0378	-152.0233
241.2179	120.5024	0.0377	87.4609	240.4904	120.5675	0.0374	88.2307
2.6993	-90.1368	0.0021	25.1845	1.5300	-107.4348	0.0022	23.0238

Gen — Load

Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
10.8055	-8.8558	0.0006	-70.3664	10.7244	-9.7401	0.0008	-49.9501
11.9398	-8.0266	0.0007	-69.3619	11.6331	-7.3268	0.0008	-54.8540
11.3994	-11.7781	0.0006	-79.1056	11.3543	-11.9241	0.0008	-52.5937
5.2975	160.2914	0.0027	-66.4021	5.2204	153.2004	0.0025	-64.7070

Appendix 13: 4800+j3581 base data value generator-load connection

Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)
239.8096	0.0000	0.0375	-31.5196	240.0850	0.0000	0.0386	-33.2047
239.4579	-119.7862	0.0378	-152.7197	239.5307	-119.7898	0.0386	-152.3859
240.8176	120.4069	0.0376	87.7469	240.8102	120.3759	0.0383	88.3232
0.0692	33.0316	0.0008	88.2171	0.0071	122.1844	0.0006	-166.2927

Gen — Load

Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
10.7853	-10.1709	0.0007	-41.1308	10.4746	-8.9874	0.0005	-38.5187
11.7127	-9.3578	0.0011	-56.2511	11.4647	-8.7332	0.0007	-56.3479
11.2862	-11.5753	0.0007	-54.6335	11.1435	-11.8224	0.0006	-53.6005
0.2507	118.2006	0.0025	-58.6356	0.0006	-13.7214	0.0028	-63.3960

Vfault(Volt)	Vfault°(deg)	Ifault(Amps)	Ifault°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
239.8921	0.0000	0.0006	119.1569	10.5623	-8.9868	0.0001	34.8151
0.0007	-96.6791	0.0009	-133.3980	0.0003	-46.9603	0.0002	68.3737

Fault

Appendix 14: 4800+j3581 before fault data value generator-load connection

Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)
211.7806	0.0000	0.1774	-4.2193	205.1922	0.0000	0.0335	-30.7200
222.7313	-117.0066	0.0370	-151.3060	230.5227	-120.2746	0.0378	-150.9008
229.5079	122.3864	0.0377	94.5654	237.2067	125.6561	0.0381	95.0881
13.8366	-178.7348	0.1413	2.1103	0.0084	128.4985	0.0078	155.7093

Gen — Load

Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
6.8570	22.9555	0.0052	21.1022	6.5426	22.3674	0.0004	2.5738
12.9813	8.4455	0.0009	-40.2793	12.2142	8.5325	0.0009	-35.7392
9.6454	-4.6869	0.0006	-54.6100	8.8020	-4.5933	0.0005	-46.5983
0.5736	-173.4600	0.0058	6.6772	0.0006	19.9084	0.0018	-41.5027

Vfault(Volt)	Vfault°(deg)	Ifault(Amps)	Ifault°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
200.3518	0.0000	0.1394	1.2088	6.6701	23.8354	0.0047	24.2645
0.0034	164.4677	0.0050	2.2585	0.0032	-22.8142	0.0002	35.1074

Fault

Appendix 15: 4800+j3581 during fault data value generator-load connection

Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)
239.7641	0.0000	0.2822	-45.1217	414.7580	0.0000	0.1641	-46.8710	239.1063	0.0000	0.1923	-33.7347	239.6505	0.0000	0.1935	-33.7773
238.9142	-119.6646	0.2833	-165.5616	415.5422	-119.5478	0.1647	-165.2364	239.9102	-119.5506	0.1953	-152.8996	240.4500	-119.6210	0.1955	-152.9419
240.6245	120.5104	0.2798	74.1198	417.8470	120.0924	0.1591	74.7556	241.0417	120.0477	0.1914	86.6658	241.5009	120.0303	0.1919	86.5771
5.3910	-67.0807	0.0013	16.5753					6.8488	-105.0266	0.0003	89.0966	6.1111	-101.4054	0.0034	-174.3519

Gen — TX Delta — TX Star — Load

Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
10.1445	9.8008	0.0030	-3.0813	1.8625	136.4631	0.0258	-56.9876	1.5833	146.4590	0.0018	75.8956	1.5108	142.8268	0.0018	74.3390
11.8295	14.9337	0.0012	176.8342	0.7062	-2.4321	0.0250	-54.1303	0.1176	-156.1256	0.0013	65.4055	0.1928	-57.4201	0.0012	66.5792
11.5049	11.8564	0.0022	-146.9980	1.4454	-59.1490	0.0237	-53.8845	0.8977	-73.9247	0.0006	98.9217	0.8325	-86.6874	0.0006	108.3231
4.4137	175.5780	0.0002	-76.6008					1.6315	115.1442	0.0001	-61.4682	2.1266	128.0589	0.0047	77.6425

Appendix 16: 960+j660 base data value generator-transformer-load connection

Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)
239.6530	0.0000	0.2715	-43.9821	414.2648	0.0000	0.1620	-46.2181	239.4513	0.0000	0.1922	-34.0095	239.1474	0.0000	0.1921	-33.8412
238.9920	-119.7107	0.2727	-164.2874	415.1097	-119.5629	0.1637	-165.3159	240.2407	-119.6261	0.1939	-152.9908	239.8298	-119.5889	0.1939	-152.8557
240.6270	120.4898	0.2695	75.3830	417.4372	120.1280	0.1584	75.2284	241.5354	120.0095	0.1925	86.5373	240.9935	120.1127	0.1924	86.6785
0.0044	154.5126	0.0053	128.7247					0.0069	122.2022	0.0026	113.6329	0.0097	124.6714	0.0035	-178.9459

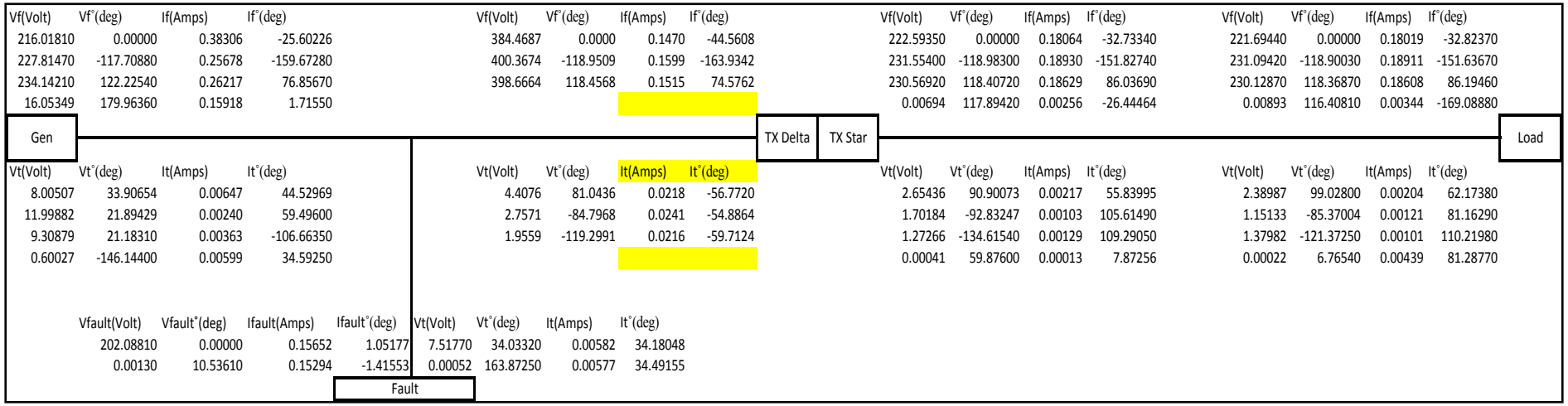
Gen — TX Delta — TX Star — Load

Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
9.8101	5.7892	0.0024	-2.6605	2.0393	126.6383	0.0253	-57.1934	1.8610	132.1060	0.0024	78.6648	1.2642	130.9662	0.0020	73.8920
11.3865	15.1357	0.0010	143.5047	0.4606	-3.1757	0.0247	-54.4375	0.6361	-60.3767	0.0012	68.2721	0.4730	-122.1330	0.0013	74.3373
11.6881	10.3054	0.0015	-142.0182	1.7973	-64.5632	0.0231	-54.0731	1.0599	-94.5935	0.0008	109.8213	0.6348	-99.6700	0.0009	105.8427
0.0040	-65.5266	0.0002	146.1413					0.0004	12.7422	0.0001	57.8587	0.0004	104.8866	0.0052	77.1311

Vfault(Volt)	Vfault°(deg)	Ifault(Amps)	Ifault°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
239.5716	0.0000	0.0007	109.0381	9.8784	6.2703	0.0002	122.3958
0.0007	177.5087	0.0056	-111.7235	0.0004	-85.8084	0.0001	-34.0483

Fault

Appendix 17: 960+j660 before fault data value generator-transformer-load connection



Appendix 18: 960+j660 during fault data value generator-transformer-load connection

Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)
240.1725	0.0000	0.2053	-50.6918	414.6692	0.0000	0.1195	-52.5427	239.9973	0.0000	0.1121	-34.5295	239.9856	0.0000	0.1129	-34.5220
239.3809	-119.6728	0.2066	-171.2005	415.9354	-119.6288	0.1194	-170.8272	241.0579	-119.6398	0.1136	-153.7053	240.7301	-119.5547	0.1133	-153.6311
241.0748	120.5289	0.2026	68.4213	417.7638	-75.9241	0.1148	68.9075	242.0741	119.9481	0.1113	85.2195	241.9498	120.0405	0.1115	85.4591
3.4170	-48.7745	0.0009	11.7716					4.1032	-90.5481	0.0002	79.4731	3.7768	-88.7742	0.0010	143.6614

Gen — TX Delta — TX Star — Load

Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
10.8060	-0.6117	0.0033	4.8910	1.9771	120.4775	0.0259	-57.4243	1.6531	133.9065	0.0014	64.9863	1.4365	142.8055	0.0012	65.9642
12.4202	4.1796	0.0015	147.8776	0.9355	-38.5070	0.0252	-55.0262	0.2318	-82.6635	0.0009	51.9119	0.2181	-109.8992	0.0009	60.7654
11.8820	2.3042	0.0019	-177.9514	1.2031	-75.9241	0.0232	-54.3308	1.0178	-91.4782	0.0004	93.2044	0.6982	-84.4172	0.0003	72.7332
5.3282	158.2010	0.0001	119.1365					1.9322	122.3448	0.0002	-19.7046	1.8503	119.9017	0.0036	68.0413

Appendix 19: 1600+j1194 base data value generator-transformer-load connection

Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)
239.6514	0.0000	0.1990	-49.8501	414.8096	0.0000	0.1200	-52.3375	239.5824	0.0000	0.1115	-34.6285	239.7239	0.0000	0.1115	-34.2469
239.2088	-119.7766	0.2005	-170.3139	416.3922	-119.6257	0.1208	-171.3354	240.2492	-119.5740	0.1117	-153.7202	240.5747	-119.5350	0.1124	-154.2882
240.7465	120.4412	0.1971	69.4034	418.5200	119.9717	0.1157	69.4177	241.5179	120.0648	0.1119	84.7778	241.8696	120.0326	0.1121	85.6695
0.0052	114.4897	0.0037	127.2060					0.0069	122.0158	0.0023	-160.2319	0.0083	120.6744	0.0010	159.0274

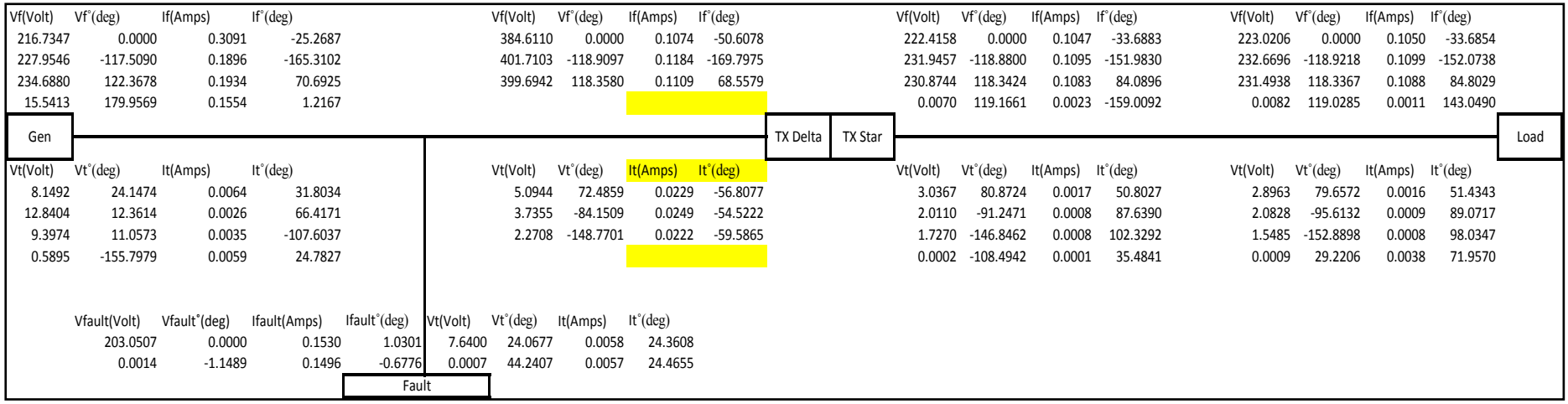
Gen — TX Delta — TX Star — Load

Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
10.7362	-2.6954	0.0031	-2.3154	2.9140	112.7773	0.0262	-56.9385	1.8295	127.4326	0.0017	66.9718	1.6396	135.7607	0.0016	71.6020
12.0068	2.5065	0.0013	175.4773	1.3812	-33.8116	0.0256	-55.0665	0.4641	-68.1739	0.0012	65.6734	0.5117	-75.1574	0.0012	67.0755
11.7557	0.7538	0.0018	-158.3701	1.9509	-90.2802	0.0233	-54.2855	1.0487	-99.1473	0.0008	96.0092	0.6503	-97.9569	0.0007	94.3300
0.0029	-78.1207	0.0002	120.1008					0.0006	-13.9741	0.0001	20.5003	0.0006	31.9652	0.0032	67.1736

Vfault(Volt)	Vfault°(deg)	Ifault(Amps)	Ifault°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
239.6834	0.0000	0.0008	69.4182	10.5132	-1.1460	0.0000	-103.7476
0.0006	112.3744	0.0042	-117.8603	0.0006	121.0807	0.0003	50.3545

Fault

Appendix 20: 1600+j1194 before fault data value generator-transformer-load connection



Appendix 21: 1600+j1194 during fault data value generator-transformer-load connection

Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)
239.5452	0.0000	0.1733	-52.0430	414.5864	0.0000	0.1003	-54.1962	239.9151	0.0000	0.0784	-29.9306	240.3626	0.0000	0.0793	-30.2269
238.9114	-119.6659	0.1740	-172.7340	415.9549	-119.6131	0.1001	-172.0408	240.9544	-119.6416	0.0801	-148.8462	241.2963	-119.6446	0.0799	-148.8273
240.5794	120.4792	0.1703	66.8729	417.6919	120.0288	0.0956	67.8472	241.8844	119.9432	0.0784	90.2420	242.2239	119.9919	0.0787	90.3147
2.3711	-70.2772	0.0008	12.9431					2.9843	-120.7200	0.0002	100.2967	2.6052	-108.2245	0.0013	158.7569

Gen — TX Delta — TX Star — Load

Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
10.5310	-5.2473	0.0036	-0.9081	2.4528	119.8114	0.0261	-58.2371	1.6613	127.1412	0.0004	82.2253	1.4739	133.2033	0.0005	84.0306
12.5015	2.0797	0.0011	167.4674	1.1492	-31.5162	0.0253	-56.1372	0.3811	-86.0899	0.0002	123.5044	0.3087	-95.4152	0.0002	102.2922
12.0590	-2.3263	0.0021	-160.6396	1.5738	-80.9302	0.0232	-54.7054	0.9702	-100.4445	0.0003	145.6753	0.7523	-94.4009	0.0002	149.4946
4.4332	157.9806	0.0001	-55.3507					1.6912	122.5589	0.0001	-121.7118	2.5992	103.0827	0.0014	101.3334

Appendix 22: 2400+j1602 base data value generator-transformer-load connection

240.2126	0.0000	0.1697	-51.3796	414.7605	0.0000	0.0996	-53.9939	240.4058	0.0000	0.0781	-30.4159	239.8809	0.0000	0.0777	-29.6880
239.6223	-119.6999	0.1711	-172.1176	415.8460	-119.5698	0.0998	-171.7465	241.1075	-119.5544	0.0786	-148.8202	240.7972	-119.6403	0.0790	-149.7651
241.3534	120.4798	0.1673	67.8172	418.0369	120.0233	0.0951	68.3980	242.2975	120.0284	0.0793	89.4834	241.7669	119.9883	0.0794	90.2767
0.0063	99.9189	0.0031	129.0616					0.0068	123.7009	0.0023	178.3264	0.0081	120.8863	0.0012	166.3027

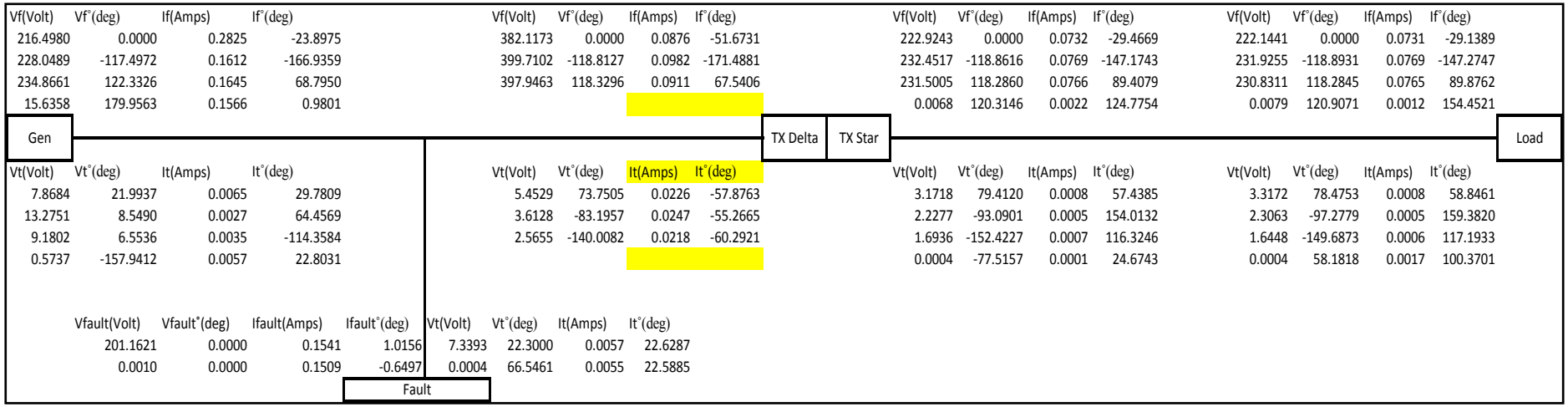
Gen — TX Delta — TX Star — Load

Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
10.5205	-8.2283	0.0029	3.3635	2.2953	117.7112	0.0259	-58.2157	1.8652	126.9972	0.0007	86.4760	1.5586	127.0927	0.0008	83.1040
12.0400	1.2809	0.0020	151.4604	1.1027	-25.4023	0.0251	-55.9498	0.3887	-77.6147	0.0004	87.3897	0.5527	-81.7068	0.0005	100.0487
11.9873	-3.0999	0.0022	-166.0694	1.6779	-83.8612	0.0233	-54.8259	1.0439	-94.3508	0.0005	96.1478	0.7347	-112.5908	0.0006	108.7992
0.0049	-105.6644	0.0003	76.1266					0.0003	13.8480	0.0001	-40.2080	0.0005	17.3852	0.0012	100.4872

Vfault(Volt)	Vfault°(deg)	Ifault(Amps)	Ifault°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
239.4536	0.0000	0.0005	85.3774	10.2834	-5.9887	0.0004	162.2494
0.0007	-170.6716	0.0037	-126.9844	0.0004	34.7012	0.0003	15.6610

Fault

Appendix 23: 2400+j1602 before fault data value generator-transformer-load connection



Appendix 24: 2400+j1602 during fault data value generator-transformer-load connection

Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)
239.7733	0.0000	0.1503	-55.8177	415.0099	0.0000	0.0884	-58.2920	240.0685	0.0000	0.0523	-29.0277	239.8225	0.0000	0.0531	-29.9713
239.0450	-119.6068	0.1516	-176.7192	416.4537	-119.6728	0.0876	-175.9809	240.9011	-119.6143	0.0538	-148.6071	240.7234	-119.5784	0.0535	-148.3296
240.8966	120.5663	0.1475	62.7974	417.9866	120.0264	0.0831	63.6285	241.9042	120.0282	0.0519	90.2850	241.8008	120.0201	0.0531	91.0492
2.1858	-57.6236	0.0007	7.6907					2.9941	-108.6423	0.0002	75.2507	2.7766	-96.4755	0.0006	148.9391

Gen — TX Delta — TX Star — Load

Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
10.7851	-10.1106	0.0036	-3.8733	2.0895	120.8510	0.0268	-58.2134	1.5234	134.1360	0.0001	16.9360	1.5259	129.5551	0.0001	119.9945
12.5823	-1.6896	0.0014	167.2898	1.1466	-44.1087	0.0256	-55.9645	0.3729	-96.4966	0.0001	-135.9146	0.4768	-101.3800	0.0002	-157.5964
12.2275	-5.0917	0.0022	-161.5237	1.3141	-73.3168	0.0239	-54.4148	0.6722	-91.4738	0.0002	151.0087	0.6433	-95.6659	0.0001	-139.0589
4.3951	154.7720	0.0001	-70.6782					1.5325	97.8172	0.0001	-51.9796	2.0635	116.7946	0.0009	104.5122

Appendix 25: 3600+j2388 base data value generator-transformer-load connection

Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)
239.6289	0.0000	0.1434	-54.9571	415.0160	0.0000	0.0865	-57.5006	239.6129	0.0000	0.0520	-30.0013	240.2511	0.0000	0.0518	-29.2671
239.1068	-119.6676	0.1452	-175.8437	416.3691	-119.6146	0.0866	-176.3756	240.4906	-119.5409	0.0521	-148.5540	241.0279	-119.5719	0.0525	-149.4836
240.8397	120.4869	0.1415	63.9501	418.4252	120.0349	0.0818	64.3162	241.6769	120.0231	0.0529	89.0117	242.0883	120.1010	0.0530	89.7682
0.0051	95.5581	0.0029	128.4499					0.0068	122.5838	0.0022	-158.3126	0.0086	124.2580	0.0006	151.3510

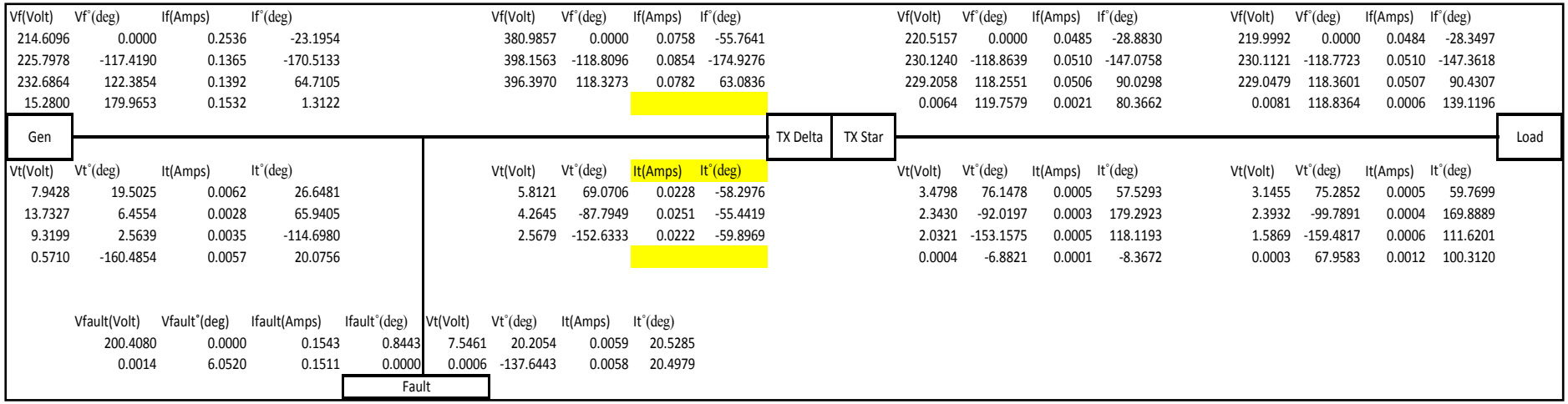
Gen — TX Delta — TX Star — Load

Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
10.7079	-11.1213	0.0029	9.3442	2.1836	110.0376	0.0264	-58.4793	1.9019	130.9689	0.0005	88.8160	1.3688	130.6658	0.0003	102.2218
12.4940	-1.9851	0.0018	143.8699	1.2854	-58.1638	0.0254	-56.4097	0.3195	-59.1947	0.0003	111.0826	0.6637	-134.2420	0.0002	73.9024
12.4480	-6.5990	0.0021	-169.0626	1.1359	-84.6128	0.0233	-54.0311	1.1116	-91.4624	0.0005	118.1375	0.6299	-69.7839	0.0004	74.7503
0.0037	-116.0230	0.0003	52.5945					0.0005	20.5853	0.0001	14.3200	0.0006	-72.7206	0.0008	105.2356

Vfault(Volt)	Vfault°(deg)	Ifault(Amps)	Ifault°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
240.1796	0.0000	0.0007	80.4933	10.8382	-8.0862	0.0001	19.2757
0.0007	-169.1408	0.0030	-121.2130	0.0008	125.2517	0.0002	70.7942

Fault

Appendix 26: 3600+j2388 before fault data value generator-transformer-load connection



Appendix 27: 3600+j2388 during fault data value generator-transformer-load connection

Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)
239.9222	0.0000	0.1372	-58.9777	415.2880	0.0000	0.0822	-61.8987	240.3467	0.0000	0.0381	-31.7030	240.4322	0.0000	0.0390	-33.2176
239.1453	-119.5580	0.1395	179.7687	416.6485	-119.6108	0.0814	-179.2957	241.1008	-119.5722	0.0395	-151.0143	241.2555	-119.5961	0.0392	-150.8595
241.0321	120.5591	0.1349	59.4776	418.3298	120.0657	0.0762	60.0114	242.2661	120.0332	0.0367	87.8105	242.2899	120.0464	0.0380	88.5680
1.7325	-31.3486	0.0006	2.6028					1.5670	-135.7257	0.0002	89.5983	1.8448	-89.9219	0.0007	-155.6605

Gen — TX Delta — TX Star — Load

Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
11.0272	-12.3389	0.0035	3.4238	2.3490	117.8963	0.0270	-58.1613	1.4332	135.2191	0.0001	-34.7590	1.4412	125.7670	0.0002	6.2436
12.8641	-3.4438	0.0018	146.1293	1.3241	-51.0137	0.0258	-55.8303	0.3969	-126.7423	0.0001	-103.9771	0.7860	-108.0716	0.0001	-83.3118
12.3104	-8.3155	0.0022	178.5083	1.2681	-74.0038	0.0241	-53.9027	0.6361	-79.0295	0.0000	-151.1261	0.4857	-101.3490	0.0001	-60.8309
4.2507	146.1813	0.0002	123.8921					1.5284	107.2198	0.0001	-139.3786	1.7352	82.2095	0.0008	70.8701

Appendix 28: 4800+j3581 base data value generator-transformer-load connection

Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)
240.1070	0.0000	0.1352	-58.4971	414.9145	0.0000	0.0828	-61.3111	239.9999	0.0000	0.0376	-33.3732	239.9224	0.0000	0.0380	-33.3850
239.7449	-119.7227	0.1376	-179.8904	416.1797	-119.5332	0.0814	-179.4756	240.7578	-119.5627	0.0378	-151.4947	240.8537	-119.5937	0.0378	-150.5799
241.4514	120.4282	0.1334	59.8710	418.3684	120.0822	0.0768	60.2003	242.0060	120.0696	0.0376	85.8117	241.9387	120.0150	0.0374	87.0677
0.0026	140.3745	0.0029	116.5008					0.0070	121.4891	0.0021	-143.3285	0.0085	122.4662	0.0007	-171.8602

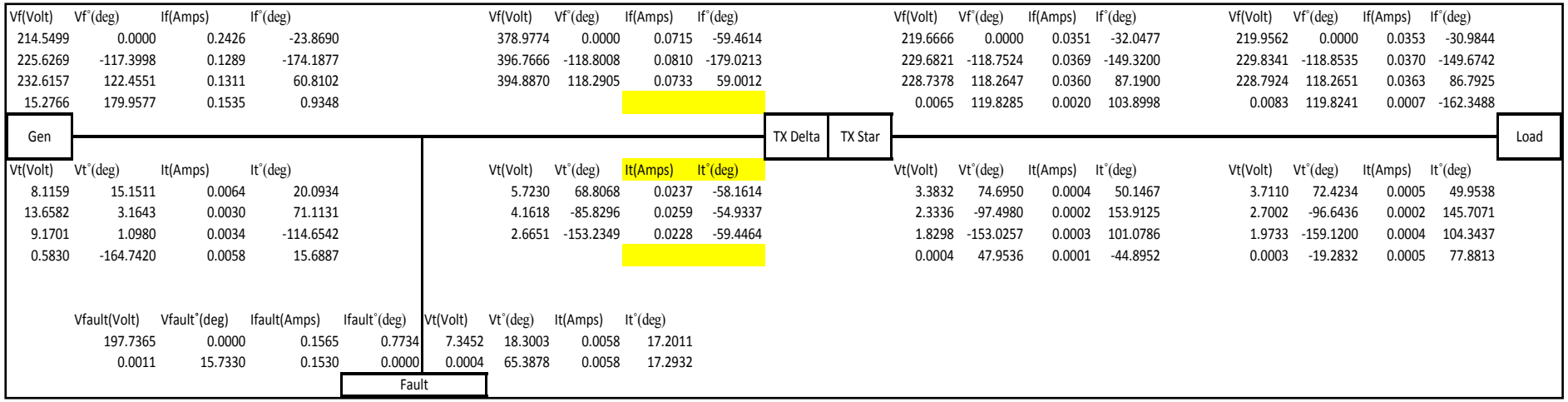
Gen — TX Delta — TX Star — Load

Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
10.9254	-12.8256	0.0035	7.5562	2.2990	126.1849	0.0272	-58.3620	1.5387	118.3198	0.0003	71.8898	1.5956	122.6718	0.0003	85.6143
12.6032	-6.9952	0.0019	148.0472	0.8486	-50.3452	0.0261	-55.6442	0.6437	-106.9508	0.0003	131.1244	0.6973	-90.6704	0.0001	22.2350
12.1489	-8.8439	0.0023	-176.8346	1.5222	-55.6669	0.0243	-53.9315	0.8007	-109.1429	0.0003	120.1187	0.6451	-114.9097	0.0002	54.3140
0.0056	-118.7444	0.0002	42.3931					0.0005	-58.3077	0.0001	43.6508	0.0002	-19.5044	0.0011	91.3615

Vfault(Volt)	Vfault°(deg)	Ifault(Amps)	Ifault°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
239.3673	0.0000	0.0007	36.8541	11.0643	-13.1704	0.0003	27.2799
0.0007	-148.7031	0.0030	-134.0009	0.0005	132.1971	0.0001	74.9022

Fault

Appendix 29: 4800+j3581 before fault data value generator-transformer-load connection



Appendix 30: 4800+j3581 during fault data value generator-transformer-load connection

Vf(Volt)	Vf˚(deg)	If(Amps)	If˚(deg)	Vf(Volt)	Vf˚(deg)	If(Amps)	If˚(deg)
232.4920	0.0000	0.1860	-33.2074	235.8638	0.0000	0.1105	-34.7573
236.9005	-119.1985	0.1111	-153.4833	237.5283	-119.6566	0.0785	-149.1156
239.9132	120.2795	0.1116	85.6897	239.3687	120.2026	0.0781	90.4817
9.0893	-88.1164	0.0741	-31.3106	4.0667	-93.1969	0.0324	-46.7124

Gen — Load

Vt(Volt)	Vt˚(deg)	It(Amps)	It˚(deg)	Vt(Volt)	Vt˚(deg)	It(Amps)	It˚(deg)
9.9039	11.5225	0.0035	-29.4535	10.4483	1.2751	0.0020	-34.6626
11.5486	3.8695	0.0025	-23.8111	11.4389	-1.3251	0.0018	-61.8536
10.5520	2.5093	0.0020	-37.1642	10.7272	-4.1365	0.0017	-63.4435
5.3419	173.5099	0.0083	-35.0295	4.8898	173.5210	0.0055	-47.2100

Appendix 31: (960+j660) + (1600+j1194) unbalanced load data value generator-load connection

Vf(Volt)	Vf˚(deg)	If(Amps)	If˚(deg)	Vf(Volt)	Vf˚(deg)	If(Amps)	If˚(deg)
229.8992	0.0000	0.1836	-33.3473	229.7280	0.0000	0.1837	-33.0720
236.5161	-119.1850	0.0779	-148.9463	236.3473	-119.1420	0.0777	-148.7053
240.0436	120.0750	0.0783	90.1272	239.8262	120.0997	0.0786	90.3758
8.7962	-92.8759	0.1056	-35.9716	8.5015	-93.0721	0.1058	-35.8278

Gen — Load

Vt(Volt)	Vt˚(deg)	It(Amps)	It˚(deg)	Vt(Volt)	Vt˚(deg)	It(Amps)	It˚(deg)
10.5578	12.3911	0.0040	-32.0747	10.3399	12.5655	0.0040	-32.0098
11.8571	0.0000	0.0020	-59.6145	11.8683	0.0000	0.0021	-52.7922
10.1366	0.0000	0.0017	-57.8453	10.2203	-0.7494	0.0019	-50.2866
4.9803	-177.7457	0.0073	-39.8845	4.5586	175.8990	0.0072	-39.5766

Appendix 32: (960+j660) + (2400+j1602) unbalanced load data value generator-load connection

Vf(Volt)	Vf˚(deg)	If(Amps)	If˚(deg)	Vf(Volt)	Vf˚(deg)	If(Amps)	If˚(deg)
228.0958	0.0000	0.1822	-33.2452	227.5866	0.0000	0.1816	-33.2294
236.3234	-118.9032	0.0526	-149.0225	235.7615	-118.8867	0.0521	-148.9155
240.3976	120.1671	0.0524	90.3082	239.9376	120.1327	0.0522	90.0614
8.0642	-89.7960	0.1299	-34.7196	7.5185	-92.8048	0.1295	-34.8679

Gen — Load

Vt(Volt)	Vt˚(deg)	It(Amps)	It˚(deg)	Vt(Volt)	Vt˚(deg)	It(Amps)	It˚(deg)
10.5071	10.4973	0.0039	-36.3240	10.4577	11.9398	0.0041	-31.4669
12.1170	-3.7653	0.0014	-68.8224	12.4658	-3.0584	0.0015	-49.8683
10.3646	-2.2611	0.0011	-62.9038	10.3712	-3.1487	0.0012	-38.5083
5.0519	-178.7918	0.0063	-42.4890	4.9630	171.7896	0.0062	-40.7396

Appendix 33: (960+j660) + (3600+j2388) unbalanced load data value generator-load connection

Vf(Volt)	Vf˚(deg)	If(Amps)	If˚(deg)	Vf(Volt)	Vf˚(deg)	If(Amps)	If˚(deg)
226.3180	0.0000	0.1809	-33.3450	226.5792	0.0000	0.1809	-33.2731
235.1552	-118.6732	0.0376	-150.7683	235.5487	-118.7885	0.0375	-150.6419
239.8631	120.2880	0.0376	87.3497	240.1087	120.2344	0.0375	87.2417
7.7513	-87.6798	0.1432	-33.5721	7.4005	-90.9381	0.1432	-33.6155

Gen — Load

Vt(Volt)	Vt˚(deg)	It(Amps)	It˚(deg)	Vt(Volt)	Vt˚(deg)	It(Amps)	It˚(deg)
10.6539	10.0757	0.0041	-35.7605	10.7243	11.0025	0.0042	-33.1285
12.3148	-4.7777	0.0011	-66.1735	12.5456	-6.3965	0.0011	-52.3943
10.4542	-4.6675	0.0010	-56.7631	10.4035	-3.9907	0.0010	-37.3341
4.7336	176.7522	0.0057	-42.1737	4.6333	169.3209	0.0057	-41.6509

Appendix 34: (960+j660) + (4800+j3581) unbalanced load data value generator-load connection

Vf(Volt)	Vf˚(deg)	If(Amps)	If˚(deg)	Vf(Volt)	Vf˚(deg)	If(Amps)	If˚(deg)
235.8638	0.0000	0.1105	-34.7573	236.8742	0.0000	0.1107	-34.5479
237.5283	-119.6566	0.0785	-149.1156	238.4374	-119.6032	0.0782	-149.2874
239.3687	120.2026	0.0781	90.4817	240.2495	120.3100	0.0784	90.3815
4.0667	-93.1969	0.0324	-46.7124	3.8549	-96.0422	0.0324	-46.7790

Gen — Load

Vt(Volt)	Vt˚(deg)	It(Amps)	It˚(deg)	Vt(Volt)	Vt˚(deg)	It(Amps)	It˚(deg)
10.4483	1.2751	0.0020	-34.6626	10.8725	0.3544	0.0020	-35.0904
11.4389	-1.3251	0.0018	-61.8536	11.0104	-1.2780	0.0015	-58.6403
10.7272	-4.1365	0.0017	-63.4435	10.9409	-2.2607	0.0014	-57.8472
4.8898	173.5210	0.0055	-47.2100	5.0640	170.4235	0.0055	-47.4839

Appendix 35: (1600+j1194) + (2400+j1602) unbalanced load data value generator-load connection

Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)
235.9506	0.0000	0.2279	-41.9123	404.2964	0.0000	0.1549	-45.9448	232.7186	0.0000	0.1886	-33.5663	231.8764	0.0000	0.1877	-33.5584
234.1539	-118.6072	0.2409	-171.1131	410.8515	-118.8011	0.1162	-169.6423	237.9718	-118.9361	0.1123	-152.8292	237.0651	-118.8817	0.1106	-153.0395
240.0191	121.2185	0.1994	69.4623	415.0145	119.8067	0.1129	69.0211	240.2507	119.6638	0.1107	85.0721	239.5544	119.6754	0.1104	85.0331
8.4872	-67.7966	0.0004	58.4632					9.0336	-96.1408	0.0001	90.7346	9.0542	-95.6429	0.0770	-32.3381

Gen — TX Delta — TX Star — Load

Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
10.1300	12.3348	0.0015	-1.6877	3.3411	96.1970	0.0233	-56.7057	1.6978	98.5120	0.0017	60.1827	1.6284	104.0216	0.0016	58.0568
13.3188	8.8144	0.0009	91.3148	2.5233	-52.3920	0.0242	-53.5073	1.2721	-81.6727	0.0006	62.3668	1.1520	-75.4223	0.0007	65.1782
11.1808	2.4594	0.0022	-131.1748	1.7852	-132.1156	0.0226	-55.1165	1.0809	-158.5922	0.0006	94.5732	1.0520	-155.5744	0.0004	85.4271
4.1005	167.5983	0.0002	-28.9782					2.4962	105.9643	0.0001	60.4207	1.8073	127.6827	0.0036	72.3106

Appendix 36: (960+j660) + (1600+j1194) unbalanced load data value generator-transformer-load connection

Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)
233.9941	0.0000	0.2071	-38.6197	401.6515	0.0000	0.1536	-45.7775	230.1074	0.0000	0.1867	-33.6260	230.4548	0.0000	0.1872	-33.4638
231.8604	-118.1027	0.2217	-173.4573	411.0403	-118.5476	0.0976	-170.6349	237.3809	-118.7205	0.0789	-147.7954	237.8319	-118.6752	0.0782	-147.8498
239.4399	121.5716	0.1640	68.8722	415.4254	119.6328	0.0946	67.6579	239.9721	119.3955	0.0777	89.6354	240.3249	119.4090	0.0785	89.9923
8.2610	-74.1738	0.0002	80.9255					8.8366	-101.5980	0.0001	108.1747	8.7603	-102.1192	0.1090	-36.2470

Gen — TX Delta — TX Star — Load

Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
10.3340	13.7773	0.0009	14.6777	3.5394	80.3337	0.0233	-56.6244	1.9625	81.1519	0.0018	51.7924	1.9897	85.3394	0.0016	50.4087
13.8923	6.5905	0.0017	75.1024	3.0349	-64.6730	0.0245	-53.9627	1.7489	-85.0942	0.0003	175.8029	1.7634	-87.8769	0.0004	-179.0233
10.8122	0.9360	0.0016	-142.8864	2.0364	-158.4302	0.0228	-56.0712	1.5098	-174.4713	0.0005	117.7912	1.3609	-174.0737	0.0003	121.2795
5.0314	160.8803	0.0003	99.8212					1.5618	122.3687	0.0001	-113.4675	2.2714	126.5989	0.0025	81.3200

Appendix 37: (960+j660) + (2400+j1602) unbalanced load data value generator-transformer-load connection

Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)
233.2784	0.0000	0.1910	-37.0506	398.8868	0.0000	0.1511	-45.5271	227.8724	0.0000	0.1845	-33.7692	228.6579	0.0000	0.1855	-33.5690
230.7686	-117.6432	0.2109	-176.1146	409.7242	-118.2615	0.0833	-174.0381	236.7212	-118.4944	0.0527	-147.3574	237.3908	-118.4803	0.0522	-147.3889
239.8045	121.9058	0.1401	65.1864	414.9695	119.5865	0.0805	63.6205	239.6749	119.2769	0.0514	89.3727	240.4119	119.3242	0.0522	89.3578
7.8243	-71.0394	0.0003	62.3928					8.3545	-100.1324	0.0001	61.8401	8.3083	-100.5445	0.1332	-35.2387

Gen — TX Delta — TX Star — Load

Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
10.3758	13.4158	0.0002	-40.9400	4.4657	69.0583	0.0228	-56.4472	2.5137	78.8292	0.0020	47.2495	2.3500	77.3839	0.0018	40.1344
14.5146	5.2046	0.0019	84.8553	4.2042	-72.0399	0.0242	-53.7325	2.2248	-78.5907	0.0003	-133.5519	2.0740	-83.1238	0.0004	-137.2987
10.6854	-1.9721	0.0021	-135.0543	2.9022	-176.5375	0.0227	-55.6161	1.9840	-173.2774	0.0004	122.1508	1.8364	-174.2884	0.0002	117.4228
4.9943	167.4169	0.0002	-174.1755					2.0701	124.6553	0.0001	179.4757	1.6134	121.2586	0.0021	65.0439

Appendix 38: (960+j660) + (3600+j2388) unbalanced load data value generator-transformer-load connection

Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)
232.7504	0.0000	0.1819	-36.2416	397.2207	0.0000	0.1507	-45.4457	227.2450	0.0000	0.1837	-33.8895	227.0572	0.0000	0.1845	-33.5048
229.8227	-117.4758	0.2070	-177.9928	408.9881	-117.9992	0.0766	-177.1904	236.7698	-118.3336	0.0384	-149.8209	236.6253	-118.3165	0.0379	-149.4541
239.6056	122.0940	0.1285	61.6572	415.0330	119.6091	0.0740	59.9097	240.0668	119.2741	0.0361	87.1395	240.0028	119.2673	0.0372	87.0009
1.4544	-82.7809	0.0005	55.4814					2.0801	-94.6394	0.0001	114.2550	1.5937	-113.4753	0.1461	-34.1527

Gen — TX Delta — TX Star — Load

Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
10.4912	13.7488	0.0004	-95.1384	4.8040	70.5660	0.0227	-56.4626	2.6537	75.5534	0.0020	42.6885	2.7090	75.6461	0.0020	39.7552
14.7951	3.2168	0.0019	87.0692	4.4085	-67.2626	0.0244	-53.1671	2.3822	-79.3916	0.0002	-115.7541	2.4728	-79.6832	0.0002	-124.0110
10.5488	-4.1553	0.0020	-129.6890	3.3257	-171.9641	0.0228	-55.5336	2.1469	-175.3372	0.0002	130.2623	2.1742	-176.3903	0.0001	156.9467
4.4506	164.7571	0.0002	-149.2815					2.1389	103.9482	0.0002	72.6519	2.1957	96.2828	0.0024	55.4453

Appendix 39: (960+j660) + (4800+j3581) unbalanced load data value generator-transformer-load connection

Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)	Vf(Volt)	Vf°(deg)	If(Amps)	If°(deg)
237.0817	0.0000	0.1813	-47.7653	409.1490	0.0000	0.1158	-52.1140	236.0818	0.0000	0.1114	-34.8688	236.3562	0.0000	0.1114	-34.6577
236.1858	-119.1268	0.1850	-173.7574	413.2720	-119.4020	0.0983	-171.5331	239.0435	-119.4276	0.0794	-148.6209	239.3212	-119.4185	0.0786	-148.5777
239.5735	120.8388	0.1656	67.6483	415.1036	119.8351	0.0941	68.0132	240.2689	119.7176	0.0775	89.9495	240.4620	119.7234	0.0785	89.8364
3.7084	-75.9562	0.0005	52.8887					4.2935	-101.6046	0.0001	94.3943	3.9706	-106.4912	0.0327	-45.9971

Gen — TX Delta — TX Star — Load

Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)	Vt(Volt)	Vt°(deg)	It(Amps)	It°(deg)
11.0284	0.7619	0.0023	0.0000	2.0569	102.2617	0.0247	-57.5161	1.1993	116.2425	0.0013	64.2404	1.3407	109.9055	0.0013	54.6995
12.5635	1.5222	0.0009	160.5849	1.5155	-54.9155	0.0246	-55.8904	0.7024	-104.6169	0.0002	144.2839	0.8417	-96.3276	0.0002	142.8081
11.5918	0.0000	0.0020	-150.0202	1.0600	-116.7848	0.0227	-55.2478	0.5191	-138.8944	0.0003	126.9778	0.6494	-148.0565	0.0003	149.1162
4.4474	163.2288	0.0001	-38.4333					1.7526	99.3406	0.0004	-49.3096	2.4566	104.0776	0.0023	79.7683

Appendix 40: (1600+j1194) + (2400+j1602) unbalanced load data value generator-transformer-load connection

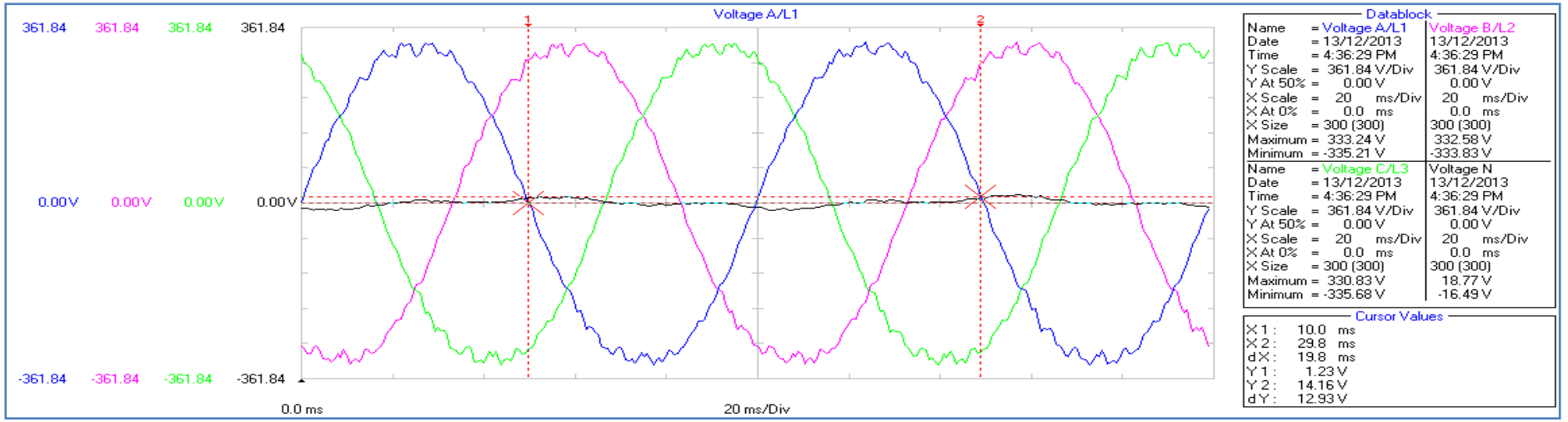


Figure 41: Fundamentals voltage waveform with harmonics distortions at generator terminal for generator-load connections.

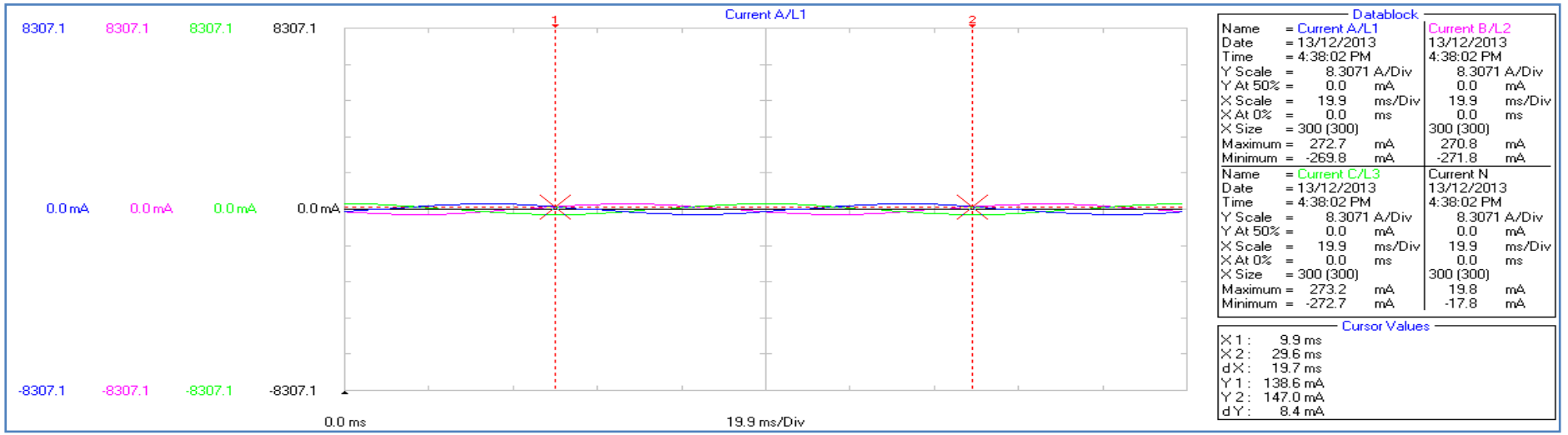


Figure 42: Fundamentals current waveform with harmonics distortions at generator terminal for generator-load connections.

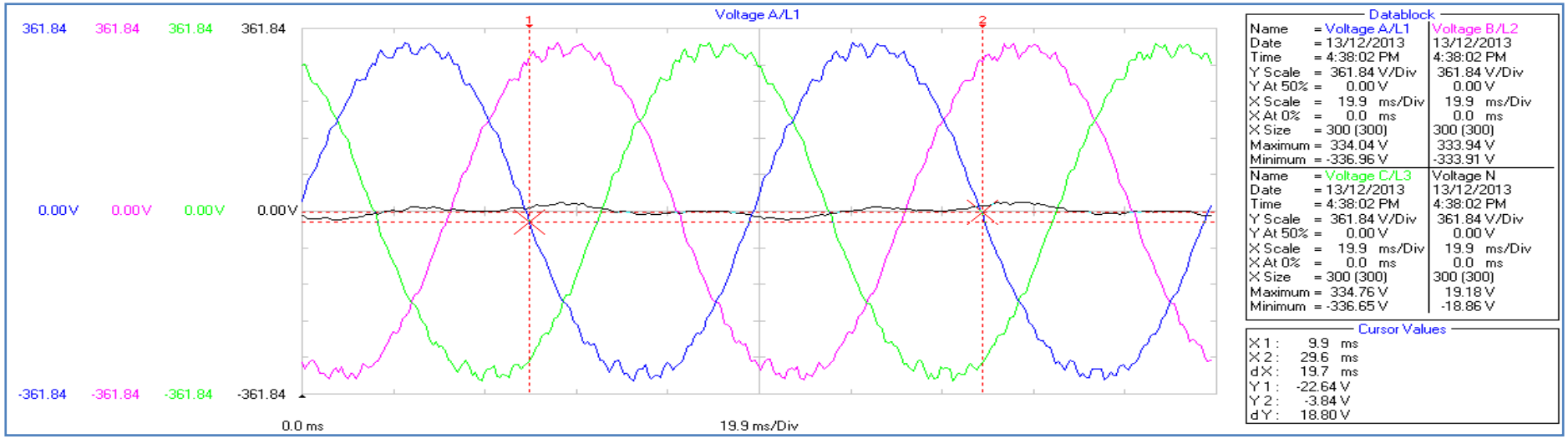


Figure 43: Fundamentals voltage waveform with harmonics distortions at load terminal for generator-load connections.

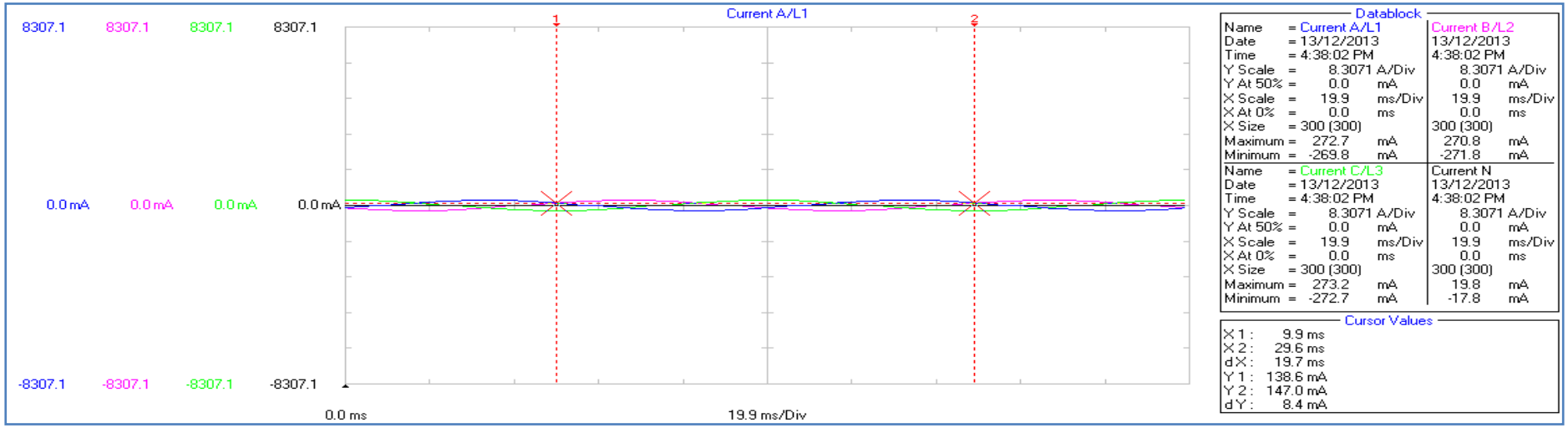


Figure 44: Fundamentals current waveform with harmonics distortions at load terminal for generator-load connections.

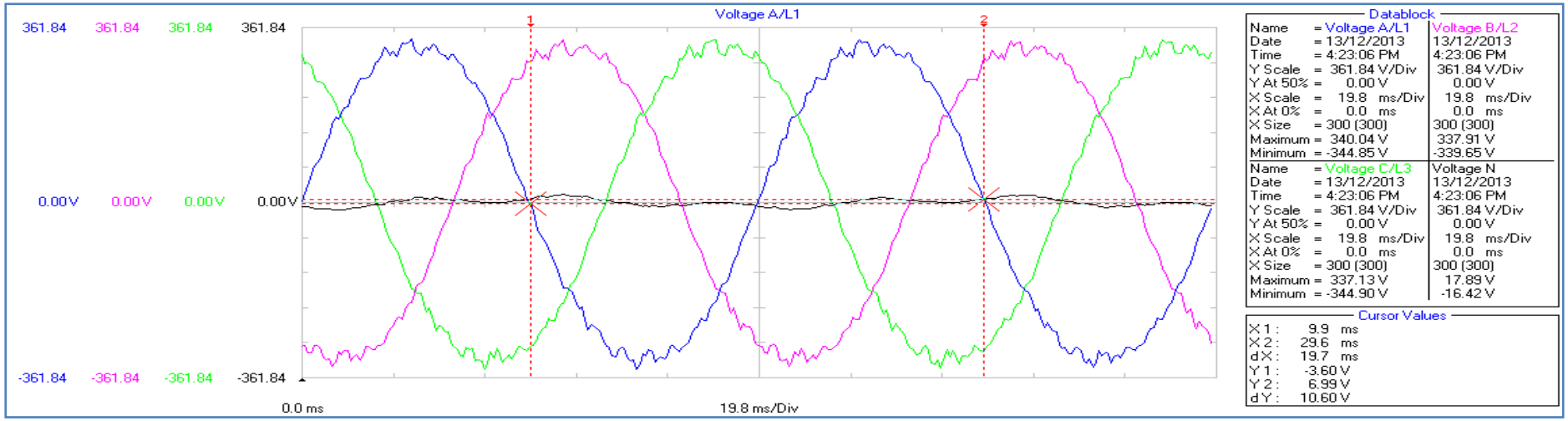


Figure 45: Fundamentals voltage waveform with harmonics distortions at generator terminal for generator-transformer-load connections.

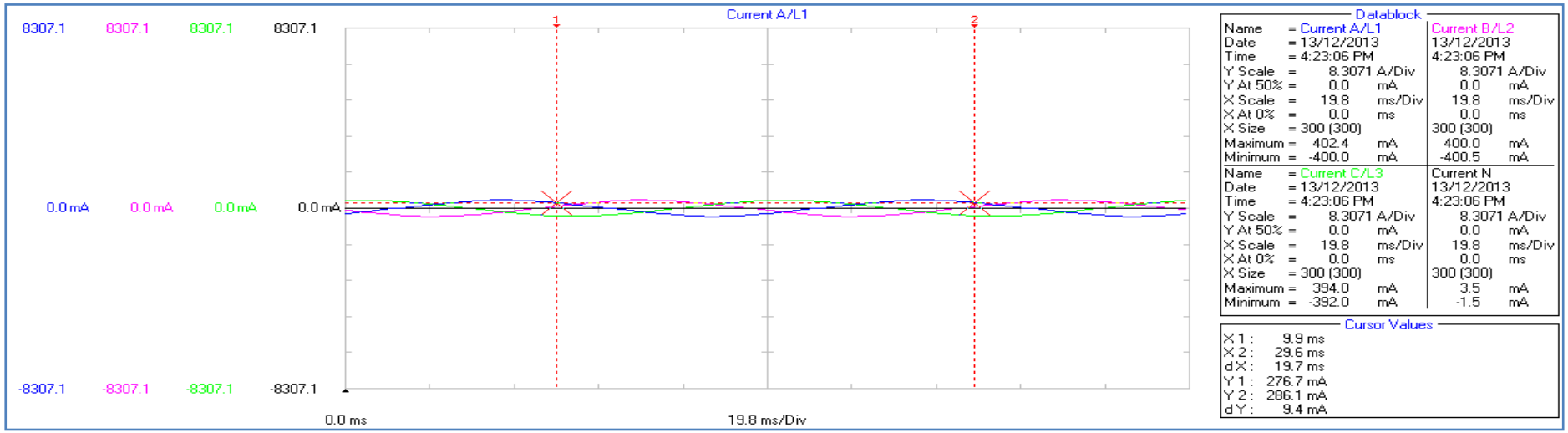


Figure 46: Fundamentals current waveform with harmonics distortions at generator terminal for generator-transformer-load connections.

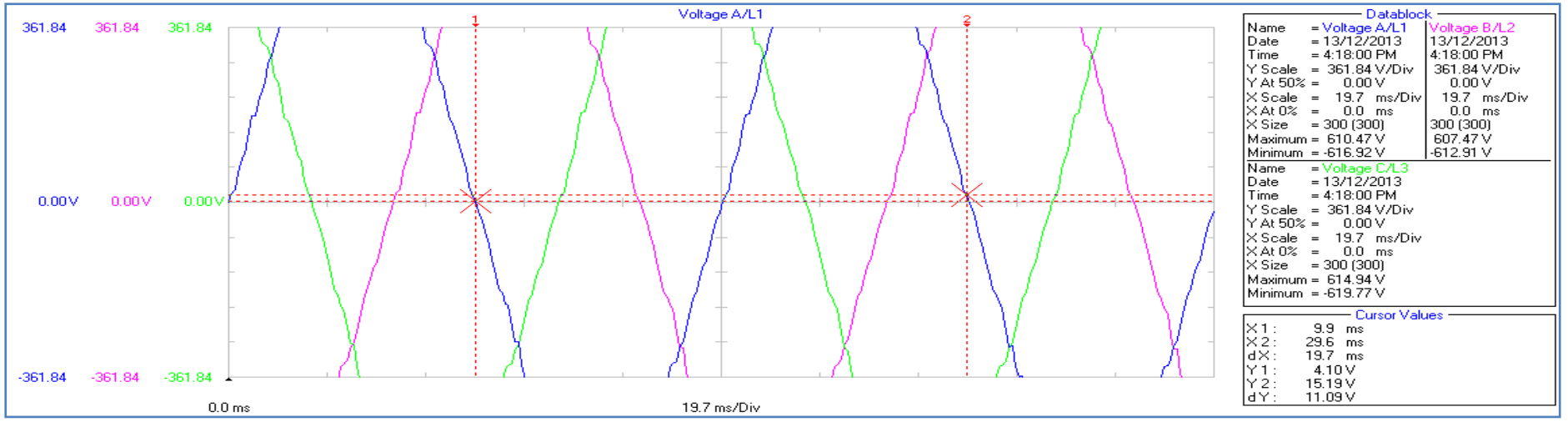


Figure 47: Fundamentals voltage waveform with harmonics distortions at tx delta terminal for generator-transformer-load connections.

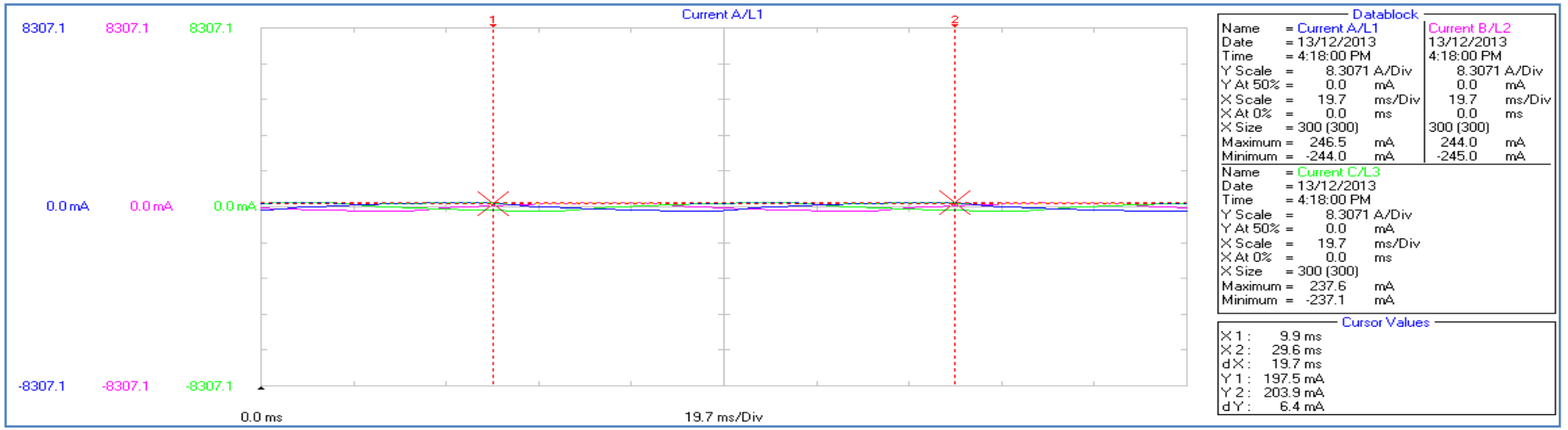


Figure 48: Fundamentals current waveform with harmonics distortions at tx delta terminal for generator-transformer-load connections.

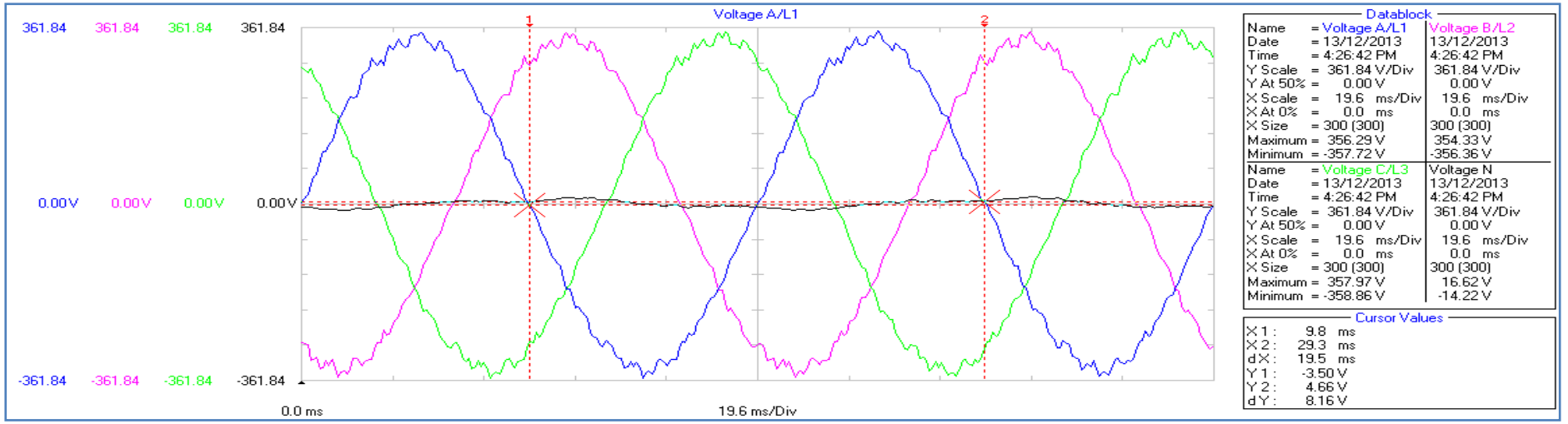


Figure 49: Fundamentals voltage waveform with harmonics distortions at tx wye terminal for generator-transformer-load connections.

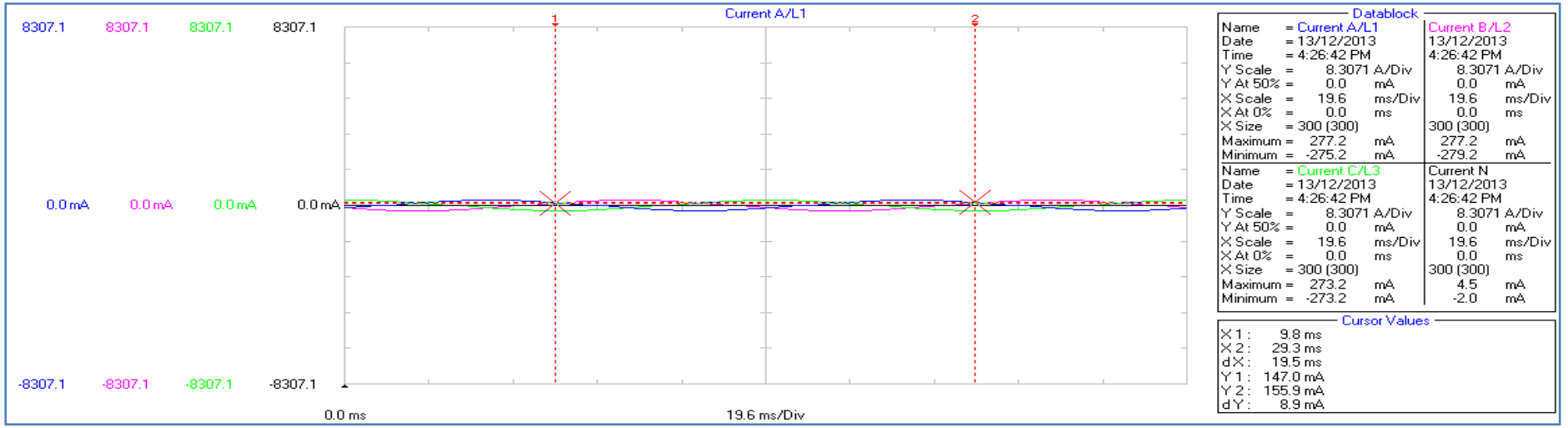


Figure 50: Fundamentals current waveform with harmonics distortions at tx wye terminal for generator-transformer-load connections.

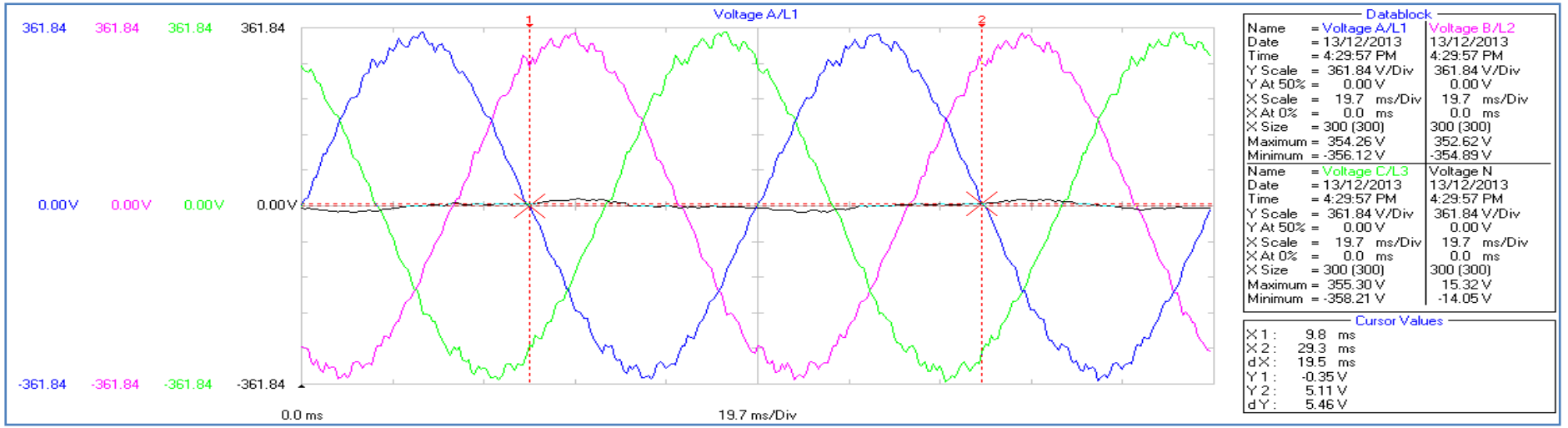


Figure 51: Fundamentals voltage waveform with harmonics distortions at load terminal for generator-transformer-load connections.

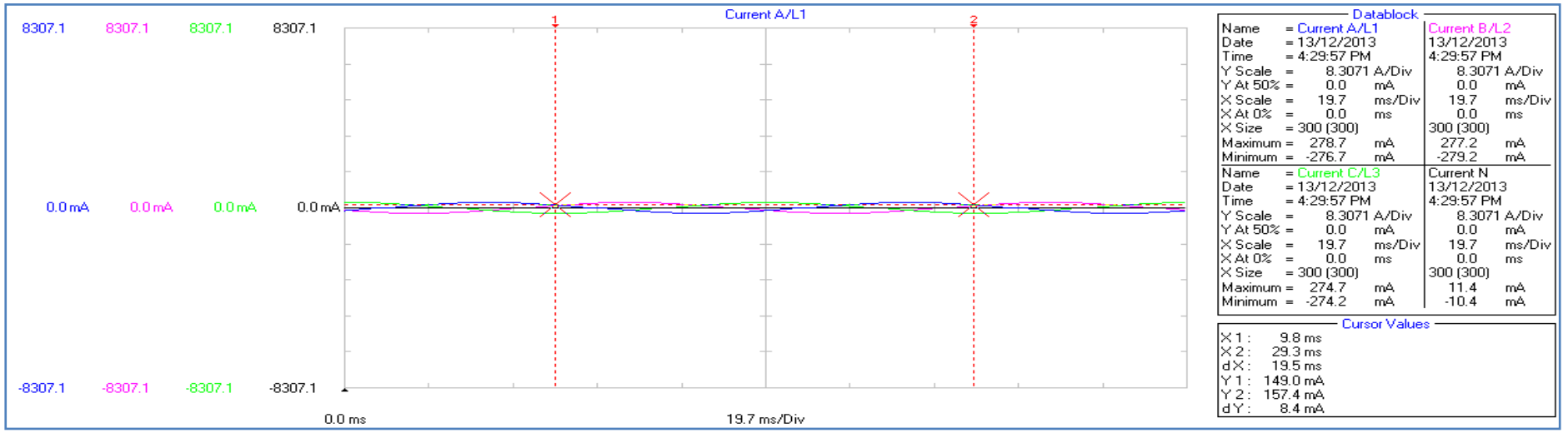


Figure 52: Fundamentals current waveform with harmonics distortions at load terminal for generator-transformer-load connections.