An-Najah National University
Faculty of Graduate Studies

Impact of Battery Charging Station on Electrical Distribution Network: Study of the Harmonic Currents Impact and Mitigation Possibilities

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Dedication

I am thrilled to dedicate this work

To those who inspire me the most

My Husband

My Daughters

My Parents

My sisters and brother

My Family

My friends

…

Acknowledgments

In the current world of competition, there is no race for existence in which they have the will to succeed. The project is like a bridge between theoretical work and particle action. With this desire I joined this particular project, first of all, I would like to thank the Supreme Power, it is evident that Almighty God has always guided me to work on the one who has always guided me to work on the right path of life. Were it not for the grace of this project, it could not have become a reality, with my parents standing beside it, and I am very indebted to me to raise them with love and encouragement for this stage.I feel compelled to take the opportunity to sincerely thank Dr. (Moein Omar), a special thanks to my worthy teacher in Electrical Power Engineering. Moreover, I am strongly committed to taking the opportunity to sincerely thank my husband, daughters, brothers and brother for their generous attitude and friendly behavior. Last but not least, I am grateful to all of my teachers and friends who have always been helping and encouraging me to think about the year. I don't have precious words to express my thanks, but my heart is still full of blessings that I revive from everyone.

الإقرار

أنا الموقعة أدناه، مقدّمة الرسالة التي تحمل العنوان:

Impact of Battery Charging Station on Electrical Distribution Network: Study of the Harmonic Currents Impact and Mitigation Possibilities

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Signature: **التوقيع:**

Date: **التاريخ:** ٢٠٢١/١/٢٨

List of Contents

List of Tables

List of Figures

List of Abbreviations

ETAP	Electronic Teaching Assistance Program
MATLAB	MATH LABoratory
AC	Alternating Current
DC	Direct current
THD	Total Harmonic Distortion
RES	Residence
IEEE	Institute of Electrical and Electronics
PHEV	Plug-in Hybrid Electric Vehicle
HEV	Hybrid Electric Vehicle
BEV	Battery Electric Vehicle
EV	Electric Vehicle
LV	Low Voltage
MV	Medium Voltage
HR	Harmonic Ratio
SAE	Society of Automotive Engineers
CHADEMO	Charge De Move
IEC	International Electrotechnical Commission
V	Volt
A	Ampere
SOC	Short Circuit Current
VTHD	Total harmonic distortion of voltage
ITHD	Total harmonic distortion of current
ITDD	Total demand distortion of current
SVC	Static VAR Compensators
VFD	Variable Frequency motor Drives
RMS	Root Mean Square
KVA	Kilo Volt Ampere
XC	Capacitor's Reaction
APF	Active Power Filters
HPF	High Pass Filter
kW	Kilo Watt
Fig	Figure
TDD	Total demand distortion
PCC	Point common coupling

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Abstract

This thesis focuses on the impacts of electrical vehicle charging stations on electrical power networks. The generated harmonic currents have negative impacts on the power system components causing more losses and voltage profile modifications. This thesis represents the impacts of PHEV charging stations in different configurations of electrical networks. Each charging station consists a three phase full wave rectifier with DC/DC converter for charging regulation. A simulation model was programmed based on MATLAB Simulink to perform harmonic analysis in two different electrical configurations AC and DC electrical networks. In AC distribution systems the impact of charging stations in three different modes shows that the voltage is reduced from 400 V to 336V while the total harmonic distortion of current and voltage reduced to 20.4% and 6.73% respectively. On the other hand, in DC electrical networks the total harmonic distortion of current and voltage are 24% and 10.9% respectively. Moreover, ETAP software was used to analyze the impacts of charging stations on electrical network in two different cases to localize the charging station downstream and upstream. Finally, in order to mitigate the harmonics, passive filter was designed to mitigate the harmonic currents which resulting to reduce

that the total harmonic distortion of current and voltage reduced to 9.2% and 5.3% respectively.

CHAPTER ONE

INTRODUCTION

1- INTRODUCTION

1.1 Problem Statement

Adding charging stations to the electrical power grid leads to undesirable issues, mainly the harmonic currents which have negative impacts on electrical power networks that include voltage drops in destination points, increasing the power losses, and reducing the capacity of electrical network components [1,4,5].

The main source of harmonic currents of the supply network is the non-linear loads. The chargers of electric vehicle are adopting power electronics technologies mainly rectifiers used to convert the AC currents to DC required for charging the battery. The rectifiers are considered as highly non-linear equipment. The impacts of such chargers is significant in case of fast charging stations which requires high charging currents as well as if many charging stations operate at the same time.

This issue creates new challenges for a safe, stable and economical distribution network [4]. Therefore, doing research on the harmonic characteristic of charging stations can provide a theoretical basis for harmonic suppression, and this is extremely important for the promotion of electric vehicles.

The electric vehicle batteries must be charged to provide energy to cars mobility. Chargers for EVs are connected with in a three-phase system, representing a non-linear load. The problem with the non-linearity characteristic of EV charger is that it produces harmonic currents and affects the network power profile voltage [5]. Distortion may also occur in the form of a voltage wave that leads to a decrease the source voltage. Another problem that a non-linear load may cause is affecting negatively the performance of the distribution transformers, through increasing the energy losses in the windings which leads to a reduction in the power output [5]. Supplying electricity for the EV's chargers negatively impacts the power quality.

To date, research on the harmonic characteristic of the charging station is still in the exploration stage and the harmonic characteristic of the charging station depends on researching the harmonic model of single charger. The harmonic of single charger produced by the rectifier has been restored and thus the use of typical harmonic data of the rate as a symmetric result of the charging devices [4]. This method caused a fairly large error. [2],[4] use the measured current waveform of the charging machine at a certain fixed moment without considering the variation of harmonics over time. Over time, the charger's harmonic characteristic changes in the charging cycle [5]. The charging station must offer a simplified engineering algorithm. The harmonic model has been established corresponding the charging power, thus the harmonic characteristic during the whole charging period can be calculated which has an important significance. Stoats and his partner put forward a method to predict charging fleet of total harmonic current. The probability density is distributed for each harmonic amplitude of the charging station by relying on probabilistic mathematical methods. But to ensure accuracy, you need this method, which depends on the central limitation theory, which requires a large number of charger samples. however, the sample size is far less than enough, therefore the result of the analysis still need further validation. [1,2,4] discovered phenomenon that harmonic ratio (HR); total harmonic distortion (THD) reduced when the number of charging machines increases. It is considered that there is no further explanation and analysis from literatures on this phenomenon.

This thesis will study the harmonic currents and mitigation possibilities by presenting different charging stations configurations depending on the power converters used as rectifiers, modeling of the system, and perform simulation in order to study the main harmonic impacts and finding the suitable filter design used to mitigate the harmonics.

1.2 Motivation

This thesis represents the impacts of charging stations on electrical networks. The impacts of harmonic currents generated by such stations, because of using rectifiers used to convert AC power to DC power, are investigated. Moreover, the thesis represents the design and analysis of using passive filters to mitigate the harmonic and currents which reduces the total harmonic distortion (THD).

1.3 Objectives

●Develop of electrical model of electric vehicle charging process to simply the analysis.

●Make a comparison between to electric network DC and AC distribution.

●Use the developed model to indicate the harmonic currents impacts on electrical networks.

●Design of passive filter to mitigate the harmonic currents, and test the impacts of adding these Filter on electrical network.

1.4 Thesis structure

This thesis is organized into seven chapters including the current chapter.

Chapter 1 introduction about thesis subject, Electric vehicles, battery, and chargers. **Chapter 2** presents the impacts of rectifier harmonics on power systems components. **Chapter 3** represents harmonics impacts on power station, harmonic distortion, power factor, IEEE standards. **Chapter 4** represents the developed model of charging station harmonics which consists three phase uncontrolled rectifier with DC/DC converter. **Chapter 5** tests the developed model to illustrate harmonic impacts on AC and DC electrical networks and shows the impacts of multiple charging station on standard IEEE 33bus network by ETAP analysis**. Chapter 6** shows the mitigation of harmonics by using of passive filters and identifies the impacts of such filters on the electrical network. **Chapter 7** represents the future work and conclusions. **Appendix A:** line and load data of IEEE 33 bus system. **Appendix B**: Load flow report When put 12.66kV at downstream. **Appendix C**: Harmonic report when put 12.66kVat downstream. **Appendix D:** load flow report when put 12.66 kV at upstream. **Appendix E:** harmonic report when put 12.66kVat upstream. **Appendix F:** All figure harmonic report when 12.66kVat upstream & 1 rectifier. **Appendix G:** load flow report when put 12.66kV at upstream and two rectifiers. **Appendix H:** All figure harmonic report when 12.66kV at upstream & two rectifiers. **Appendix I:** All fig. harmonic for case two rectifiers without any pulse.

CHAPTER TWO
ELECTRIC VEHICLES AND CHARGERS

2- ELECTRIC VEHICLES AND CHARGERS

2.1 Background

Electric vehicles (EVs) have gain a great interest in order to achieve reduction in the air pollution in urban areas. Many benefits of EVs such as saving the environment, reduce petroleum consumption become concerns of governments around the world [1,2]. Moreover, the development of new energy vehicles has become an indispensable option for the world's governments is contributing to the development of the local car industry and improving the competitiveness of the national economy because in recent years, the petroleum price has increased year after year due to a shortage of oil resources. [1]. The typical layout of an electric vehicle with charging station is depicted in Figure 2.1.

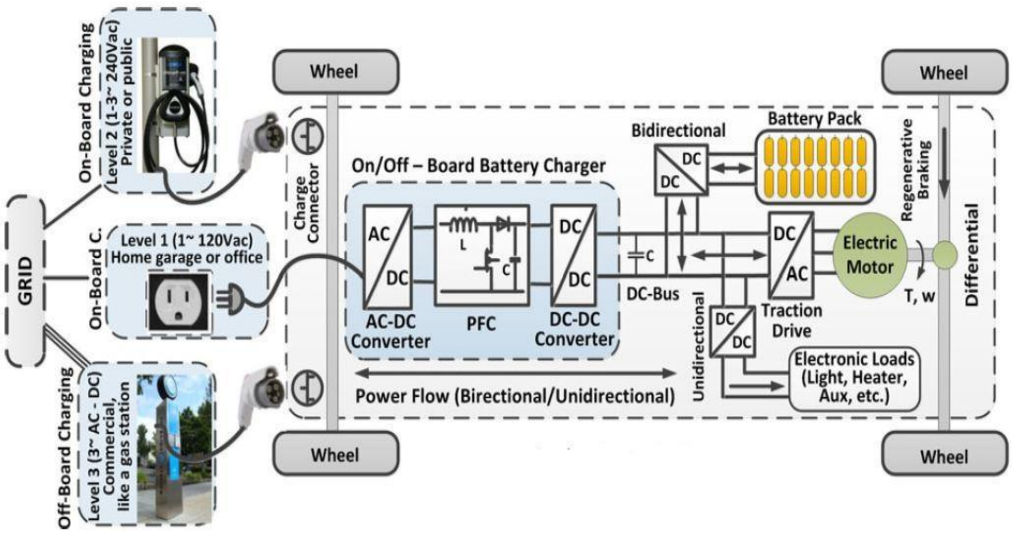


Fig 2.1: Electric vehicle with charging station [2]

2.1.1 Types of electric vehicle

There are three types of electric vehicles, the first type is plug-in-hybrid electrical vehicle (PHEV). It has an internal combustion engine (ICE) and electric motor, where the battery of the vehicle can be charged from the engine as well as from the grid. The second type hybrid electrical vehicle (HEV) is similar to PHEV but can’t be charged from the grid, it is charged only from the rotation of the engine. Therefore, there is no charging connector. The battery electrical vehicle (BEV) does not have a fossil fuel engine or generator. It is driven purely by an electric motor with battery energy storage.

From previous types, PHEV and BEV can be charged from electrical power networks, where, the AC power converted to DC power is suitable to charge the battery of these vehicles. Integration of such vehicles into the electrical power distribution system is on the rise. Therefore, many challenges and drawbacks effects to the system. Mainly, the integrating the PHEV into the power distribution system lead to increased harmonic voltage and current distortions [1,2]. Moreover, the widespread integration of PHEV is a challenge for the power system operators because most electric vehicles are fully or partially charged with electricity which makes it for a long time connected to the distribution network [1]. Some studies have shown that without any kind of mitigation, the PHEV charging causes the electrical network to incur additional loads, which leads to an increase in the combined load within hours and therefore affects the overall reliability of the network. The main issue need to be addressed; the power quality issues they may causing service interruptions and harmonic distortion in voltage and current waveforms [6]. Harmonic currents may cause abnormal conditions such as increasing system losses, impacts power system components such as de-rating power transformer, and failure some of electric equipment such as protective devices and rotating electrical motors.

A distortion system may cause significant harmonic distortion in network voltage due to harmonic current due to a high number of single-phase electronic loads.

2.1.2 EV battery

Every electric vehicle is equipped with an energy store to provide the vehicle's motive power. The rechargeable battery system is the most common type of energy storage used in commercial electric vehicles. There is a difference from one company to another manufacturer in terms of cell technology, configuration and battery pack capacity. For example, in 2016 Nissan leaf model S electric car is equipped with a 24kWh Li-Ion battery of 192 cells [2,3] will as shown in Table 2.1below the battery pack main parameters list.

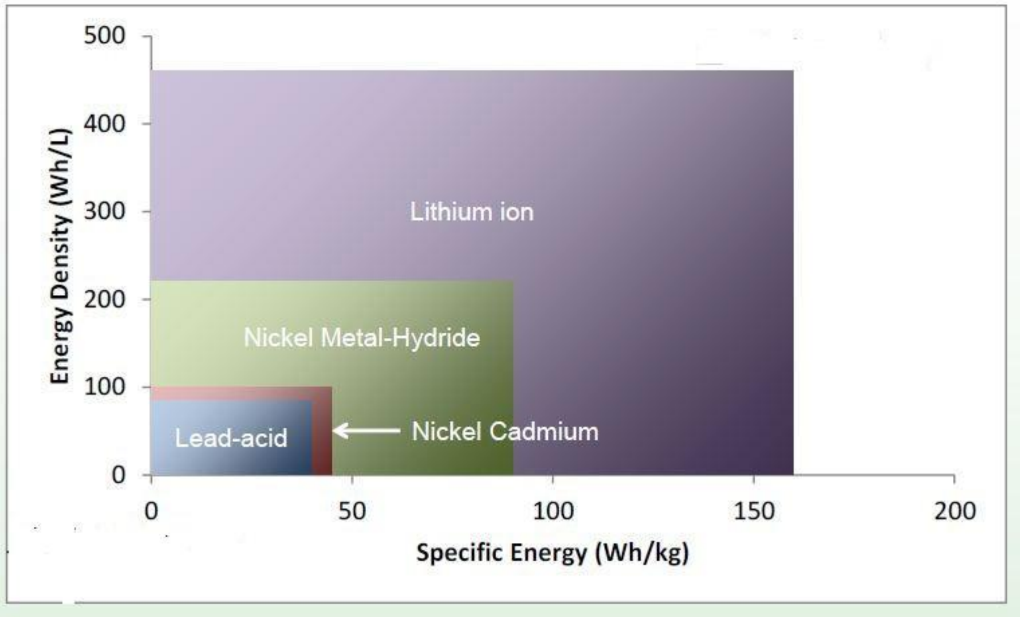


Fig 2.2: Comparison of battery technologies [2]

Improvements in battery technology have paved the way for the rapid growth of the electric vehicle market. One of the most important key critical parameters for battery performance is energy density, which is defined as the amount of energy stored in a unit volume of electrolyte. Figure 2.2 illustrates the comparison of the energy densities of commercially available battery technologies. Currently, Li-Ion technology is considered to have the highest energy density economically possible and thus allows more energy in a particular cell. Moreover, using of lithium-ion batteries in electric cars have several advantages, including higher efficiency, higher specific energy and lower density. One of the advantages of this feature is that it improves the miles traveled by an electric vehicle to attract more consumers to the electric vehicle market.

Table 2.1: Lists of the main parameters of battery pack of 2016 Nissan leaf model [2,7]

Parameter	**Value**
Nominal Battery Capacity	24kWh / 66Ah
Nominal Voltage	360 V
No. of cells	192
No. of Modules in Series	48
Cell configuration in a module	2 in series and 2 in parallel
Electrolyte	LiPF6 EC type

The nominal voltage of lithium-ion is 3.75V/cell. Therefore, for each module the nominal voltage amounts to 2x3.75= 7.5V. The nominal voltage of battery back amounts to 7.5x 48 =360V.

2.1.3 Electric vehicle charger

The battery of the electric car must be recharged as in the case of refueling a conventional car, in order to continue moving. Thus, electric vehicle charging is classified into two categories, on-board and off-ship charging. All the charging infrastructure and control are located inside the vehicle is on- board charging while theoff board charger is located outside the vehicle. In any case, source shall be utility grid, either LV or MV whereas the battery charging current is a regulated DC current.

Since regulated DC current and voltage shall be applied to the battery, power electronic converters are used to convert AC voltage to DC voltage. The charging capacity depends on the battery capacity and level of the charger. Number of charging levels and standards will be discussed in the later parts of this section. The EV charger is used to convert the utility AC inlet into a DC regulated output as shown Figure 2.3. Waveform at the point of common coupling shall be maintained at desired limits. Power electronic converters along with closed loop control system are equipped with an EV charger.

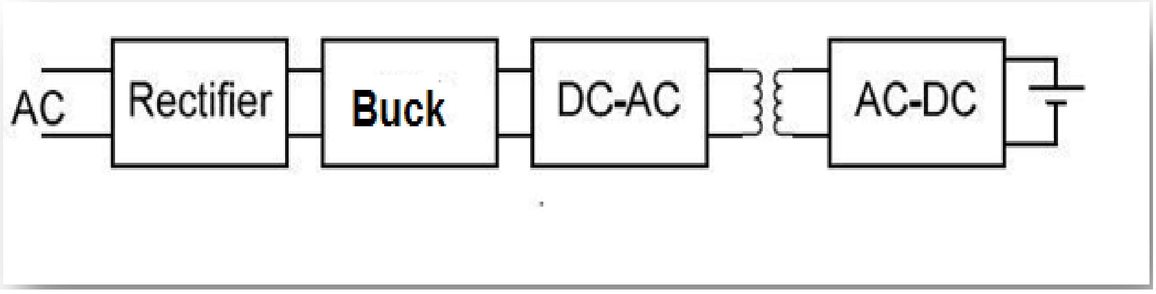


Fig 2.3: Block diagram of Level 2 charger.

2.1.4 Charging standards and levels

The battery terminals are equipped with a DC voltage to charge the battery. Usually, the utility predominantly is AC and therefore it needs to be converted into DC to meet the changing requirements.

There are two types of charging, inductive/wireless charging and connector charging. In inductive/wireless charging, there is no physical connection between the vehicle and the source during the charging. conductive, In the conductive charge the power source and the electric vehicle are connected.

The most common charging method is conductive charging at present. Stable charging has become common in recent years.

There are international standards that define electric vehicle charging levels of charging energy, associated with transportation and various configurations. NEC 625 standards are common in North America, while IEC-62196 and IEC-61851 are common in Europe. In the United States, the Society of Automotive Engineers (SAE) developed standard power connectors and also specified charging power levels. The Japan Institute has developed the Charge De Move (CHAdeMO) charging protocol that is very popular in high-power DC charging.

IEC standards for electric vehicle charging determine four charging modes based on voltage level, power source type, control lines, presence or absence of grounding and protecting device.

The type of power source can be either DC or single-phase / three-phase AC. In our research, we used the three-phase AC type where the voltage level is about 220V single phase, or 400 V in three phase.

The four modes of EV charging are described as follows:

Mode 1: slow charging from a household-type socket-outlet in AC.

Mode 2: slow charging from a household-type socket-outlet with an in-cable protection device in AC.

Mode 3: slow or fast charging using a specific EV socket outlet with control and protection function installed in AC.

Mode 4: fast charging using an external charger in DC.

Table 2.2: Lists the charging connection and power levels as per IEC-62196 a IEC-61851. [3,9]

Charging Mode	Connection	Power (kW)	Maximum Current (A)	Charger Location
Mode 1	Single phase AC	<3.7	16	ON Board
Mode 2	Single or three phase AC	3.7-22	32	ON Board
Mode 3	Three phase AC	>22	>32	Off Board
Mode 4	DC	>22	>32	Off Board

CHAPTER THREE

HARMONIC IMPACT ON POWER STATION

3- HARMONIC IMPACT ON POWER STATION

The harmonic ~~s~~ current is created by nonlinear loads, which generated by a non-sinusoidal current in the power distribution system. The current waveform is often distorted by an increase in electronic and other nonlinear loads. Through wave harmonic analysis, the distorted waveform is analyzed to understand the phenomenon of distortion [10]. A distorted waveform is the sum of the DC components, the basic sine wave, and a series of pure sine waves. These sinusoidal waves are with different amplitudes, and their frequencies are integer multiples of the basic distorted wave shape. In this chapter, we analyze the harmonics. The distorted waveform, effective value, total harmonic distortion (THD) and harmonic effect on power factor are analyzed by Fourier series. It also shows the symmetrical component properties and their relationship with the harmonic sequence in the three-phase distribution system. The end of this chapter is to describe the current harmonic generation by a three-phase rectifier.

Harmonics are periodic fixed voltage condition distortions and current waveforms in the power system [Gary W. Chang, 2001] [11]. The purpose of this chapter is to present the basic harmonic theory. Initially, the Fourier series and the method of analysis are reviewed. We then describe the theory of general harmonics, harmonic definitions, and harmonic indicators in common use, and energy system response.

The main source of ~~the~~ harmonics is any non-linear load ~~s~~ that produces voltage and current harmonics. Some examples of common sources of power distribution system harmonics which causing serious problems are fluorescent lighting, computer switch mode power supplies, static VAR compensators (SVC), variable frequency motor drives (VFD), DC-DC converters, inverters and television power supplies [12].

3.2 Harmonic Impacts on Power System Components

The distortion effect on energy supply systems is serious because the flow of current in the system increases. After all, the harmonic current does not save power but consumes the system- capacity and reduces the loads that can be operated [13].

When the harmonic current occurs in the facility, it causes equipment failure, data distortion, transformers warming, engine isolation failure, high neutral bus temperature, circuit breakers failure, and solid-state component collapse. The cost of these problems can be enormous.

Harmonic currents increase heat loss in transformers and wires. The impedance depends on the frequency which increases, with the harmonic number. The frequency of the fifth harmonic is five times the base frequency. So each ampere of the fifth harmonic current causes the fifth times the ampere affecting much electrical equipment, machines, and engines [14].

3.2.1 Effects of harmonics on transformers

Voltage has a significant contribution to the additional heating and distorts harmonic current in particular. Three effects result in increased transformer heating when the load current includes harmonic components [15]: RMS current: Harmonic currents can cause the transformer's RMS current to rise above its capacity if the converter size meets only the KVA load requirements. Increased RMS current results increase in conductor losses and Eddy current losses. Currents induced in transformers are produced by magnetic flows and flow in the coils, in the core, and other connected objects exposed to the transformer's magnetic field and cause additional heating. This component increases the transformer's losses with the current frequency square that causes Eddy current. Therefore, it is an important component of the transformer losses for harmonic Heating. Core losses: The increase in core losses in the presence of harmonics depends on their effect on the applied voltage and the transformer core design, an increase in voltage distortion leads to an increase in eddy currents in the core laminations [16]. The net effect depends on the thickness of the core laminations and the quality of the core steel. Increasing the losses from the harmonics is not as important as the previous two items.

3.2.2 Effects of harmonics on lines and cables

A major issue with the harmonics is: increase losses and heating, serious damages in the dielectric for capacitor banks and cables, the appearance of the corona (the amount of the ionization of the air around the conductor or the transmission line) due to higher peak voltages and corrosion in aluminum cables due to DC.

3.2.3 Effects of harmonics on converter equipment

Equipment is considered as switches or on-off equipment due to current and voltage switching by some devices such as diodes and thyristors [17]. These converters switch the current, so they create cracks in voltage waveforms that cause a defect in the thyristors and create other unordered releases of the other thyristors in the device, which may affect the synchronization of other converter equipment.

3.2.4 Effects of harmonics on capacitor banks

It is well known that the power suppliers and customers use capacitors to improve the power factor. There is a medium range of the frequencies in which they are at capacitive and inductive effects that can combine to give very high impedance. Resonance is a small harmonic current in the frequency range and provides harmonic voltage too high and undesirable [18].

From the perspective of harmonic sources, at harmonic frequencies, shunt capacitors appear to be in parallel with the equivalent system inductance, the nearest point is the additional installation. At the frequency in which the capacitor's reaction X_C and the whole system's reactor are equal, the apparent impedance of the parallel combination of inductance and capacitance becomes too large. This results in a typical parallel resonance condition.

3.3 Power Quality Limits

IEEE standard 519 was first introduced in 1981 to provide direction on dealing with harmonics introduced by static power converters and other nonlinear loads so that power quality problems could be averted. IEEE 519 defines three parameters with respect to harmonic distortion [19,25].

$$THD_V = \sqrt{\frac{V2^2+V3^2+V4^2+\cdots}{V1^2}} \times 100\% \qquad (1)$$

$$THD_I = \sqrt{\frac{I2^2+I3^2+I4^2+\cdots}{I1^2}} \times 100\% \qquad (2)$$

where:

THD_V _Total harmonic distortion of voltage.

THD_I _ Total harmonic distortion of current.

V_n _ rms value of nth harmonic of voltage (current).

IEEE 519-2014 standards shown in Table 3.1 for Current distortion limit for general distribution systems (120V through 69000V).

Maximum harmonic current distortion in percent of I_L Individual harmonic order (Odd Harmonics).

Note: these values are not recognized by us.

Table 3.1: IEEE 519 Limits for current harmonics [3]

$\frac{I_{sc}}{I_L}$	**3≤n<11**	**11≤n<17**	**17≤n<23**	**23≤n<35**	**35≤n**	**TDD**
<20*	4	2	1.5	0.6	0.3	5
20<50	7	3.5	2.5	1	0.5	8
50<100	10	4.5	4	1.5	0.7	12
100<1000	12	5.5	5	2	1	15
>1000	15	7	6	2.5	1.4	20

$$TDD = \frac{\sqrt{\sum_{n=2}^{\infty} I_n^2}}{I_L} \times 100\% \qquad (3)$$

Where:

TDD = total demand distortion.

I_{sc} = maximum short-circuit current at PCC.

I_L = maximum demand load current (fundamental frequency component at PCC).

(n): harmonic order.

CHAPTER FOUR

DEVELOPED MODEL OF FAST CHARGING STATION

4- DEVELOPED MODEL OF FAST CHARGING STATION

This chapter represents the modeling of fast charging station which consists of three phase uncontrolled full-wave rectifier with DC/DC converter in order to control the voltage and current required to charge the vehicle battery depending on the charging process requirements, constant current and constant voltage. Fig.4.1 shows the power converters used in the charging station.

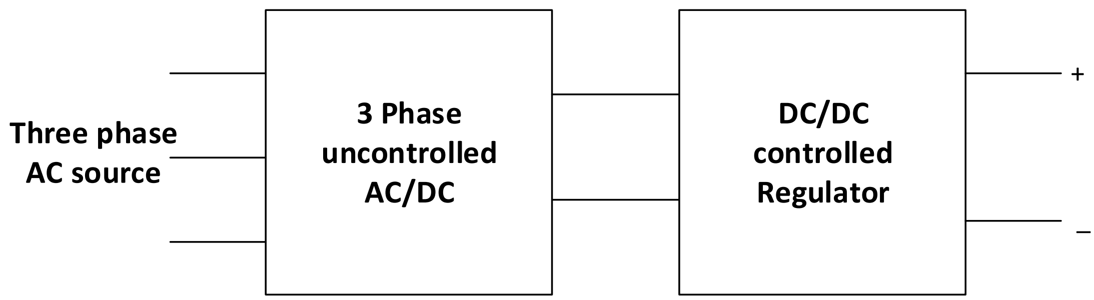


Fig.4.1: Schematic diagram of charging converters

4.1 The Three Phase Uncontrolled Full Wave Rectifier

The following circuit in Fig.4.1 represents three phase uncontrolled rectifier consisting of six diodes used in the first conversion stage AC to DC.

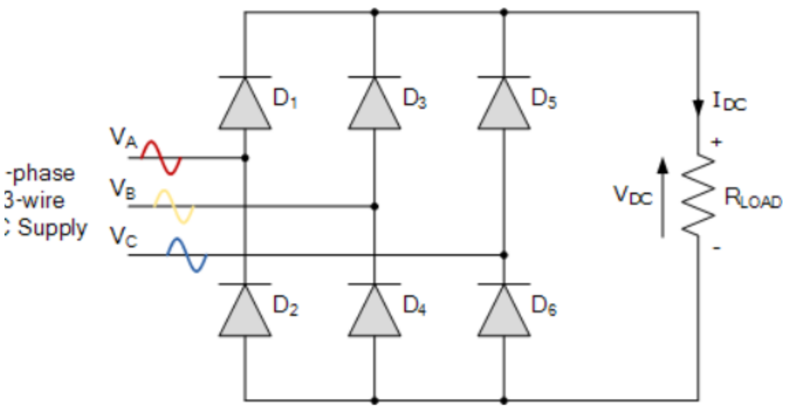


Fig. **4.2**: Three phase uncontrolled rectifier

4.2 Calculating of AC/DC Rectifier Parameters

The derivation of the equations can be obtained from the Fig 4.3 to calculating the average output voltage of AC/DC rectifier

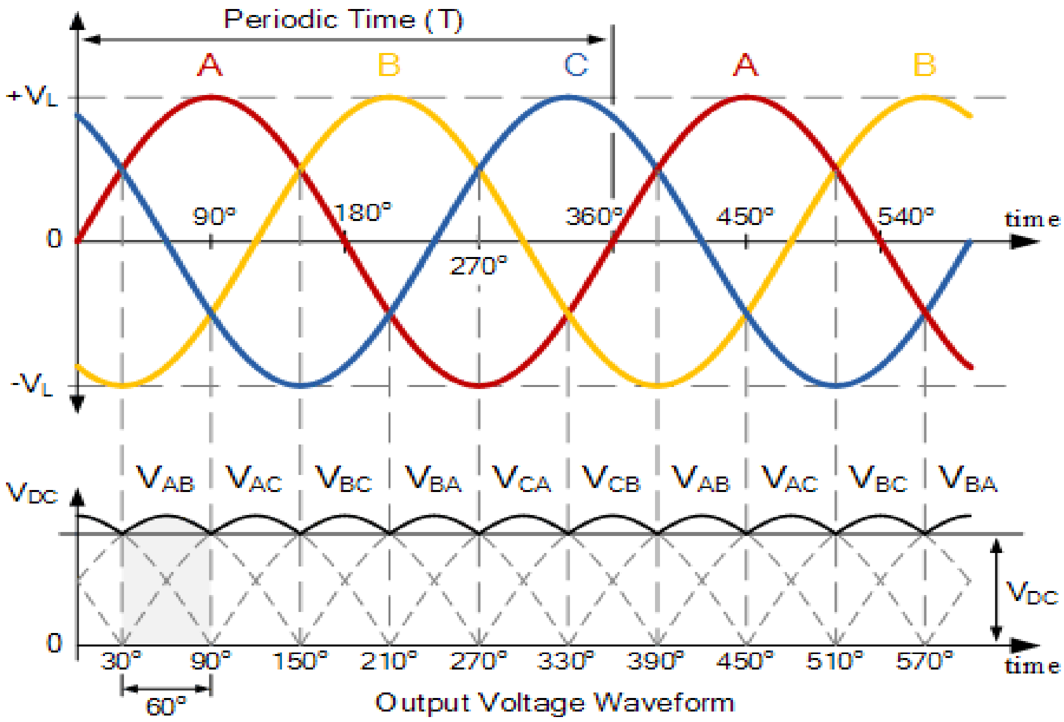


Fig 4.3: Output voltage waveform

Calculating the average output voltage of AC/DC rectifier

$$V_{dc} = \frac{6}{2\pi}\int_{\frac{\pi}{6}}^{\frac{\pi}{2}} \sqrt{3}\,V_p \ \ sin\left(\omega t + \frac{\pi}{6}\right) d\omega t$$

$$V_{dc} = \frac{6}{2\pi}\sqrt{3}\,V_p = 1.65\,V_p$$

(4)

Calculating the power factor:

In case of output constant current **(**I_{dc} **)**

$$3 * \frac{V_p}{\sqrt{2}} * \sqrt{\frac{2}{3}} * I_{dc} * P.F = V_{dc} * I_{dc}$$

$$\mathrm{P.F} = \frac{V_{dc}}{3*\frac{V_p}{\sqrt{2}}*\sqrt{\frac{2}{3}}} = \frac{1.65V_p}{\sqrt{3}\,V_p} = 0.95 \qquad (5)$$

Fourier series analysis:

A distorted waveform can be analyzed using Fourier series representation given as the following equation

$$f(t) = F_0 + \sum_{n=1}^{\infty} f_{n(t)} = \frac{1}{2}A_{dc} + \sum_{n=1}^{\infty}(a_n \cos h\omega t + b_n \sin h\omega t) \qquad (6)$$

where:

f(t) is called non sinusoidal periodic of the function

$$A_{dc} = \frac{1}{2\pi}\int_0^{2\pi} f(t)\, d(\omega t) \qquad (7)$$

$\omega = \frac{2\pi}{T}$ and T is periodic of the function f(t) and $T = \frac{1}{f}$

f = frequency

a_n and b_n is series coefficient that can be determined as follow:

$$a_n = \frac{1}{\pi}\int_0^{2\pi} f(t)\cos(n\omega t)\, d(\omega t) \qquad \mathbf{n} = 1, 2, 3, ..$$

$$b_n = \frac{1}{\pi}\int_0^{2\pi} f(t)\sin(n\omega t)\, d(\omega t) \qquad \mathbf{n} = 1, 2, 3, ..$$

where:

ω is angular angle

π constantan (=3.14)

t is time

4.3 DC/DC Regulator, Buck Converter

As the average DC voltage from the first conversion stage AC/DC converter is larger than the battery required voltage, the buck converter is used to charge the battery. To simplify the simulation process, the battery is represented as a resistor depending on the voltage and current used in charging process. This resistor is on the low voltage side of DC/DC regulator. It can be reflected to higher side of the converter by using the following equations:

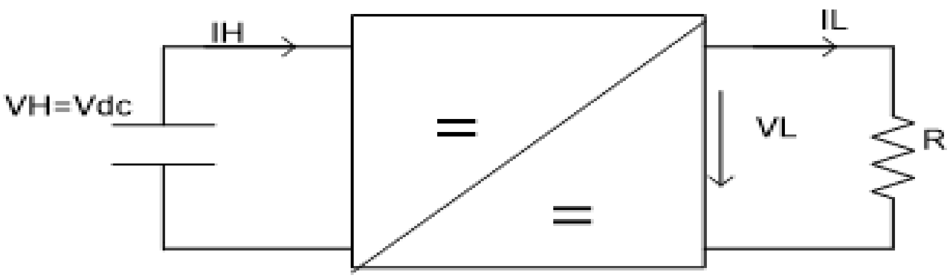


Fig.4.4: Block diagram DC/DC buck converter

$$V_L = D * V_H$$

Assuming the converter lossless ideal converter:

$$V_H * I_H = V_L * I_L$$

$$\frac{V_H}{V_L} = \frac{I_L}{I_H} = \frac{1}{\mathrm{D}}$$

$$R_L = \frac{V_L}{I_L}$$

$$R_H = \frac{V_H}{I_H}$$

$$\frac{\frac{V_L}{\mathrm{D}}}{\mathrm{D} * I_L} = \frac{V_L}{I_L * \mathrm{D}^2}$$

$$R_H = R_L * \frac{1}{\mathrm{D}^2}$$

4.4 Representation of Charging Process

The charging process is shown in Fig.4.5; it can be seen that the constant current is used for charging the battery with high current after that the constant voltage is used where the current is reduced as the battery becomes near fully charged.

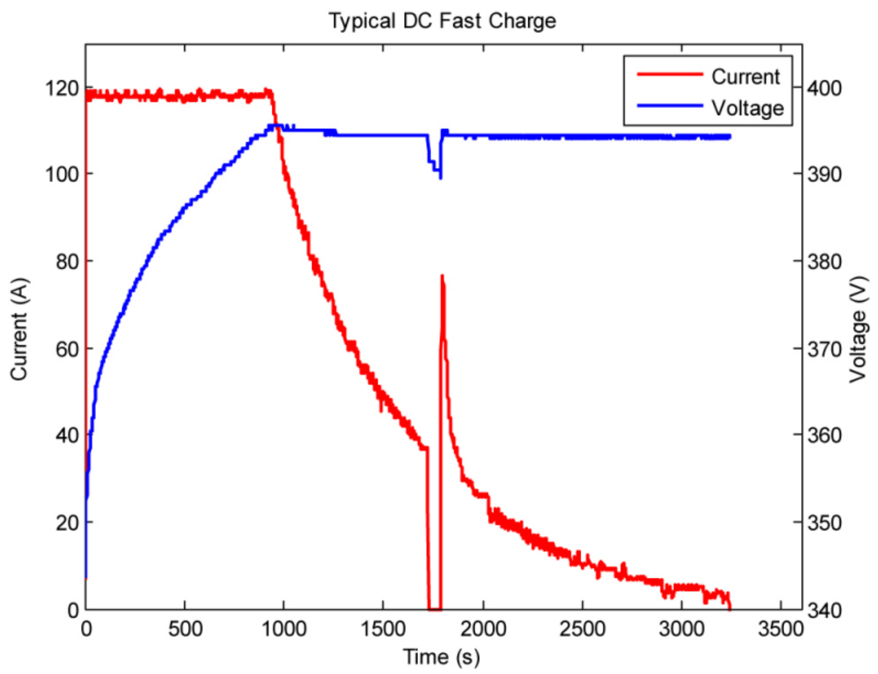


Fig 4.5: DC fast charging for a 2012 Nissan Leaf charged with a 50kW fast charger

The values of current and voltage with respect to charging time are listed in Table 4.1 .As shown the charging process starts first with constant current mode with supplying 120 A, during this period the voltage increases fast to reach 395 V. Thereafter the constant voltage mode is used to complete the charging process. Extracting the values of current and voltage from the figure to illustrate them in the following table:

Table 4.1: Charging process parameters

Time (sec)	Voltage (V)	Current (A)	Resistance (Ω)
250	375	120	3.12
500	385	120	3.20
1000	395	120	3.29
1250	395	70	5.64
1500	395	50	7.90

The three-phase uncontrolled rectifier connected to 400V line to line voltage, the peak voltage of phase voltage amounts to 325V (peak). The average output voltage of the rectifier as is equation (4) will be 1.65Vp.

Therefore, the average voltage will be 537.2V. This voltage is greater than the battery voltage then we use buck converter to match between the battery and the rectifier and to control the current and voltage. For simplifying the model, the DC/DC buck converter model is replaced by reflecting the value of the resistance in Table 4.2.

Table 4.2: The value of resistance on high voltage side

Rectifier output voltage	Battery voltage (V)	Duty ratio	Resistance (Ω) on the high side
537.2	375	0.70	6.41
537.2	385	0.72	6.25
537.2	395	0.74	6.09
537.2	395	0.74	10.44
537.2	395	0.74	14.61

CHAPTER FIVE
ANALYSIS OF HARMONIC CURRENTS AND IMPACTS ON DIFFERENT ELECTRICAL NETWOR

5- ANALYSIS OF HARMONIC CURRENTS AND IMPACTS ON DIFFERENT ELECTRICAL NETWORK

This chapter deals with the proposed model of charging station in chapert4 and adapt such model to figure out the impacts of charging station on different networks represented in low voltage network with AC/DC and higher network with AC.

5.1 Charging station in LV distribution network

5.1.1 DC distribution system

It can be seen in Fig 5.1 that the rectifier converts the AC power to DC power which is transmitted to three different nodes. The harmonic currents are only in the input of the AC/DC rectifier. On the DC distribution system there are no harmonic currents as the system is DC .

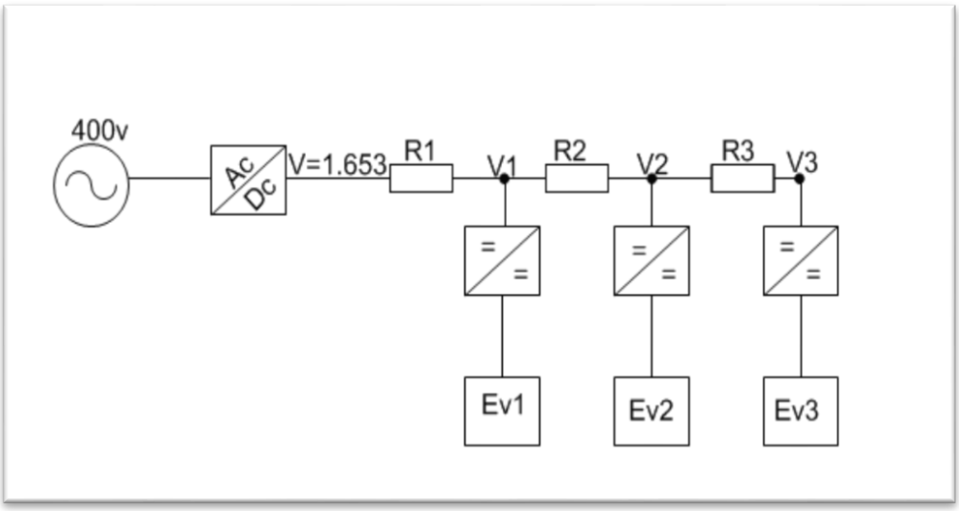


Fig 5.1: DC- distribution network

The voltage waveforms are shown in Fig. 5.2 and its harmonic spectrum is shown in Fig. 5.3.

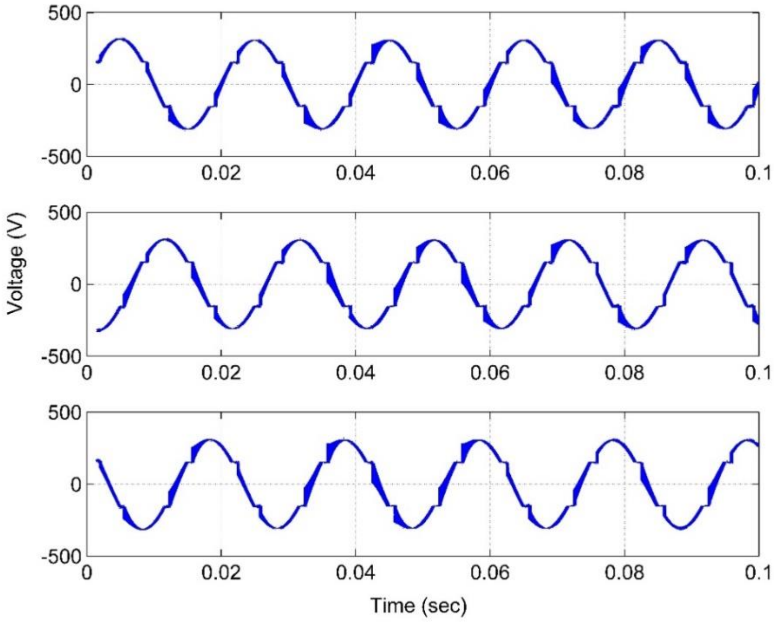


Fig 5.2: DC distribution system three phase voltage waveforms (V)

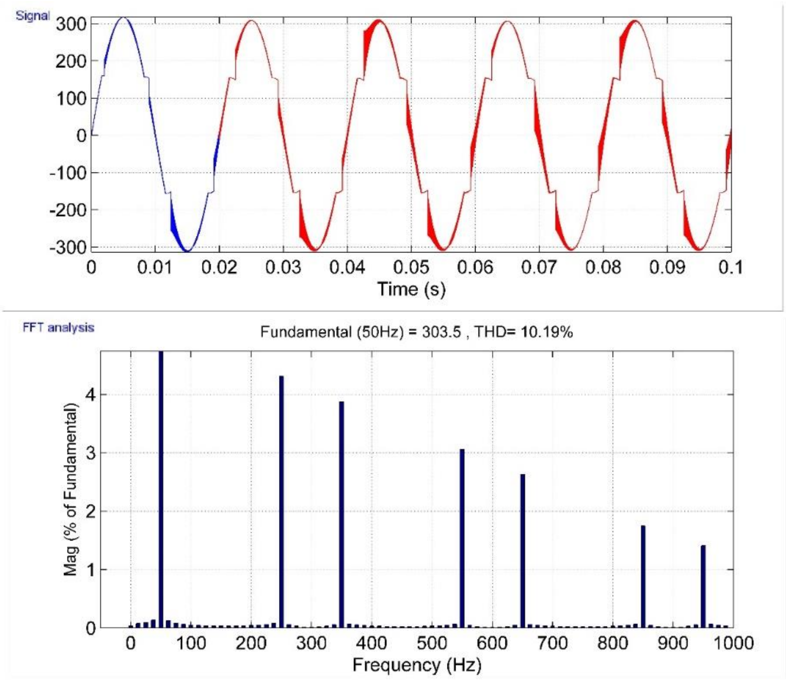


Fig 5.3: Fast Fourier analysis of voltage waveforms (V)

It can be seen the total harmonic distortion of voltage waveform amounts to 10.19% and this percent depends on the harmonic contents of currents waveforms explained in the next figure. The AC currents waveforms are shown in Fig.5.4. These waveforms are non-sinusoidal currents with high harmonic contents.

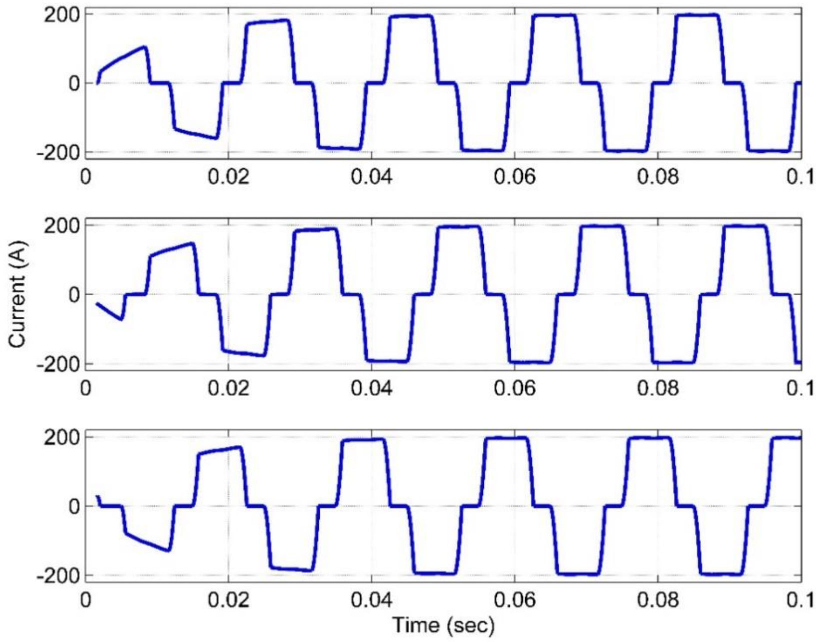


Fig.5.4: DC distribution system PCC current (A)

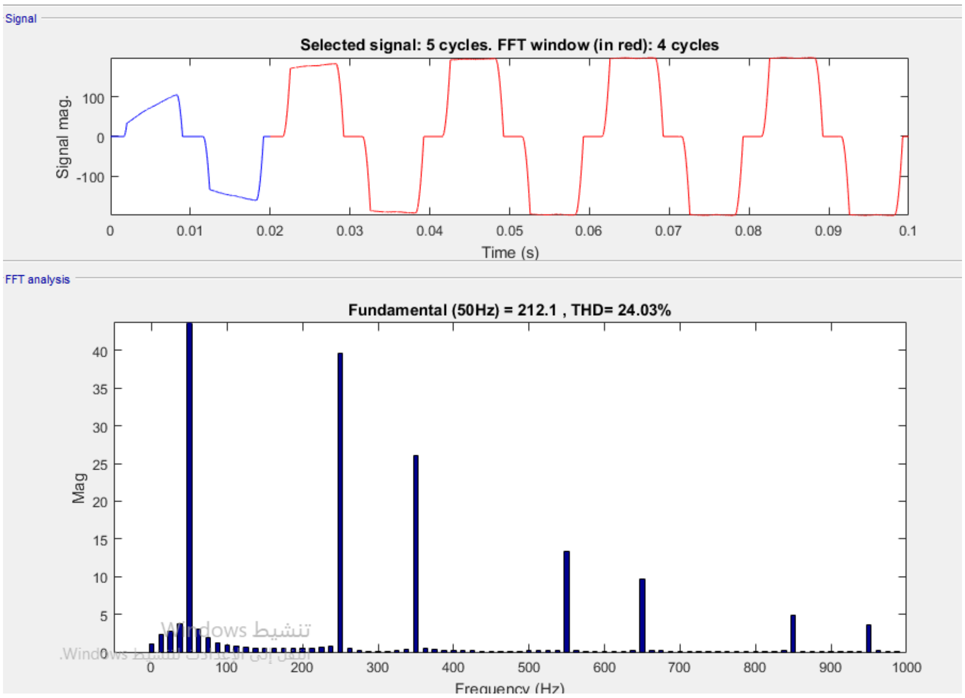


Fig 5.5: Fast Fourier spectrum DC distribution system PCC current (A)

In Fig 5.5, the FFT analysis shows the spectrum of the phase current. The fundamental component with 212.1A, the fifth harmonic component h5 amounts to 39.69A and the value decrease to reach 3.57A at h=19. The harmonic contents especially in lower frequency components results to have high THD which amounts to 24.03%.

5.1.2 AC distribution system

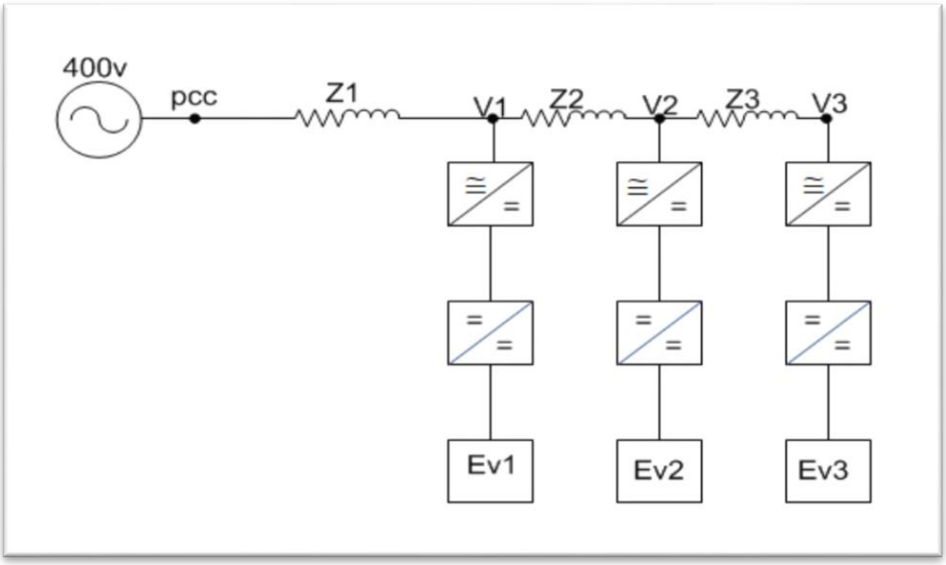


Fig. 5.6: AC- distribution network

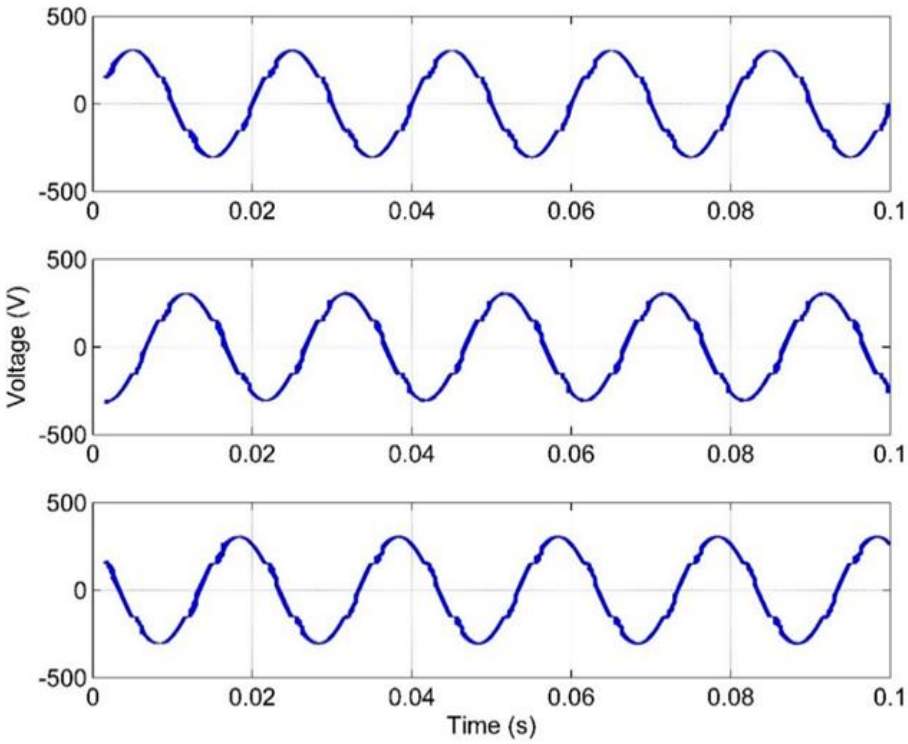


Fig 5.7: AC distribution system (Node1) three phase voltage waveforms (V)

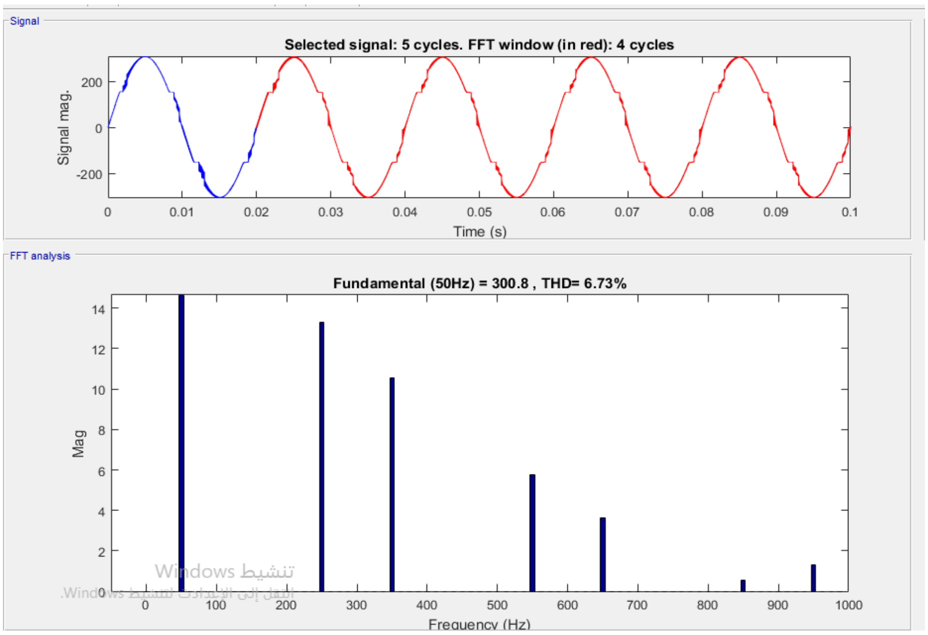


Fig 5.8 Harmonic spectrum AC distribution system (Node1) three phase voltage waveforms

In Fig 5.8, the FFT of voltage waveform phase (a), the analysis shows the spectrum components that includes the fundamental component of 300.8 V, fifth harmonic component amounts to 13.32 V and reduced to reach 1.30 V at h=19. The value of THD amounts 6.37%.

The current waveforms of node-1 are shown in Fig 5.9.

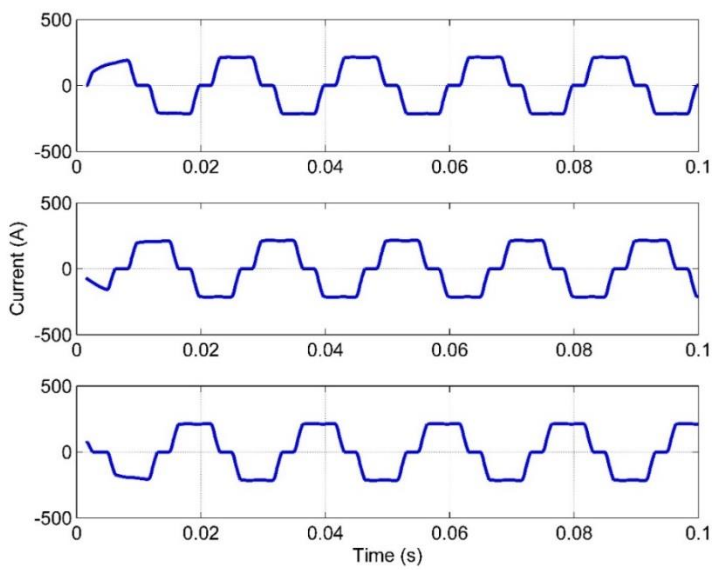


Fig 5.9: AC distribution system (Node1) three phase current waveforms (A)

In Fig 5.10, the FFT analysis of current waveform of phase (a), the spectrum includes the following components, the fundamental(50Hz) =234.1 A, h5(250Hz) =40.41 A, h7 (350Hz) =23.41 A, h11(550Hz) =8.28 A, h13 (650Hz) =4.41 A, h17(850Hz) =0.50 A , h19 (950Hz) =1.08 A resulting the THD =20.39% .

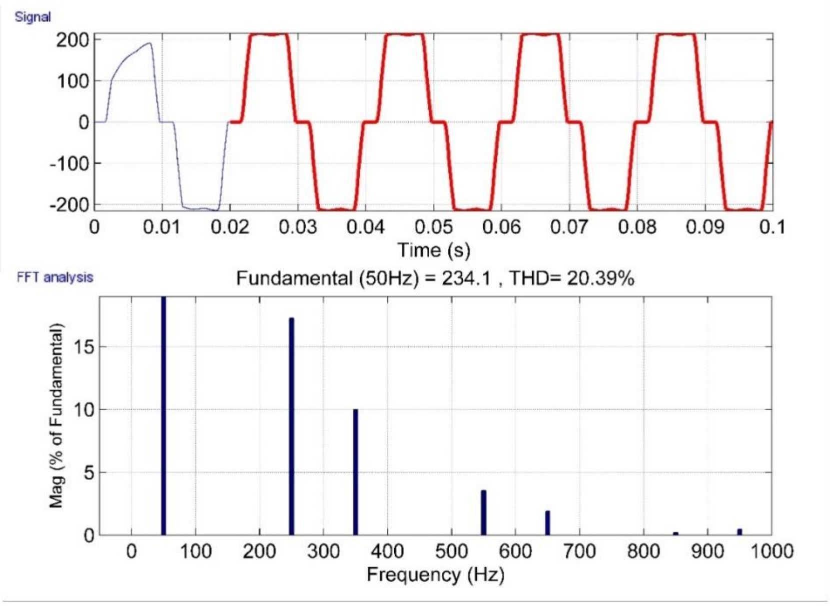


Fig 5.10: Harmonic spectrum AC distribution system (Node1) three phase current waveforms

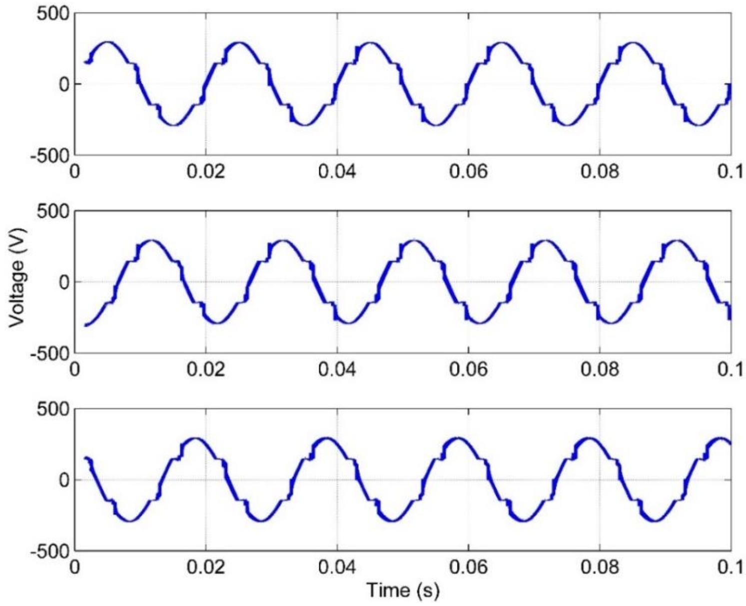


Fig 5.11: AC distribution system (Node2) three phase voltage waveforms (V)

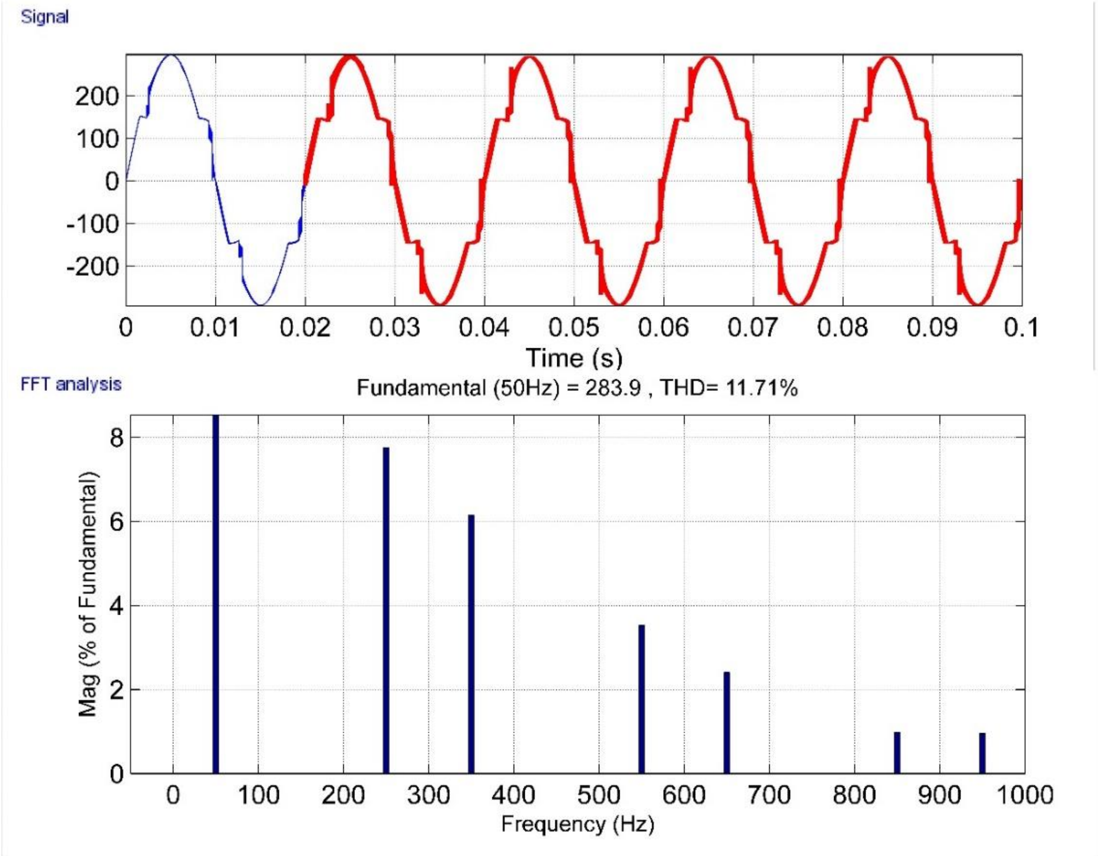


Fig 5.12: Harmonic spectrum AC distribution system (Node2) three phase voltage waveforms

In Fig 5.12, at FFT analysis of node (2) voltage waveform. The fundamental component (50Hz) =283.9V, h5(250Hz) =22.02 V, h7(350Hz) =17.44 V, h11(550Hz) =9.99 V, h13(650Hz) =6.83 V, h17(850Hz) =2.79 V, h19(950Hz) =2.70 V and the THD =11.71%.

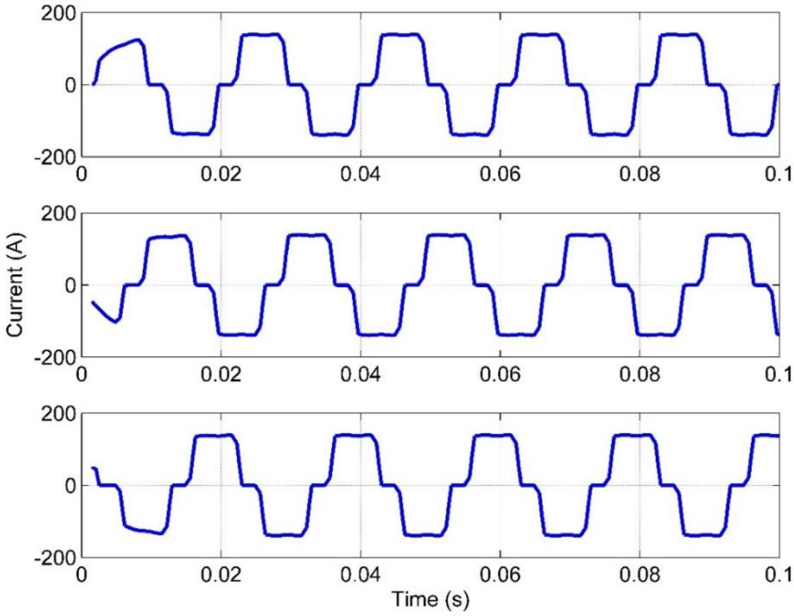


Fig 5.13: AC distribution system (Node2) three phase voltage waveforms (A)

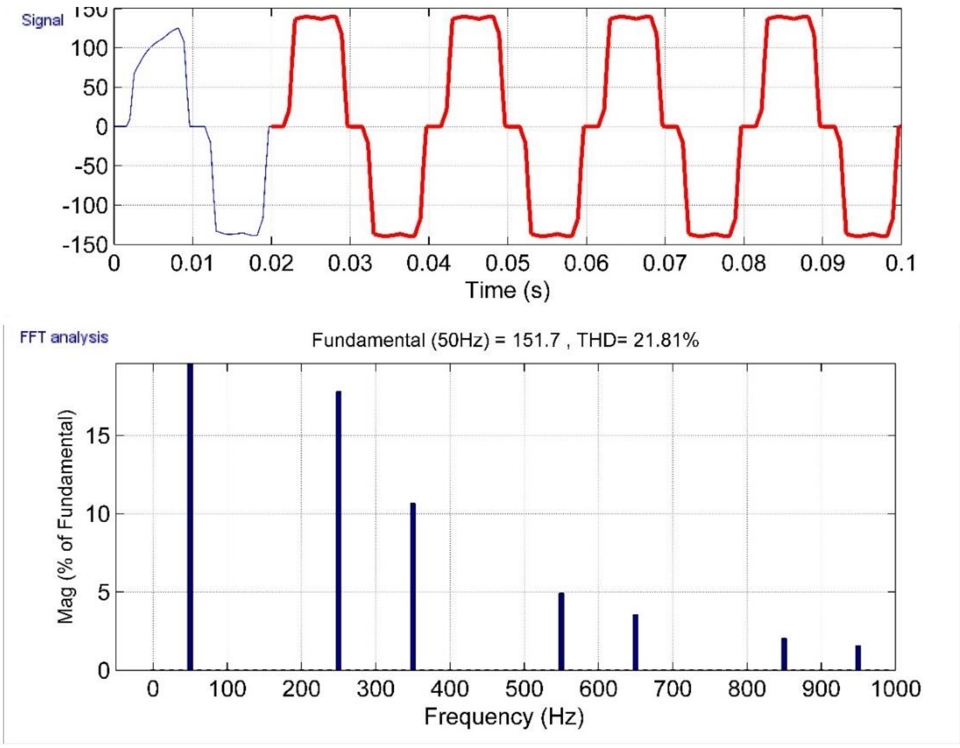


Fig. 5.14: Harmonic spectrum AC distribution system (Node2) three phase current waveforms

Fig 5.14 shows the FFT analysis of node (2) currents. The fundamental (50Hz) =151.7A, h5(250Hz) =27.02 A, h7(350Hz) =16.16A, h11(550Hz)

=7.46A, h13(650Hz) =5.4 A, h17(850Hz) =3.08A, h19(950Hz) =2.38A and the THD =21.81%.

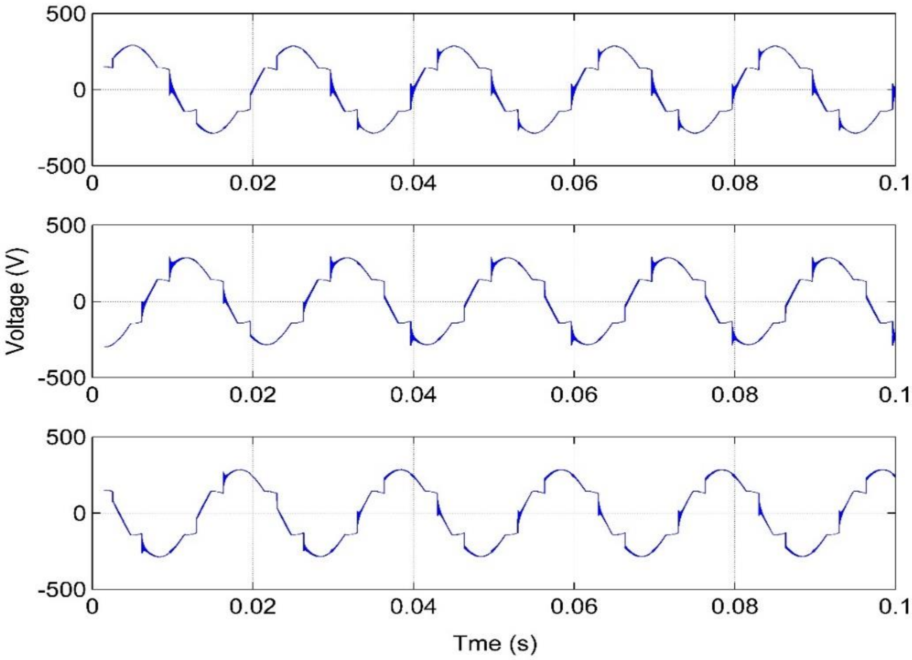


Fig 5.15: AC distribution system (Node3) three phase voltage waveforms (V)

Fig 5.16 shows the FFT analysis of voltage waveform of node (3). The fundamental(50Hz) =275.5V, h5(250Hz) =25.99 V, h7(350Hz) =20.26 V, h11(550Hz) =11.33V, h13(650Hz) =7.88V, h17(850Hz) =5.32V, h19(950Hz) =5.48V and the THD =14.94%.

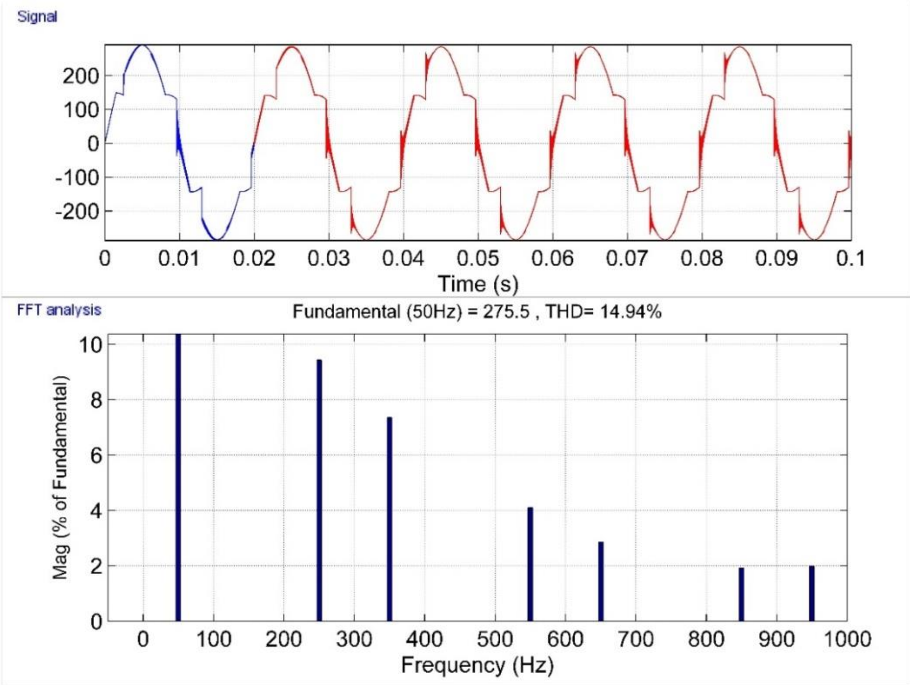


Fig 5.16: Harmonic spectrum AC distribution system (Node3) three phase voltage waveforms

Figure 5.17 shows the current waveforms of node (3) which is less than the currents of node 2 and node (1) because the current in node (1) is the sum of currents in node (2) and node (3).

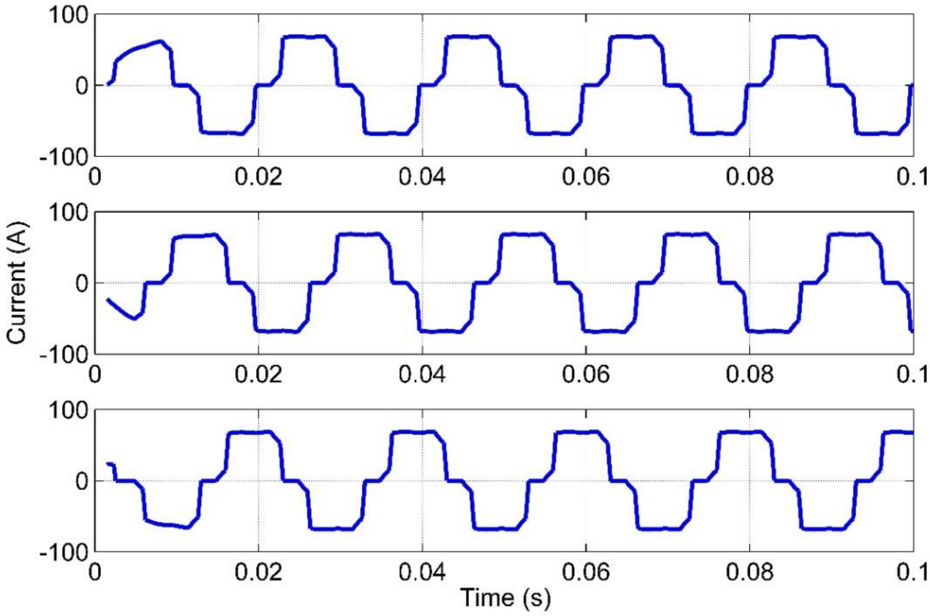


Fig 5.17: AC distribution system (Node3) three phase current waveforms (A)

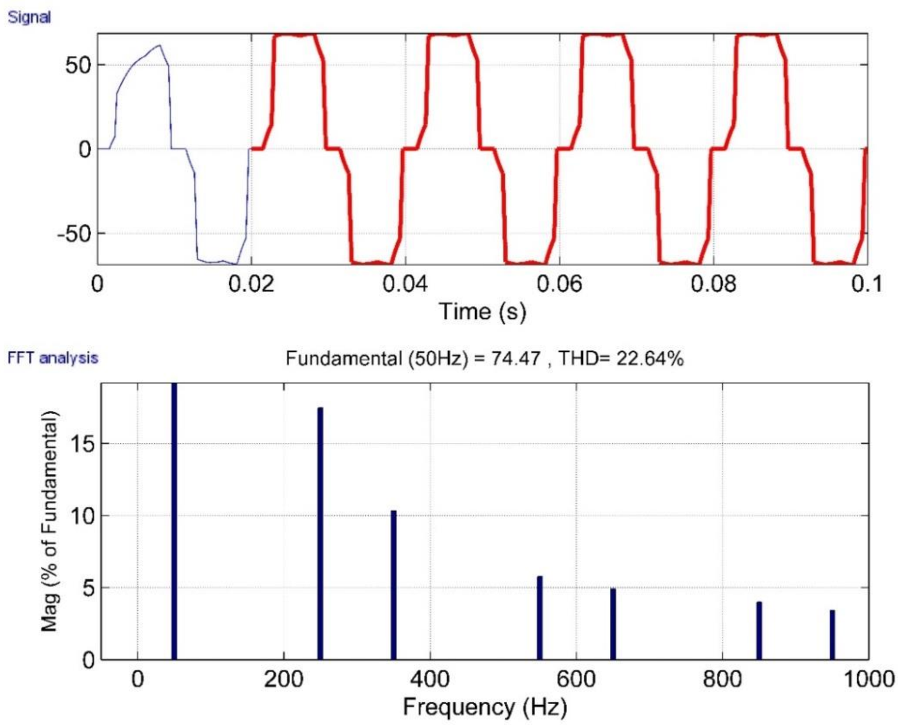


Fig 5.18: Harmonic spectrum AC distribution system (Node3) three phase current waveforms

In Fig 5.18, at FFT analysis the fundamental (50Hz) =74.47A, h5(250Hz) =12.99 A, h7(350Hz) =7.69 A, h11(550Hz) =4.3 A, h13(650Hz) =3.66 A, h17(850Hz) =2.97 A, h19(950Hz) =2.55A and the THD =22.64%. Comparison between nodes in AC system near the source and far for THD of current and voltage:

Table 4.3: Comparison between nodes in AC system near the source and far for THD of current and voltage.

		Node 1 (near the source)	Node 2	Node 3 (far the source)
Voltage(V)	Fundamental (50Hz)	300.8	283.9	275.5
	THD	6.73%	11.71%	14.94%
Current(A)	Fundamental(50Hz)	234.1	151.7	74.47
	THD	20.39%	21.81%	22.64%

In Table 4.3 it can be observed that the THD in node (3) more than in node (1) because the impedance increased with distance that makes the voltage distorted and THD for voltage and current related to each other.

Table 4.4 shows a comparison between AC system and DC system for THD of current and voltage.

Table 4.4: Comparison between DC system and AC system for THD of current and voltage

		DC system	AC system Node 1	AC system Node 2	AC system Node 3
Voltage(V)	Fundamental (50Hz)	303.5	300.8	283.9	275.5
	THD	10.19%	6.73%	11.71%	14.94%
Current(A)	Fundamental(50Hz)	212.1	234.1	151.7	74.47
	THD	24.03%	20.39%	21.81%	22.64%

In Table 4.4, the THD in DC network is more than the THD in AC network because of the impedance in AC network acts as filter that mitgates some harmonics and therfore reduced the THD.

5.2 Harmonic analysis of AC networks on medium voltage

5.2.1 Description of the ETAP network

The single line diagram of standard 33 bus distribution system in figure 5.19 is ETAP's network that was used for doing many tests on it. First, I put a rectifier load (charging station) in bus upstream and get the results to compare them with the status of the rectifier load (charging station) in bus downstream to find the best place to get the required results. I also did an experiment in the case of one rectifier at bus1 and the case of developing two rectifiers at bus1 and bus6. Finally, I put two rectifiers without any pulse and get the waveform and results.

What is rectifier?

The rectifier is Electrical device that converts alternating current (AC) which periodically reverse direction to direct current (DC)which flows in only one direction.

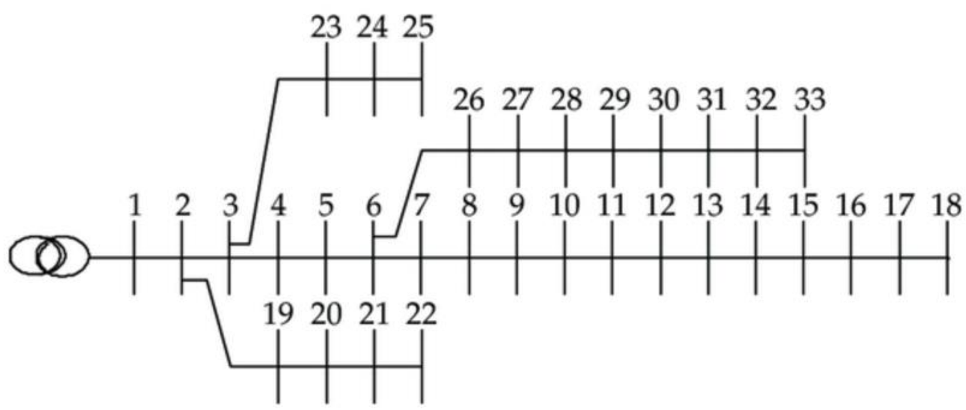


Fig 5.19: Single line diagram of standard 33-bus distribution system (ETAPA's network)

5.2.2 Analysis state 1 When putting 12.66kV at downstream

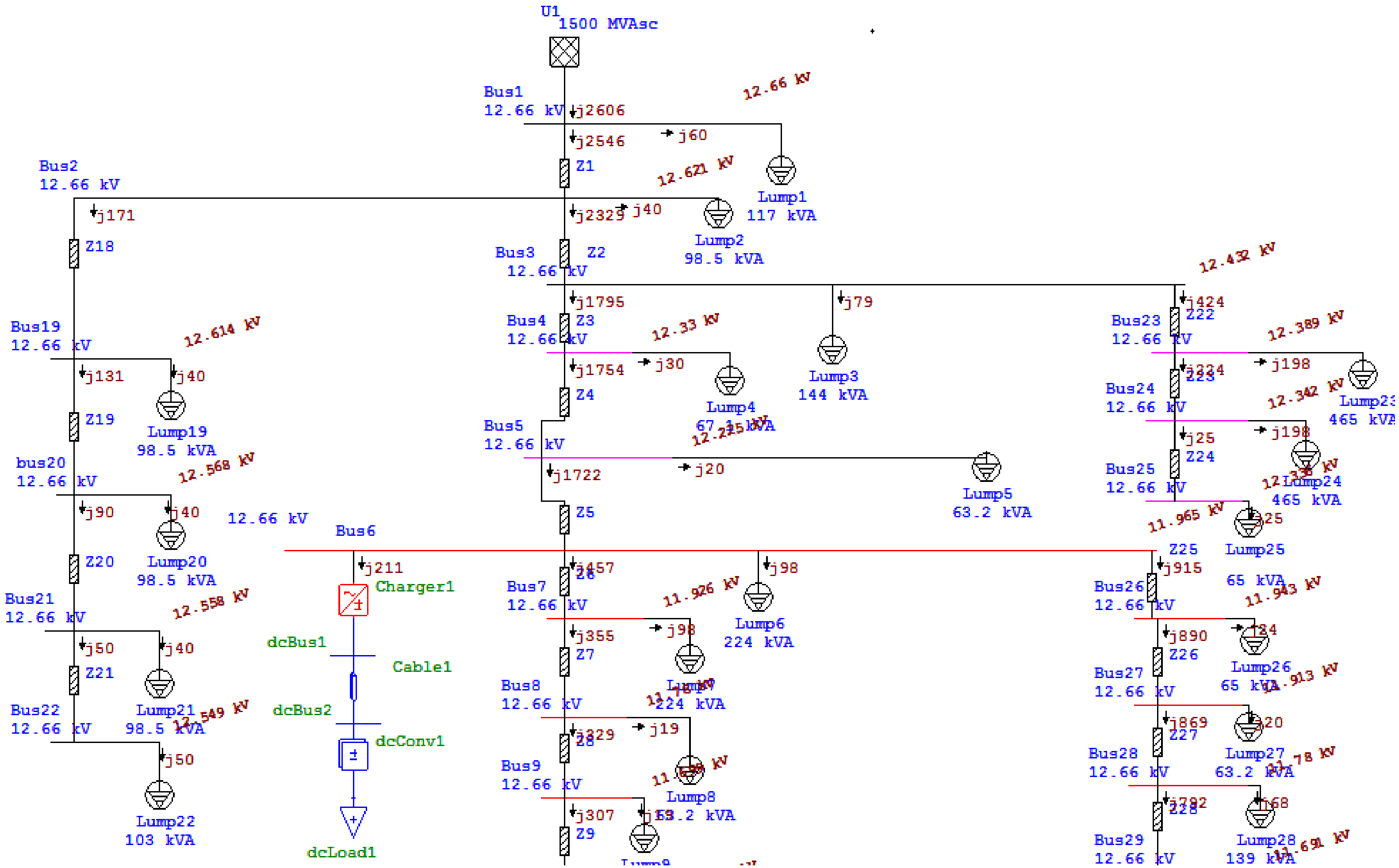


Fig 5.20: Network when putting 12.66kv at downstream(bus6)

Table 5.1: Load flow when putting 12.66kV at downstream

Generation			Load		Load flow				
	MW	**MVAr**	**MW**	**MVAr**		**MW**	**MVAr**	**A**	**PF%**
Mmbvfkkzxxzxs Bus1	3.829	2.375	0.1	0.06	Bus 2	3.729	2.315	200.2	85
Bu 6	0	0	0.196	0.098	Bus 5	-2.017	-1.474	119.6	80.7
					Bus 7	0.961	0.458	51	90.3
					Bus26	0.859	0.917	60.2	68.4
Bus14	0	0	0.058	0.01	Bus13	-0.349	-0.127	18.5	94
					Bus15	0.291	0.117	15.6	92.8

Table 5.2: Harmonic when putting 12.66kV at downstream

Bus	Voltage distortion %
Bus 1	0
Bus 6	0.02
Bus 14	0

5.3 Analysis state2 when putting the charging station at upstream

Table 5.3: Load flow when locating the charging station at upstream

Generation			**Load**		**Load flow**				
	MW	**MVAr**	**MW**	**MVAr**		**MW**	**MVAr**	**A**	**PF%**
Bus 1	4.169	2.586	0.44	0.271	Bus 2	3.729	2.315	200.2	85
Bus 6	0	0	0.196	0.098	Bus 5	-2.017	-1.474	119.6	80.7
					Bus7	0.961	0.458	51	90.3
					Bus26	0.859	0.917	60.2	68.4
Bus 14	0	0	0.058	0.01	Bu 13	-0.349	-0.127	18.5	94
					Bus15	0.291	0.117	15.6	92.8

Table 5.4: Voltage total harmonic distortion with locating the charging station at upstream

Bus	Voltage distortion %
Bus 1	0
Bus 6	0
Bus 14	0

The best place to put the charging station is upstream because it is not affected much by losses.

5.4 Analysis state 3 harmonic when 12.66 kV at upstream and one rectifier

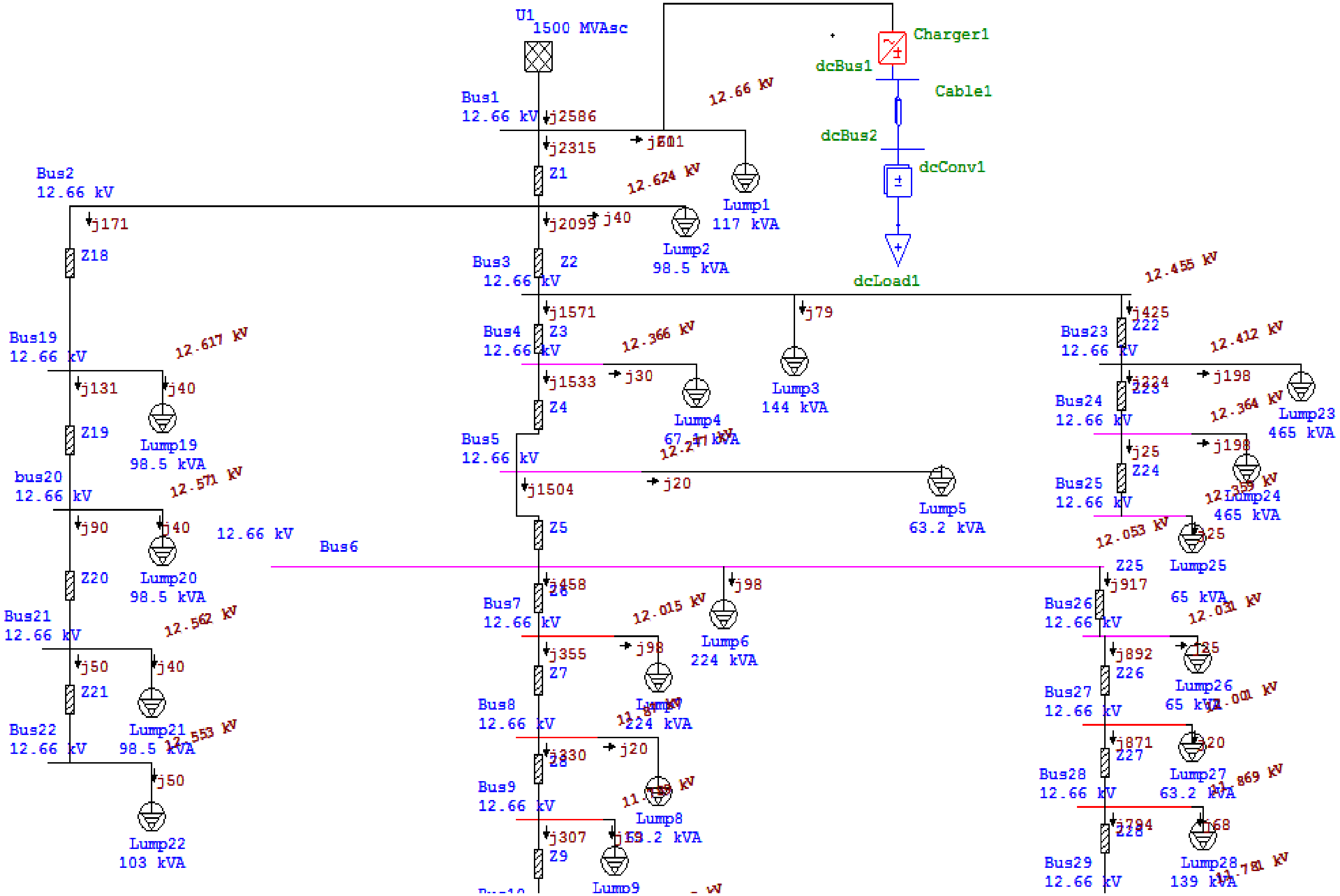


Fig 5.21: Network when putting 12.66kv at upstream(bus1)

Table 5.5: Current distortion when 12.66kV at upstream & one rectifier

From bus	To bus	Fund. Amp	THD%
Bus 1	Bus 2	200.17	0.04
Bus 6	Bus 5	119.64	0.04
	Bus7	51	0.04
	Bus 26	60.21	0.03
Bus 14	Bus 13	18.51	0.04
	Bus 15	15.63	0.04

Table 5.6: Harmonic voltage (% of fundamental voltage) when 12.66kV at upstream & one rectifier

Bus	Fund. kV	Order5	Order 3
Bus 1	12.66	0.03	0.03
Bus 14	11.579	0.03	0.02

5.5 Analysis state 4 harmonic when 12.66kV at upstream and two rectifiers

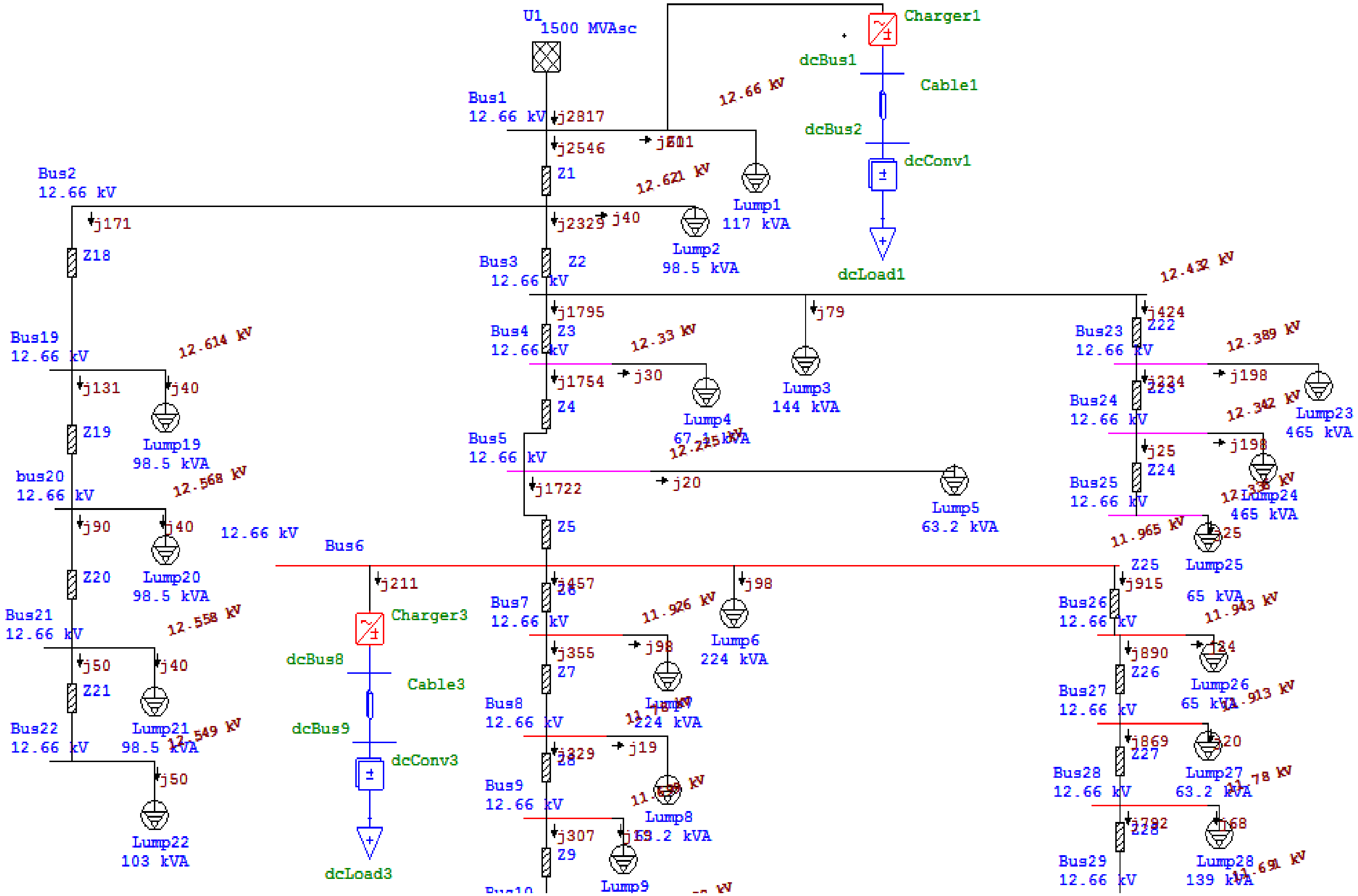


Fig 5.22: Network with two rectifiers at bus 1& bus6

Table 5.7: Load flow when putting 12.66kV at upstream & two rectifiers

Generation			Load		Load flow				
	MW	M VAr	MW	MVAr		MW	M var	A	PF%
Bus1	4.541	2.817	0.44	0.271	Bus2	4.101	2.546	220.1	85
Bus 6	0	0	0.536	0.309	Bus5	-2.352	-1.681	139.5	81.4
					Bus7	0.959	0.457	51.3	90.3
					Bus26	0.857	0.915	60.5	68.4
Bus14	0	0	0.058	0.01	Bus13	-0.348	-0.126	18.6	94
					Bus15	0.29	0.117	15.6	92.8

Table 5.8: Current distortion when 12.66kV at upstream & two rectifiers

From bus	To bus	Fund. Amp	THD%
Bus 1	Bus 2	220.14	2.23
Bus 6	Bus 5	139.49	3.55
	Bus7	51.26	0.66
	Bus 26	60.5	0.51
Bus 14	Bus 13	18.61	0.66
	Bus 15	15.72	0.66

Table 5.9: Harmonic voltage (% of fundamental voltage) when 12.66kV at upstream & two rectifier

Bus	Fund. kV	Order5	Order 3
Bus 1	12.66	0.05	0.05
Bus 14	11.488	0.44	0.4

5.6 Analysis state 5 harmonic with two rectifiers & without any pulse

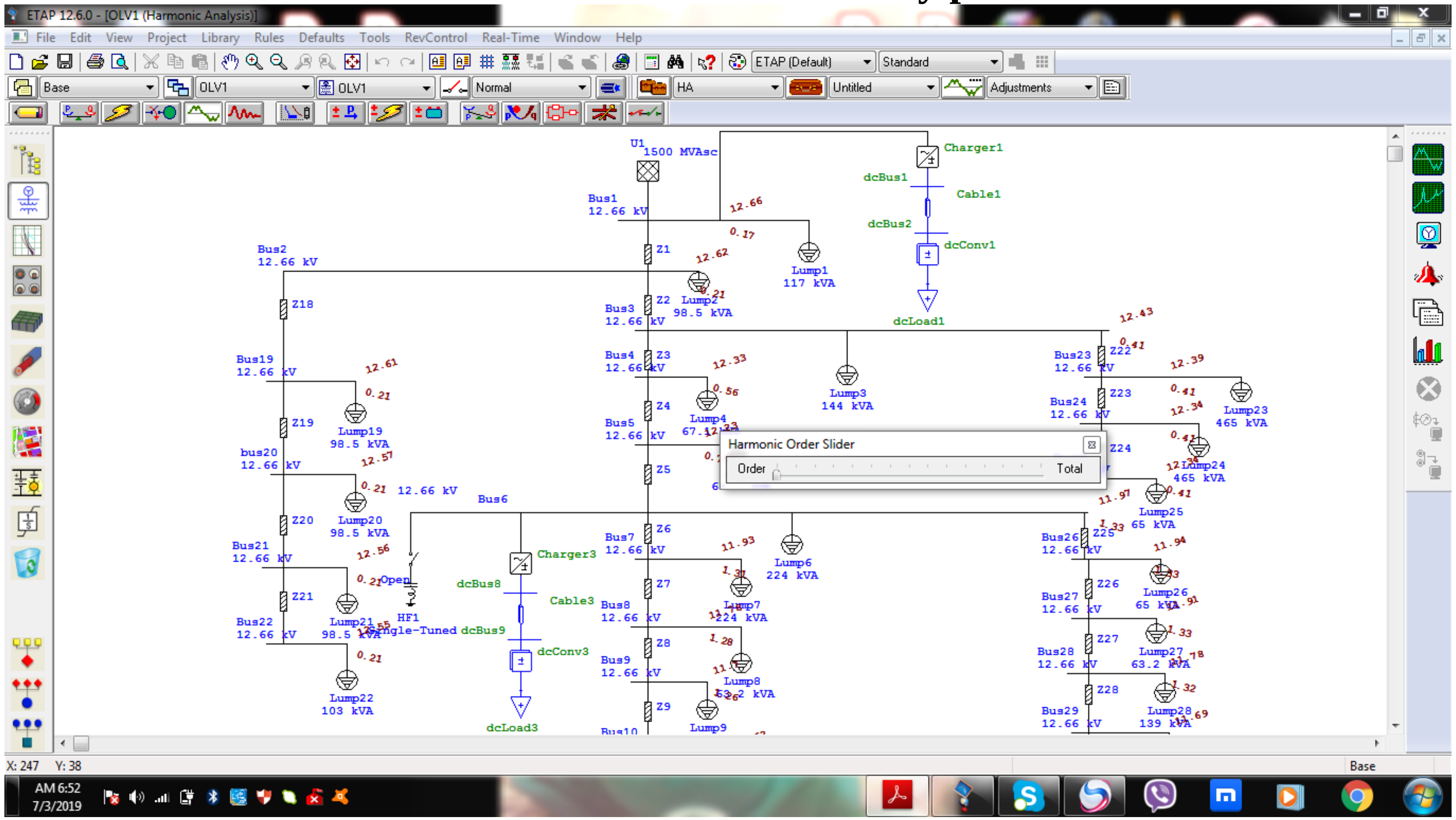


Fig 5.23: This is network with 2 rectifier & without any pulse

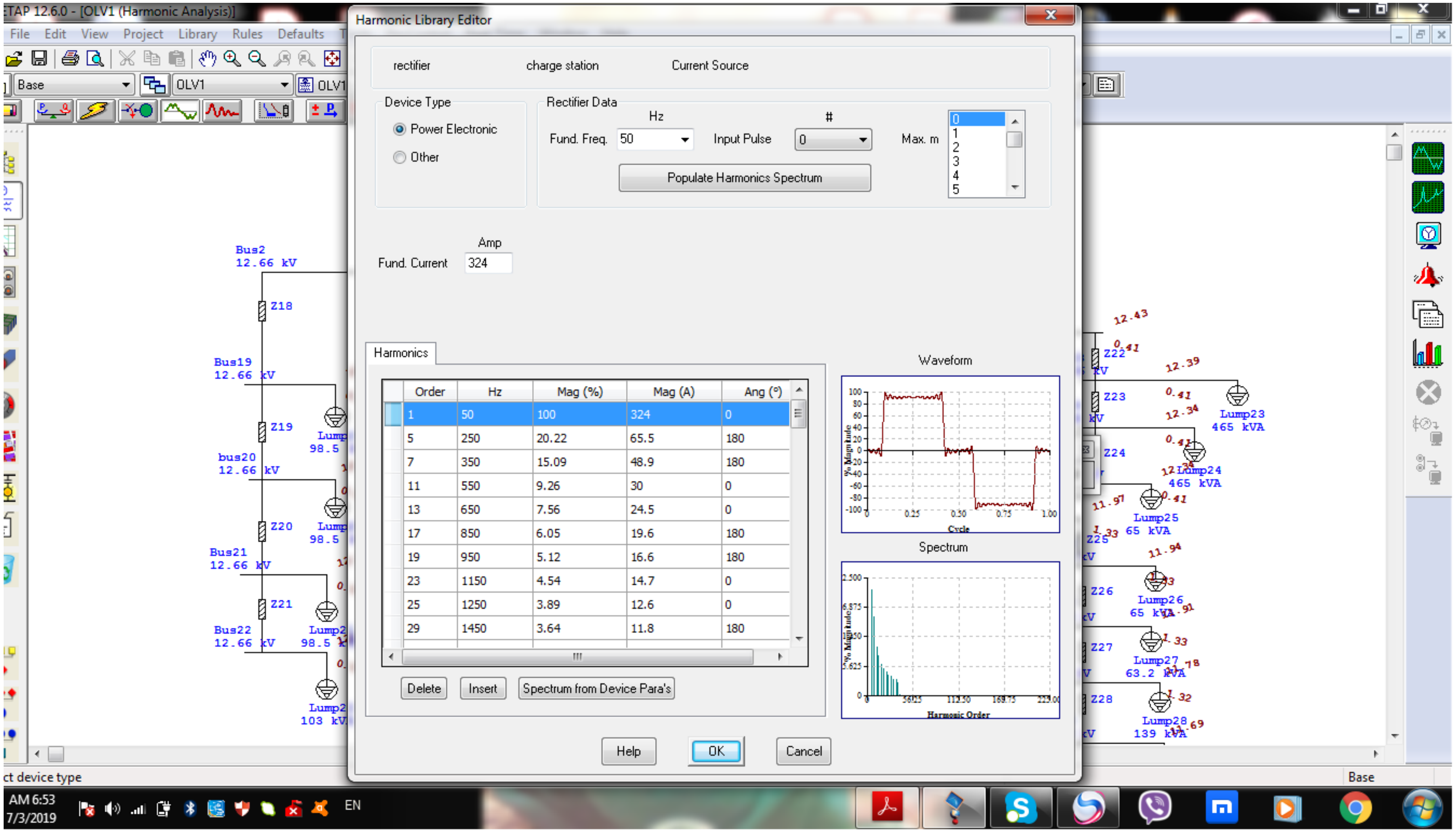


Fig 5.24: Show table without any pulse

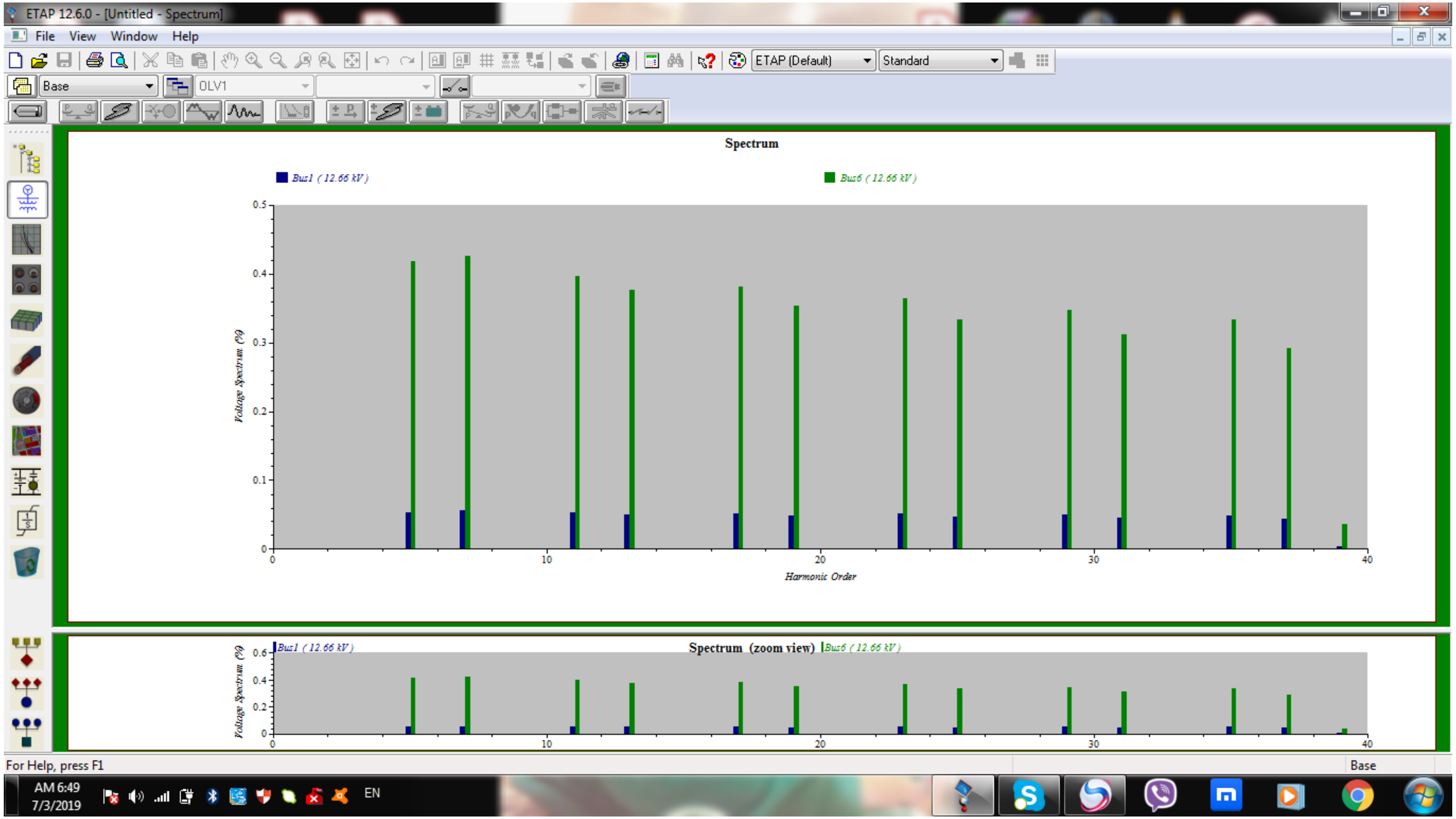


Fig 5.25: Harmonic spectrum bus1 & bus 6 without any pulse

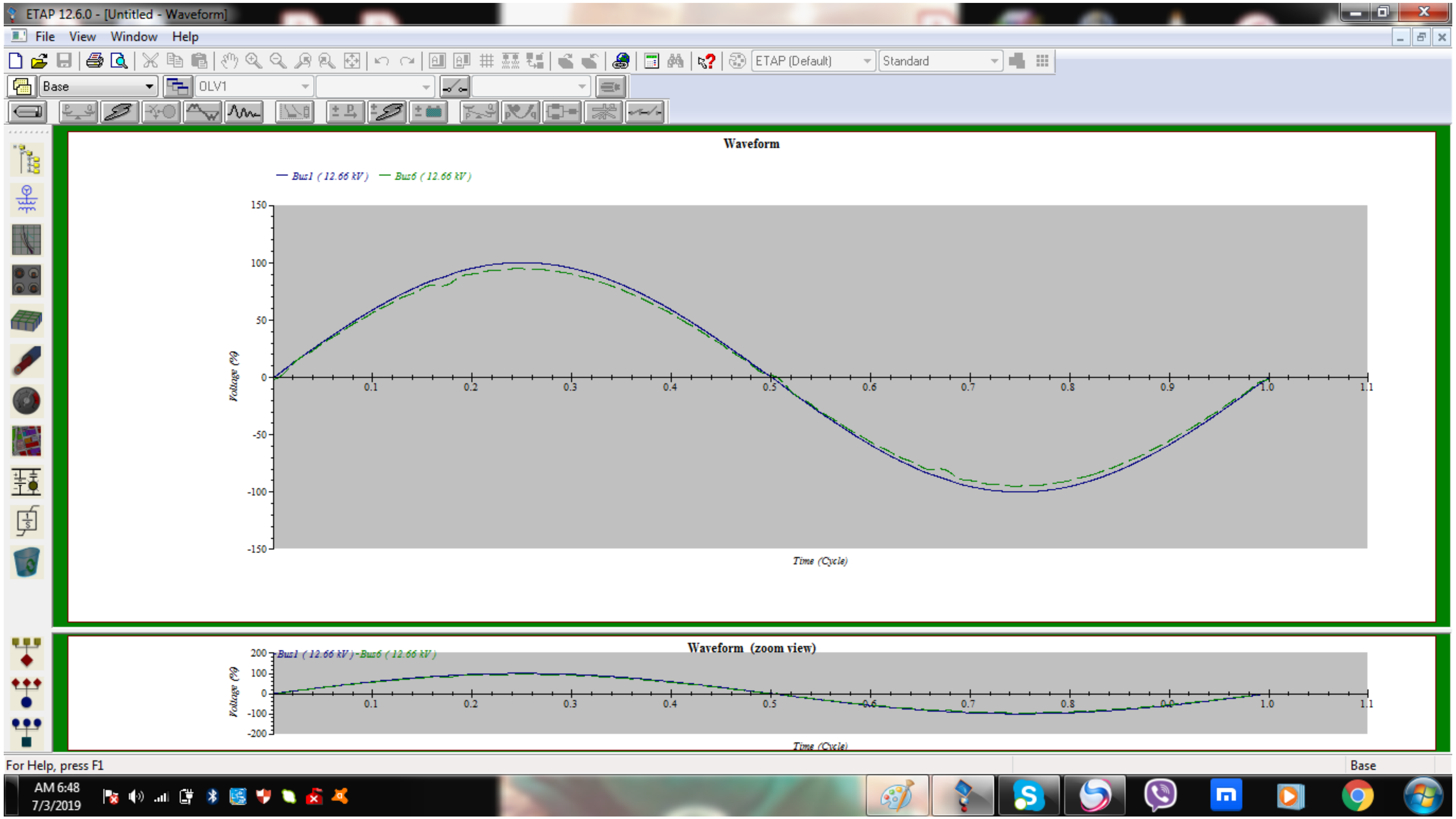


Fig 5.26: Waveform bus1 & bus 6 without any pulse

Table 5.10: Current distortion when 12.66kV without any pulse

From bus	To bus	Fund. Amp.	THD%
Bus 1	Bus 2	220.14	2.43
Bus 6	Bus 5	139.49	3.86
	Bus7	51.26	0.98
	Bus 26	60.5	0.79
Bus 14	Bus 13	18.61	0.99
	Bus 15	15.72	0.98

Table 5.11: Harmonic voltage (% of fundamental voltage) when 12.66kV without any pulse

Bus	Fund. kV	Order5	Order 3	Order 37
Bus 1	12.66	0.05	0.05	0.04
Bus 14	11.488	0.44	0.39	0.25

Note: there is information about harmonic for fundamental and nominal voltage for all buses.

Table 5.12: Harmonic order of charging current

Frequency(Hz)	Peak current (A)
50	324
5*50	65.5
7*50	48.87
11*50	30
13*50	24.51
17*50	19.63
19*50	16.64
23*50	14.66
25*50	12.55
29*50	11.76
31*50	10.05
35*50	9.85
37*50	8.36
39*50	1.00

CHAPTER SIX

MITIGATION OF HARMONICS BY FILTERS

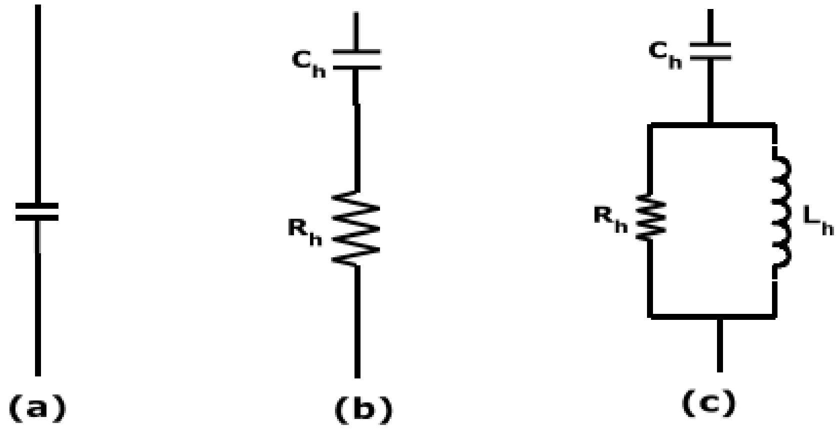
6- MITIGATION OF HARMONICS BY FILTERS

6.1 Harmonic Distortion Mitigation Techniques

There are three main ways to reduce harmonic distortion in power systems [20]. These are: second passive candidate, active power filter and active hybrid power filter. In this section, we will discuss various techniques for mitigating harmonic distortion, advantages, disadvantages and limitations of these technologies.

6.1.1 Passive filter

The first method shown in Fig. 6.1 is the most traditional method of mitigating harmonic components and is the simplest method of suppressing harmonics in power systems [22], [20-23]. This type of filter consists of simple passive elements (resistor, inductor, and capacitor) and is adjusted to remove a specific frequency component. The single filter is connected with the power system and is adjusted respectively to provide a low impedance to a particular harmonic current. Then the harmonic currents will divert from their natural path through the filter. A high-pass filter is one of passive filters types. They allow a large percentage of harmonics to pass through it over the corner frequency [22], [21]. It is typically one of the three types shown in Fig. 6.1.



a. first order HPF b. second order HPF c. third order HPF

Fig. 6.1: Passive high pass filters of different orders

The first-order HPF resonance problem limits its utilization. To solve the resonance problem, the resistance is connected in series with a capacitor to solve the resonance problem, but at high power loss, which is also undesirable. The second-order filter is the most effective for use when considering both design complexity and harmonic distortion mitigation capacity. The third-order filter provides improved performance compared to the second-order filter. Therefore, we use a limited third-order filter for the LV/MV application system, due to the complexity of the design, reliability, and economic factors. Although passive filters are easy to design and operate, they do not always respond to power system dynamics. Other disadvantages of passive filters are: (1) their size is heavy and large due to passive elements. The harmonics that will be suppressed are usually low-order [22,23]. (2) A resonance or tuning problem affects power system network stability [20,23,24]. (3) Filter characteristics are affected by the frequency variations in the power system, the frequency of elements, and the size of the component does not achieve in a variable frequency environment. (4) Constant compensation, (5) noise and (6) increased loss [23].

6.1.2 Active power filter

Remarkable advances in the field of power electronics had sparked interest in APF for harmonic distortion mitigation [19], [20], [24-25]. The primary technology of APF is to use power electronics technologies to produce current harmonic components so that the source provides only the fundamental part of the current required by the load. The total system consists mainly of two circuits, the power circuit and the control circuit. The control circuit reference current feds with information regarding harmonic current and other system variables to generate the control signal, which causes the APF to generate the required compensation current. Active power filter is shown in Fig 6.2 as shunt active filter

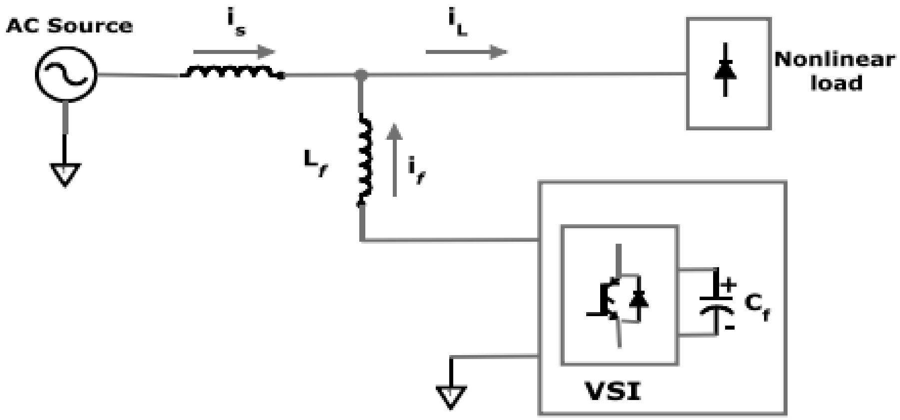


Fig 6.2: Basic configuration of shunt APF

6.2 Passive filter design for harmonic filter

In this section passive filter design with RLC elements is discussed. This filter is a three phase filter used for reactive power compensation and to eliminate the dominant harmonics such as 7th and 5th harmonic. The filter design criteria is as follows:

$$X_c = \frac{V^2}{Q_c}$$

$$X_L = \frac{X_c}{{n_t}^2}$$

$$R = \frac{X_L}{QF}$$

$$C = \frac{1}{2 \times \pi \times f \times X_c}$$

$$L = \frac{X_L}{2 \times \pi \times f}$$

Where:

Q_c: the reactive power required from the filter

n_t the harmonic order of harmonic component required to be eliminated

f: Fundamental frequency

QF: quality factor

Considering the AC network shown in Fig. 5.6, a passive filter is used to deliver 18 kVar (the reactive power consumed by the network) that makes power factor in the point of common coupling unity. The three phase filter is connected in delta to obtain three times reactive power if filter connected in star. The filter designed to eliminate the 5th harmonic which has the highest harmonic current in order to reduce the total harmonic distortion for both current and voltage.

The filter is connected in delta configuration to gain more reactive power with less capacitance.

V_{LL}=400V, Qc=18kVar

$X_c = 26.66\ \Omega$

$X_L = 1.06\ \Omega$

Quality factor = 30

R= 0.0355 Ω

L= 0.003395 H

C=0.00011F

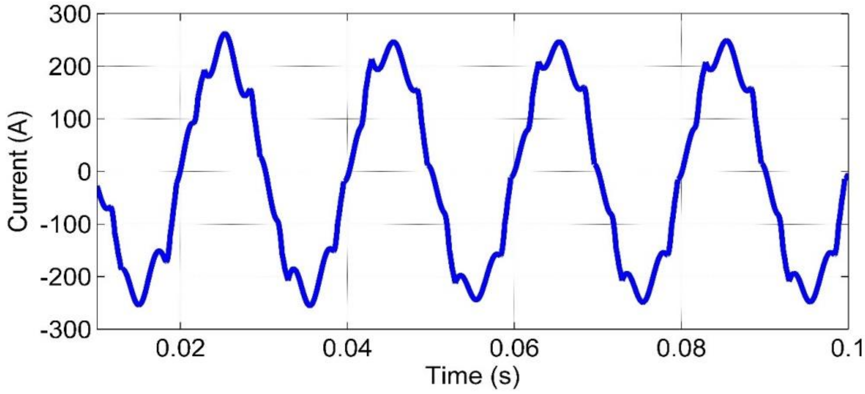


Fig 6.3: The AC current after adding passive filter to eliminate 5th harmonics

Fig.6.3 shows the current waveform at PCC after adding passive filter with elimination of 5^{th} harmonics with quality factor 30.

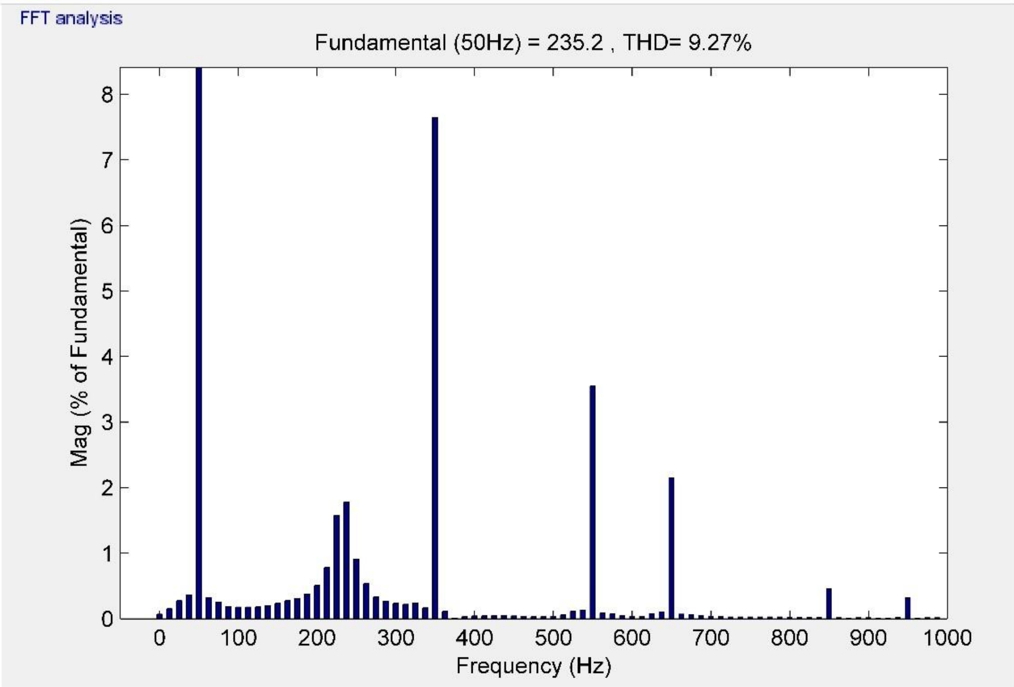


Fig 6.4: Current harmonic spectrum after adding passive filter (AC distribution)

It can be seen in Fig. 6.4 the 5^{th} harmonic is suppressed and the THD of the current decreased from 20.4% to 9.2%. whereas, the THD for voltage decreased from 6.7% to 5.3%.

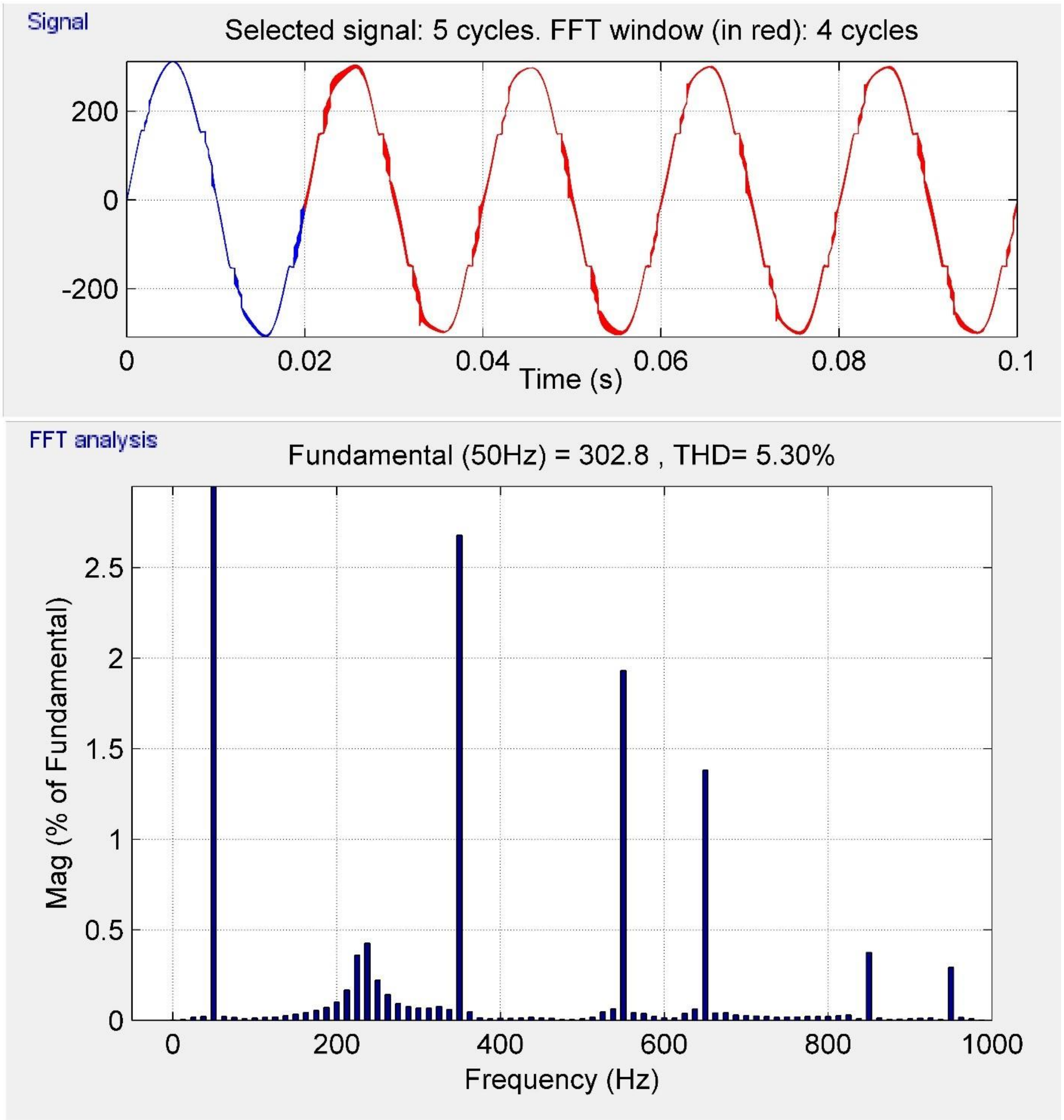


Fig 6.5: Voltage harmonic spectrum after adding passive filter (AC distribution)

CHAPTER SEVEN
CONCLUSIONS

7- CONCLUSIONS

A computer model is programmed in MATLAB Simulink to perform harmonic analysis in two different electrical configurations AC and DC. In AC distribution systems the impact of charging stations in three different modes shows that the voltage is reduced from 400 V to 336V. The total harmonic distortion of current and voltage amount to 20.4% and 6.73% respectively. On the other hand, in DC system the total harmonic distortion of current and voltage amount to 24% and 10.9% respectively. Moreover, ETAP software was used to perform the impacts of charging stations on electrical network in two different cases to localize the charging station downstream and upstream. Finally, in order to mitigate the harmonics, passive filter is designed and the total harmonic distortion of current and voltage reduced to 9.2% and 5.3% respectively.

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APPENDICES

Appendix A

line and load data of IEEE 33 bus system

LINE Number	Sending bus no.	Receiving bus no.	Resistance (Ω)	Resistance (Ω)	load at receiving end bus	
					real power (kW)	Reactive Power (KVAR)
1	1	2	0.0922	0.0477	100	60
2	2	3	0.493	0.2511	90	40
3	3	4	0.366	0.1864	120	80
4	4	5	0.3811	0.1941	60	30
5	5	6	0.819	0.707	60	20
6	6	7	0.1872	0.6188	200	100
7	7	8	1.7114	1.2351	200	100
8	8	9	1.03	0.74	60	20
9	9	10	1.04	0.74	60	20
10	10	11	0.1966	0.065	45	30
11	11	12	0.3744	0.1238	60	35
12	12	13	1.468	1.155	60	35
13	13	14	0.5416	0.7129	120	80
14	14	15	0.591	0.526	60	10
15	15	16	0.7463	0.545	60	20
16	16	17	1.289	1.721	60	20
17	17	18	0.732	0.574	90	40
18	18	19	0.164	0.1565	90	40
19	19	20	1.5042	1.3354	90	40
20	20	21	0.4095	0.4784	90	40
21	21	22	0.7089	0.9373	90	40
22	22	23	0.4512	0.3083	90	50
23	23	24	0.898	0.7091	420	200
24	24	25	0.896	0.7011	420	200
25	25	26	0.203	0.1034	60	25
26	26	27	0.2842	0.1447	60	25
27	27	28	1.059	0.9337	60	20
28	28	29	0.8042	0.7006	120	70
29	29	30	0.5075	0.2585	200	600
30	30	31	0.9744	0.963	150	70
31	31	32	0.3105	0.3619	210	100
32	32	33	0.341	0.5302	60	40

Appendix B

Load flow report When put 12.66kV at downstream

LOAD FLOW REPORT

Bus		Voltage		Generation		Load		Load Flow					XFMR
ID	kV	% Mag.	Ang.	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	%PF	%Tap
* Bus1	12.660	100.000	0.0	3.829	2.375	0.100	0.060	Bus2	3.729	2.315	200.2	85.0	
Bus2	12.660	99.717	0.0	0	0	0.090	0.040	Bus1	-3.718	-2.310	200.2	84.9	
								Bus3	3.268	2.099	177.6	84.1	
								Bus19	0.360	0.171	18.2	90.4	
Bus3	12.660	98.379	0.1	0	0	0.119	0.079	Bus2	-3.221	-2.075	177.6	84.1	
								Bus4	2.205	1.571	125.5	81.4	
								Bus23	0.897	0.425	46.0	90.4	
Bus4	12.660	97.681	0.2	0	0	0.059	0.030	Bus3	-2.188	-1.562	125.5	81.4	
								Bus5	2.128	1.533	122.4	81.1	
Bus5	12.660	96.973	0.2	0	0	0.059	0.020	Bus4	-2.111	-1.524	122.4	81.1	
								Bus6	2.052	1.504	119.6	80.6	
Bus6	12.660	95.208	0.1	0	0	0.196	0.098	Bus5	-2.017	-1.474	119.6	80.7	
								Bus7	0.961	0.458	51.0	90.3	
								Bus26	0.859	0.917	60.2	68.4	
Bus7	12.660	94.905	-0.1	0	0	0.196	0.098	Bus6	-0.960	-0.454	51.0	90.4	
								Bus8	0.764	0.355	40.5	90.7	
Bus8	12.660	93.757	-0.2	0	0	0.059	0.020	Bus7	-0.755	-0.349	40.5	90.8	
								Bus9	0.697	0.330	37.5	90.4	
Bus9	12.660	93.118	-0.3	0	0	0.058	0.019	Bus8	-0.692	-0.327	37.5	90.4	
								Bus10	0.634	0.307	34.5	90.0	
Bus10	12.660	92.524	-0.3	0	0	0.044	0.029	Bus9	-0.630	-0.305	34.5	90.0	

								Bus10	0.634	0.307	34.5	90.0
Bus10	12.660	92.524	-0.3	0	0	0.044	0.029	Bus9	-0.630	-0.305	34.5	90.0
								Bus11	0.586	0.276	31.9	90.5
Bus11	12.660	92.434	-0.3	0	0	0.058	0.034	Bus10	-0.586	-0.275	31.9	90.5
								Bus12	0.528	0.241	28.6	90.9
Bus12	12.660	92.280	-0.3	0	0	0.058	0.034	Bus11	-0.527	-0.241	28.6	90.9
								Bus13	0.468	0.207	25.3	91.5
Bus13	12.660	91.654	-0.4	0	0	0.116	0.077	Bus12	-0.466	-0.205	25.3	91.5
								Bus14	0.349	0.127	18.5	93.9
Bus14	12.660	91.463	-0.5	0	0	0.058	0.010	Bus13	-0.349	-0.127	18.5	94.0
								Bus15	0.291	0.117	15.6	92.8
Bus15	12.660	91.304	-0.5	0	0	0.058	0.019	Bus14	-0.290	-0.117	15.6	92.8
								Bus16	0.232	0.097	12.6	92.2
Bus16	12.660	91.149	-0.6	0	0	0.058	0.019	Bus15	-0.232	-0.097	12.6	92.3
								Bus17	0.174	0.078	9.5	91.3
Bus17	12.660	90.904	-0.6	0	0	0.087	0.039	Bus16	-0.174	-0.077	9.5	91.4
								Bus18	0.087	0.039	4.8	91.4

Appendix C

Harmonic report when put 12.66kVat downstream

System Harmonics Bus Information

Bus		Voltage Distortion								
ID	kV	Fund. %	RMS %	ASUM %	THD %	TIF	TIHD %	TSHD %	THDG %	THDS %
Bus1	12.660	100.00	100.00	100.00	0	0.42	0.00	0.00	0.00	0.00
Bus2	12.660	99.69	99.69	99.69	0.01	0.42	0.00	0.00	0.00	0.00
Bus3	12.660	98.20	98.20	98.20	0	0.42	0.00	0.00	0.00	0.00
Bus4	12.660	97.39	97.39	97.39	0	0.42	0.00	0.00	0.00	0.00
Bus5	12.660	96.57	96.57	96.57	0.01	0.42	0.00	0.00	0.00	0.00
Bus6	12.660	94.51	94.51	94.51	0.02	0.42	0.00	0.00	0.00	0.00
Bus7	12.660	94.21	94.21	94.21	0	0.42	0.00	0.00	0.00	0.00
Bus8	12.660	93.05	93.05	93.05	0	0.42	0.00	0.00	0.00	0.00
Bus9	12.660	92.41	92.41	92.41	0	0.42	0.00	0.00	0.00	0.00
Bus10	12.660	91.81	91.81	91.81	0	0.42	0.00	0.00	0.00	0.00
Bus11	12.660	91.72	91.72	91.72	0.02	0.42	0.00	0.00	0.00	0.00
Bus12	12.660	91.57	91.57	91.57	0.02	0.42	0.00	0.00	0.00	0.00
Bus13	12.660	90.94	90.94	90.94	0	0.42	0.00	0.00	0.00	0.00
Bus14	12.660	90.75	90.75	90.75	0	0.42	0.00	0.00	0.00	0.00
Bus15	12.660	90.59	90.59	90.59	0.02	0.42	0.00	0.00	0.00	0.00
Bus16	12.660	90.43	90.43	90.43	0	0.42	0.00	0.00	0.00	0.00
Bus17	12.660	90.18	90.18	90.18	0.02	0.42	0.00	0.00	0.00	0.00
Bus18	12.660	90.13	90.13	90.13	0.02	0.42	0.00	0.00	0.00	0.00
Bus19	12.660	99.63	99.63	99.63	0	0.42	0.00	0.00	0.00	0.00
bus20	12.660	99.27	99.27	99.27	0	0.42	0.00	0.00	0.00	0.00
Bus21	12.660	99.20	99.20	99.20	0	0.42	0.00	0.00	0.00	0.00
Bus22	12.660	99.13	99.13	99.13	0	0.42	0.00	0.00	0.00	0.00
Bus23	12.660	97.86	97.86	97.86	0.01	0.42	0.00	0.00	0.00	0.00
Bus24	12.660	97.49	97.49	97.49	0.02	0.42	0.00	0.00	0.00	0.00
Bus24	12.660	97.49	97.49	97.49	0.02	0.42	0.00	0.00	0.00	0.00
Bus25	12.660	97.44	97.44	97.44	0	0.42	0.00	0.00	0.00	0.00
Bus26	12.660	94.33	94.33	94.33	0	0.42	0.00	0.00	0.00	0.00
Bus27	12.660	94.10	94.10	94.10	0	0.42	0.00	0.00	0.00	0.00
Bus28	12.660	93.05	93.05	93.05	0.02	0.42	0.00	0.00	0.00	0.00
Bus29	12.660	92.35	92.35	92.35	0	0.42	0.00	0.00	0.00	0.00
Bus30	12.660	92.17	92.17	92.17	0	0.42	0.00	0.00	0.00	0.00
Bus31	12.660	91.91	91.91	91.91	0.02	0.42	0.00	0.00	0.00	0.00
Bus32	12.660	91.89	91.89	91.89	0.02	0.42	0.00	0.00	0.00	0.00
Bus33	12.660	91.89	91.89	91.89	0.02	0.42	0.00	0.00	0.00	0.00

* IndicatesTHD (Total Harmonic Distortion) Exceeds the Limit.
# Indicates IHD (Individual Harmonic Distortion) Exceeds the Limit.

Appendix D

load flow report when put 12.66kv at upstream

LOAD FLOW REPORT

Bus ID	Bus kV	Voltage % Mag.	Voltage Ang.	Generation MW	Generation Mvar	Load MW	Load Mvar	Load Flow ID	Load Flow MW	Load Flow Mvar	Load Flow Amp	Load Flow %PF	XFMR %Tap
* Bus1	12.660	100.000	0.0	4.169	2.586	0.440	0.271	Bus2	3.729	2.315	200.2	85.0	
Bus2	12.660	99.717	0.0	0	0	0.090	0.040	Bus1	-3.718	-2.310	200.2	84.9	
								Bus3	3.268	2.099	177.6	84.1	
								Bus19	0.360	0.171	18.2	90.4	
Bus3	12.660	98.379	0.1	0	0	0.119	0.079	Bus2	-3.221	-2.075	177.6	84.1	
								Bus4	2.205	1.571	125.5	81.4	
								Bus23	0.897	0.425	46.0	90.4	
Bus4	12.660	97.681	0.2	0	0	0.059	0.030	Bus3	-2.188	-1.562	125.5	81.4	
								Bus5	2.128	1.533	122.4	81.1	
Bus5	12.660	96.973	0.2	0	0	0.059	0.020	Bus4	-2.111	-1.524	122.4	81.1	
								Bus6	2.052	1.504	119.6	80.6	
Bus6	12.660	95.208	0.1	0	0	0.196	0.098	Bus5	-2.017	-1.474	119.6	80.7	
								Bus7	0.961	0.458	51.0	90.3	
								Bus26	0.859	0.917	60.2	68.4	
Bus7	12.660	94.905	-0.1	0	0	0.196	0.098	Bus6	-0.960	-0.454	51.0	90.4	
								Bus8	0.764	0.355	40.5	90.7	
Bus8	12.660	93.757	-0.2	0	0	0.059	0.020	Bus7	-0.755	-0.349	40.5	90.8	
								Bus9	0.697	0.330	37.5	90.4	
Bus9	12.660	93.118	-0.3	0	0	0.058	0.019	Bus8	-0.692	-0.327	37.5	90.4	
								Bus10	0.634	0.307	34.5	90.0	
Bus10	12.660	92.524	-0.3	0	0	0.044	0.029	Bus9	-0.630	-0.305	34.5	90.0	
								Bus10	0.634	0.307	34.5	90.0	
Bus10	12.660	92.524	-0.3	0	0	0.044	0.029	Bus9	-0.630	-0.305	34.5	90.0	
								Bus11	0.586	0.276	31.9	90.5	
Bus11	12.660	92.434	-0.3	0	0	0.058	0.034	Bus10	-0.586	-0.275	31.9	90.5	
								Bus12	0.528	0.241	28.6	90.9	
Bus12	12.660	92.280	-0.3	0	0	0.058	0.034	Bus11	-0.527	-0.241	28.6	90.9	
								Bus13	0.468	0.207	25.3	91.5	
Bus13	12.660	91.654	-0.4	0	0	0.116	0.077	Bus12	-0.466	-0.205	25.3	91.5	
								Bus14	0.349	0.127	18.5	93.9	
Bus14	12.660	91.463	-0.5	0	0	0.058	0.010	Bus13	-0.349	-0.127	18.5	94.0	
								Bus15	0.291	0.117	15.6	92.8	
Bus15	12.660	91.304	-0.5	0	0	0.058	0.019	Bus14	-0.290	-0.117	15.6	92.8	
								Bus16	0.232	0.097	12.6	92.2	
Bus16	12.660	91.149	-0.6	0	0	0.058	0.019	Bus15	-0.232	-0.097	12.6	92.3	
								Bus17	0.174	0.078	9.5	91.3	
Bus17	12.660	90.904	-0.6	0	0	0.087	0.039	Bus16	-0.174	-0.077	9.5	91.4	
								Bus18	0.087	0.039	4.8	91.4	

Appendix E

harmonic report when put 12.66kVat upstream

System Harmonics Bus Information

Bus		Voltage Distortion								
ID	kV	Fund. %	RMS %	ASUM %	THD %	TIF	TIHD %	TSHD %	THDG %	THDS %
Bus1	12.660	100.00	100.00	100.00	0	0.42	0.00	0.00	0.00	0.00
Bus2	12.660	99.72	99.72	99.72	0	0.42	0.00	0.00	0.00	0.00
Bus3	12.660	98.38	98.38	98.38	0.01	0.42	0.00	0.00	0.00	0.00
Bus4	12.660	97.68	97.68	97.68	0	0.42	0.00	0.00	0.00	0.00
Bus5	12.660	96.97	96.97	96.97	0	0.42	0.00	0.00	0.00	0.00
Bus6	12.660	95.21	95.21	95.21	0	0.42	0.00	0.00	0.00	0.00
Bus7	12.660	94.90	94.90	94.90	0	0.42	0.00	0.00	0.00	0.00
Bus8	12.660	93.76	93.76	93.76	0	0.42	0.00	0.00	0.00	0.00
Bus9	12.660	93.12	93.12	93.12	0	0.42	0.00	0.00	0.00	0.00
Bus10	12.660	92.52	92.52	92.52	0.01	0.42	0.00	0.00	0.00	0.00
Bus11	12.660	92.43	92.43	92.43	0.01	0.42	0.00	0.00	0.00	0.00
Bus12	12.660	92.28	92.28	92.28	0.01	0.42	0.00	0.00	0.00	0.00
Bus13	12.660	91.65	91.65	91.65	0	0.42	0.00	0.00	0.00	0.00
Bus14	12.660	91.46	91.46	91.46	0	0.42	0.00	0.00	0.00	0.00
Bus15	12.660	91.30	91.30	91.30	0.02	0.42	0.00	0.00	0.00	0.00
Bus16	12.660	91.15	91.15	91.15	0.02	0.42	0.00	0.00	0.00	0.00
Bus17	12.660	90.90	90.90	90.90	0.01	0.42	0.00	0.00	0.00	0.00
Bus18	12.660	90.84	90.84	90.84	0	0.42	0.00	0.00	0.00	0.00
Bus19	12.660	99.66	99.66	99.66	0	0.42	0.00	0.00	0.00	0.00
bus20	12.660	99.30	99.30	99.30	0	0.42	0.00	0.00	0.00	0.00
Bus21	12.660	99.22	99.22	99.22	0.01	0.42	0.00	0.00	0.00	0.00
Bus22	12.660	99.16	99.16	99.16	0.01	0.42	0.00	0.00	0.00	0.00
Bus23	12.660	98.04	98.04	98.04	0.02	0.42	0.00	0.00	0.00	0.00
Bus24	12.660	97.67	97.67	97.67	0	0.42	0.00	0.00	0.00	0.00
Bus24	12.660	97.67	97.67	97.67	0	0.42	0.00	0.00	0.00	0.00
Bus25	12.660	97.62	97.62	97.62	0.01	0.42	0.00	0.00	0.00	0.00
Bus26	12.660	95.03	95.03	95.03	0.02	0.42	0.00	0.00	0.00	0.00
Bus27	12.660	94.80	94.80	94.80	0	0.42	0.00	0.00	0.00	0.00
Bus28	12.660	93.75	93.75	93.75	0.01	0.42	0.00	0.00	0.00	0.00
Bus29	12.660	93.05	93.05	93.05	0.01	0.42	0.00	0.00	0.00	0.00
Bus30	12.660	92.88	92.88	92.88	0.01	0.42	0.00	0.00	0.00	0.00
Bus31	12.660	92.62	92.62	92.62	0	0.42	0.00	0.00	0.00	0.00
Bus32	12.660	92.60	92.60	92.60	0	0.42	0.00	0.00	0.00	0.00
Bus33	12.660	92.60	92.60	92.60	0	0.42	0.00	0.00	0.00	0.00

* IndicatesTHD (Total Harmonic Distortion) Exceeds the Limit.

\# Indicates IHD (Individual Harmonic Distortion) Exceeds the Limit.

Appendix F

All figure harmonic report when 12.66kVat upstream & 1 rectifier

System Harmonics Branch Information

Bus		Current Distortion											
From Bus ID	To Bus ID	Fund. Amp	RMS Amp	ASUM Amp	THD %	TIF	IT Amp	ITB Amp	ITR Amp	TIHD %	TSHD %	THDG %	THDS %
Bus1	Bus2	200.17	200.17	200.33	0.04	0.72	144.75	144.75	0.00	0.00	0.00	0.04	0.04
Bus2	Bus1	200.17	200.17	200.33	0.04	0.72	144.75	144.75	0.00	0.00	0.00	0.04	0.04
	Bus3	177.62	177.62	177.76	0.04	0.71	126.99	126.99	0.00	0.00	0.00	0.04	0.04
	Bus19	18.23	18.23	18.25	0.05	0.80	14.51	14.51	0.00	0.00	0.00	0.05	0.05
Bus3	Bus2	177.62	177.62	177.76	0.04	0.71	126.99	126.99	0.00	0.00	0.00	0.04	0.04
	Bus4	125.51	125.51	125.60	0.04	0.69	86.95	86.95	0.00	0.00	0.00	0.04	0.04
	Bus23	46.00	46.00	46.04	0.05	0.78	35.87	35.87	0.00	0.00	0.00	0.05	0.05
Bus4	Bus3	125.51	125.51	125.60	0.04	0.69	86.95	86.95	0.00	0.00	0.00	0.04	0.04
	Bus5	122.44	122.44	122.54	0.04	0.69	84.63	84.63	0.00	0.00	0.00	0.04	0.04
Bus5	Bus4	122.44	122.44	122.54	0.04	0.69	84.63	84.63	0.00	0.00	0.00	0.04	0.04
	Bus6	119.64	119.64	119.73	0.04	0.69	82.41	82.41	0.00	0.00	0.00	0.04	0.04
Bus6	Bus5	119.64	119.64	119.73	0.04	0.69	82.41	82.41	0.00	0.00	0.00	0.04	0.04
	Bus7	51.00	51.00	51.04	0.04	0.72	36.82	36.82	0.00	0.00	0.00	0.04	0.04
	Bus26	60.21	60.21	60.25	0.03	0.64	38.75	38.75	0.00	0.00	0.00	0.03	0.03
Bus7	Bus6	51.00	51.00	51.04	0.04	0.72	36.82	36.82	0.00	0.00	0.00	0.04	0.04
	Bus8	40.47	40.47	40.51	0.04	0.72	29.09	29.09	0.00	0.00	0.00	0.04	0.04
Bus8	Bus7	40.47	40.47	40.51	0.04	0.72	29.09	29.09	0.00	0.00	0.00	0.04	0.04
	Bus9	37.49	37.49	37.52	0.04	0.72	26.85	26.85	0.00	0.00	0.00	0.04	0.04
Bus9	Bus8	37.49	37.49	37.52	0.04	0.72	26.85	26.85	0.00	0.00	0.00	0.04	0.04
	Bus10	34.50	34.50	34.53	0.04	0.71	24.62	24.62	0.00	0.00	0.00	0.04	0.04
Bus10	Bus9	34.50	34.50	34.53	0.04	0.71	24.62	24.62	0.00	0.00	0.00	0.04	0.04
	Bus11	31.94	31.94	31.96	0.04	0.72	22.84	22.84	0.00	0.00	0.00	0.04	0.04
Bus11	Bus10	31.94	31.94	31.96	0.04	0.72	22.84	22.84	0.00	0.00	0.00	0.04	0.04

Bus10	Bus9	34.50	34.50	34.53	0.04	0.71	24.62	24.62	0.00	0.00	0.00	0.04	0.04
	Bus11	31.94	31.94	31.96	0.04	0.72	22.84	22.84	0.00	0.00	0.00	0.04	0.04
Bus11	Bus10	31.94	31.94	31.96	0.04	0.72	22.84	22.84	0.00	0.00	0.00	0.04	0.04
	Bus12	28.63	28.63	28.65	0.04	0.72	20.50	20.50	0.00	0.00	0.00	0.04	0.04
Bus12	Bus11	28.63	28.63	28.65	0.04	0.72	20.50	20.50	0.00	0.00	0.00	0.04	0.04
	Bus13	25.31	25.31	25.33	0.04	0.72	18.16	18.16	0.00	0.00	0.00	0.04	0.04
Bus13	Bus12	25.31	25.31	25.33	0.04	0.72	18.16	18.16	0.00	0.00	0.00	0.04	0.04
	Bus14	18.51	18.51	18.52	0.04	0.73	13.44	13.44	0.00	0.00	0.00	0.04	0.04
Bus14	Bus13	18.51	18.51	18.52	0.04	0.73	13.44	13.44	0.00	0.00	0.00	0.04	0.04
	Bus15	15.63	15.63	15.65	0.04	0.72	11.27	11.27	0.00	0.00	0.00	0.04	0.04
Bus15	Bus14	15.63	15.63	15.65	0.04	0.72	11.27	11.27	0.00	0.00	0.00	0.04	0.04
	Bus16	12.59	12.59	12.60	0.04	0.72	9.04	9.04	0.00	0.00	0.00	0.04	0.04
Bus16	Bus15	12.59	12.59	12.60	0.04	0.72	9.04	9.04	0.00	0.00	0.00	0.04	0.04
	Bus17	9.54	9.54	9.55	0.04	0.71	6.82	6.82	0.00	0.00	0.00	0.04	0.04
Bus17	Bus16	9.54	9.54	9.55	0.04	0.71	6.82	6.82	0.00	0.00	0.00	0.04	0.04
	Bus18	4.77	4.77	4.78	0.04	0.71	3.41	3.41	0.00	0.00	0.00	0.04	0.04
Bus18	Bus17	4.77	4.77	4.78	0.04	0.71	3.41	3.41	0.00	0.00	0.00	0.04	0.04
Bus19	Bus2	18.23	18.23	18.25	0.05	0.80	14.51	14.51	0.00	0.00	0.00	0.05	0.05
	bus20	13.73	13.73	13.74	0.05	0.79	10.89	10.89	0.00	0.00	0.00	0.05	0.05
bus20	Bus19	13.73	13.73	13.74	0.05	0.79	10.89	10.89	0.00	0.00	0.00	0.05	0.05
	Bus21	9.22	9.22	9.23	0.05	0.79	7.28	7.28	0.00	0.00	0.00	0.05	0.05

Bus		Current Distortion											
From Bus ID	To Bus ID	Fund. Amp	RMS Amp	ASUM Amp	THD %	TIF	IT Amp	ITB Amp	ITR Amp	TIHD %	TSHD %	THDG %	THDS %
Bus21	bus20	9.22	9.22	9.23	0.05	0.79	7.28	7.28	0.00	0.00	0.00	0.05	0.05
	Bus22	4.72	4.72	4.72	0.05	0.78	3.68	3.68	0.00	0.00	0.00	0.05	0.05
Bus22	Bus21	4.72	4.72	4.72	0.05	0.78	3.68	3.68	0.00	0.00	0.00	0.05	0.05
Bus23	Bus3	46.00	46.00	46.04	0.05	0.78	35.87	35.87	0.00	0.00	0.00	0.05	0.05
	Bus24	24.53	24.53	24.55	0.05	0.78	19.11	19.11	0.00	0.00	0.00	0.05	0.05
Bus24	Bus23	24.53	24.53	24.55	0.05	0.78	19.11	19.11	0.00	0.00	0.00	0.05	0.05
	Bus25	3.01	3.01	3.01	0.05	0.79	2.37	2.37	0.00	0.00	0.00	0.05	0.05
Bus25	Bus24	3.01	3.01	3.01	0.05	0.79	2.37	2.37	0.00	0.00	0.00	0.05	0.05
Bus26	Bus6	60.21	60.21	60.25	0.03	0.64	38.75	38.75	0.00	0.00	0.00	0.03	0.03
	Bus27	57.43	57.43	57.47	0.03	0.64	36.60	36.60	0.00	0.00	0.00	0.03	0.03
Bus27	Bus26	57.43	57.43	57.47	0.03	0.64	36.60	36.60	0.00	0.00	0.00	0.03	0.03
	Bus28	54.87	54.87	54.90	0.03	0.63	34.54	34.54	0.00	0.00	0.00	0.03	0.03
Bus28	Bus27	54.87	54.87	54.90	0.03	0.63	34.54	34.54	0.00	0.00	0.00	0.03	0.03
	Bus29	48.70	48.70	48.73	0.03	0.62	30.03	30.03	0.00	0.00	0.00	0.03	0.03
Bus29	Bus28	48.70	48.70	48.73	0.03	0.62	30.03	30.03	0.00	0.00	0.00	0.03	0.03
	Bus30	22.45	22.45	22.47	0.04	0.73	16.30	16.30	0.00	0.00	0.00	0.04	0.04
Bus30	Bus29	22.45	22.45	22.47	0.04	0.73	16.30	16.30	0.00	0.00	0.00	0.04	0.04
	Bus31	14.55	14.55	14.56	0.04	0.72	10.52	10.52	0.00	0.00	0.00	0.04	0.04
Bus31	Bus30	14.55	14.55	14.56	0.04	0.72	10.52	10.52	0.00	0.00	0.00	0.04	0.04
	Bus32	3.45	3.45	3.45	0.04	0.70	2.41	2.41	0.00	0.00	0.00	0.04	0.04
Bus32	Bus31	3.45	3.45	3.45	0.04	0.70	2.41	2.41	0.00	0.00	0.00	0.04	0.04
	Bus33	0	0	0	0	0	0.00	2.41	0.00	0.00	0.00	0.00	0.00
Bus33	Bus32	0	0	0	0	0	0.00	2.41	0.00	0.00	0.00	0.00	0.00

Bus Tabulation

Harmonic Voltages (% of Fundamental Voltage)

Bus ID: Bus1
Fund. kV: 12.660

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.03	7.00	350.00	0.03	11.00	550.00	0.03	13.00	650.00	0.03						

Bus ID: Bus10
Fund. kV: 11.713

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.03	7.00	350.00	0.03	11.00	550.00	0.03	13.00	650.00	0.02						

Bus ID: Bus11
Fund. kV: 11.702

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.03	7.00	350.00	0.03	11.00	550.00	0.03	13.00	650.00	0.02						

Bus ID: Bus12
Fund. kV: 11.683

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.03	7.00	350.00	0.03	11.00	550.00	0.03	13.00	650.00	0.02						

Bus ID: Bus13
Fund. kV: 11.603

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.03	7.00	350.00	0.03	11.00	550.00	0.03	13.00	650.00	0.02						

Bus ID: Bus14
Fund. kV: 11.579

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.03	7.00	350.00	0.03	11.00	550.00	0.03	13.00	650.00	0.02						

Bus ID: Bus14
Fund. kV: 11.579

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.03	7.00	350.00	0.03	11.00	550.00	0.03	13.00	650.00	0.02						

Bus ID: Bus15
Fund. kV: 11.559

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.03	7.00	350.00	0.03	11.00	550.00	0.03	13.00	650.00	0.02						

Bus ID: Bus16
Fund. kV: 11.539

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.03	7.00	350.00	0.03	11.00	550.00	0.03	13.00	650.00	0.02						

Bus ID: Bus17
Fund. kV: 11.508

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.03	7.00	350.00	0.03	11.00	550.00	0.03	13.00	650.00	0.02						

Bus Tabulation

Harmonic Voltages (% of Fundamental Voltage)

Bus ID: Bus18
Fund. kV: 11.501

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.03	7.00	350.00	0.03	11.00	550.00	0.03	13.00	650.00	0.02						

Bus ID: Bus19
Fund. kV: 12.617

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.03	7.00	350.00	0.03	11.00	550.00	0.03	13.00	650.00	0.03						

Bus ID: Bus2
Fund. kV: 12.624

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.03	7.00	350.00	0.03	11.00	550.00	0.03	13.00	650.00	0.03						

Bus ID: bus20
Fund. kV: 12.571

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.03	7.00	350.00	0.03	11.00	550.00	0.03	13.00	650.00	0.03						

Bus ID: Bus21
Fund. kV: 12.562

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.03	7.00	350.00	0.03	11.00	550.00	0.03	13.00	650.00	0.03						

Bus ID: Bus22
Fund. kV: 12.553

Order	Freq.	Mag.	Order	Freq.	Mag.	Order	Freq.	Mag.	Order	Freq.	Mag.	Order	Freq.	Mag.	Order	Freq.	Mag.

Bus ID: Bus22
Fund. kV: 12.553

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.03	7.00	350.00	0.03	11.00	550.00	0.03	13.00	650.00	0.03						

Bus ID: Bus23
Fund. kV: 12.412

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.03	7.00	350.00	0.03	11.00	550.00	0.03	13.00	650.00	0.03						

Bus ID: Bus24
Fund. kV: 12.364

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.03	7.00	350.00	0.03	11.00	550.00	0.03	13.00	650.00	0.03						

Bus ID: Bus25
Fund. kV: 12.359

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.03	7.00	350.00	0.03	11.00	550.00	0.03	13.00	650.00	0.03						

Harmonic Voltages (% of Fundamental Voltage)

Bus ID: Bus26
Fund. kV: 12.031

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.03	7.00	350.00	0.03	11.00	550.00	0.03	13.00	650.00	0.03						

Bus ID: Bus27
Fund. kV: 12.001

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.03	7.00	350.00	0.03	11.00	550.00	0.03	13.00	650.00	0.03						

Bus ID: Bus28
Fund. kV: 11.869

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.03	7.00	350.00	0.03	11.00	550.00	0.03	13.00	650.00	0.03						

Bus ID: Bus29
Fund. kV: 11.781

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.03	7.00	350.00	0.03	11.00	550.00	0.03	13.00	650.00	0.03						

Bus ID: Bus3
Fund. kV: 12.455

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.03	7.00	350.00	0.03	11.00	550.00	0.03	13.00	650.00	0.03						

Bus ID: Bus30
Fund. kV: 11.758

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.03	7.00	350.00	0.03	11.00	550.00	0.03	13.00	650.00	0.03						

Bus ID: Bus30
Fund. kV: 11.758

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.03	7.00	350.00	0.03	11.00	550.00	0.03	13.00	650.00	0.03						

Bus ID: Bus31
Fund. kV: 11.725

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.03	7.00	350.00	0.03	11.00	550.00	0.03	13.00	650.00	0.03						

Bus ID: Bus32
Fund. kV: 11.723

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.03	7.00	350.00	0.03	11.00	550.00	0.03	13.00	650.00	0.03						

Bus ID: Bus33
Fund. kV: 11.723

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.03	7.00	350.00	0.03	11.00	550.00	0.03	13.00	650.00	0.03						

Appendix G

load flow report when put 12.66kV at upstream and two rectifiers

LOAD FLOW REPORT

Bus		Voltage		Generation		Load		Load Flow					XFMR
ID	kV	% Mag.	Ang.	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	%PF	%Tap
* Bus1	12.660	100.000	0.0	4.541	2.817	0.440	0.271	Bus2	4.101	2.546	220.1	85.0	
Bus2	12.660	99.688	0.0	0	0	0.090	0.040	Bus1	-4.088	-2.539	220.1	84.9	
								Bus3	3.638	2.329	197.6	84.2	
								Bus19	0.360	0.171	18.2	90.4	
Bus3	12.660	98.200	0.1	0	0	0.119	0.079	Bus2	-3.580	-2.299	197.6	84.1	
								Bus4	2.564	1.795	145.4	81.9	
								Bus23	0.896	0.424	46.0	90.4	
Bus4	12.660	97.391	0.2	0	0	0.059	0.030	Bus3	-2.541	-1.784	145.4	81.9	
								Bus5	2.482	1.754	142.3	81.7	
Bus5	12.660	96.567	0.2	0	0	0.059	0.020	Bus4	-2.459	-1.742	142.3	81.6	
								Bus6	2.400	1.722	139.5	81.2	
Bus6	12.660	94.511	0.1	0	0	0.536	0.309	Bus5	-2.352	-1.681	139.5	81.4	
								Bus7	0.959	0.457	51.3	90.3	
								Bus26	0.857	0.915	60.5	68.4	
Bus7	12.660	94.206	-0.1	0	0	0.195	0.098	Bus6	-0.957	-0.452	51.3	90.4	
								Bus8	0.762	0.355	40.7	90.7	
Bus8	12.660	93.053	-0.2	0	0	0.058	0.019	Bus7	-0.753	-0.349	40.7	90.8	
								Bus9	0.695	0.329	37.7	90.4	
Bus9	12.660	92.410	-0.3	0	0	0.058	0.019	Bus8	-0.691	-0.326	37.7	90.4	
								Bus10	0.632	0.307	34.7	90.0	
Bus10	12.660	91.812	-0.3	0	0	0.044	0.029	Bus9	-0.629	-0.304	34.7	90.0	
Bus10	12.660	91.812	-0.3	0	0	0.044	0.029	Bus9	-0.629	-0.304	34.7	90.0	
								Bus11	0.585	0.275	32.1	90.5	
Bus11	12.660	91.722	-0.3	0	0	0.058	0.034	Bus10	-0.584	-0.275	32.1	90.5	
								Bus12	0.526	0.241	28.8	90.9	
Bus12	12.660	91.568	-0.3	0	0	0.058	0.034	Bus11	-0.525	-0.240	28.8	90.9	
								Bus13	0.467	0.207	25.4	91.5	
Bus13	12.660	90.938	-0.4	0	0	0.116	0.077	Bus12	-0.464	-0.204	25.4	91.5	
								Bus14	0.349	0.127	18.6	93.9	
Bus14	12.660	90.746	-0.5	0	0	0.058	0.010	Bus13	-0.348	-0.126	18.6	94.0	
								Bus15	0.290	0.117	15.7	92.8	
Bus15	12.660	90.586	-0.5	0	0	0.058	0.019	Bus14	-0.290	-0.116	15.7	92.8	
								Bus16	0.232	0.097	12.7	92.2	
Bus16	12.660	90.431	-0.6	0	0	0.058	0.019	Bus15	-0.231	-0.097	12.7	92.3	
								Bus17	0.174	0.078	9.6	91.3	
Bus17	12.660	90.184	-0.7	0	0	0.087	0.039	Bus16	-0.173	-0.077	9.6	91.4	

Appendix H

All figure harmonic report when 12.66kV at upstream & two rectifiers

System Harmonics Bus Information

Bus		Voltage Distortion								
ID	kV	Fund. %	RMS %	ASUM %	THD %	TIF	TIHD %	TSHD %	THDG %	THDS %
Bus1	12.660	100.00	100.00	100.21	0.10	1.42	0.00	0.00	0.10	0.10
Bus2	12.660	99.69	99.69	99.94	0.13	1.71	0.00	0.00	0.13	0.13
Bus3	12.660	98.20	98.20	98.70	0.26	3.30	0.00	0.00	0.26	0.26
Bus4	12.660	97.39	97.39	98.08	0.36	4.54	0.00	0.00	0.36	0.36
Bus5	12.660	96.57	96.57	97.46	0.46	5.85	0.00	0.00	0.46	0.46
Bus6	12.660	94.51	94.51	96.10	0.84	10.70	0.00	0.00	0.84	0.84
Bus7	12.660	94.21	94.21	95.78	0.84	10.63	0.00	0.00	0.84	0.84
Bus8	12.660	93.05	93.06	94.60	0.83	10.54	0.00	0.00	0.83	0.83
Bus9	12.660	92.41	92.41	93.95	0.83	10.50	0.00	0.00	0.83	0.83
Bus10	12.660	91.81	91.82	93.34	0.83	10.48	0.00	0.00	0.83	0.83
Bus11	12.660	91.72	91.73	93.25	0.83	10.48	0.00	0.00	0.83	0.83
Bus12	12.660	91.57	91.57	93.09	0.83	10.48	0.00	0.00	0.83	0.83
Bus13	12.660	90.94	90.94	92.45	0.83	10.47	0.00	0.00	0.83	0.83
Bus14	12.660	90.75	90.75	92.26	0.83	10.46	0.00	0.00	0.83	0.83
Bus15	12.660	90.59	90.59	92.09	0.83	10.46	0.00	0.00	0.83	0.83
Bus16	12.660	90.43	90.43	91.94	0.83	10.46	0.00	0.00	0.83	0.83
Bus17	12.660	90.18	90.19	91.69	0.83	10.46	0.00	0.00	0.83	0.83
Bus18	12.660	90.13	90.13	91.63	0.83	10.46	0.00	0.00	0.83	0.83
Bus19	12.660	99.63	99.63	99.89	0.13	1.71	0.00	0.00	0.13	0.13
bus20	12.660	99.27	99.27	99.52	0.13	1.70	0.00	0.00	0.13	0.13
Bus21	12.660	99.20	99.20	99.45	0.13	1.70	0.00	0.00	0.13	0.13
Bus22	12.660	99.13	99.13	99.38	0.13	1.70	0.00	0.00	0.13	0.13
Bus23	12.660	97.86	97.86	98.36	0.26	3.30	0.00	0.00	0.26	0.26

Bus21	12.660	99.20	99.20	99.45	0.13	1.70	0.00	0.00	0.13	0.13
Bus22	12.660	99.13	99.13	99.38	0.13	1.70	0.00	0.00	0.13	0.13
Bus23	12.660	97.86	97.86	98.36	0.26	3.30	0.00	0.00	0.26	0.26
Bus24	12.660	97.49	97.49	97.99	0.26	3.30	0.00	0.00	0.26	0.26
Bus25	12.660	97.44	97.44	97.94	0.26	3.30	0.00	0.00	0.26	0.26
Bus26	12.660	94.33	94.34	95.92	0.84	10.70	0.00	0.00	0.84	0.84
Bus27	12.660	94.10	94.10	95.68	0.84	10.69	0.00	0.00	0.84	0.84
Bus28	12.660	93.05	93.05	94.61	0.84	10.67	0.00	0.00	0.84	0.84
Bus29	12.660	92.35	92.35	93.90	0.84	10.67	0.00	0.00	0.84	0.84
Bus30	12.660	92.17	92.17	93.72	0.84	10.67	0.00	0.00	0.84	0.84
Bus31	12.660	91.91	91.91	93.45	0.84	10.67	0.00	0.00	0.84	0.84
Bus32	12.660	91.89	91.89	93.43	0.84	10.67	0.00	0.00	0.84	0.84
Bus33	12.660	91.89	91.89	93.43	0.84	10.67	0.00	0.00	0.84	0.84

* IndicatesTHD (Total Harmonic Distortion) Exceeds the Limit.
# Indicates IHD (Individual Harmonic Distortion) Exceeds the Limit.

System Harmonics Branch Information

Bus		Current Distortion											
From Bus ID	To Bus ID	Fund. Amp	RMS Amp	ASUM Amp	THD %	TIF	IT Amp	ITB Amp	ITR Amp	TIHD %	TSHD %	THDG %	THDS %
Bus1	Bus2	220.14	220.19	229.28	2.23	17.36	3821.52	3821.52	0.00	0.00	0.00	2.23	2.23
Bus2	Bus1	220.14	220.19	229.28	2.23	17.36	3821.52	3821.52	0.00	0.00	0.00	2.23	2.23
	Bus3	197.58	197.64	206.72	2.49	19.33	3821.22	3821.22	0.00	0.00	0.00	2.49	2.49
	Bus19	18.23	18.23	18.27	0.11	1.56	28.47	28.47	0.00	0.00	0.00	0.11	0.11
Bus3	Bus2	197.58	197.64	206.72	2.49	19.33	3821.22	3821.22	0.00	0.00	0.00	2.49	2.49
	Bus4	145.38	145.46	154.57	3.40	26.41	3841.63	3841.63	0.00	0.00	0.00	3.40	3.40
	Bus23	46.05	46.05	46.25	0.22	2.90	133.44	133.44	0.00	0.00	0.00	0.22	0.22
Bus4	Bus3	145.38	145.46	154.57	3.40	26.41	3841.63	3841.63	0.00	0.00	0.00	3.40	3.40
	Bus5	142.31	142.39	151.50	3.48	26.99	3843.43	3843.43	0.00	0.00	0.00	3.48	3.48
Bus5	Bus4	142.31	142.39	151.50	3.48	26.99	3843.43	3843.43	0.00	0.00	0.00	3.48	3.48
	Bus6	139.49	139.58	148.69	3.55	27.55	3845.76	3845.76	0.00	0.00	0.00	3.55	3.55
Bus6	Bus5	139.49	139.58	148.69	3.55	27.55	3845.76	3845.76	0.00	0.00	0.00	3.55	3.55
	Bus7	51.26	51.26	51.93	0.66	8.26	423.42	423.42	0.00	0.00	0.00	0.66	0.66
	Bus26	60.50	60.51	61.12	0.51	6.44	389.46	389.46	0.00	0.00	0.00	0.51	0.51
Bus7	Bus6	51.26	51.26	51.93	0.66	8.26	423.42	423.42	0.00	0.00	0.00	0.66	0.66
	Bus8	40.68	40.68	41.21	0.65	8.19	333.11	333.11	0.00	0.00	0.00	0.65	0.65
Bus8	Bus7	40.68	40.68	41.21	0.65	8.19	333.11	333.11	0.00	0.00	0.00	0.65	0.65
	Bus9	37.69	37.69	38.17	0.65	8.13	306.49	306.49	0.00	0.00	0.00	0.65	0.65
Bus9	Bus8	37.69	37.69	38.17	0.65	8.13	306.49	306.49	0.00	0.00	0.00	0.65	0.65
	Bus10	34.68	34.68	35.12	0.64	8.08	280.05	280.05	0.00	0.00	0.00	0.64	0.64
Bus10	Bus9	34.68	34.68	35.12	0.64	8.08	280.05	280.05	0.00	0.00	0.00	0.64	0.64
	Bus11	32.10	32.10	32.52	0.65	8.11	260.26	260.26	0.00	0.00	0.00	0.65	0.65
Bus11	Bus10	32.10	32.10	32.52	0.65	8.11	260.26	260.26	0.00	0.00	0.00	0.65	0.65

	Bus10	34.68	34.68	35.12	0.64	8.08	280.05	280.05	0.00	0.00	0.00	0.64	0.64
Bus10	Bus9	34.68	34.68	35.12	0.64	8.08	280.05	280.05	0.00	0.00	0.00	0.64	0.64
	Bus11	32.10	32.10	32.52	0.65	8.11	260.26	260.26	0.00	0.00	0.00	0.65	0.65
Bus11	Bus10	32.10	32.10	32.52	0.65	8.11	260.26	260.26	0.00	0.00	0.00	0.65	0.65
	Bus12	28.77	28.77	29.15	0.65	8.13	233.94	233.94	0.00	0.00	0.00	0.65	0.65
Bus12	Bus11	28.77	28.77	29.15	0.65	8.13	233.94	233.94	0.00	0.00	0.00	0.65	0.65
	Bus13	25.44	25.45	25.77	0.65	8.16	207.66	207.66	0.00	0.00	0.00	0.65	0.65
Bus13	Bus12	25.44	25.45	25.77	0.65	8.16	207.66	207.66	0.00	0.00	0.00	0.65	0.65
	Bus14	18.61	18.61	18.85	0.66	8.35	155.43	155.43	0.00	0.00	0.00	0.66	0.66
Bus14	Bus13	18.61	18.61	18.85	0.66	8.35	155.43	155.43	0.00	0.00	0.00	0.66	0.66
	Bus15	15.72	15.72	15.92	0.66	8.24	129.45	129.45	0.00	0.00	0.00	0.66	0.66
Bus15	Bus14	15.72	15.72	15.92	0.66	8.24	129.45	129.45	0.00	0.00	0.00	0.66	0.66
	Bus16	12.65	12.65	12.82	0.65	8.18	103.50	103.50	0.00	0.00	0.00	0.65	0.65
Bus16	Bus15	12.65	12.65	12.82	0.65	8.18	103.50	103.50	0.00	0.00	0.00	0.65	0.65
	Bus17	9.59	9.59	9.71	0.64	8.09	77.59	77.59	0.00	0.00	0.00	0.64	0.64
Bus17	Bus16	9.59	9.59	9.71	0.64	8.09	77.59	77.59	0.00	0.00	0.00	0.64	0.64
	Bus18	4.80	4.80	4.86	0.64	8.09	38.78	38.78	0.00	0.00	0.00	0.64	0.64
Bus18	Bus17	4.80	4.80	4.86	0.64	8.09	38.78	38.78	0.00	0.00	0.00	0.64	0.64
Bus19	Bus2	18.23	18.23	18.27	0.11	1.56	28.47	28.47	0.00	0.00	0.00	0.11	0.11
	bus20	13.73	13.73	13.76	0.11	1.55	21.34	21.34	0.00	0.00	0.00	0.11	0.11
bus20	Bus19	13.73	13.73	13.76	0.11	1.55	21.34	21.34	0.00	0.00	0.00	0.11	0.11
	Bus21	9.22	9.22	9.25	0.11	1.54	14.24	14.24	0.00	0.00	0.00	0.11	0.11

Bus		Current Distortion												
From Bus ID	To Bus ID	Fund. Amp	RMS Amp	ASUM Amp	THD %	TIF	IT Amp	ITB Amp	ITR Amp	TIHD %	TSHD %	THDG %	THDS %
Bus21	bus20	9.22	9.22	9.25	0.11	1.54	14.24	14.24	0.00	0.00	0.00	0.11	0.11
	Bus22	4.72	4.72	4.73	0.11	1.51	7.13	7.13	0.00	0.00	0.00	0.11	0.11
Bus22	Bus21	4.72	4.72	4.73	0.11	1.51	7.13	7.13	0.00	0.00	0.00	0.11	0.11
Bus23	Bus3	46.05	46.05	46.25	0.22	2.90	133.44	133.44	0.00	0.00	0.00	0.22	0.22
	Bus24	24.55	24.55	24.66	0.22	2.89	71.04	71.04	0.00	0.00	0.00	0.22	0.22
Bus24	Bus23	24.55	24.55	24.66	0.22	2.89	71.04	71.04	0.00	0.00	0.00	0.22	0.22
	Bus25	3.01	3.01	3.03	0.23	2.95	8.87	8.87	0.00	0.00	0.00	0.23	0.23
Bus25	Bus24	3.01	3.01	3.03	0.23	2.95	8.87	8.87	0.00	0.00	0.00	0.23	0.23
Bus26	Bus6	60.50	60.51	61.12	0.51	6.44	389.46	389.46	0.00	0.00	0.00	0.51	0.51
	Bus27	57.72	57.72	58.29	0.50	6.27	362.11	362.11	0.00	0.00	0.00	0.50	0.50
Bus27	Bus26	57.72	57.72	58.29	0.50	6.27	362.11	362.11	0.00	0.00	0.00	0.50	0.50
	Bus28	55.14	55.14	55.67	0.48	6.07	334.90	334.90	0.00	0.00	0.00	0.48	0.48
Bus28	Bus27	55.14	55.14	55.67	0.48	6.07	334.90	334.90	0.00	0.00	0.00	0.48	0.48
	Bus29	48.95	48.95	49.39	0.46	5.74	280.72	280.72	0.00	0.00	0.00	0.46	0.46
Bus29	Bus28	48.95	48.95	49.39	0.46	5.74	280.72	280.72	0.00	0.00	0.00	0.46	0.46
	Bus30	22.56	22.56	22.86	0.66	8.35	188.43	188.43	0.00	0.00	0.00	0.66	0.66
Bus30	Bus29	22.56	22.56	22.86	0.66	8.35	188.43	188.43	0.00	0.00	0.00	0.66	0.66
	Bus31	14.62	14.62	14.81	0.65	8.28	121.04	121.04	0.00	0.00	0.00	0.65	0.65
Bus31	Bus30	14.62	14.62	14.81	0.65	8.28	121.04	121.04	0.00	0.00	0.00	0.65	0.65
	Bus32	3.47	3.47	3.51	0.61	7.76	26.92	26.92	0.00	0.00	0.00	0.61	0.61
Bus32	Bus31	3.47	3.47	3.51	0.61	7.76	26.92	26.92	0.00	0.00	0.00	0.61	0.61
	Bus33	0	0	0	0	0	0.00	26.92	0.00	0.00	0.00	0.00	0.00
Bus33	Bus32	0	0	0	0	0	0.00	26.92	0.00	0.00	0.00	0.00	0.00

Bus Tabulation

Harmonic Voltages (% of Fundamental Voltage)

Bus ID: Bus1
Fund. kV: 12.660

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.05	7.00	350.00	0.05	11.00	550.00	0.05	13.00	650.00	0.05						

Bus ID: Bus10
Fund. kV: 11.623

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.44	7.00	350.00	0.42	11.00	550.00	0.41	13.00	650.00	0.40						

Bus ID: Bus11
Fund. kV: 11.612

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.44	7.00	350.00	0.42	11.00	550.00	0.41	13.00	650.00	0.40						

Bus ID: Bus12
Fund. kV: 11.592

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.44	7.00	350.00	0.42	11.00	550.00	0.41	13.00	650.00	0.40						

Bus ID: Bus13
Fund. kV: 11.513

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.44	7.00	350.00	0.43	11.00	550.00	0.41	13.00	650.00	0.40						

Bus ID: Bus14
Fund. kV: 11.488

Order	Freq.	Mag.	Order	Freq.	Mag.	Order	Freq.	Mag.	Order	Freq.	Mag.	Order	Freq.	Mag.	Order	Freq.	Mag.

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.44	7.00	350.00	0.43	11.00	550.00	0.41	13.00	650.00	0.40						

Bus ID: Bus14
Fund. kV: 11.488

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.44	7.00	350.00	0.43	11.00	550.00	0.41	13.00	650.00	0.40						

Bus ID: Bus15
Fund. kV: 11.468

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.44	7.00	350.00	0.43	11.00	550.00	0.41	13.00	650.00	0.40						

Bus ID: Bus16
Fund. kV: 11.449

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.44	7.00	350.00	0.43	11.00	550.00	0.41	13.00	650.00	0.40						

Bus ID: Bus17
Fund. kV: 11.417

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.44	7.00	350.00	0.43	11.00	550.00	0.41	13.00	650.00	0.40						

Bus ID: Bus18
Fund. kV: 11.410

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.44	7.00	350.00	0.43	11.00	550.00	0.41	13.00	650.00	0.40						

Bus ID: Bus19
Fund. kV: 12.614

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.07	7.00	350.00	0.06	11.00	550.00	0.06	13.00	650.00	0.06						

Bus ID: Bus2
Fund. kV: 12.621

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.07	7.00	350.00	0.06	11.00	550.00	0.06	13.00	650.00	0.06						

Bus ID: bus20
Fund. kV: 12.568

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.07	7.00	350.00	0.06	11.00	550.00	0.06	13.00	650.00	0.06						

Bus ID: Bus21
Fund. kV: 12.558

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.07	7.00	350.00	0.06	11.00	550.00	0.06	13.00	650.00	0.06						

Bus ID: Bus22
Fund. kV: 12.549

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.07	7.00	350.00	0.06	11.00	550.00	0.06	13.00	650.00	0.06						

Bus ID: Bus22
Fund. kV: 12.549

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.07	7.00	350.00	0.06	11.00	550.00	0.06	13.00	650.00	0.06						

Bus ID: Bus23
Fund. kV: 12.389

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.13	7.00	350.00	0.13	11.00	550.00	0.13	13.00	650.00	0.12						

Bus ID: Bus24
Fund. kV: 12.342

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.13	7.00	350.00	0.13	11.00	550.00	0.13	13.00	650.00	0.12						

Bus ID: Bus25
Fund. kV: 12.336

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.13	7.00	350.00	0.13	11.00	550.00	0.13	13.00	650.00	0.12						

Bus Tabulation

Harmonic Voltages (% of Fundamental Voltage)

Bus ID: Bus26
Fund. kV: 11.943

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.44	7.00	350.00	0.43	11.00	550.00	0.41	13.00	650.00	0.41						

Bus ID: Bus27
Fund. kV: 11.913

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.44	7.00	350.00	0.43	11.00	550.00	0.41	13.00	650.00	0.41						

Bus ID: Bus28
Fund. kV: 11.780

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.44	7.00	350.00	0.43	11.00	550.00	0.41	13.00	650.00	0.40						

Bus ID: Bus29
Fund. kV: 11.691

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.44	7.00	350.00	0.43	11.00	550.00	0.41	13.00	650.00	0.40						

Bus ID: Bus3
Fund. kV: 12.432

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.13	7.00	350.00	0.13	11.00	550.00	0.13	13.00	650.00	0.12						

Bus ID: Bus30
Fund. kV: 11.669

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.44	7.00	350.00	0.43	11.00	550.00	0.41	13.00	650.00	0.40						

Bus ID: Bus31
Fund. kV: 11.635

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.44	7.00	350.00	0.43	11.00	550.00	0.41	13.00	650.00	0.40						

Bus ID: Bus32
Fund. kV: 11.633

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.44	7.00	350.00	0.43	11.00	550.00	0.41	13.00	650.00	0.40						

Bus ID: Bus33
Fund. kV: 11.633

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.44	7.00	350.00	0.43	11.00	550.00	0.41	13.00	650.00	0.40						

Bus Tabulation

Harmonic Voltages (% of Fundamental Voltage)

Bus ID: Bus4
Fund. kV: 12.330

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.18	7.00	350.00	0.18	11.00	550.00	0.17	13.00	650.00	0.17						

Bus ID: Bus5
Fund. kV: 12.225

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.24	7.00	350.00	0.23	11.00	550.00	0.23	13.00	650.00	0.22						

Bus ID: Bus6
Fund. kV: 11.965

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.44	7.00	350.00	0.43	11.00	550.00	0.41	13.00	650.00	0.41						

Bus ID: Bus7
Fund. kV: 11.927

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.44	7.00	350.00	0.43	11.00	550.00	0.41	13.00	650.00	0.40						

Bus ID: Bus8
Fund. kV: 11.780

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.44	7.00	350.00	0.43	11.00	550.00	0.41	13.00	650.00	0.40						

Harmonic Voltages (% of Nominal Voltage)

Bus ID: Bus1
Nom. kV: 12.660

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.05	7.00	350.00	0.05	11.00	550.00	0.05	13.00	650.00	0.05						

Bus ID: Bus10
Nom. kV: 12.660

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.40	7.00	350.00	0.39	11.00	550.00	0.37	13.00	650.00	0.36						

Bus ID: Bus11
Nom. kV: 12.660

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.40	7.00	350.00	0.39	11.00	550.00	0.37	13.00	650.00	0.36						

Bus ID: Bus12
Nom. kV: 12.660

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.40	7.00	350.00	0.39	11.00	550.00	0.37	13.00	650.00	0.36						

Bus ID: Bus13
Nom. kV: 12.660

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.40	7.00	350.00	0.39	11.00	550.00	0.37	13.00	650.00	0.36						

Bus ID: Bus14
Nom. kV: 12.660

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.40	7.00	350.00	0.39	11.00	550.00	0.37	13.00	650.00	0.36						

Nom. kV: 12.660

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.40	7.00	350.00	0.39	11.00	550.00	0.37	13.00	650.00	0.36						

Bus ID: Bus14
Nom. kV: 12.660

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.40	7.00	350.00	0.39	11.00	550.00	0.37	13.00	650.00	0.36						

Bus ID: Bus15
Nom. kV: 12.660

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.40	7.00	350.00	0.39	11.00	550.00	0.37	13.00	650.00	0.36						

Bus ID: Bus16
Nom. kV: 12.660

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.40	7.00	350.00	0.38	11.00	550.00	0.37	13.00	650.00	0.36						

Bus ID: Bus17
Nom. kV: 12.660

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.39	7.00	350.00	0.38	11.00	550.00	0.37	13.00	650.00	0.36						

Bus ID: Bus4
Nom. kV: 12.660

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.18	7.00	350.00	0.18	11.00	550.00	0.17	13.00	650.00	0.17						

Bus ID: Bus5
Nom. kV: 12.660

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.23	7.00	350.00	0.23	11.00	550.00	0.22	13.00	650.00	0.21						

Bus ID: Bus6
Nom. kV: 12.660

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.41	7.00	350.00	0.40	11.00	550.00	0.39	13.00	650.00	0.38						

Bus ID: Bus7
Nom. kV: 12.660

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.41	7.00	350.00	0.40	11.00	550.00	0.39	13.00	650.00	0.38						

Bus ID: Bus8
Nom. kV: 12.660

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.41	7.00	350.00	0.40	11.00	550.00	0.38	13.00	650.00	0.37						

Bus ID: Bus9
Nom. kV: 12.660

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.40	7.00	350.00	0.39	11.00	550.00	0.38	13.00	650.00	0.37						

Appendix I

All this fig harmonic for case two rectifiers without any pulse

System Harmonics Bus Information

Bus		Voltage Distortion								
ID	kV	Fund. %	RMS %	ASUM %	THD %	TIF	TIHD %	TSHD %	THDG %	THDS %
Bus1	12.660	100.00	100.00	100.60	0.17	8.47	0.00	0.00	0.17	0.17
Bus2	12.660	99.69	99.69	100.41	0.21	10.18	0.00	0.00	0.21	0.21
Bus3	12.660	98.20	98.20	99.60	0.41	19.55	0.00	0.00	0.41	0.41
Bus4	12.660	97.39	97.39	99.30	0.56	26.78	0.00	0.00	0.57	0.57
Bus5	12.660	96.57	96.57	99.01	0.73	34.43	0.00	0.00	0.73	0.73
Bus6	12.660	94.51	94.52	98.88	1.33	62.78	0.00	0.00	1.33	1.33
Bus7	12.660	94.21	94.21	98.47	1.31	60.84	0.00	0.00	1.31	1.31
Bus8	12.660	93.05	93.06	97.15	1.28	58.06	0.00	0.00	1.28	1.28
Bus9	12.660	92.41	92.42	96.43	1.26	56.92	0.00	0.00	1.26	1.26
Bus10	12.660	91.81	91.82	95.78	1.25	56.13	0.00	0.00	1.25	1.25
Bus11	12.660	91.72	91.73	95.68	1.25	56.09	0.00	0.00	1.25	1.25
Bus12	12.660	91.57	91.58	95.52	1.25	56.00	0.00	0.00	1.25	1.25
Bus13	12.660	90.94	90.95	94.84	1.25	55.36	0.00	0.00	1.25	1.25
Bus14	12.660	90.75	90.75	94.63	1.24	55.16	0.00	0.00	1.24	1.24
Bus15	12.660	90.59	90.59	94.46	1.24	55.07	0.00	0.00	1.24	1.24
Bus16	12.660	90.43	90.44	94.29	1.24	55.01	0.00	0.00	1.24	1.24
Bus17	12.660	90.18	90.19	94.03	1.24	54.94	0.00	0.00	1.24	1.24
Bus18	12.660	90.13	90.13	93.97	1.24	54.95	0.00	0.00	1.24	1.24
Bus19	12.660	99.63	99.63	100.36	0.21	10.17	0.00	0.00	0.21	0.21
bus20	12.660	99.27	99.27	99.99	0.21	10.14	0.00	0.00	0.21	0.21
Bus21	12.660	99.20	99.20	99.92	0.21	10.14	0.00	0.00	0.21	0.21
Bus22	12.660	99.13	99.13	99.85	0.21	10.14	0.00	0.00	0.21	0.21
Bus23	12.660	97.86	97.86	99.25	0.41	19.50	0.00	0.00	0.41	0.41
Bus24	12.660	97.49	97.49	98.87	0.41	19.46	0.00	0.00	0.41	0.41
Bus25	12.660	97.44	97.44	98.83	0.41	19.46	0.00	0.00	0.41	0.41
Bus26	12.660	94.33	94.34	98.68	1.33	62.60	0.00	0.00	1.33	1.33
Bus27	12.660	94.10	94.11	98.43	1.33	62.37	0.00	0.00	1.33	1.33
Bus28	12.660	93.05	93.05	97.29	1.32	61.34	0.00	0.00	1.32	1.32
Bus29	12.660	92.35	92.35	96.54	1.31	61.06	0.00	0.00	1.31	1.31
Bus30	12.660	92.17	92.18	96.36	1.31	61.02	0.00	0.00	1.31	1.31
Bus31	12.660	91.91	91.92	96.09	1.31	60.98	0.00	0.00	1.31	1.31
Bus32	12.660	91.89	91.89	96.06	1.31	60.98	0.00	0.00	1.31	1.31
Bus33	12.660	91.89	91.89	96.06	1.31	60.98	0.00	0.00	1.31	1.31

* Indicates THD (Total Harmonic Distortion) Exceeds the Limit.
\# Indicates IHD (Individual Harmonic Distortion) Exceeds the Limit.

System Harmonics Branch Information

Bus		Current Distortion											
From Bus ID	To Bus ID	Fund. Amp	RMS Amp	ASUM Amp	THD %	TIF	IT Amp	ITB Amp	ITR Amp	TIHD %	TSHD %	THDG %	THDS %
Bus1	Bus2	220.14	220.20	234.46	2.43	48.76	10737.04	10731.48	345.47	0.00	0.00	2.43	2.43
Bus2	Bus1	220.14	220.20	234.46	2.43	48.76	10737.04	10731.48	345.47	0.00	0.00	2.43	2.43
	Bus3	197.58	197.65	211.89	2.71	54.22	10717.69	10712.16	344.43	0.00	0.00	2.71	2.71
	Bus19	18.23	18.23	18.35	0.19	9.08	165.48	165.34	6.75	0.00	0.00	0.19	0.19
Bus3	Bus2	197.58	197.65	211.89	2.71	54.22	10717.69	10712.16	344.43	0.00	0.00	2.71	2.71
	Bus4	145.38	145.48	159.78	3.70	74.17	10789.93	10784.31	348.44	0.00	0.00	3.70	3.70
	Bus23	46.05	46.05	46.62	0.36	16.96	780.77	779.97	35.28	0.00	0.00	0.36	0.36
Bus4	Bus3	145.38	145.48	159.78	3.70	74.17	10789.93	10784.31	348.44	0.00	0.00	3.70	3.70
	Bus5	142.31	142.41	156.71	3.78	75.80	10795.19	10789.55	348.66	0.00	0.00	3.78	3.78
Bus5	Bus4	142.31	142.41	156.71	3.78	75.80	10795.19	10789.55	348.66	0.00	0.00	3.78	3.78
	Bus6	139.49	139.59	153.90	3.86	77.38	10802.38	10796.74	348.96	0.00	0.00	3.86	3.86
Bus6	Bus5	139.49	139.59	153.90	3.86	77.38	10802.38	10796.74	348.96	0.00	0.00	3.86	3.86
	Bus7	51.26	51.26	53.00	0.98	43.80	2245.32	2243.07	100.44	0.00	0.00	0.98	0.98
	Bus26	60.50	60.51	62.16	0.79	36.62	2216.03	2213.51	105.53	0.00	0.00	0.79	0.79
Bus7	Bus6	51.26	51.26	53.00	0.98	43.80	2245.32	2243.07	100.44	0.00	0.00	0.98	0.98
	Bus8	40.68	40.68	42.04	0.97	43.14	1754.88	1753.15	77.95	0.00	0.00	0.97	0.97
Bus8	Bus7	40.68	40.68	42.04	0.97	43.14	1754.88	1753.15	77.95	0.00	0.00	0.97	0.97
	Bus9	37.69	37.69	38.94	0.97	42.80	1612.82	1611.23	71.56	0.00	0.00	0.97	0.97
Bus9	Bus8	37.69	37.69	38.94	0.97	42.80	1612.82	1611.23	71.56	0.00	0.00	0.97	0.97
	Bus10	34.68	34.68	35.82	0.96	42.46	1472.35	1470.90	65.27	0.00	0.00	0.96	0.96
Bus10	Bus9	34.68	34.68	35.82	0.96	42.46	1472.35	1470.90	65.27	0.00	0.00	0.96	0.96
	Bus11	32.10	32.10	33.17	0.96	42.60	1367.65	1366.31	60.59	0.00	0.00	0.96	0.96
Bus11	Bus10	32.10	32.10	33.17	0.96	42.60	1367.65	1366.31	60.59	0.00	0.00	0.96	0.96
	Bus12	28.77	28.78	29.73	0.97	42.69	1228.54	1227.34	54.39	0.00	0.00	0.97	0.97

	Bus10	34.68	34.68	35.82	0.96	42.46	1472.35	1470.90	65.27	0.00	0.00	0.96	0.96
Bus10	Bus9	34.68	34.68	35.82	0.96	42.46	1472.35	1470.90	65.27	0.00	0.00	0.96	0.96
	Bus11	32.10	32.10	33.17	0.96	42.60	1367.65	1366.31	60.59	0.00	0.00	0.96	0.96
Bus11	Bus10	32.10	32.10	33.17	0.96	42.60	1367.65	1366.31	60.59	0.00	0.00	0.96	0.96
	Bus12	28.77	28.78	29.73	0.97	42.69	1228.54	1227.34	54.39	0.00	0.00	0.97	0.97
Bus12	Bus11	28.77	28.78	29.73	0.97	42.69	1228.54	1227.34	54.39	0.00	0.00	0.97	0.97
	Bus13	25.44	25.45	26.29	0.97	42.84	1090.05	1088.98	48.23	0.00	0.00	0.97	0.97
Bus13	Bus12	25.44	25.45	26.29	0.97	42.84	1090.05	1088.98	48.23	0.00	0.00	0.97	0.97
	Bus14	18.61	18.61	19.24	0.99	43.83	815.46	814.66	36.05	0.00	0.00	0.99	0.99
Bus14	Bus13	18.61	18.61	19.24	0.99	43.83	815.46	814.66	36.05	0.00	0.00	0.99	0.99
	Bus15	15.72	15.72	16.24	0.98	43.20	678.94	678.28	30.01	0.00	0.00	0.98	0.98
Bus15	Bus14	15.72	15.72	16.24	0.98	43.20	678.94	678.28	30.01	0.00	0.00	0.98	0.98
	Bus16	12.65	12.65	13.07	0.97	42.89	542.68	542.15	23.98	0.00	0.00	0.97	0.97
Bus16	Bus15	12.65	12.65	13.07	0.97	42.89	542.68	542.15	23.98	0.00	0.00	0.97	0.97
	Bus17	9.59	9.59	9.91	0.96	42.41	406.73	406.33	17.97	0.00	0.00	0.96	0.96
Bus17	Bus16	9.59	9.59	9.91	0.96	42.41	406.73	406.33	17.97	0.00	0.00	0.96	0.96
	Bus18	4.80	4.80	4.95	0.96	42.38	203.31	203.11	8.98	0.00	0.00	0.96	0.96
Bus18	Bus17	4.80	4.80	4.95	0.96	42.38	203.31	203.11	8.98	0.00	0.00	0.96	0.96
Bus19	Bus2	18.23	18.23	18.35	0.19	9.08	165.48	165.34	6.75	0.00	0.00	0.19	0.19
	bus20	13.73	13.73	13.82	0.19	9.03	123.95	123.84	5.06	0.00	0.00	0.19	0.19
bus20	Bus19	13.73	13.73	13.82	0.19	9.03	123.95	123.84	5.06	0.00	0.00	0.19	0.19
	Bus21	9.22	9.22	9.28	0.18	8.95	82.60	82.53	3.37	0.00	0.00	0.18	0.18

Bus		Current Distortion											
From Bus ID	To Bus ID	Fund. Amp	RMS Amp	ASUM Amp	THD %	TIF	IT Amp	ITB Amp	ITR Amp	TIHD %	TSHD %	THDG %	THDS %
Bus21	bus20	9.22	9.22	9.28	0.18	8.95	82.60	82.53	3.37	0.00	0.00	0.18	0.18
	Bus22	4.72	4.72	4.75	0.18	8.75	41.29	41.26	1.68	0.00	0.00	0.18	0.18
Bus22	Bus21	4.72	4.72	4.75	0.18	8.75	41.29	41.26	1.68	0.00	0.00	0.18	0.18
Bus23	Bus3	46.05	46.05	46.62	0.36	16.96	780.77	779.97	35.28	0.00	0.00	0.36	0.36
	Bus24	24.55	24.55	24.86	0.36	16.92	415.50	415.08	18.77	0.00	0.00	0.36	0.36
Bus24	Bus23	24.55	24.55	24.86	0.36	16.92	415.50	415.08	18.77	0.00	0.00	0.36	0.36
	Bus25	3.01	3.01	3.05	0.36	17.24	51.91	51.86	2.35	0.00	0.00	0.36	0.36
Bus25	Bus24	3.01	3.01	3.05	0.36	17.24	51.91	51.86	2.35	0.00	0.00	0.36	0.36
Bus26	Bus6	60.50	60.51	62.16	0.79	36.62	2216.03	2213.51	105.53	0.00	0.00	0.79	0.79
	Bus27	57.72	57.72	59.26	0.77	35.67	2058.65	2056.31	97.99	0.00	0.00	0.77	0.77
Bus27	Bus26	57.72	57.72	59.26	0.77	35.67	2058.65	2056.31	97.99	0.00	0.00	0.77	0.77
	Bus28	55.14	55.14	56.56	0.75	34.50	1902.31	1900.15	90.52	0.00	0.00	0.75	0.75
Bus28	Bus27	55.14	55.14	56.56	0.75	34.50	1902.31	1900.15	90.52	0.00	0.00	0.75	0.75
	Bus29	48.95	48.95	50.14	0.70	32.53	1592.29	1590.48	75.73	0.00	0.00	0.70	0.70
Bus29	Bus28	48.95	48.95	50.14	0.70	32.53	1592.29	1590.48	75.73	0.00	0.00	0.70	0.70
	Bus30	22.56	22.56	23.36	1.03	47.64	1074.81	1073.59	51.15	0.00	0.00	1.03	1.03
Bus30	Bus29	22.56	22.56	23.36	1.03	47.64	1074.81	1073.59	51.15	0.00	0.00	1.03	1.03
	Bus31	14.62	14.62	15.14	1.02	47.20	690.25	689.46	32.84	0.00	0.00	1.02	1.02
Bus31	Bus30	14.62	14.62	15.14	1.02	47.20	690.25	689.46	32.84	0.00	0.00	1.02	1.02
	Bus32	3.47	3.47	3.58	0.95	44.23	153.39	153.21	7.30	0.00	0.00	0.95	0.95
Bus32	Bus31	3.47	3.47	3.58	0.95	44.23	153.39	153.21	7.30	0.00	0.00	0.95	0.95
	Bus33	0	0	0	0	0	0.00	153.21	7.30	0.00	0.00	0.00	0.00
Bus33	Bus32	0	0	0	0	0	0.00	153.21	7.30	0.00	0.00	0.00	0.00

Bus ID: Bus1
Fund. kV: 12.660

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.05	7.00	350.00	0.06	11.00	550.00	0.05	13.00	650.00	0.05	17.00	850.00	0.05	19.00	950.00	0.05
23.00	1150.00	0.05	25.00	1250.00	0.05	29.00	1450.00	0.05	31.00	1550.00	0.04	35.00	1750.00	0.05	37.00	1850.00	0.04
39.00	1950.00	0.00															

Bus ID: Bus10
Fund. kV: 11.623

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.44	7.00	350.00	0.45	11.00	550.00	0.41	13.00	650.00	0.39	17.00	850.00	0.39	19.00	950.00	0.35
23.00	1150.00	0.36	25.00	1250.00	0.32	29.00	1450.00	0.33	31.00	1550.00	0.29	35.00	1750.00	0.30	37.00	1850.00	0.26
39.00	1950.00	0.03															

Bus ID: Bus11
Fund. kV: 11.612

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.44	7.00	350.00	0.45	11.00	550.00	0.41	13.00	650.00	0.39	17.00	850.00	0.39	19.00	950.00	0.35
23.00	1150.00	0.36	25.00	1250.00	0.32	29.00	1450.00	0.33	31.00	1550.00	0.29	35.00	1750.00	0.30	37.00	1850.00	0.26
39.00	1950.00	0.03															

Bus ID: Bus12
Fund. kV: 11.592

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.44	7.00	350.00	0.45	11.00	550.00	0.41	13.00	650.00	0.39	17.00	850.00	0.39	19.00	950.00	0.35
23.00	1150.00	0.36	25.00	1250.00	0.32	29.00	1450.00	0.33	31.00	1550.00	0.29	35.00	1750.00	0.30	37.00	1850.00	0.26

Bus ID: Bus13
Fund. kV: 11.513

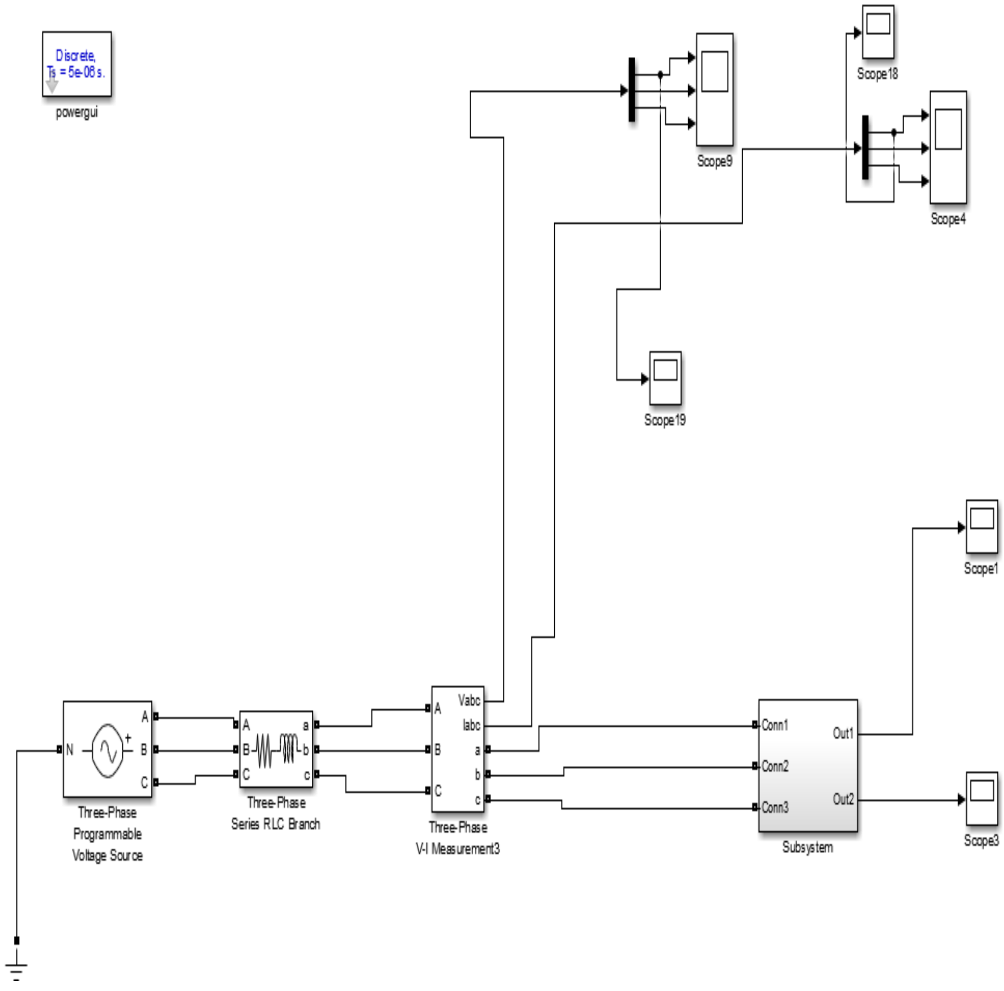
Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.44	7.00	350.00	0.45	11.00	550.00	0.41	13.00	650.00	0.39	17.00	850.00	0.38	19.00	950.00	0.35
23.00	1150.00	0.35	25.00	1250.00	0.32	29.00	1450.00	0.32	31.00	1550.00	0.29	35.00	1750.00	0.29	37.00	1850.00	0.25
39.00	1950.00	0.03															

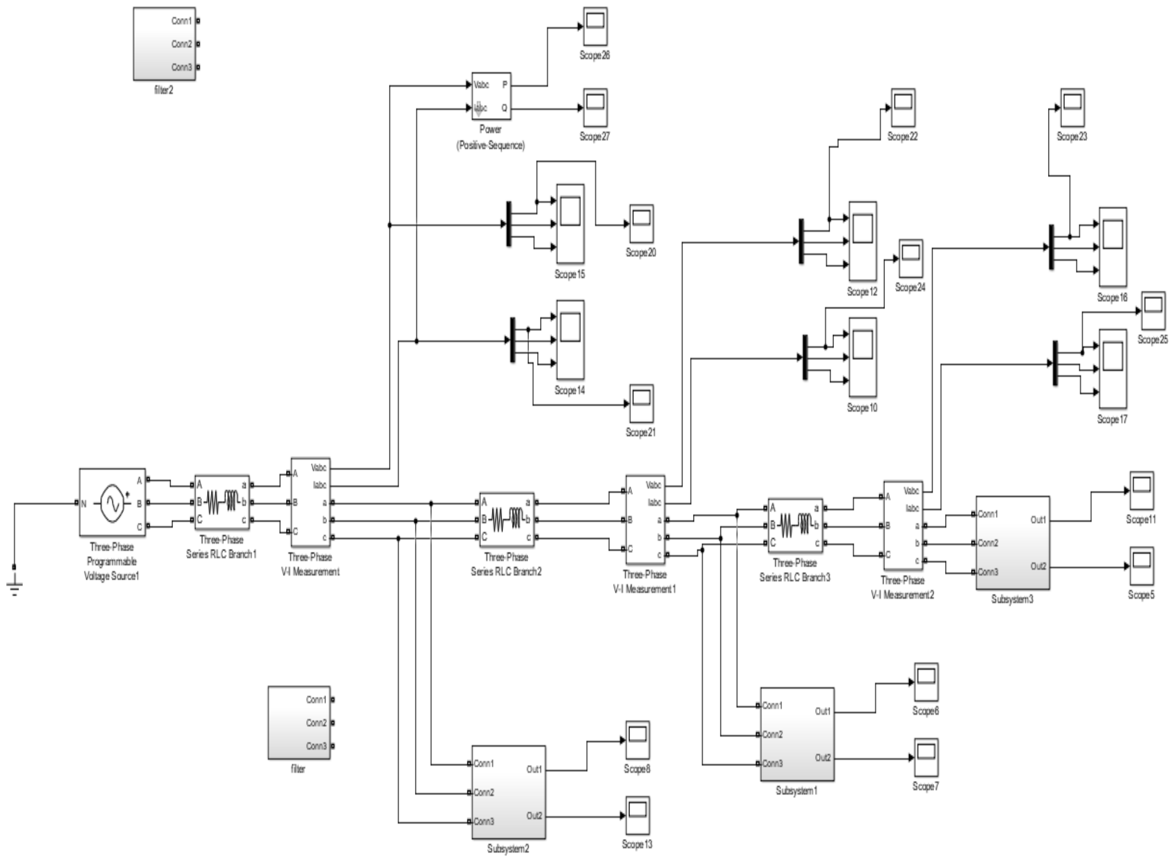
Bus ID: Bus14
Fund. kV: 11.488

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
5.00	250.00	0.44	7.00	350.00	0.45	11.00	550.00	0.41	13.00	650.00	0.39	17.00	850.00	0.38	19.00	950.00	0.35
23.00	1150.00	0.35	25.00	1250.00	0.32	29.00	1450.00	0.32	31.00	1550.00	0.28	35.00	1750.00	0.29	37.00	1850.00	0.25

Appendix J

This Fig scheme of MATLAB




filter2
Power
(Positive-Sequence)
Scope26
Scope27
Scope15
Scope20
Scope14
Scope21
Scope22
Scope12
Scope24
Scope10
Scope23
Scope16
Scope25
Scope17
Three-Phase
Programmable
Voltage Source1
Three-Phase
Series RLC Branch1
Three-Phase
V-I Measurement
Three-Phase
Series RLC Branch2
Three-Phase
V-I Measurement1
Three-Phase
Series RLC Branch3
Three-Phase
V-I Measurement2
Subsystem3
Scope11
Scope5
filter
Subsystem2
Scope8
Scope13
Subsystem1
Scope6
Scope7

جامعة النجاح الوطنية

كلية الدراسات العليا

أثر محطات شحن البطاريات على الشبكة الكهربائية: دراسة أثر التيارات التوافقية وامكانية تقليلها

إعداد

ريم طلعت عبد اللطيف عمر

إشراف

د. معين عمر

قدمت هذه الاطروحة استكمالاً لمتطلبات الحصول على درجة الماجستير في هندسة القوى الكهربائية، بكلية الدراسات العليا، في جامعة النجاح الوطنية، نابلس– فلسطين.

2021

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الملخص

تركز هذه الأطروحة على دراسة تأثير محطات شحن المركبات الكهربائية على شبكات الطاقة الكهربائية حيث أن التيارات التوافقية المتولدة تؤثر سلبيا على مكونات الشبكات الكهربائية مما يتسبب في مزيد من الخسائر التشوهات لنقاط الجهد على الشبكة. تتكون كل محطة شحن من مقوم كامل الموجة ثلاثي الطور مع منظم لعملية الشحن.

تمت برمجة نموذج محاكاة باستخدام برنامج MATLAB Simulink لإجراء دراسة وتحليل أثر محطات الشحن في نوعين من الشبكات الكهربائية النوع الاول الشبكات ذات الكهرباء المترددة والنوع الاخر الشبكات ذات الكهرباء الثابت حيث بينت نتائج الدراسة أنه في أنظمة توزيع التيار المتردد وفي ثلاثة أوضاع مختلفة أن الجهد ينخفض من 400 فولت إلى 336 فولت بينما ينخفض التشوه التوافقي الكلي للتيار والجهد إلى 20.4٪ و 6.73٪ على التوالي. من ناحية أخرى ، في الشبكات الكهربائية ذات التيار الثابت فان إجمالي معدل التشوه التوافقي للتيار والجهد 24٪ و 10.9٪ على التوالي. علاوة على ذلك ، تم استخدام برنامج ETAP لتحليل تأثيرات محطات الشحن على الشبكة الكهربائية في حالتين مختلفتين وذلك اذا كانت محطة الشحن بالقرب من نقطة الربط االحالة الثانية ان يكون موقع محطة الشحن في نقطة بعيدة عن نقطة الربط.

وأخيرًا تم تصميم مرشح للتخفيف من التيارات التوافقية حيث أدى ذلك الى تقليل التشوه التوافقي الكلي للتيار والجهد إلى 9.2٪ و 5.3٪ على التوالي.