A Study On The Problem Of Heating Effect At The Generator's Neutral Earthing Resistor (NER) In UTP Gas District Cooling (GDC) When The Generator Is Connected In Parallel With TNB Supply

by

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PROJECT DISSERTATION

Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
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(Electrical & Electronics Engineering)

Universiti Teknologi Petronas
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CERTIFICATION OF APPROVAL

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Approved:

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(Ir. Mohd Faris bin Abdullah)
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

December 2009

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.

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Nik Siti Rashidah binti Hashim

ABSTRACT

This report basically discusses the preliminary studies done and overview of the chosen topic, which is **A Study On The Problem Of Heating Effect At The Generator's Neutral Earthing Resistor (NER) In UTP Gas District Cooling (GDC) When The Generator Is Connected In Parallel With TNB Supply.** The objective of the project is to study the heating effect on the generator's NER at GDC during parallel operation with TNB supply and propose recommendation to mitigate this problem. In UTP, electrical power is supplied from two generator units at Gas District Cooling (GDC). During parallel operation with TNB supply, it is observed that the generator's neutral earthing resistor (NER) is getting hot. The primary purpose of inserting NER between the star point of a generator and earth is to limit earth fault current. The temperature of NER is rising due to circulating current during island operation and parallel operation. The scopes of study for this project are literature review on embedded generator parallel operation with grid supply. Then, study GDC, UTP and TNB single line diagram follow by running simulation for the entire system using PSCAD software and also MATLAB. Besides that, the scope of this project also to conduct the data measurement and do the analysis to prove with the simulation. Lastly, propose recommendation action to improve the system.

ACKNOWLEDGEMENTS

All Praises to Allah, the Almighty for enabling me to have the courage and determination to complete this project with success. I would like to express my heartfelt thanks and gratitude to;

- My supervisor, Ir. Mohd Faris Abdullah, for his continuous guidance, constructive critics and invaluable contribution for improvement,
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- Fellow friends who shared the good and bad times and gave the true meaning of friendship and teamwork,
- Family members for inspiration and encouragement.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

In Universiti Teknologi PETRONAS (UTP), electrical power is supplied from two gas turbine generator (GTG) units at Gas District Cooling (GDC). The highest recorded maximum demand is 7.1MW with each generator capable of delivering 4.2 MW. Under circumstances when one of the generators at GDC is shutdown due to maintenance or other causes, UTP will require Tenaga Nasional Berhad (TNB) supply to cater for the entire load. Below is the information about GDC plant:

Year Of Construction	:	2000
Year Of Commercial Operation	:	2001
Owner	:	Universiti Teknologi Petronas (UTP)
Operator	:	Makhostia Sdn. Bhd.
Product	:	Electricity and chilled water for UTP campus
Plant Capacity	:	8.4 MW- Electricity; 4000 RT- Chilled water

1.2 Problem Statement

During parallel operation with TNB supply, it was observed that the GTG's neutral earthing resistor (NER) had experienced excessive heat as compared to during islanding operation. The table below shows the data measured on 21/1/09 during parallel operation with TNB supply.

Table 1: NER current and temperature measurement

time	outside temp	NER temp.	NER Amp		GTG LOAD (kW)		GTG VAR (kVAR)		pf		Voltage (V)		Current (A)	
			GTG A		GTG A	TNB	GTG A	TNB	GTG A	TN B	GTG A	TNB	GTG A	TNB (calc)
		GTG A	from Gen.	to earth										
0800					3867	1336	1575		0.92		11348		209	73.9
0900	29.1	61	12.4	12.4	3937									
1000					3954	1688	1560		0.93		11201		218	93.6
1100	31.2	68.6	12.4	12.4	3928									
1200					3936	1891	1545		0.93		11358		215	103
1300	34.9	71.6	11.7	11.7	3842									
1400					4040	1885	1580		0.93		11316		211	103
1500	35	71.8	11.7	11.7	3862									
1600					3949	2138	1536		0.93		11295		214	118
1700	34.5	70.6	11.7	11.7	3881									
1800					3993	1994	1535		0.93		11327		208	109
1900	31.4	57.6	12.3	12.3	3855									
2000					3950	1400	1600		0.93		11191		220	77.7

From the figure below, we can see that the NER cable insulation had been damaged by the excessive heat. Appendix C and Appendix D are the reports from GDC about this problem.

Figure 1: Cable Damage

1.3 Objective and Scope of Study

The objective of the project is to study the heating effect on the generator's NER at GDC during parallel operation with TNB supply and propose recommendation to mitigate the problem.

CHAPTER 2
LITERATURE REVIEW

2.1 Earthing

In electrical systems, the neutral earthing is used to:

- Limit the potential of current-carrying conductors with respect to the general mass of earth.
- Provide a current return path for unbalance current and earth faults in order to allow protective devices to operate.

Within the generation, distribution, transmission and industrial networks, the neutral earthing is typically used on the secondary winding transformer and on the windings of generators. Usually, electrical systems are earthed via their star point or neutral. There are three types of neutral earthing;

- Neutral solidly earthed
- Neutral earthed via impedance (resistors, inductors, resonant devices)
- Isolated or unearthed

Where there is more than one generator operating in parallel, the subject of neutral/earthing circulating currents can be dealt with following arrangements;

a) A neutral earthing transformer connected between the phases and earth. This enables the neutral of the installations to be permanently earthed, with the generators connected to the busbars as three-wire machines.
b) Star-point switching to connect the star point of only one generator to earth during parallel operation.

c) A suitable reactor in the neutral connection of each generator which will attenuate higher frequency currents without offering significant impedance at mains frequency [1].

2.2 Neutral Earthing Resistor (NER)

Neutral earthing resistors (NER) are used in power system as neutral earthing for generator or transformer winding, shown in Figure 1. If the generators operate in island or stand-by mode then each generator shall be separately earthed via an earthing resistor.

NER is designed to limit the current flow to earth under earth fault condition. This limited fault current is low enough to prevent damage to the generation, distribution and other associated equipment yet high enough to operate fault clearing relays. The rating of the NER is chosen so that the fault current is limited to that necessary to operate the protection relays within the required time. For maximum benefit, it is necessary to detect, locate and clear earth faults as quickly as possible.

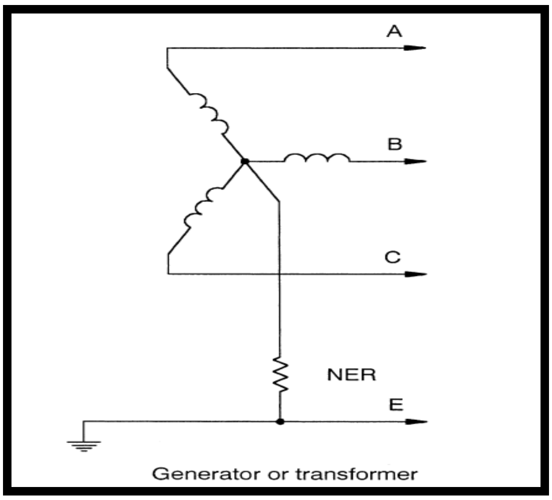

Figure 2: Earthing a high voltage system by using a neutral earthing resistor [2].

2.3 Harmonics Current

Harmonics are currents and voltages that are continuous multiples of the fundamental frequency of 50 Hz such as 100 Hz (2nd harmonic) and 250 Hz (5th harmonic). Harmonic currents provide power that cannot be used and also takes up electrical system capacity. Large quantities of harmonics can lead to malfunctioning of the system that results in downtime and increase in operating costs.

The third harmonic signals produced by a generator are dependent on:

- The generator construction
- Generator excitation
- Generator loading

The third harmonic current, which is generated, does not cancel each other but sum up together causing a significantly higher current flow in neutral conductor, ground conductor, and ground loop. Native characteristic of third harmonic current is a zero sequence component. This means that the third harmonic current in each line conductor will not cancel at neutral point but they will sum up and increase their magnitude significantly in neutral conductor.

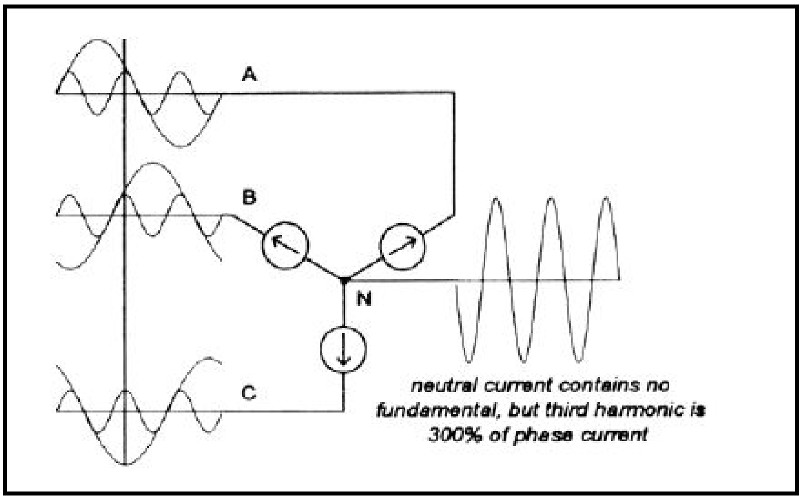

Figure 3: The summation of third harmonic current in neutral conductor.

In normal operating condition, if loads in each phase are not balance then there is still be a current flow through neutral conductor. The magnitude of this current depends on the degree of load unbalance in each phase. Normally, in three phase power system, degree of load unbalance is rather small. The current will flow back to the point of generator via several paths. The highest magnitude current will flow in lowest impedance [4].

2.3.1 Flow of Third Harmonic Current

Concerning the flow of harmonic current, we can consider harmonic producing load (nonlinear) as a harmonic current sources. Nonlinear load generate a high quantity of third harmonic current which is the zero sequence component. Almost all of this current will flow out from line conductor of load side through the lowest impedance path (in this case is generator). When each third harmonic in three line conductors reach the neutral point of generator, they will not cancel each other but sum up together and increase their magnitude significantly[4].

2.4 Symmetrical Components

Symmetrical component, introduced by C. L. Fortescue in 1918, is a powerful technique for analyzing unbalanced three phase systems [4]. This technique is to break up asymmetrical three-phase voltages and currents into three sets of symmetrical components as follows [3, 4]:

1. Positive-sequence components.
2. Negative-sequence components.
3. Zero-sequence components.

For zero phase sequence currents, they can be designated as:

$$I_a^0 = I_b^0 = I_c^0$$

In a three-phase Y-connected system, the neutral current, I_n is the sum of the line current:

$$I_n = I_a + I_b + I_c$$

This means that, the neutral current equals three times the zero-sequence current.

$$I_n = 3I_0$$

In a balance Y-connection, line currents have no zero-sequence component, since the neutral current is zero. Besides that, on a three-wire system (Δ-connection or ungrounded Y-connection), line currents have no zero-sequence component.

CHAPTER 3
METHODOLOGY

3.1 Procedure Identification

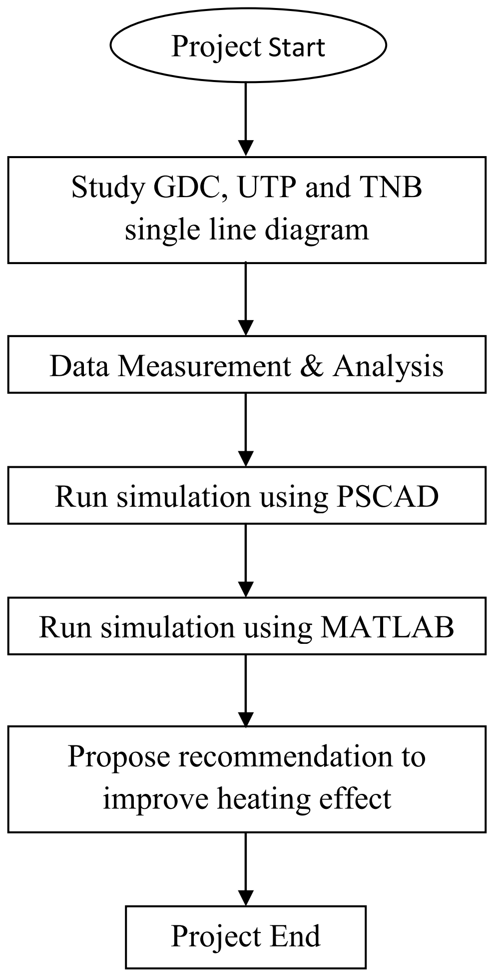

Figure 4: Flow Chart of Project

3.2 Tools and Equipment Required

3.2.1 Hardware

- Power Quality Analyzer, Fluke 43B

The “Power Quality Analyzer, Fluke 43B” is used to measure the harmonics current at each NER.

3.2.2 Software

- PSCAD EMTDC Software

PSCAD (Power System CAD) enables the user to schematically construct a power system, run a simulation, analyze the results, and manage the data in a completely integrated and graphical environment.

- MATLAB Software

MATLAB is the high-performance language for technical computing, computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation.

3.3 Procedure

3.3.1 Study GDC, UTP and TNB Single Line Diagram.

At the beginning of the project, the study on single line diagram of GDC, UTP, and TNB is carried out to get better understanding about generation and distribution system.

3.3.2 Data Measurement and Analysis

The next step is the data measurement. The data is collected at GDC UTP. The NER current and temperature are measured for various mode of operation. The analysis is done from the measured data.

3.3.3 Run Simulation Using PSCAD.

During this process, the first step is to start constructing the simulation case. The simulation case is based on mode of operation of generator. The simulation is performed to see the current flowing through each NER and to prove that this current is the same with the actual current measured at site.

3.3.4 Run Simulation Using MATLAB.

In this step, the simulation using MATLAB with symmetrical component method is done to prove that the unbalance current is the same with the one that flow through the NER. The unbalance current is computed using GTG terminal phase current values extracted from SCADA software at GDC UTP.

3.3.5 Propose Recommendation to Improve Heating Effect

The last step is to propose the recommendation to improve the NER heating effect. This recommendation is needed so that the problem which is brought by the heating effect is eliminated.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 GDC Mode of Operation

There are 4 possible mode of operation at GDC and the NER current and temperature measurements are taken for the studies. The mode of operation is as below:

MODE	OPERATION
1	ISLAND(1 GTG)
2	ISLAND(2 GTG)
3	PARALLEL(1 GTG + TNB)
4	PARALLEL(2 GTG + TNB)

In order to observe the effect on NER current and temperature by varying NER resistance, 2 cases of NER value are considered which are as below:

CASE	NER RESISTANCE (Ω)
1	BOTH GTGs 31.75 Ω
2	GTG-A 31.75 Ω & GTG-B 10.58 Ω (1/3 of GTG-A)

The data measured for different mode of operations and different cases of NER value are at different dates because the measurements for different condition cannot be done at a same time.

4.2 NER Current and Temperature Measurement

Case 1: Both NER resistance 31.75 Ω

The typical value of NER current and temperature of all modes is as below:

Table 2: NER current and temperature measurement

MODE	DATE	TIME	OUTSIDE TEMP(°C)	NER TEMP(°C)		NER CURRENT (AMP)		OPERATE		
				GTG A	GTG B	GTG A	GTG B	GTG A	GTG B	TNB
1	20/06/09	1300	36.8	52.4	-	7.7	-			
2	30/01/09	1300	33.8	45.4	45.6	4.3	4.8			
3	19/06/09	1700	35.3	65	-	11.6	-			
4	14/07/09	2045	28.8	41.2	45.6	7.0	8.8			

Colour legend:

IN SERVICE

NOT OF SERVICE

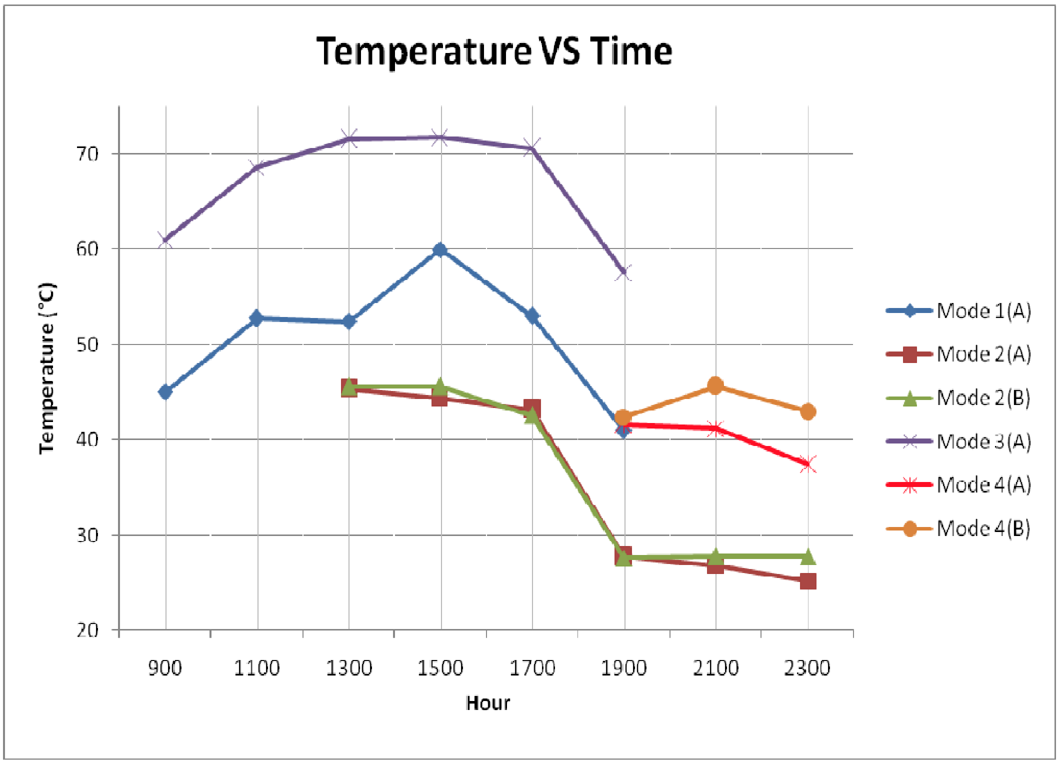

Figure 5: Daily Spectrum of NER Temperature vs. Time

*Legend: Mode 1(A) = Mode 1 NER GTG-A, Mode 2(A) = Mode 2 NER GTG-A, etc.

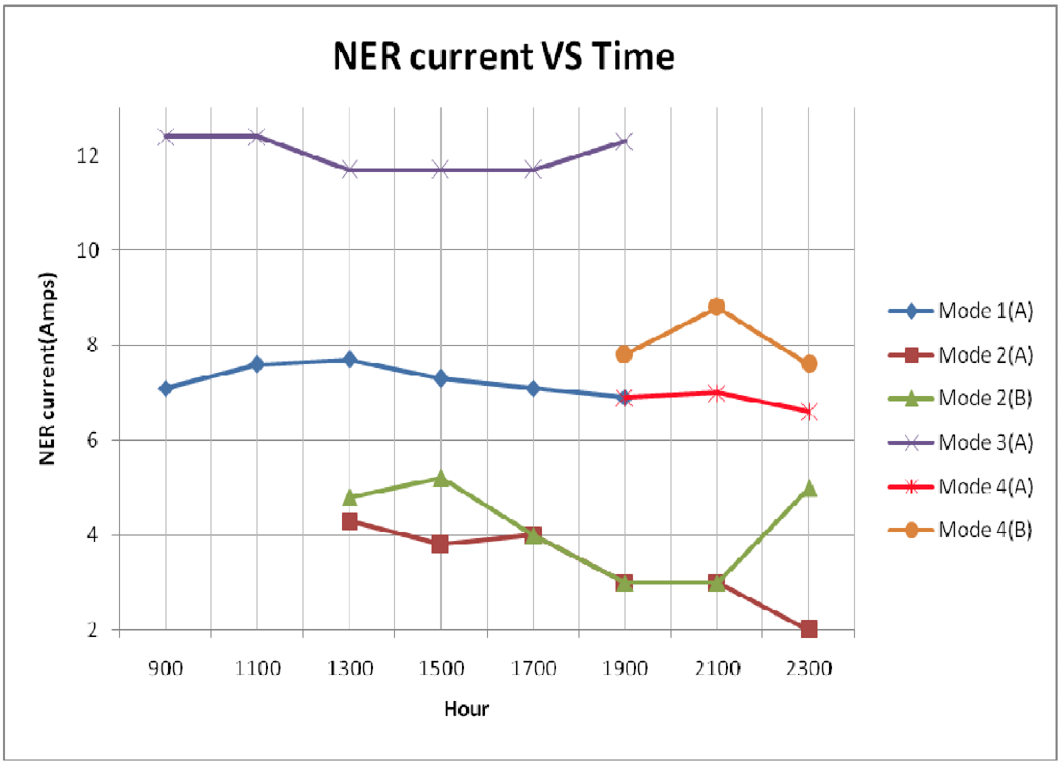

Figure 6: Daily Spectrum NER Current vs. Time.

Observations from table and graph:

NER Temperature:

- NER temperature was influenced by ambient temperature since high temperature between 1300 – 1700 hrs and low temperature at early morning & night.
- Direct correlation between NER temperature and NER current for all modes of operation

NER current:

- Mode 1 – Maximum unbalance UTP system was almost 8 Amps
- Mode 2 - Mode 1 current was shared by 2 NER equally around 4 Amps each since both NER were having the same value.
- Mode 3 - Additional approximately 4 Amps current came from unbalanced between TNB-UTP system.
- Mode 4 - Each NER was taking additional 4 Amps coming from unbalanced between TNB-UTP system.

Case 2: NER GTG A resistance 31.75 Ω & NER GTG B resistance 10.58 Ω (1/3 of GTG)

The typical value of NER current and temperature of all modes is as below:

Table 3: NER current and temperature measurement

MODE	DATE	TIME	OUTSIDE TEMP(°C)	NER TEMP(°C)		NER CURRENT (AMP)		OPERATE		
				GTG A	GTG B	GTG A	GTG B	GTG A	GTG B	TNB
1	22/06/09	2300	23	-	25	-	9.2			
2	24/06/09	1300	34	42	44	3.5	5.8			
3	25/06/09	700	24	-	53	-	16			
4	25/06/09	1100	32.8	50.1	65.4	7.4	19.2			

Colour legend:

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NOT OF SERVICE

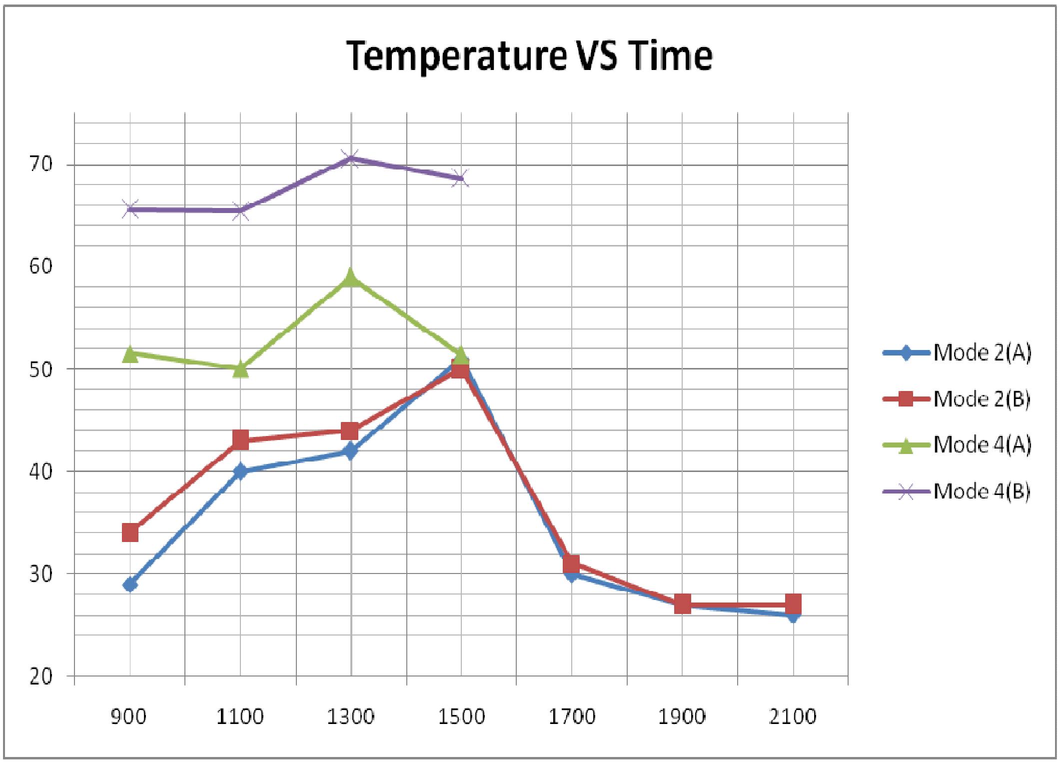


Figure 7: Daily Spectrum of NER Temperature vs. Time

*Legend: Mode 1(A) = Mode 1 NER GTG-A, Mode 2(A) = Mode 2 NER GTG-A, etc.

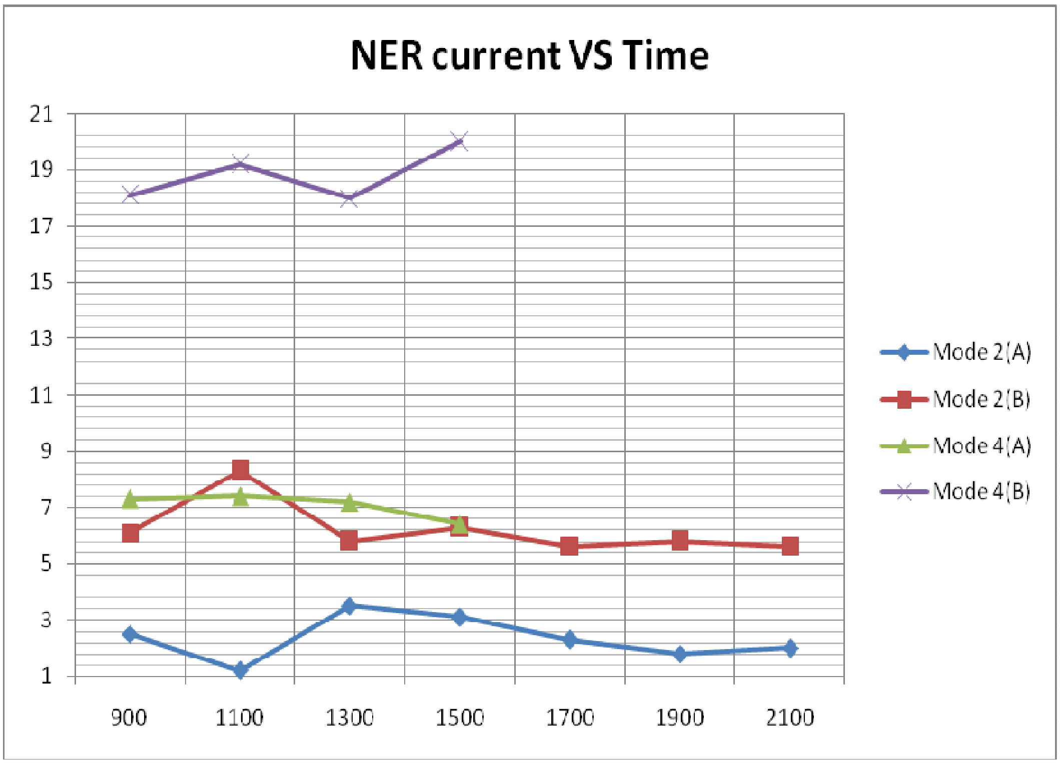


Figure 8: Daily Spectrum of NER Current vs. Time

Observations from table and graph:

NER Temperature:

- NER temperature was influenced by ambient temperature since high temperature between 1100 – 1500 hrs and low temperature at early morning & night.
- Direct correlation between NER temperature and NER current for modes 2 & 4.

NER current:

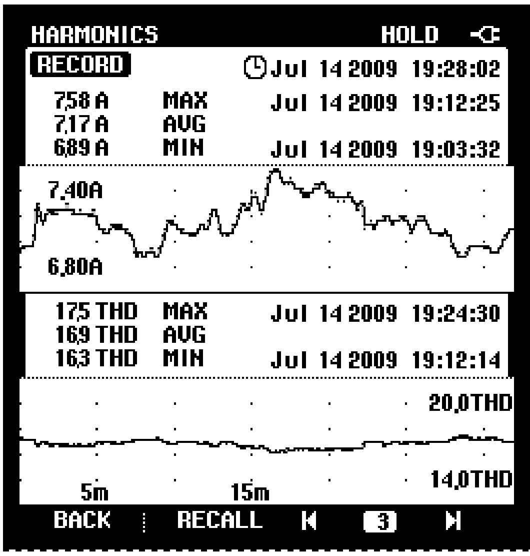
- Mode 2 - The current measured at NER GTG-B was around 6 Amps and GTG-A was around 2 Amps due to value of NER GTG-B was 1/3 of NER GTG-A.
- Mode 4 - The current measured at NER GTG-B was around 19 Amps and GTG-A was around 7 Amps due to value of NER GTG-B was 1/3 of NER GTG-A & unbalance contributed by TNB-UTP system.

**Due to non availability of data, the graph can be plotted for Mode 2 and Mode 4 only*

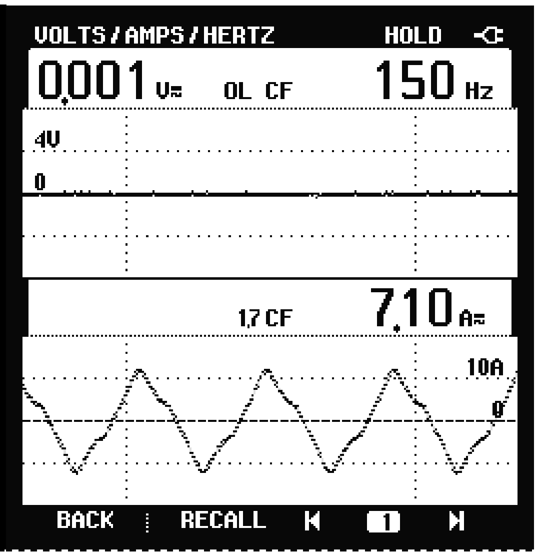
4.3 Harmonic Current Measurement

The measurements at GDC UTP are recorded on 14th July 2009 during 2 generator are parallel with TNB (Mode 4). The measurements also been done to all mode of operations. All these results such as THDi, harmonic and current spectrums are showed in figure below;

Mode 4 (NER GTG-A)



RMS current and THDi(NER A)



current waveform(NER A)

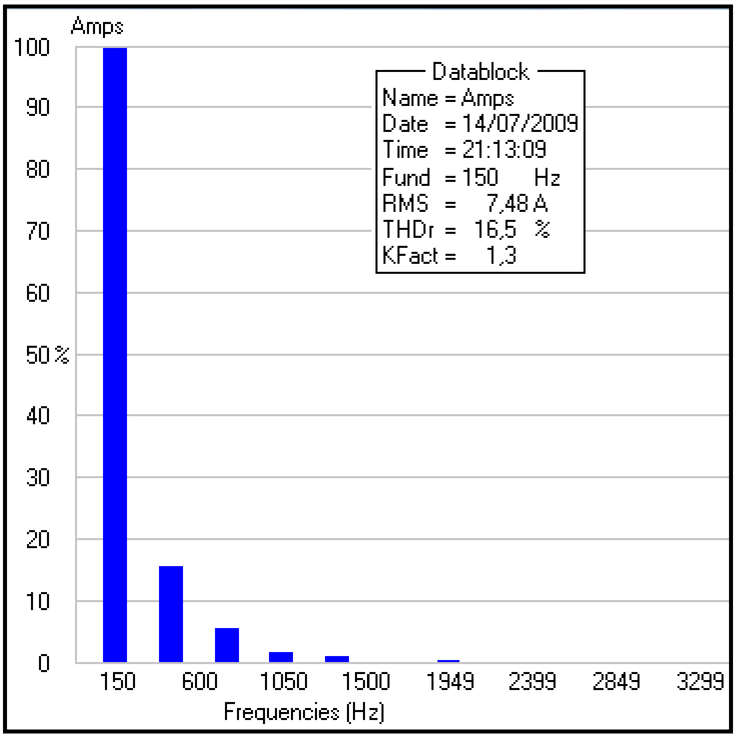


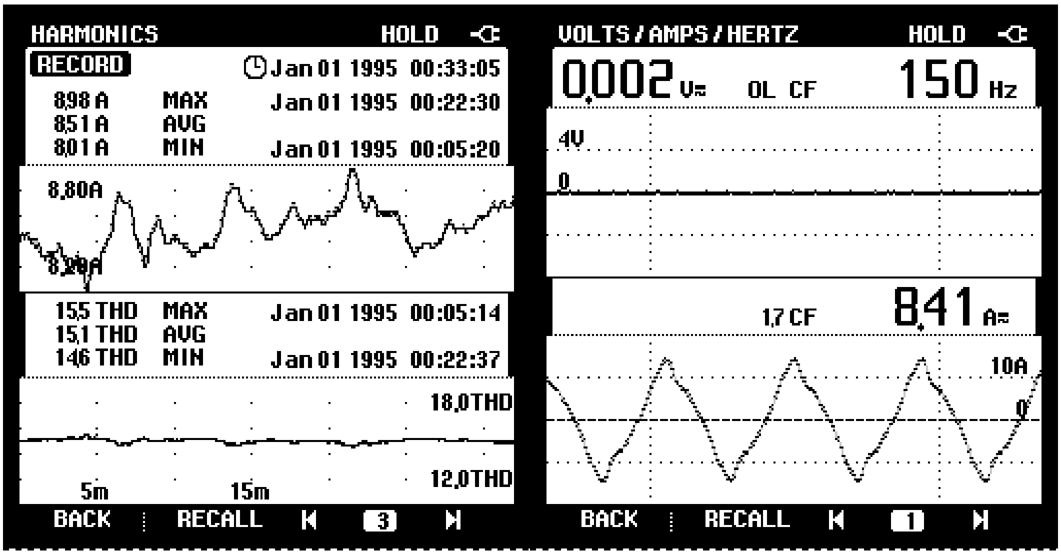
Figure 9: NER A Harmonic Measurement

Table 4: NER A Harmonic Current

ORDER	FREQ(HZ)	% AMPS	AMPS
1	50	0.00	0
3	150	100.00	7.48
5	250	0.00	0
7	350	0.00	0
9	450	15.70	1.17
11	550	0.00	0
13	650	0.00	0
15	750	5.40	0.40

It is found that magnitude of third harmonic current is the fundamental current because since no current for frequency 50 Hz then 150 become fundamental hence become 100%.

Mode 4 (NER GTG-B)



RMS current and THDi (NER B)　　　Current Waveform (NER B)

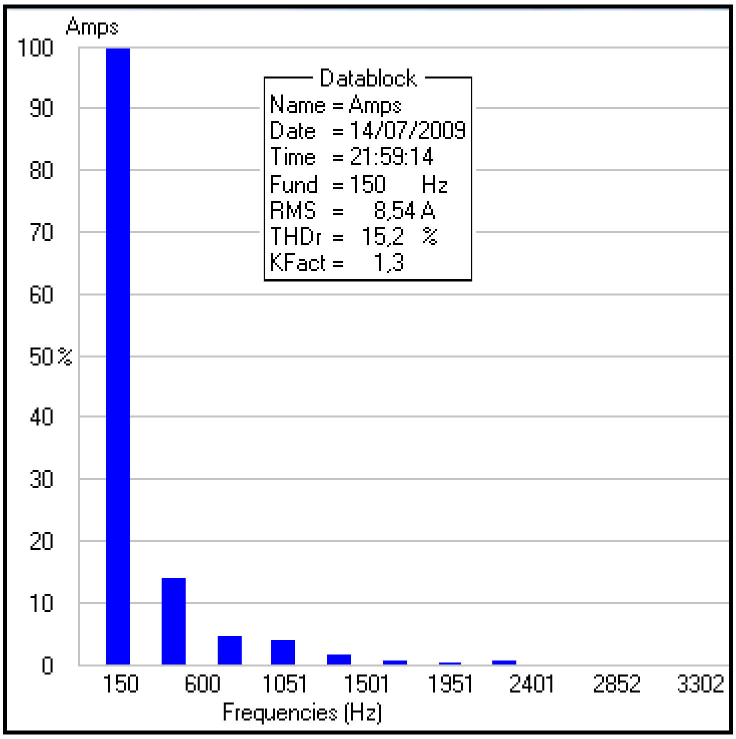


Figure 10: NER B Harmonic Measurement

Table 5: NER B Harmonic Current

ORDER	FREQ(HZ)	% AMPS	AMPS
1	50	0.00	0
3	150	100.00	8.54
5	250	0.00	0
7	350	0.00	0
9	450	14.10	1.20
11	550	0.00	0
13	650	0.00	0
15	750	4.60	0.39

It is found that magnitude of third harmonic current is the fundamental current because since no current for frequency 50 Hz then 150 become fundamental hence become 100%.

Based on observation to the pattern with the different mode of operation, it can be observed that the third harmonic current is the fundamental current due to no current for frequency 50 Hz. Whenever the current waveform in the power system is no longer sinusoidal, it is distorted , or that there is harmonic distortion..

The NER current measurement also had been done at TNB substation Seri Iskandar on 15th October 2009. Figure below shows 11 KV NER current value. This measurement was during generators at GDC UTP were not in parallel with TNB.

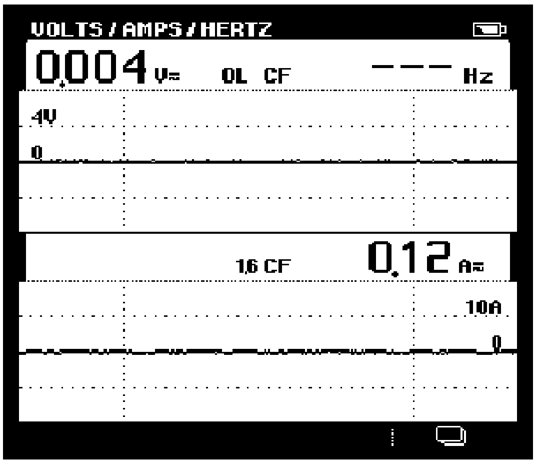


Figure 11: TNB Substation Current Measurement

The current which flow through NER is about 0.12 Amps. Due to small NER current, the PQ meter was not be able to compute the harmonics spectrum.

4.4 EMTDC Simulation

The simulation was done to prove whether the parameters (load, cable impedance, terminal voltage) give the current unbalance to the system. The EMTDC simulation was conducted on Mode 1 model.

CASE 1: LOAD BALANCE VS LOAD UNBALANCE

The simulation below is done when load side is balance.

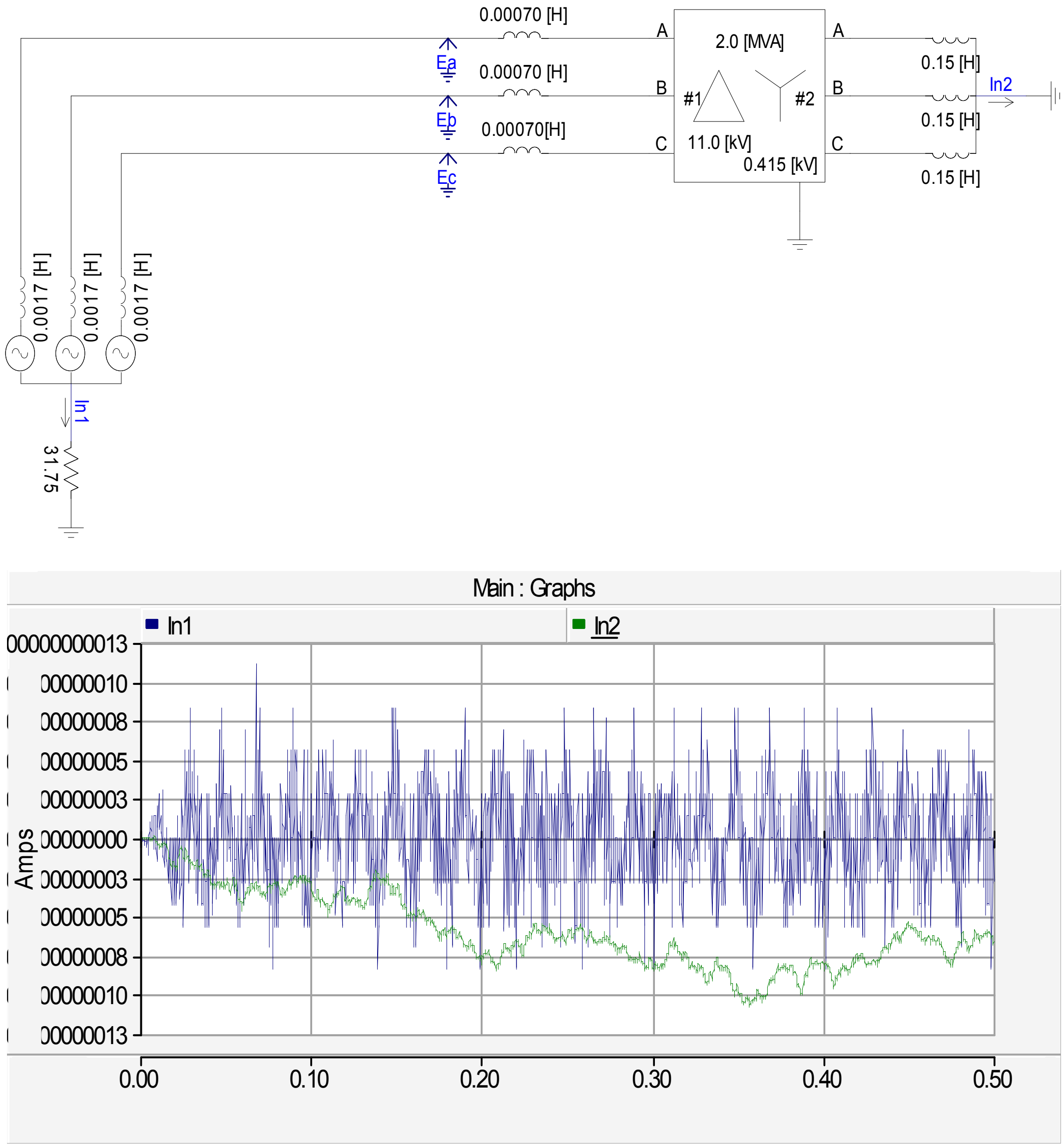
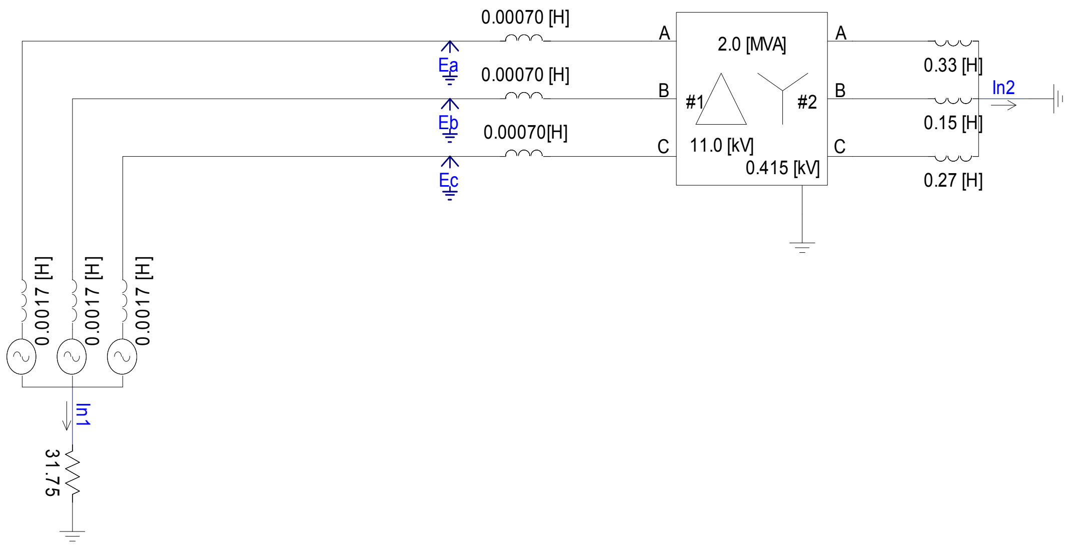


Figure 12: Simulation for load balance

The simulation below is done when load side is unbalance.



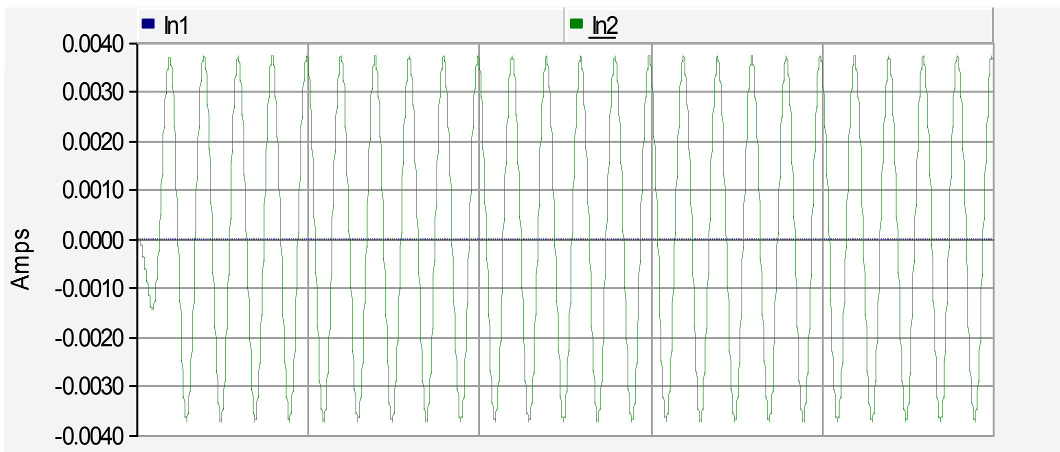


Figure 13: Simulation for load unbalance

Observation:

The magnitude of NER currents (very small) were almost the same had indicated unbalance load could not contribute to NER current . Unbalance load doesn't contribute to the unbalance current that flow through NER due to star-delta transformer.

Compare In1 between balance and unbalance load.

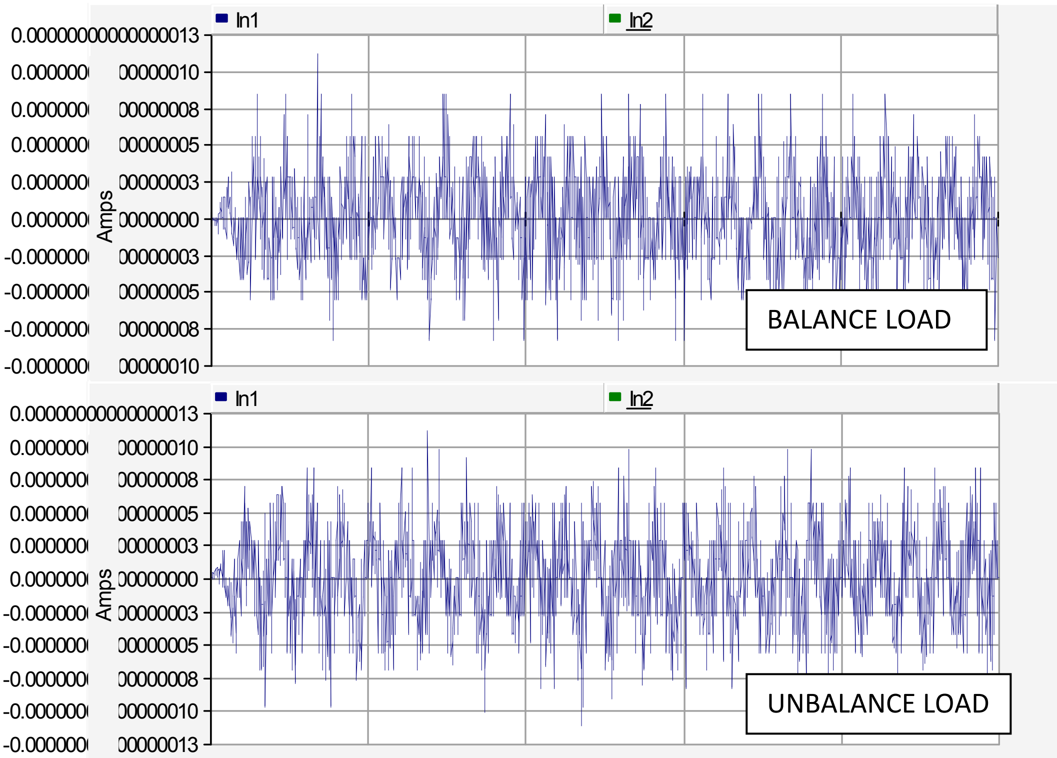


Figure 14: Graph for In1 (Balance vs. unbalance load)

Compare In2 between balance and unbalance load.

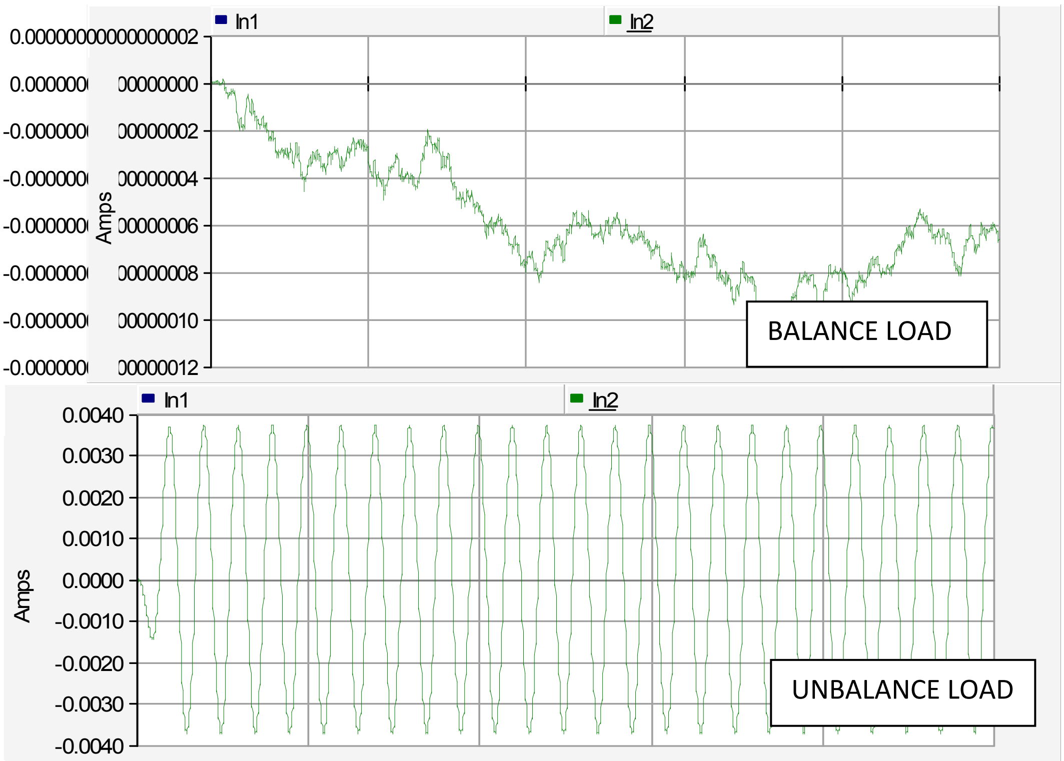


Figure 15: Graph for In2 (Balance vs. unbalance load)

CASE 2: LINE CABLE IMP BALANCE VS LINE CABLE IMP UNBALANCE

The simulation below is done when line cable impedance is balance.

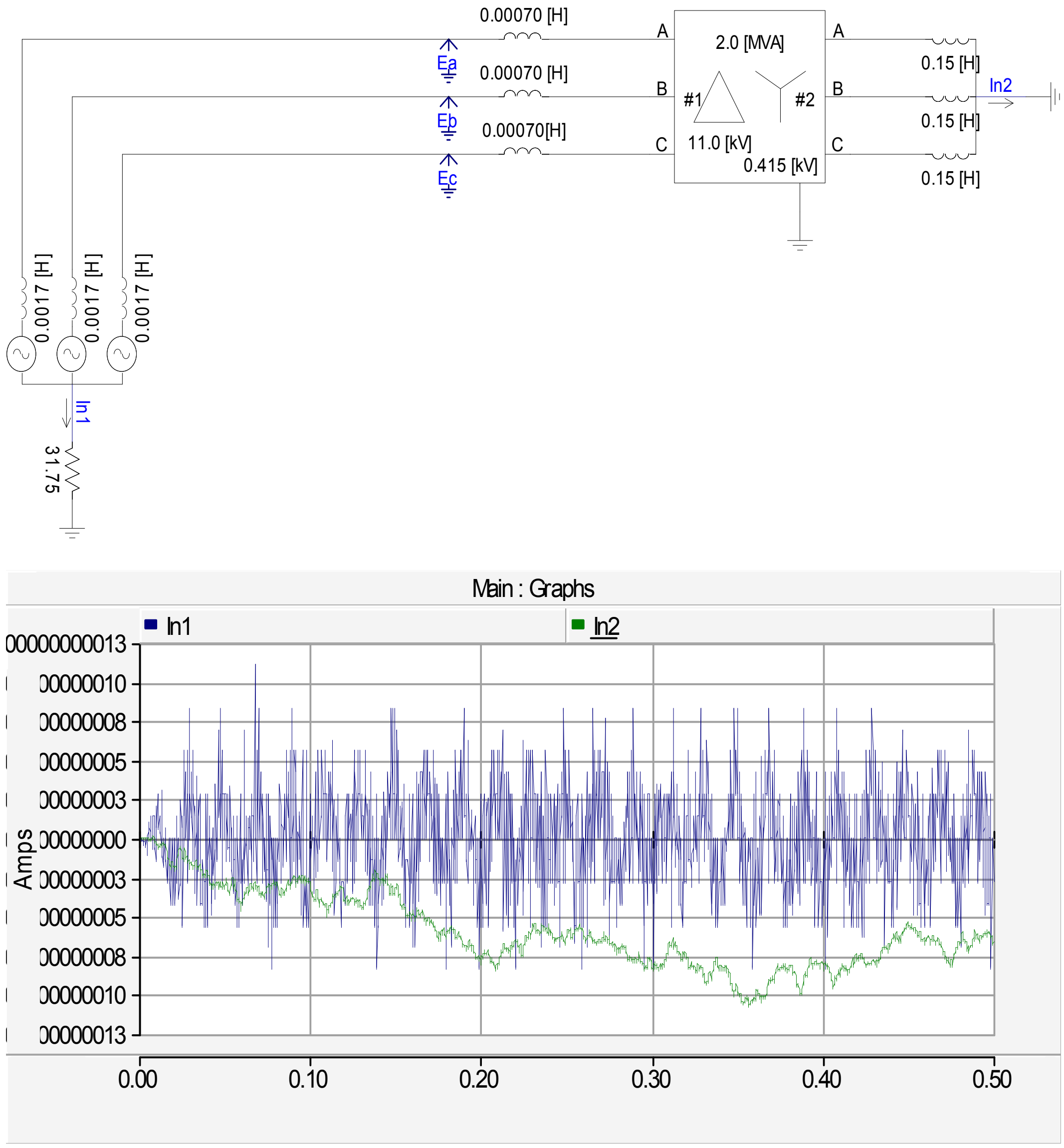


Figure16: Simulation for line cable impedance balance

The simulation below is done when line cable impedance is unbalance.

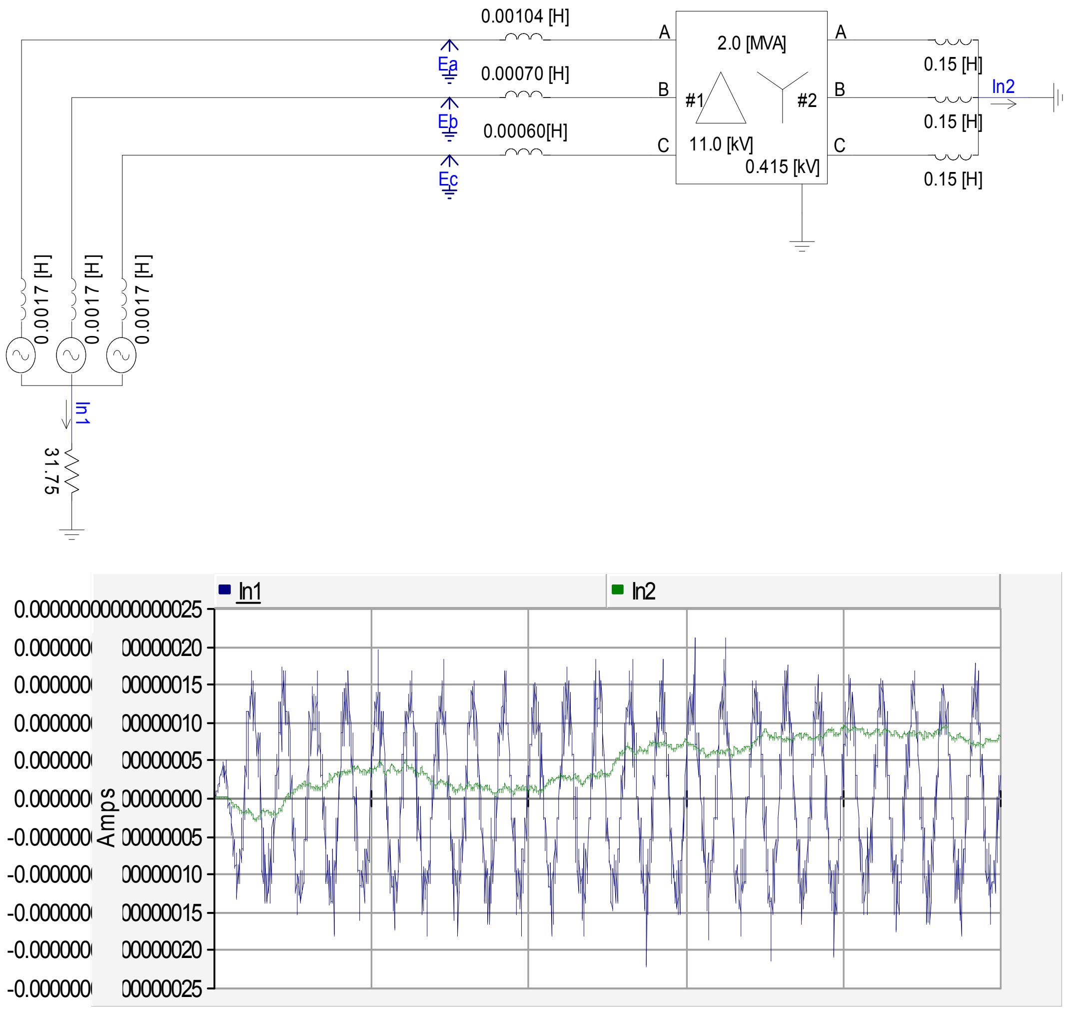


Figure17: Simulation for line cable impedance unbalance

Observation:

Unbalance cable impedance could contribute to NER current.

Compare In1 between line cable impedance balance and unbalance.

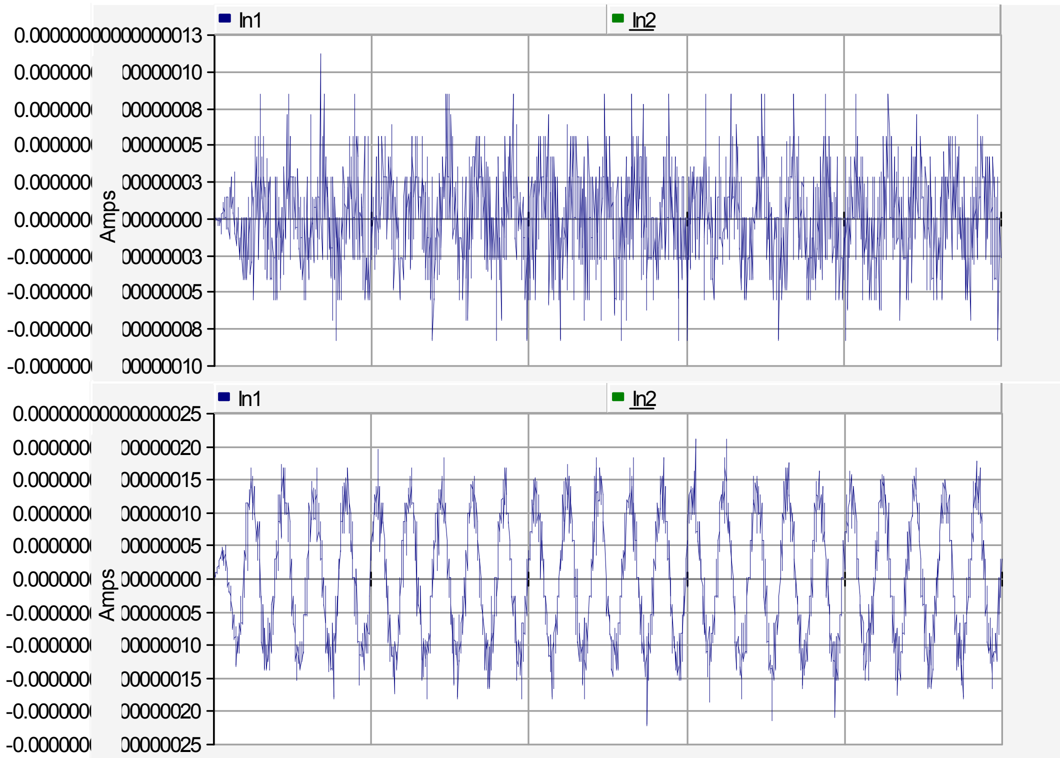


Figure 18: Graph for In1 (Balance vs. unbalance line cable impedance)

Compare In2 between line cable impedance balance and unbalance.

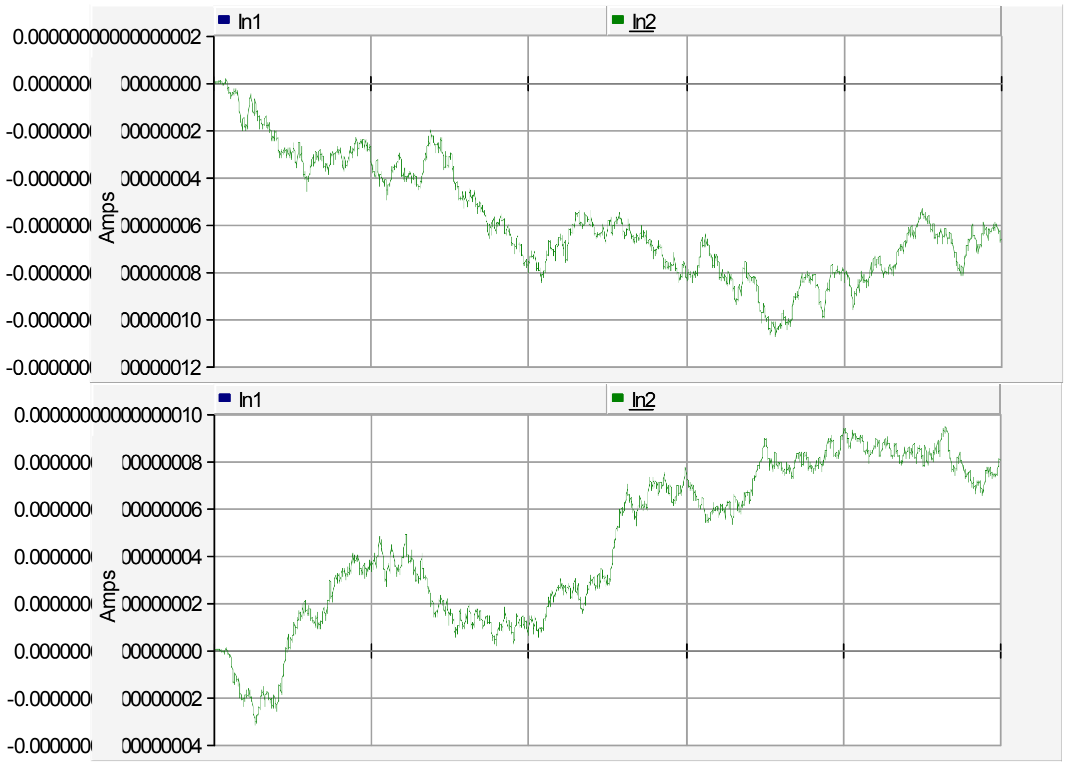
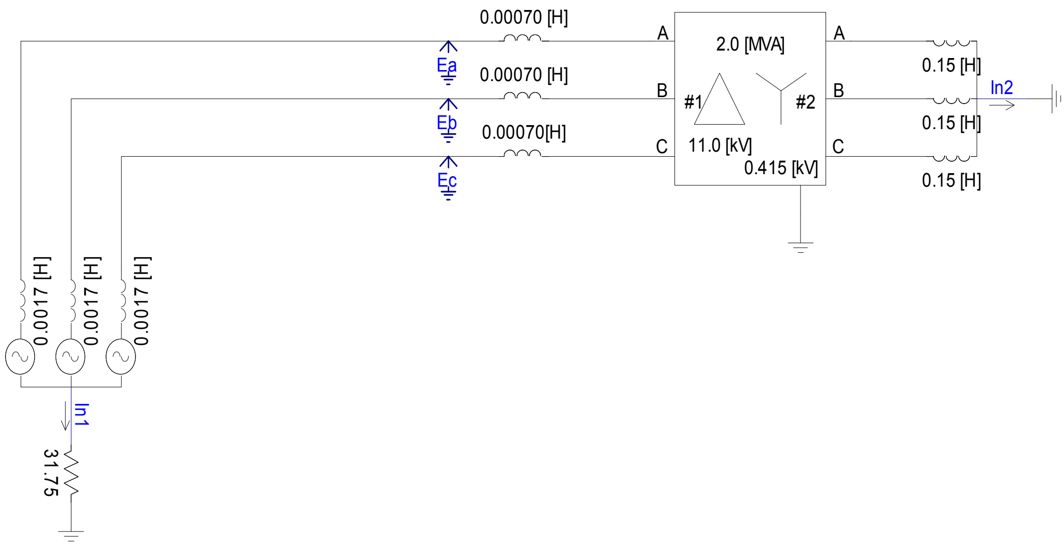


Figure19: Graph for In2 (Balance vs. unbalance line cable impedance)

CASE 3: TERMINAL VOLTAGE BALANCE VS UNBALANCE

The simulation below is done when Vt is balance



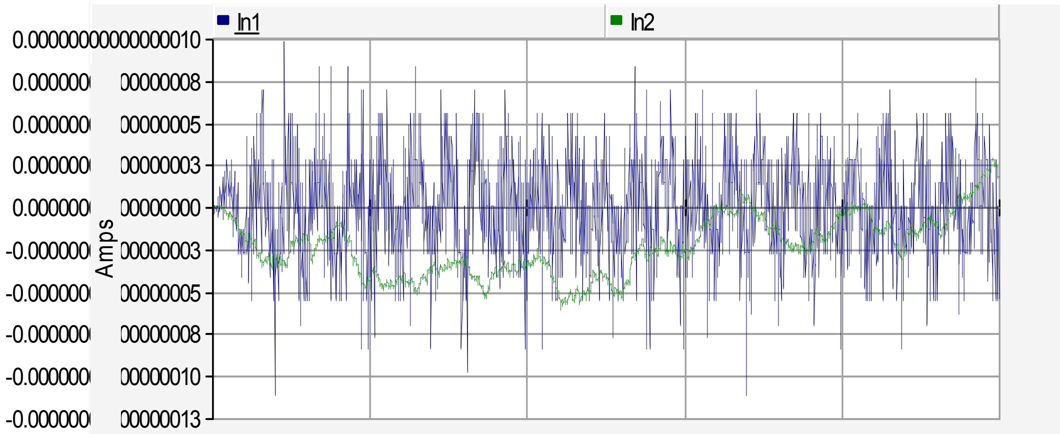
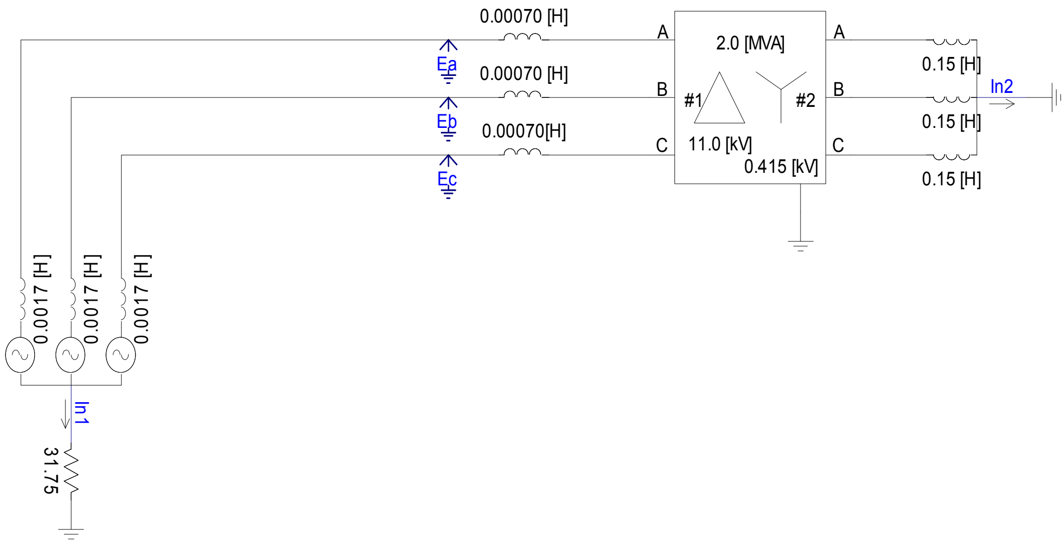


Figure 20: Simulation for Vt balance

The simulation below is done when Vt is unbalance



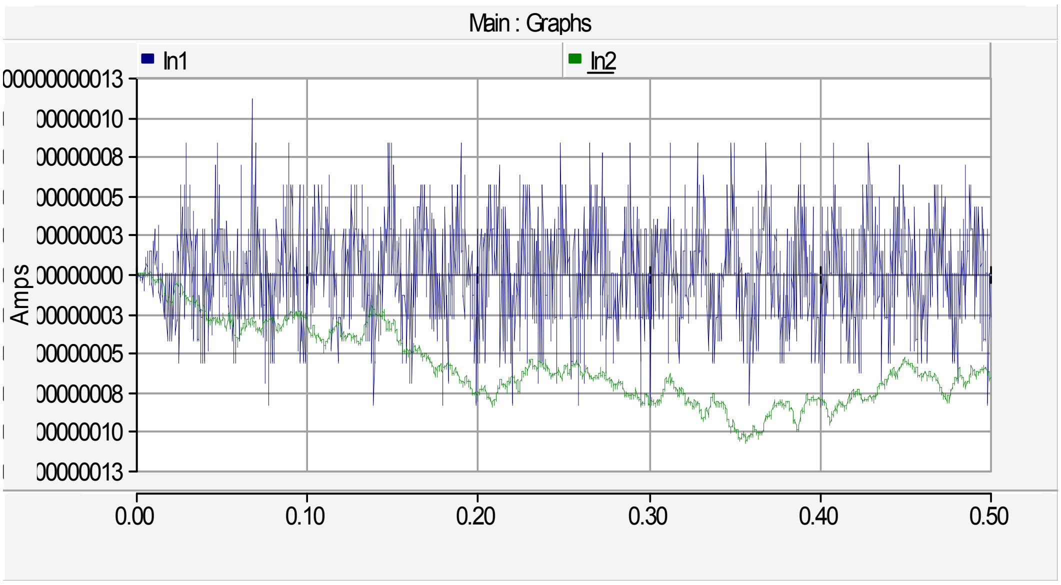


Figure 21: Simulation for Vt unbalance

Observation:

Unbalance GTG terminal voltage could contribute to NER current to a small percentage

Compare In1 between Vt balance and unbalance.

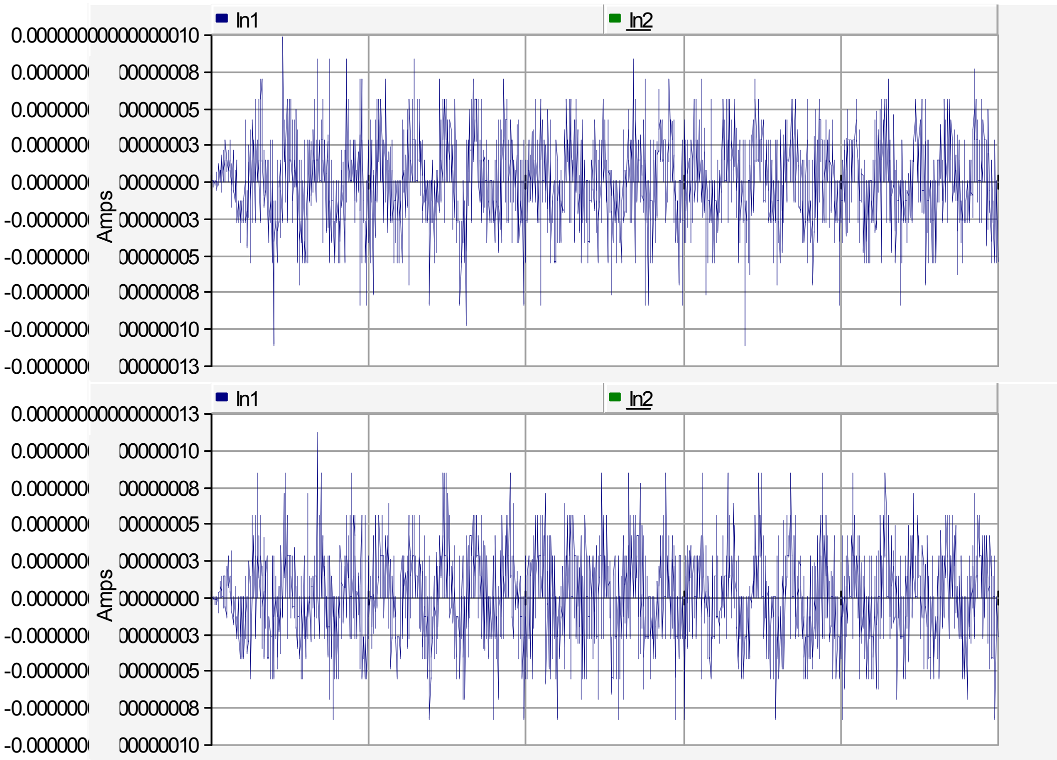


Figure 22: Graph for In1 (Balance vs. unbalance Vt)

Compare In2 between Vt balance and unbalance

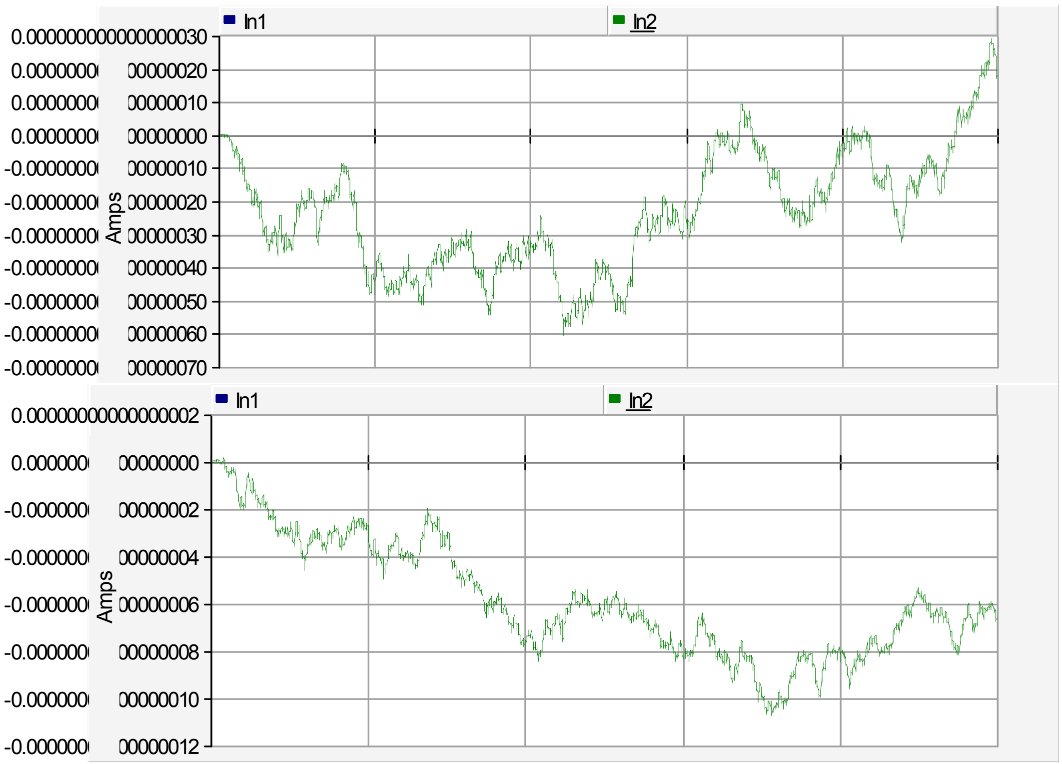


Figure 23: Graph for In2 (Balance vs. unbalance Vt)

4.5 MATLAB Simulation

Case 1: Both NER resistance 31.75 Ω

Table 6: NER current (MATLAB)

DATE	TIME	NER CURRENT (AMP)				MODE	OPERATE		
		GTG A		GTG B					
		ACTUAL	MATLAB	ACTUAL	MATLAB		GTG A	GTG B	TNB
20/06/2009	1300	7.7	6.25	-	-	ISLAND			
30/01/2009	1300	4.3		4.8		ISLAND			
19/06/2009	1700	11.6	2.65	-	-	PARALLEL			
14/07/2009	2045	7.0	1.73	8.8	1	PARALLEL			

Case 2: NER GTG A resistance 31.75 Ω & NER GTG B resistance 10.58 Ω (1/3 of GTG)

Table 7: NER current (MATLAB)

DATE	TIME	NER CURRENT (AMP)				MODE	OPERATE		
		GTG A		GTG B					
		ACTUAL	MATLAB	ACTUAL	MATLAB		GTG A	GTG B	TNB
22/06/2009	2300	-	-	9.2	7.81	ISLAND			
24/06/2009	1300	3.5	3.61	5.8	3.61	ISLAND			
25/06/2009	700	-	-	16	2.65	PARALLEL			
25/06/2009	1100	7.4	1	19.2	1	PARALLEL			

Observation:

In both cases, the actual NER current was almost the same as MATLAB simulation for Mode 1 and Mode 2. However, for Mode 3 and Mode 4 the result was different due to contribution from TNB system

**Due to non availability of data, the simulation for Mode 2 could not be done.*

4.6 Leakage Current Measurement

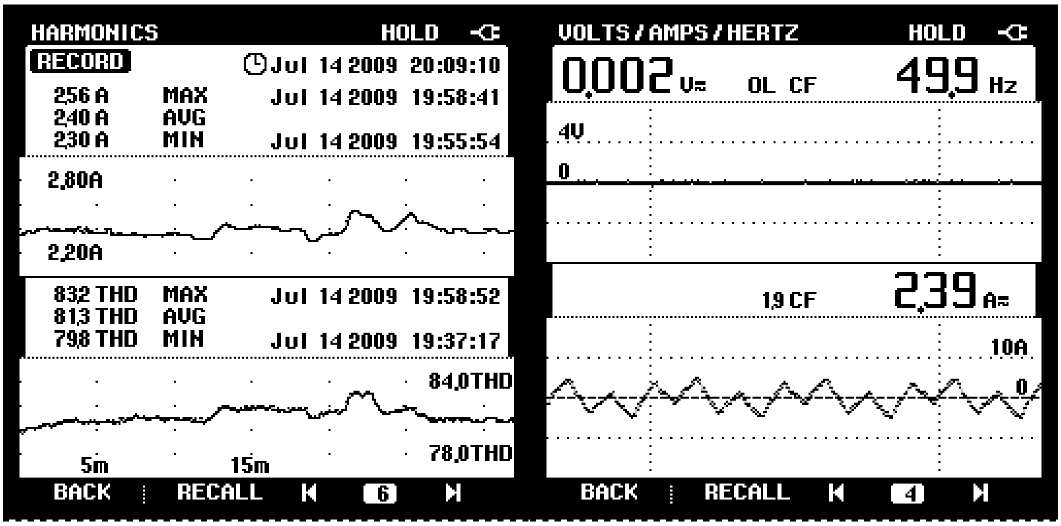
Leakage current is the current that flow from the body of generator to the earth. From the data measurement and observation, the leakage current is consistent regardless the mode of operation which is about 2-3 Amps.

Table 8: Leakage current measurement

		LEAKAGE CURRENT (AMP)	
DATE	TIME	GTG A	GTG B
14/07/2009	1845	2.2	2.7
	1945	2.3	2.8
	2045	2.2	3.0
	2145	2.3	2.9
	2245	2.2	2.7

The measurement above is during mode 4 which is when 2 generators are parallel with TNB. The harmonic content also measured for leakage current.

Mode 4 (Leakage Current GTG-A)



RMS current & THDi (Leakage Current A) current waveform(Leakage current A)

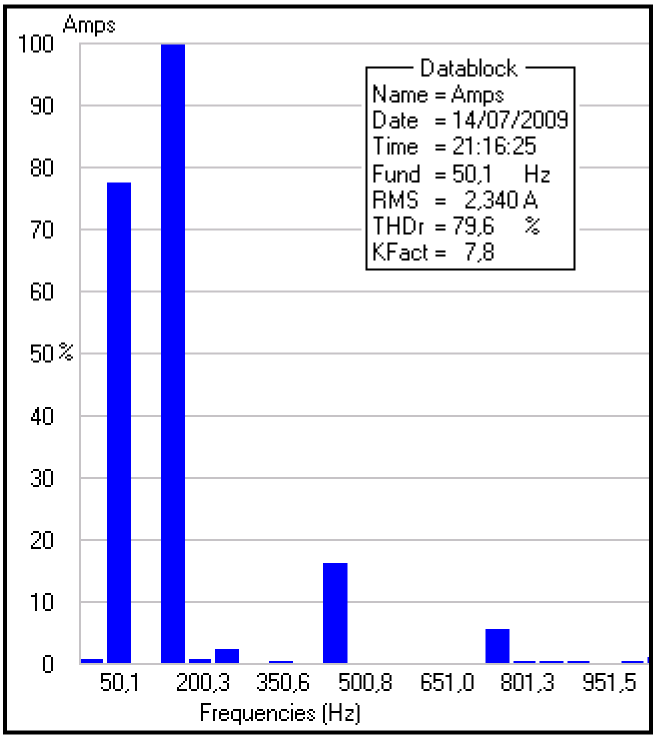


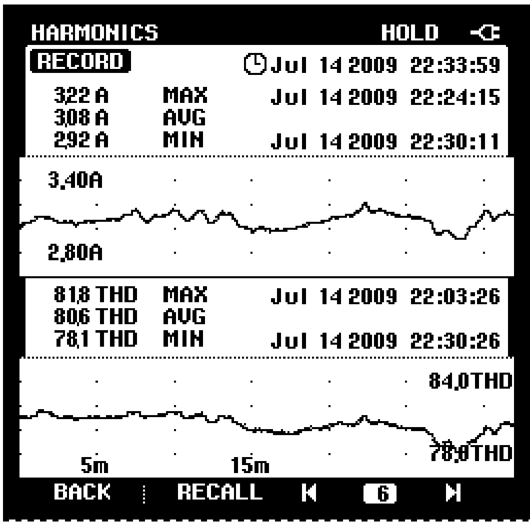
Figure 24: Leakage Current NER A Harmonic Measurement

Table 9: Leakage Current NER A Harmonic Current

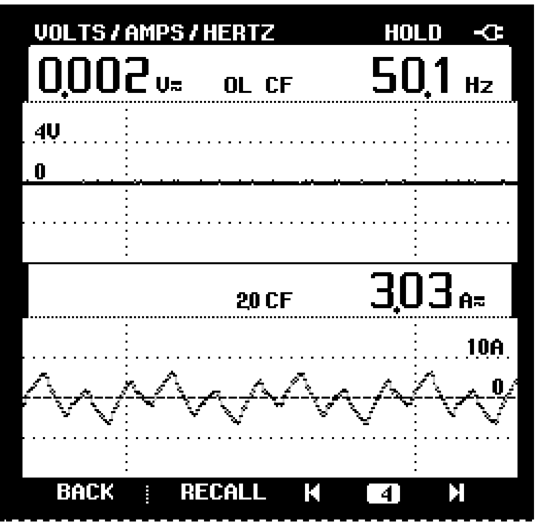
ORDER	FREQ(HZ)	% AMPS	AMPS
1	50	77.30	1.81
3	150	100.00	2.34
5	250	2.20	0.05
7	350	0.50	0.01
9	450	16.00	0.37
11	550	0.10	0.00
13	650	0.10	0.00
15	750	5.50	0.13

It is obviously found that magnitude of third harmonic current is about 100% of fundamental current.

Mode 4 (Leakage Current GTG-B)



RMS current & THDi(Leakage current B)



Current Waveform(Leakage Current B)

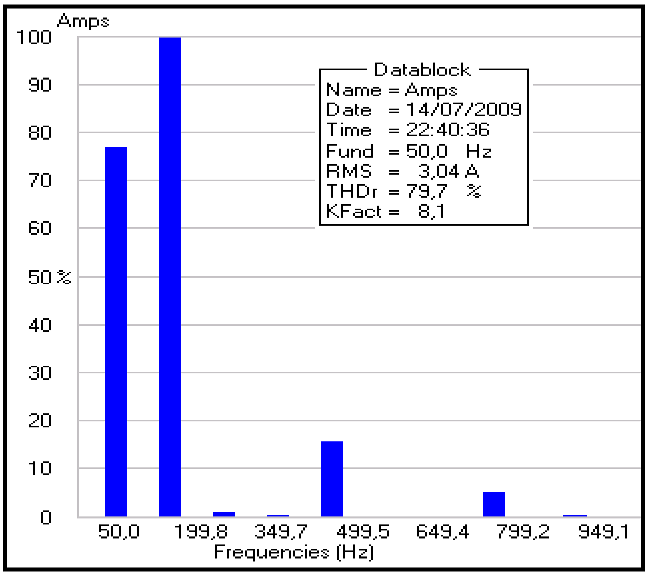


Figure 25: Leakage Current NER B Harmonic Measurement

Table 10: Leakage Current NER B Harmonic Current

ORDER	FREQ(HZ)	% AMPS	AMPS
1	50	76.90	2.34
3	150	100.00	3.04
5	250	0.90	0.03
7	350	0.30	0.01
9	450	15.70	0.48
11	550	0.10	0.00
13	650	0.10	0.00
15	750	5.20	0.16

It is obviously found that magnitude of third harmonic current is about 100% of fundamental current.

Leakage current from both GTGs contained fundamental and triplen harmonics where the third harmonic was dominant

4.7 Discussion

Principally, NER is design to carry current during earth fault or a small unbalance current that flow back to the neutral. NER at GDC was manufactured complying with IEEE 32-1972 standard, which means that the temperature of the NER will not go higher than temperature rise of 760°C. However no continuous current rating given and from manufacturer's (Fortress Systems Pty Ltd.) information, these NER units have not been designed for any significant value of continuous current flow but the design is for the short time current only. The effective rating of NER under short time current depends on the mass of the resistor material. For continuous current, the available cooling and ventilation has the most significant influence, so vented enclosures, different spacing on the resistors and different insulator materials may be used.

Heating of NER is caused by current flowing through the NER resistor elements. The long term concern with overheating is the degradation of the insulation life. For every 10°C cooler, the insulation life is double and for every 10°C hotter the insulation life is halved.

Heat is power (P) dissipated and can be deduced from I^2R. The total heating effect is power x time (P x t) also expressed as I^2Rt. The thermal effect (I^2t) referred to, is the heating effect on the conductors created by the fault current. If the fault current is not interrupted, the heating effect can be such as to melt the conductor through which it is flowing. The I^2t term is used on thermal capability curves which describe the amount of current that the NER can sustain for how long. At GDC, the earth fault current for NER is limited to 200 Amps for 10 seconds.

The specification for NER at GDC UTP is as below:

Table 11: NER Nameplate

Line to Neutral Voltage	6.35 V
Initial Current	200 Amps
Resistance	31.75 Ohm @ 25°C
Time	10 Secs
Phases	1
Frequency	50 Hz
Type	GRID
BIL of Line kV	60

As manufacturer said, the resistor used in these NERs should still function reliably for a short time event (earth fault) even with 12A of continuous current, as long as the resistor insulation has not been damaged or degraded. However, over time the elevated temperature of the resistor and surrounding air will degrade the insulation, if this breakdown then a short circuit to ground can occur before the fault is cleared by the protection scheme.

4.7.1 Unbalance Current in the System

There is always circulating current at the generator NER especially when there are two or more generator sets (even they are connected in island mode). The main factor of the unbalance current is the difference terminal voltage at the generator. Besides that, the unbalance current comes from unbalance impedance of the cable. The unbalance cable impedance will give unbalance current to the system. The unbalance current will flow through NER which give the heating effect to the NER.

The unbalance load between the three phases which are connected to the system also will result in unbalance current. But, since loads in UTP/GDC are at LV level, this unbalance load will not contribute to the unbalance current because the load is connected at star side of delta-star transformer.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Different mode gives different NER current, but there is always current that flowing through NER. Among the 4 mode, mode 3 gives the highest NER current measurement . This mode is during 1 generator is parallel with TNB.

All in all, the neutral current exist due to difference in terminal voltage of parallel operation generators and also unbalance of phase impedance of all circuit components in the system. Practically, there will always be an unbalance in the system. The more the system is balanced, the less current is in the neutral. If high currents are measured in the neutral, or at least higher than we expect, problems may result.

5.2 Recommendation

From this study, there are a few recommendations to mitigate this NER heating effect which are:

1. Increase NER impedance.

   Increases in NER impedance will result in reduce in current flowing in NER. However, this solution will increase the cost, as the impedance increase and also result in too small ground fault which makes the earth fault or standby earth fault relays inoperable.

2. Install interface transformer.

   To ensure robustness of system earths, it is recommended that generation systems are interconnected to the distribution network by installing the interface transformer. By using interface transformer, it can be ensuring that the earthing systems of the generating unit and distribution system are adequately and independently earthed. This interface transformer also could reduce the number of generator tripping due to under/over voltage protection when in certain cases, the generator will experience less voltage dips originating from the Distribution Network. This solution is also costly.

3. Isolate NER during parallel with TNB.

   During GTG is parallel with TNB, the circulating current is high. If the NER is isolated during parallel mode, there will be no current flowing through NER and there will be no heating effect at NER. But, by operating the generator without NER will give high voltage during fault occur.

4. Filtering triplen harmonics current

   Since all the currents flowing to NER is triplen harmonics current, then the actual unbalance current is (1/3) of that current. If we can use harmonic filter, we can eliminate the harmonic distortion current and the remaining current then is actual unbalance which is small. However the cost of filter is very expensive.

5. Removing excess heat from NER

   Since NER enclosure design is not for continuous current heat dissipation, and then the option of creating louver, Figure 26 to release the heat can be considered. Replacing the enclosure side panels with louvered units to improve the enclosure ventilation. The mesh fitted id to prevent vermin and insects entering.

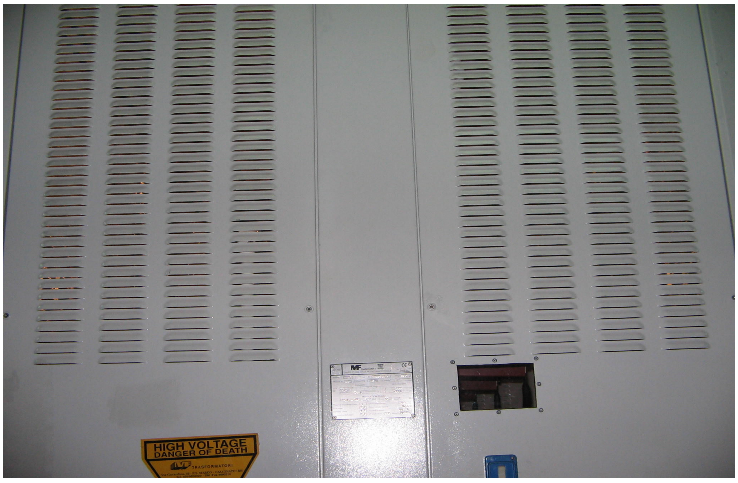


Figure 26: Louvers

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[1] Alan L Sheldrake, *Handbook of electrical engineering for practitioners in the oil, gas and petroleum.*

[2] British Standard BS 7430:1998, *Code of Practice for Earthing.*

[3] Hadi Saadat, *Power System Analysis,* Mc Graw Hill, 2004.

[4] Grainger, J.J., and Stevenson, W.D., *Power System Analysis,* Mc Graw Hill, 1994.

[5] Manat Arunvatanaporn, and Anucha Harirak, *Impact of Third Harmonic Current to Earth Fault Protection System,*Research and Development Department Metropolitan Electricity Authority (MEA) Bangkok, Thailand.

[6] ANSI/IEEE Std 32-1972, *IEEE Standard Requirements, Terminology, and Test Procedure for Neutral Grounding Devices*.

APPENDICES

APPENDIX A
PROJECT SCHEDULE – GANTT CHART

PROJECT SCHEDULE

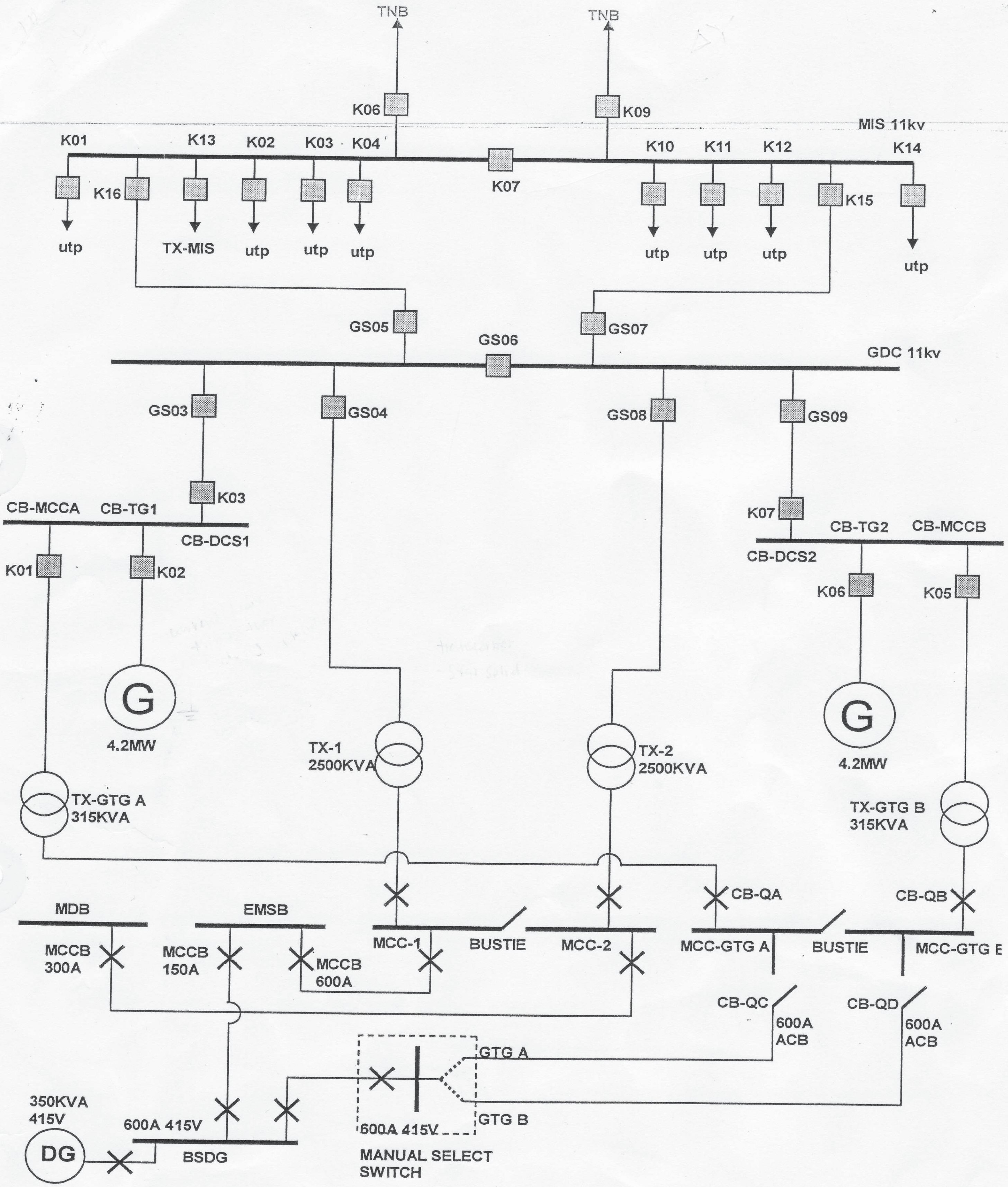
GANTT CHART

	Weeks																											
	FYP I														FYP II													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Deliverable																												
a) Project proposal		■																										
b) Preliminary Report				■																								
c) Progress Report								■																				
d) Draft Report												■																
e) Interim Report													■															
f) Oral Presentation I														■														
g) Progress Report II																		■										
h) Final Report (Softbound)																								■				
i) Oral Presentation II																												■
j) Final Report (Hardbound)																												■
Literature review			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					
Gathering Data					■	■	■	■	■																			
Study GDC, UTP and TNB Single Line Diagram					■	■	■	■																				
Data Measurement & Analysis										■	■	■	■	■	■	■	■	■	■	■								
Run simulation using PSCAD															■	■	■	■	■	■	■	■	■					
Run simulation using MATLAB															■	■	■	■	■	■	■	■	■					
Propose Recommendation to Improve Heating Effect																							■	■	■	■	■	■

APPENDIX B

SINGLE LINE DIAGRAM GDC UTP

SINGLE LINE DIAGRAM GDC UTP



Draw by i/e tech

APPENDIX C
NER READING (ISLAND MODE)

NER reading
date 30/01/09 (friday)
status GTG A & GTG B (ISLAND MODE)

time	outside temp	NER temp.		NER Amp				GTG LOAD	
		GTG A	GTG B	GTG A		GTG B		GTG A	GTG B
				from Gen.	to earth	from Gen.	to earth		
900	28,2	33	32,4	4,9	4,9	3,4	3,5	3358	2850
1100									
1300	33,8	45,4	45,6	4,3	4,3	4,8	4,6	3531	3276
1500	34,9	44,4	45,6	3,8	3,8	5,2	5,2	3599	3527
1700	35	43,2	42,6	4	4	4	4	3536	3405
1900	26,7	27,8	27,6	3	3	3	3	2527	2589
2100	27,5	26,8	27,8	3	3	3	3	2528	2495
2300	25,7	25,2	27,8	2	2	5	5	1407	2572

APPENDIX D

NER READING (PARALLEL MODE)

NER reading (PARALLEL)
date 21/01/09 (Wednesday)
status GTG A & KO6

time	outside temp ºC	NER temp.ºC	NER Amp		GTG A load (KW)	mode
			from Gen.	to earth		
900	29,1	61	12,4	12,4	3937	parallel
1100	31,2	68,6	12,4	12,4	3928	parallel
1300	34,9	71,6	11,7	11,7	3842	parallel
1500	35	71,8	11,7	11,7	3862	parallel
1700	34,5	70,6	11,7	11,7	3881	parallel
1900	31,4	57,6	12,3	12,3	3855	parallel
2100						

APPENDIX E
DATA MEASUREMENT

NER Current Measurement

ON (green) | OFF (yellow)

N= 31.75 Ω
L= 10.58 Ω

DATE	TIME	OUTSIDE TEMP(°C)	NER TEMP(°C)		NER AMPS		LOAD (KW)		MODE	OPERATE			NER		MODE
			GTG A	GTG B	GTG A	GTG B	GTG A	GTG B		GTG A	GTG B	TNB	GTG A	GTG B	
21/01/2009	900	29.1	61	-	12.4		3937	-	PARALLEL	ON	OFF	ON	N	N	3
	1100	31.2	68.6	-	12.4		3928	-	PARALLEL	ON	OFF	ON	N	N	3
	1300	34.9	71.6	-	11.7		3842	-	PARALLEL	ON	OFF	ON	N	N	3
	1500	35.0	71.8	-	11.7		3862	-	PARALLEL	ON	OFF	ON	N	N	3
	1700	34.5	70.6	-	11.7		3881	-	PARALLEL	ON	OFF	ON	N	N	3
	1900	31.4	57.6	-	12.3		3855	-	PARALLEL	ON	OFF	ON	N	N	3
30/01/2009	900	28.2	33	32.4	4.9	3.4	3358	2850	ISLAND	ON	ON	OFF	N	N	2
	1300	33.8	45.4	45.6	4.3	4.8	3531	3276	ISLAND	ON	ON	OFF	N	N	2
	1500	34.9	44.4	45.6	3.8	5.2	3599	3527	ISLAND	ON	ON	OFF	N	N	2
	1700	35.0	43.2	42.6	4	4	3536	3405	ISLAND	ON	ON	OFF	N	N	2
	1900	26.7	27.8	27.6	3	3	2527	2589	ISLAND	ON	ON	OFF	N	N	2
	2100	27.5	26.8	27.8	3	3	2528	2495	ISLAND	ON	ON	OFF	N	N	2
	2300	25.7	25.2	27.8	2	5	1407	2572	ISLAND	ON	ON	OFF	N	N	2
19/06/2009	1500	36.6	70	-	11.4	-	3726	-	PARALLEL	ON	OFF	ON	N	N	3
	1700	35.3	65	-	11.6	-	3625	-	PARALLEL	ON	OFF	ON	N	N	3
	1900	31.3	64	-	11.6	-	3777	-	PARALLEL	ON	OFF	ON	N	N	3
	2100	30.2	65	-	11.6	-	3634	-	PARALLEL	ON	OFF	ON	N	N	3
	2300	29.7	47	-	7.3	-	3428	-	ISLAND	ON	OFF	OFF	N	N	1
20/06/2009	900	30.8	45	-	7.1	-	2922	-	ISLAND	ON	OFF	OFF	N	N	1
	1100	33.3	52.8	-	7.6	-	3518	-	ISLAND	ON	OFF	OFF	N	N	1
	1300	36.8	52.4	-	7.7	-	3504	-	ISLAND	ON	OFF	OFF	N	N	1

	1500	38.5	60	-	7.3	-	3296	-	ISLAND				N	N	1
	1700	35.6	53	-	7.1	-	3280	-	ISLAND				N	N	1
	1900	30	41	-	6.9	-	3243	-	ISLAND				N	N	1
	2100	25	41	-	7.2	-	3366	-	ISLAND				N	N	1
	2300	25	41	-	7	-	3257	-	ISLAND				N	N	1
21/06/2009	900	32.1	48.6	-	5.8	-	2588	-	ISLAND				N	N	1
	1100	34.9	54	-	7.2	-	3559	-	ISLAND				N	N	1
	1300	36.7	56	-	6.9	-	3407	-	ISLAND				N	N	1
	1500	33.3	-	42	-	0.9	-	3452	ISLAND				N	L	1
	1700	33.6	-	42	-	0.91	-	3404	ISLAND				N	L	1
	1900	30.7	-	38	-	0.9	-	3309	ISLAND				N	L	1
	2100	27.9	-	37	-	0.9	-	3542	ISLAND				N	L	1
22/06/2009	900	30.2	35	37	3.4	5.5	3343	3084	ISLAND				N	L	2
	1100	33.1	45	45	1.9	7.3	3380	3382	ISLAND				N	L	2
	1300	36	49	51	1.7	7.6	3392	3538	ISLAND				N	L	2
	1500	35	41	44	1.8	7.8	3350	3622	ISLAND				N	L	2
	1700	28	33	31	2.9	5.1	2935	2716	ISLAND				N	L	2
	1900	27	28	27	4.1	2.9	2761	1947	ISLAND				N	L	2
	2100	24	26	27	1.9	5.3	2016	2524	ISLAND				N	L	2
	2300	23	-	25	-	9.2	-	3396	ISLAND				N	L	1
23/06/2009	900	31	37	37	3.2	5.2	3345	2946	ISLAND				N	L	2
	1100	33	46	46	2.8	6.1	3269	3214	ISLAND				N	L	2
	1300	36	46	48	2.2	7.2	3280	3488	ISLAND				N	L	2
	1500	36	49	50	1.9	7.8	3314	3516	ISLAND				N	L	2
	1700	34	40	38	3.6	4.3	3283	2400	ISLAND				N	L	2
	1900	27	29	29	2.6	4.6	2880	2331	ISLAND				N	L	2
	2100	27	27	30	1.8	6.6	2302	3008	ISLAND				N	L	2

	2300	26	-	31	-	9.3	-	3498	ISLAND				N	L	1
24/06/2009	900	28	29	34	2.5	6.1	3486	3036	ISLAND				N	L	2
	1100	38	40	43	1.2	8.3	3477	3492	ISLAND				N	L	2
	1300	34	42	44	3.5	5.8	3648	3399	ISLAND				N	L	2
	1500	41	51	50	3.1	6.3	3628	3382	ISLAND				N	L	2
	1700	28	30	31	2.3	5.6	2819	2772	ISLAND				N	L	2
	1900	28	27	27	1.8	5.8	2526	2700	ISLAND				N	L	2
	2100	27	26	27	2	5.6	2528	2600	ISLAND				N	L	2
	2300	26.5	-	42	-	19.6	-	2931	PARALLEL				N	L	3
25/06/2009	200	24	-	53	-	17.9	-	2449	PARALLEL				N	L	3
	700	24	-	53	-	16	-	1974	PARALLEL				N	L	3
	800	28.2	39.8	53.1	7.5	19.9	3206	3033	PARALLEL				N	L	4
	900	30	51.6	65.6	7.3	18.1	3135	2960	PARALLEL				N	L	4
	1100	32.8	50.1	65.4	7.4	19.2	3212	2934	PARALLEL				N	L	4
	1300	35.3	59	70.6	7.2	18	2986	2889	PARALLEL				N	L	4
	1500	36.6	51.4	68.6	6.4	20	3078	3301	PARALLEL				N	L	4
14/07/2009	1845	35.4	41.6	42.4	6.9	7.8			PARALLEL				N	N	4
	1945	32	41.2	44.2	7.6	8.3			PARALLEL				N	N	4
	2045	28.8	41.2	45.6	7.0	8.8			PARALLEL				N	N	4
	2145	25.4	39.6	46.8	7.2	8.4			PARALLEL				N	N	4
	2245	26.4	37.4	43	6.6	7.6			PARALLEL				N	N	4

APPENDIX F
MATLAB CODING

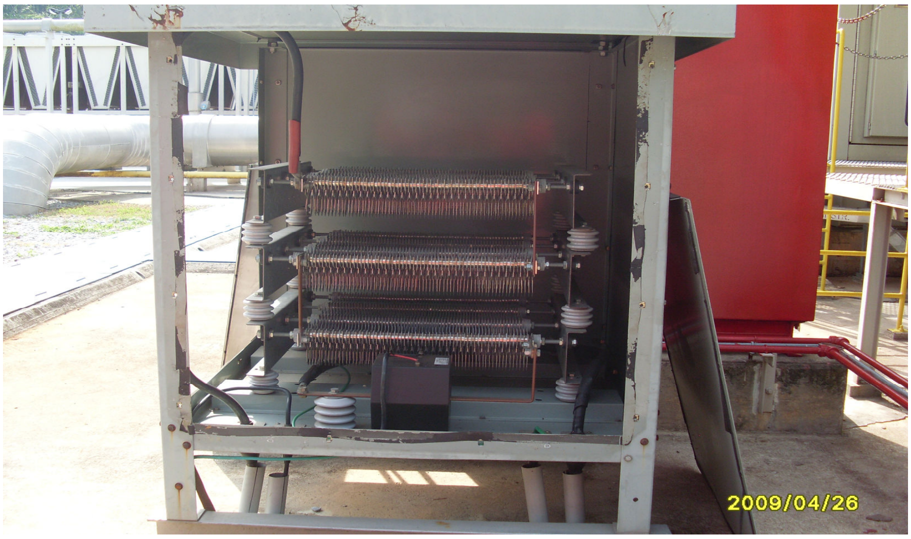
```
%Project Objective : This Program Open GDC Data File And Compute Seq Current & Voltage ↙
%
clear;
%Select & Read GDC Data File
[filename,pathname]=uigetfile({'*.csv';'*.txt'},'Select The .csv or .txt Data File');
datafile=csvread(filename);
%Assign Currents & Voltages
Ig1rp = datafile(:,2);
Ig1yp = datafile(:,3);
Ig1bp = datafile(:,4);
Ig2rp = datafile(:,14);
Ig2yp = datafile(:,15);
Ig2bp = datafile(:,16);
a = cos(2*pi/3)+j*sin(2*pi/3);
angpf = rad2deg(acos(0.8));
angIrp = 0-angpf;
angIyp = 240-angpf;
angIbp = 120-angpf;
angVrp = 0;
angVyp = 240;
angVbp = 120;
%Calculate Seq Currents For GTG-A
Ig1a = Ig1rp*exp(j*deg2rad(angIrp));
magIg1a = abs(Ig1a);
angIg1a = rad2deg(angle(Ig1a));
Ig1b = Ig1yp*exp(j*deg2rad(angIyp));
magIg1b = abs(Ig1b);
angIg1b = rad2deg(angle(Ig1b));
Ig1c = Ig1bp*exp(j*deg2rad(angIbp));
magIg1c = abs(Ig1c);
angIg1c = rad2deg(angle(Ig1c));
Ig1a0 = (1/3)*(Ig1a+Ig1b+Ig1c);
magIg1a0 = abs(Ig1a0);
angIg1a0 = rad2deg(angle(Ig1a0));
Ig1a1 = (1/3)*(Ig1a+a*Ig1b+a^2*Ig1c);
magIg1a1 = abs(Ig1a1);
angIg1a1 = rad2deg(angle(Ig1a1));
Ig1a2 = (1/3)*(Ig1a+a^2*Ig1b+a*Ig1c);
magIg1a2 = abs(Ig1a2);
angIg1a2 = rad2deg(angle(Ig1a2));
Ig1n = 3*Ig1a0;
magIg1n = abs(Ig1n);
angIg1n = rad2deg(angle(Ig1n));
Ig1b0 =(1/3)*(Ig1a+Ig1b+Ig1c);
magIg1b0 = abs(Ig1b0);
angIg1b0 = rad2deg(angle(Ig1b0));
Ig1b1 =(1/3)*((a^2*Ig1a)+Ig1b+(a*Ig1c));
magIg1b1 = abs(Ig1b1);
angIg1b1 = rad2deg(angle(Ig1b1));
Ig1b2 =(1/3)*((a*Ig1a)+Ig1b+(a^2*Ig1c));
magIg1b2 = abs(Ig1b2);
angIg1b2 = rad2deg(angle(Ig1b2));
Ig1c0 =(1/3)*(Ig1a+Ig1b+Ig1c);
magIg1c0 = abs(Ig1c0);
angIg1c0 = rad2deg(angle(Ig1c0));
Ig1c1 =(1/3)*((a*Ig1a)+(a^2*Ig1b)+Ig1c);
```

```
magIg1c1 = abs(Ig1c1);
angIg1c1 = rad2deg(angle(Ig1c1));
Ig1c2 =(1/3)*((a^2*Ig1a)+(a*Ig1b)+Ig1c);
magIg1c2 = abs(Ig1c2);
angIg1c2 = rad2deg(angle(Ig1c2));
%Calculate Seq Currents For GTG-B
Ig2a = Ig2rp*exp(j*deg2rad(angIrp));
magIg2a = abs(Ig2a);
angIg2a = rad2deg(angle(Ig2a));
Ig2b = Ig2yp*exp(j*deg2rad(angIyp));
magIg2b = abs(Ig2b);
angIg2b = rad2deg(angle(Ig2b));
Ig2c = Ig2bp*exp(j*deg2rad(angIbp));
magIg2c = abs(Ig2c);
angIg2c = rad2deg(angle(Ig2c));
Ig2a0 = (1/3)*(Ig2a+Ig2b+Ig2c);
magIg2a0 = abs(Ig2a0);
angIg2a0 = rad2deg(angle(Ig2a0));
Ig2a1 = (1/3)*(Ig2a+a*Ig2b+a^2*Ig2c);
magIg2a1 = abs(Ig2a1);
angIg2a1 = rad2deg(angle(Ig2a1));
Ig2a2 = (1/3)*(Ig2a+a^2*Ig2b+a*Ig2c);
magIg2a2 = abs(Ig2a2);
angIg2a2 = rad2deg(angle(Ig2a2));
Ig2n = 3*Ig2a0;
magIg2n = abs(Ig2n);
angIg2n = rad2deg(angle(Ig2n));
Ig2b0 =(1/3)*(Ig2a+Ig2b+Ig2c);
magIg2b0 = abs(Ig2b0);
angIg2b0 = rad2deg(angle(Ig2b0));
Ig2b1 =(1/3)*((a^2*Ig2a)+Ig2b+(a*Ig2c));
magIg2b1 = abs(Ig2b1);
angIg2b1 = rad2deg(angle(Ig2b1));
Ig2b2 =(1/3)*((a*Ig2a)+Ig2b+(a^2*Ig2c));
magIg2b2 = abs(Ig2b2);
angIg2b2 = rad2deg(angle(Ig2b2));
Ig2c0 =(1/3)*(Ig2a+Ig2b+Ig2c);
magIg2c0 = abs(Ig2c0);
angIg2c0 = rad2deg(angle(Ig2c0));
Ig2c1 =(1/3)*((a*Ig2a)+(a^2*Ig2b)+Ig2c);
magIg2c1 = abs(Ig2c1);
angIg2c1 = rad2deg(angle(Ig2c1));
Ig2c2 =(1/3)*((a^2*Ig2a)+(a*Ig2b)+Ig2c);
magIg2c2 = abs(Ig2c2);
angIg2c2 = rad2deg(angle(Ig2c2));
%Seq Operation & Array
Ig1a02sum = Ig1a0+Ig1a2;
magIg1a02sum = abs(Ig1a02sum);
angIg1a02sum = rad2deg(angle(Ig1a02sum));
Ig1a02sub = Ig1a0-Ig1a2;
magIg1a02sub = abs(Ig1a02sub);
angIg1a02sub = rad2deg(angle(Ig1a02sub));
%Display Results In Array
Ig1abc = [magIg1a,angIg1a,magIg1b,angIg1b,magIg1c,angIg1c];
Ig1a012n = [magIg1a0,angIg1a0,magIg1a1,angIg1a1,magIg1a2,angIg1a2,magIg1n,angIg1n];
Ig1b012 = [magIg1b0,angIg1b0,magIg1b1,angIg1b1,magIg1b2,angIg1b2];
```

```
Ig1c012 = [magIg1c0,angIg1c0,magIg1c1,angIg1c1,magIg1c2,angIg1c2];
Ig2abc = [magIg2a,angIg2a,magIg2b,angIg2b,magIg2c,angIg2c];
Ig2a012n = [magIg2a0,angIg2a0,magIg2a1,angIg2a1,magIg2a2,angIg2a2,magIg2n,angIg2n];
Ig2b012 = [magIg2b0,angIg2b0,magIg2b1,angIg2b1,magIg2b2,angIg2b2];
Ig2c012 = [magIg2c0,angIg2c0,magIg2c1,angIg2c1,magIg2c2,angIg2c2];
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%
```

APPENDIX G
PHOTOS TAKEN DURING MEASUREMENT

MEASUREMENT AT GDC UTP



MEASUREMENT AT TNB SUBSTATION (15TH OCT 2009)