HARMONICS FROM NON-LINEAR LOAD

By

AHMAD HAFIZ BIN CHE HUSSIN

FINAL PROJECT REPORT

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

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CERTIFICATION OF APPROVAL

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Approved:

_____

(IR Dr Perumal)

Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

September 2014

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 here have not undertaken or done by unspecified sources or persons.

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Ahmad Hafiz Bin Che Hussin

ABSTRACT

In these modern day, to maintain the sinusoidal waveform in the system had become a challenge to the electrical engineers when there a present of waveform distortion know as harmonics. The usage of non-linear in the system is the contribution of the harmonic present in the system. Harmonic is not a new thing but problem occur to the system caused by harmonic detected in the past few years. Harmonics component in an AC power system is defined as a sinusoidal component of periodic waveform that has a frequency equal to an integer multiple of the fundamental frequency of system (50Hz). Most of the load in these modern day full with electronic component especially solid state component that produce harmonic and they can varies from load to load. The increasing of current harmonic in the system that exceeded the limit stated by IEEE 519 standard will affect the system voltage and lead to problem in the system performance such as overheating problem, failure of insulation, failure of control system and affect the behavior of protection device that connected in the system. Harmonic is not a problem until they had exceeded the standard limit.

ACKNOWLEDGEMENT

First and foremost I would like to express my humble gratitude to Allah S.W.T, because of His blessings and guidance to me throughout completing my final year project. I would also like to sincerely acknowledge for those who had assist on me on this achievement of my project.

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LIST OD ABBREVIATIONS

VFD   Variable Frequency Drive

THDi   Total Harmonic Distortion Current

THDv Total Harmonic Distortion Voltage

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Harmonic is not a new thing but problem occur to the system caused by harmonic detected in the past few years. Harmonics component in an AC power system is defined as a sinusoidal component of periodic waveform that has a frequency equal to an integer multiple of the fundamental frequency of system (50Hz). Most of the load in these modern day full with electronic component especially solid state component that produce harmonic and they can varies from load to load. The increasing of current harmonic in the system that exceeded the limit stated by IEEE 519 standard will affect the system voltage and lead to problem in the system performance such as overheating problem, failure of insulation, failure of control system and affect the behavior of protection device that connected in the system. **Harmonic is not a problem until they had exceeded the standard limit**.

1.2 OBJECTIVE

- To study about harmonic in power system
- To study about the significance effect of harmonic
- Analysis of harmonic measurement
- Design a harmonic filter for harmonic mitigation

1.3 PROBLEM STATEMENT

In this day, and age of advance electronics, monitoring power quality has become too important to be ignore by the industrial players. The widely usage of high tech device has complicated many aspect of electrical power. All of these device are more sensitive and had effect the power system network especially with the power quality issues. Poor power quality can result in low productivity, loss and corrupt data, damage equipment and lack of power efficiency.

1.4 SCOPE OF STUDY

This project is to study about the harmonics in the power system with the present of non-linear load. The example of non-linear load are rectifier circuit, variable frequency drive etc. For this project the author will focus on rectifier circuit throughout simulation. The simulation to show about rectifier circuit was done in the MATLAB Simulink. The author also will propose simple but efficient harmonic filter which is passive shunt filter. For the configuration the author use single tuned and high pass filter.

CHAPTER 2: LITERATURE REVIEW

2.1 POWER QUALITY

The worse thing when have a low power quality in the power system network is when people did not know the causes of that event. As more electronic device are connected to the system the quality of the power become more essential to the user. The definition of 'quality' can be describe in the many way. Undistorted waveform and stable voltage are the main factor in describing the 'quality'.

2.2 VARIABLE FREQUENCY DRIVE

Variable frequency rive also known as adjustable frequency drive, variable speed drive and AC drive. VFD essentially a type of adjustable speed drive used in electro-mechanical drive system to control AC motor speed and torque by manipulate motor input frequency and voltage to maintain the rated volts/hertz ratio to get the desire speed(Aditya, 2013).

2.3 VARIABLE FREQUENCY DRIVE OPERATION

Understanding of VFD operation basic principle require the three basic section in the VFD which are rectifier, DC bus and inverter.
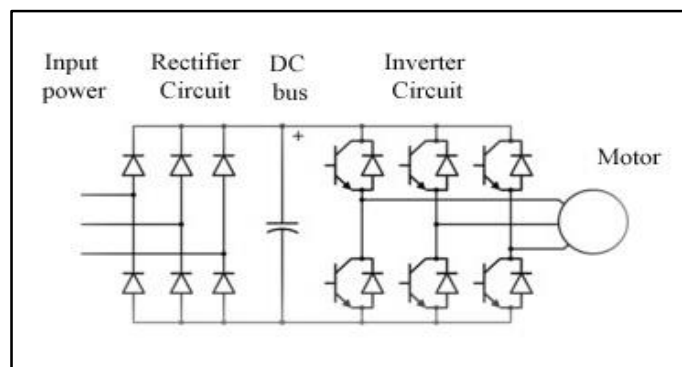
RECTIFIER	DC BUS	INVERTER

Figure 1: VFD circuit diagram

- **RECTIFIER CIRCUIT**
    - Convert incoming AC power to DC power
    - Diodes, silicon controlled rectifier (SCR) or transistor can be used to rectify power.
    - At the moment, only two rectifier will work. First rectifier is to allow power to pass through when voltage is positive. Second rectifier is to allow power to pass through when voltage is negative.

- **DC BUS**
    - Contain capacitor to accept power from rectifier.
    - Store power and deliver power to the inverter section when get a signal.
    - Important function of DC bus is to smoothing power supply that come from rectifier circuit.

- **INVERTER CIRCUIT**
    - Contain transistor that will deliver power to the motor.
    - Insulated Gate Bipolar Transistor (IGBT) are the best transistor use as it can switch ON and OFF several thousand times per second and has precise control to delivered power to the motor.
    -

2.4 HARMONIC

Harmonics are mathematical model of real world use to analyse distorted waveform(Marty Martin, 2014). Harmonics is use to analyse the current drawn by device in the power system which have modem transformer less power supplies.

Ohm's Law in electrical engineering state that current will flow through the system when a voltage is applied through the resistance. This is how all electrical and electronic equipment works. In Malaysia the voltage supply to the power system is a sinewave which operated 50 Hertz (cycle per second).
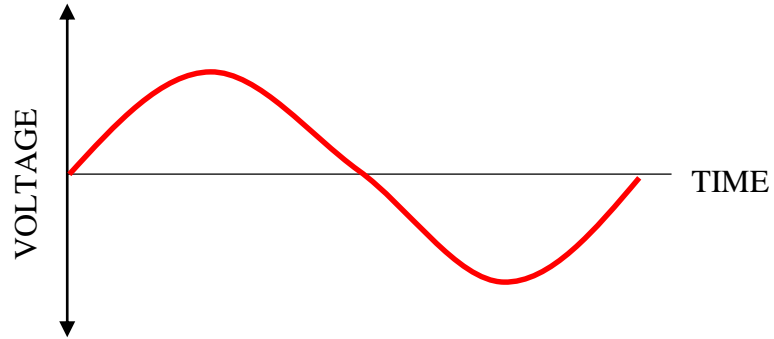
Figure 2: Voltage Waveform

From the above figure show that the utilities do a wonderful job in generating voltage sinewave which have constant amplitude and constant frequency. The theory of Ohm's law only can be use when the voltage is applied to the device. According to the Ohm's law, the magnitude of current is equal to voltage applied divided by resistance.

$$I = \frac{V}{R}$$

As a result, the current output will produce another sinewave, since the resistance is a constant value. Stated by Ohm's law, the frequency of current waveform is also at 50 Hertz same as the voltage waveform.
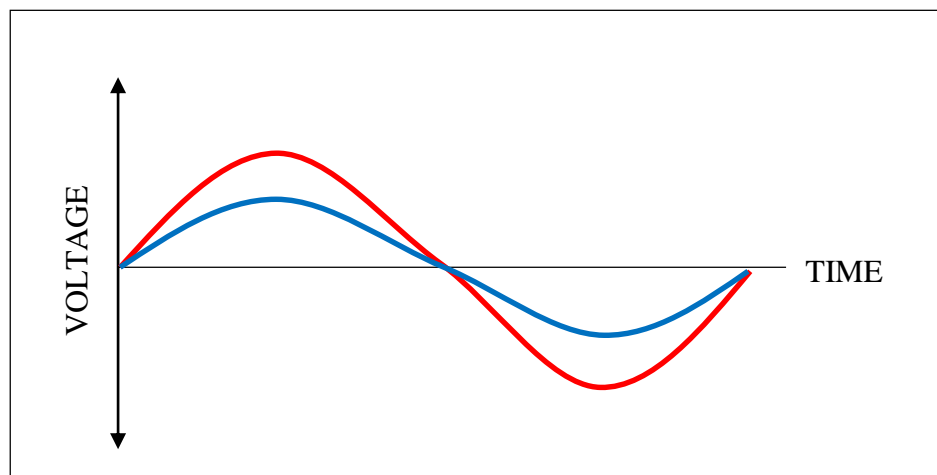
Figure 3: Voltage and Current Waveform

When a sinusoidal current are drawn from the sinusoidal voltage this are called linear system. Example of linear device are incandescent lamps, heaters and motor.

In the modern day, there are many high tech device cannot be in the linear systems category. This result from the resistance of these device are not constant and in fact it is varying in each sinewave. These modern device are draw current in pulse that why the current waveform output is not sinusoidal.
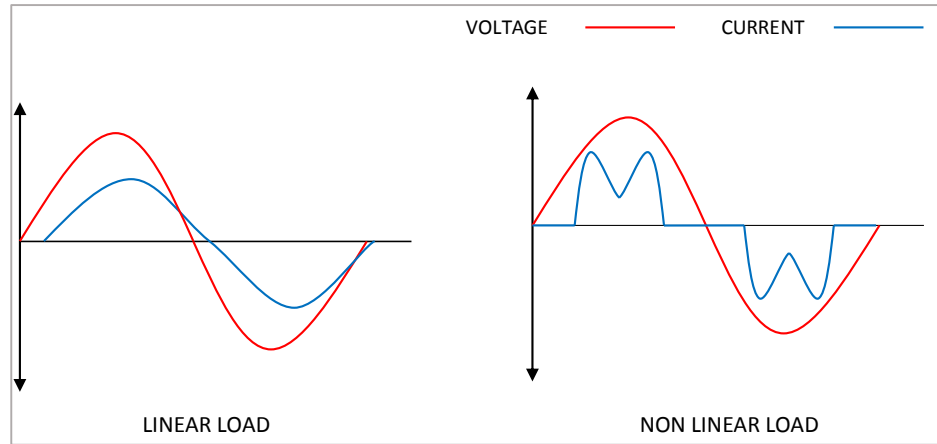
Figure 4: Linear Load and Non-linear Load Waveform

On the 3 phase system, the three phase are 120 degree of power system for each phase. The phase B current will draw 120 degree after the phase A current. For phase C, the current will draw 120 degree after the phase B. This sequence, had cancel the neutral current from the system, hence the neutral current will be zero

However, when harmonics current are present these harmonic currents come together on the neutral conductor than on phase conductor. This harmonic current are not being cancel but increase more current on the neutral conductor.

2.4.1 HARMONIC SOURCES

As stated before harmonics are generated by a device connected to the power system network also known as non-linear load.

- Arching Devices; Equipment that created arcs as part of normal operation, such as electrical arc welders.

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- Magnetic Circuit Magnetic devices such as transformer, produces distorted wave shapes when they are operated in their nonlinear regions.
- Power electronics: The switching of such as devices as Silicon Controlled Rectifier (SCR) are not sinusoidal in nature. These device include Variable Frequency Device or electronic power supplies.

2.4.2 HARMONIC EFFECT

- Raise temperature of neutral conductor lead to overheat of surrounding conductor and insulation failure.
- Transformer sources which supply the power system will overheat.
- Frequent circuit breakers tripping.
- Malfunction of UPS systems and generator systems.
- Metering problems
- Computer malfunctions.
- Overvoltage problems.
- Capacitor failure.
- Electronic equipment shutting down.
- Fuse blowing for no apparent reason.
- Overheating of metal enclosures
- Flickering of fluorescent light.
- Motor failure.
- Transformer failure.

2.5 CRITICAL ANALYSIS OF PREVIOUS RESEARCH HARMONIC DISTORTION

The investigation of input harmonic distortion of variable frequency drive was done by take a field measurement at the input of single voltage source of VFD connected to the power system network (Liang , Luy , & Don , 2007). The field measurement was taken at input of 55 voltage source. Beside field measurement, simulation of input harmonic distortion when drive load factor fixed at 100% also was done. The result for Current Total Harmonic Distortion (ITHD) and Voltage Total Harmonic Distortion (VTHD) was analysed for a 6 pulse VFD. From the field measurement and simulation done can conclude that factor that impacting input harmonic distortion is drive load factor and system impedance at drive input.

VFD also have been use in the oil and gas field. Chatt (2006) stated that oil and gas field also face with the power quality issue with the usage of variable speed drive at the electric submersible pump (ESD). To determine the level of power quality a measurement was taken at the 380V VFD and switchgear of each individual pad of substation. In case to identifying the best way to improve power quality, computer simulation was done using ETAP power station software with and without harmonic filter. The investigation at the oil production found that the temperature of oil rise above the normal point. However, more analysis about the oil need to be done to found out if there any chemical product resulted from heat generation produce by harmonics.

Variable frequency drive also one of the device that can enhance energy saving (Aditya, 2013). This paper had provide basic understanding of VFD terms, VFD operation and power factor improvement, harmonic mitigation by VFD. The simulation was done using MATLAB to show how VFD beneficial in energy saving. This simulation is using 3HP and 4 pole motor while the inverter of VFD is using pulse width modulation (PWM) method. Harmonic analysis was done using by FFT tool. Data of motor speed, order of harmonic, VTHD and ITHD are differ because of varying input frequency from 45 Hz to 80 Hz with 5 Hz gap. In general from this study proved that VTHD and ITHD is higher at the highest and lowest frequency. Too much variation of frequency also lead to increase

in VTHD and ITHD. Thus VFD can work both as to control motor speed and also as energy saving device.

The speed, torque, current and voltage of the 30 kW motor was analysed in the MATLAB simulation (Mistry , Solanki , & Vala , 2012). THD waveform was analysed when the motor input frequency was varied from 30 Hz to 60 Hz by using the VFD. As the motor speed increase, THD voltage and current also increasing.

Beside the effect of VFD usage to the power system network. There are also study that had be done to know the performance of VFD because of the regular voltage fluctuation. Voltage fluctuation also known as voltage sags or surges, this event are short term event that happen during under or over voltage condition that can last at least one cycle to several cycle. Usually happen because of load suddenly drawing current from the line, lightning strikes, fault clearing and from power factor switching (Power Problems and Voltage Regulator Technologies, n.d.). When VFD operating in open loop, the effect of power supply fluctuating will lead to an increase in rectifier capacitor RMS current. Hence this will lead the fluctuation of induction motor stator current because AC supply side fluctuation can pass through rectifier and inverter and go straight to the motor stator. This study show that the fluctuation event at the motor is not because usage of VFD as a motor drive but because fluctuation event that happen at the power supply ((Zhao, Ciufo, & Perera, 2014).

In conjunction to optimize power quality in offshore oil field a MATLAB simulation was done by include Series Active Conditioner (SAC) in the power system network (Verma , Singh , & Chandra , 2010). The performance of SAC was demonstrated in compensate current harmonics and reduce harmonic distortion, regulate voltage at load terminal, maintain DC-link voltage and mitigate fluctuation at the voltage source. Effectiveness of proposed SAC to provide harmonic compensation and ability to regulate bus voltage against odd event make it suitable scheme to make VFD operation more reliable when connected to the bus.

Ching (2008) studied on electrical performance of VFD for residential air conditioning application to compare the performance of conventional single phase induction motor and variable frequency drive on DC motor compressor. This is to

determine the needed component to increase power efficiency, providing power density and better performance at low cost. The increasing of application harmonic generating power electronic converter in these recent year also effect the electromagnetic environment and power quality. Hence it is important to know the fact about the performance of VFD compare to the conventional method. The speed of single phase compressor cannot be vary. It only operate with ON (at the maximum load) and will switched OFF by the thermistor. This conventional method is lack of efficiency because of frequent ON/OFF and constant frequency. Result in more stress to the motor and compressor also produce more noise. While in the point of electrical properties, the ITHD of VFD is higher compare to conventional method if there are no proper power factor correction at the system.

Variable speed drive is one of the major generator of harmonic within power system network (Abraham & Cronje, 2012). There are many device in the market that claim that they are able to eliminate or mitigate the present of harmonics in the power system. Study done by Abraham & Cronje is to see the overall effectiveness of existing harmonic mitigation. In order to see the effectiveness of harmonic mitigation the parameter was focused are on overall power factor and total ITHD when operate with different load in a time. The test conducted was done with and without harmonic mitigation to have a comparable result. Result from RHT show the best result when it show less harmonics present in the power system as well as to draw less current.

CHAPTER 3: PROJECT METHODOLOGY

3.1 RESEARCH METHODOLOGY

START

↓

LITERATURE REVIEW

↓

VFD

- Basic operation
- Function of VFD
- Advantage & Disadvantage

↓

HARMONICS

- Source of harmonics
- Effect of harmonic

↓

PREVIOUS RESEARCH

- Done to study about performance of VFD
- Effect of VFD in various application

↓

INTRODUCTION TO SIMULATION SOFTWARE

- MATLAB 2013
- ETAP POWERSTATION 4

↓

FINISH FYP 1
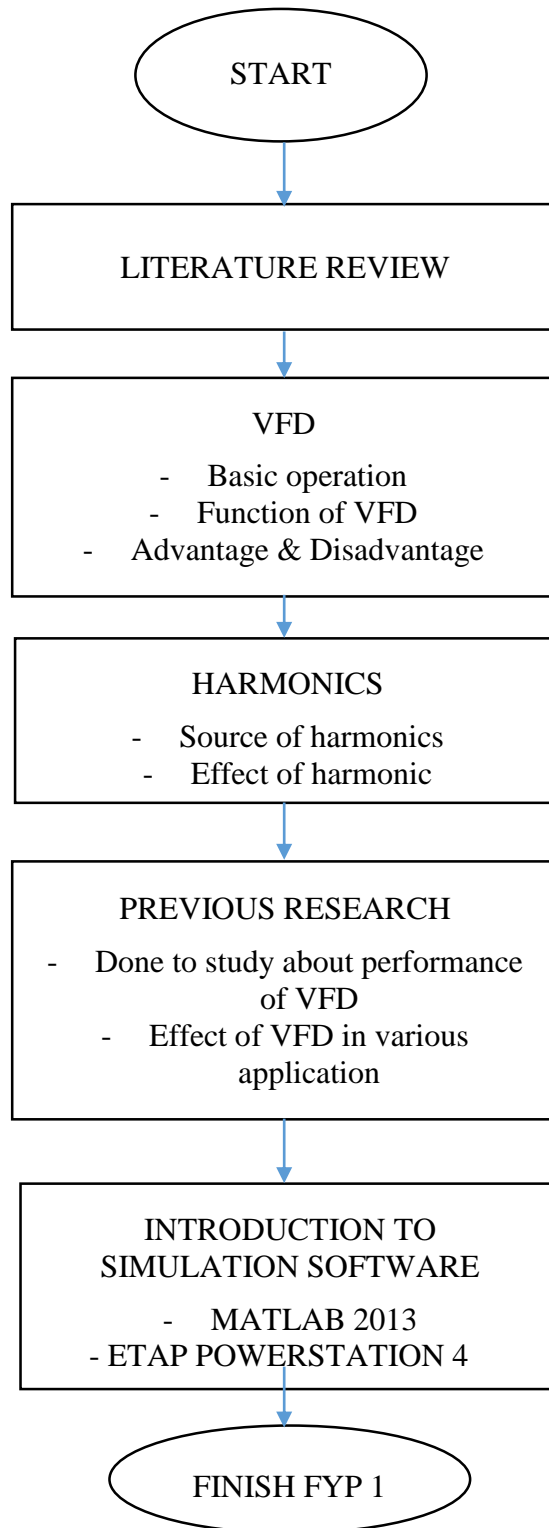
3.2 SUMMARY OF PROJECT ACTIVITIES (GANTT CHART)

No	Work Detail	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Project title selection and briefing by FYP coordinator	■													
2	Preliminary research work and extended proposal preparation	■	■	■	■	■	■								
3	Extended proposal submission						★								
4	Research work and proposal defence preparation						■	■	■	■					
5	Proposal defence									★					
6	Project work continues									■	■	■	■	■	■
7	Submission of Interim draft report												★		
8	Submission of final Interim report													★	

FYP 1

★ KEY MILESTONE   ■ PROCESS

12

3.3 PROJECT METHODOLOGY

```
                    ┌─────────────┐
                    │    START    │
                    └──────┬──────┘
                           │
                           ▼
        ┌──────────────────────────────────────┐
        │       ANALYSE COLLECTED DATA         │
        └──────────────────┬───────────────────┘
                           │
                           ▼
        ┌──────────────────────────────────────┐
        │    BUILD SIMULATION CIRCUIT          │
        │  SAME SPECIFICATION AS A CASE        │
        │              STUDY                   │
        └──────┬────────────────────────┬──────┘
               │                        │
               ▼                        ▼
   ┌───────────────────────┐  ┌───────────────────────┐
   │ SIMULATION WITHOUT NON-│  │ SIMULATION WITH NON-LINEAR│
   │     LINEAR LOAD        │  │         LOAD          │
   └───────────┬───────────┘  └───────────┬───────────┘
               └────────────┬─────────────┘
                            ▼
        ┌──────────────────────────────────────┐
        │        ANALYSE THE RESULT.           │
        │       IMPORTANT PARAMETER:           │
        │              -ITHD                   │
        │              -VTHD                   │
        └──────────────────┬───────────────────┘
                           │
                           ▼
        ┌──────────────────────────────────────┐
        │    COMPARE SIMULATION RESULT         │
        │   WITH DATA FROM CASE STUDY          │
        └──────────────────┬───────────────────┘
                           │
                           ▼
        ┌──────────────────────────────────────┐
        │    CRYTICAL ANALYSIS & REPORT        │
        └──────────────────┬───────────────────┘
                           │
                           ▼
                    ┌─────────────┐
                    │ FINISH FYP 2│
                    └─────────────┘
```
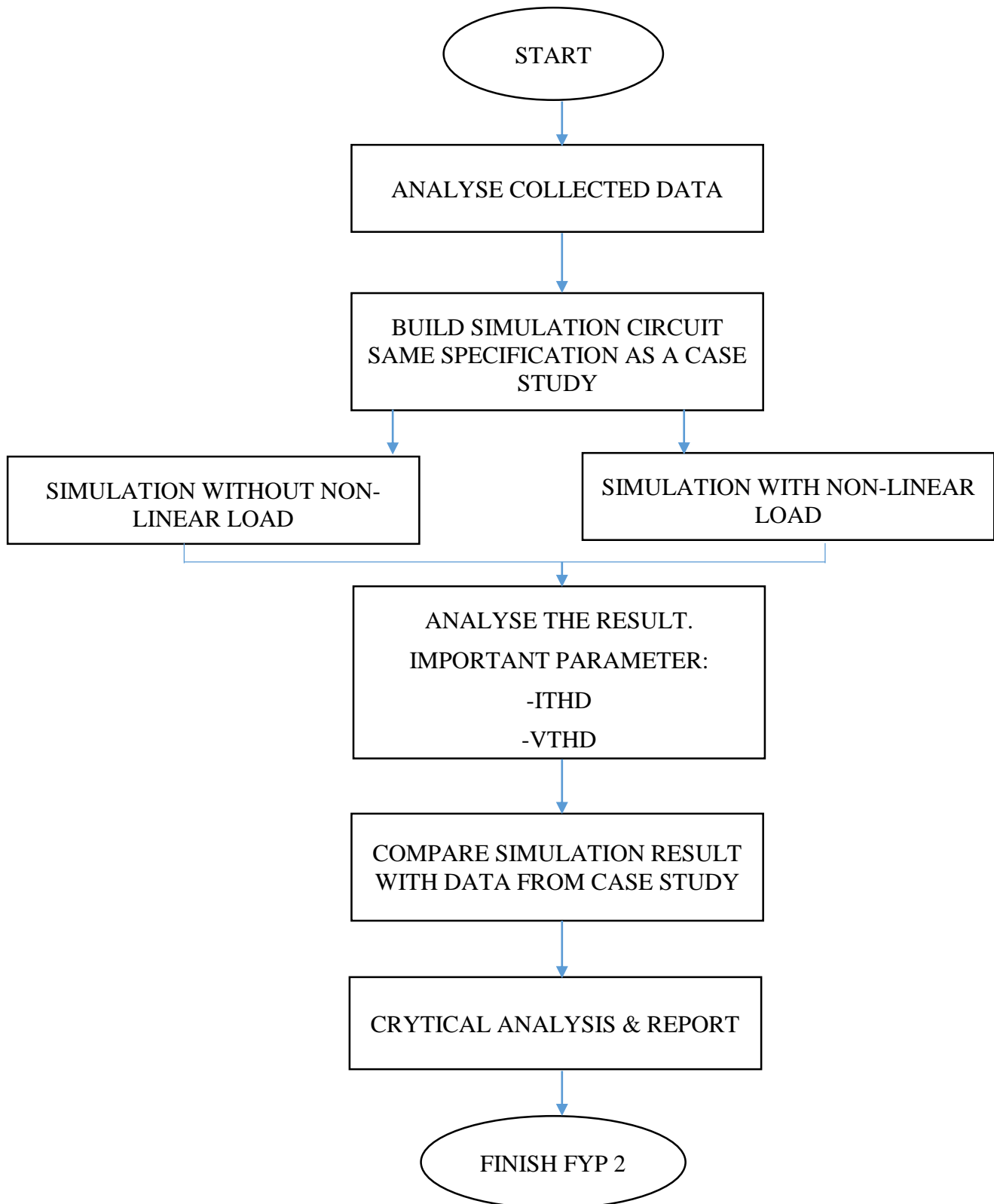
3.4 Summary of Future Work (Gantt chart)

No	Work Detail	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Project work continues Collect data from real case study Do simulation test Analyze data from simulation test and real case study	■	■	■	■	■	■	■							
2	Submission of Progress Report														
3	Project work continues							★	■	■	■	■	■		
4	Submission of draft final report											★			
5	Submission of Dissertation												★		
6	Submission of Technical paper												★		
7	Viva													★	
8	Submission of Project Dissertation														★

FYP 2

★ KEY MILESTONE   ■ PROCESS

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3.5 Equipment and Software

List below are the following tools and equipment required for completing this project.
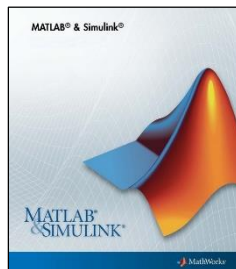
- ELSPEC Power Logger

Figure 5: Model G4500

Figure 6: Model G3500

- MATLAB & SIMULINK 2013

- ETAP 4 (POWER SYSTEM ANALYSIS)

CHAPTER 4: RESULT AND DISCUSSION

PART 1

4.1 HARMONIC MEASUREMENT

Harmonic measurement was done at the one of the factory in Malaysia. The measurement was done using power logger as stated in the equipment and software section. There are 8 point of measurement was done at this factory (see single line diagram below).
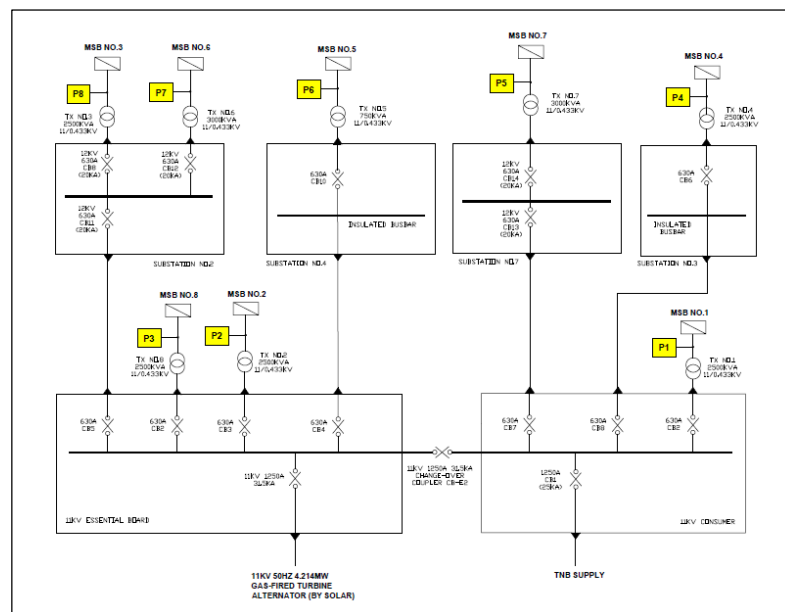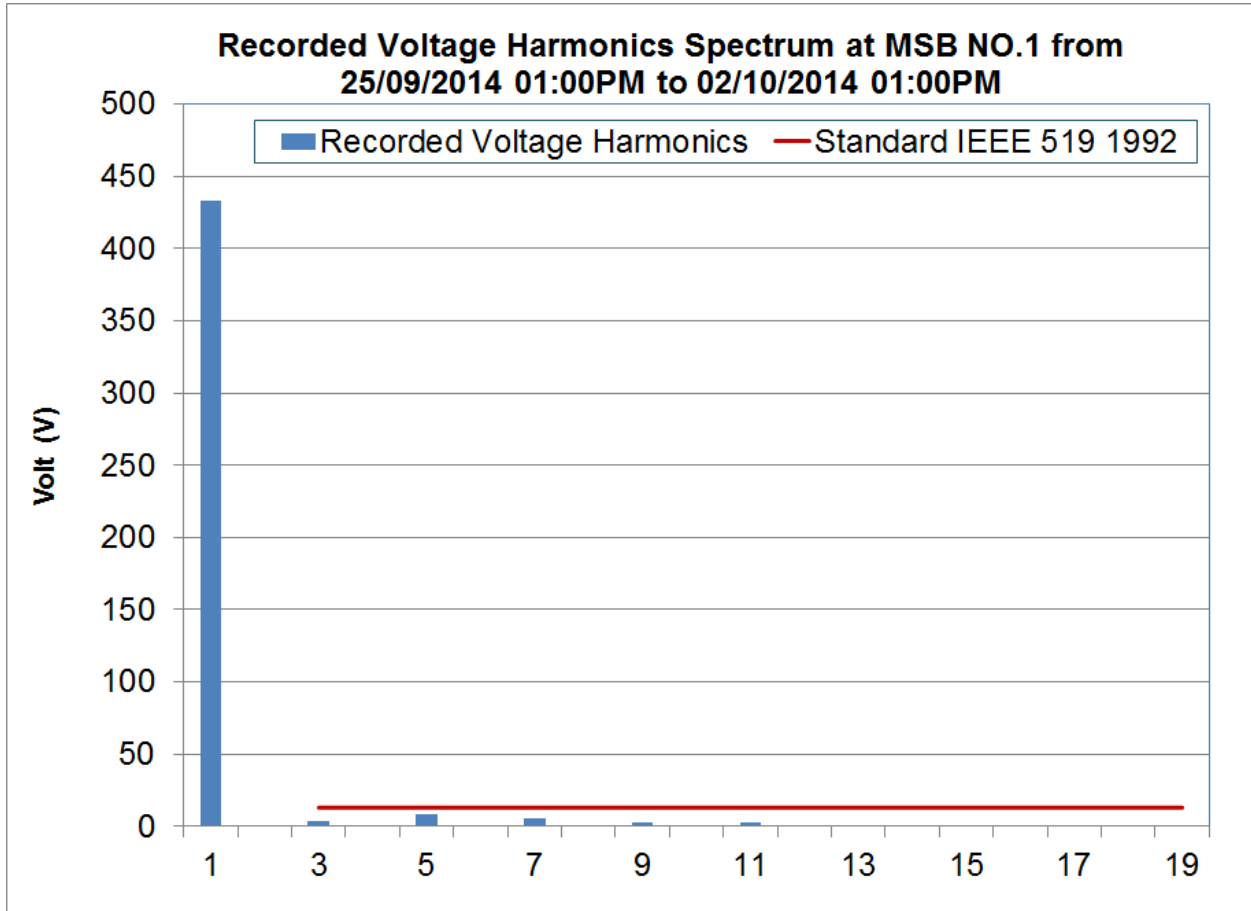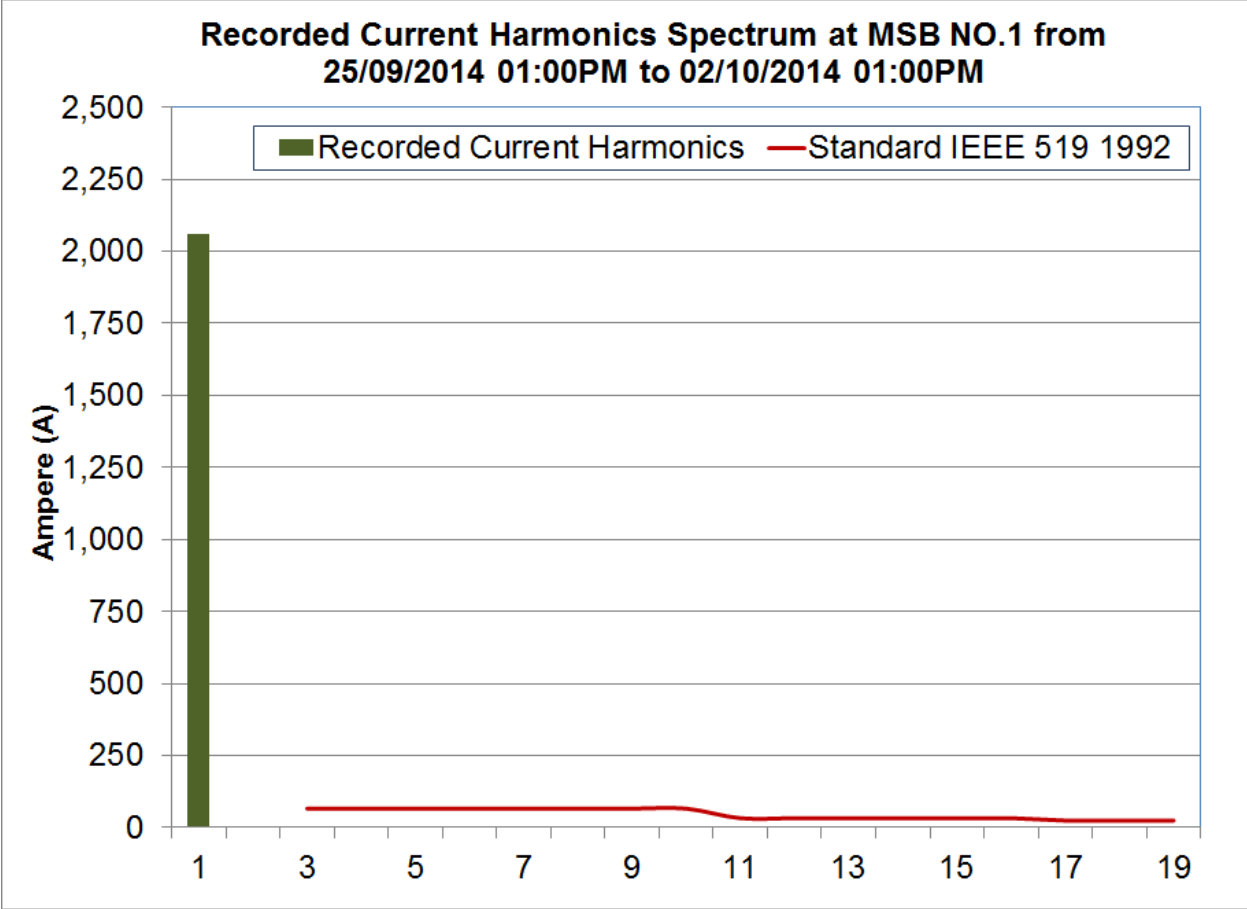

Figure 7: Point of Measurement

For the result the author focus on the voltage and current distortion. The author also analysis the relationship between power factor and distortion occur at the each of the point of measurement.

4.1.1 Recorded Harmonic Spectrum at Point 1

Recorded Voltage Harmonics Spectrum at MSB NO.1 from 25/09/2014 01:00PM to 02/10/2014 01:00PM

Harmonic Order	Voltage (V)	Percentage (vs Fundamental)	Standard IEEE 519 1992 (%)	Compliance
1	433.08			
3	3.31	0.80	3.00	COMPLY
5	8.17	1.97	3.00	COMPLY
7	5.40	1.30	3.00	COMPLY
9	2.96	0.71	3.00	COMPLY
11	2.26	0.54	3.00	COMPLY
13	1.16	0.28	3.00	COMPLY
15	0.52	0.13	3.00	COMPLY
17	0.60	0.14	3.00	COMPLY
19	1.18	0.28	3.00	COMPLY

Recorded Current Harmonics Spectrum at MSB NO.1 from 25/09/2014 01:00PM to 02/10/2014 01:00PM

Harmonic Order	Current (A)	Percentage (vs Fundamental)	Standard IEEE 519 1992 (%)	Compliance
1	2,060.06			
3	0.00	0.00	4.00	COMPLY
5	0.00	0.00	4.00	COMPLY
7	0.00	0.00	4.00	COMPLY
9	0.00	0.00	4.00	COMPLY
11	0.00	0.00	2.00	COMPLY
13	0.00	0.00	2.00	COMPLY
15	0.00	0.00	2.00	COMPLY
17	0.00	0.00	1.50	COMPLY
19	0.00	0.00	1.50	COMPLY

4.1.2. Recorded Harmonic Spectrum at Point 2
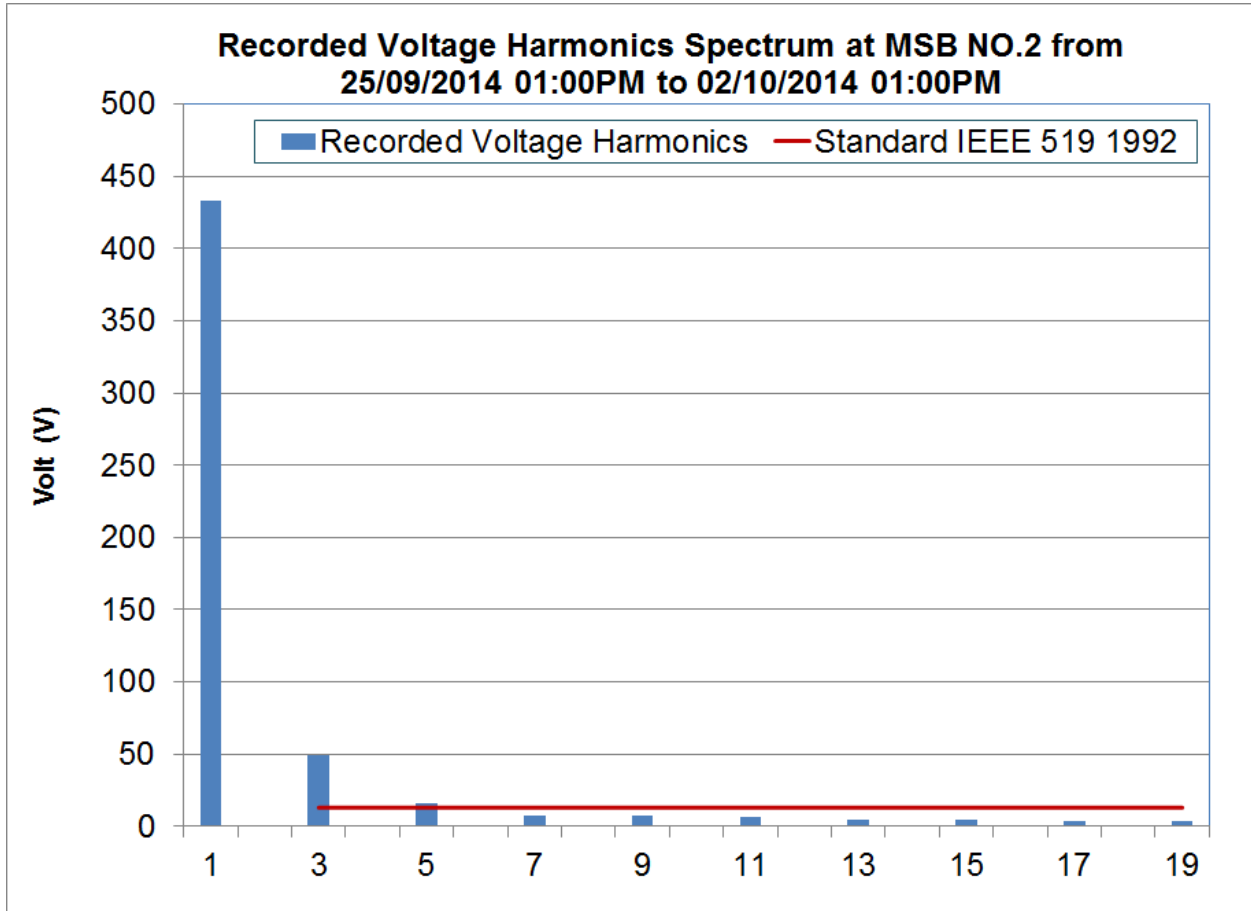
Recorded Voltage Harmonics Spectrum at MSB NO.2 from 25/09/2014 01:00PM to 02/10/2014 01:00PM

Harmonic Order	Voltage (V)	Percentage (vs Fundamental)	Standard IEEE 519 1992 (%)	Compliance
1	433.37			
3	49.48	11.92	3.00	NOT COMPLY
5	16.00	3.86	3.00	NOT COMPLY
7	7.87	1.90	3.00	COMPLY
9	6.97	1.68	3.00	COMPLY
11	6.30	1.52	3.00	COMPLY
13	4.72	1.14	3.00	COMPLY
15	4.35	1.05	3.00	COMPLY
17	3.93	0.95	3.00	COMPLY
19	3.98	0.96	3.00	COMPLY

Recorded Current Harmonics Spectrum at MSB NO.2 from 25/09/2014 01:00PM to 02/10/2014 01:00PM
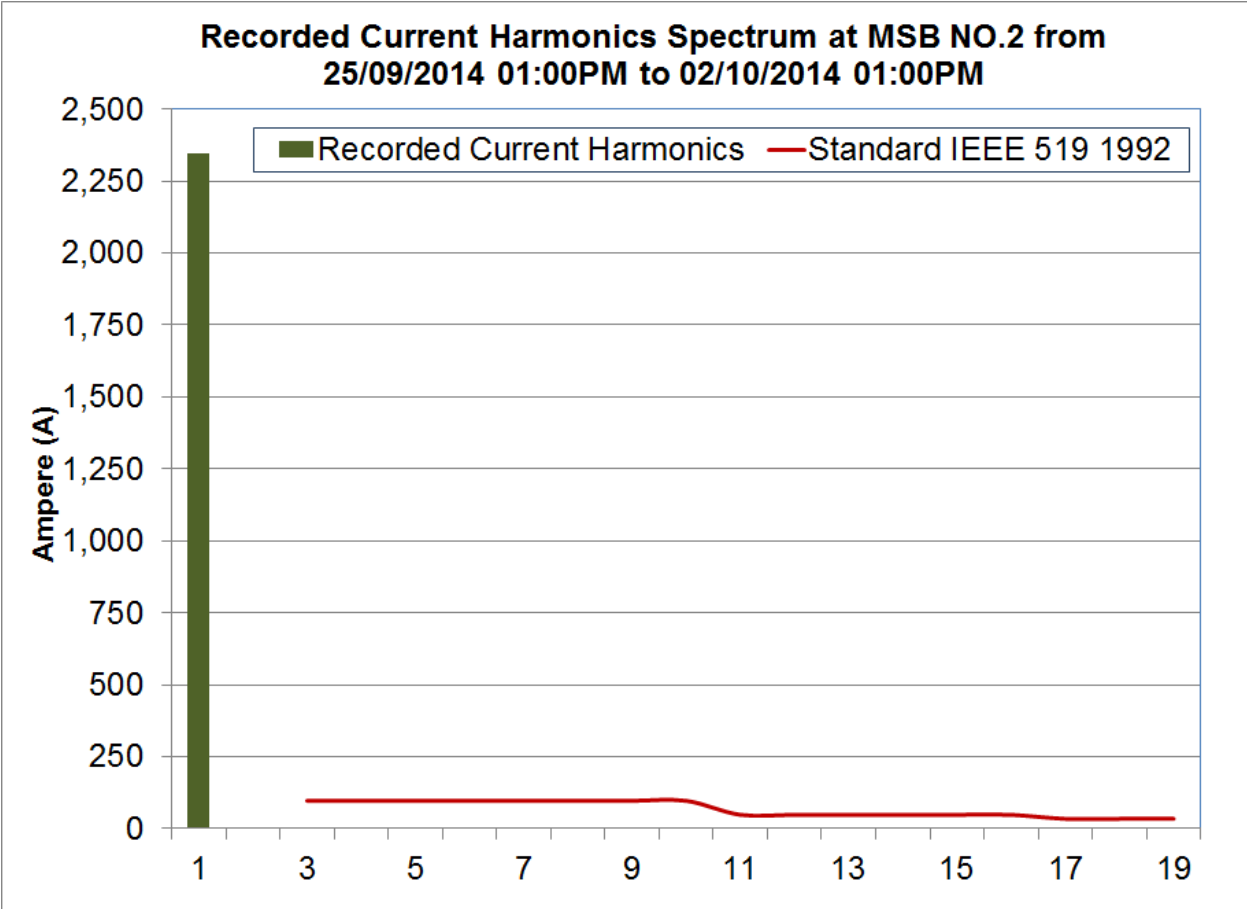
Harmonic Order	Current (A)	Percentage (vs Fundamental)	Standard IEEE 519 1992 (%)	Compliance
1	2,347.82			
3	0.00	0.00	7.00	COMPLY
5	0.00	0.00	7.00	COMPLY
7	0.00	0.00	7.00	COMPLY
9	0.00	0.00	7.00	COMPLY
11	0.00	0.00	3.50	COMPLY
13	0.00	0.00	3.50	COMPLY
15	0.00	0.00	3.50	COMPLY
17	0.00	0.00	2.50	COMPLY
19	0.00	0.00	2.50	COMPLY

20

4.1.3 Recorded Harmonic Spectrum at Point 3
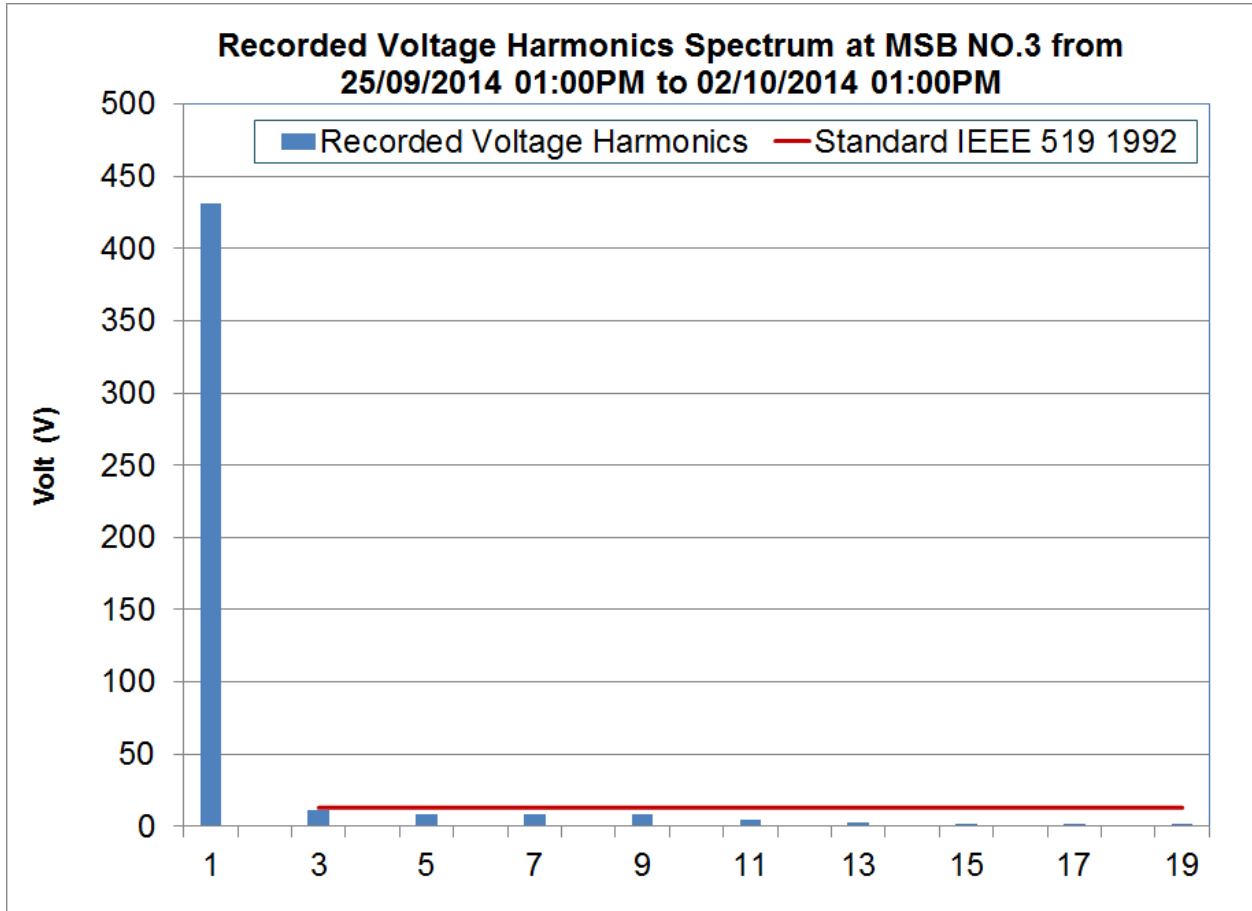
Recorded Voltage Harmonics Spectrum at MSB NO.3 from 25/09/2014 01:00PM to 02/10/2014 01:00PM

Harmonic Order	Voltage (V)	Percentage (vs Fundamental)	Standard IEEE 519 1992 (%)	Compliance
1	430.80			
3	10.84	2.61	3.00	COMPLY
5	8.23	1.98	3.00	COMPLY
7	8.05	1.94	3.00	COMPLY
9	8.66	2.09	3.00	COMPLY
11	4.60	1.11	3.00	COMPLY
13	2.98	0.72	3.00	COMPLY
15	1.88	0.45	3.00	COMPLY
17	1.82	0.44	3.00	COMPLY
19	1.76	0.42	3.00	COMPLY

Recorded Current Harmonics Spectrum at MSB NO.3 from
25/09/2014 01:00PM to 02/10/2014 01:00PM
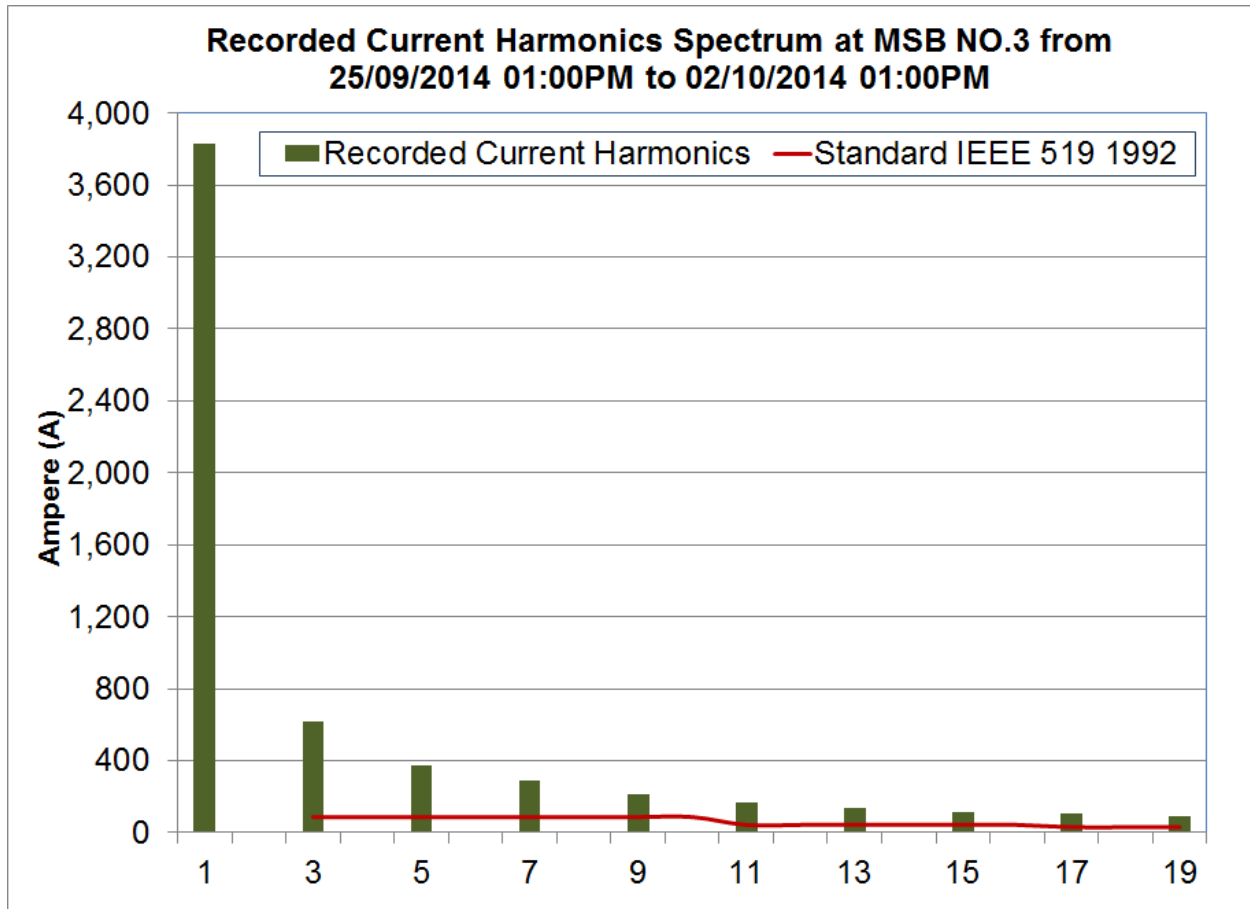
Harmonic Order	Current (A)	Percentage (vs Fundamental)	Standard IEEE 519 1992 (%)	Compliance
1	3,831.31			
3	617.07	49.31	7.00	NOT COMPLY
5	370.42	29.60	7.00	NOT COMPLY
7	289.09	23.10	7.00	NOT COMPLY
9	210.09	16.79	7.00	NOT COMPLY
11	168.52	13.47	3.50	NOT COMPLY
13	135.46	10.82	3.50	NOT COMPLY
15	117.77	9.41	3.50	NOT COMPLY
17	104.18	8.32	2.50	NOT COMPLY
19	92.54	7.40	2.50	NOT COMPLY

4.1.4 Recorded Harmonic Spectrum at Point 4
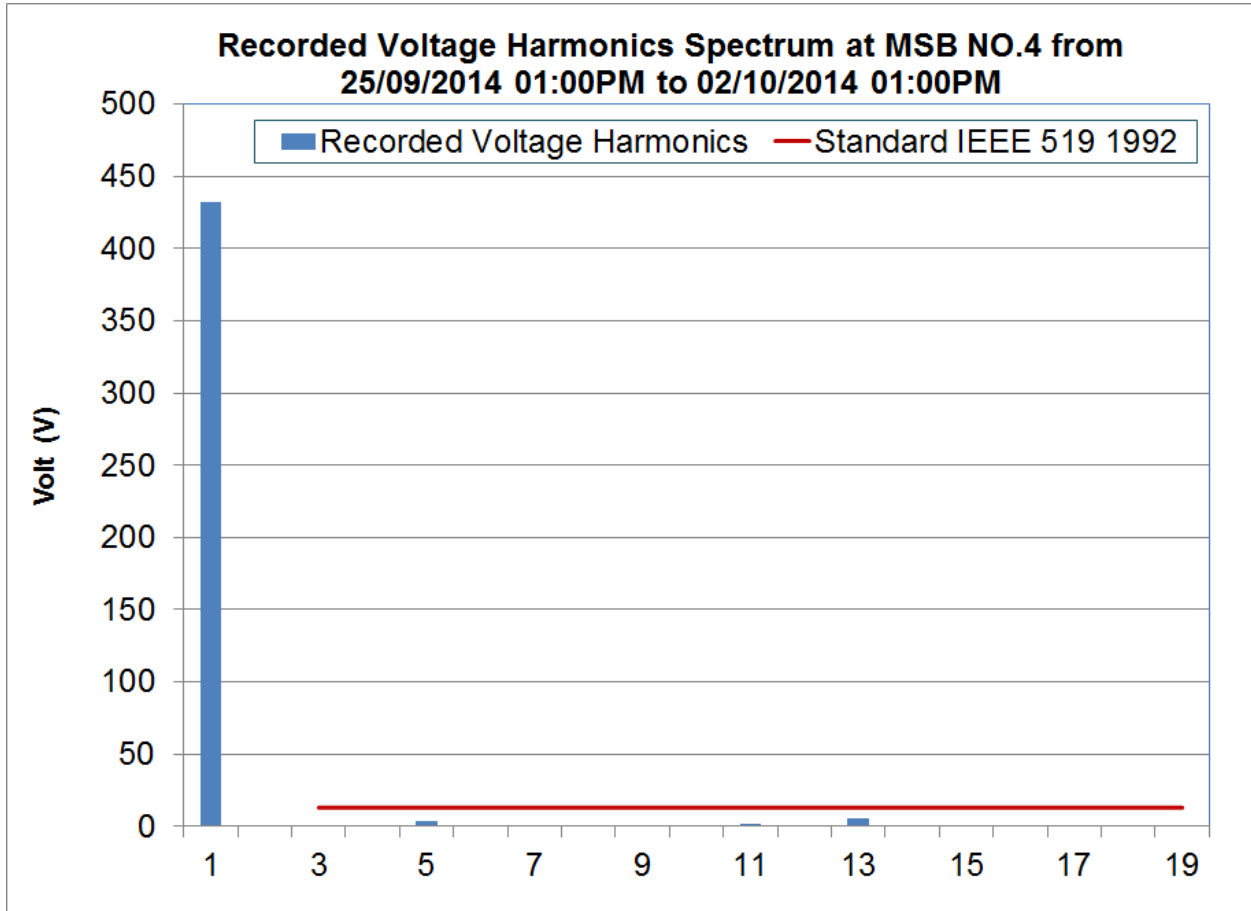
Recorded Voltage Harmonics Spectrum at MSB NO.4 from 25/09/2014 01:00PM to 02/10/2014 01:00PM

Harmonic Order	Voltage (V)	Percentage (vs Fundamental)	Standard IEEE 519 1992 (%)	Compliance
1	431.86			
3	0.42	0.10	3.00	COMPLY
5	3.96	0.95	3.00	COMPLY
7	1.16	0.28	3.00	COMPLY
9	0.58	0.14	3.00	COMPLY
11	1.40	0.34	3.00	COMPLY
13	5.14	1.24	3.00	COMPLY
15	0.23	0.06	3.00	COMPLY
17	0.42	0.10	3.00	COMPLY
19	0.68	0.16	3.00	COMPLY

Recorded Current Harmonics Spectrum at MSB NO.4 from 25/09/2014 01:00PM to 02/10/2014 01:00PM
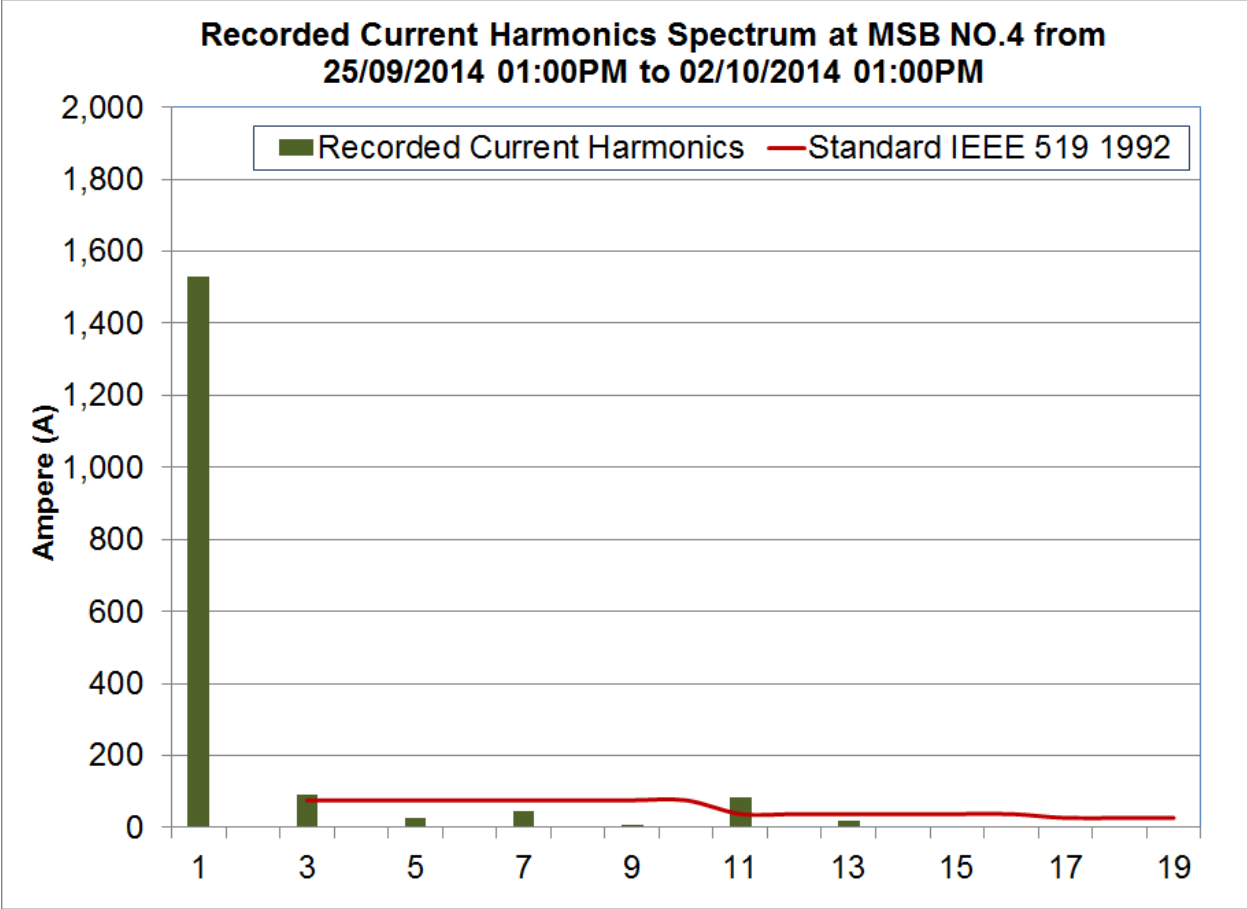
Harmonic Order	Current (A)	Percentage (vs Fundamental)	Standard IEEE 519 1992 (%)	Compliance
1	1,527.71			
3	90.18	8.31	7.00	NOT COMPLY
5	27.20	2.51	7.00	COMPLY
7	45.60	4.20	7.00	COMPLY
9	6.18	0.57	7.00	COMPLY
11	85.09	7.84	3.50	NOT COMPLY
13	17.69	1.63	3.50	COMPLY
15	1.95	0.18	3.50	COMPLY
17	4.37	0.40	2.50	COMPLY
19	1.95	0.18	2.50	COMPLY

4.1.5 Recorded Harmonic Spectrum at Point 5
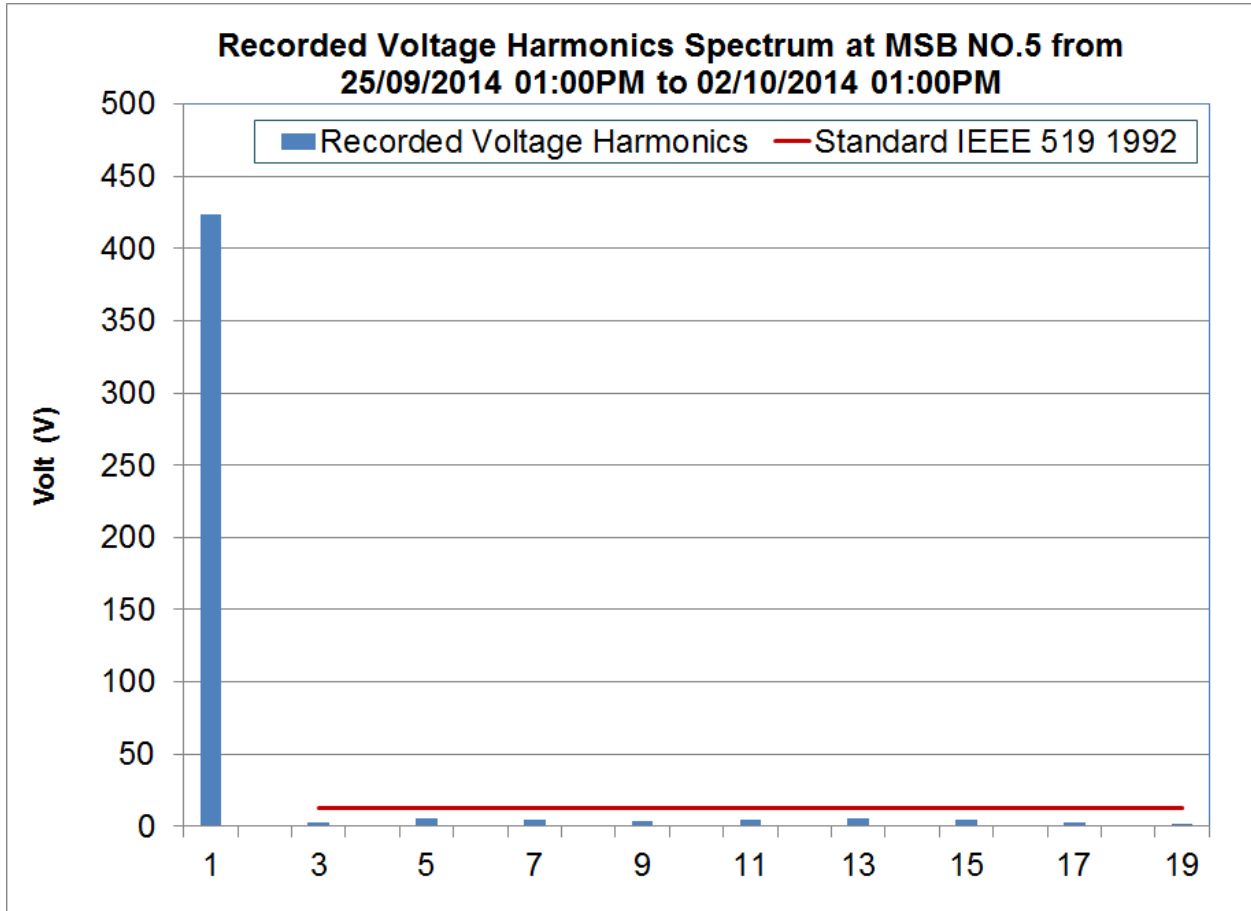
Recorded Voltage Harmonics Spectrum at MSB NO.5 from 25/09/2014 01:00PM to 02/10/2014 01:00PM

Harmonic Order	Voltage (V)	Percentage (vs Fundamental)	Standard IEEE 519 1992 (%)	Compliance
1	423.75			
3	2.62	0.63	3.00	COMPLY
5	5.51	1.33	3.00	COMPLY
7	4.11	0.99	3.00	COMPLY
9	3.67	0.88	3.00	COMPLY
11	4.48	1.08	3.00	COMPLY
13	5.17	1.25	3.00	COMPLY
15	4.26	1.03	3.00	COMPLY
17	2.46	0.59	3.00	COMPLY
19	1.87	0.45	3.00	COMPLY

Recorded Current Harmonics Spectrum at MSB NO.5 from 25/09/2014 01:00PM to 02/10/2014 01:00PM
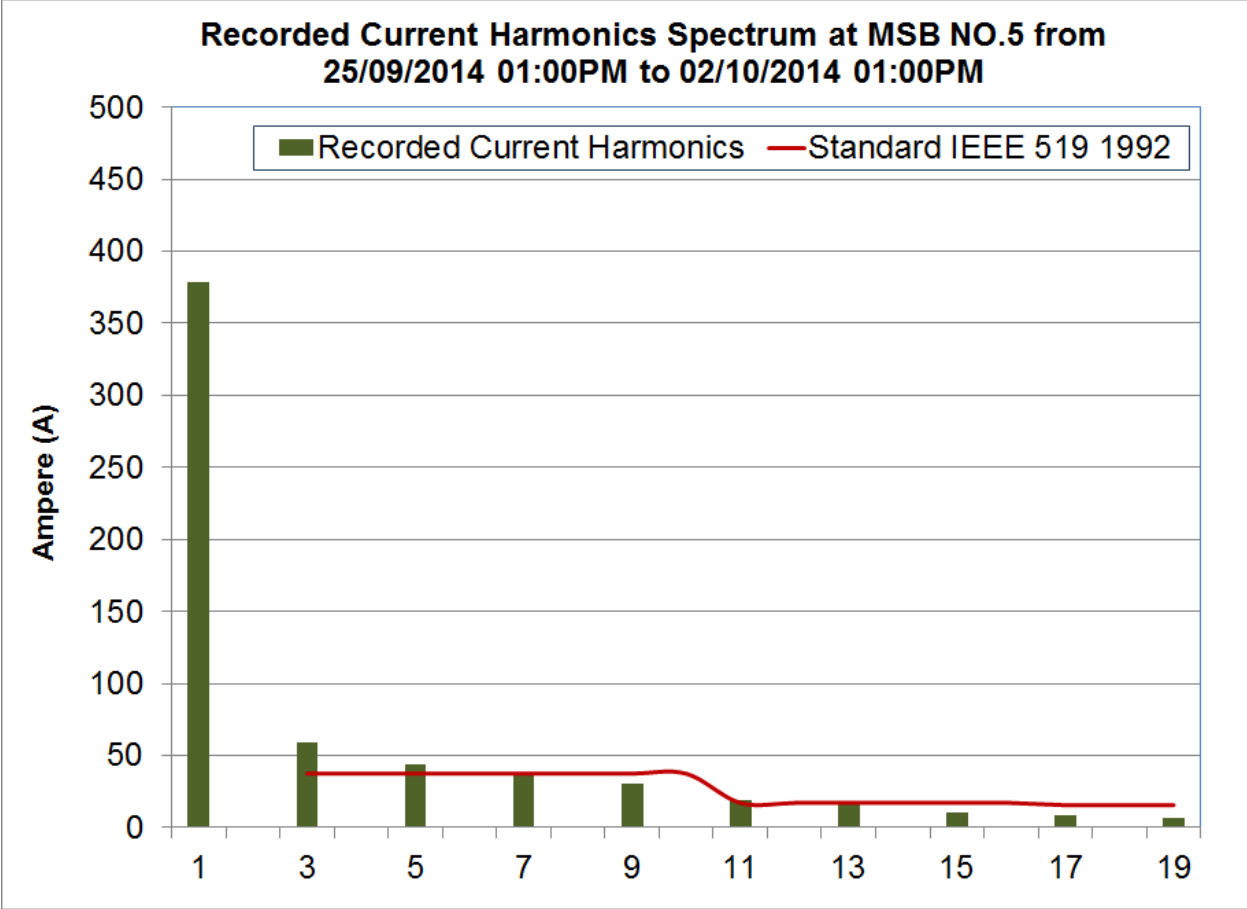
Harmonic Order	Current (A)	Percentage (vs Fundamental)	Standard IEEE 519 1992 (%)	Compliance
1	378.49			
3	58.73	18.80	12.00	NOT COMPLY
5	43.55	13.94	12.00	NOT COMPLY
7	36.24	11.60	12.00	COMPLY
9	30.39	9.73	12.00	COMPLY
11	19.37	6.20	5.50	NOT COMPLY
13	18.40	5.89	5.50	NOT COMPLY
15	10.48	3.36	5.50	COMPLY
17	8.22	2.63	5.00	COMPLY
19	6.34	2.03	5.00	COMPLY

4.1.6 Recorded Harmonic Spectrum at Point 6
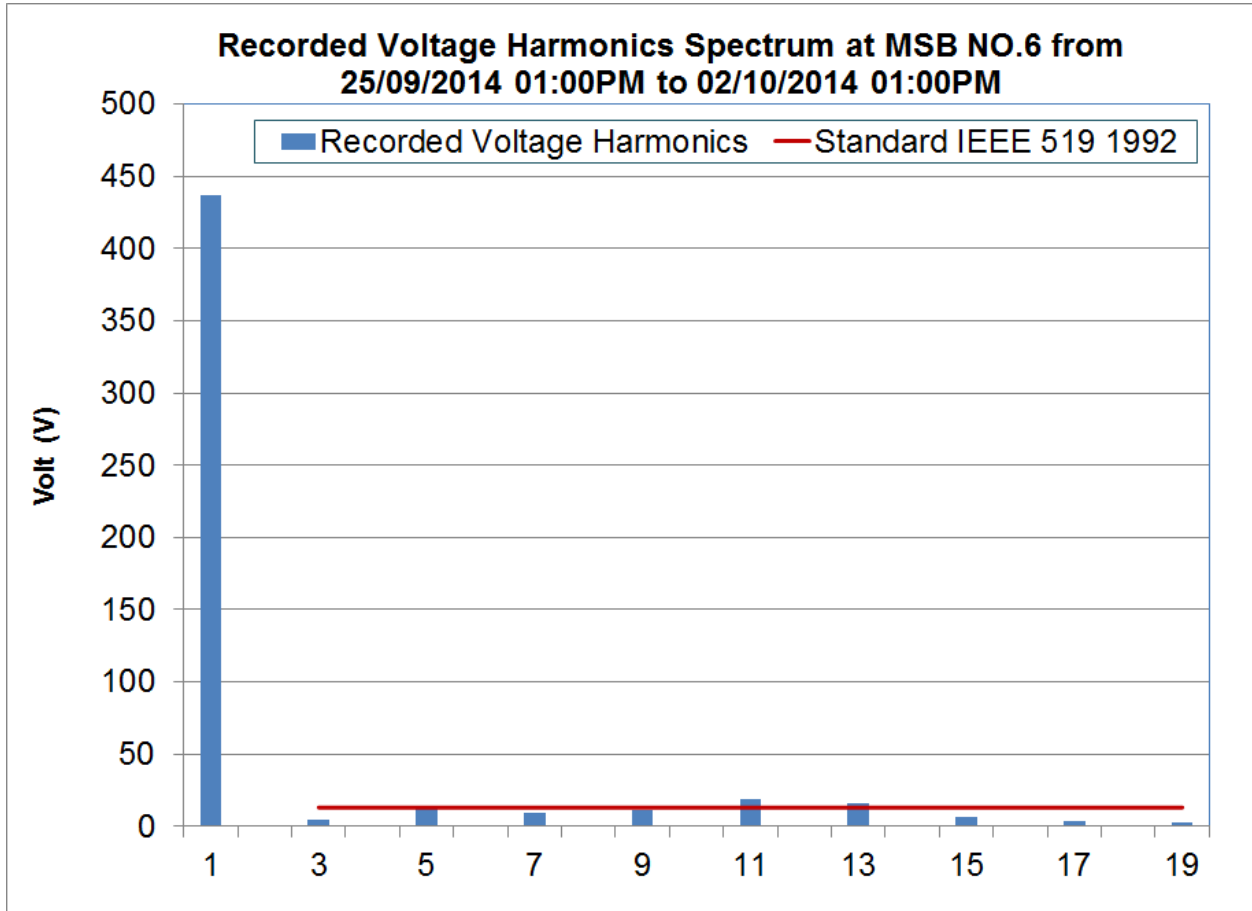
Harmonic Order	Voltage (V)	Percentage (vs Fundamental)	Standard IEEE 519 1992 (%)	Compliance
1	436.60			
3	4.64	1.12	3.00	COMPLY
5	12.98	3.13	3.00	NOT COMPLY
7	8.91	2.15	3.00	COMPLY
9	11.04	2.66	3.00	COMPLY
11	18.93	4.56	3.00	NOT COMPLY
13	16.42	3.96	3.00	NOT COMPLY
15	6.16	1.48	3.00	COMPLY
17	4.08	0.98	3.00	COMPLY
19	3.15	0.76	3.00	COMPLY

Recorded Current Harmonics Spectrum at MSB NO.6 from 25/09/2014 01:00PM to 02/10/2014 01:00PM
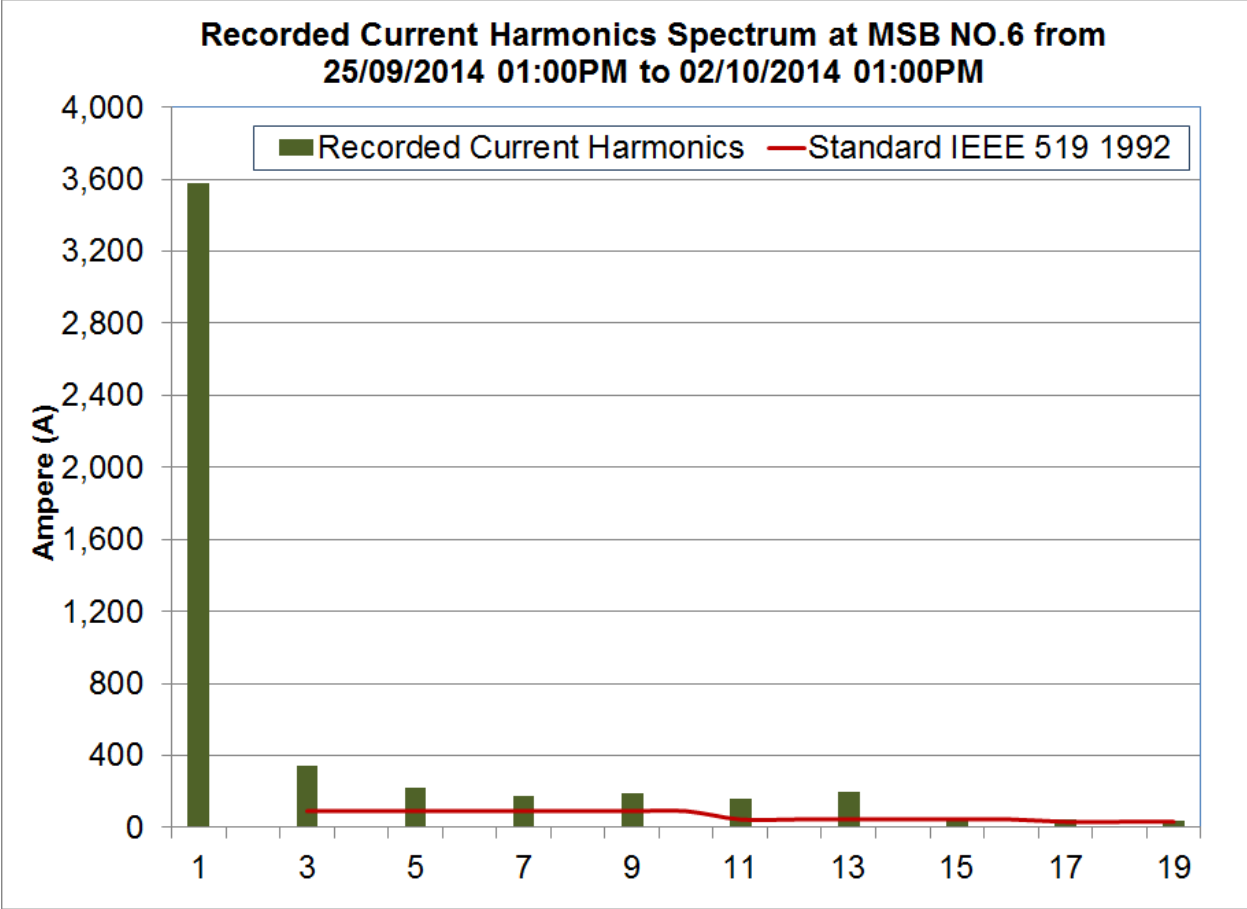
Harmonic Order	Current (A)	Percentage (vs Fundamental)	Standard IEEE 519 1992 (%)	Compliance
1	3,575.92			
3	339.58	25.99	7.00	NOT COMPLY
5	218.16	16.70	7.00	NOT COMPLY
7	172.63	13.21	7.00	NOT COMPLY
9	187.48	14.35	7.00	NOT COMPLY
11	159.61	12.22	3.50	NOT COMPLY
13	201.09	15.39	3.50	NOT COMPLY
15	49.43	3.78	3.50	NOT COMPLY
17	44.55	3.41	2.50	NOT COMPLY
19	39.37	3.01	2.50	NOT COMPLY

4.1.7 Recorded Harmonic Spectrum at Point 7
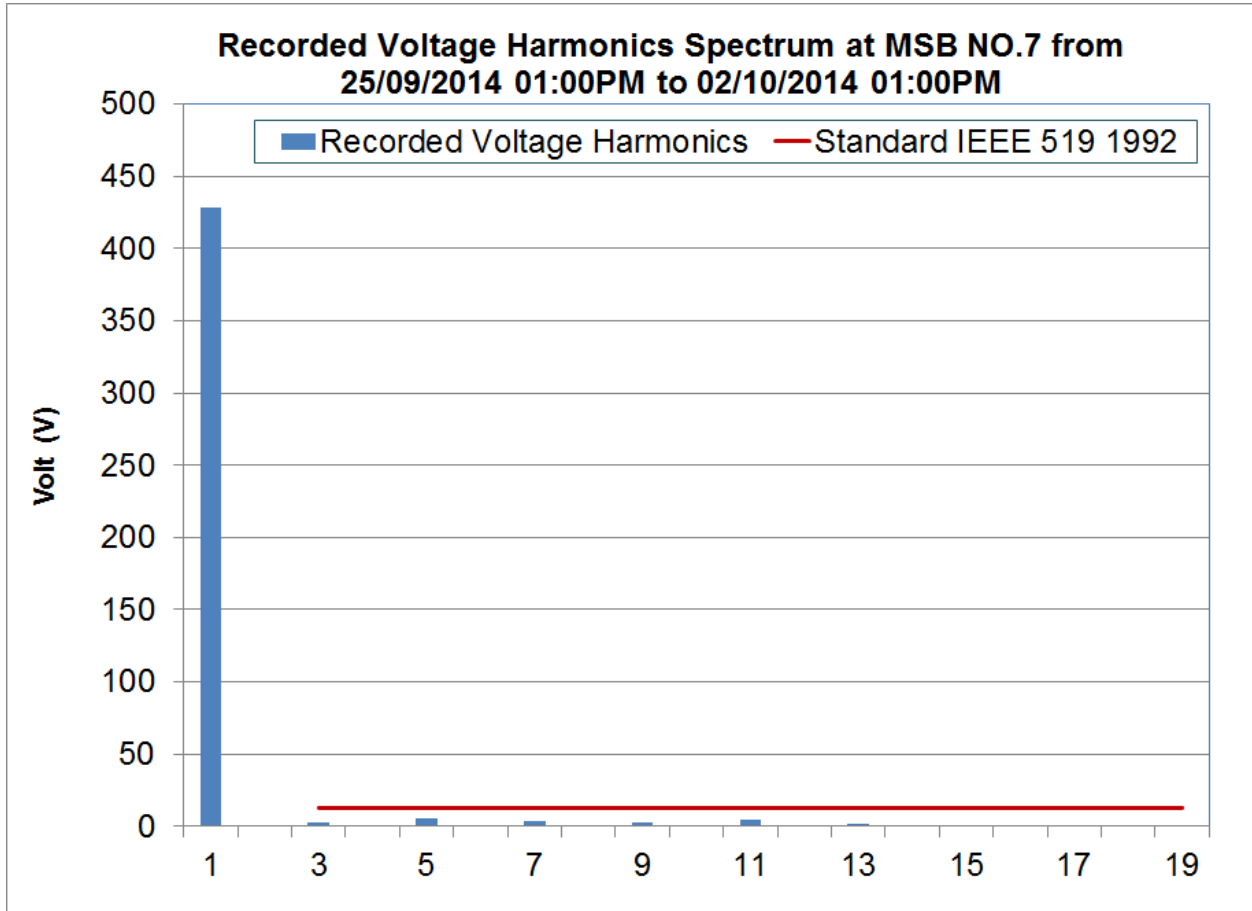
Recorded Voltage Harmonics Spectrum at MSB NO.7 from 25/09/2014 01:00PM to 02/10/2014 01:00PM

Harmonic Order	Voltage (V)	Percentage (vs Fundamental)	Standard IEEE 519 1992 (%)	Compliance
1	428.52			
3	2.96	0.71	3.00	COMPLY
5	5.90	1.42	3.00	COMPLY
7	3.24	0.78	3.00	COMPLY
9	2.90	0.70	3.00	COMPLY
11	4.88	1.18	3.00	COMPLY
13	1.82	0.44	3.00	COMPLY
15	0.52	0.13	3.00	COMPLY
17	0.12	0.03	3.00	COMPLY
19	0.00	0.00	3.00	COMPLY

Recorded Current Harmonics Spectrum at MSB NO.7 from 25/09/2014 01:00PM to 02/10/2014 01:00PM
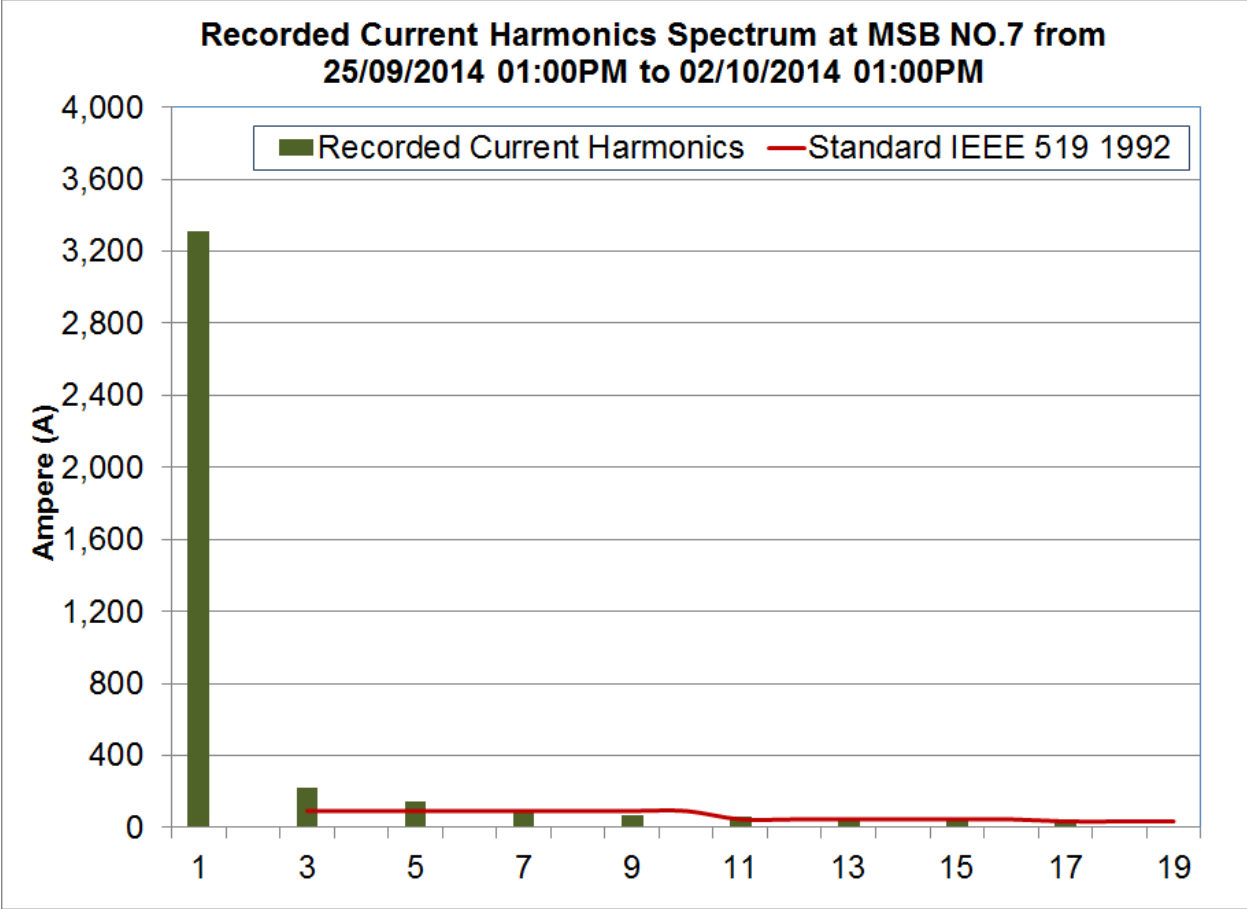
Harmonic Order	Current (A)	Percentage (vs Fundamental)	Standard IEEE 519 1992 (%)	
1	3,307.36			
3	219.78	9.48	4.00	NOT COMPLY
5	141.62	6.11	4.00	NOT COMPLY
7	90.63	3.91	4.00	COMPLY
9	66.10	2.85	4.00	COMPLY
11	61.76	2.67	2.00	NOT COMPLY
13	50.98	2.20	2.00	NOT COMPLY
15	39.14	1.69	2.00	COMPLY
17	26.97	1.16	1.50	COMPLY
19	0.00	0.00	1.50	COMPLY

4.1.8 Recorded Harmonic Spectrum at Point 8
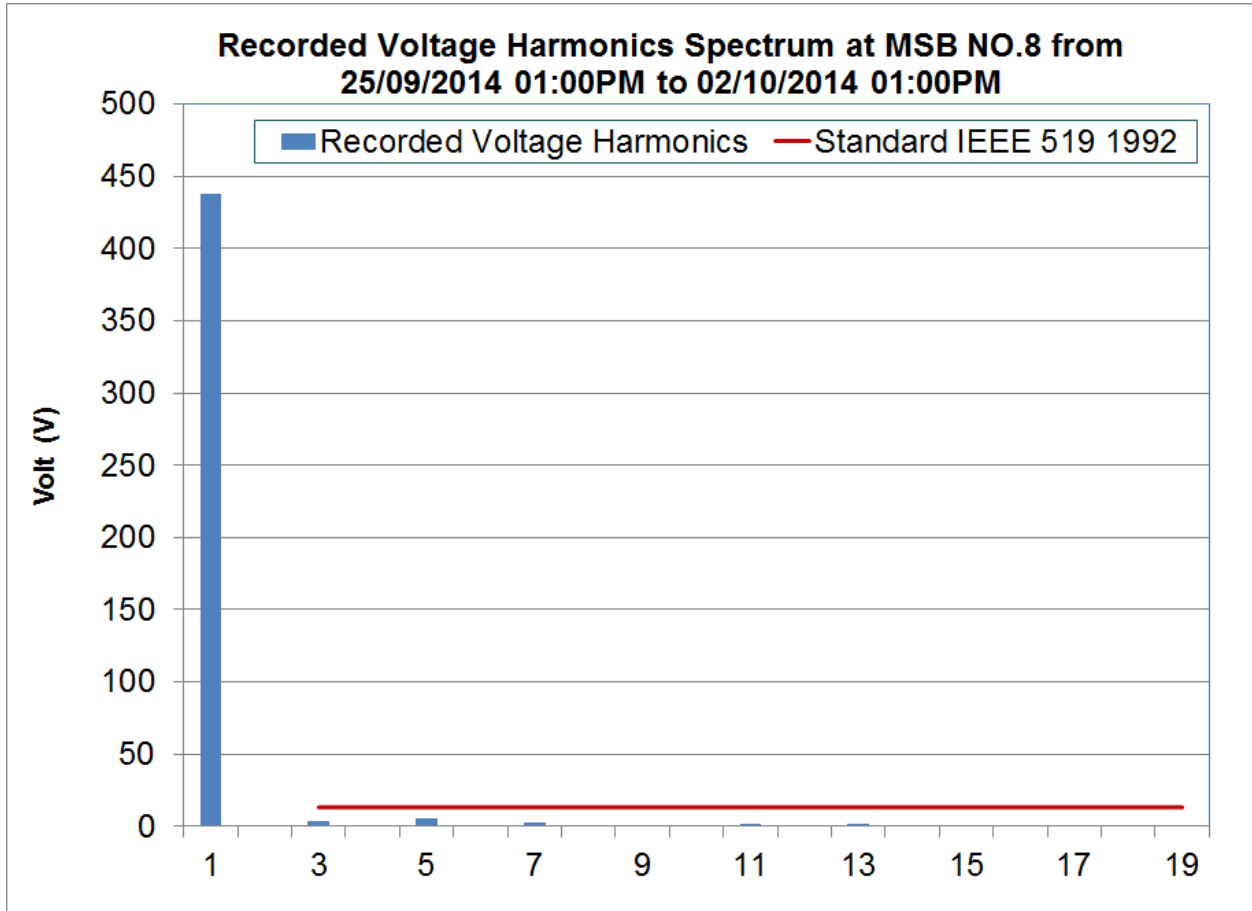
Recorded Voltage Harmonics Spectrum at MSB NO.8 from 25/09/2014 01:00PM to 02/10/2014 01:00PM

Harmonic Order	Voltage (V)	Percentage (vs Fundamental)	Standard IEEE 519 1992 (%)	Compliance
1	437.54			
3	3.38	0.81	3.00	COMPLY
5	5.82	1.40	3.00	COMPLY
7	2.63	0.63	3.00	COMPLY
9	0.60	0.14	3.00	COMPLY
11	1.56	0.38	3.00	COMPLY
13	1.68	0.40	3.00	COMPLY
15	0.00	0.00	3.00	COMPLY
17	0.50	0.12	3.00	COMPLY
19	0.12	0.03	3.00	COMPLY

Recorded Current Harmonics Spectrum at MSB NO.8 from 25/09/2014 01:00PM to 02/10/2014 01:00PM
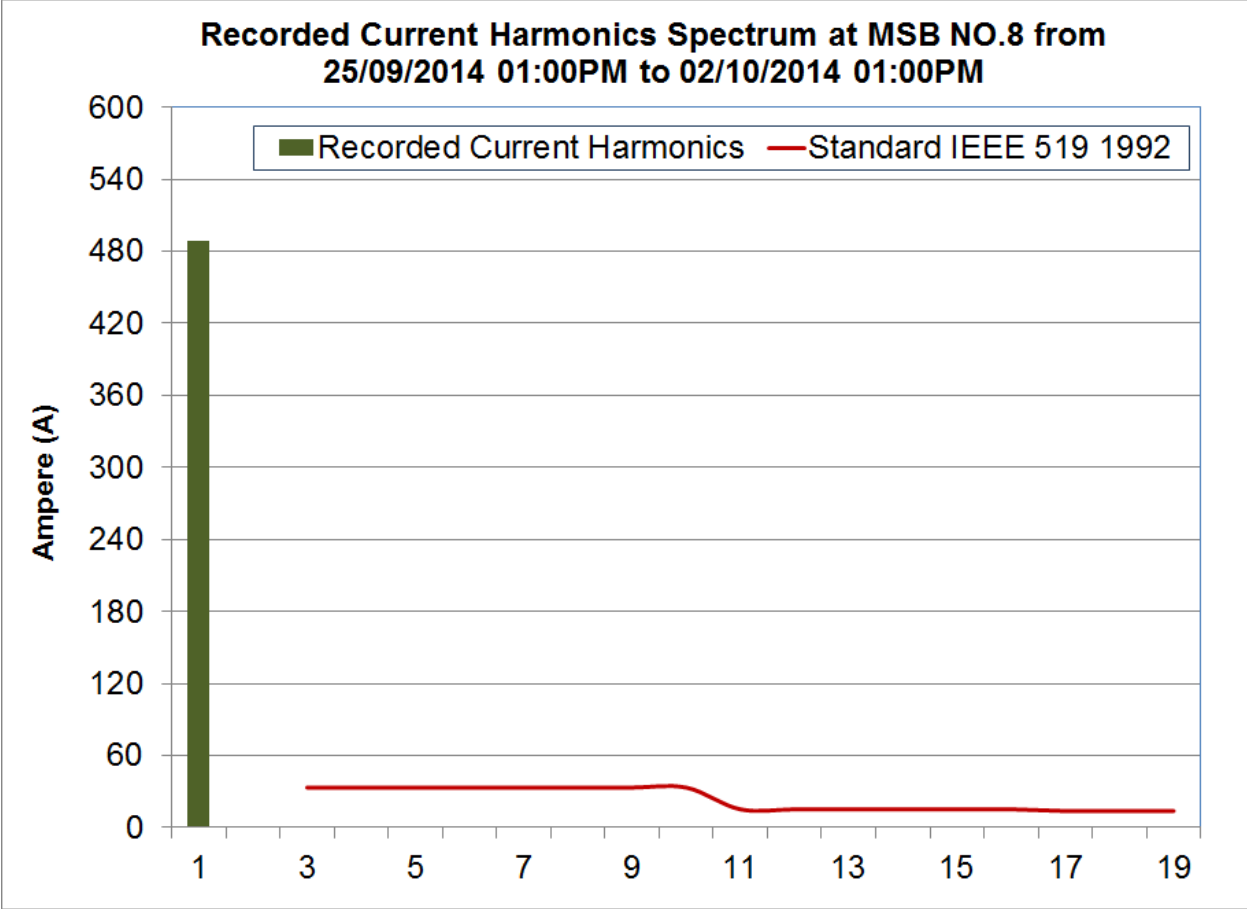
Harmonic Order	Current (A)	Percentage (vs Fundamental)	Standard IEEE 519 1992 (%)	
1	488.28			
3	0.00	0.00	12.00	COMPLY
5	0.00	0.00	12.00	COMPLY
7	0.00	0.00	12.00	COMPLY
9	0.00	0.00	12.00	COMPLY
11	0.00	0.00	5.50	COMPLY
13	0.00	0.00	5.50	COMPLY
15	0.00	0.00	5.50	COMPLY
17	0.00	0.00	5.00	COMPLY
19	0.00	0.00	5.00	COMPLY

4.2 Total Harmonic Distortion and Power Factor

Point	THDv (%)	THDi (%)	PF
1	2.92	0 (5%)	0.99 lag
2	13.03	0 (8%)	0.95 lag
3	4.60	68.07 (8%)	0.98 lag
4	1.64	12.57 (8%)	0.97 lag
5	2.87	29.54 (15%)	0.89 lag
6	7.9	41.09 (8%)	0.97 lag
7	2.28	12.91 (5%)	0.86 lag
8	7.62	0 (15%)	0.91 lag

From the above table we can see the effect of THDi on THDv. The data show that although there are no current distortion at that point, for example point 1 2 and 8 but there are some value for voltage distortion. The highest voltage distortion was recorded at point 2 although it current distortion is zero. The highest current distortion is at point 3. However at point 3, voltage distortion is remain under the limit.

Voltage distortion is recorded exceeded the limit which is 5% only at 3 point which are point 2, 6 and 8. While for point 2 and 8 the current distortion was recorded 0.

For current distortion there are 5 point that exceeded the limit stated by IEEE 519. Fortunately, the high current distortion at all those point is not effect much on the voltage distortion. Only 1 point from affected that their voltage distortion is exceeded the limit stated by IEEE 519.

All point of measurement also have good power factor which is more than 0.85 lagging which is good. As a conclusion the current distortion at each point in this case study seem like does not affect much on voltage distortion although they already exceeded the limit far away.

4.3 HARMONIC MITIGATION
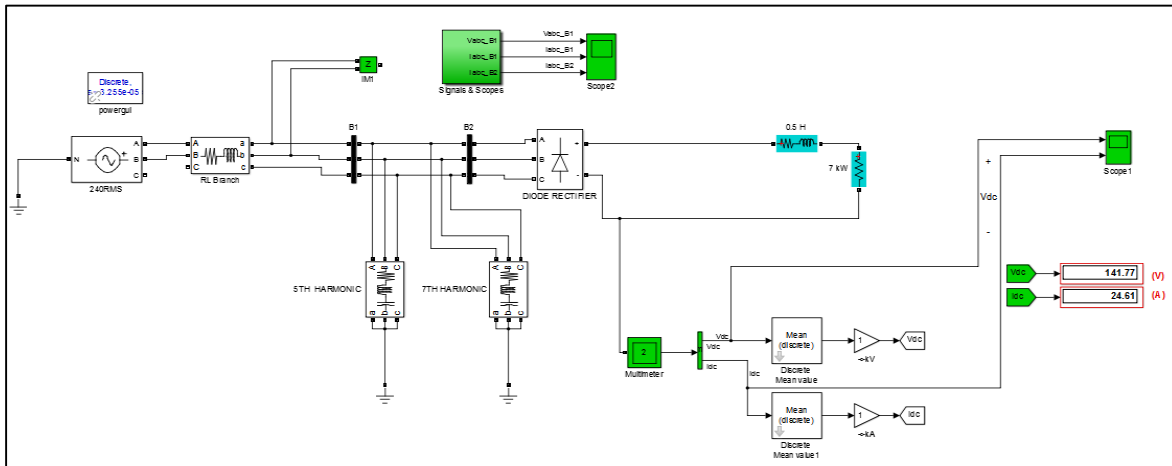
Using two single tuned filter in this simulation.
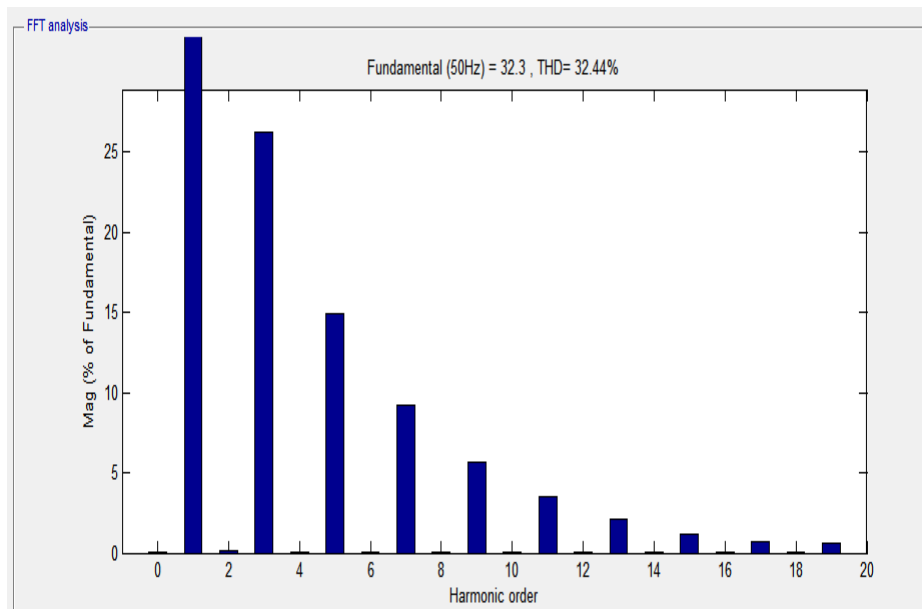

Figure 8: Simulation Circuit in Matlab

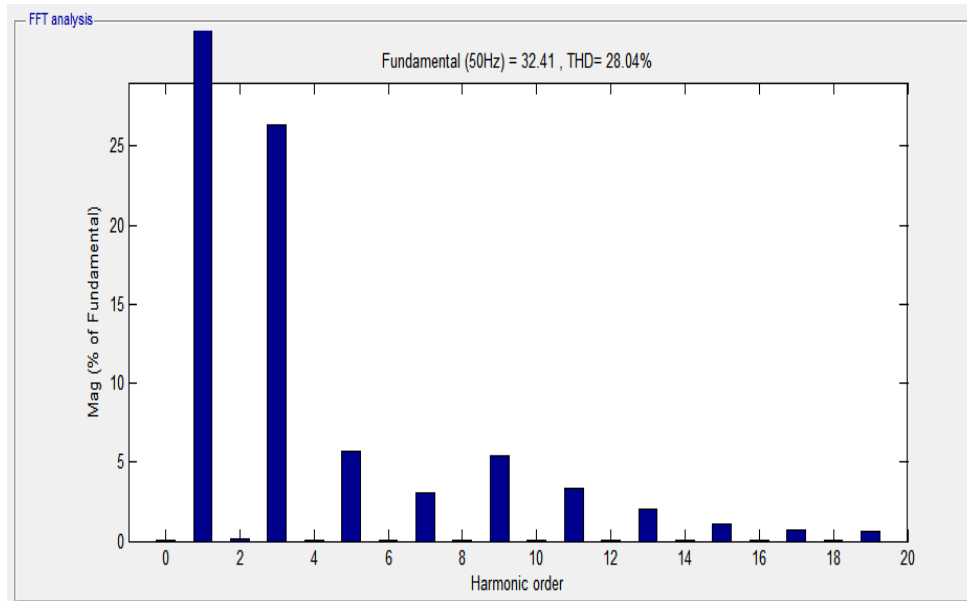*Figure 9: FFT analysis before install filter*

Figure 10: FFT analysis after install filter

	BEFORE (%)	AFTER (%)
THDi	30.30	28.04
5th	13.50	5.68
7th	7.96	3.06
THDv	15.53	19.59
5th	4.84	2.04
7th	3.72	1.44

CHAPTER 5: CONCLUSION

The main goal for this project is to study about harmonic in the power system. The author give more focus on non-linear load like rectifier to show their contribution in the current harmonic distortion. The author also got the real data for power quality measurement to do analysis. From the data that author got, the author suspected the place of case study already install the capacitor to compensate the voltage distortion only and to have higher power factor. But they did not care much on harmonic distortion which is almost of the point is exceeded the limit stated in the IEEE 519.

REFERENCES

[1] Abraham , A., & Cronje, W. A. (2012). Power Quality Surrounding Variable Speed Drives. Johannesburg: IEEE.

[2] Aditya, T. (2013). Research to study Variable Frequency Drive and its Energy Saving. *International Journal of Science and Research (IJSR), India Online*, 253-256.

[3] Chatt, B. (2006). *Power Quality Issue with Variable Speed Drive.* Texas.

[4] Ching , T. W. (2008). An Investigation on Electrical Performamce of Variable Frequency Drive for Air Conditioning Applications. *IEEE Electrical Power & Energy*.

[5] Liang , X., Luy , Y., & Don , O. K. (2007). *Investigation of Input Harmonic Distortions of Variable Frequency Drives.* IEEE.

[6] Marty Martin, P. (2014). *Two Modern Power Quality Issues-Harmonic and Grouding*. Retrieved from Copper Development Association: http://www.copper.org/applications/electrical/pq/issues.html

[7] Mistry , J. N., Solanki , H. D., & Vala , T. M. (2012). Variable Frequency Drive. *International Refereed Research Journal* , 252-256 .

[8] *Power Problems and Voltage Regulator Technologies*. (n.d.). Retrieved from Controlled Power Company : http://www.controlledpwr.com/help-regulator-technologies.php

[9] Verma , V., Singh , B., & Chandra , A. (2010). Power Conditioner for VFD in Offshore Oil Field. *IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS*, 731-739.

[10] Zhao, K., Ciufo, P., & Perera, S. (2014). Performance of Adjustable Speed Drives Subject to Regular Voltage Fluctuations. *IEEE*, 253-257.