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HARMONIC STUDY ON UTP NEW BUILDING NETWORK

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Wan Shahira Binti Mohd Aziz

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Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Electrical & Electronic)

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Universiti Teknologi PETRONAS
Bandar Seri Iskandar
32610 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

Electrical and Electronics Programme

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Approved by,

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(Puan Khairul Nisak Binti Md Hasan)

FYP Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

January 2016

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this report, 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 taken or done by unspecified sources or persons.

WAN SHAHIRA BINTI MOHD AZIZ

ABSTARCT

In this study, frequency scan analysis and harmonic resonance modal analysis are two techniques that have been chosen to analyse the present of resonance in a network. The presence of resonance is the factor that contributes to the amplification of harmonic which exist along with the current from non-linear load. Harmonic that occurs contributes to several negative effects to the power system and has potential to cause the equipment to damage. Universiti Teknologi PETRONAS (UTP) new building network, or to be more specific, the network at new academic buildings is an interesting place to conduct this study. This is because in UTP there are various types of electrical machines, high voltage machines and high technology computers and equipments especially in block 5,17 and 22; that may contribute to harmonic. The whole UTP network is first simplified and the cable is present in pi impedance form. After that, the power flow study of the network is conducted using a MATLAB Simulink. The potential resonance from UTP network is analysed using the two techniques that have been mentioned above. The techniques are also run using MATLAB. The measurement of harmonic current and voltage at the respective buildings are then performed for six (6) days at the sub switch board (SSB) of the three blocks that have been chosen as the case studies. The data obtained from the data logging are compared with the data obtained using the two techniques mentioned earlier. The expected results are high harmonics is present at the harmonic frequencies which are high in resonance.

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ABBREVIATION AND NOMENCLATURES

FYP	Final Year Project
HRMA	Harmonic Resonance Modal Analysis
MSB	Main Switch Board
PMMD	Property Management and Maintenance
SLD	Single Line Diagram
SSB	Sub Switch Board
UTP	Universiti Teknologi PETRONAS

CHAPTER 1

INTRODUCTION

This chapter provides brief description of the background of this project, the problem statement that inspiring this project to be done, as well as the objectives and the scope of study.

1.1 Background

In power system, voltage and current waveform distortions issues have arisen since the early days of alternating current. One of the distortions is harmonics. The definition of harmonic given by IEEE 519-1992 is “A sinusoidal component of a periodic wave or quantity having a frequency that is an integral multiple of the fundamental frequency” [3]. The existence of this distortion which affects the power quality may come from generator as well as from the load. At the generator, the generation of harmonic is actually very minimum and is estimated around 1% to 2% of the total percentage. Due to non-uniform in winding distribution and magnetic field from AC machine causes the distortion in the pure sinusoidal voltage waveform. Meanwhile, the generation of harmonics at the load is caused by the non-linear load. Generally, when the load is connected to the power supply, the current will be drawn. For non-linear load, the drawn current waveform does not displayed in sinusoidal when the sinusoidal voltage is injected. The production of harmonics is actually coming from the switch in the loads where the switching activity (e.g: from AC to DC) cuts the sinusoidal waveform and cause notching in the waveform [4].

1.2 Problem Statement

Harmonic can give undesirable effects to each elements of the power system. The existence of series and parallel resonance from the impedance may cause the amplification of voltage and current harmonics in the power system. This may causes the efficiency of generation, transmission and utilisation of electric energy to be reduced, the reduction in insulation of electrical plant component life span as well as the failure of system or plant component to perform its functions [4]. Realising harmful effects of harmonics to the power system, this project is carried out in order to assist harmonic measurement in UTP new building network and to prove that the frequency scan analysis and harmonic resonance modal analysis techniques can be used to analyse the harmonic in the network.

1.3 Objectives and Scope of Study

1.3.1 Objectives

There are three objectives that meant to be achieved in this study including:

1) To model and simulate UTP new building network by using MATLAB Simulink
2) To assist in harmonic measurement of UTP new building network
3) To perform the harmonic analysis study using frequency scan analysis and harmonic resonance modal analysis techniques and do comparison against the measured data

1.3.2 Scope of study

In order to carry out this project, the author has to have clear picture on the basic understanding of harmonic including the sources of harmonic and the effect of harmonic to the power system. Understanding the techniques used to analyse the harmonic in UTP new building is also essential for the author so that the project can be conducted efficiently and continuously. All of these requirements can be satisfied by doing lot of research and reading of related materials such as book, journal as well as conference paper.

The 5 bus and 14 bus test systems also have been used in the early stage to build better understanding on how to analyse the harmonic resonance using frequency scan analysis and harmonics resonance modal analysis techniques using MATLAB.

In this project, it is necessary for the author to visit UTP property management and maintenance department (PMMD) to get clearer interpretation on UTP network as well as to get the latest update regarding the harmonic issues which occur in UTP power system. The measurement of harmonics current and voltage in UTP network is also conducted with the help from a staff from PMMD, Mr. Tarmizi and the lab technician, Mr Zuraimi.

Harmonic study on UTP new building is a relevant topic for electrical and electronic engineering student final year project since it is related to power system which is one of the major offered by UTP.

CHAPTER 2

LITERATURE REVIEW AND THEORY

Chapter 2 describes the technical aspect of the project. In the first section harmonic and resonance are defined, followed by the harmonic analysis and its subtopic, resonance analysis is emphasised in this chapter.

2.1 Harmonic

As what have been mentioned in the Chapter 1, harmonics has been manifested as the current and voltages that have frequencies which the integers multiplied by the fundamental frequency. For example, the second and third harmonics for fundamental power frequency of 50Hz are 100Hz and 150Hz [2]. The waveform produced is the additional of harmonics from all orders that superimposed with the fundamental sinusoidal waveform. All of the harmonic components can be decomposed using Fourier Transform [9].

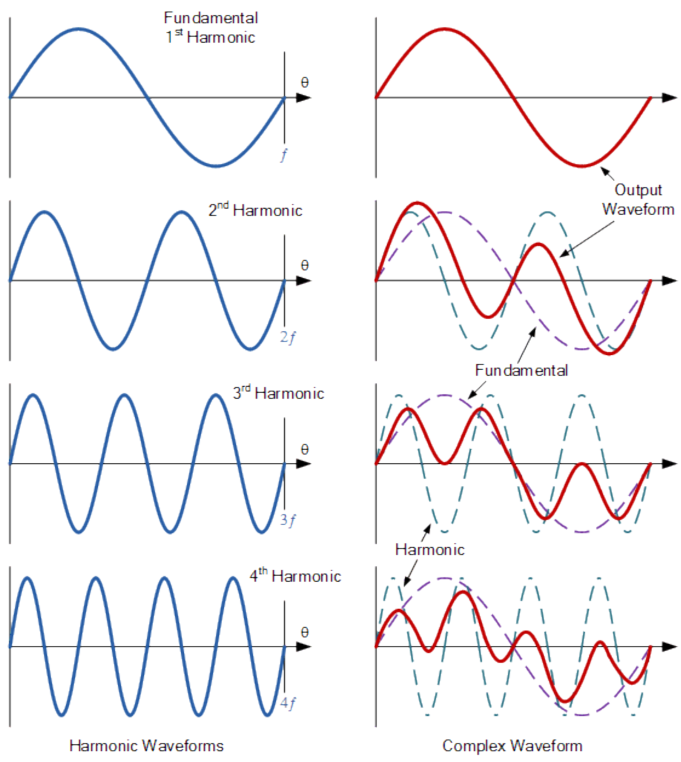

FIGURE 1 The formation of non-sinusoidal waveform

There are two types of harmonics that exist in the power systems. They are current harmonics and voltage harmonics. The components of harmonics are started from zero order. Each order can be classified into balanced voltage and current system known as zero sequence, positive sequence and negative sequence. The following table describe the components from zero order to 7^{th} order of harmonics and their sequences

TABLE 1 Harmonics components

Component	**Description**	**Sequence**
0	DC component	Zero sequence
1	Fundamental	Positive sequence
2	Even	Negative sequence
3	Odd	Zero sequence
4	Even	Positive sequence
5	Odd	Negative sequence
6	Even	Zero sequence
7	Odd	Positive sequence
8	Even	Negative sequence

Even harmonics such as 2^{nd} and 4^{th} usually do not appear in a properly operating power system because based on the Fourier transform, the event harmonics are cancelling each other due to the symmetrical characteristic of the waveform (positive and negative halves are the same). However, if the positive and negative halves are different, both odd and even harmonics will appear [10]. This condition shows that the waveform is asymmetrical.

On the neutral line of the three-phase system, triplen harmonics is the biggest concern. Triplen harmonics is the harmonics which the order are multiplied by 3 (3, 6, 9, …). The triplen harmonics are of the zero sequence. Therefore, they are additive in the neutral line. The existence of the triplen harmonics on the neutral line is starting from the three phase power system that is supplied to the load. Each phase is 120^o apart. When all of the phases are added together on the neutral line, theoretically, they will cancel out each other and this will prevent the utility from creating return wiring to the power plant (refer to the left hand side of Figure 2). However, the current is actually is not equal to zero if the triplen harmonics are present in the three phases. This condition causes the huge current to circulate in the neutral wire and may lead to fire as the neutral wire is designed only to handle low current [11].

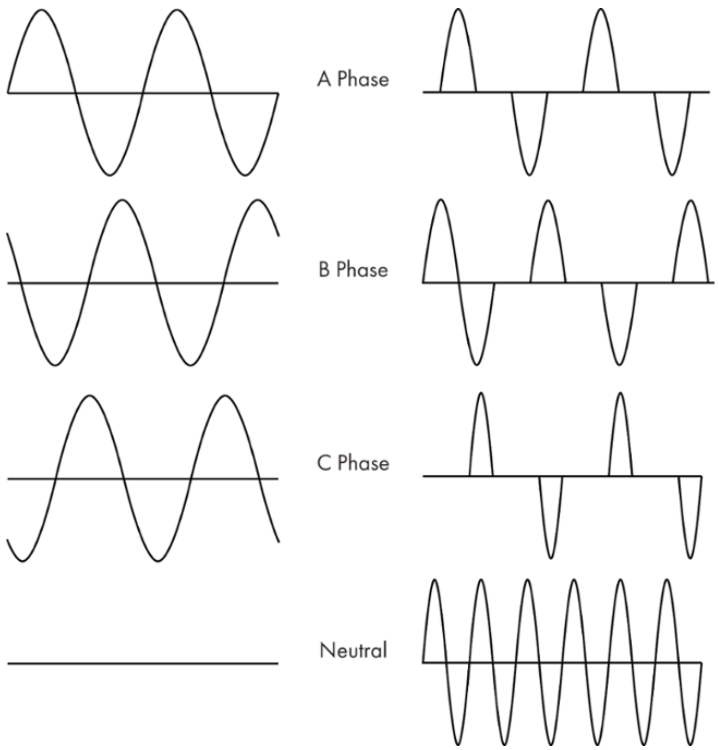

FIGURE 2 The three phase system without 3rd harmonic verses the three phase system with third harmonic

2.2 Resonance

The growing numbers of nonlinear loads and the rise of the potential for the harmonic resonance to take place have become the biggest concern [6]. This is because the distortion of voltage at particular the load terminals which is the harmonics, occurs in the existence of system impedance where the current lead to a non-sinusoidal voltage to drop. The present of shunt capacitors element in power system which most of the circuit elements are made up of inductive, may cause cyclic energy transfer between the two elements at resonance natural frequency. The two types of resonance which is series and parallel resonance may occur in this condition. The sources of reactance and shunt reactance have combined together at the particular place and is resulting the impedance to be huge [6].

The condition when the resonance that the inductive element reactance is in aligned with the capacitive element reactance is called as parallel resonance. Both of these elements eventually are erasing each other [5]. The result from parallel resonant shows that impedance level at resonant frequency that is presented to the harmonic source is high. Each leg of parallel impedance experiences in increased of harmonic voltages and high harmonic currents as the main harmonic sources are the current sources. [4]. Series resonant happens when low impedance is observed at resonance frequency. This leads the current and voltage distortion level to be high even though the area has no or little harmonic emission [6]. The circuit quality factor, Q determines the actual current will flow. [4]

2.3 Harmonic Analysis

The mathematical procedure of calculating the magnitudes and phases of the harmonic periodic waveform is known as the harmonic analysis. [4]. The objective of carrying out the harmonic analysis is to identify the harmonic distribution in currents, voltages as well as the harmonic distortion in a power system [5]. There are four (4) types of the basic techniques that are available to analyse the harmonic which are frequency domain, time domain and the hybrid techniques which is the combination of both frequency domain as well as time domain; and resonance analysis [6].

TABLE 2 Harmonic analysis basic technique

Techniques	Methodology
Resonance Analysis	Frequency Scan Analysis
	Modal Analysis
	State-space analysis
Frequency Domain	Current-source
	Harmonic Power Flow
Time Domain	Time variant analysis
Hybrid Techniques	Norton
	Transfer function
	Harm admittance matrix
	Forward/ Backward

From this analysis, the harmonic filter design and the effect of harmonics on the power system can be analysed. [5].

2.3.1 Resonance Analysis

Frequency scan analysis is the frequently used method to determine resonance. It has been used extensively in filter design and in electromagnetic transients simulation as the initial procedure in frequency-dependent equivalents derivation [4]. Frequency scan analysis can be used to analyse the harmonic resonance for the system that has numerous source of harmonic as long as the principal of superimposition is valid [5]. This technique uses nodal analysis. The evaluation of the nodal admittance manipulation matrix technique is carried out at every frequency for every harmonic current [4][6].

$$[I_h] = [Y_h] \cdot [V_h] \qquad for \qquad h \neq 1 \tag{1}$$

Where,

$[I_h]$ is the nodal current injection

$[Y_h]$ is the matrix of system admittance

$[V_h]$ is the matrix of nodal voltage

The admittance matrix is separately done for every frequency of interest. The matrix below shows the network nodal admittance matrix at frequency f [4].

$$[Y_f] = \begin{bmatrix} Y_{11} & Y_{12} & \dots & Y_{1i} & \dots & Y_{1k} & \dots & Y_{1n} \\ Y_{21} & Y_{22} & \dots & Y_{2i} & \dots & Y_{2k} & \dots & Y_{2n} \\ \vdots\,\vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \\ Y_{i1} & Y_{i2} & \dots & Y_{ii} & \dots & Y_{ik} & \dots & Y_{in} \\ \vdots\,\vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \\ Y_{k1} & Y_{k2} & \dots & Y_{ki} & \dots & Y_{kk} & \dots & Y_{kn} \\ \vdots\,\vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \\ Y_{n1} & Y_{n2} & \dots & Y_{ni} & \dots & Y_{nk} & \dots & Y_{nn} \end{bmatrix} \tag{2}$$

Where,

$[Y_f] = [Y_h]$, is the admittance matrix

$[Y_{ki}]$ is the admittance between busbars k and i at frequency f

$[Y_{ii}]$ is the self-admittance of busbar i at frequency f

The inverse of nodal admittance matrix gives the impedance of the nodal harmonic. For this method, the harmonic problem can be identified by injecting a 1.0 per unit (p.u) sinusoidal harmonic current to the respective node at a range of frequencies [4][6]. The voltage response also can be calculated by using equation (1) [4]. From the voltage calculation, the driving point and transfer impedance can be identified in both modulus and phase angle [5]. The Y_{bus} actually holds linear elements only for each frequency. Therefore, by repeating the calculation at discrete frequency steps covering particular frequency spectrum gives a series of impedances that can be marked to indicate the resonant condition. [4][5]. The peaks, which indicate the maximum level of impedance, from the impedance scan plot shows the parallel resonance, while the lowest points of the impedance plots indicate the series resonance [5][6].

Phase and sequence component also can be used in this method where in the latter case, the injection of a 1.0 p.u positive-sequence or zero-sequence current derives the impedance of positive-sequence or zero-sequence driving point network that can be detected from the specified bus. The effect of background harmonic voltages that exist in at any particular point in power system network can be studied by using frequency scan analysis method where a 1.0 p.u voltage is injected to node instead of current. The derivation of harmonic voltage transfer to the network can be obtained from the set of equation (1) [4]. The weakness of this method is that it is a viable technique that only provide the information about the present of harmonic, however of the level of severity of the harmonic problem cannot be identified [6][8].

In order to cover up the weakness of frequency scan analysis, harmonic resonance mode analysis (HRMA) is utilized to analyse the resonance of harmonics. The nodal admittance matrix modal analysis is performed and uses eigenvalue-senitivity approach to analyse the harmonic resonance. Harmonic resonance is presented when the nodal voltages are very big. This phenomenon occurs with the admittance matrix approaches singularly as the value of eigenvalue is very small and approaching zero. According to eigen-analysis theory, the decomposition of Y is stated as below:[6][8]

$$[Y] = [L][\Lambda][T] \tag{3}$$

Where,

$[L]$ is left eigenvector

$[T]$ is righ eigenvector

$[\Lambda]$ is the matrix of diagonal eigenvalue

Note that subscript f or h for admittance matrix Y is omitted for the sake of simplification. The inversion of $[\Lambda]$ gives the modal impedance $[Z_m]$.

$$[V] = [L][\Lambda]^{-1}[T][I] \tag{4}$$

The inversion of the right eigenvector is equal to the left eigenvector. Critical mode can be defined at the point where Z_M is at the highest point and the value of corresponding λ is the smallest. As the result from Z_M plot, the modal impedance as well as the critical mode which is the resonance point can be determined. The critical eigenvectors mode, which is the value of eigenvector corresponding to the critical mode, for left and right eigenvectors are very important in analyzing the observability or excitability and controllability of the bus.[6][8] The product of [T] and $[L]$ determines the sensitivity analysis. The diagonal element from three by three sensitive matrix is the participation factors (PF) of corresponding buses where it can measure how strong each buses involve in resonance at critical mode frequency. It can be summarized that the highest PF can be interpreted as the bus with maximum excitability and observability. It also shows that particular location is the most strategic place to inject signals in order to delete the harmonic resonance [5].

CHAPTER 3

METHODOLOGY

This chapter illustrates the overall process of the project until its completion during the entire period the author involves in this final year project. The research methodologies applied for this study are elaborated, followed by the time allocations for each step as shown in the Gantt Chart and key milestone. Besides, the tools required in the process are also mentioned in this chapter.

3.1 Methodology

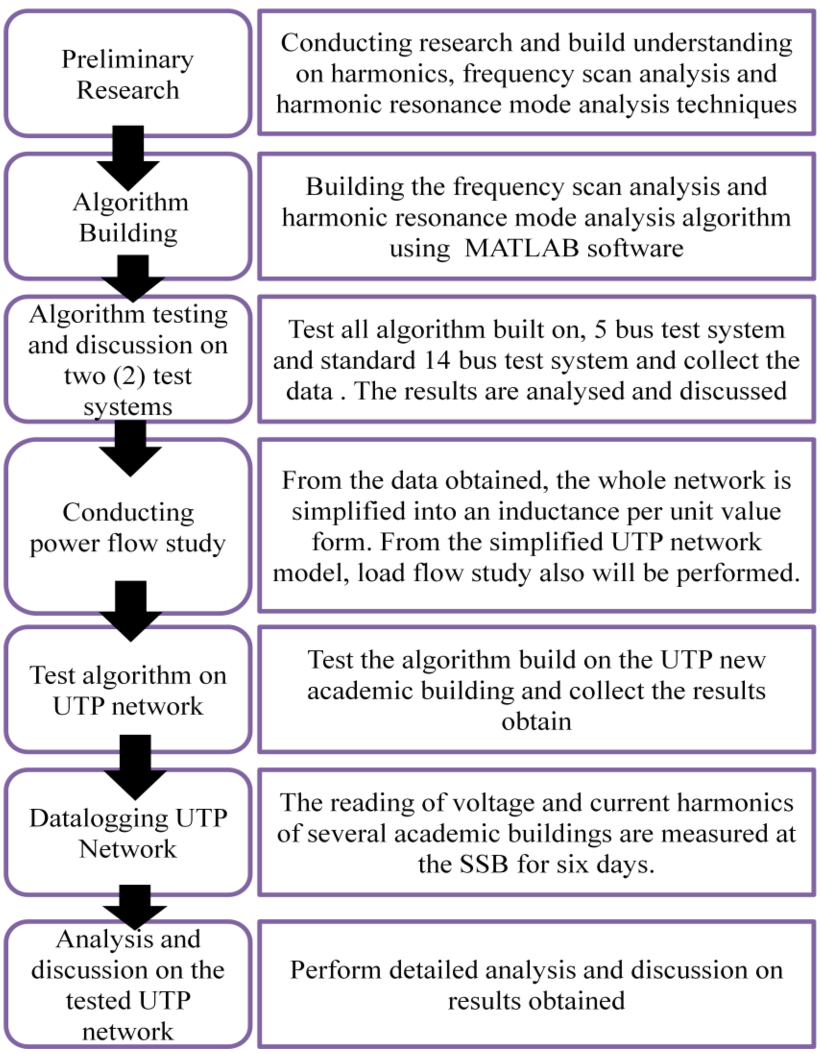

FIGURE 3 Methodology used to carry out the project

3.1.1 Preliminary Research

In the preliminary research phase, the author has made research regarding the harmonic and resonance, the techniques that will be used in this project which are **frequency scan analysis** and **harmonic resonance mode analysis**. Both of these techniques are based on the resonance analysis. The sources of references are including books, journal as well as online sources.

3.1.2 Algorithm Building

Algorithm building is the main part of analysing the impedance characteristic of the network. The algorithm is built in the M-file in MATLAB where it responsible to calculate the line admittance, the admittance in generators, load admittance, eigenvalue, left eigenvector and right eigenvector

Among the parameter needed to be known in order to use the frequency scan analysis and harmonic resonance mode analysis are

1) Number of node
2) Number of transmission element
3) Number of generator
4) First harmonic
5) Harmonic step
6) Voltage
7) Voltage angle
8) Active power
9) Reactive power
10) Resistance
11) Inductance
12) Capacitance

The voltage, voltage angle, active power and reactive power can be obtained from the load flow study. The load flow study 14 Bus test system is available in the PSAT test folder. For UTP New Building Network, the load flow study will be build by referring to the single line diagram as well as having a fieldtrip around UTP substation.

3.1.3 Algorithm Testing On the Test System

For understanding and getting the overview of the flow overall project purpose, the author will conduct a test algorithm of frequency scan analysis and harmonic resonance mode analysis using MATLAB on two test systems which are five (5) bus test system and standard IEEE 14 bus test system. All the parameter needed (as mentioned in the 3.1.2) can be obtained from the research paper and reference book.

3.1.4 Conducting power flow study

The single line diagram (SLD) is simplified into impedance form. Matlab PSAT is used in order to construct this model. The actual value of impedance, power and voltage of the cable, transformer and the load are needed to be known in order to complete the model. From the simplified UTP network model, load flow study will be conducted. The model is also used for simulation purpose. MATLAB simulink is used to build the simulation. Harmonics which is generated from the load is the main concerned in this study. Therefore, in the simulation, the harmonics source is injected to the every line (red, yellow, blue and neutral) to see the effect of harmonics to the voltage and current waveform.

3.1.5 Algorithm Testing on the UTP Network

Next, the algorithms to test on UTP network are constructed to test the harmonics resonance available in the system. The parameters for UTP network can be obtained from PMMD. In order to gain the parameter, the visit to UTP control room and the respective UTP substation is made. This process is conducted with the help from Mr Tarmizi, the charge man from UTP PMMD.

3.1.6 Datalogging activity on UTP Network

The research is continued by data logging the measurement of UTP network by using Circutor AR6, a portable network analyze. In is this step, the reading of voltage and current harmonics of academic buildings are recorded for six (6) days at SSB of each block. Three (3) voltage probes are connected to Line 1 (L1), Line 2 (L2) and Line 3 (L3). L1, L2 and L3 also can be represented as Red, Yellow and Blue. Four (4) current probes are used to connect to L1, L2, L3 and LN (Neutral). The datalogging activity has been conducted with the help from the lab technician, Mr. Zuraimi and the charge man from UTP PMMD, Mr. Tarmizi.

TABLE 3 Schedule for datalogging activity

Block	**Block description**	**Location**	**Measurement Period**			
			Start		**End**	
			Date & Day	**Time**	**Date & Day**	**Time**
Block 22	Electrical & Electronics Engineering	SSB 22-01/2	12 February 2016 (Friday)	8.30 am	18 February 2016 (Thursday)	11.30 am
Block 5	Chemical Engineering	SSB 05-01/1	19 February 2016 (Friday)	8.30 am	25 February 2016 (Thursday)	11.30 am
Block 17	Mechanical Engineering	SSB 17-01/1	26 February 2016 (Friday)	8.30 am	3 March 2016 (Thursday)	11.30 am
Block 17	Mechanical Engineering	SSB 17-01/2	3 March 2016 (Thursday)	12.00 pm	10 March 2016 (Thursday)	11.30 am
Block 5	Chemical Engineering	SSB 05-01/1	10 March 2016 (Thursday)	12.00 pm	17 March 2016 (Thursday)	11.30 am
Block 22	Electrical & Electronic Engineering	SSB 22-01/1	17 March 2016 (Thursday)	12.00 pm	24 March 2016 (Thursday)	11.30 am
Block 22	Electrical & Electronic Engineering	SSB 22-01/2	24 March 2016 (Thursday)	12.00 pm	31 March 2016 (Thursday)	11.30 am

Data logging at SSB 22-01/2 and SSB 05-01/1 have to be made twice as there mistake were made while setting the portable power analyzer.

3.1.7 Analysis and Discussion

The data logging data recorded by Circutor AR6 is extracted by using software known as PowerVision Plus. The result from the frequency scan analysis and harmonic resonance modal analysis can determine the impedance characteristic in the network. Thus, the relationships between these two results are compared and the detailed analysis and discussion is performed.

3.2 Gantt Chart and Key Milestone

To ensure the project can be finished within the period given, a scheduled is drafted as a guideline to be followed throughout the project. Both gantt chart and key milestone of the project are available in Appendices section.

3.3 Tools

In order to complete this project, there are several tools need to be used by the author, such as

1) **Circutor AR6**

   Circutor AR6 is a portable network analyze that has been used to measured voltage and current harmonics in UTP network

2) **PowerVison Plus Software**

   A software used to extract the data recorded from Circutor AR6

3) **MATLAB**

   MATLAB Simulink is a powerful tool to run the simulation of UTP network model. PSAT, one of the MATLAB toolbox is used to conduct the load flow study. The M-file is used to analyse the impedance characteristic of the network based on frequency scan analysis and harmonics resonance modal analysis techniques.

4) **Personal Computer**

   PC is the most important tools to complete this project. It has been used to access to the internet to find reference, to use the software (MATLAB) as well as for report writing and presentation slide purpose.

5) **Google Chrome**

Google search engine has been utilized to find the information, collecting research paper in IEEE Explore and to search the relevant books which is related to the title of the author's final year project.

6) **Microsoft Office**

Microsoft Office 2007 has been used by the author to gather data and information as well as to assist in project continuity.

CHAPTER 4

RESULT AND DISCUSSION

This chapter compile the result obtained from the analysis of two test systems- five (5) bus test system and standard 14 bust test system as well as the analysis of UTP new building network of voltage and current harmonics that have been measured.

4.1 Five (5) Bus Test System

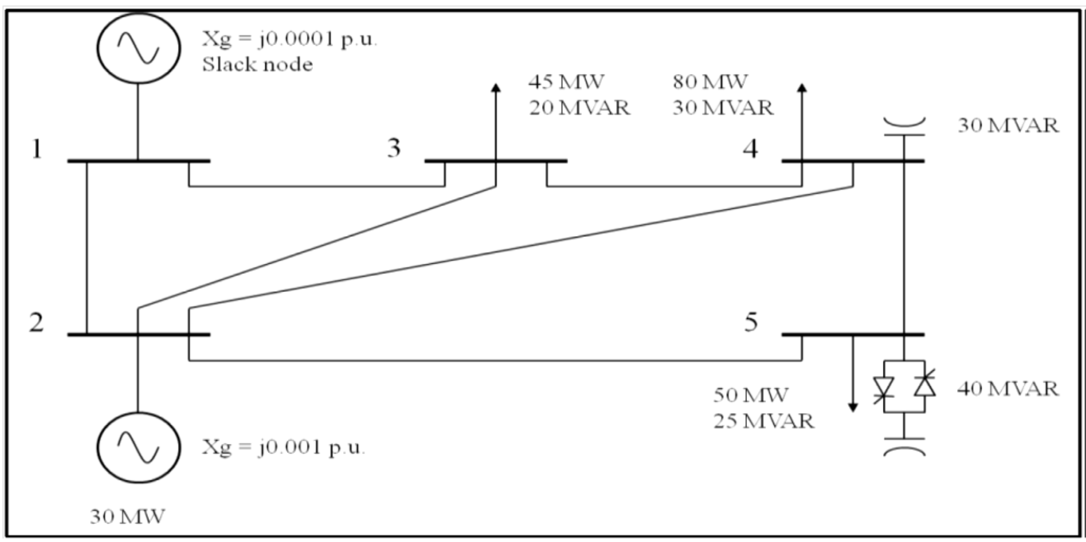

FIGURE 4 Five (5) bus test system with SVC

The five bus test system is a test system that consists of five buses and seven (7) transmission element. A static VAR compensator or in short form it is called as SCV is connected to node five. The function of SCV is to supply voltage at the particular node. It also acts as the constant source of harmonic current. Given, the base values of this test system are 100kV and 100MVA. The other detail such as the value of transmission lines and the power flow study are tabulated in Table and Table below:

TABLE 4: The Parameters of Transmission Line for 5 Bus Test System

Line	Impedance (p.u)	Line charging (p.u)
1-2	0.02+j0.06	0.0+j0.030
1-3	0.08+j0.24	0.0+j0.025
2-3	0.06+j0.18	0.0+j0.020
2-4	0.06+j0.18	0.0+j0.020
2-5	0.04+j0.12	0.0+j0.015
3-4	0.01+j0.03	0.0+j0.010
4-5	0.08+j0.24	0.0+j0.025

TABLE 5: Power Flow Study for 5 Bus Test System

Node	Voltage, |V|	Voltage angle, θ	Active Power Load, P_L	Reactive Power Load, Q_L
1	1.0500	0.00000	0.00	0.00
2	1.0000	-2.6944	0	0
3	0.9796	-6.2114	0.45	0.20
4	0.9776	-6.9232	0.80	0.30
5	0.9922	-6.6963	0.50	0.25

All of the data available are recorded in the MATLAB editor and the parameter is called when the code to compose frequency scan analysis as well as harmonic resonance modal analysis is run. The code for both of this techniques can be reviewed in Appendix 3.

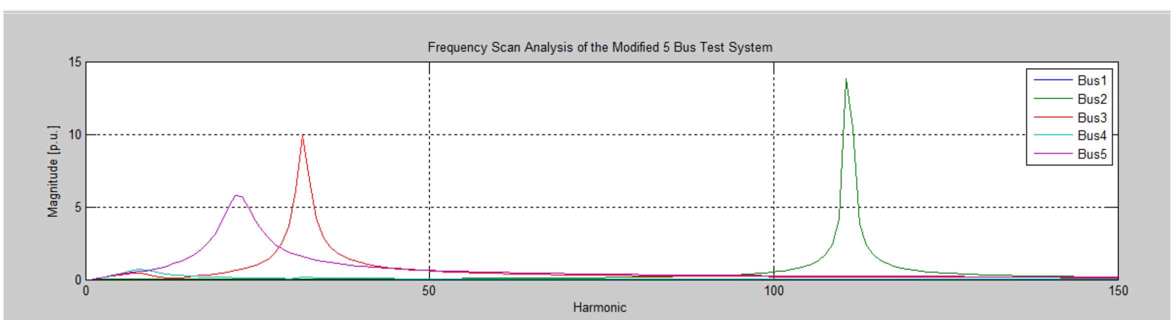

FIGURE 5: Frequency Scan Analysis Result for Five Bus Test System

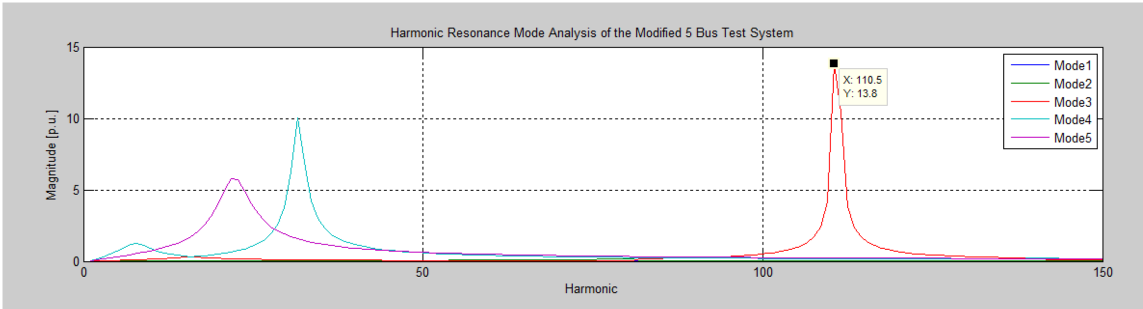

FIGURE 6: Harmonic Resonance Mode Analysis for Five Bus Test System

Figure 3 and 4 show the results of frequency scan analysis and harmonic resonance modal analysis of five bus system. In figure 3, it can be seen that the resonance exist at bus 2, 3 and 5. While in figure 4, Modal 3, 4 and 5 show the presence of resonance at those particular frequencies. In order to show the significant between these results, the participation factors (PF) for the three models are conducted base on the equation:

$$PF_{bm} = T_{bm} \text{ x } L_{bm}$$

where,

PF_{bm} is the participation factor

T_{bm} is the right eigenvector

L_{bm} is the left eigenvector

TABLE 6: Five Bus Test System Modal Analysis Result

Resonance frequency (p.u.)		21.25 (Mode 5)	29.54 (Mode 4)	103.2 (Mode 3)
Critical eigenvalue		5.452281257 /89.94715531	4.452492725 /89.99160574	7.328380243 /89.95921677
Right eigenvector [T]	Bus 1	T_{51} = 1.487280256X10^-6 /0.2591158451	T_{41} =1.381822018x10^-6 /0.2610560193	T_{31} = 4.169018882x10^-4 /-179.8689768
	Bus 2	T_{52} = 5.966788361X10^-4 /0.1316173141	T_{42} = 0.9999882702 /-6.17306618x10^-6	T_{32} = 4.749233164x10^-3 /0.1314284506
	Bus 3	T_{53} = 4.141509283X10^-4 /0.3841663483	T_{43} = 4.762118465x10^-3 /-179.8680191	T_{33} = 0.9998341657 /-1.52187364X10^-4
	Bus 4	T_{54} = 0.4965240862 /-179.0949743	T_{44} = 3.072795485x10^-4 /177.5728334	T_{34} = 0.01505298408 /179.3312042
	Bus 5	T_{55} = 0.8684373556 /-0.8786750775	T_{45} =8.296108625x10^-4 /179.9664572	T_{35} = 9.086520832X10^-3 /-178.9236259
Left eigenvector [L]	Bus 1	L_{15} = 8.513657977 X10^-4 /1.913290595	L_{14} = 1.492437723x10^-3 /0.1279066371	L_{13} = 4.471567455X10^-4 /0.1468506417
	Bus 2	L_{25} = 0.4962613646 /1.783706195	L_{24} = 0.8679933683018 /0	L_{23} =0.01756739858 /0.2365507641
	Bus 3	L_{35} = 9.084922462X^-3 /-178.0453107	L_{34} = 0.01504756706 /-179.7899947	L_{33} = 0.999834154880242 /0
	Bus 4	L_{45} = 8.293123202X10^-4 /-179.1548677	L_{44} =3.0716897x10^-4 /178.4516342	L_{43} = 4.762118414X10^-3 /-179.8678669
	Bus 5	L_{55} =0.868124841210402 /0	L_{54} = 0.4963454055 /-178.2161736	L_{53} = 4.141509238X10^-4 /0.3843185356
Participation Factor (PF)	Bus 1	PF_{15} = 1.266219542x10^-9 /2.17240644	PF_{14} = 2.062283306X10^-9 /0.3889626564	PF_{13} = 1.864204915X10^-7 /-179.7221262
	Bus 2	PF_{25} = 2.9610865534x10^-4 /1.915323509	**PF_{24} = 0.8679831869 /-6.17306618X10^-6**	PF_{23} = 8.343167194X10^-5 /0.3679792147
	Bus 3	PF_{35} = 3.762529071X10^-6 /-177.661144	PF_{34} =1.791760916X10^-8 /2.4708369	**PF_{33} = 0.9996683481 /-1.52187364**
	Bus 4	PF_{45} = 4.11773542X10^-4 /1.750158	PF_{44} = 9.438674241X10^-8 /-3.9755324	PF_{43} = 7.168409267x10^-5 /-0.5366627
	Bus 5	**PF_{55} = 0.7539120414 /-0.8786750775**	PF_{45} = 4.1177354X10^-4 /1.7502836	PF_{53} = 3.763190997x10^-6 /-178.5393074

Base on table above, the participating bus for a particular mode is bolded. Mode 5 that has resonance value of 21.25 p.u shows that the actual bus that contributes to resonance is Bus 5 as it has the highest participation factor among the other buses. Therefore, base on both graphs, Bus 5 and Mode 5 have same amplitude at frequency 21.25 p.u. Same goes to the other modes- Mode 4 and Mode 3; where for Mode 4 that has resonance at frequency 29.54 p.u, is contributed by Bus 2 and that the reason for Bus 2 and Mode 4b to have similar value of amplitude at resonance frequency of 29.54 p.u. Last but not least, at frequency 103.2 p.u the resonance which exists for mode 3 is participated by bus 3.

In short, based on the result obtained for 5 Bus Test System, it can be said that there is significant relationship between frequency scan analysis and harmonic resonance modal analysis. HRMA is actually able to provide the information regarding the location to observe or excite the harmonic resonance. In this case, the magnitude of impedance in per unit and modal impedance are the same. However, for the other cases, the scenario might not be the same.

4.2 Standard 14 Bus Test System

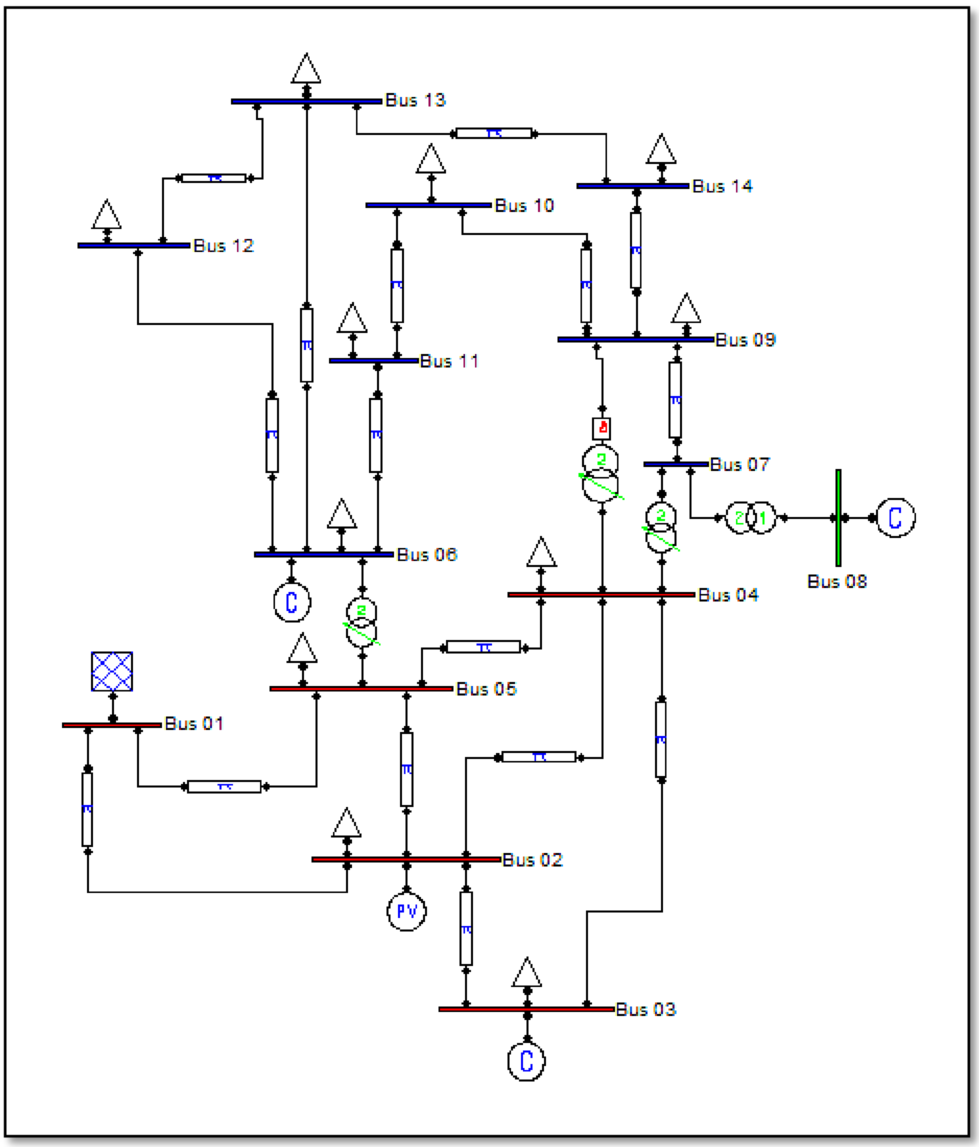

FIGURE 7: Standart14 Bus Test System

Figure 5 shows the standard 14 Bus system which can be obtained from PSAT MATLAB Toolbox. The power flow study of standard 14 Bus Test system are then tabulated in the table below. The graphs in Figure 6 and 7 are obtained from the algorithm that has been design for this test system.

TABLE 7: Power Flow Study for Standard 14 Bus Test System

Node	**Voltage, |V|**	**Voltage angle, θ**	**Active Power Load, P_L**	**Reactive Power Load, Q_L**
1	1.0600	0	0	0
2	1.0450	-4.973	0.217	0.127
3	1.0100	-12.686	0.942	0.19
4	1.0150	-10.266	0.478	-0.04
5	1.0174	-8.8123	0.076	0.016
6	1.0700	-14.806	0.112	0.075
7	1.0494	-14.213	0	0
8	1.0900	-14.213	0	0
9	1.0321	-16.263	0.295	0.166
10	1.0311	-16.292	0.09	0.058
11	1.0466	-15.685	0.035	0.018
12	1.0535	-15.713	0.061	0.016
13	1.0467	-15.846	0.135	0.058
14	1.0202	-17.084	0.149	0.05

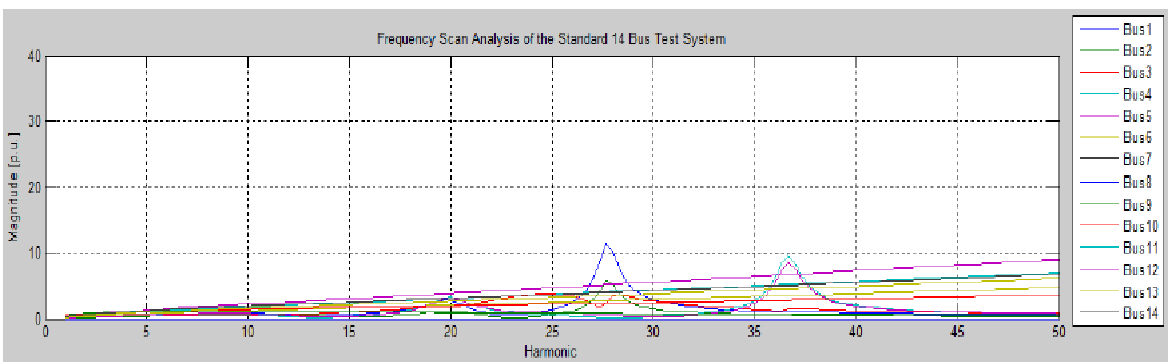

FIGURE 8: Frequency Scan Analysis of 14 Bus Test System

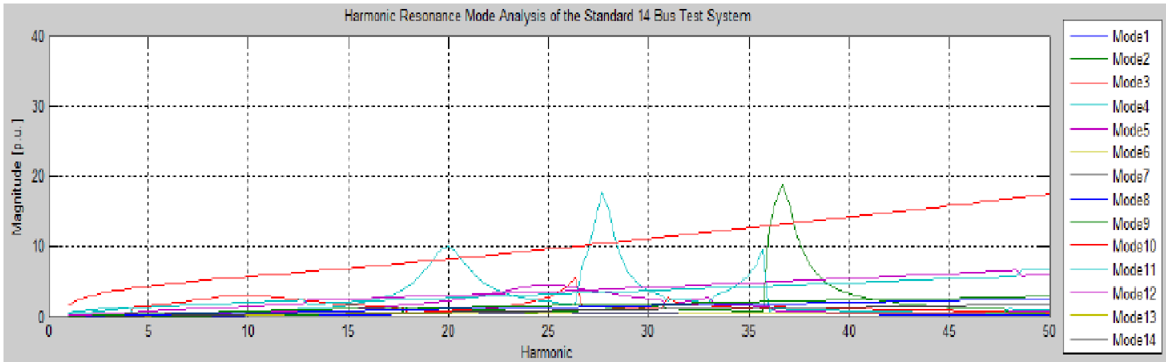

FIGURE 9 Harmonic Resonance Modal Analysis of 14 Bus Test System

Base on Figure 6 and Figure 7, there are differences in both frequency scan analysis graph as well as harmonic resonance modal analysis graph. In Figure 7, resonances are detected from Mode 4 at harmonic frequency of 20.0, 27.6 and 35.7 p.u; Mode 3 at harmonic frequency of 26.3 p.u; and lastly at Mode 2 at harmonic frequency of 36.7 p.u. This case is not the same as the case of the previous test system. Thus, participation factor is calculated for further analysis for this Standard 14 Bus Test System. The result is tabulated in Table below:

TABLE 8: Standard 14 Bus Test System Modal Analysis Result

Resonant frequency (p.u.)		20.0 (Mode 4)	26.3 (Mode 3)	27.6 (Mode 4)	35.7 (Mode 4)	36.7 (Mode 2)
Critical eigenvalue (D)		0.0993/9.0356	0.1813/-72.20	0.05739/-13.09	0.10/-56.36	0.05375/10.83
Right eigenvector (R)	Bus 1	R41=0.5298/178.80	R31=0.7897/-7.904	R41=0.8273/-10.88	R41=0.082/-2.667	R21=0.081/-2.685
	Bus 2	R42=0.3438/173.69	R32=-0.6086/175.86	R42=0.5938/173.33	R42=0.0111/180.00	R22=0.01/180.00
	Bus 3	R43=0.2098/-28.46	R33=0.3368/23.9	R43=0.4111/26.06	R43=0.1556/-171.69	R23=0.160/-171.72
	Bus 4	R44=0.5724/1.902	R34=0.0116/114.36	R44=0.0172/136.17	R44=0.7208/2.067	R24=0.7191/2.008
	Bus 5	R45=0.5482/8.4228	R35=0.0805/-32.62	R45=0.0765/-51.84	R45=0.6731/179.51	R25=0.6738/179.51
	Bus 6 – Bus 14	R46-R414=0.0/0.0	R36-R314=0.0/0.0	R46-R414=0.0/0.0	R46-R414=0.0/0.0	R26-R214=0.0/0.0
Left eigenvector (L)	Bus 1	L14=0.5119/176.89	L13=0.7482 /0.000	L14=0.7514/0.173	L14=0.0816/-4.781	L12=0.0809/-4.675
	Bus 2	L24=0.3321/171.78	L23=0.5766/-176.23	L24=0.5393/-175.79	L24=0.011/177.91	L22=0.011/177.91
	Bus 3	L34=0.2028/-30.36	L33=0.3191/31.81	L34=0.3734/36.94	L34=0.1553/-173.75	L32=0.16/-173.72
	Bus 4	L44=0.5531/0.000	L43=0.0111/122.11	L44=0.0156/147.02	L44=0.7195/0.0	L42=0.7178/0.0
	Bus 5	L54=0.5297/6.525	L53=0.0762/-24.72	L54=0.0695/-40.97	L54=0.6719/177.45	L52=0.6726/177.5
	Bus 6 – Bus 14	L64-L144=0.0/0.0	L63-L143=0.0/0.0	L64-L144=0.0/0.0	L64-L144=0.0/0.0	L62-L142=0.0/0.0
Participation factor (RxL in magnitude)	Bus 1	PF14=0.2712	**PF13=0.5908**	**PF14=0.6216**	PF14=6.69912x10^-3	PF12=0.06553
	Bus 2	PF24=0.1142	PF23=0.3509	PF24=0.3202	PF24=1.221x10^-4	PF22=1.1x10^-3
	Bus 3	PF34=0.0425	PF33=0.1075	PF34=0.1535	PF34=0.0242	PF32=0.0256
	Bus 4	**PF44=0.3166**	PF43=1.2876x10^-4	PF44=2.6832x10^-4	**PF44=0.5186**	**PF42=0.5161**
	Bus 5	PF54=0.2904	PF53=6.1341x10^-3	PF54=5.3168x10^-3	PF54=0.4523	PF52=0.4532
	Bus 6 – Bus 14	PF64-PF144=0.00	PF63-PF143=0.00	PF64-PF144=0.00	PF64-PF144=0.00	PF62-PF142=0.00

Base on the analysis above, resonance at frequency 26.3 (Mode 3) is caused by Bus 1 while resonance at frequency 36.7 (Mode 2) is contributed by Bus 4.

At frequency of 20.0 p.u in figure 6, there are more than one resonance have occurred. Base on the calculated PF, it shows that the resonance at 20.0 p.u in Mode 4 (refer to Figure 7) is caused by Bus 4. While at frequency 27.6 p.u, Bus 1 has been detected as the major cause of resonance at that particular frequency. For frequency of 35.7p.u, the main bus that contributes to resonance is Bus 4.

From this analysis, it can be concluded that for standard 14 bus system, the buses that excite resonance the most are Bus 1 and Bus 4.

4.3 UTP New Building Network (Academic Building)

Voltage in UTP network is supplied by two generators in GDC. It is also supported by two 11kV incoming from TNB which act as backup. From GDC, the voltage supplies to 10 feeders. The feeders which are concerned in this study are only K03, K04, K10 and K11 because they are responsible to provide voltage to the whole UTP new building. The voltage supplied to K03 and K11 are connected to the main intake high voltage (HV) located at Main Building 3A HV Room while K04 and K10 are connected to main intake HV at Block 5 HV Room. At both HV rooms, there are 10 feeders in each room. The feeders are either act as a spare feeder for future development or connected to the transformer. For the transformer, each transformer is assigned to step down the voltage from 11kV to 413V. In total, there are nine transformers involve in UTP new building network. They are named as TX-PD/1, TX-PC/1, TX-MB/1, TX-5/1, TX-MB/2, TX-5/2, TXPD/2, TX-PC/2 and TX-MB/3.

The stepped down voltage is then supply to the Main Switchboard (MSB) before distributing the voltage to the academic building through the respective Sub-Switchboard (SSB). There are five (5) MSB available in UTP new building network but only three of them are involved in this study. The voltage from TX-PD1 and TX-PD2 to MSB at Pocket D, the voltage from TX-05/1 to MSB at Block 5 and last but not least the voltage from TX-MB/1 and TX-MB/2 to MSB at Main Building 3A. As per mentioned above, from each MSB the voltage are continued to be supplied to SSB of all 16 academic blocks as well as chancellor complex.

The single line diagram of UTP new building is simplified using Matlab Simulink into impedance form. In order to build this model, the author must first identify the number of bus in the network. In this study, the UTP new building has 54 buses in total. The other parameters are obtained from UTP control room as well as the visit to UTP substations.

FIGURE 10 The delta connection (left) and star connection (right) of transformer at block 5

FIGURE 11 Cable and the bus bar

FIGURE 12 Sub switch board (SSB) at block 22

For cable, the values of impedance of the cable are calculated base on the length, type and the area of the cable used. The general value of impedance per kilometer and the calculated impedances are tabulated in two separate the tables as below:

TABLE 9: The general value of the impedance per kilometer according to the cable type

Type of Cable	Area of cable (mm^2)	Resistance per kilometer (ohm/km)	Inductance per kilometer (mH/km)	Capacitance per kilometer (uF/km)
Single-Core	185	0.128	0.26292	$1x10^{-3}$
	240	0.0988	0.258467	$1x10^{-3}$
	300	0.0801	0.254966	$1x10^{-3}$
	400	0.0643	0.252101	$1x10^{-3}$
	500	0.0521	0.249873	$1x10^{-3}$
	630	0.0428	0.24700	$1x10^{-3}$
Three-Core	185	0.128	0.29285	0.43
	240	0.0984	0.2833	0.48

TABLE 10 The specified value of impedance as per cable used in UTP Network

Type of Cable	Area of cable (mm^2)	Location of cable	Length of cable (km)	Resistance (ohm)	Inductance (mH)	Capacitance (uF)
Single-Core	185	MSB-PD/1 to SSB18-01/2	0.138	0.017664	0.03628296	1.38x10^{-4}
		MSB-PC/1 to SSB14-01/2	0.125	0.016	0.032865	1.25 x10^{-4}
		MSB-PC/2 to SSB15-01/1	0.133	0.017024	0.03496836	1.33 x10^{-4}
		MSB-05/1 to SSB03-01/2	0.098	0.012544	0.02576616	0.98 x10^{-4}
	240	MSB-PC/1 to SSB13-01/1	0.165	0.016302	0.004213529034	1.65 x10^{-4}
		MSB-PC/2 to SSB16-01/1	0.17	0.016796	0.004341211732	1.7 x10^{-4}
		MSB-PC/2 to SSB13-01/2	0.162	0.0160056	0.004136919	1.62 x10^{-4}
		MSB-PC/2 to SSB13	0.18	0.17784	0.004596577	1.8 x10^{-4}
	300	MSB-PD/2 to SSB17-01/1	0.181	0.0144981	0.046148846	1.81 x10^{-4}
		MSB-PD/2 to SSB20-01/2	0.145	0.0116145	0.03697007	1.45 x10^{-4}
		MSB-SB/1 to SSB22-01/1	0.164	0.0131364	0.041814424	1.64 x10^{-4}
		MSB-SB/2 to MCC-CHWP	0.062	0.0049662	0.015807892	0.62 x10^{-4}
		MSB-SB/2 to SSB-22-01/2	0.167	0.0133767	0.042579322	1.67 x10^{-4}
		MSB-05/2 to SSB 03-01/1	0.096	0.0076896	0.024476736	0.96 x10^{-4}
		TX-MB/3 to MSB-ZC	0.055	0.0044055	0.01402313	0.55 x10^{-4}
	400	MSB-PD/1 to SSB 17-01/1	0.184	0.0118312	0.046386584	0.184 x10^{-4}
		MSB-PD/1 to SSB20-01/1	0.142	0.0091306	0.035798342	1.84 x10^{-4}
		MSB-PD/1 to SSB-CB-PD	0.01	0.000643	0.00252101	0.1 x10^{-4}
		MSB-PD/2 to SSB18-01/1	0.141	0.00900663	0.035546241	1.41 x10^{-4}
		MSB-PD/2 to SSB21-01/2	0.194	0.0124742	0.0489007594	1.94 x10^{-4}
		MSB-05/1 to SSB 05-01/1	0.01	0.000643	0.00252101	0.1 x10^{-4}
		MSB-05/1 to SSB04-01/1	0.046	0.0029578	0.011596646	0.46 x10^{-4}

		MSB-05/1 to SSB 05-01/1	0.01	0.000643	0.00252101	0.1 $\times10^{-4}$
		MSB-05/1 to SSB04-01/1	0.046	0.0029578	0.011596646	0.46 $\times10^{-4}$
	500	MSB-SB/1 to SSB-ERC	0.01	0.000521	0.00249873	0.1 $\times10^{-4}$
		MSB-SB/1 to SSB23-01/1	0.113	0.005887	0.028235649	1.13 $\times10^{-4}$
		MSB-SB/2 to SSB-MH	0.062	0.0032302	0.015492126	0.62 $\times10^{-4}$
		MSB-SB/2 to SSB-ERC	0.014	0.007294	0.003498222	0.14 $\times10^{-4}$
		MSB-PC/1 to SSB-CB-PC	0.008	0.0004168	0.001998984	0.08 $\times10^{-4}$
		MSB-05/2 to SSB02-01/1	0.145	0.0075545	0.036231585	1.45 $\times10^{-4}$
	630	MSB-PD/2 to SSB19-01/1	0.085	0.003638	0.020995	0.85 $\times10^{-4}$
		MSB-PD/2 to SSB21-01/1	0.191	0.0081748	0.047177	1.91 $\times10^{-4}$
		MSB-SB/1 to SSB-RC	0.01	0.000428	0.00247	0.1 $\times10^{-4}$
		MSB-SB/2 to SSB01-01/1	0.062	0.0026536	0.015314	0.62 $\times10^{-4}$
Three-Core	185	Block 5 HV to TX-PD/1	0.688	0.088064	0.2014808	0.29584
		Block 5 HV to TX-PC/1	0.983	0.125824	0.28787155	0.42269
		Block 5 HV to TX-MB/1	0.341	0.043648	0.09986185	0.14663
		Block 5 HV to TX-5/1	0.014	0.001792	0.0040999	0.00602
		3A HV Room to TX-MB/2	0.014	0.001792	0.0040999	0.00602
		3A HV Room to TX-05/2	0.339	0.043392	0.09927615	0.14577
		3A HV Room to TX-PC/2	0.673	0.086144	0.19708805	0.28939
		3A HV Room to TX-MB/3	0.012	0.001536	0.0035142	0.00516
	240	K04 to Block 5HV	0.55	0.05412	0.155815	0.264
		K10 to Block 5HV	0.546	0.0537264	0.1546818	0.26208
		K03 to 3A HV Room	0.864	0.085017	0.2396718	0.41472
		K11 to 3A HV Room	0.86	0.084624	0.243638	0.4128

4.3.1 Load Flow Study and Simulation

All the parameters required are keyed into the respective blocks that are built in Matlab Simulink for load flow study as well as for simulation purpose.

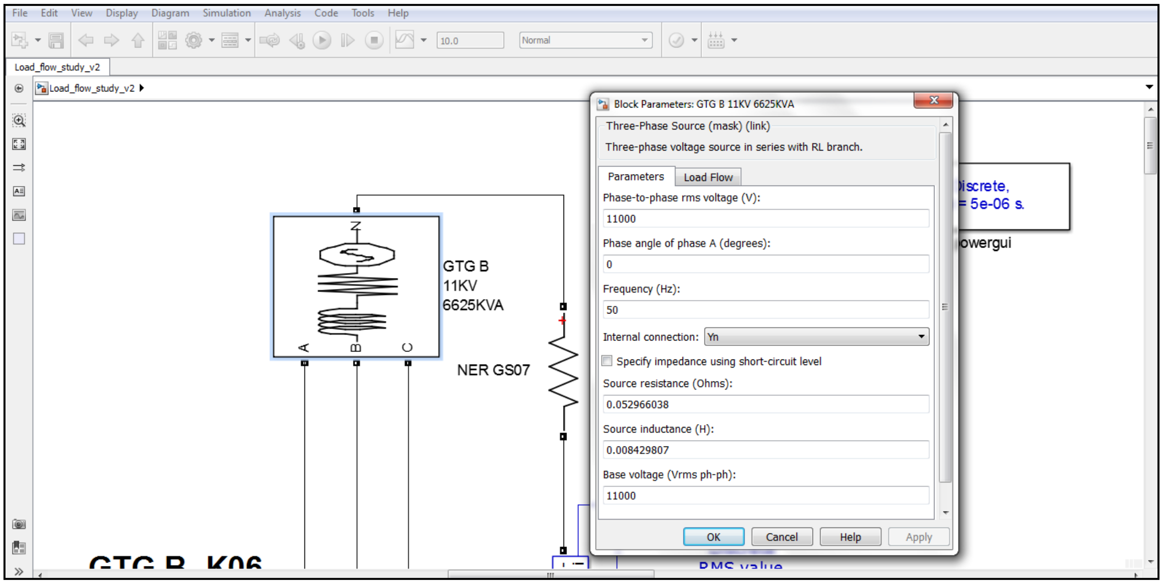

FIGURE 13 The generator block

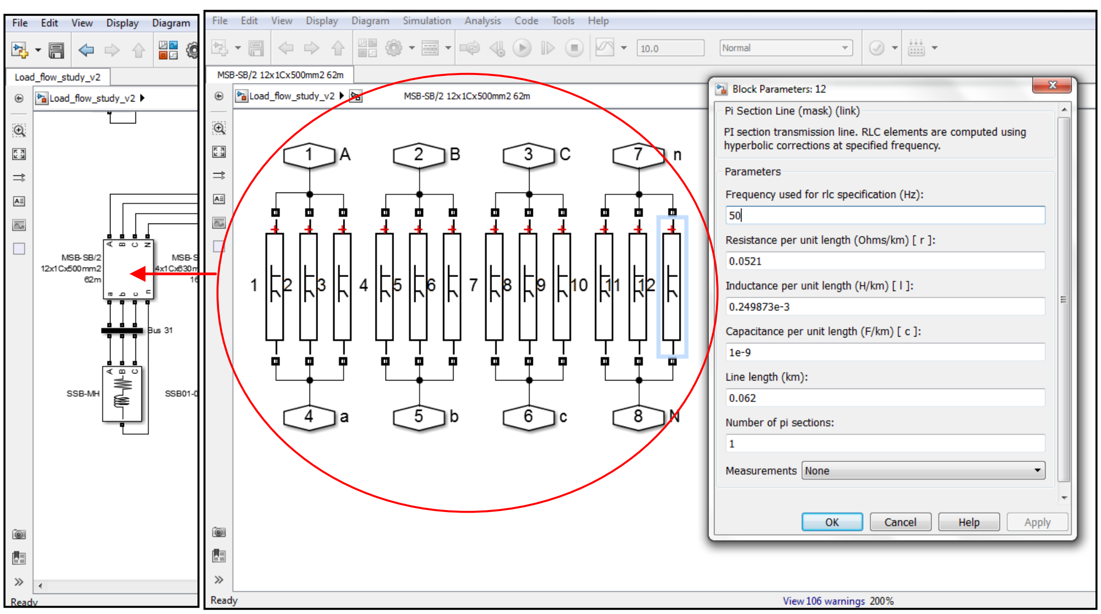

FIGURE 14 The cable block

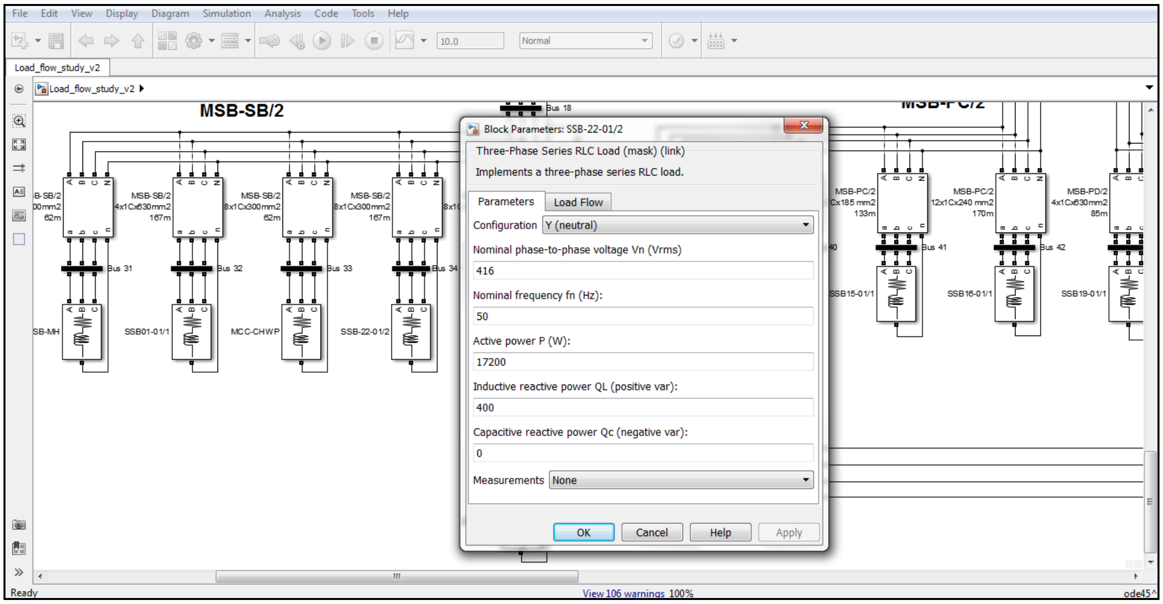

FIGURE 15 The load block

The full model of load flow study and the simulation can be viewed in **Appendix 6** and **Appendix 7.**

In the simulation, the UTP new building network model is injected with the 3rd , 5th and 7th order harmonic (and other relevant harmonic order) to represent the harmonics which generated by the load. In order to produce the 3rd harmonic, AC source is set to 150Hz which indicates the 3rd order of harmonics. For 5th and 7th harmonics, the frequencies are set to 250 Hz and 350 Hz.

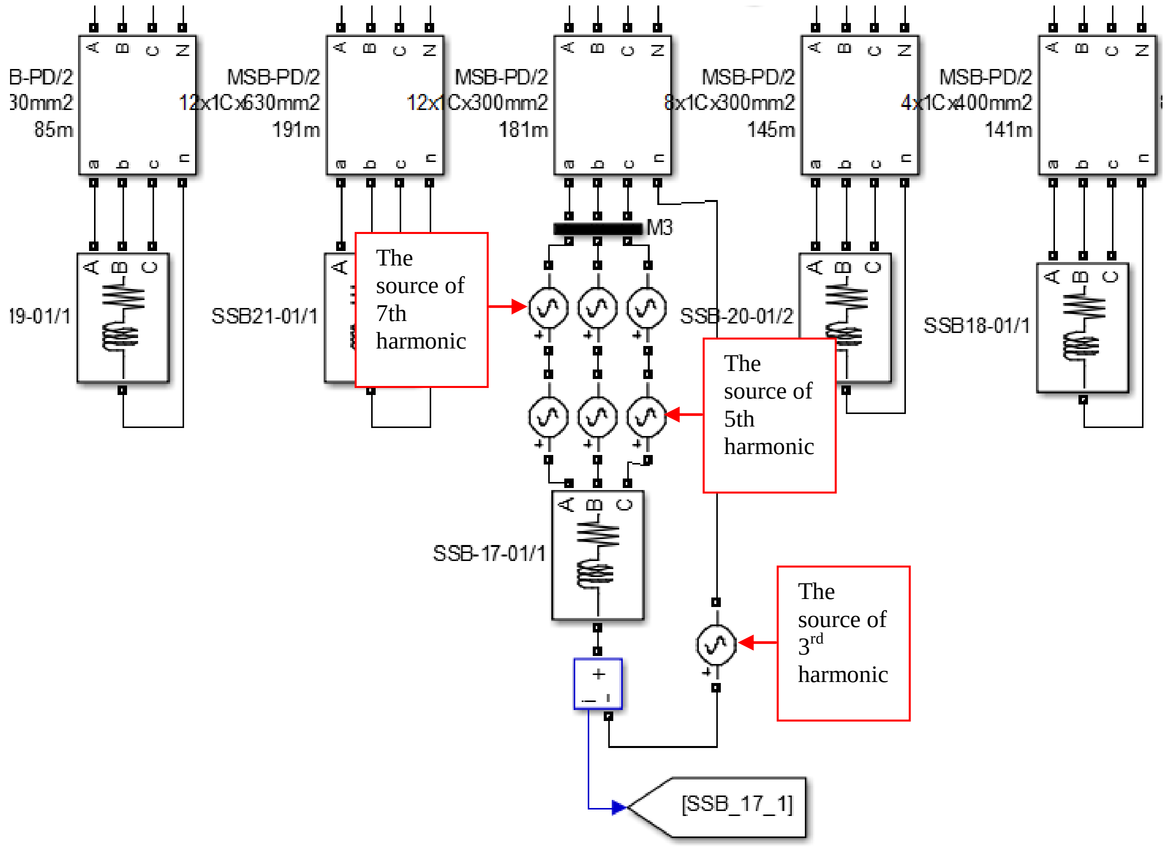

FIGURE 16 The source of harmonics

The network is first simulated without the source of harmonics so that the comparison between the current and voltage waveforms with and without harmonic can be made. The second simulation is conducted to see the waveforms after the harmonics is present. The voltage and current waveforms produced in the simulations are shown below:

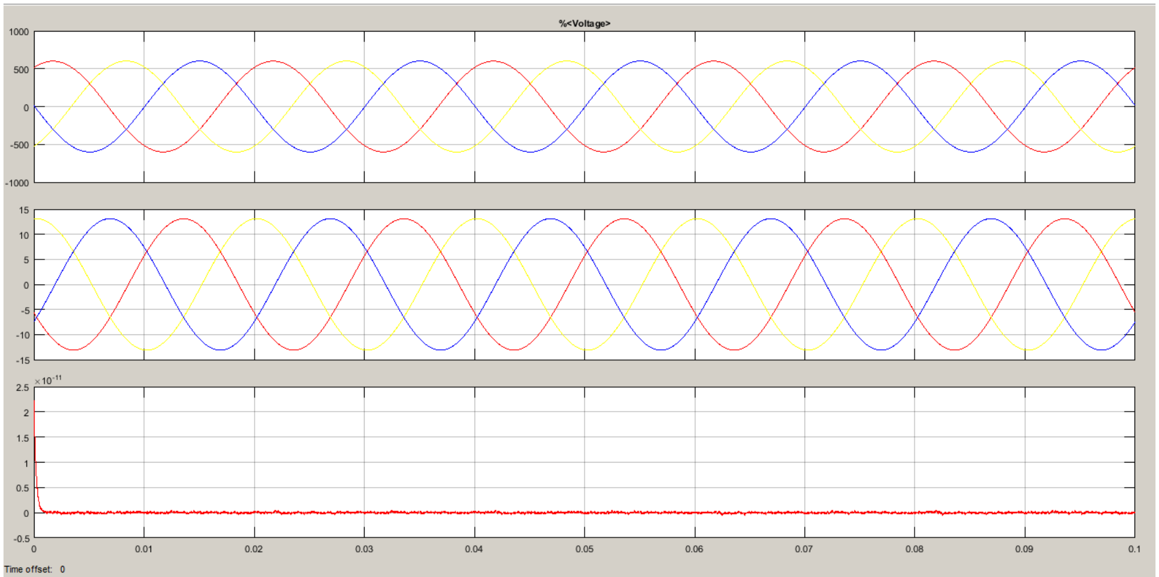

FIGURE 17 Waveforms of phase voltage, phase current and neutral current without harmonics injection at SSB17-01/1

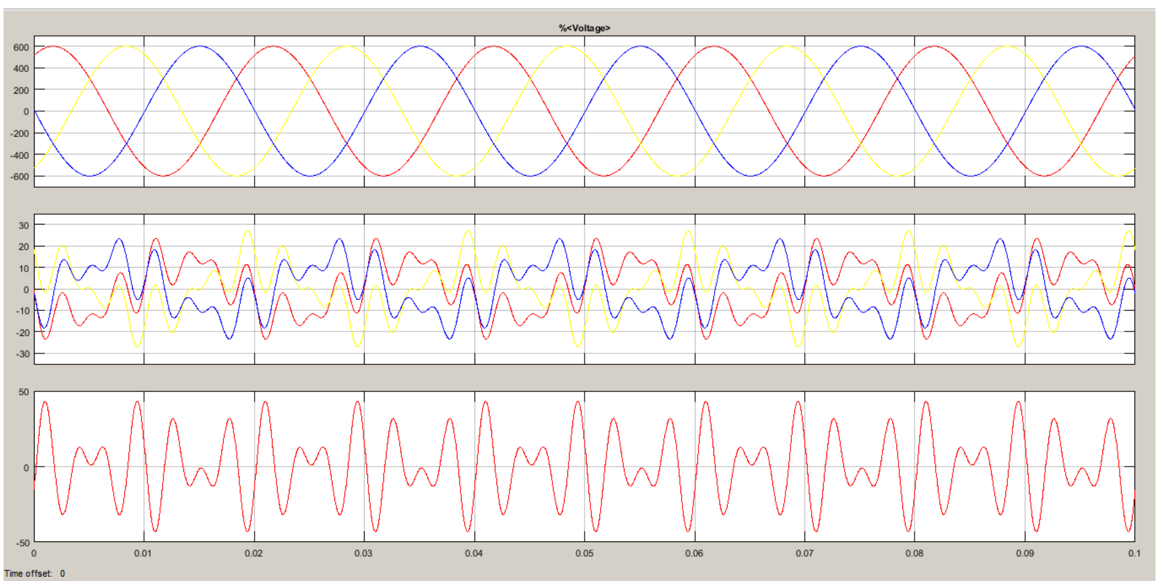

FIGURE 18 Waveforms of phase voltage, phase current and neutral current with harmonics injection at SSB17-01/1

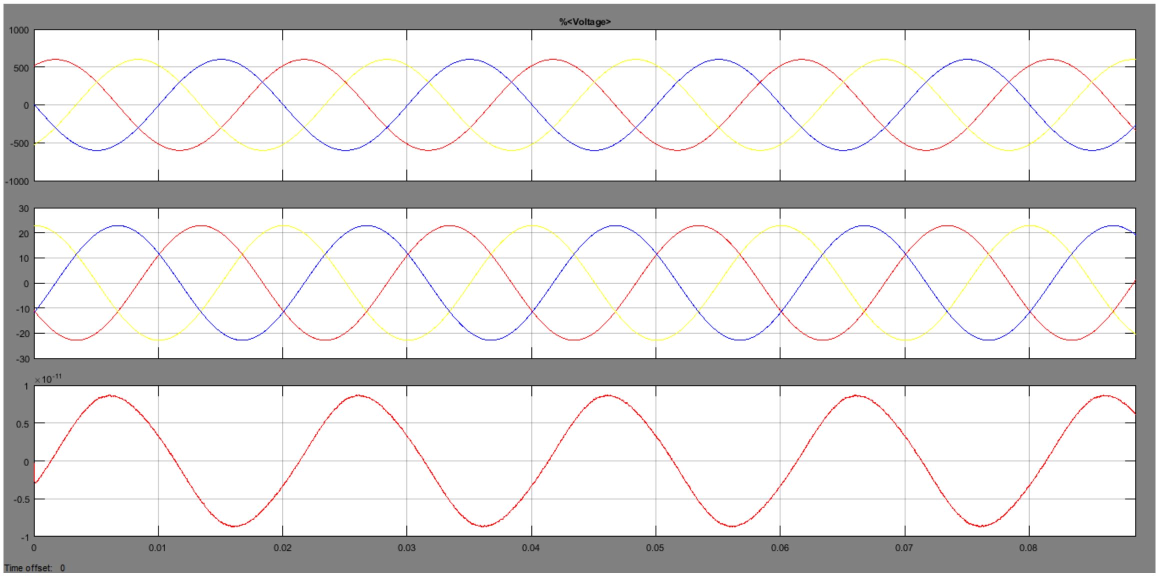

FIGURE 19 Waveforms of phase voltage, phase current and neutral current without harmonics injection at SSB-17-01/2

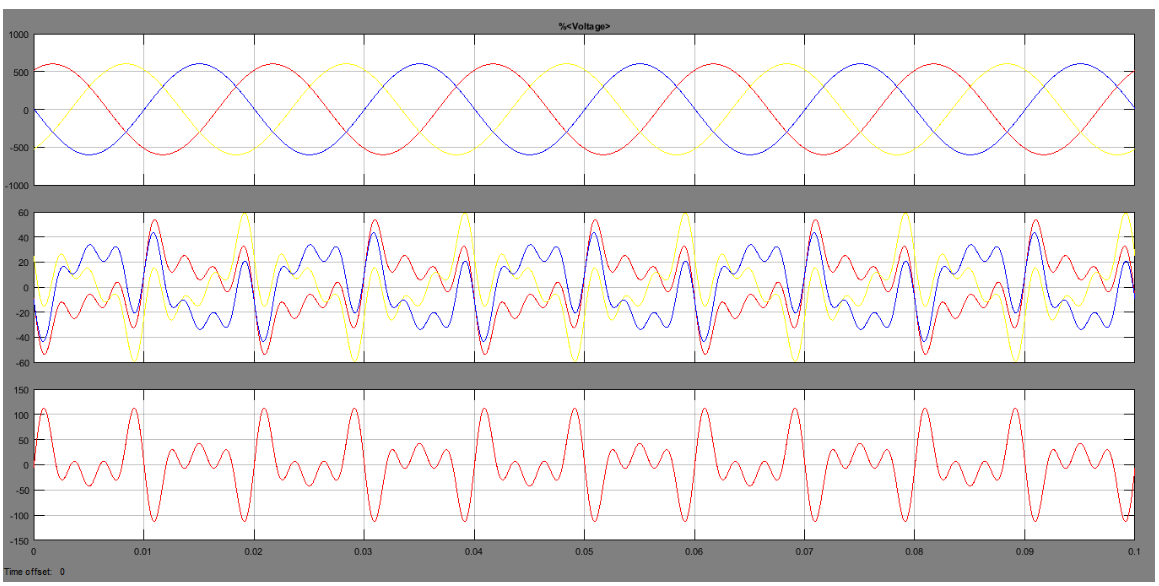

FIGURE 20 Waveforms of phase voltage, phase current and neutral current with harmonics injection at SSB-17-01/2

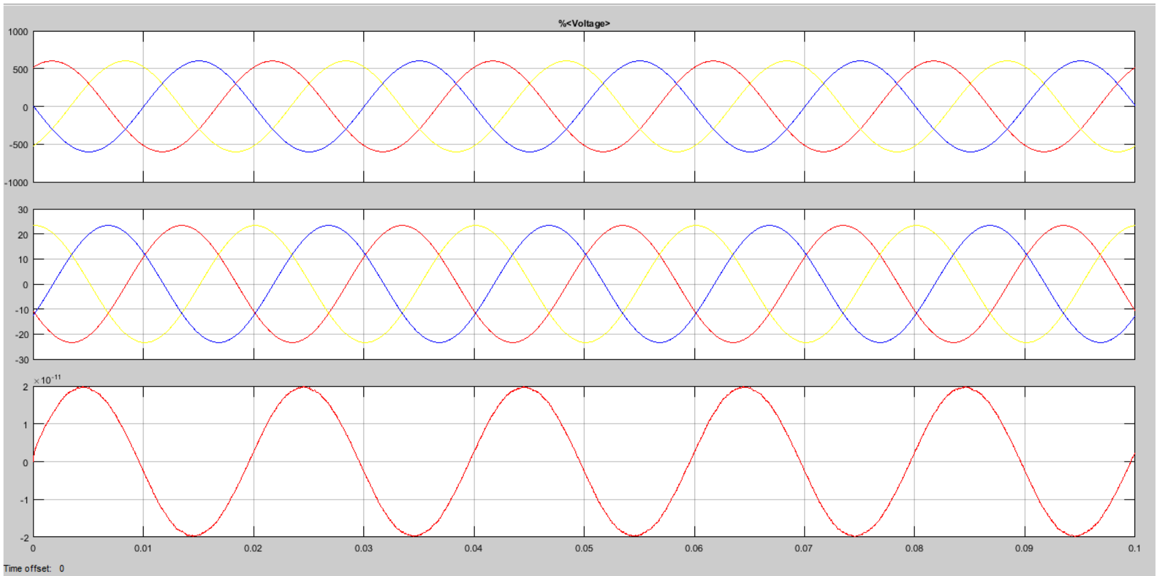

FIGURE 21 Waveforms of phase voltage, phase current and neutral current without harmonics injection at SSB-22-01/1

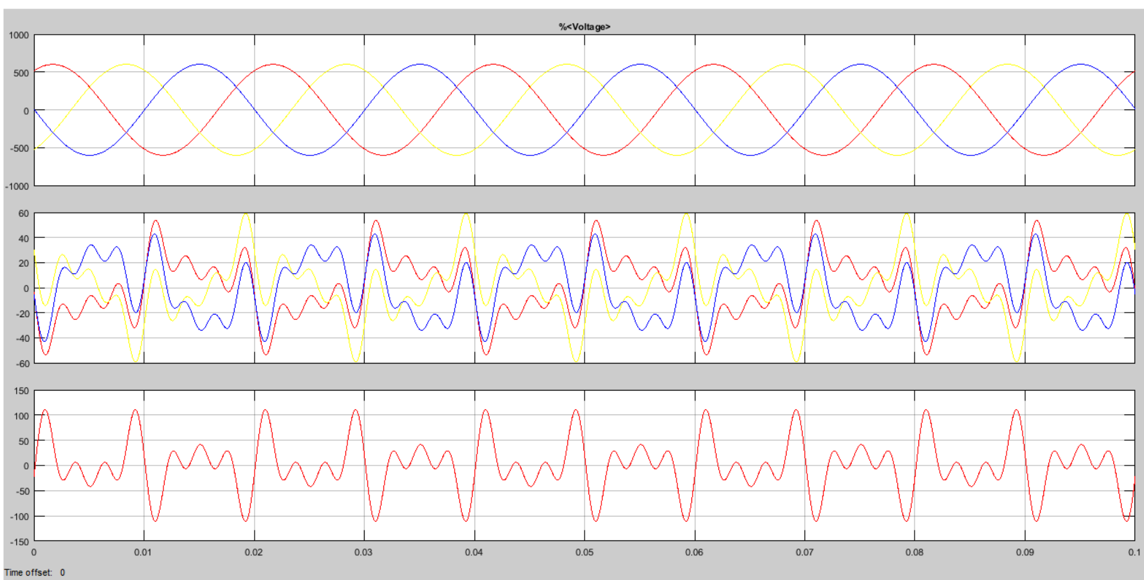

FIGURE 22 Waveforms of phase voltage, phase current and neutral current with harmonics injection at SSB-22-01/1

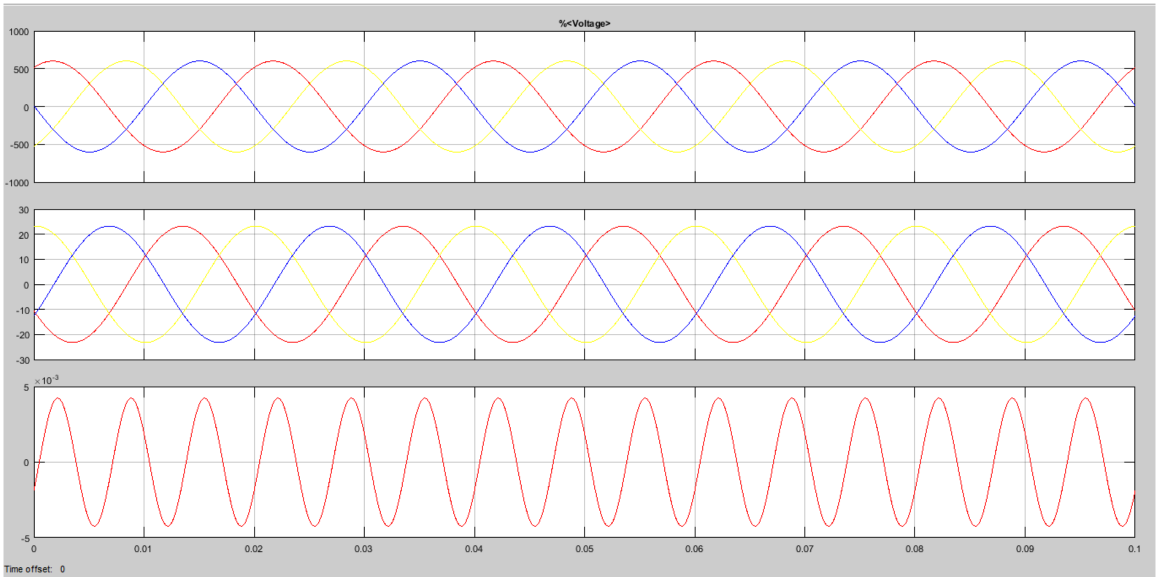

FIGURE 23 Waveforms of phase voltage, phase current and neutral current without harmonics injection at SSB-22-01/2

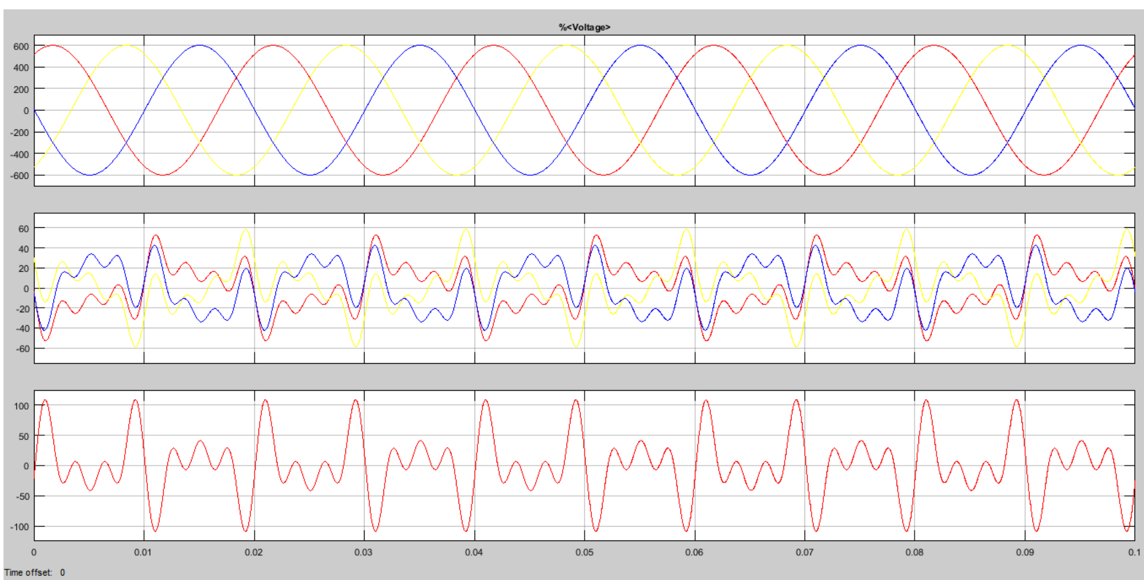

FIGURE 24 Waveforms of phase voltage, phase current and neutral current with harmonics injection at SSB-22-01/2

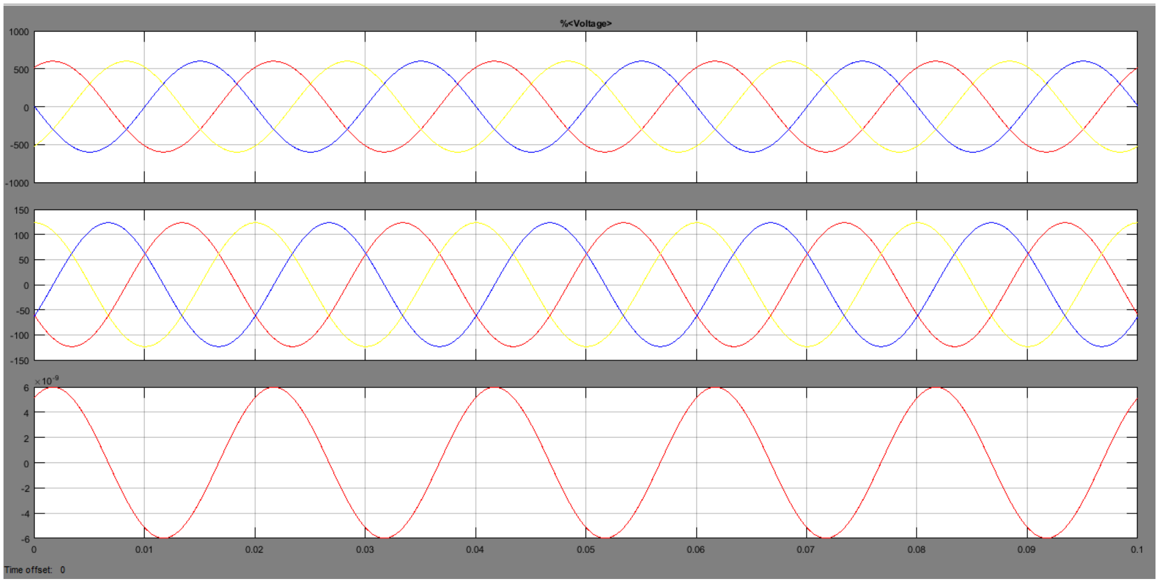

FIGURE 25 Waveforms of phase voltage, phase current and neutral current without harmonics injection at SSB-05-01/1

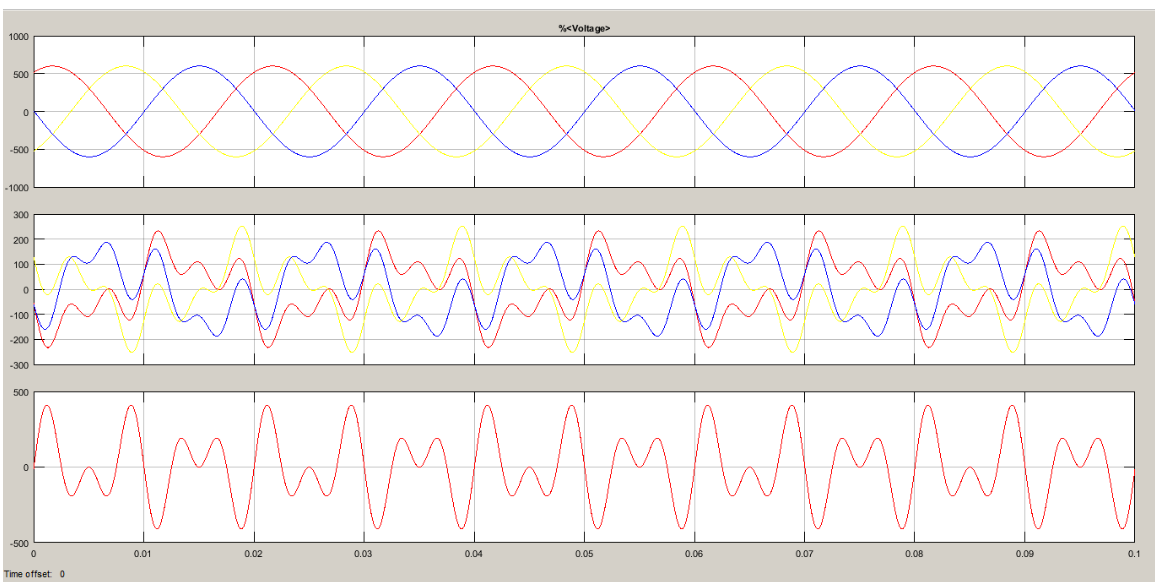

FIGURE 26 Waveforms of phase voltage, phase current and neutral current with harmonics injection at SSB-05-01/1

Base on the result from the simulation, it shows that the injection of harmonics causes the current waveform to lose its sinusoidal shape. The voltage waveform seems to be not effected much with the harmonics. The existence of harmonics causes the current in three phase system to not be cancelling each other and cause the current to be non-zero. Referring to the result from the comparison between the waveforms with and without harmonics in Figure 17 until Figure 26, it can be proven the theory where the magnitude of the odd triplen harmonics which is in zero sequence is additive in the neutral line. Thus, large amount of current pass through the line even though the original amount of current in the neutral line should be very small.

4.3.2 Load Flow Study

To gain the load flow study, UTP new network model is built by using PSAT in Matlab. The full UTP new building network model is available in **Appendix 6**.

The table below shows the result gained when the model is run. All of this information is important and will be used in simulating the harmonic resonance through frequency scan analysis and harmonic resonance mode analysis techniques.

TABLE 11 The load flow study

Bus	V	phase	P gen	Q gen	P load	Q load
	[p.u.]	[rad]	[p.u.]	[p.u.]	[p.u.]	[p.u.]
Bus01	1	0	0.347741433	0.162115358	0	0
Bus02	0.99447975	-0.00134296	6.94046E-15	-9.36366E-14	0	0
Bus03	0.99532535	-0.00041513	-1.13132E-13	5.66247E-14	0	0
Bus04	0.99358000	-0.00172489	1.76495E-15	-3.04436E-18	0	0
Bus05	0.99089194	-0.00399665	-9.61575E-16	-9.01214E-13	0	0
Bus06	0.99439843	-0.00135247	-1.13868E-14	-5.23144E-14	0	0
Bus07	0.98160696	-0.02540170	1.04643E-14	-4.78365E-17	0	0
Bus08	0.98034571	-0.02472919	-8.72138E-16	-4.64743E-17	0	0
Bus09	0.99382522	-0.00144562	-5.67423E-	-1.53651E-	0	0

			15	15		
Bus10	0.98978985	-0.00955437	1.66963E-15	1.98915E-17	0	0
Bus11	0.98862593	-0.00896992	-6.58531E-16	5.90713E-18	0	0
Bus12	0.99364869	-0.00038317	-2.28479E-15	2.20722E-15	0	0
Bus13	0.98101879	-0.01781131	-9.69908E-19	-5.44488E-17	0	0
Bus14	0.97851896	-0.01596975	-5.21431E-15	5.95109E-17	0	0
Bus15	0.99424978	-0.00034730	-3.54991E-16	8.83195E-16	0	0
Bus16	0.98959323	-0.00611204	-1.0912E-18	-1.7853E-16	0	0
Bus17	0.98855928	-0.00526561	-6.58648E-16	-2.39702E-17	0	0
Bus18	0.99532234	-0.00041555	-6.35346E-14	-9.27961E-14	0	0
Bus19	0.99477729	-0.00145104	5.54036E-17	1.25651E-16	0	0
Bus20	0.99078320	0.00067129	-4.33681E-17	-2.1684E-19	0.0017	0.0009
Bus21	0.98638277	-0.00303365	5.8463E-16	-1.31591E-15	0	0
Bus22	0.96634743	-0.04879311	1.25196E-15	-6.51219E-17	0	0
Bus23	0.95983361	-0.04593439	-3.41498E-15	-2.97066E-17	0	0
Bus24	0.99009297	-0.00198080	1.70447E-16	-6.59873E-16	0	0
Bus25	0.98117388	-0.01697514	5.08489E-18	2.9952E-16	0	0
Bus26	0.97849635	-0.01535174	-6.5142E-16	3.03727E-17	0	0
Bus27	0.98169726	-0.03462703	-8.19892E-16	-8.44044E-16	0	0
Bus28	0.96244520	-0.11723151	6.84164E-15	-3.75385E-16	0	0
Bus29	0.95817133	-0.11635642	-3.63255E-15	7.65045E-17	0	0
Bus30	0.99088761	-0.00400692	1.60042E-15	2.99885E-13	0	0
Bus31	0.98435741	-0.02007909	-1.74657E-15	1.17055E-16	0	0
Bus32	0.98135005	-0.01884750	3.24006E-16	-1.5424E-16	0	0
Bus33	0.97538929	-0.02749435	6.93889E-18	-1.00614E-16	0.0097	0.0051
Bus34	0.97233266	-0.02046955	1.63064E-16	0	0.0097	0.0051
Bus35	0.97514642	-0.02197509	4.04191E-16	8.67362E-19	0.0097	0.0051

Bus36	0.97607696	-0.02247309	4.82253E-16	-2.25514E-17	0.0097	0.0051
Bus37	0.98323703	-0.00626794	-3.55618E-17	8.67362E-19	0.0066	0.0033
Bus38	0.98512553	-0.00722152	0	3.03577E-18	0.0066	0.0033
Bus39	0.97387830	-0.01254708	1.65666E-16	2.60209E-18	0.007	0.0051
Bus40	0.97387830	-0.01254708	1.65666E-16	2.60209E-18	0.007	0.0051
Bus41	0.97387830	-0.01254707	-2.04697E-16	-1.73472E-18	0.007	0.0051
Bus42	0.97387830	-0.01254708	1.65666E-16	2.60209E-18	0.007	0.0051
Bus43	0.98447737	-0.00192023	1.88217E-16	8.67362E-19	0.00313	0.00255
Bus44	0.98541109	-0.00268763	2.03396E-16	-8.67362E-19	0.00313	0.00255
Bus45	0.98689954	-0.00391186	-1.58727E-16	3.46945E-18	0.00313	0.00255
Bus46	0.95448167	-0.04358388	-3.90313E-16	3.29597E-17	0.0119	0.0051
Bus47	0.95448167	-0.04358388	-3.90313E-16	3.29597E-17	0.0119	0.0051
Bus48	0.94977446	-0.04148654	1.37043E-16	8.67362E-19	0.0119	0.0051
Bus49	0.94977446	-0.04148654	1.37043E-16	8.67362E-19	0.0119	0.0051
Bus50	0.95177463	-0.04237758	-3.46945E-18	1.04083E-17	0.0119	0.0051
Bus51	0.95177463	-0.04237758	-3.46945E-18	1.04083E-17	0.0119	0.0051
Bus52	0.97238364	-0.01162983	-6.50521E-17	3.46945E-18	0.006	0.0036
Bus53	0.97452534	-0.01294009	-1.11022E-16	-7.80626E-18	0.006	0.0036
Bus54	0.97238364	-0.01162983	-6.50521E-17	3.46945E-18	0.006	0.0036
Bus55	0.97238364	-0.01162983	-6.50521E-17	3.46945E-18	0.006	0.0036
Bus56	0.94413750	-0.11348940	1.249E-16	1.00614E-16	0.0254	0.0051
Bus57	0.94667180	-0.11401917	-4.3715E-16	9.19403E-17	0.0254	0.0051
Bus58	0.93642106	-0.11187568	6.03684E-16	3.55618E-17	0.0254	0.0051
Bus59	0.93642106	-0.11187568	6.03684E-16	3.55618E-17	0.0254	0.0051
Bus60	0.94413750	-0.11348940	1.249E-16	1.00614E-16	0.0254	0.0051
Bus61	0.97567066	-0.01651969	-1.04083E-16	1.30104E-17	0.0086	0.0035
Bus62	0.97567066	-0.01651969	-1.04083E-16	1.30104E-17	0.0086	0.0035
Bus63	0.96998113	-0.01416482	-2.94903E-17	2.1684E-18	0.0086	0.0035

4.3.3 Data Logging Activity

The data logging of voltage and current waveform at the respective SSB of the academic blocks have been conducted. This data obtained is the actual measurement that will be compared to the result from the analysis using frequency scan analysis and harmonics resonance modal analysis. The data is recorded for six (6) days using Circutor AR6 portable power analyzer. The analyzer is set to record the data required for every 10 minutes. The instantaneous, maximum and maximum value of the particular data within the 10 minutes interval are also recorded. The author is assisted by UTP lab technician, Mr Zuraimi and PMMD charge man, Mr. Tarmizi to conduct this activity.

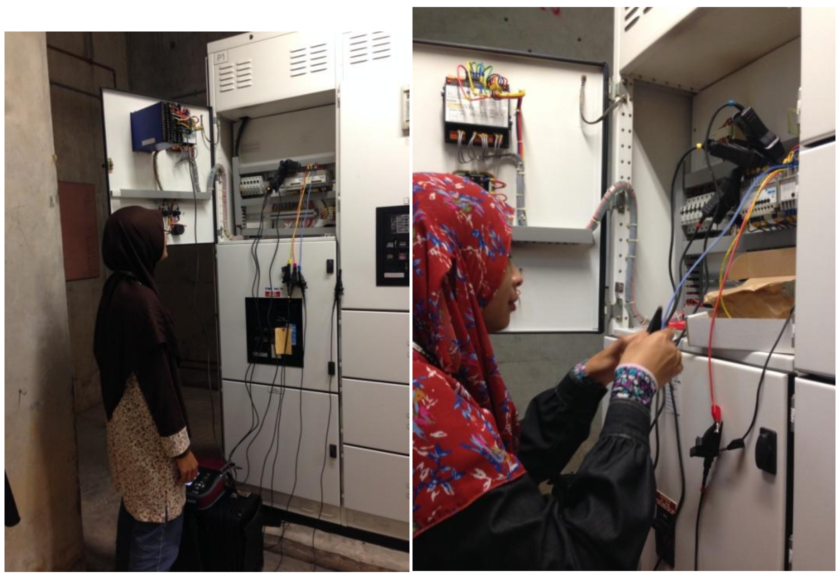

FIGURE 27 The process of installing the power analyzer to the SSB

SSB 17-01/1

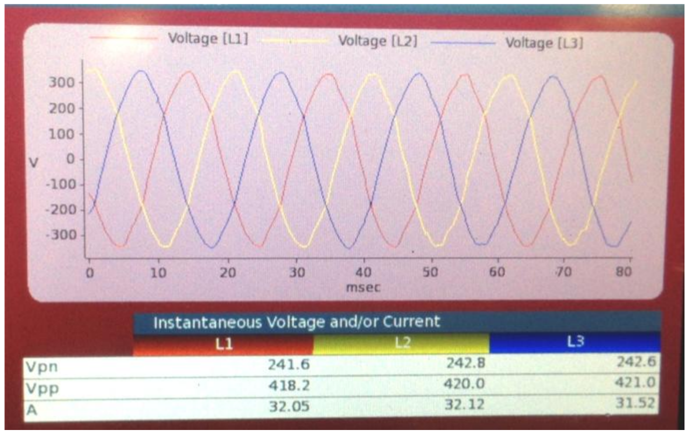

FIGURE 28 The three phase voltage waveform of SSB 17-01/1

Figure 28 shows the voltage waveform at SSB 17-01/1. The voltage harmonic at every 10 minutes interval for six (6) days of each phase is captured using Portable Power Analyzer AR6 and represented in the graph form as below:

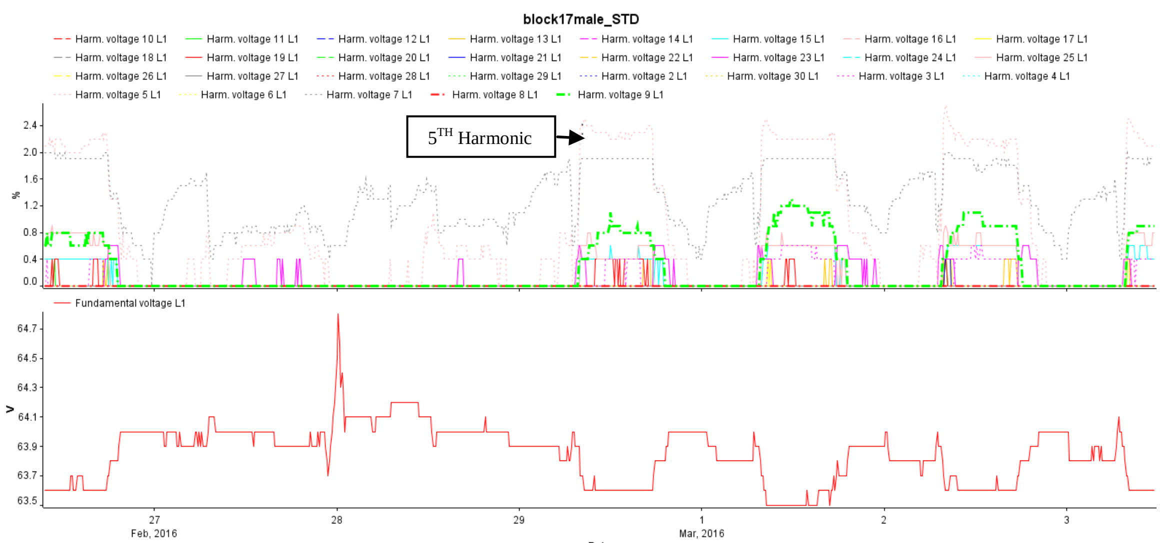

FIGURE 29 The harmonic voltage of L1

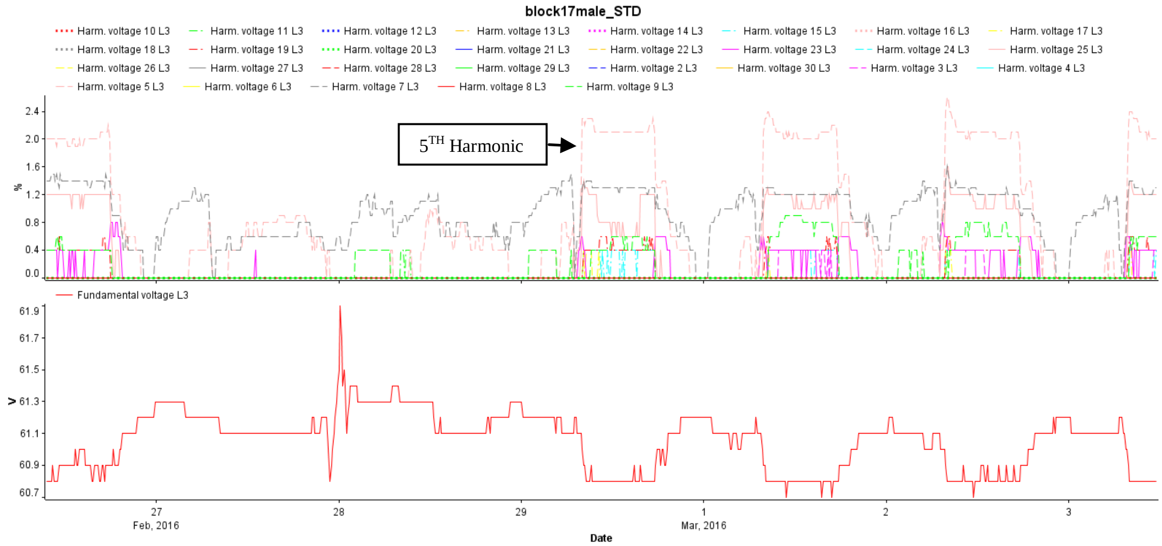

FIGURE 30 The harmonic voltage of L2

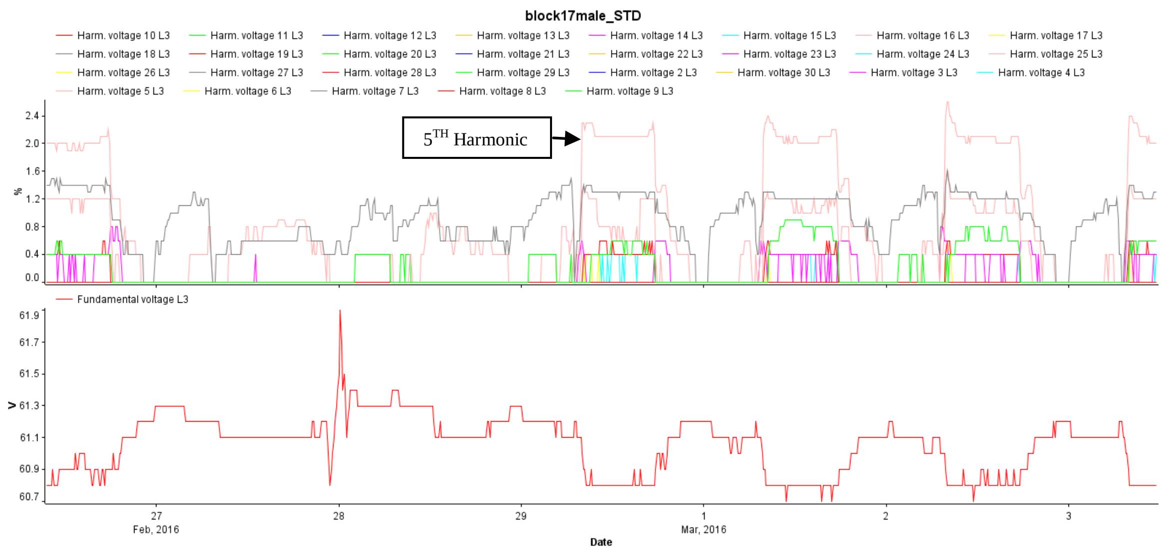

FIGURE 31 The harmonic voltage of L3

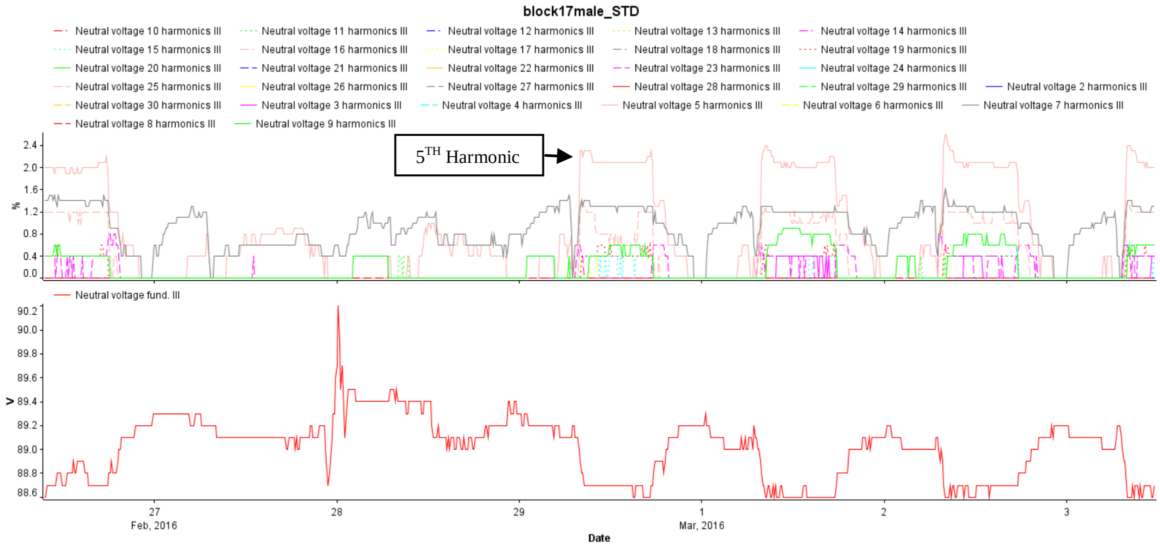

FIGURE 32 The harmonic voltage of LN

Base on the measured data, the highest percentage of harmonic voltage is 2.7% which contributed by the 5th harmonics. Besides the 5th harmonics, 7th harmonic is also significant in harmonics voltage.

The average and highest percentages of the contributed harmonics are tabulated in the table below:

TABLE 12 Percentage of contributed harmonics to voltage at SSB 17-01/1

Line	Most significant Harmonic (Order)	Average percentage (%)	The highest percentage (%)
L1	5th Harmonic	0.88	2.70
	7th Harmonic	1.33	2.00
L2	5th Harmonic	0.92	2.60
	7th Harmonic	0.99	1.70
L3	5th Harmonic	0.86	2.60
	7th Harmonic	0.92	1.60
LN	5th Harmonic	0.86	2.60
	7th Harmonic	0.92	1.60

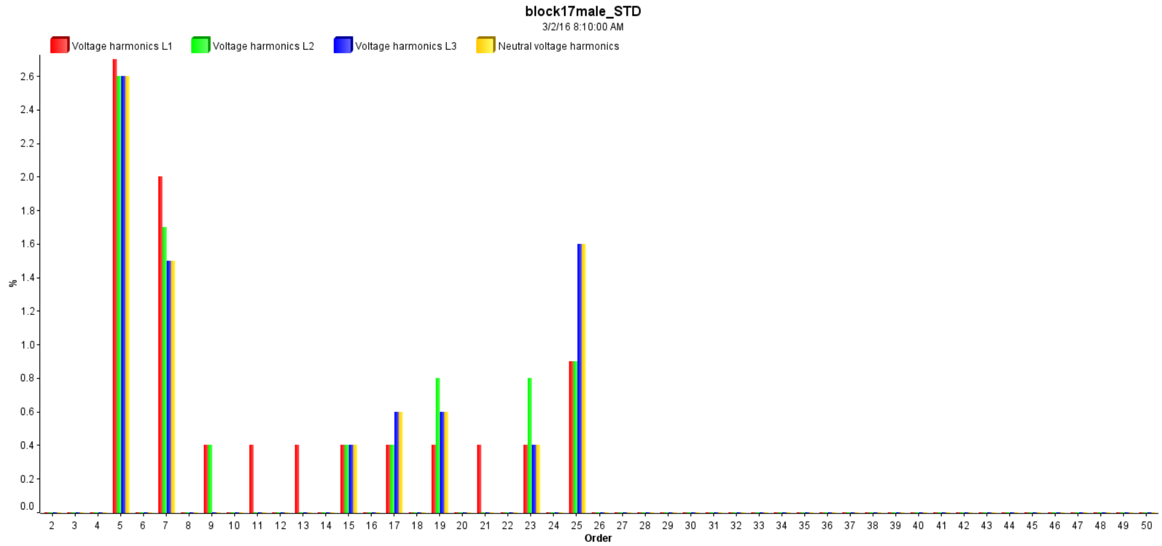

FIGURE 33 The graph that shows the highest voltage harmonic

Figure 33 shows the spectrum of harmonics which has the highest value of harmonics voltage in the interval of six (6) days.

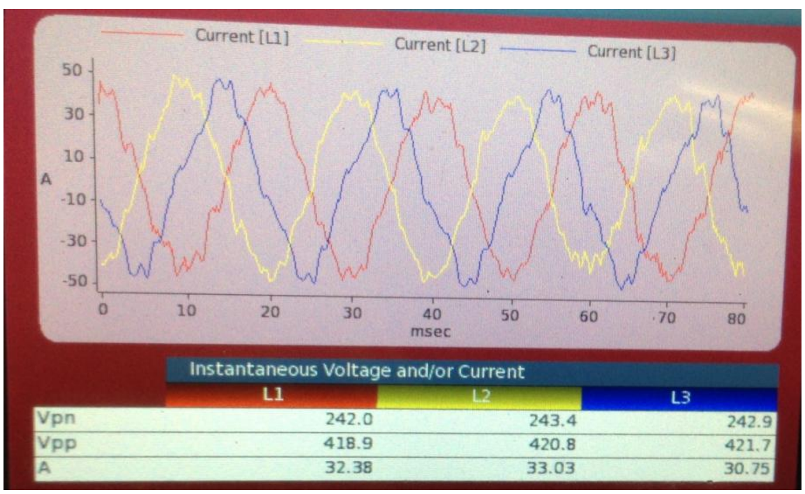

FIGURE 34 The current waveform at SSB-17/1-01

The recorded data of current harmonic per phase of SSB 17/1-01 is summarized in the graphs below

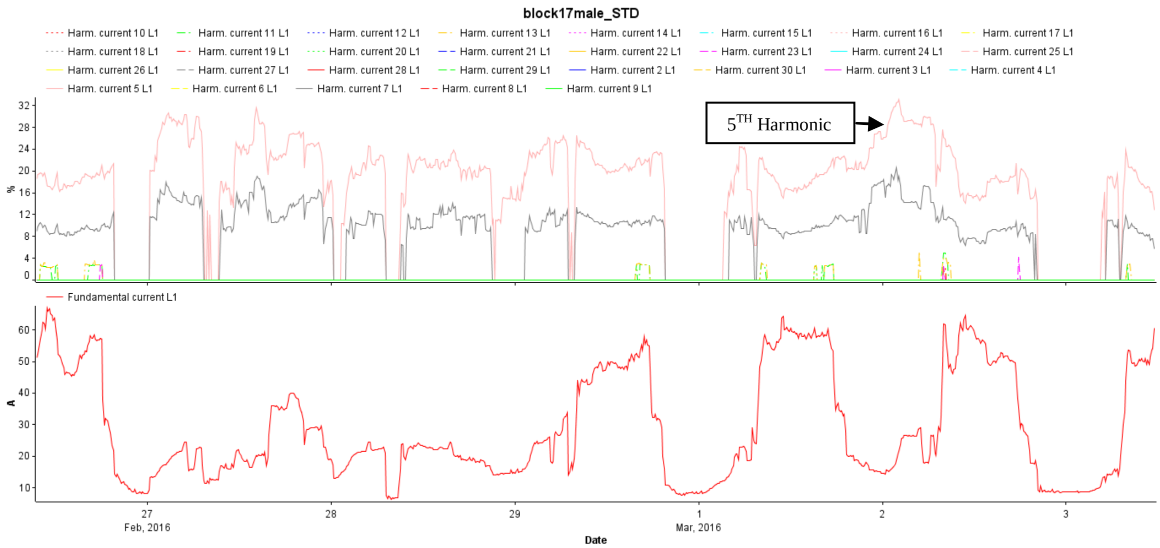

FIGURE 35 The Harmonic Current of L1

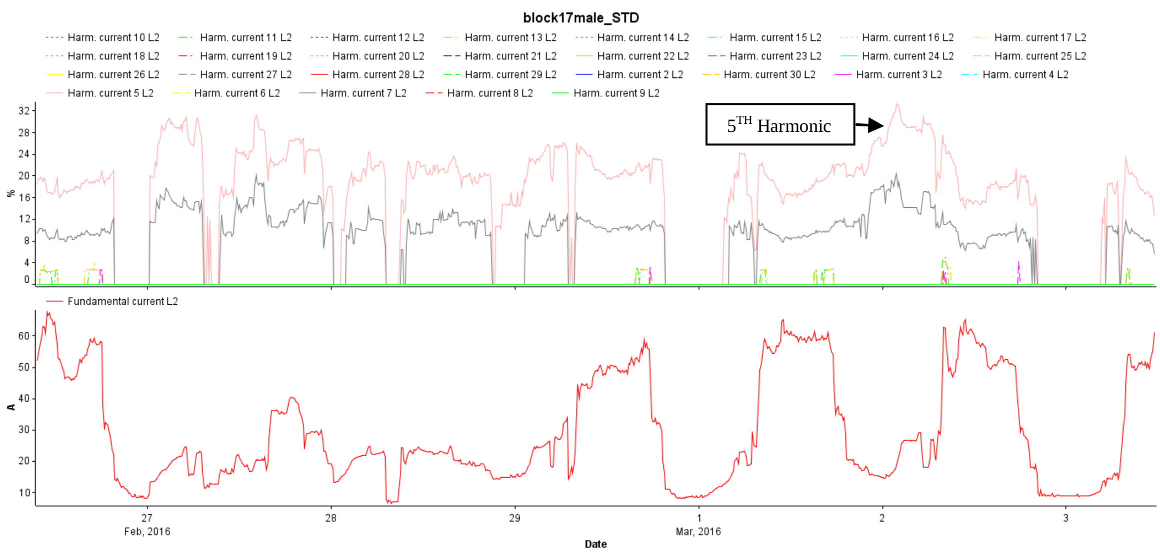

FIGURE 36 The Harmonic Current of L2

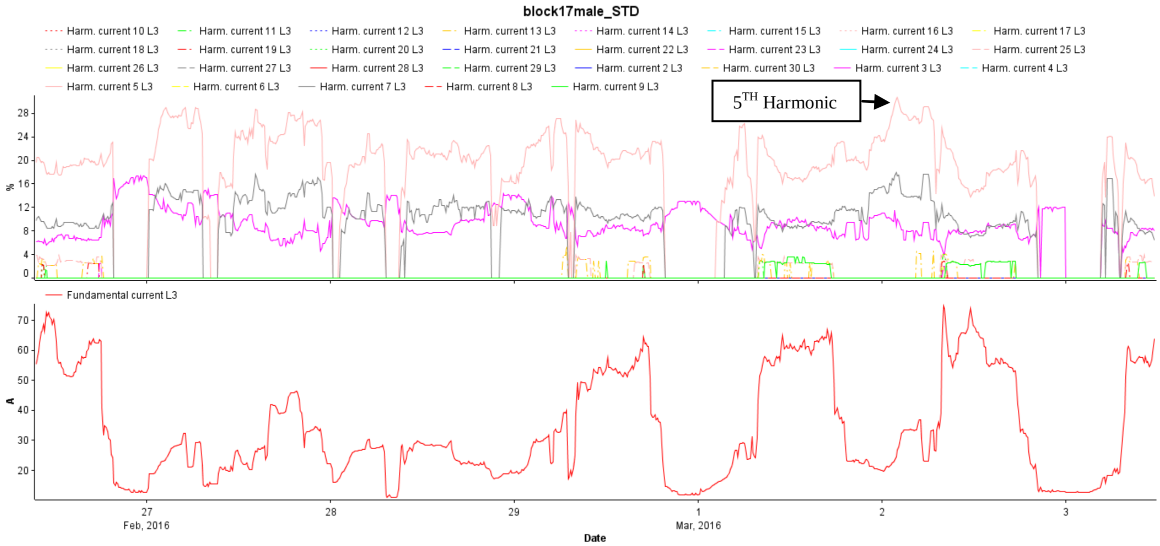

FIGURE 37 The Harmonic Current L3

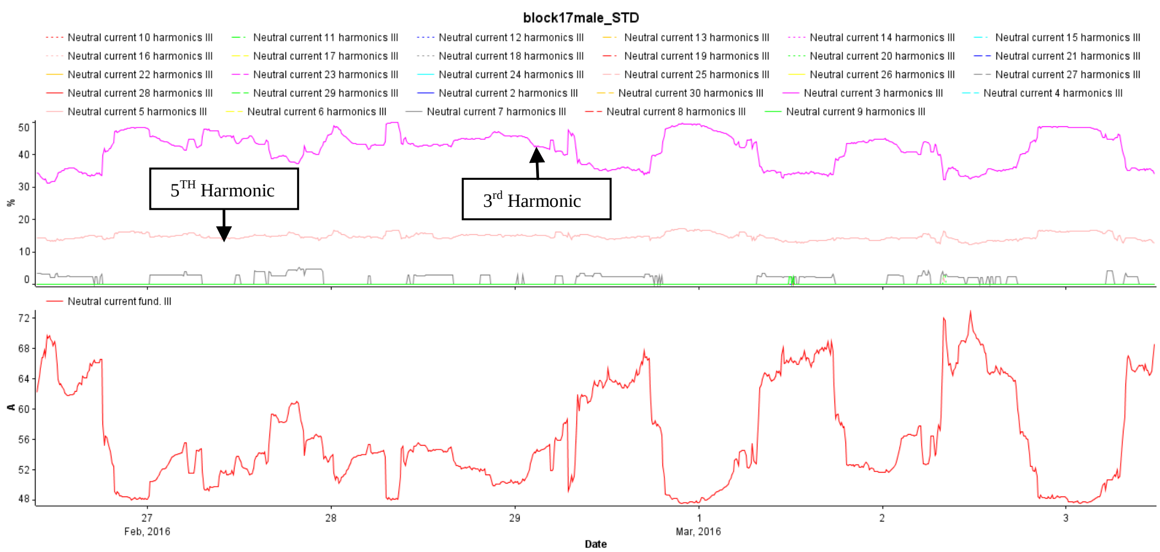

FIGURE 38 The Harmonic Current of LN

Base on the data recorded using Circutor AR6, the same harmonics orders which are 5th order as well as 7th order that present in voltage waveform also present in current waveform at line 1, line 2, line 3 and neutral line. However, there is an additional of 3rd order harmonic at neutral line and contribute in big amount of average percentage which is 41.60%. The overall percentage of harmonic in current waveform is tabulated in Table 12 below.

TABLE 13 Percentage of contributed harmonics to current at SSB 17-01/1

Line	Most significant Harmonic (Order)	Average percentage (%)	The highest percentage (%)
L1	5th Harmonic	17.17	32.60
	7th Harmonic	8.56	19.80
L2	5th Harmonic	17.01	33.20
	7th Harmonic	8.53	19.70
L3	5th Harmonic	17.40	30.70
	7th Harmonic	9.01	17.40
LN	3rd Harmonic	41.60	49.90
	5th Harmonic	14.75	16.80
	7th Harmonic	1.30	2.90

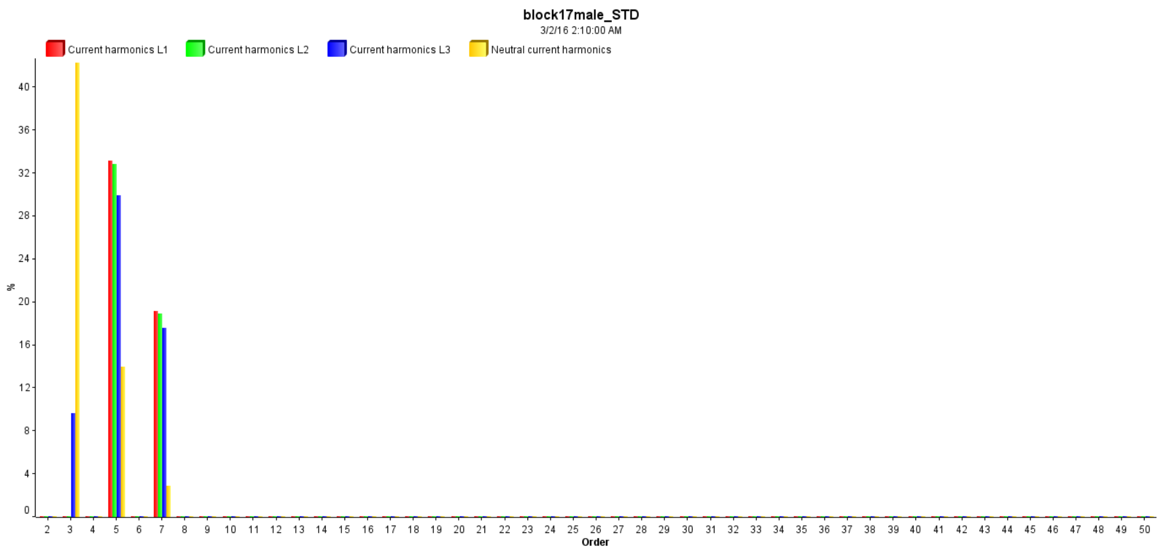

FIGURE 39 The graph that shows the highest current harmonic

The data gained shows that the highest percentage of current harmonic is 49.9%. This percentage is also contributed by the 3rd harmonic in the neutral line. It is higher than the others due to the triplen harmonics effect where the large currents circulate in the neutral because the per phase current is not able to cancel out each other. Besides, 5th and7th harmonic are also most significant in current harmonic.

SSB-17/01-2

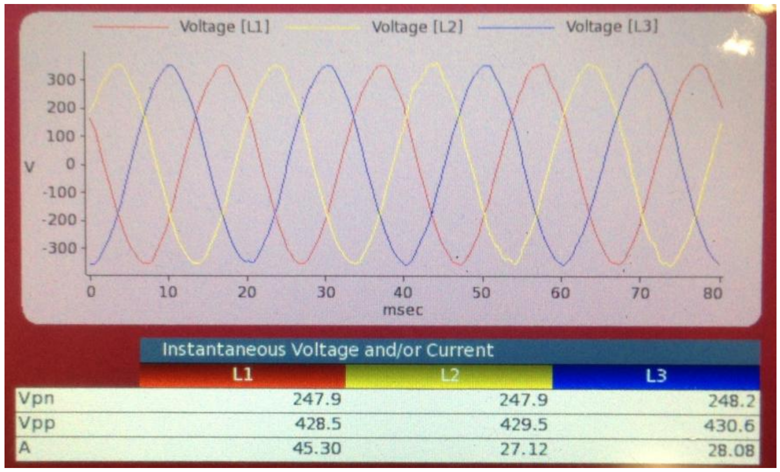

FIGURE 40 Voltage waveform at SSB 17/1-02

The voltage waveform of SSB 17/1-02 is captured using portable voltage analyzer. The voltage harmonic is sampled for 10 minutes in the duration of 144 hours. The result is represented as the graph below.

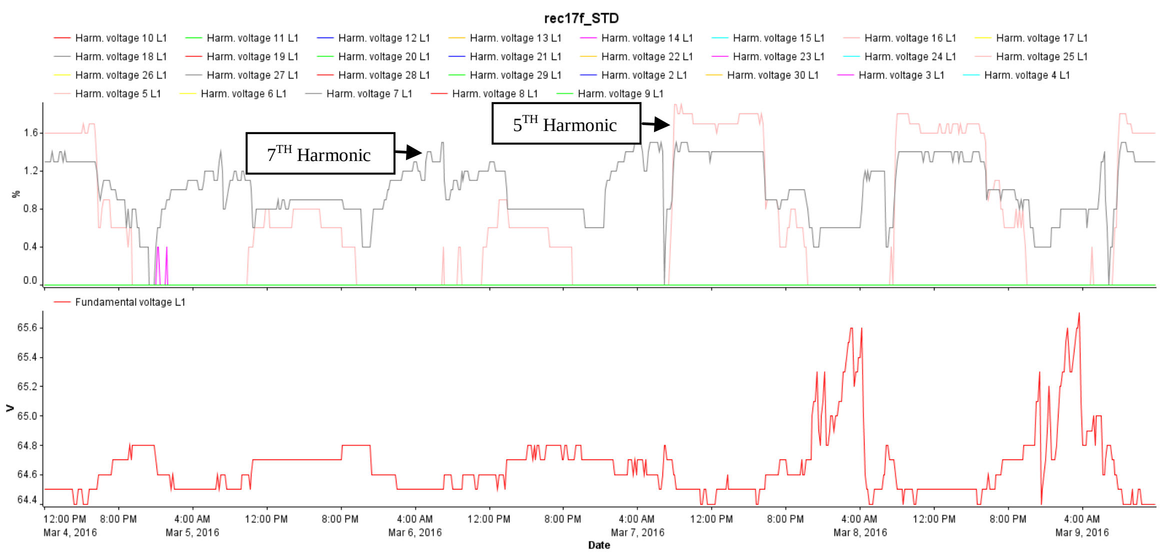

FIGURE 41 The harmonic voltage of L1

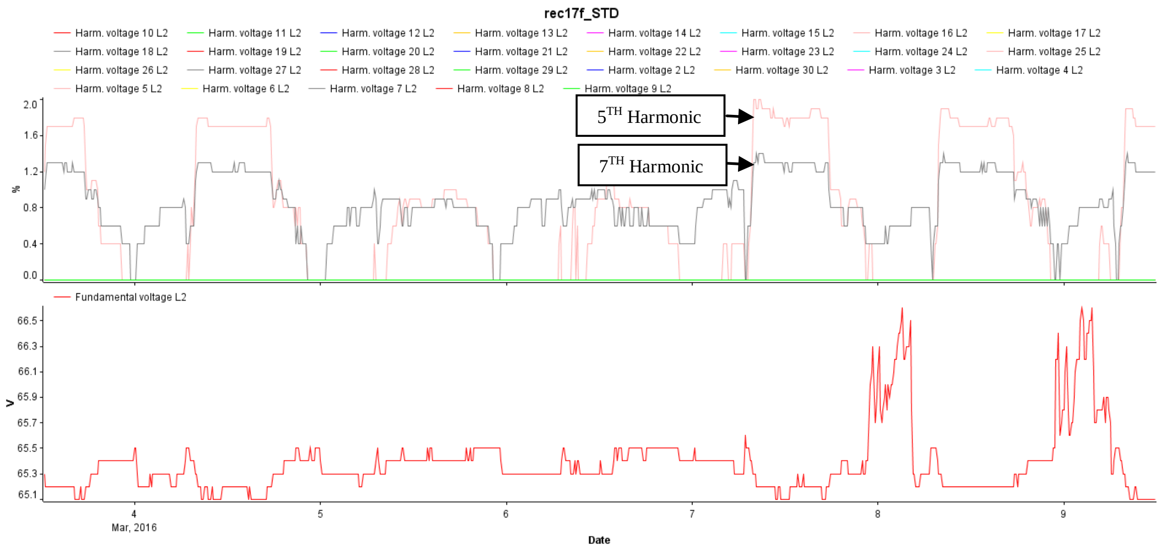

FIGURE 42 The harmonic voltage of L2

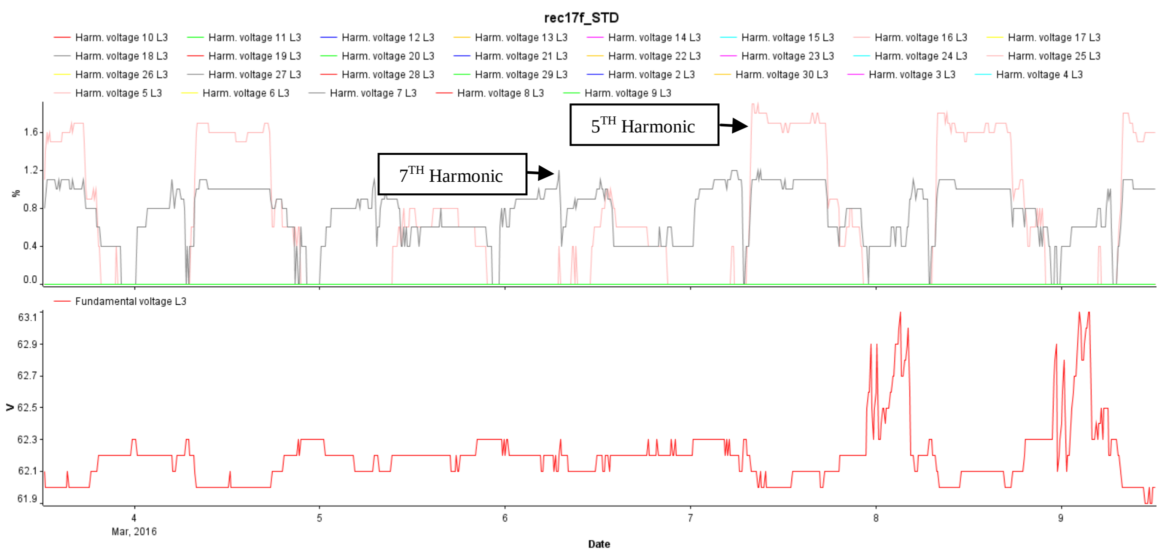

FIGURE 43 The harmonic voltage of L3

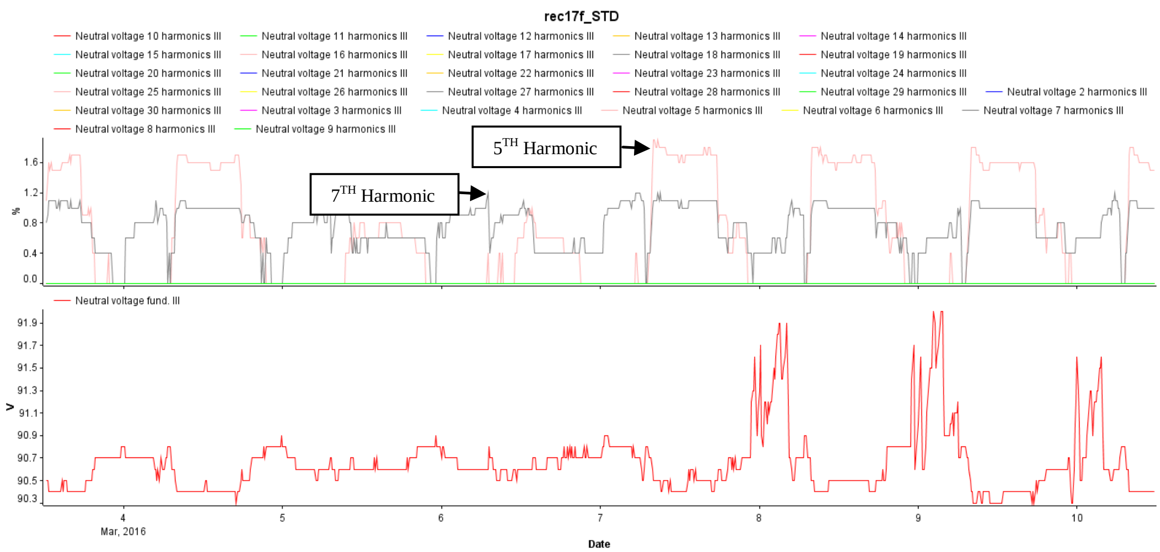

FIGURE 44 The harmonic voltage of LN

The result from the FIGURE 41 to FIGURE 44 are simplified into table below

TABLE 14 Percentage of contributed harmonics to voltage at SSB 17-01/2

Line	Most significant Harmonic (Order)	Average percentage (%)	The highest percentage (%)
L1	5^{th} Harmonic	0.65	1.90
	7^{th} Harmonic	1.03	1.50
L2	5^{th} Harmonic	0.78	2.00
	7^{th} Harmonic	0.85	1.30
L3	5^{th} Harmonic	0.65	1.90
	7^{th} Harmonic	0.75	1.10
LN	5^{th} Harmonic	0.65	1.90
	7^{th} Harmonic	0.75	1.10

From TABLE 14, it can be concluded that the harmonics that contribute to voltage waveform are from the 5^{th} and 7^{th} order harmonic. However the average and highest percentages are low and did not exceed 2.00%.

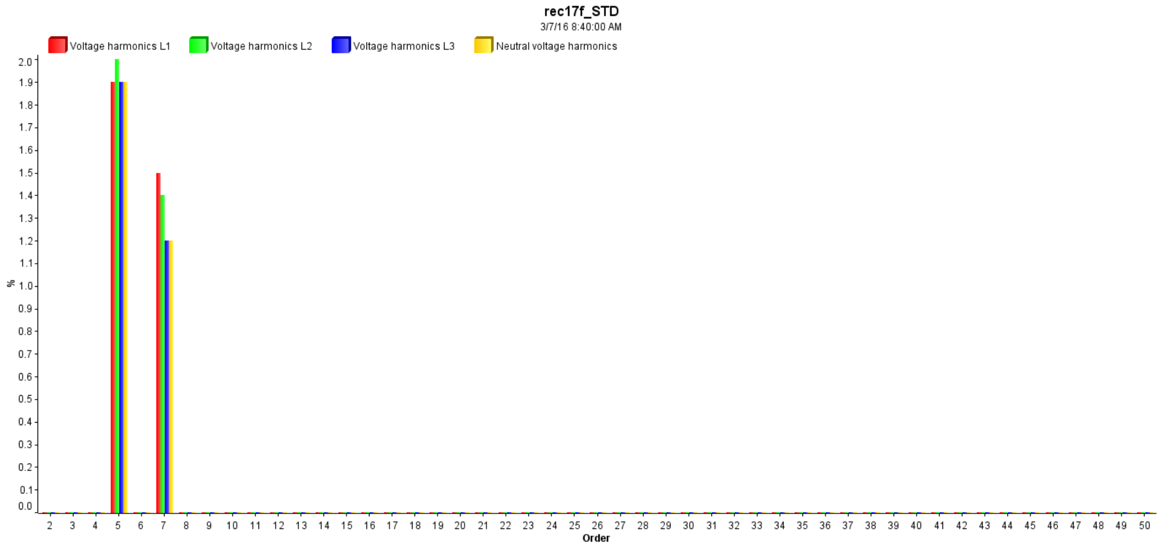

FIGURE 45 The graph that shows the highest voltage harmonic

Figure above shows the harmonic spectrum during the highest contribution of harmonic. Line 1, 2, 3 and neutral line have high 5th and 7th harmonic in the waveform.

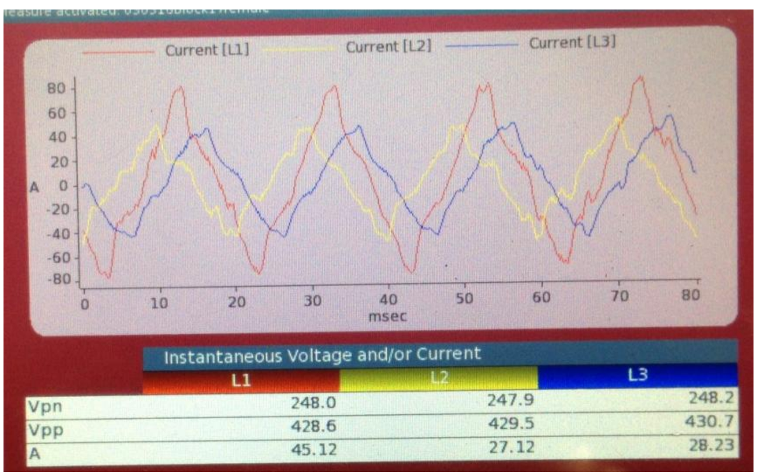

FIGURE 46 The current waveform of SSB17/1-02

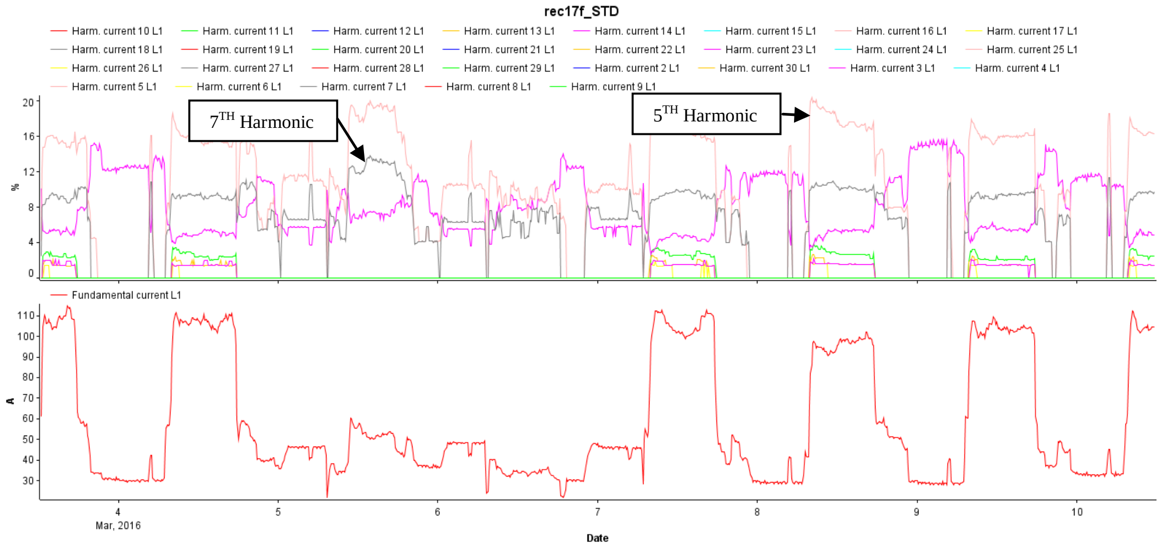

FIGURE 47 The current waveform at L1

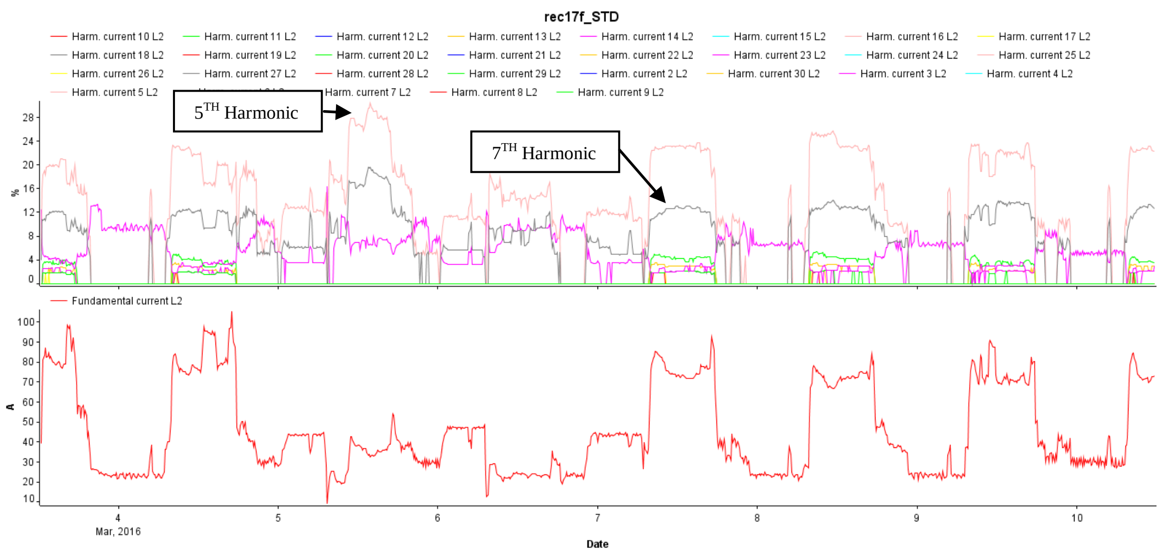

FIGURE 48 The current harmonics at L2

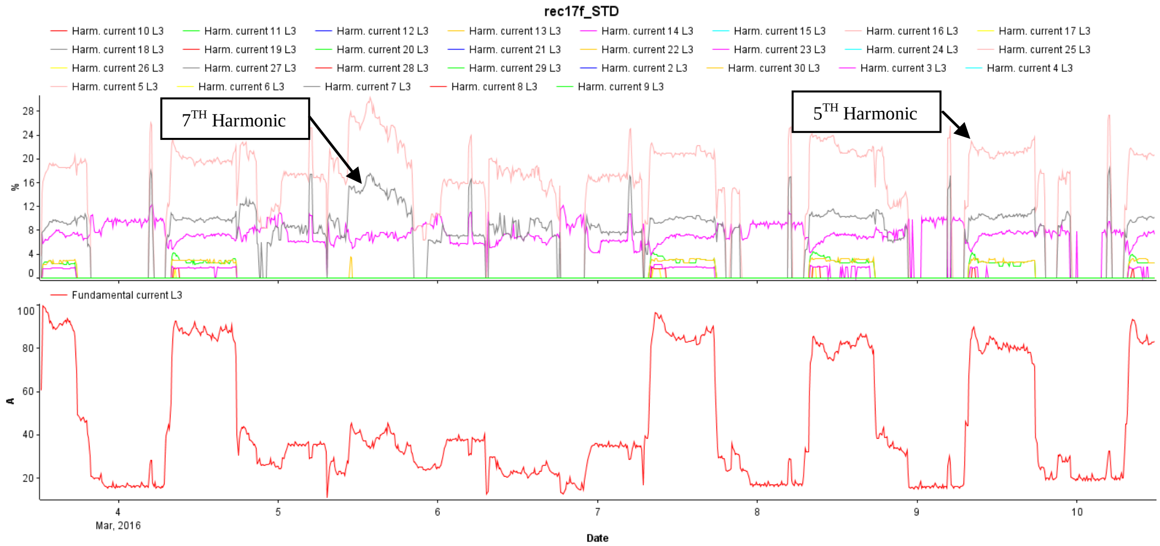

FIGURE 49 The current harmonics at L3

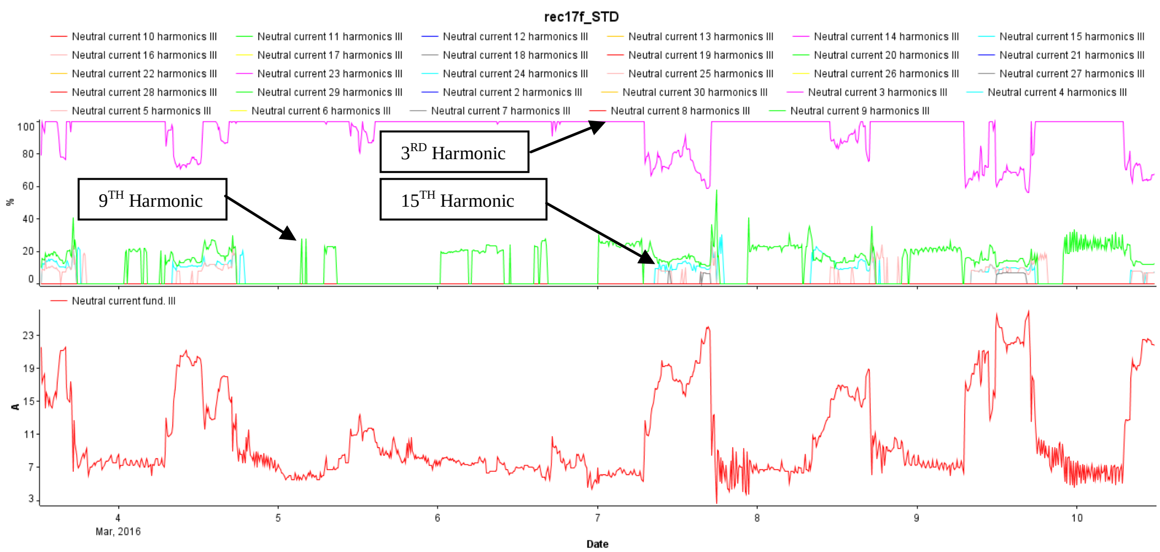

FIGURE 50 The current harmonics at LN

TABLE 15 Percentage of contributed harmonics to current at SSB 17-01/2

Line	Most significant Harmonic (Order)	Average percentage (%)	The highest percentage (%)
L1	3^{rd} Harmonic	8.09	15.30
	5^{th} Harmonic	9.90	20.40
	7^{th} Harmonic	6.26	13.80
L2	3^{rd} Harmonic	5.47	16.40
	5^{th} Harmonic	12.55	30.40
	7^{th} Harmonic	7.13	19.60
L3	3^{rd} Harmonic	7.18	12.40
	5^{th} Harmonic	13.96	30.30
	7^{th} Harmonic	7.00	18.40
LN	3^{rd} Harmonic	94.13	99.90
	9^{th} Harmonic	11.94	57.7
	15^{th} Harmonic	3.43	30.10

In current at SSB 17-01/2, 3^{rd} order, 5^{th} order and 7^{th} order of harmonic are highly contributed to the current at Line 1, Line 2 and Line 3. In the case of neutral line, odd triplen harmonics give significant effect to this line.

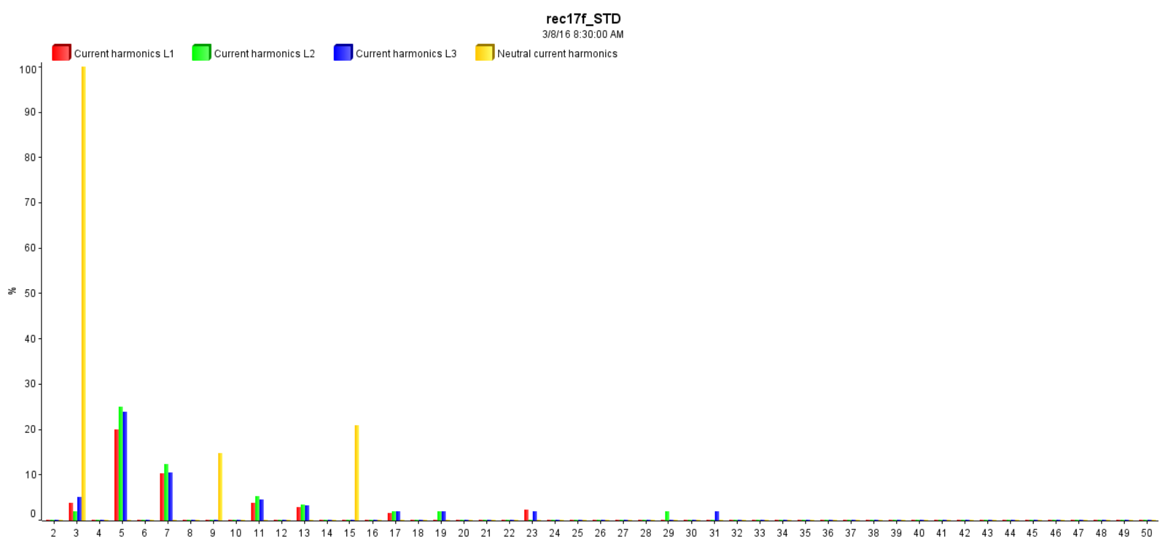

FIGURE 51 The graph that shows the highest current harmonic

Base on the observation, the odd triplen harmonics (3, 9 and 15) give huge contribution to the current harmonics at SSB 17/01-2. The percentage value of the current harmonics is reaching 100% in the neutral line. It is higher than the other line due to the triplen harmonics effect where the large currents circulate in the neutral because the per phase current is not able to cancel out each other.

SSB 22/01-1

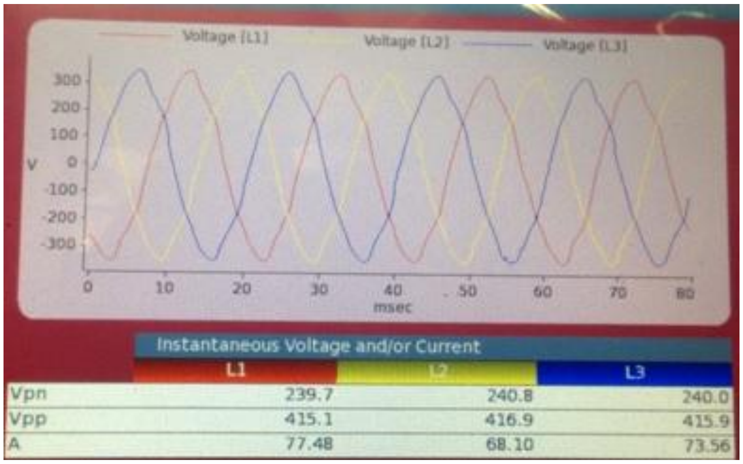

FIGURE 52 Voltage waveform at SSB 22/01-1

Figure above shows the voltage waveform of SSB 22/01-1 that had been captured at a particular time. The contain of harmonics in the waveform at every line is analysed and presented in the graphs below

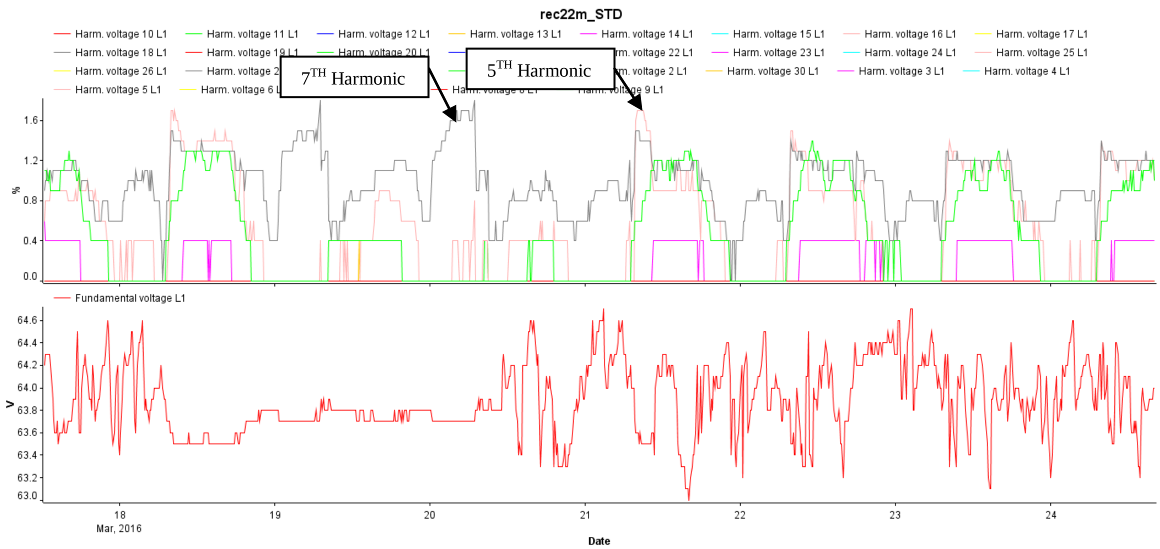

FIGURE 53 The harmonic voltage of L1

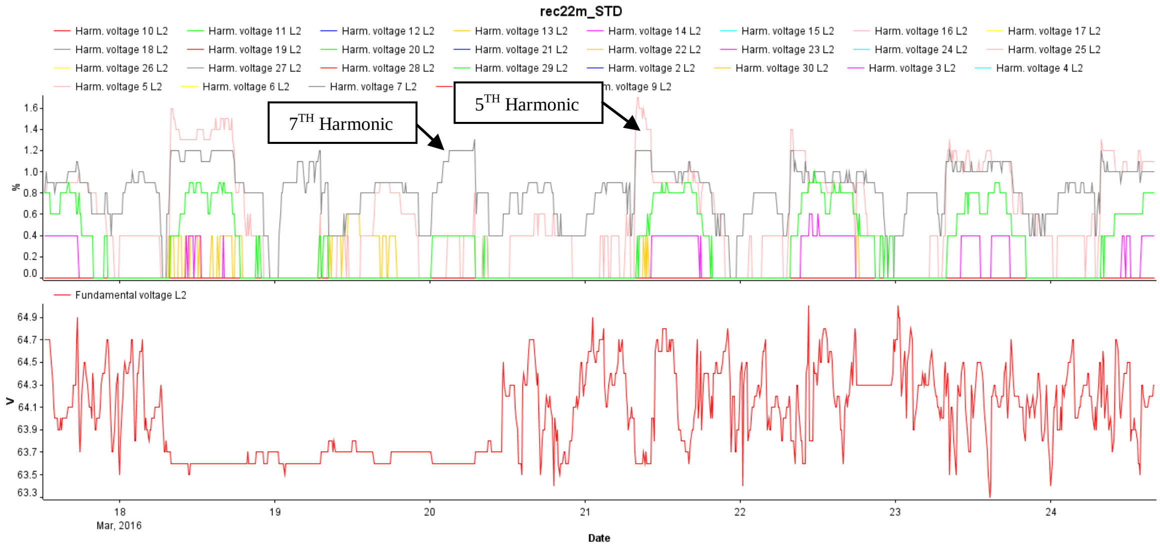

FIGURE 54 The harmonic voltage of L2

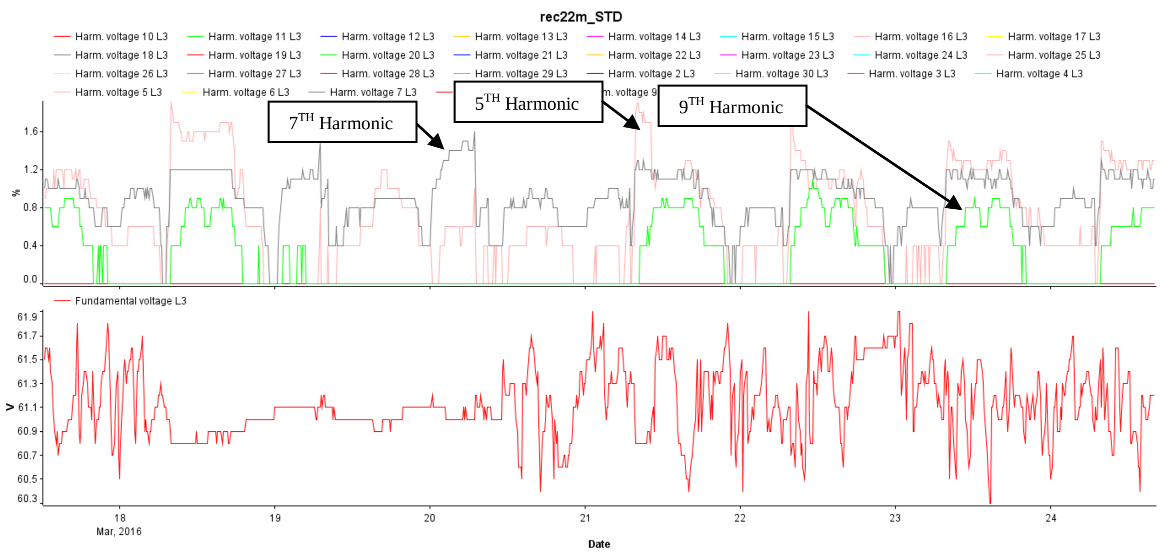

FIGURE 55 The harmonic voltage of L3

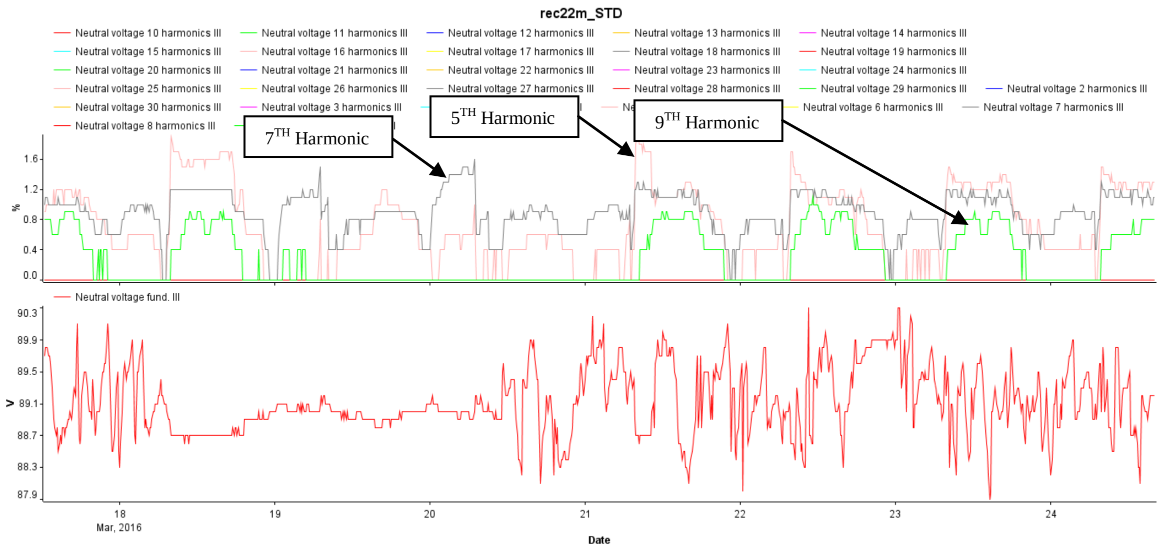

FIGURE 56 The harmonic voltage of LN

The information obtained from the graphs is summarized in the table below. The average percentage of each harmonic order is calculated and the highest percentage of harmonic is determined.

TABLE 16 Percentage of contributed harmonics to voltage at SSB 22-01/1

Line	Most significant Harmonic (Order)	Average percentage (%)	The highest percentage (%)
L1	5th Harmonic	0.53	1.7
	7th Harmonic	0.98	1.8
L2	5th Harmonic	0.56	1.7
	7th Harmonic	0.81	1.3
L3	5th Harmonic	0.71	1.9
	7th Harmonic	0.89	1.6
	9th Harmonic	0.26	1.1
LN	5th Harmonic	0.71	1.9
	7th Harmonic	0.89	1.6
	9th Harmonic	0.26	1.1

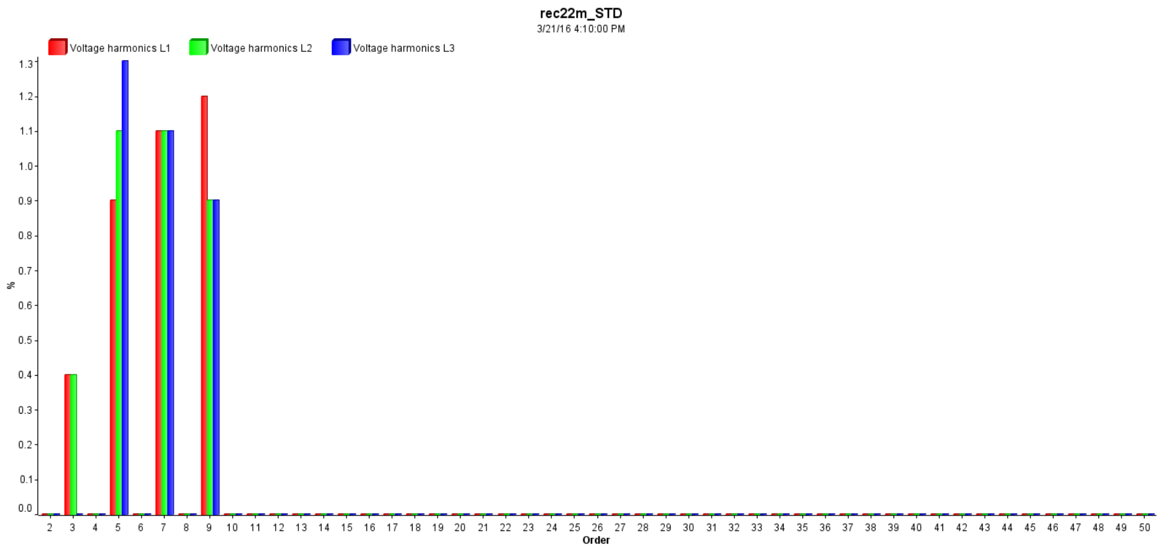

FIGURE 57 The graph that shows the highest voltage harmonic

The graph in the figure above shows the voltage harmonic spectrum that had been captured during the highest amount of harmonic present in the voltage waveform.

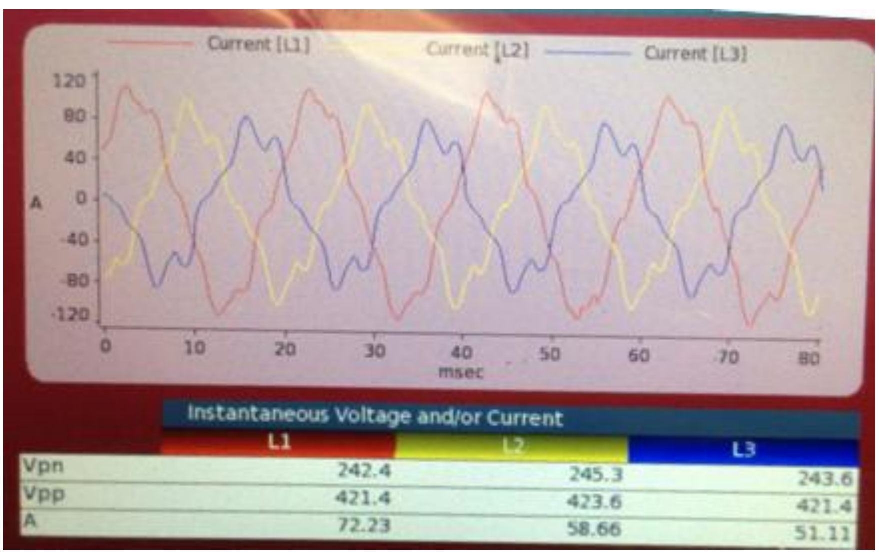

FIGURE 58 The current waveform of SSB22/01-1

The harmonic that causes the current waveform to lose it sinusoidal shape is analysed using PowerVision Plus software. The graph obtained from the analysis is presented as below:

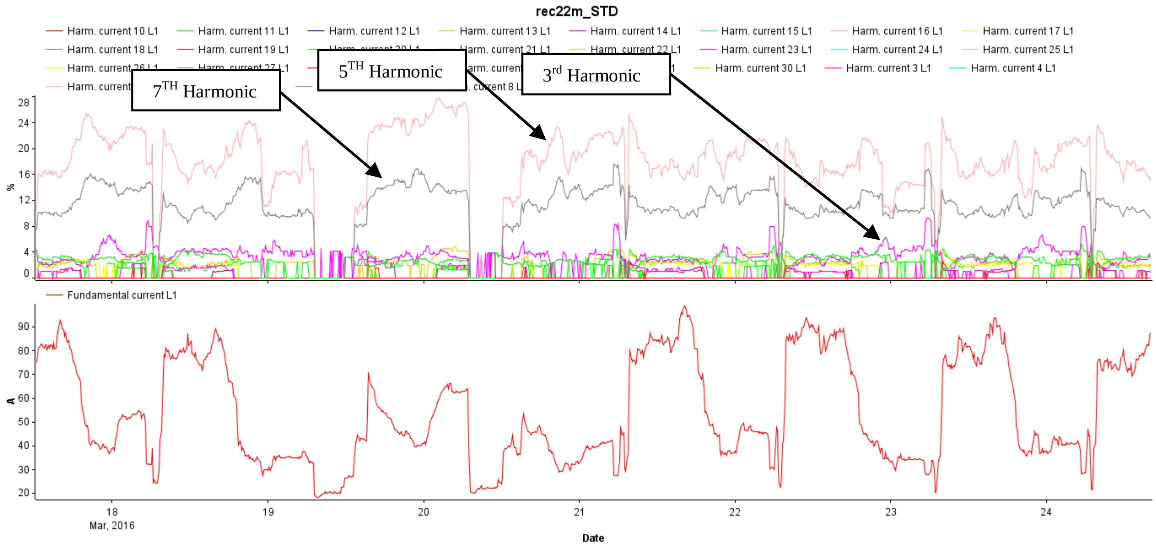

FIGURE 59 The current waveform at L1

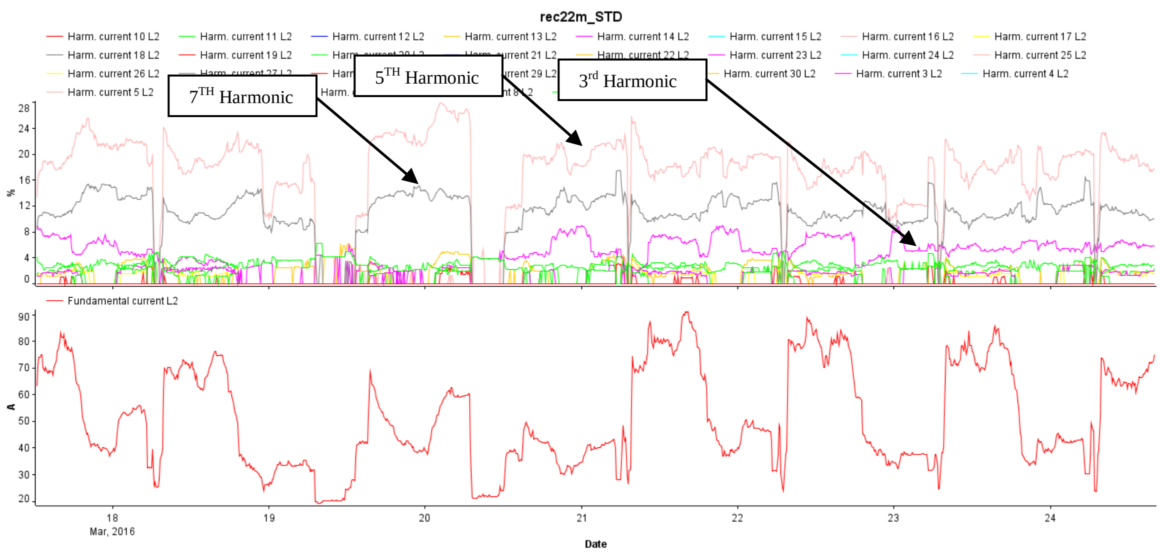

FIGURE 60 The current waveform at L2

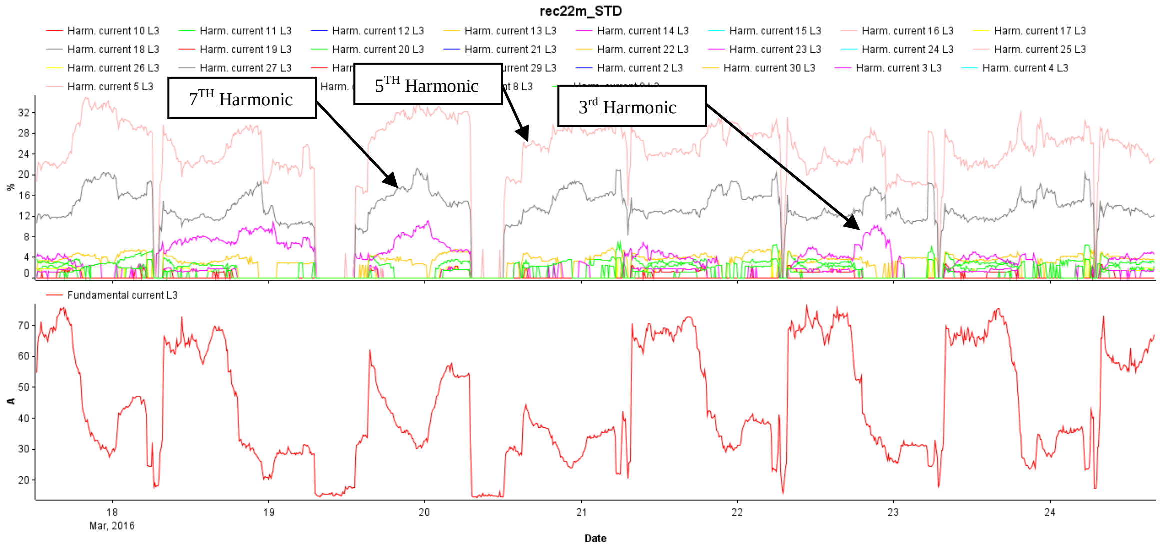

FIGURE 61 The current waveform at L3

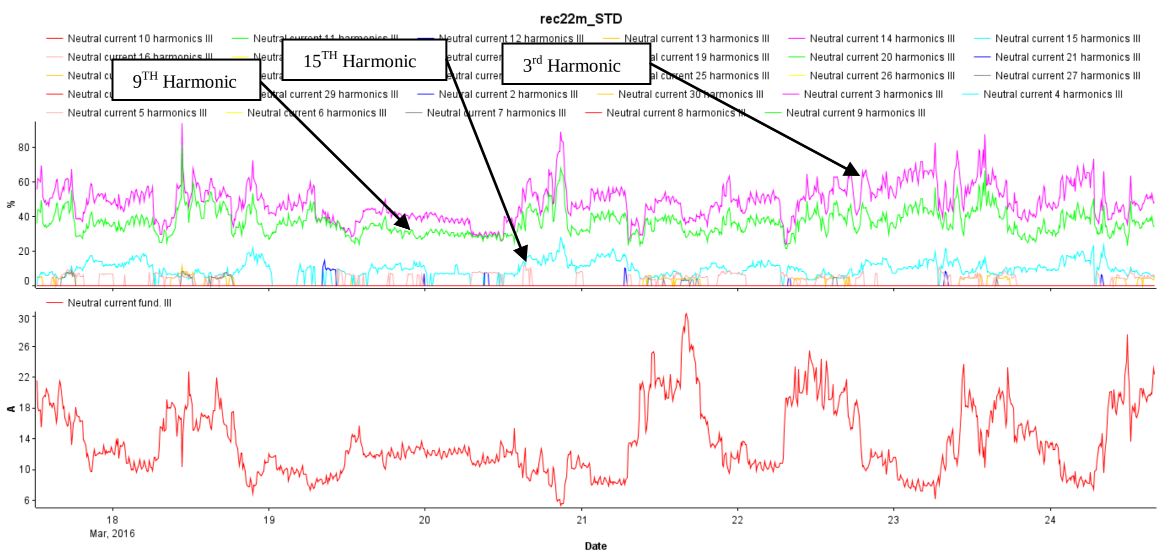

FIGURE 62 The current waveform at LN

The information obtained from the graphs is summarized in the table below. The average percentage of each harmonic order is calculated and the highest percentage of harmonic is determined.

TABLE 17 Percentage of contributed harmonics to current at SSB 22-01/1

Line	Most significant Harmonic (Order)	Average percentage (%)	The highest percentage (%)
L1	3^{rd} Harmonic	3.35	9.30
	5^{th} Harmonic	17.33	27.90
	7^{th} Harmonic	10.88	17.60
L2	3^{rd} Harmonic	4.62	9.00
	5^{th} Harmonic	17.43	27.90
	7^{th} Harmonic	10.71	17.50
L3	3^{rd} Harmonic	3.39	11.10
	5^{th} Harmonic	23.85	35.00
	7^{th} Harmonic	12.98	21.20
LN	3^{rd} Harmonic	48.76	93.9
	9^{th} Harmonic	36.81	81.00
	15^{th} harmonic	9.44	27.70

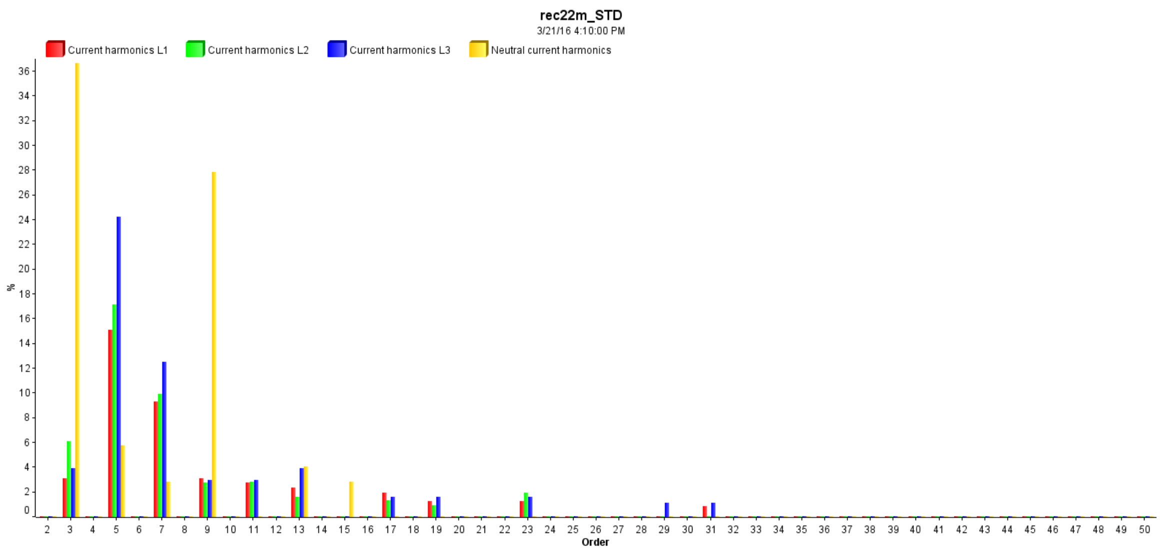

FIGURE 63 The graph that shows the highest current harmonic

SSB 22/01-2

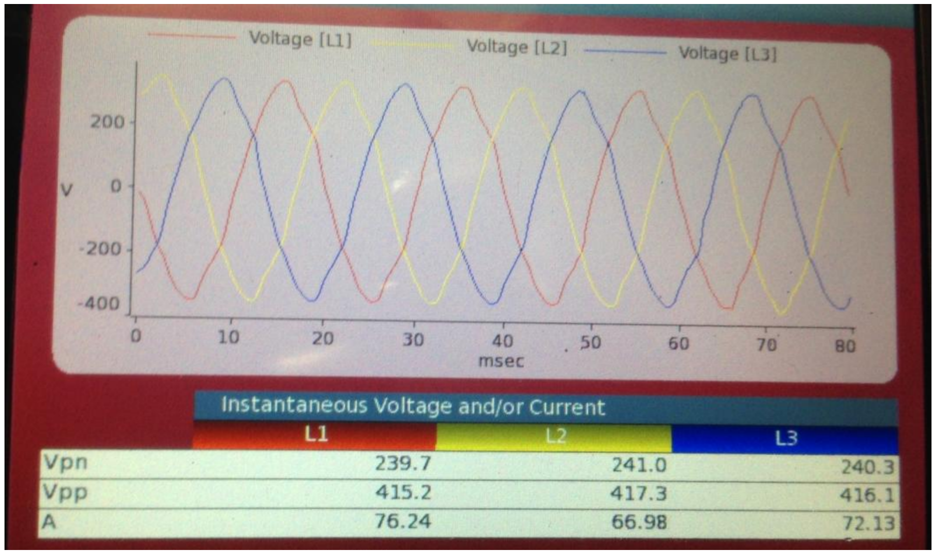

FIGURE 64 Voltage waveform at SSB 22/01-2

Figure above shows the voltage waveform at SSB 22/01-2 which had almost perfect sinusoidal shape. Base on the shape waveform, it can be conclude that the percentage of harmonics that give significant effect is low. Futher analysis is done by measuring the present of harmonic using portable power analyser. The results is shown below.

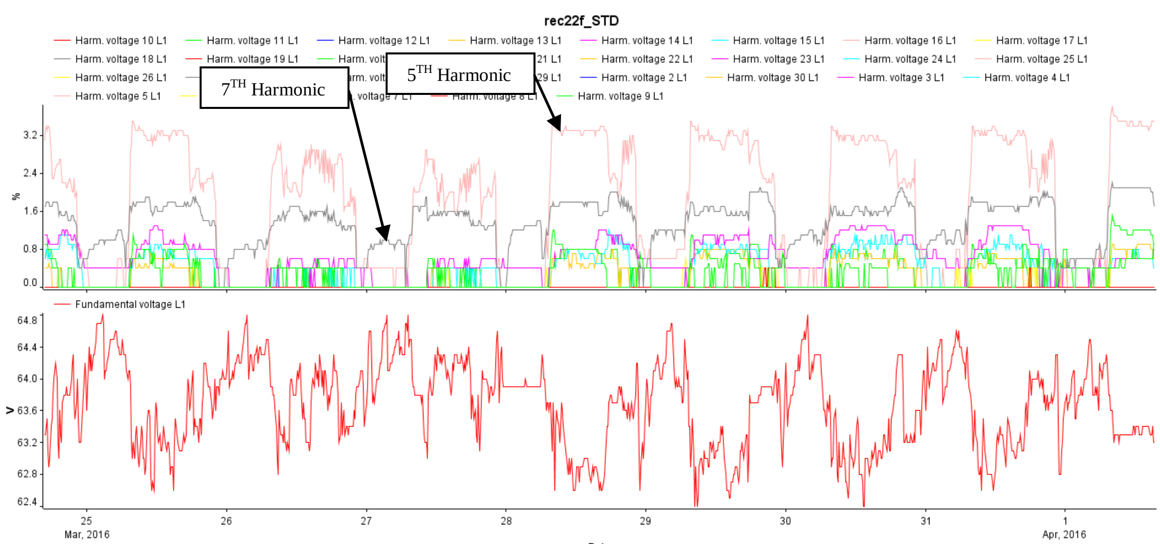

FIGURE 65 The harmonic voltage of L1

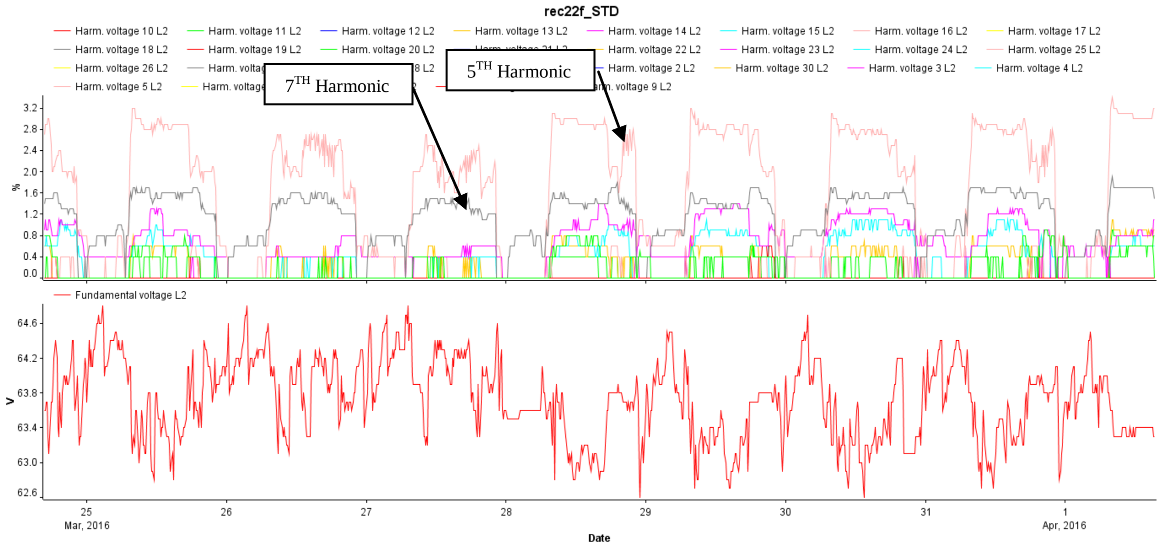

FIGURE 66 The harmonic voltage of L2

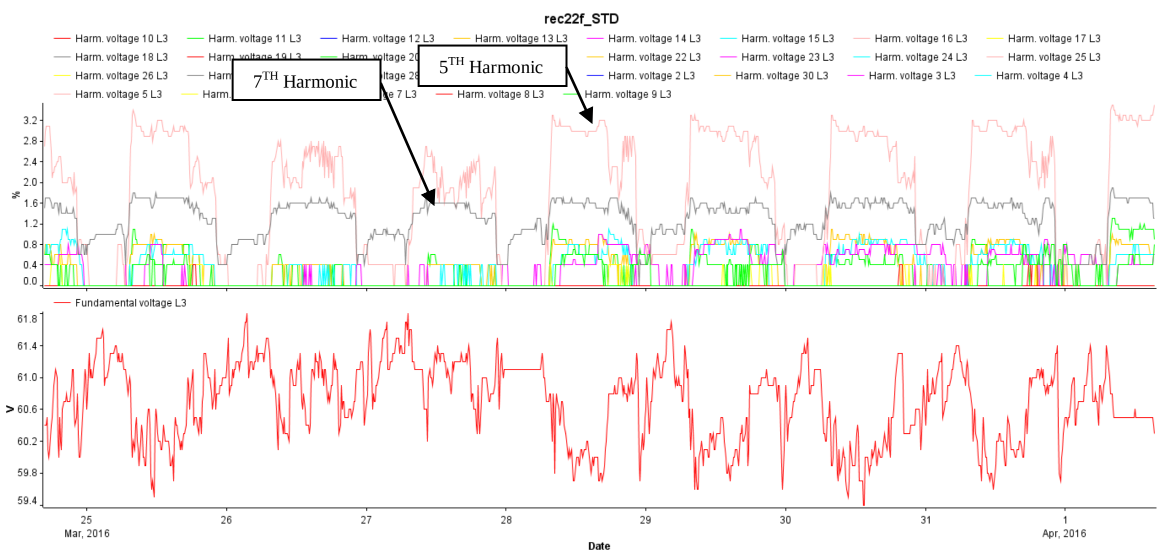

FIGURE 67 The harmonic voltage of L3

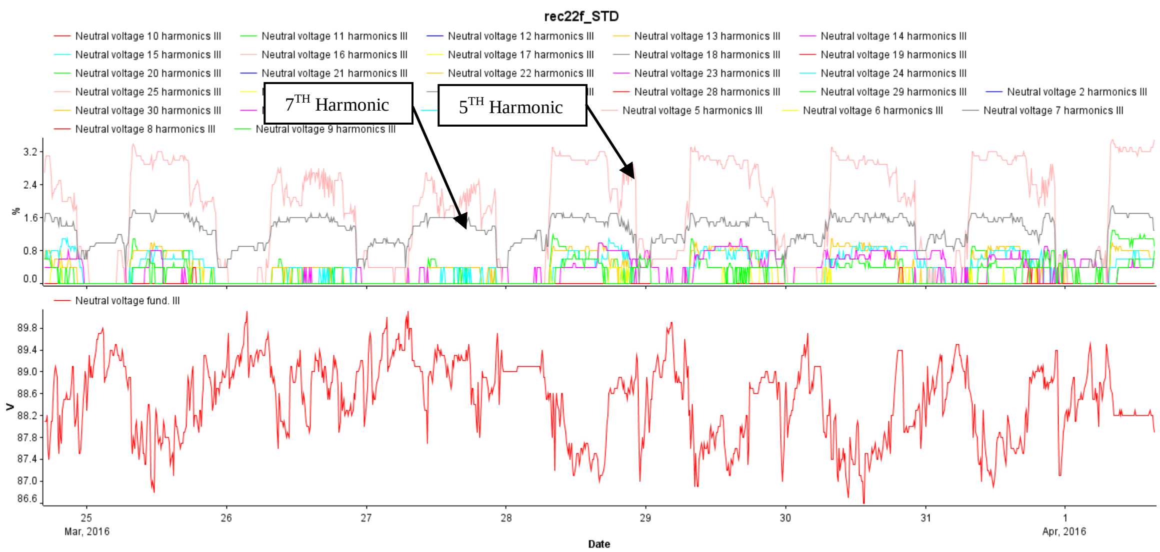

FIGURE 68 The harmonic voltage of LN

The analysis is simplified by tabulating the percentage of present harmonic in the table below.

TABLE 18 Percentage of contributed harmonics to voltage at SSB 22-01/2

Line	Most significant Harmonic (Order)	Average percentage (%)	The highest percentage (%)
L1	5^{th} Harmonic	1.85	3.80
	7^{th} Harmonic	1.36	2.20
L2	5^{th} Harmonic	1.70	3.40
	7^{th} Harmonic	1.14	1.90
L3	5^{th} Harmonic	1.77	3.50
	7^{th} Harmonic	1.28	1.90
LN	5^{th} Harmonic	1.77	3.5
	7^{th} Harmonic	1.28	1.90

Base on the table, the average percentage of the 5^{th} order and 7^{th} harmonic in every line does not exceed 2.00%. The low significant amount of harmonic causes the waveform to maintain its shape in sinusoidal.

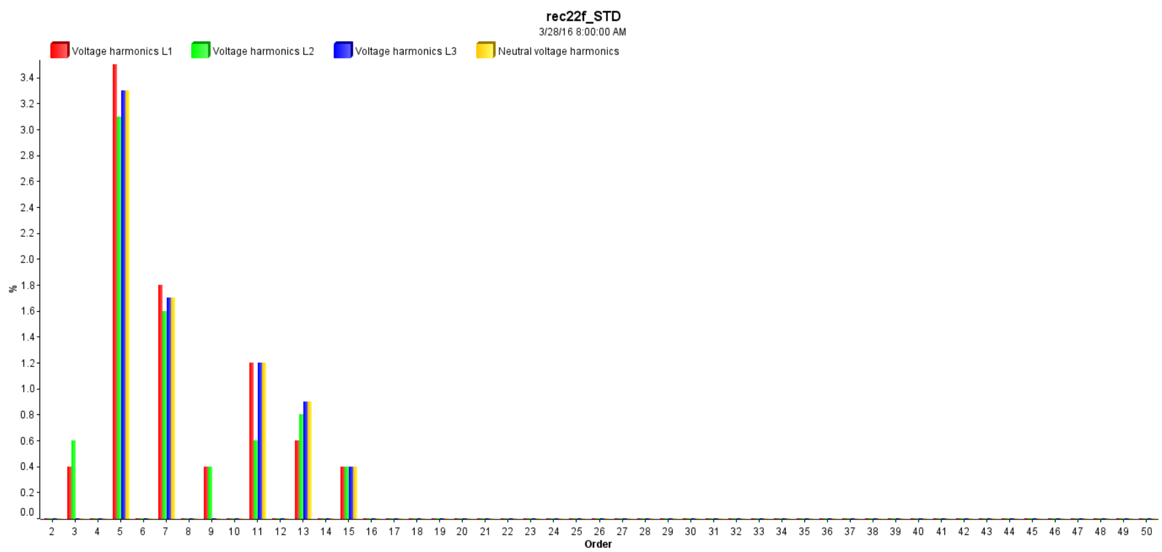

FIGURE 69 The graph that shows the highest voltage harmonic

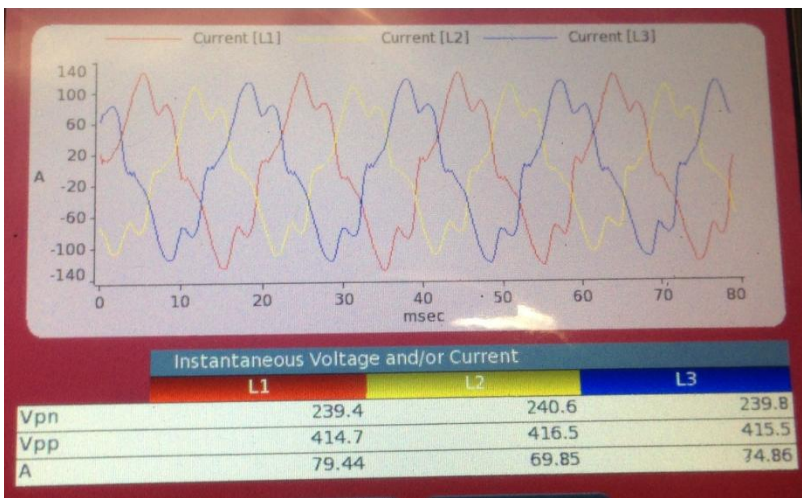

FIGURE 70 The current waveform of SSB22/1-02

Figure above shows the current waveform that has lost its sinusoidal shape due to the present of certain order of harmonic. The analysis of the waveform is continued and is presented in the graphs below:

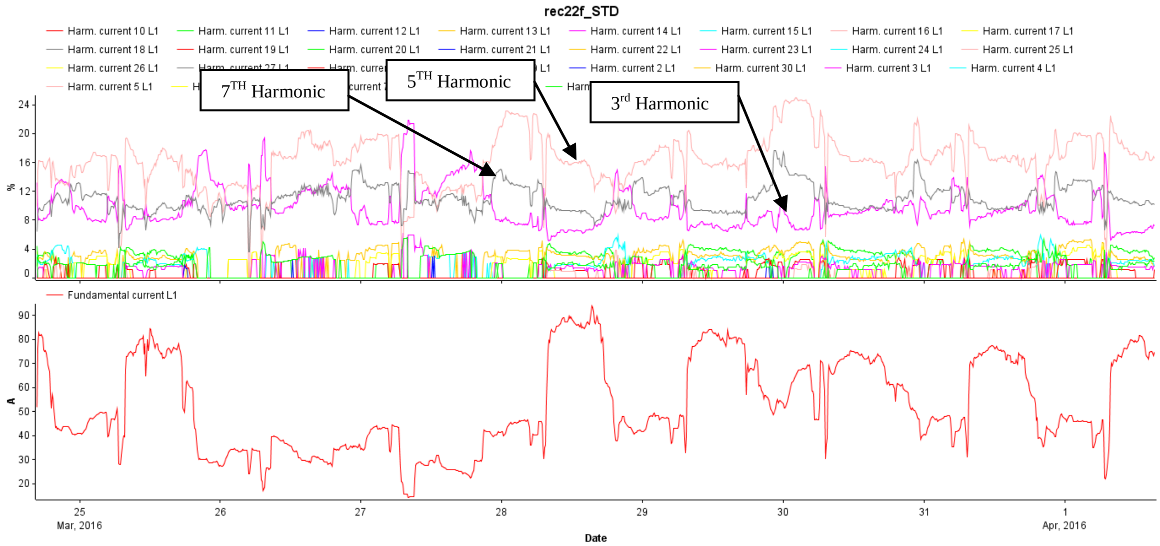

FIGURE 71 The current harmonic at L1

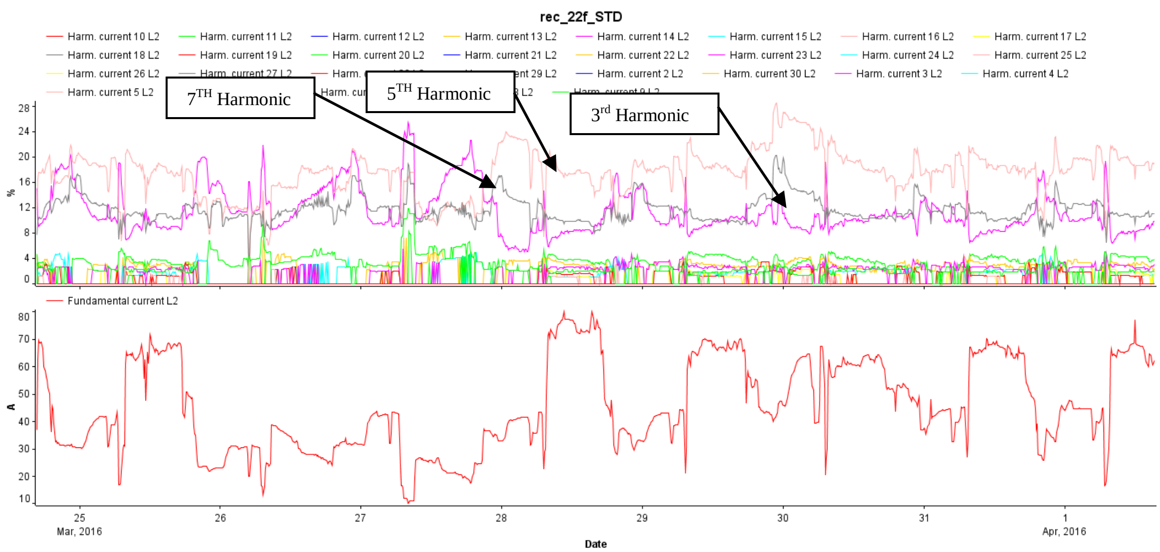

FIGURE 72 The current harmonic at L2

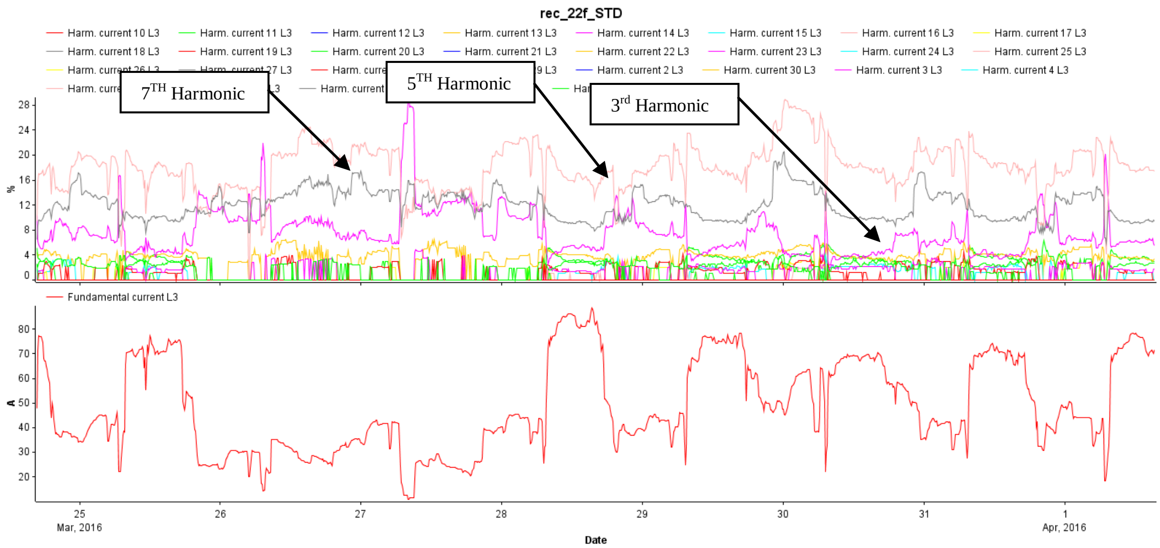

FIGURE 73 The current harmonic at L3

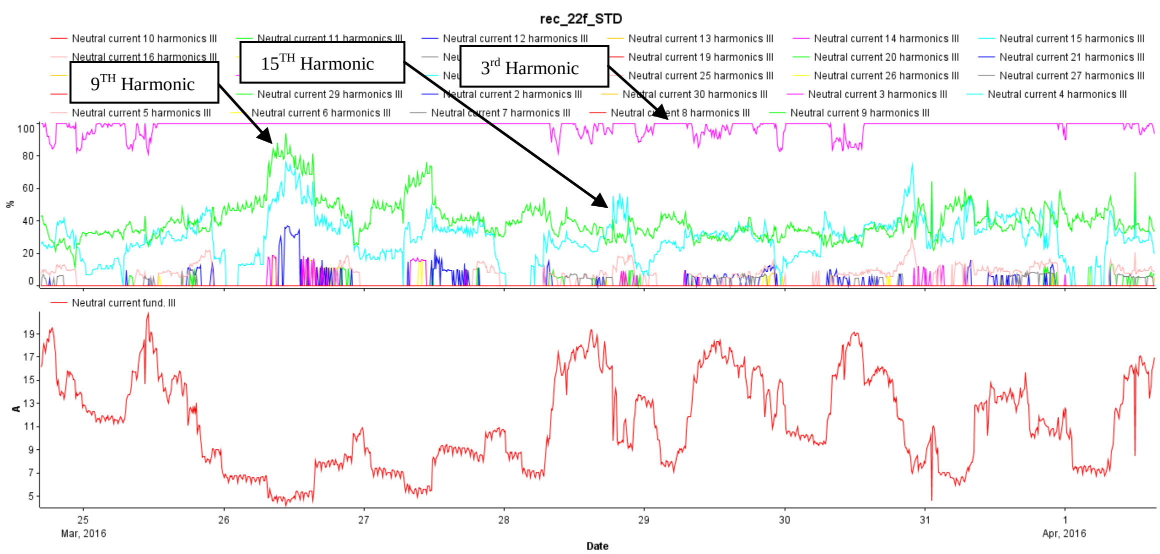

FIGURE 74 The current harmonic at LN

The percentage of the harmonic that has significant effect is tabulated in the table below:

TABLE 19 Percentage of contributed harmonics to current at SSB 22-01/2

Line	Most significant Harmonic (Order)	Average percentage (%)	The highest percentage (%)
L1	3rd Harmonic	9.70	21.90
	5th Harmonic	16.31	25.00
	7th Harmonic	10.99	17.6
L2	3rd Harmonic	11.42	25.40
	5th Harmonic	17.52	28.50
	7th Harmonic	11.67	20.3
L3	3rd Harmonic	7.57	28.90
	5th Harmonic	18.03	28.90
	7th Harmonic	11.98	20.50
LN	3rd Harmonic	98.25	99.90
	9th Harmonic	40.20	93.50
	15th Harmonic	28.66	76.20

In current waveform, the percentage of harmonic is very high especially in the neutral line. The percentage value of the current harmonics is reaching 100% in the neutral line. It is higher than the other line due to the triplen harmonics effect where the large currents circulate in the neutral because the per phase current is not able to cancel out each other.

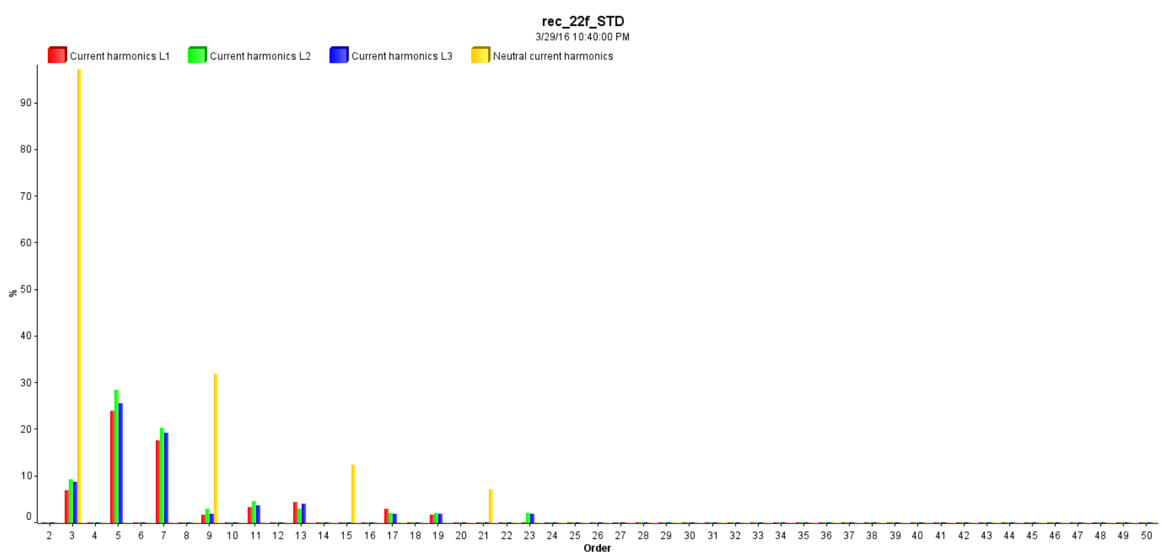

FIGURE 75 The graph that shows the highest current harmonic

SSB 05/01-1

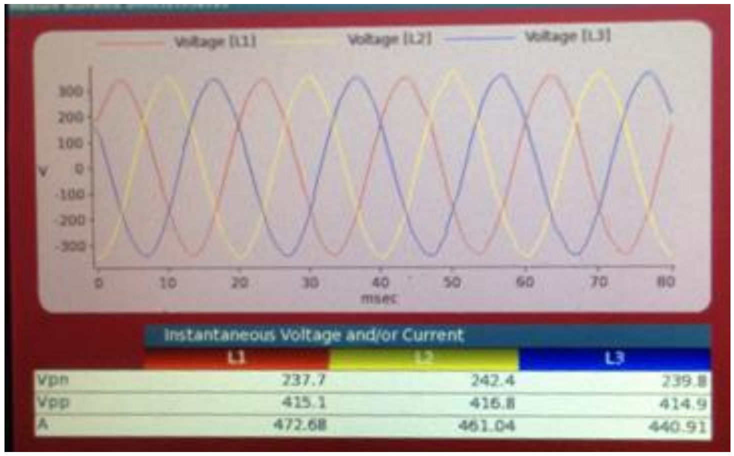

FIGURE 76 The voltage waveform of SSB05/01-1

The voltage waveform of SSB05/01-1 is shown in figure above. The shape of the waveform is almost pure sinusoidal. The small conclusion that can be drawn from this figure is that, the percentage of harmonic in the current waveform is very small. Further analysis is then conducted to confirm this condition.

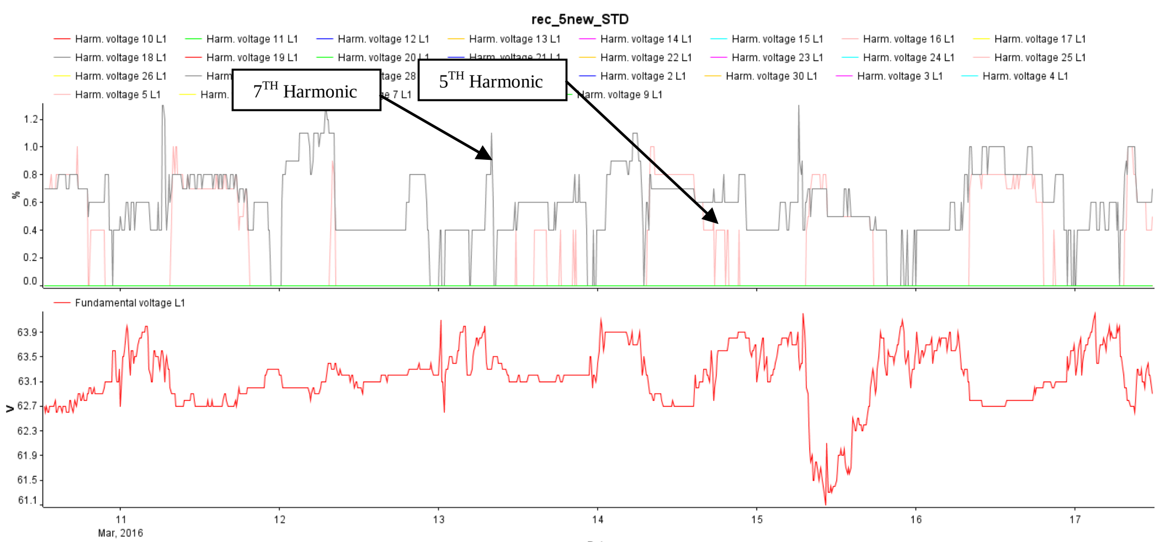

FIGURE 77 The voltage harmonic at L1

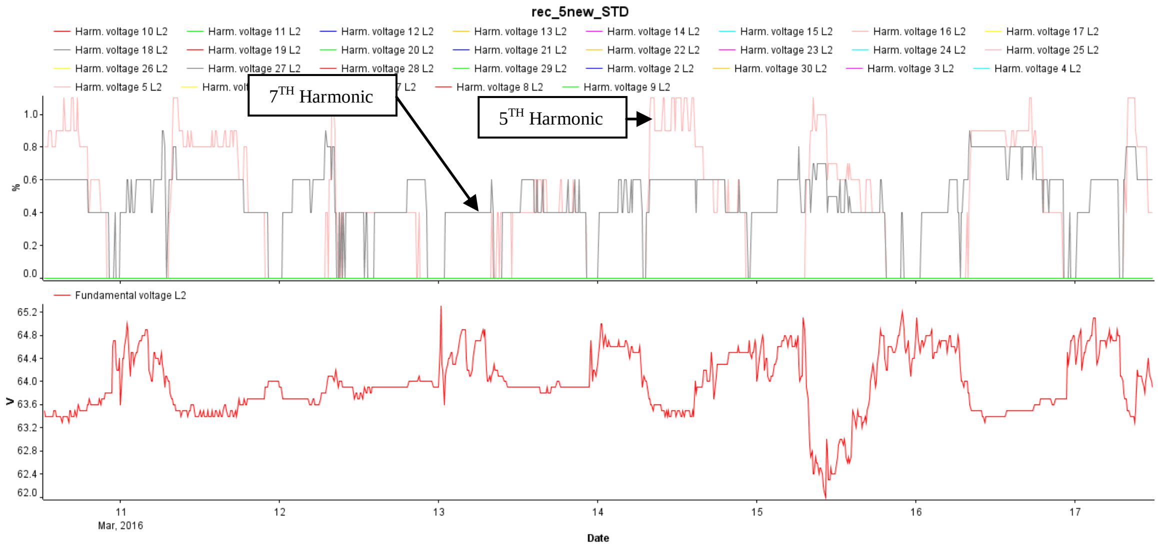

FIGURE 78 The voltage harmonic at L2

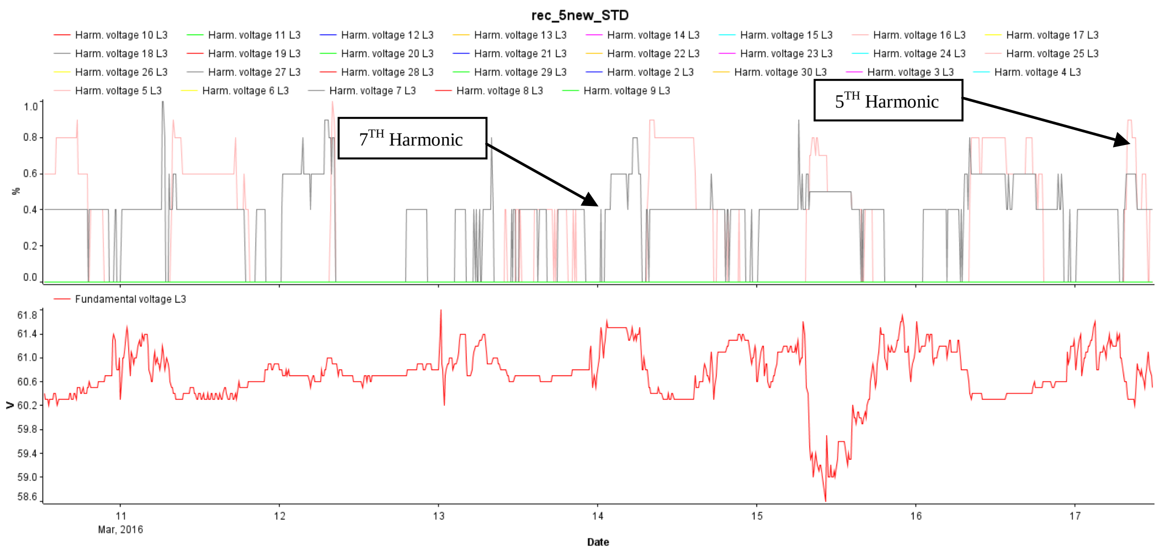

FIGURE 79 The voltage harmonic at L3

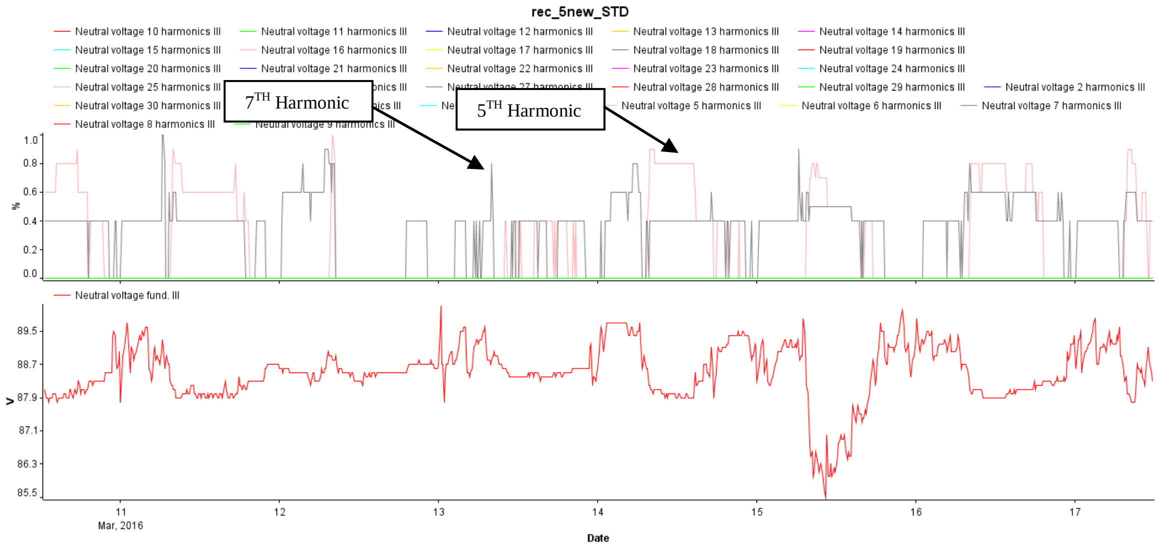

FIGURE 80 The voltage harmonic at LN

Base on the graph above, the most participating harmonics in all lines are from 5th and 7th order. However, the percentage is very small. The highest percentage as well as the average percentage of harmonic per line is determined and tabulated in the table below:

TABLE 20 Percentage of contributed harmonics to voltage at SSB 05-01/1

Line	Most significant Harmonic (Order)	Average percentage (%)	The highest percentage (%)
L1	5th Harmonic	0.24	1.00
	7th Harmonic	0.59	1.30
L2	5th Harmonic	0.38	1.10
	7th Harmonic	0.47	0.90
L3	5th Harmonic	0.23	1.00
	7th Harmonic	0.34	1.00
LN	5th Harmonic	0.23	1.00
	7th Harmonic	0.34	1.00

Base on the analysis that had been tabulated in the table above, it shows that the highest harmonic percentage is 1.3% which comes from the 7th order harmonic in Line 1 (L1). Since the percentage is very small, it does not give effect to the shape of the waveform.

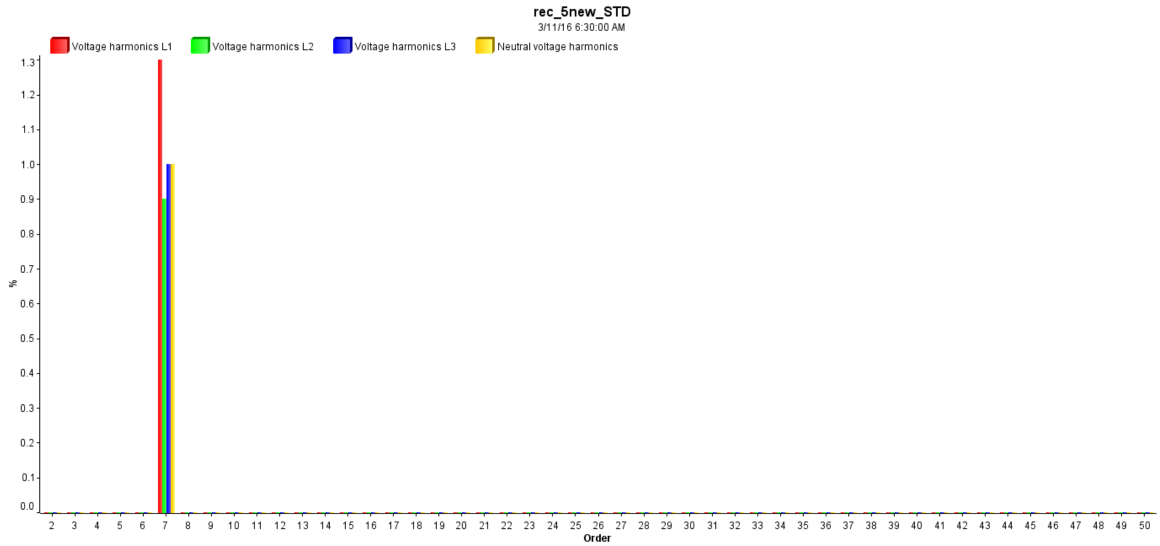

FIGURE 81 The graph that shows the highest voltage harmonic

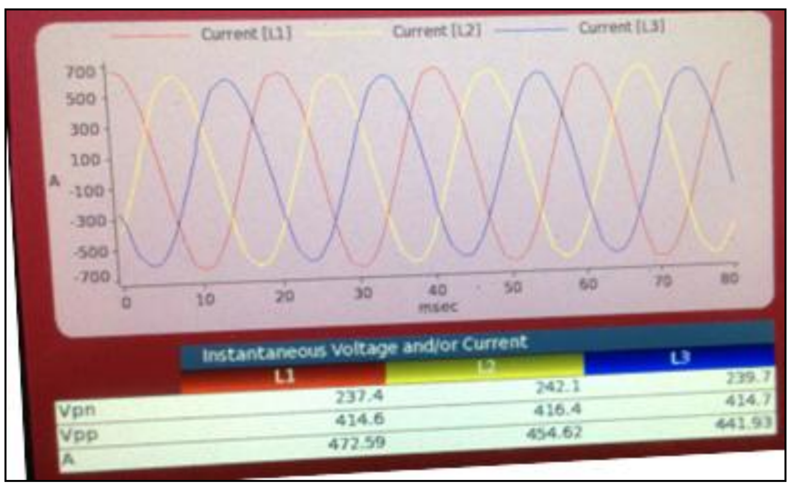

FIGURE 82 The current waveform of SSB 05/01-1

In figure above shows the current waveform at SSB 05/01-1. The current in Line 1, Line 2 and Line 3 seem to contain less percentage of harmonic since the shape is still in sinusoidal. The analysis is then continue and presented in the graph below:

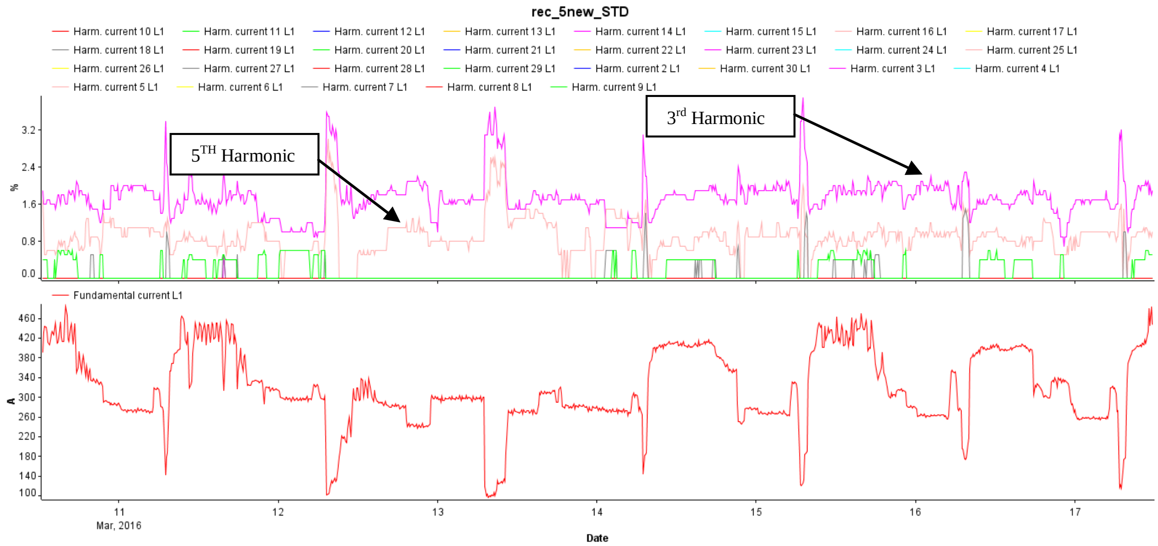

FIGURE 83 The current harmonic at L1

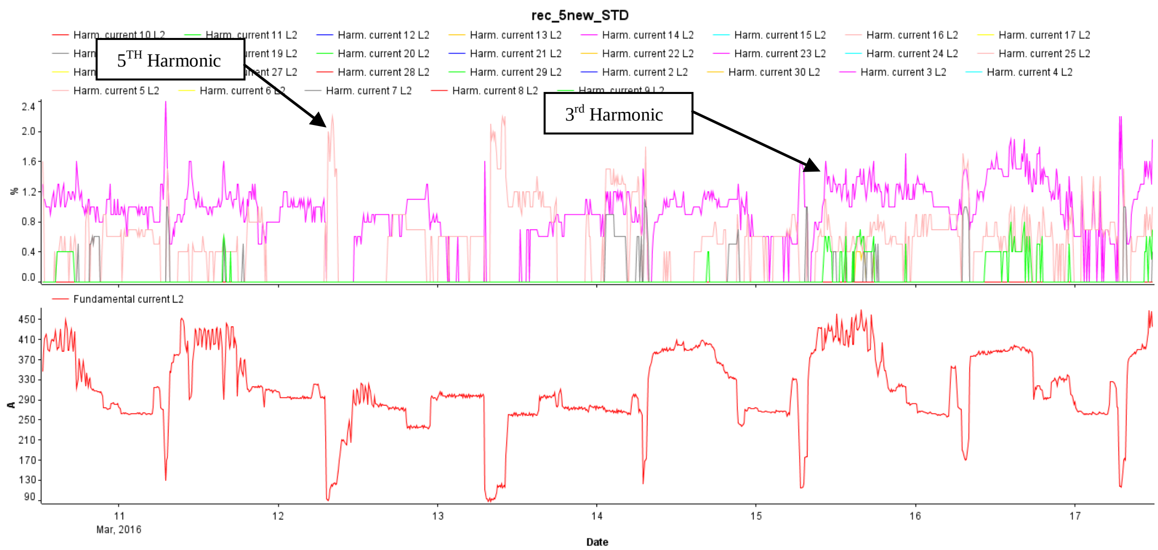

FIGURE 84 The current harmonic at L2

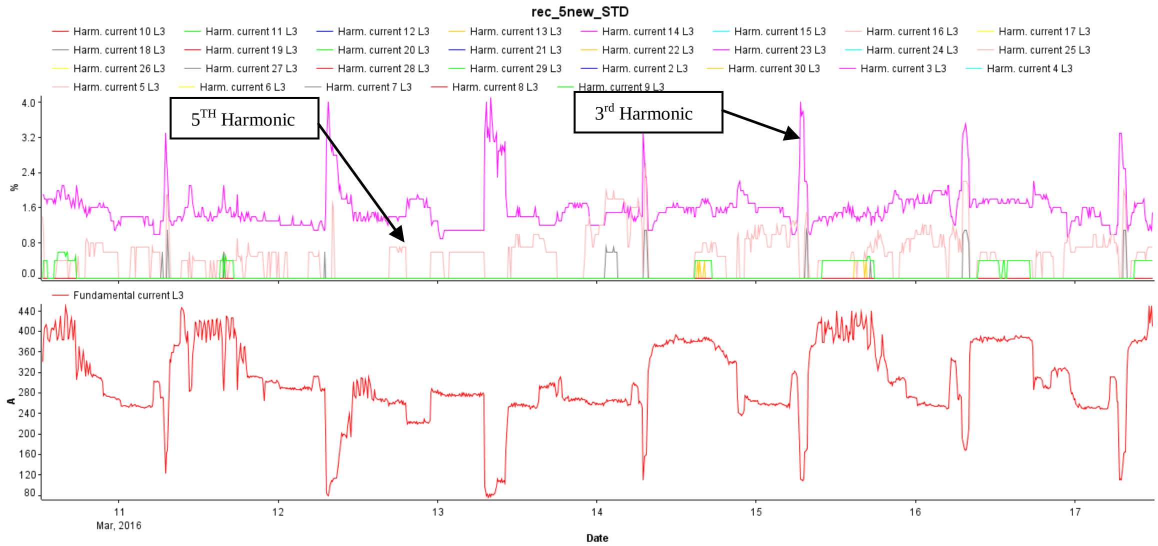

FIGURE 85 The current harmonic at L3

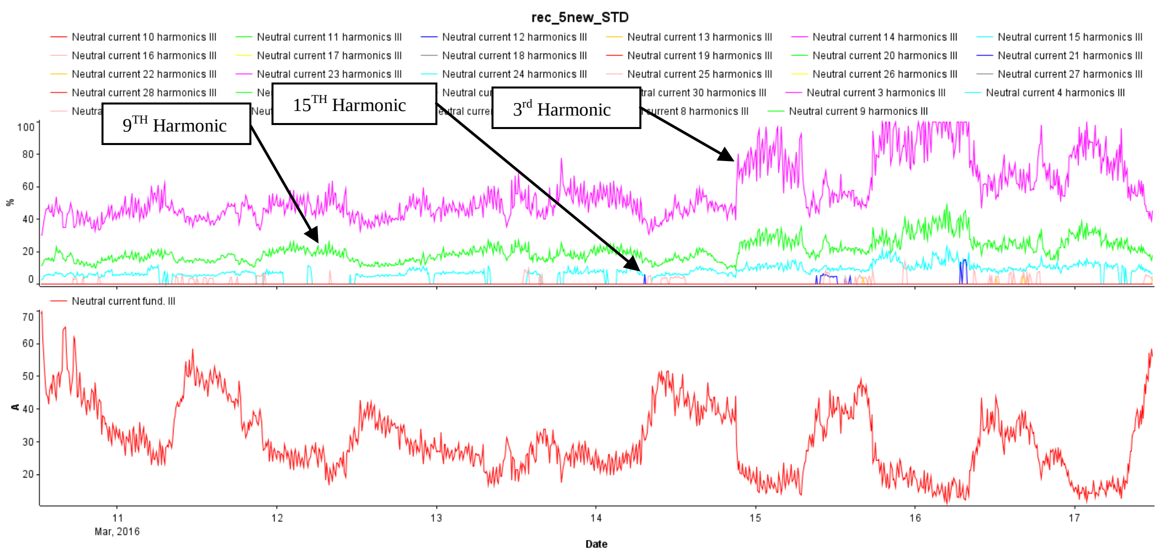

FIGURE 86 The current harmonic at LN

The data obtained from the graphs above are tabulated in the table below. The average harmonic percentage and the highest harmonic percentage are analysed.

TABLE 21 Percentage of contributed harmonics to current at SSB 05-01/1

Line	Most significant Harmonic (Order)	Average percentage (%)	The highest percentage (%)
L1	3^{rd} Harmonic	1.75	3.90
	5^{th} Harmonic	0.90	3.00
L2	3^{rd} Harmonic	0.90	2.40
	5^{th} Harmonic	0.52	2.20
L3	3^{rd} Harmonic	1.58	4.10
	5^{th} Harmonic	0.50	2.60
LN	3^{rd} Harmonic	56.20	99.90
	9^{th} Harmonic	20.48	49.30
	15^{th} Harmonic	7.23	23.20

Base on the analysis, in Line 1, Line 2 and Line 3 the percentage of 3^{rd} and 5^{th} harmonic are very small. Therefore, it does not really give significant effect to the waveform. However, in the neutral line, the odd triplen harmonics give high significant to the waveform with the percentage of 3^{rd} harmonic is almost reaching 100%.

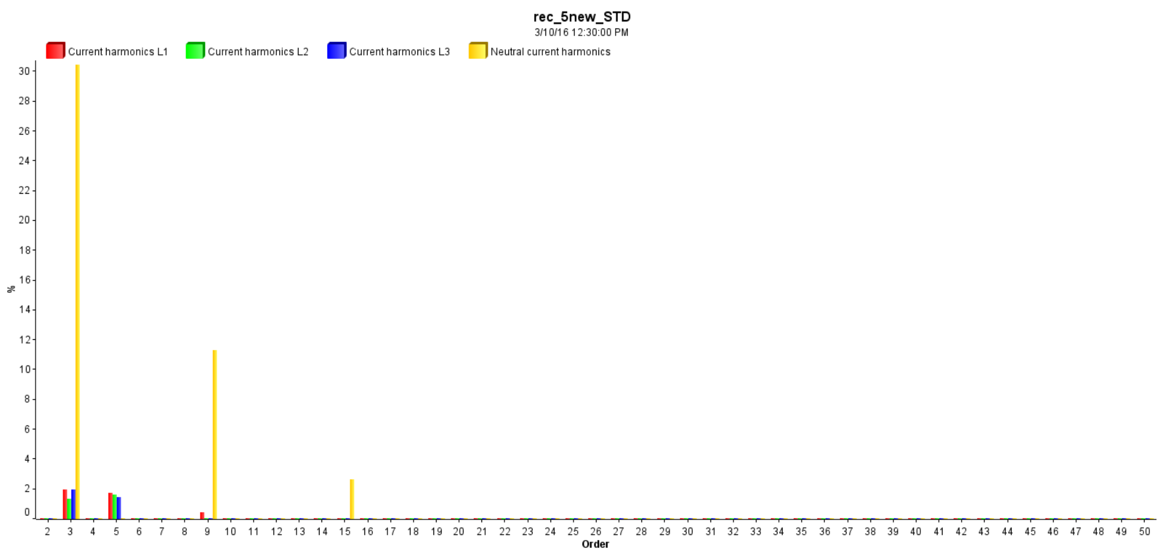

FIGURE 87 The graph that shows the highest current harmonic

The current harmonic spectrum above shows the condition where harmonics did not contribute high percentage in Line 1, Line 2, and Line 3. In contrast, the triplen harmonics are significant in the neutral line.

Base on the analysis of the five SSB, it can be summarize that in voltage waveform 5th order and 7th order harmonic usually present in all lines including the neutral line. However the percentages of harmonic are low.

On the other hand, in current waveform, usually the 5th and 7th harmonics only available at Line 1, Line 2 and Line 3 with larger percentage as compare to voltage waveform. Usually, the 3rd harmonic present in all lines and the odd triplen harmonic are dominating with the percentage reaching 100% of the fundamental current in the neutral line.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

In this project, there are three objectives that need to be achieved. The first one is to model and simulate UTP new building network by using Matlab Simulink. This objective is achieved by simplifying the single line diagram of UTP new building network into impedance form. This model is available in **Appendix 7.** This model can be simulated with or without the presence of harmonic. The recommendation for further study is that, the injection of harmonic into the system can be improved by providing a better source of harmonic so that the waveform produces from simulation will be more accurate.

The second objective is to assist in harmonic measurement in UTP new building network. In this part, the author had conducted data logging activities with the help from Mr. Tarmizi from PMMD as well as Mr. Zuraimi and Puan Noralyza the lab technicians. In this activity, the author was able to do data logging at five sub switchboards (SSB). The analysis that had been done was by looking at the percentage of contribution of harmonic in the system. In order to get proper analysis, the data obtained can be compared with the IEEE stad 519-1992 or any other relevant standard to see either the harmonic present in the system is harmful and exceeding the limit given or will not give significant effect to the overall system.

The last objective is to perform the harmonic analysis study using frequency scan analysis and harmonic resonance modal analysis techniques and do comparison against the measured data. In this activity, the author is able to do the analysis for two test system which 5 Bus Test System and Standard 14 Bus Test system. For UTP new building network, the author was able to complete the task up until load flow study. The analysis using frequency scan analysis and harmonic resonance modal analysis is not able to be done due to the time constrain. Therefore, the last objective of this project is not achieved. As the recommendation, the project can be continued by adding the analysis using these two techniques. For comparison propose, it is recommended to do the data logging process at the Main Switchboard (MSB) instead of SSB. It is because in UTP new building network, there are 26 SSB. Longer time is taken to data log all of the SSB as compared to MSB which is only 9 in total.

In short, it can be conclude that the objectives of this project are not achieved. There are still lot of room of improvement available to improve the outcome of this project.

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[8] W. Xu, Z. Y. Huang, Y. Cui, and H. Z. Wang, "Harmonic Resonance Mode Analysis," *IEEE Trans. Power Del.*, vol. 20, pp. 1182-1190, 2005.

Appendices

Appendix 1: Gantt Chart

TABLE 22 Gantt Chart for FYP 1

No	Activities/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.	Selection of project topic														
2.	Build understanding on the chosen topic by studying the previous fyp report and other related research paper.														
3.	Preparation for Extended Proposal														
4.	Discussion with supervisor on extended proposal														
5.	Submission of extended proposal														
6.	Build test algorithm for several test system														
7.	Converting data of UTP network into standard per unit value														
8.	Preparation for proposal defense														
9.	Performing load flow study to obtain the bus voltages, active and reactive power of the network.														
10.	Preparation for interim draft report														
11.	Preparation for interim final report														

Appendix 2: Key Milestone

TABLE 23: Key Milestone for FYP1

No	Detail Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.	Selection of project topic														
2.	Preliminary Research Work														
3.	Submission of Extended Proposal														
4.	Proposal Defense														
5.	Project work continue														
6.	Submission of Interim Draft Report														
7.	Submission of Interim Report														

Process

Suggested milestone

Appendix 3: Gantt Chart for FYP2

TABLE 24: Gantt Chart for FYP 2

No	Activities/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1.	Discussion on datalogging activity	■	■														
2.	Start to datalog voltage and current waveform at the academic building				■	■	■	■	■	■	■	■					
3.	Completing the construction of UTP network model for simulation	■	■	■	■	■	■	■	■	■	■	■	■				
4.	Preparation for Progress Report								■								
	Performing Load flow study													■	■		
	Analysis using frequency scan analysis and harmonic resonance modal analysis														■	■	
5.	Analysing the data obtained							■	■	■	■	■	■	■	■	■	■
6.	Preparation for Pre-Sedex										■	■					
7.	Preparation for Draft Final Report												■	■			
8.	Preparation for Final Report and													■	■		

	Technical paper																
9.	Viva																
10.	Preparation for Final Report (hardbound)																

Appendix 4: Key Milestone for FYP2

TABLE 25: Key Milestone for FYP 2

No	Detail Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Progress Report	■	■	■	■	■	■	■	●								
2	ELECTREX									■	■	●					
3	Draft Final Report												■	●			
4	Final Report & Technical Paper														●		
5	Viva															●	
6	Final Report																●

● Suggested Milestone

■ Process

Appendix 5: The MATLAB code for 5 Bus Test System

```
clear all
datadpi
z=(h1:dh:h2)*0;
k=0;
H=linspace(1,150,152);
for h=h1:dh:h2
    Y=zeros(nN,nN);
    for n=1:nL %calculate line admittance
        node1=n1(n);
        node2=n2(n);
        y12=1/(rl(n)+1i*h*xl(n));
        y00=1i*h*b2(n);
        Y(node1, node1)=Y(node1, node1)+y12+y00;
        Y(node2, node2)=Y(node2, node2)+y12+y00;
        Y(node1, node2)=Y(node1, node2)-y12;
        Y(node2, node1)=Y(node2, node1)-y12;
    end
    for n=1:nG %calculate admittance at the generators
        node1=ng(n);
        yg=1/(1i*h*xg(n));
        Y(node1, node1)=Y(node1, node1)+yg;
    end
    for n=1:nN %calculate load admittance
        node1=nn(n);
        if PL(n)~=0;
            R=V(n)^2/PL(n);
            Xl=1i*h*R/(6.7*(QL(n)/PL(n)-0.74));
            Xs=1i*h*0.073*R;
            yl=1/(R*Xl/(R+Xl)+Xs);
            Y(node1, node1)=Y(node1, node1)+yl;
        end
        yc=1i*h*Qc(n)/(V(n)^2);
        Y(node1, node1)=Y(node1, node1)+yc;
    end
    k=k+1;
    %frequency scan analysis starts here
    Z=inv(Y);
    z11(k)=Z(1,1);
    z11=abs(z11);
    z22(k)=Z(2,2);
    z22=abs(z22);
    z33(k)=Z(3,3);
    z33=abs(z33);
    z44(k)=Z(4,4);
    z44=abs(z44);
    z55(k)=Z(5,5);
    z55=abs(z55);

    %HRMA starts here
    [L,D] = eig(Y); %compute D (eigenvalue) and L (left eigenvector)
    R=inv(L); %compute R (right eigenvector)
    Y=L*D*R; % check L*D*R = Y
    Zm=pinv(D);
    zm11(k)=Zm(1,1);
    zm11=abs(zm11);
    zm22(k)=Zm(2,2);
    zm22=abs(zm22);
```

```
    zm33(k)=Zm(3,3);
    zm33=abs(zm33);
    zm44(k)=Zm(4,4);
    zm44=abs(zm44);
    zm55(k)=Zm(5,5);
    zm55=abs(zm55);
end

%plotting Frequency Scan Analysis graph
subplot(2,1,1);
plot(H,z11,H,z22,H,z33,H,z44,H,z55);
axis([0,150,0,15]);
title('Frequency Scan Analysis of the Modified 5 Bus Test System');
xlabel('Harmonic');
ylabel('Magnitude [p.u.]');
legend ('Bus1','Bus2','Bus3','Bus4','Bus5');
grid on;

%plotting Harmonic Resonance Mode Analysis graph
subplot(2,1,2);
plot(H,zm11,H,zm22,H,zm33,H,zm44,H,zm55);
axis([0,150,0,15]);
title('Harmonic Resonance Mode Analysis of the Modified 5 Bus Test
System');
xlabel('Harmonic');
ylabel('Magnitude [p.u.]');
legend ('Mode1','Mode2','Mode3','Mode4','Mode5');
grid on;
```

Appendix 6: Load Flow Study

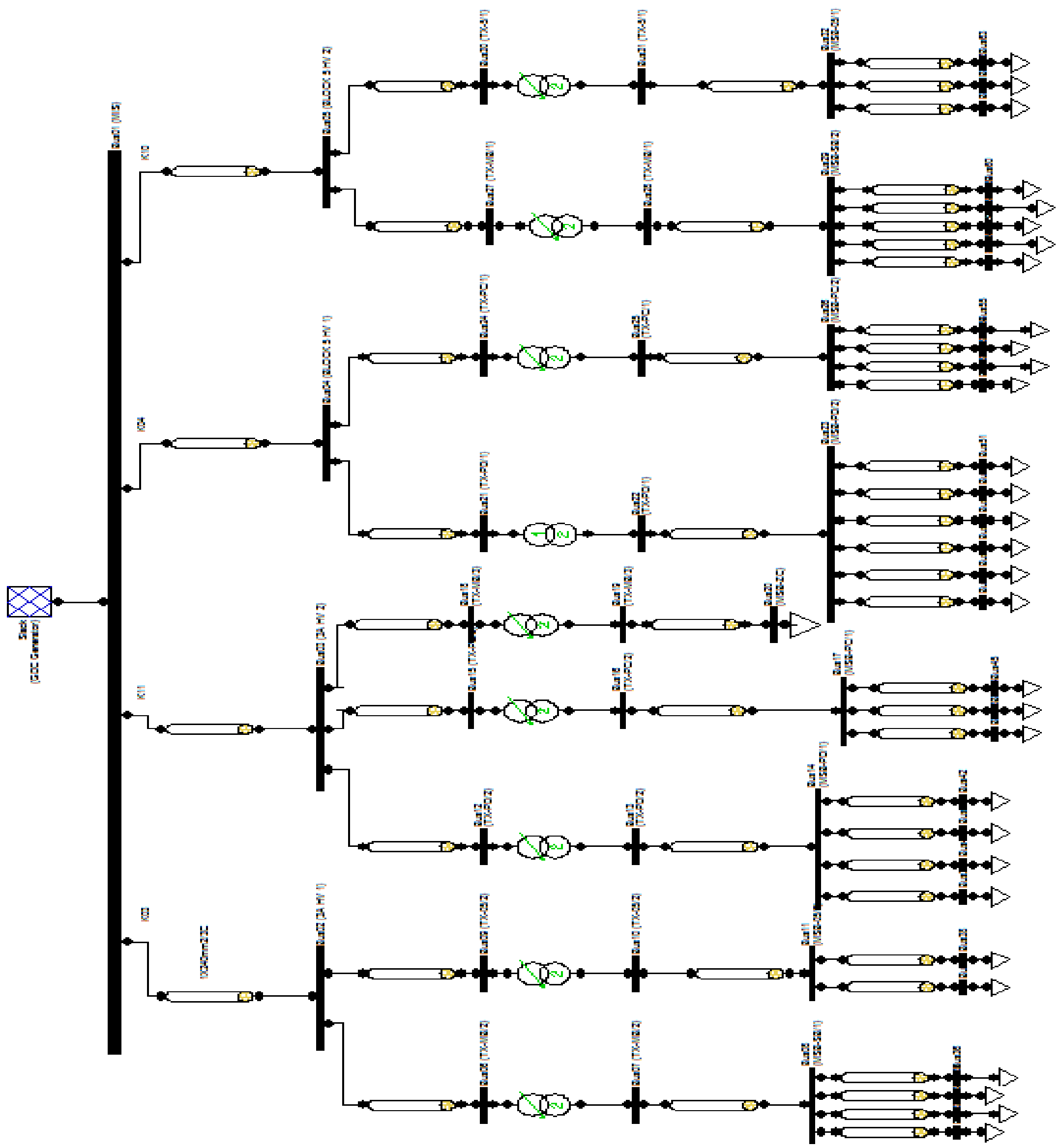

FIGURE 88 The Load Flow Study

Appendix 7: UTP New Building Network model

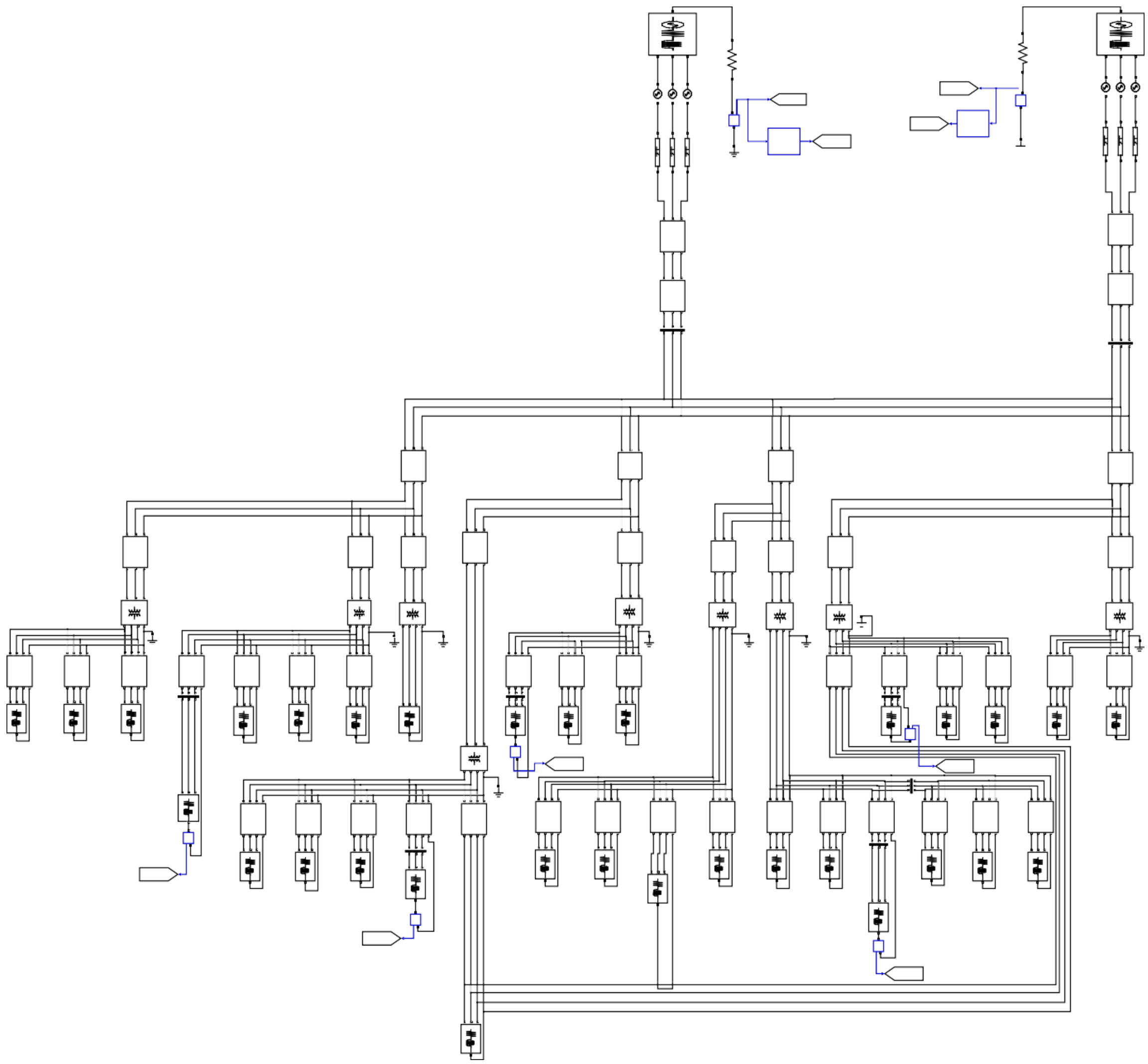

FIGURE 89 The simplified UTP New Building Network Model