MODELLING AND SIMULATION OF FUEL CELL BASED STATIONARY STAND ALONE POWER GENERATION SYSTEM

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May, 2013

MODELLING AND SIMULATION OF FUEL CELL BASED STATIONARY STAND ALONE POWER GENERATION SYSTEM

A thesis submitted in partial fulfillment of the requirements for the Degree of

Master of Technology

(ENERGY SYSTEM)

By

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ACKNOWLEDGEMENT

I am thankful to College of Engineering Studies at University of Petroleum and Energy Studies to carry out this project.

I would like to thank my supervisors Mr. Agam Kumar Tyagi for help, inspiration, encouragement and his continuous guidance throughout this work.
I would also like to thank my examiner Mrs. Madhu Sharma for valuable comments and encouragement.
I would love to thank my parents for their everlasting support, generous love, patience, and inspiration.

Finally, I would love to thank my supportive friends for their valuable time and support.

Abstract

Energy storage as a natural process is as old as the universe itself - the energy present at the initial formation of the universe has been stored in stars such as the Sun, and now humans are using it directly (e.g. through solar heating), or indirectly (e.g. by growing crops or conversion into electricity in solar cells).
Energy storage became a dominant factor in economic development with the widespread introduction of electricity and refined chemical fuels, such as gasoline and natural gas etc. in the late 19th century. An early solution to the problem of storing energy for electrical purposes was the development of the battery as an electrochemical storage device. But with the limited storage capacity and lower reliability; the battery solution has been out dated in the present scenario, which in turn paves a path for a further development into the era of fuel cells.

A **fuel cell** is a device that converts the chemical energy from a fuel into electricity through a chemical reaction with oxygen or another oxidizing agent. This project in its due course of completion will lay emphasis on various prospective of fuel cells based on stand-alone stationary generation.

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CHAPTER 1

INTRODUCTION

1.1 Background

Fast developing technology has changed the energy conservation scenario around the globe. Technological advances will be of critical importance in improving living conditions. Today the consumer require compact, clean, affordable and readily available portable energy source. All the primary energy sources are depleting and they have thermal and chemical effect on the surroundings. Renewable energy sources have come up as an alternative. Fuel cells, Biogas/Biomass, Wind Turbines, Photovoltaic, Tidal energy sources have been developed and extensively used to meet the world's growing energy demand. Fuel cells are electrochemical devices that convert the chemical energy in fuel into electrical energy directly, within combustion, with high electrical efficiency and low pollutant emissions. Although not new in concept, fuel cells have received considerable attention lately for their potential to be clean and reliable devices for generating electricity. Today fuel cell finds applications in stationary, residential, transportation and portable power supplies.

Fuel cells are electrochemical devices that convert the chemical energy in fuel into electrical energy directly, without combustion, with high electrical efficiency and low pollutant emissions. They represent a new type of power generation technology that offers modularity, efficient operation across a range of load conditions, and opportunities for integration into co-generation systems (Appleby and Foulkes, 1989;

Berkovski et al., 1989; Lucerne, 2002). There are currently very few fuel cells available that are not financially viable. Demand has therefore been limited to niche applications, where the end user is willing to pay the premium for what they consider to be the associated key benefits. However, fuel cell technology has made significant progress in recent years, with prices predicted to approach those of the principal competitor in near future (Bose, 2000; Tyagi, 2005).

1.2 Objective

The main objective of this project is to develop a dynamic model and analysis steady state performance of Fuel cell by representing it as a rectifier .we aim to develop a model of fuel cell based stand alone generating unit to serve electricity supply to remote areas.

The analysis of fuel cell working is not done directly but considering it as a rectifier which converts AC into DC and measure the performance of the system. The modeling of the system is done on MATLAB and the steady state performance will be evaluated by changing different parameters and different load condition. the main objective of the system is to develop an DC/AC/DC converting system by using simulink feature of MATLAB and get an pure sinusoidal supply at the load side with minimum level of total harmonic distortion which can be reduced by using different type of filters.

Hence the project aims to develop a model of standalone generating unit which supplies sinusoidal output without much distortion using fuel cell technology. It aims to utilize chemical energy of fuel cell to get electrical energy at the output side to electrify remote areas which dosent has the facility of Grid system.

The objective of using Fuel cell is to utilize pollution free with high electrical efficiency and low pollutant emissions qualities of this technique. Hence developing a system using serves two objectives, one is to generate power which is renewable and needs less maintenance as well as it is pollution free.

1.3 Methodology

Methodology adopted in order to carry out the research work:

The complete modeling of Fuel Cell based stand alone power system is done using matlab and simulink in order to make its mathematical model and analyze it so that its behavior during transient and steady state conditions can be determined.

It is to be analyzed how the fuel cell model will react during different load conditions

BLOCK DIAGRAM

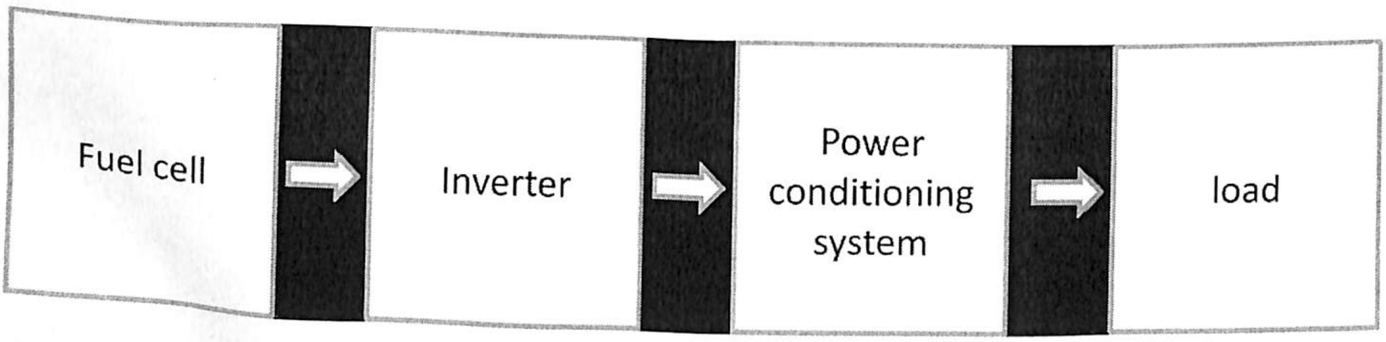


Fig 1.1: Basic block diagram of the generation system

As the figure shows fuel cell generates DC power which is converted into AC using Inverter. To represent the working of fuel cell, it is represented as rectifier which converts AC power into DC power.

Fuel cell is connected with Inverter which converts DC output into AC power to feed the load. In this model PWM inverter is used for the application.

Then power conditioning system is used to filter the switching frequency Harmonics and generate a high quality sinusoidal power. Total Harmonic distortion is maintained to the accepted limits of industry i.e. 4%.for this application 3 three phase harmonic filter is connected after inverter and before load.

CHAPTER 2

LITERATURE REVIEW

2.1) FUEL CELL

In principle, fuel cell operates like a battery.fuel cell doesn't require recharging back to back like a battery. It produces electricity and heat as long as fuel is supplied to it.

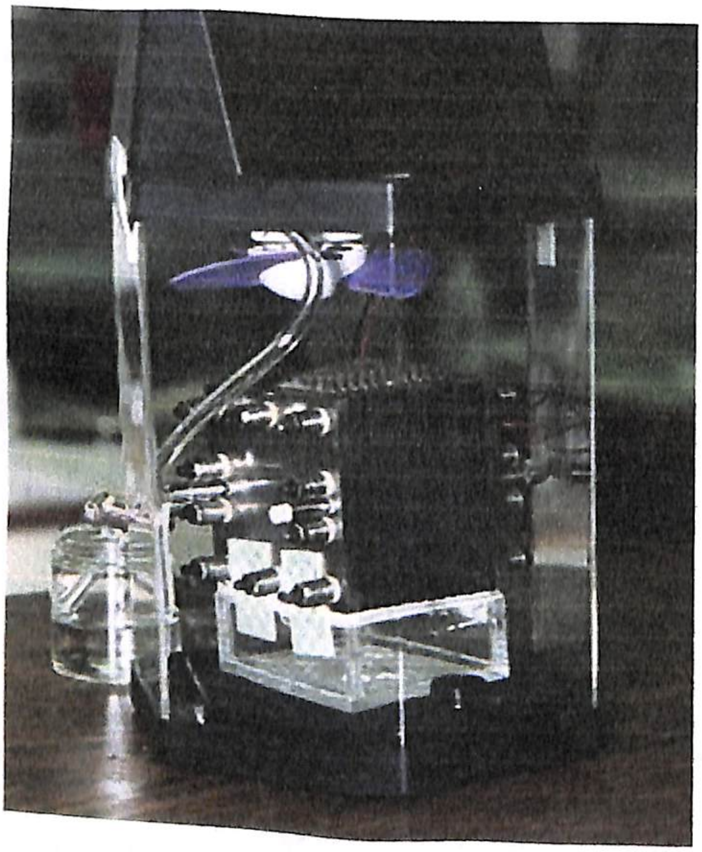


Fig 2.1: typical fuel cell

A fuel cell consists of two electrodes sandwiched around an electrolyte. In this O_2 passes over one electrode and H_2 over the other which in turn generates electricity, water and heat .

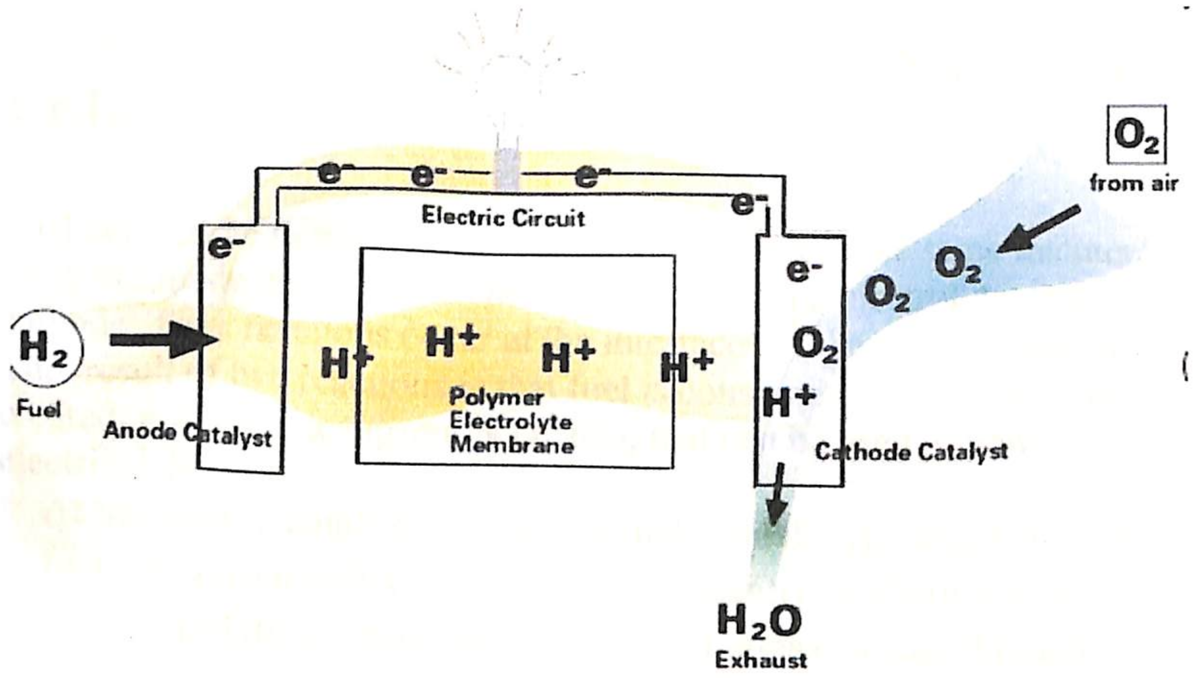


Fig 2.2: working of fuel cell

Hydrogen fuel is fed into the "anode" of the fuel cell. Oxygen (or air) enters the fuel cell through the cathode.

- Encouraged by a catalyst, the hydrogen atom splits into a proton and an electron.

- The proton passes through the electrolyte. The electrons creates separate current that can be utilized

before they return to the cathode, which is reunited with the H_2 and O_2 in a molecule of water.

- A fuel cell system which includes a "fuel reformer" can utilize the hydrogen from any hydrocarbon fuel - from natural gas to methanol.

• Since it relies on chemistry and not combustion, emissions from this type of a system would still be much smaller than emissions from the cleanest fuel combustion processes.

2.1.1 TYPICAL DESIGN FEATURES OF FUEL CELL

Fuel cells come in many varieties; but they work in the same manner. They are made up of 3 adjacent segments: anode, electrolyte, and cathode. Two reactions occur at the interfaces of the three segments. The result of two reactions is that fuel is consumed, water or CO_2 is created, and electric current is created, that can be used to power electrical devices.

At the anode a catalyst oxidizes the fuel, usually H_2, which turns the fuel into a positively charged ion and a negatively charged electron. The electrolyte is a substance designed so ions can pass through it, but the electrons can't. Electrons which are freed travel through a wire creating the electric current. The ions travel via electrolyte to the cathode. Once reaching cathode, ions are reunited with the electrons and the two react with a third chemical, usually O_2, to create water or CO_2.

2.1.2 TYPES OF FUEL CELL

Fuel cells come in many varieties; but they all work in the similar general manner

1. Phosphoric Acid
2. Proton Exchange Membrane
3. Molten Carbonate

4. Solid Oxide
5. Alkaline
6. Direct Methanol
7. Regenerative
8. Zinc Air
9. Protonic Ceramic
10. Microbial Fuel Cell

2.1.3 BENEFITS OF FUEL CELLS

- Low to Zero Emissions
- High Efficiency
- High Reliability/High Quality Power
- Fuel Flexibility
- Security
- Modularity
- Lightweight

Long-lasting Battery Alternative

2.1.4 EQUIVALENT MODEL OF FUEL CELL:

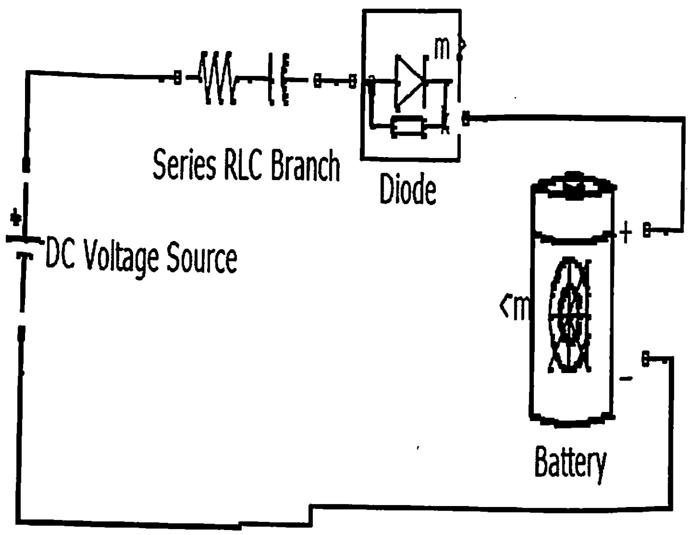


Fig 2.3: equivalent circuit of fuel cell

In this DC voltage source represents the fuel cell which is modeled as rectifier in this system.

Series RLC branch represents resistance and inductance of the fuel cell. diode works as a switch which make sure that current doesn't flow in the reverse direction from battery to fuel cell.

2.2 Rectifier (Three phase uncontrolled rectifier) :

Rectifier represents the equivalence of fuel cell which converts AC to DC. it is included in the circuit just for the modeling purpose so that it can be connected in the model before inverter to show that how we are getting DC power in the system so that we convert it in AC by using PWM inverter.
In this system three phase full wave uncontrolled inverter is used.

The functions of a three-phase full-wave rectifier are similar to that of a single-phase full-wave rectifier except that the input signal is three phase and six diodes are used for rectification.
The three-phase rectifier can be used for converting a three-phase AC supply into a DC or high voltage DC supply. A bridge-type three-phase full-wave rectifier model is shown in Fig. It contains six diodes D1, D2, D3, D4, D5, and D6. Diodes D1, D3, and D5 are ON when phase voltages V1, V2, and V3 are positive. Similarly, diodes D2, D6, and D4 are ON when phase voltages V1, V2, and V3 are negative.

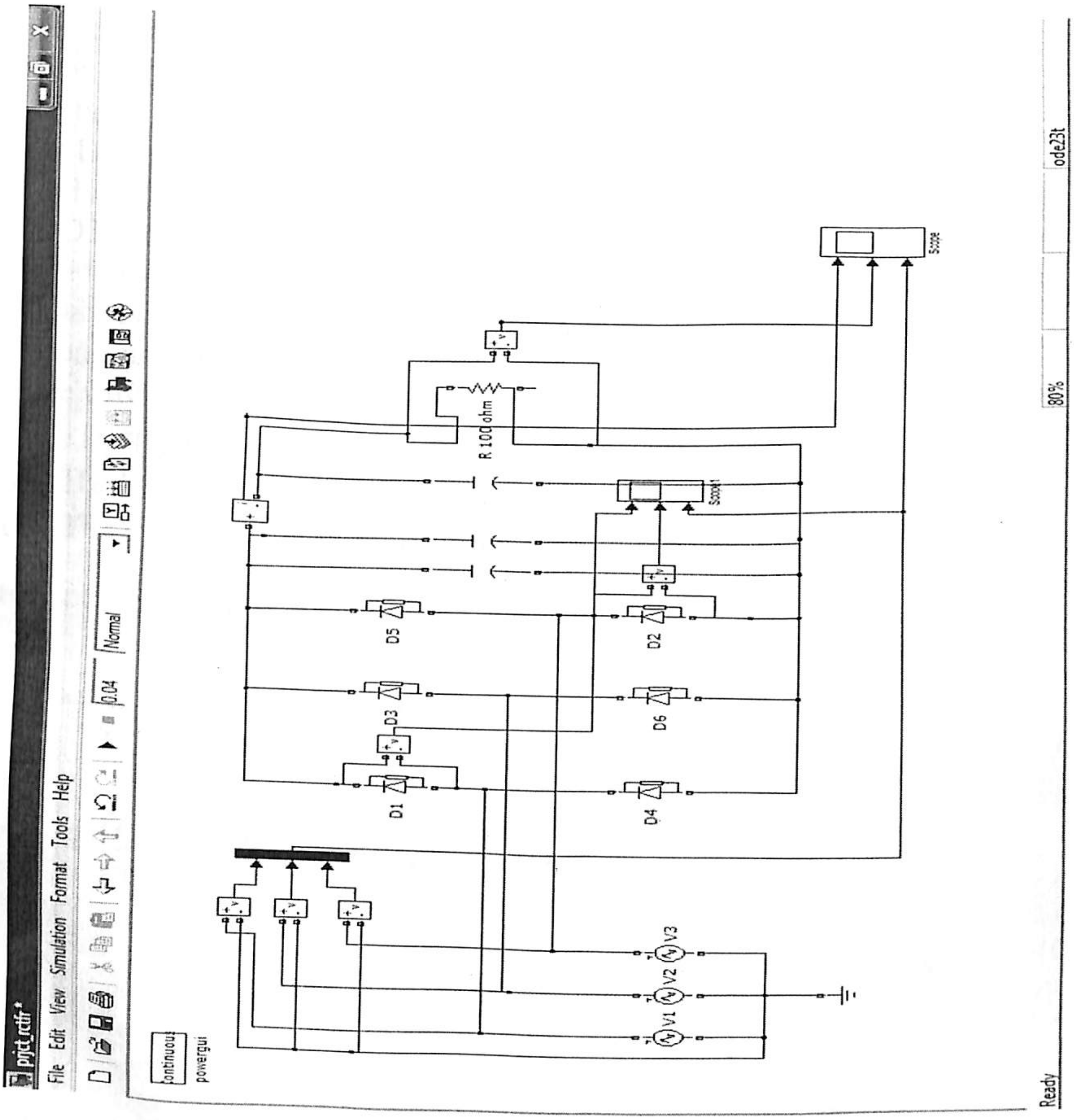


Fig 2.4 : MATLAB model of Three phase uncontrolled full wave rectifier

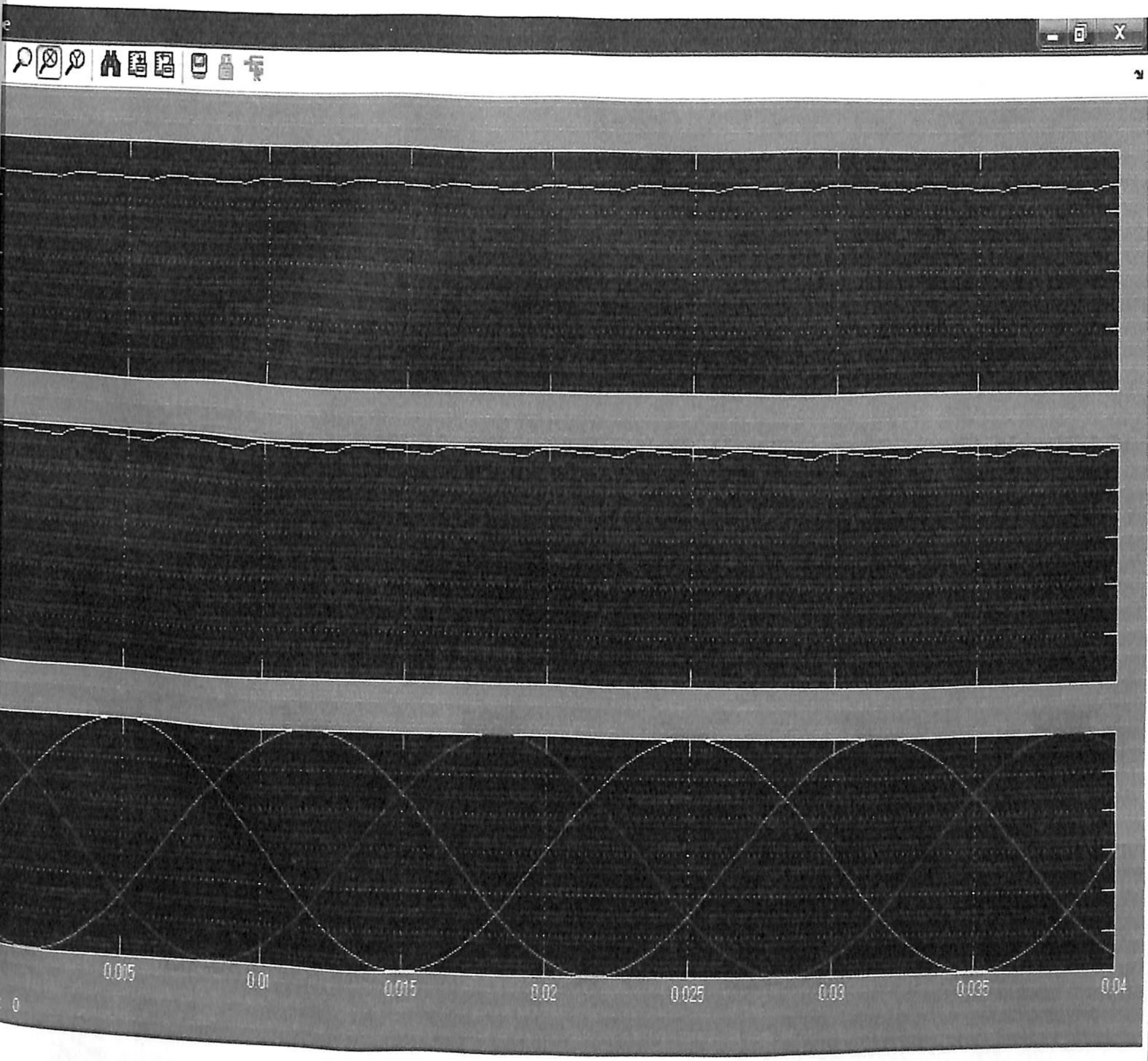
For the continuous supply of current to the load, it is necessary that any one pair of diodes is ON at any instant of time during each input cycle. For instance pulse V1 is most positive and V3 is most negative, then diodes D1 and D2 are ON and the load current flows from A to B. similarly, when phase V2 is most positive and V3 is most negative, diode D3 and D2 are ON. In the model shown in Fig. , the supply voltage the supply voltage is 315 V, 50 Hz, three-phase and the load resistance is of 105 Ω. The voltage across diode D1 and D2 is shown in Fig. Load current and
voltage waveforms are shown in Fig. It can be observed that the load voltage is in phase with the load current and the output ripple frequency is 300 Hz. So, each diode conducts for the period of 2π/6 in one output cycle. The following measurements are taken for the model:

$Vavg$ and $Vrms$ can be evaluated as follows:

$$V_{avg} = \frac{6}{\pi} \int_0^{\pi/6} 315 \sin(\omega t)\, d\,(\omega t)$$

$$V_{rms} = \left[\frac{6}{\pi} \int_0^{\pi/6} \{315 \sin(\omega t)\}^2\, d(\omega t)\right]^{0.5}$$

Figure 2.5 Current and voltage waveform of three phase rectifier for the resistive load



2.3 PWM (PULSE WIDTH MODULATED)INVERTER :

As we know Inverter is used to convert DC to AC to supply the load. In this PWM inverter is used for the same application.PWM inverter generates three level output. In this inverter MOSFet are used because its response time is very less or switching frequency is very high. Output of this inverter is connected with three phase harmonic filter to get the sinusoidal waveform with very less switching harmonics at the load. Load is considered as RL load.

The order commands for the controlled semiconductors of the two level converters can be generator according to the different laws called "Modulation". In this section we present most commonly used modulation techniques.

2.3.1 SINUSOIDAL PULSE WIDTH MODULATION (PWM)

This modulation is a widely extended modulation technique among voltage sourced converters. By using triangular signal and comparing it with the reference signal, it creates the output voltage according to the following law:

$$S_j = 1 \; if \; V_j > V_{tri} \; with \; j = a, b, c$$

Where,

V_a, V_b, V_c= Reference Voltage for each phase
V_{tri}= triangular voltage

The relationships between amplitudes and frequencies of the signal need the following indexes:

1. Frequency Modulation Index (m_f): the relationship between the frequency of the triangular signal and the reference signal can be expressed as

$$m_f = \frac{f_{tri}}{f_{ref}}$$

2. Amplitude Modulation Index (m_a): the relation between the amplitude of the reference signal and the triangular signal can be expressed as

$$m_a = |V| / |Vtri|$$

Under ideal condition, the amplitude relationship between the fundamental component of the achieved output voltage and the DC bus voltage is given by the Amplitude Modulation Index as follows:

$$\langle V_{an} \rangle = m_a \cdot \frac{V_{bus}}{2} \quad if\ m_a \leq 1$$

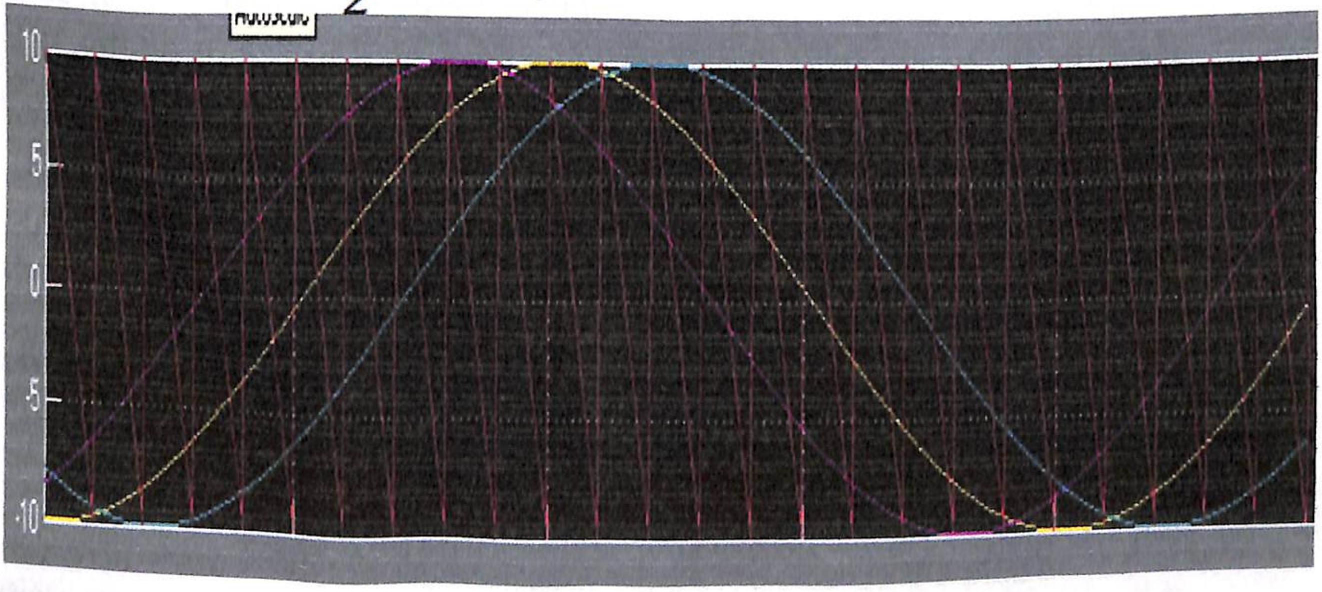


Fig2.6: Pulse Width Modulation Signal

2.3.2PWM INVERTER

In most of the inverter industrial application, the magnitude of the output voltage and the input of the DC voltage varies continuously, This requires continuous variation of the control pulse width in order to achieve the desire output voltage waveform. In this method, a reference signal is compare with high frequency triangular wave to generate PWM signal, If the reference signal is sin wave, the modulation is called sin wave pulse width modulation (SPWM).

The SPWM is realized by comparing a sin wave reference signal (Vr) with high frequency triangular or swatooth wave signal (Vc). The ratio of Vr /Vc is called modulation index (MI), and it determine the harmonic contain in the inverter output voltage. The frequency of the reference determines the output voltage frequency. And it peak magnitude determine the modulation index, which is turn determines the RMS output voltage. When the reference signal is compare with the carrier signal, their intersection is determine the switching instants of the inverter switches. When the magnitude of the reference signal is greater than the carrier signal the output of the comparator is high, otherwise the output is low. the output of the comparator is is further processed such that the output pulse width of the inverter is same as that comparator . The circuit model of the PWM is shown below. This consist of sin wave block, Signal generator, switches, Constant block constant block, sum block, gain block and a scope. The sine wave signal is of amplitude 10 and frequency of 314 rad/sec. The carrier wave is saw-toothed signal of amplitude 10 and frequency 1KHz. The carrier signal is subtract from the reference signal for their comparison, The output is obtained is a PWM signal of varying magnitude. This signal is fed to input2 of the switch block. Input1 of the switch block is connected with a constant value of 5 and Input3 of the switch is connect to the constant value 0.. the selection criteria is taken as u2>= threshold values is zero, the output of the switch is 5, otherwise zero. for three phase system we have to take three different PWM inverter signal, where we change the phase difference of 120 degree.

A block diagram of three phase PWM generator is shown below. The inverter consists of IGBT switches connect to the DC supply. When signal one is high then switches IGBT1 and IGBT2 is connected, when signal2 is high than IGBT5 and IGBT6 is connected, otherwise IGBT3 and IGBT4 is connected. Figure of PWM modulation is shown below:

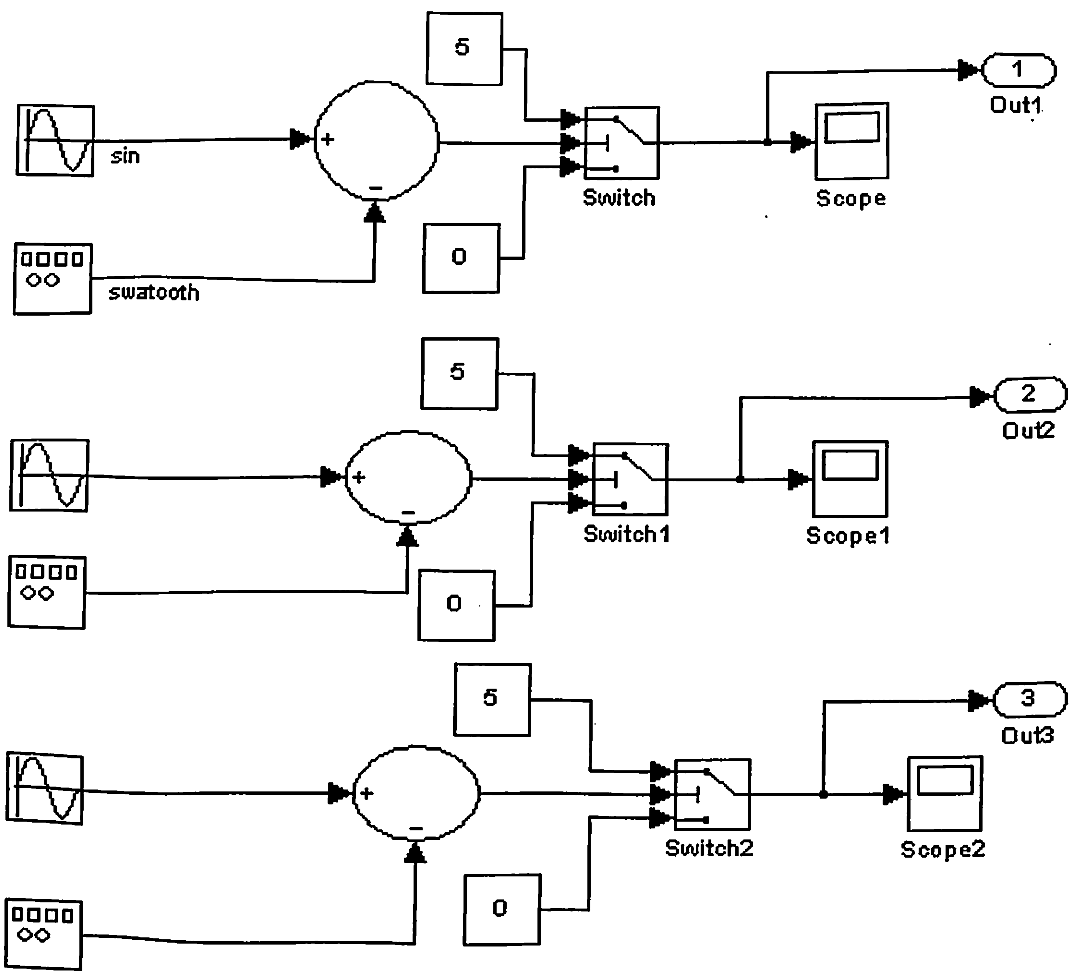


Fig 2.7: Simplified block diagram of the Sinusoidal PWM schema

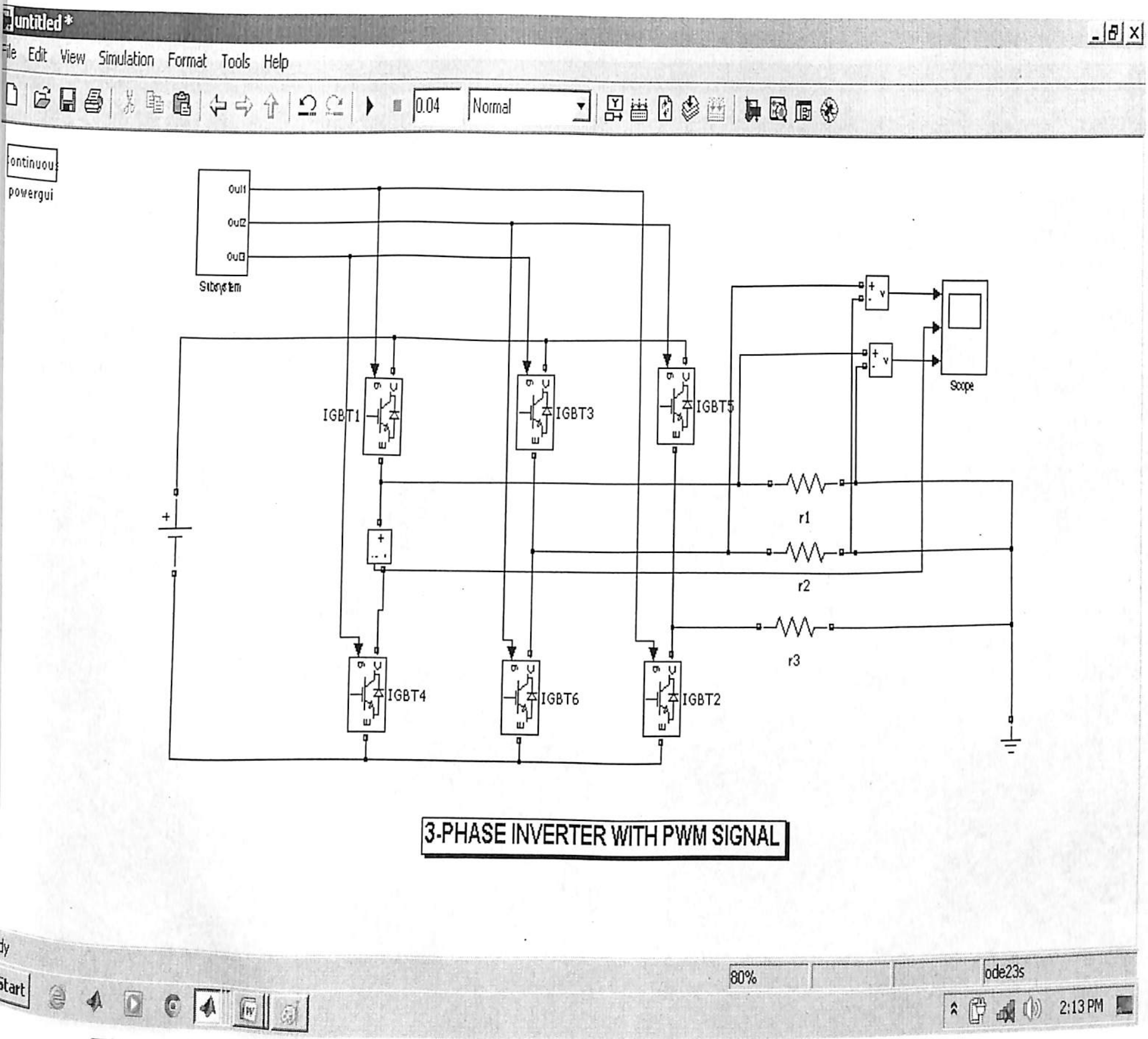


Figure 2.8 PWM control Inverter

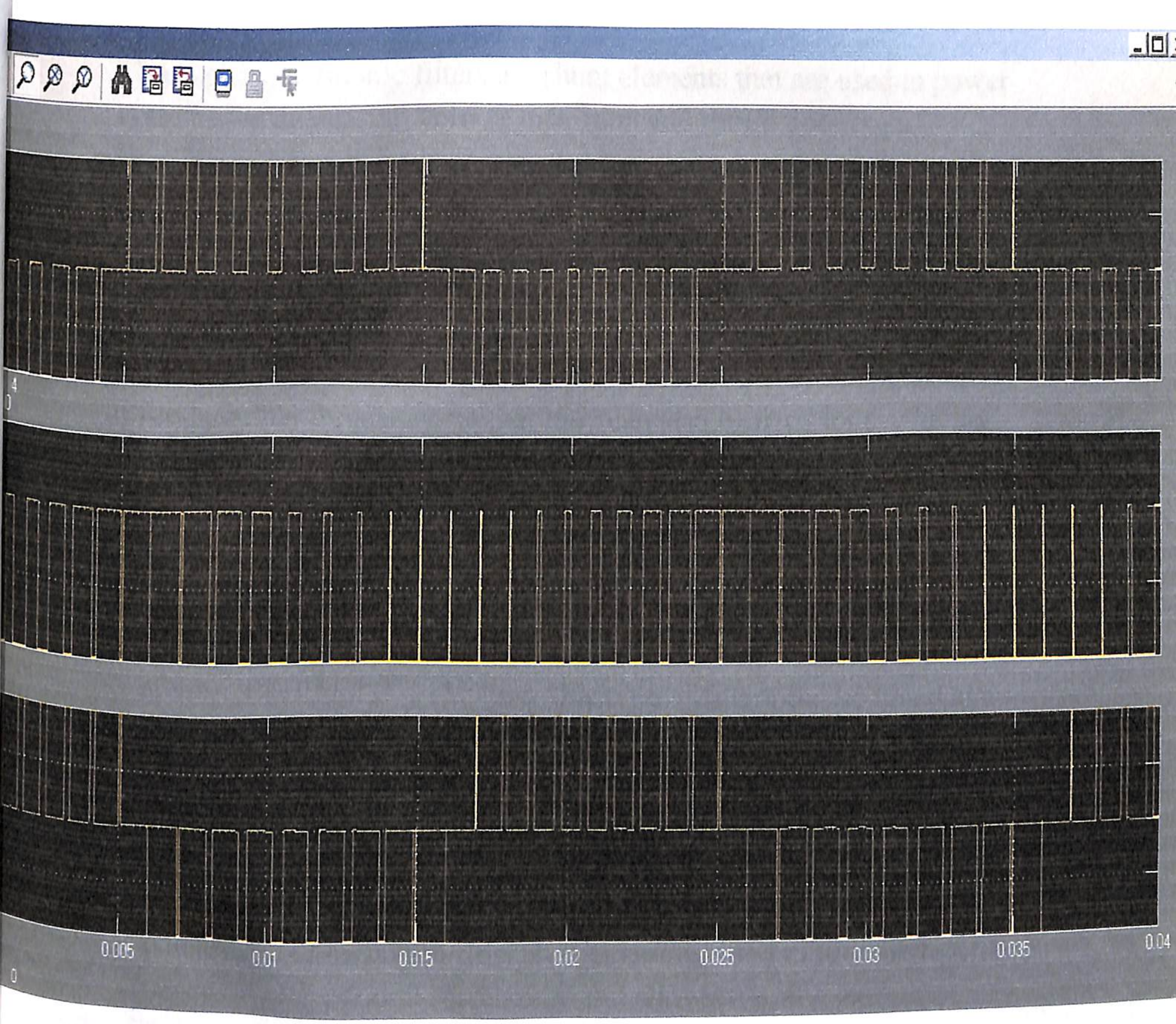


Fig 2.9:Waveforms of output voltage of inverter

2.4 FILTER (THREE PHASE HARMONIC FILTER):

Three-phase harmonic filters are shunt elements that are used in power systems for decreasing voltage distortion and for PF correction. Nonlinear elements for example power electronic converters generate harmonic currents or harmonic voltages,that is injected into power system. The resulting distorted currents which flow through the system impedance produce harmonic voltage distortion. Harmonic filters reduce this distortion by diverting these harmonic currents in low impedance paths. Harmonic filters are generally designed to be capacitive in nature at fundamental frequency, so that they can also be used for producing reactive power output required by converters and for power factor correction.

The most commonly used filter types are

Band-pass filters, which are used to filter lowest order harmonics such as 5^{th} , 7^{th} , 11^{th} , 13^{th} , etc. this type of filters can be tuned at a single frequency (single-tuned filter) or at two frequencies (double-tuned filter).

High-pass filters, which are used to filter high-order harmonics and cover a very wide range of frequencies. C-type high-pass filter is a special type of high pass filter, it is generally used to provide reactive power , avoids parallel resonances and allows filtering low order harmonics (such as third).

The Three-Phase Harmonic Filter is built of RLC elements.

The value of resistance, inductance, and the capacitance are determined from the filter type and from the following parameters:

Quality factor. The quality factor is a measure of the sharpness of the tuning frequency. It is generally determined by the resistance value.

The four types of filters which can be modeled with the Three-Phase Harmonic Filter block are shown below:

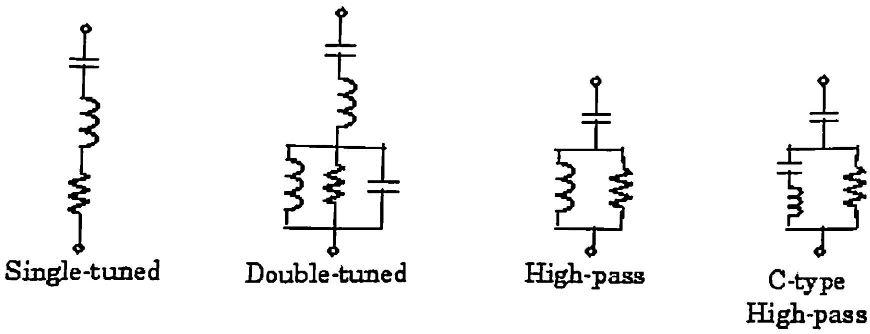


Fig 2.10 : different types of filter

The simplest filter type is the single-tuned filter. The quality factor Q of the filter is the quality factor of the reactance at the tuning frequency Q = (nXL)/R. The quality factor is the measurement of the bandwidth B, which is a measurement of the sharpness of the tuning frequency as shown in the figure.

Tuned harmonic order n = fn/f1
f1 = fundamental frequency
Quality factorQ = nXL/R = XC/(nR)
ω = 2πf1 = angular frequency
Bandwidth B = fn/Q where fn = tuning frequency Reactive power at f1QC = (V2/XC)·n2/(n2 − 1) n = harmonic order = (fn/f1) Active power at f1
(losses)P ≈ (QC/Q)·n/(n2 − 1) V = nominal line-line voltage
XL = inductor reactance at fundamental frequency = Lω

XC = capacitor reactance at fundamental frequency = 1/(Cω)

The functions performed bydouble-tuned filter are same as two single-tuned filters although it has certain advantages: its losses are much lower and the impedance magnitude at the frequency of the parallel resonance that arises between the two tuning frequencies is lower.

The double-tuned filter consists of a series LC circuit and a parallel RLC circuit. If f1 and f2 are the two tuning frequencies, both the series and the parallel circuit are tuned to approximately the mean geometric frequency .

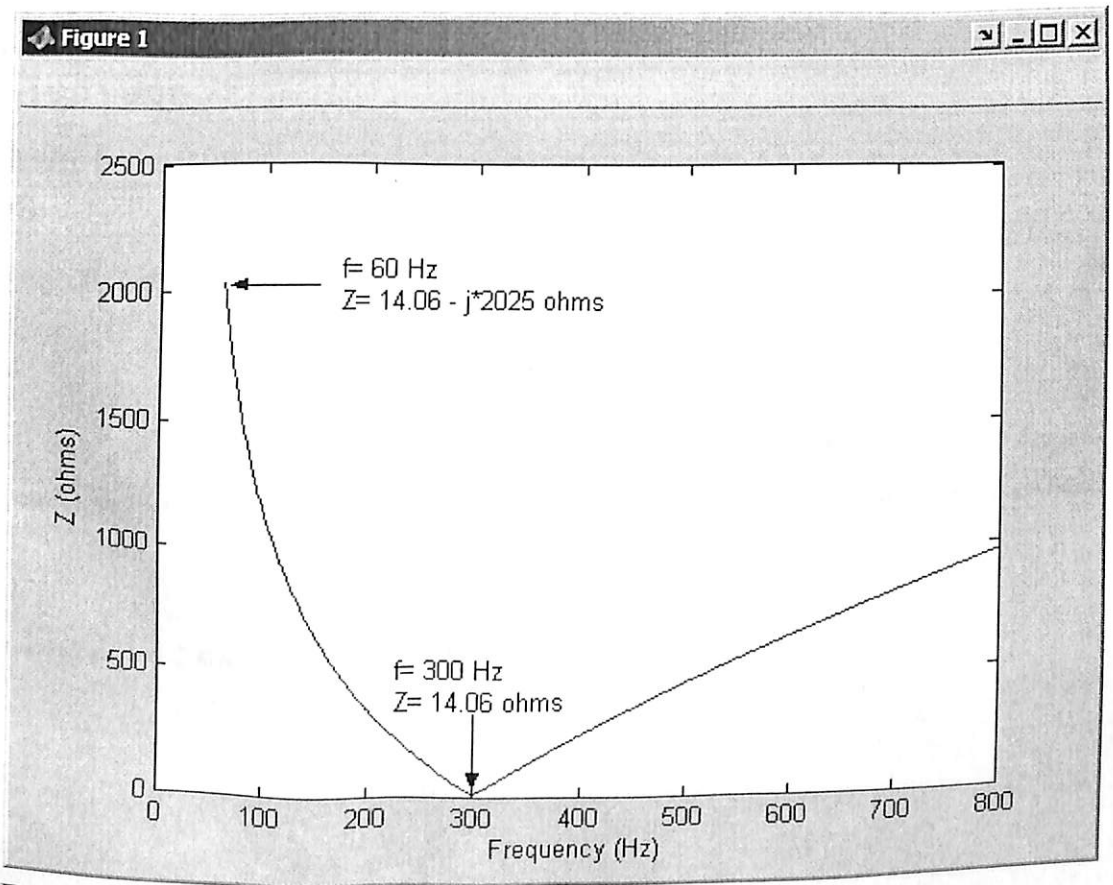


Fig 2.11 : performance graph of filter

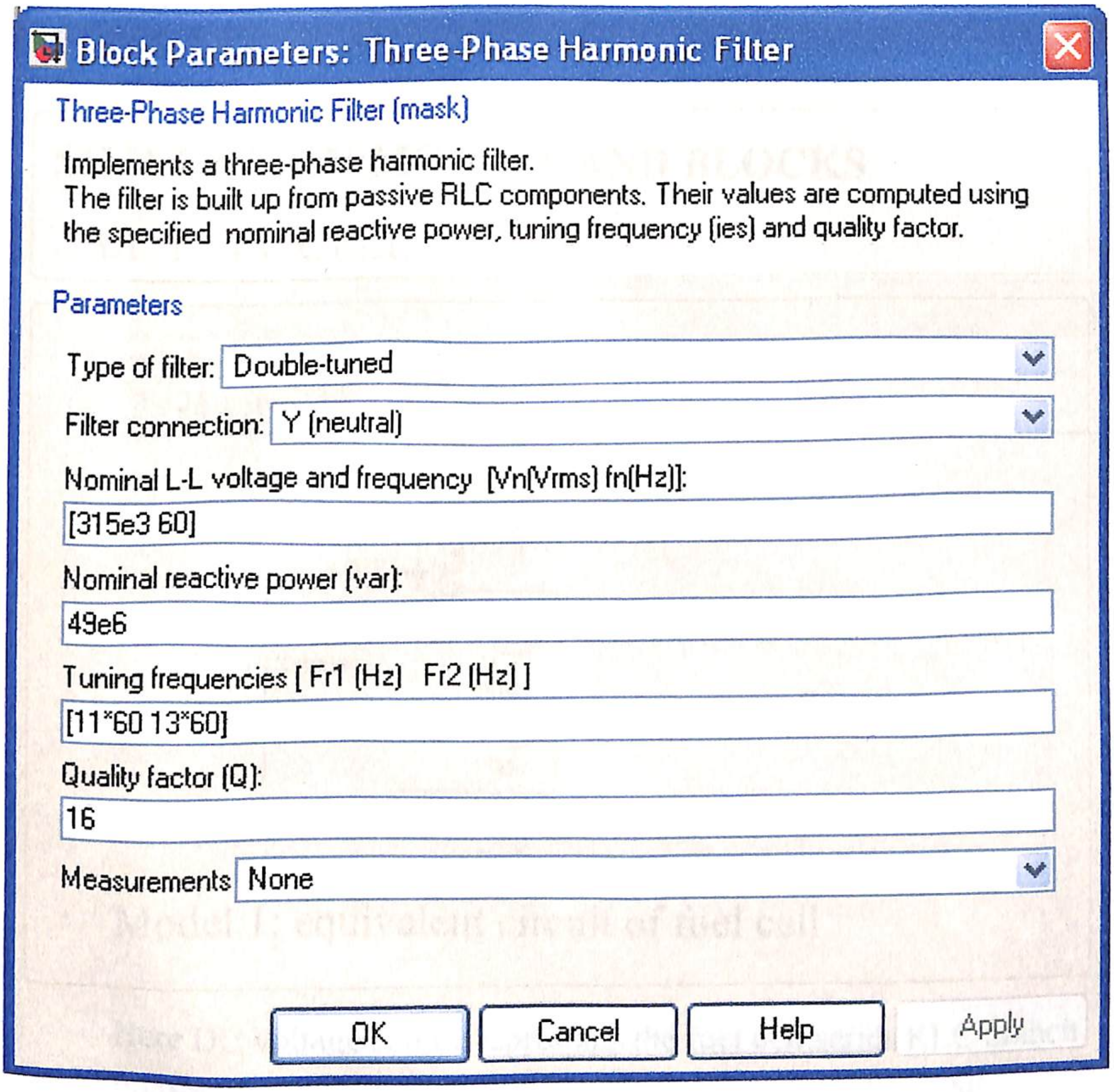
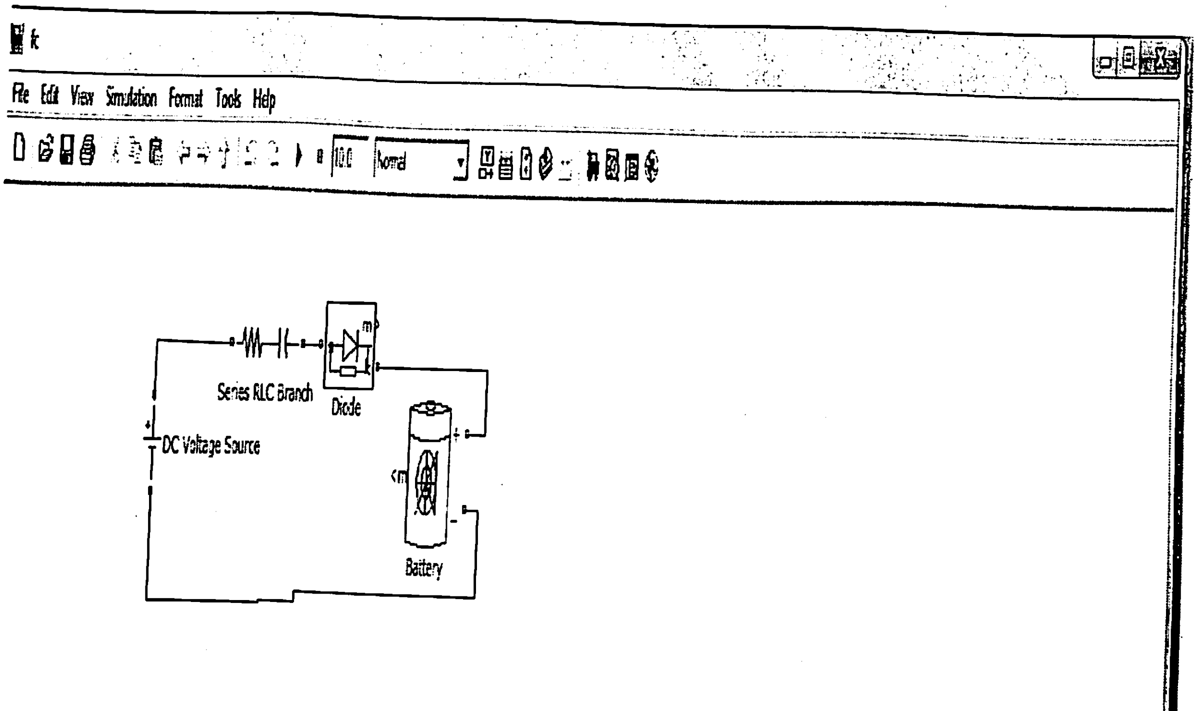


Fig 2.12 : example of block parameter of filter

CHAPTER 3

SIMULATION MODELS AND BLOCKS

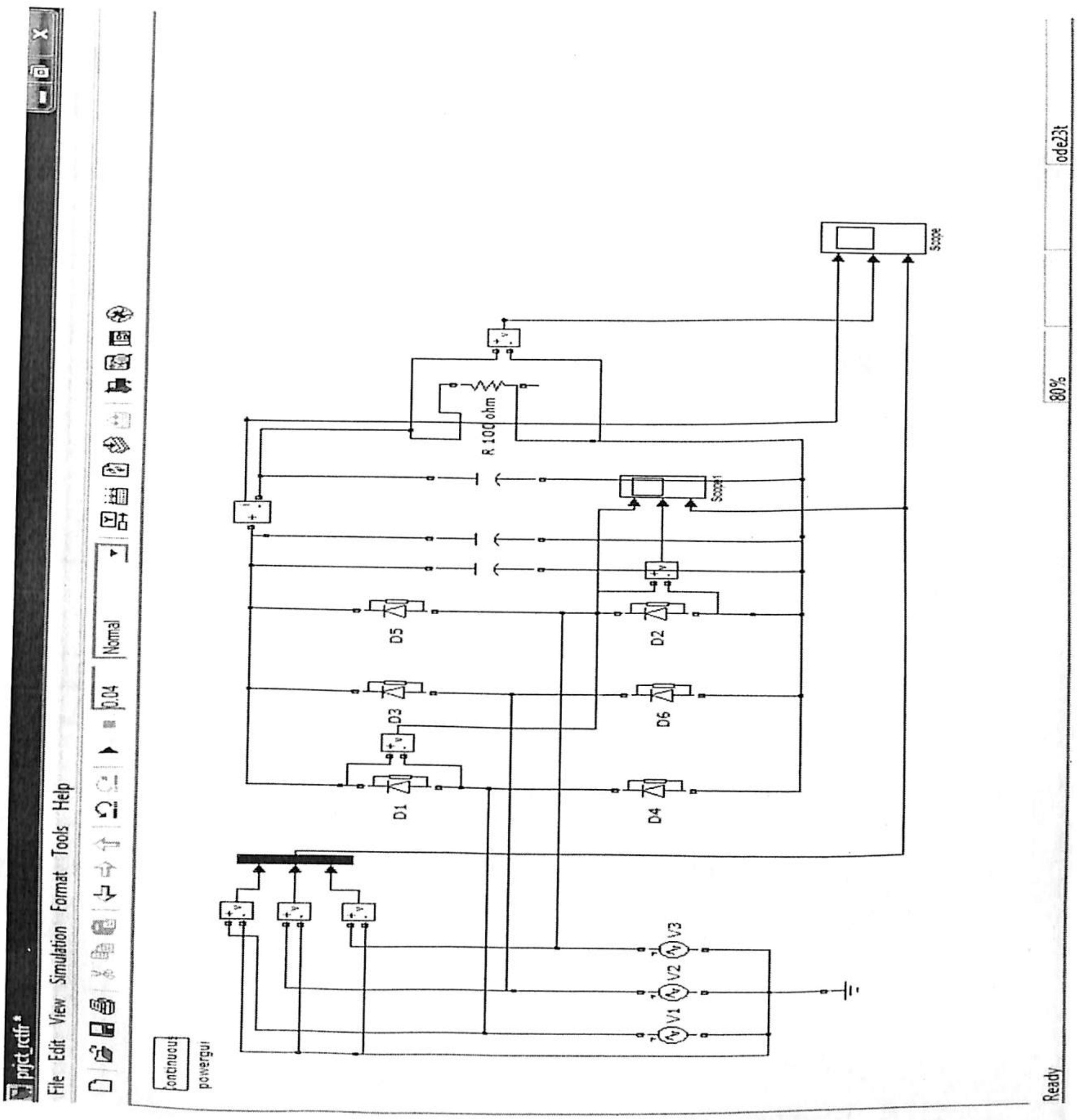
3.1 FUEL CELL



Model 1: equivalent circuit of fuel cell

Here DC voltage source represents the fuel cell.series RLC branch represents resistance and inductance of the source and diode represents a switch.

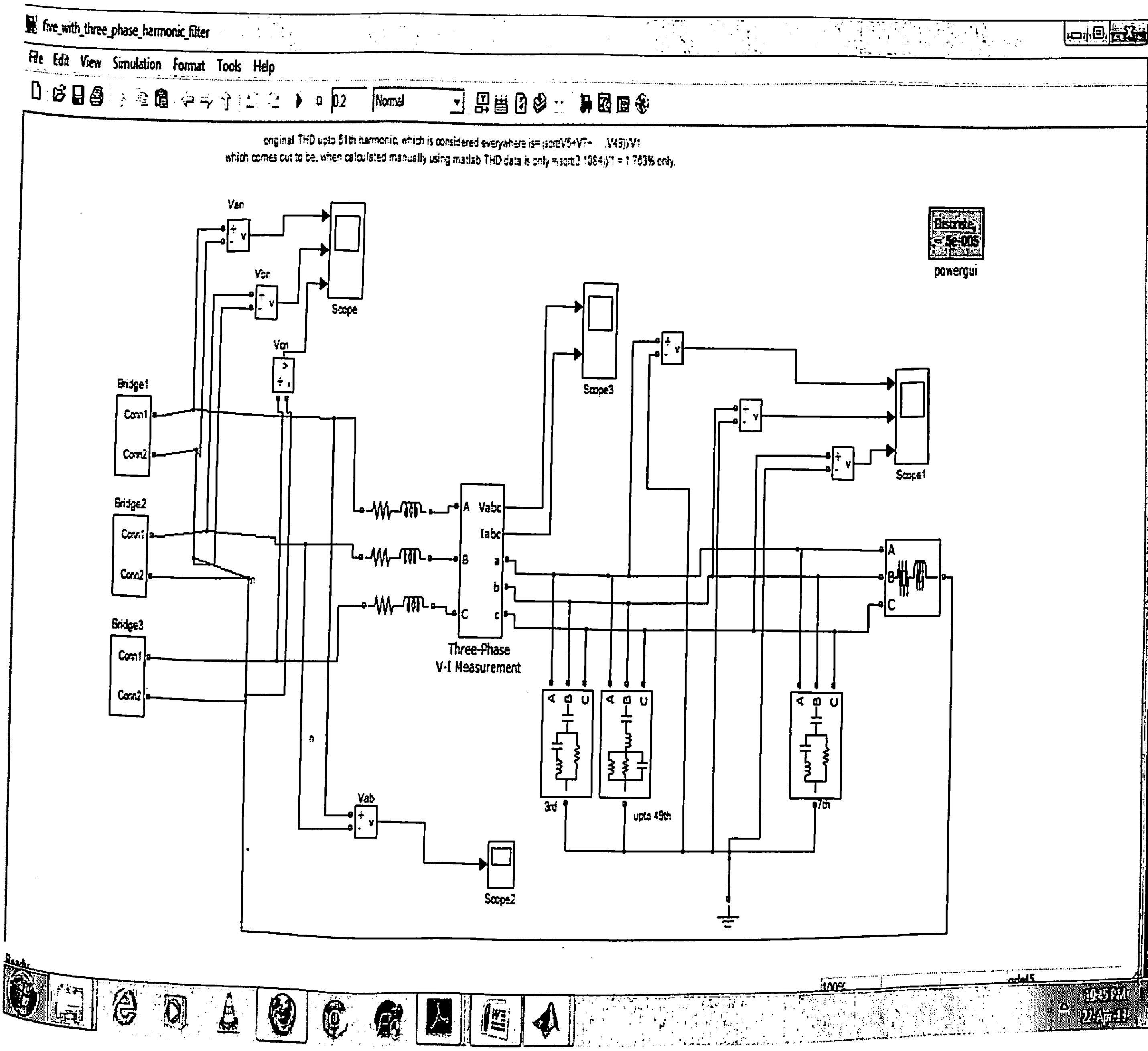
3.2 Three phase full wave uncontrolled rectifier



Model 2 : model of three phase full wave uncontrolled rectifier

Three phase full wave uncontrolled rectifier represents the unit which converts AC supply into DC which is fed to inverter.It is modeled in place of fuel cell.It generates 100 v DC output which is fed to PWM inverter.

3.3 THREE LEVEL PWM INVERTER WITH THREE PHASE HARMONIC FILTERS AND RL LOAD

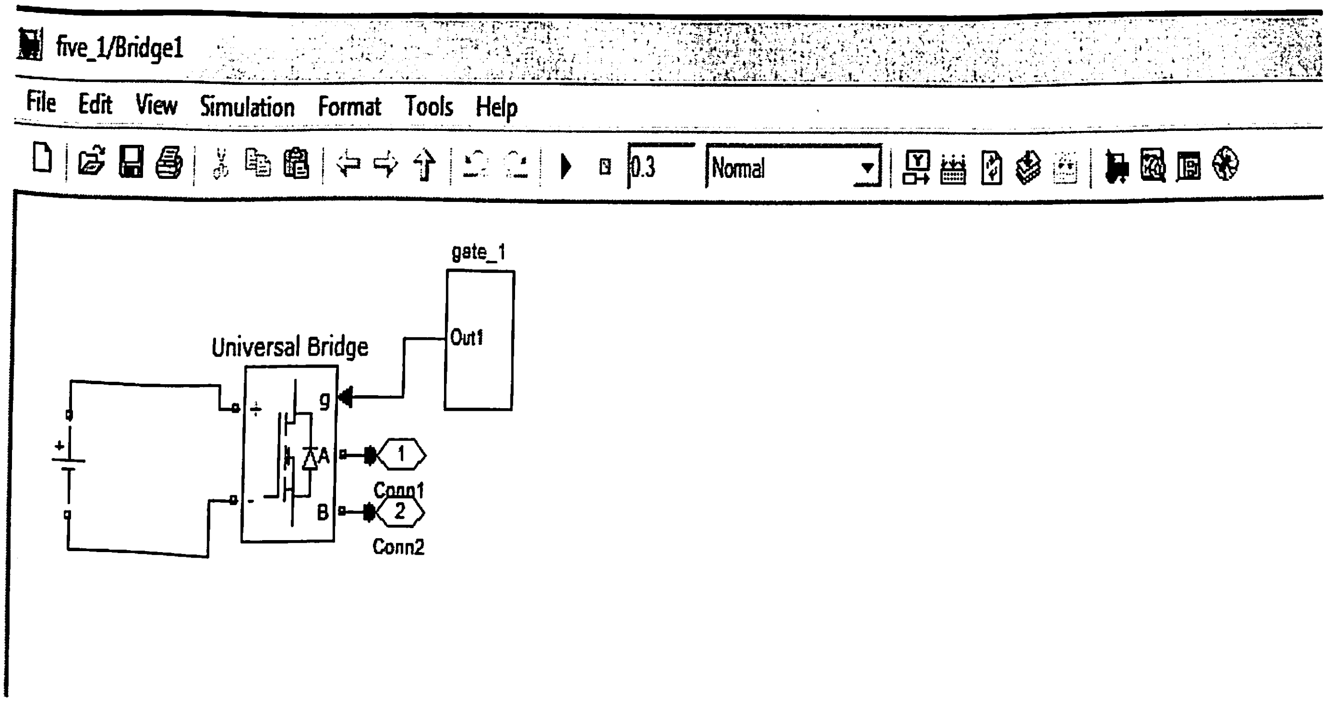


Model 3: three level PWM inverter with three phase harmonic filters and RL load

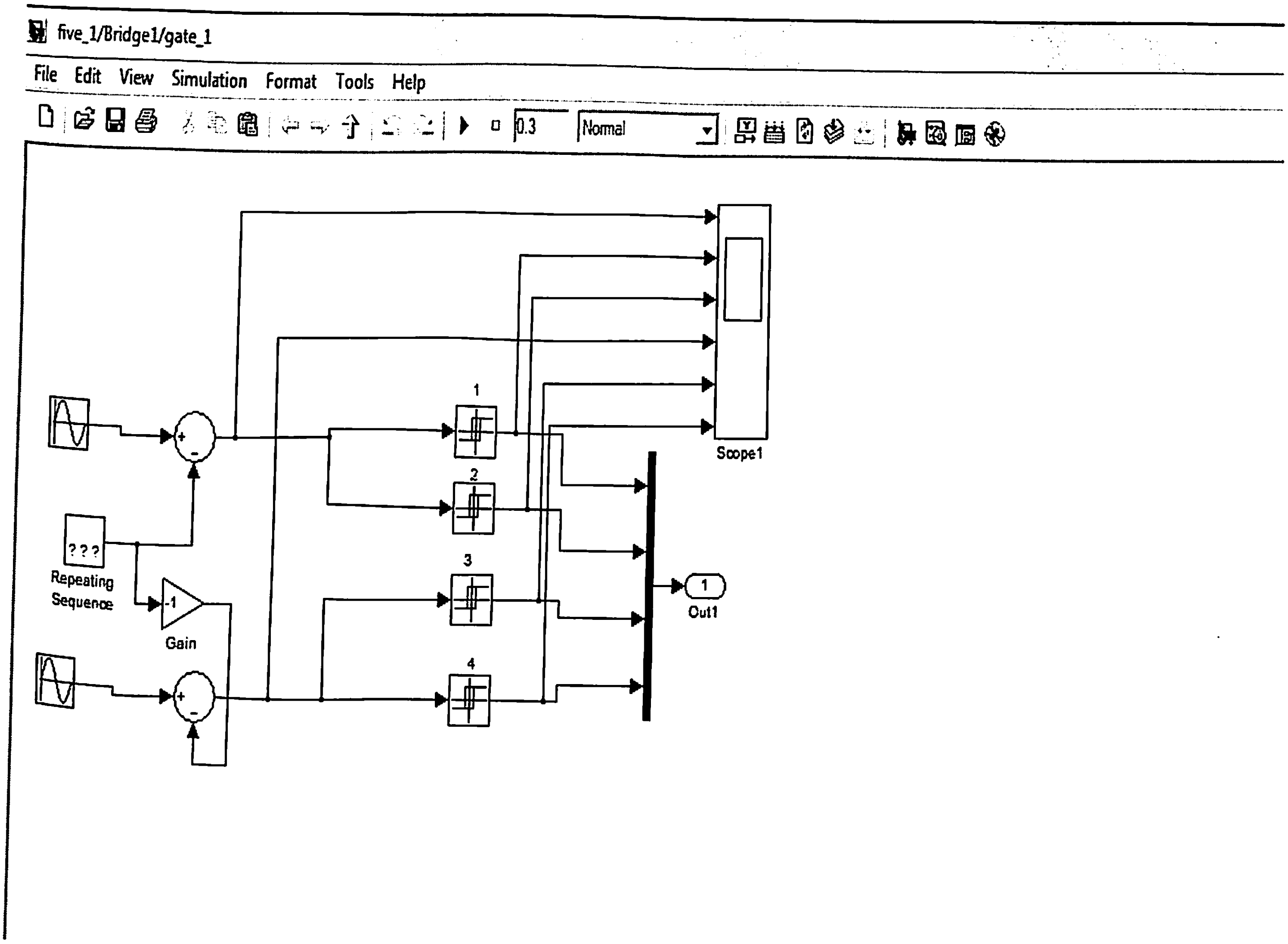
In this three bridges are connected using MOSFET and RL filters are connected in series with pwm inverter. The Amplitude of the input DC voltage to the Inverter is 100 volt.

In this three harmonic filters are connected after measurement unit to filter the harmonics of 3^{rd},7^{th},11^{th} and 13^{th} order to obtain the voltage THD upto 2%.Two harmonic filters are C type high pass and one is double tuned filter.

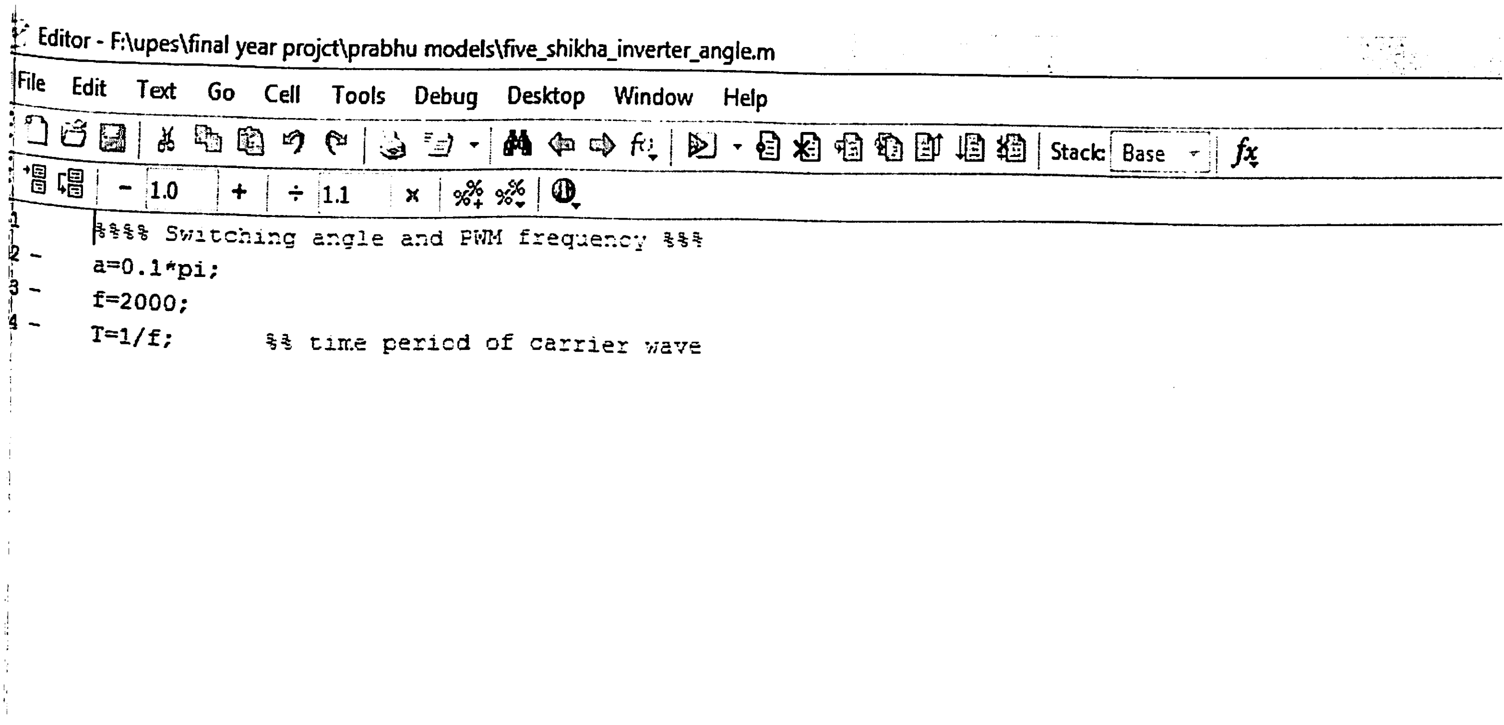
At the output three phase RL load is connected with 1000 w active power and .8 power factor i.e. 700 var reactive power.



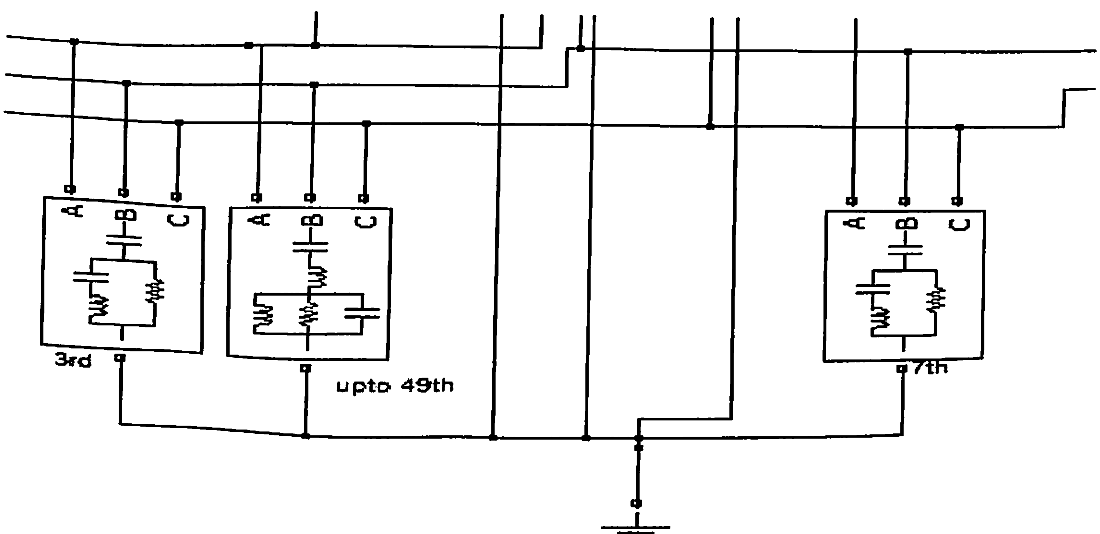
Model 4: Model of universal bridge



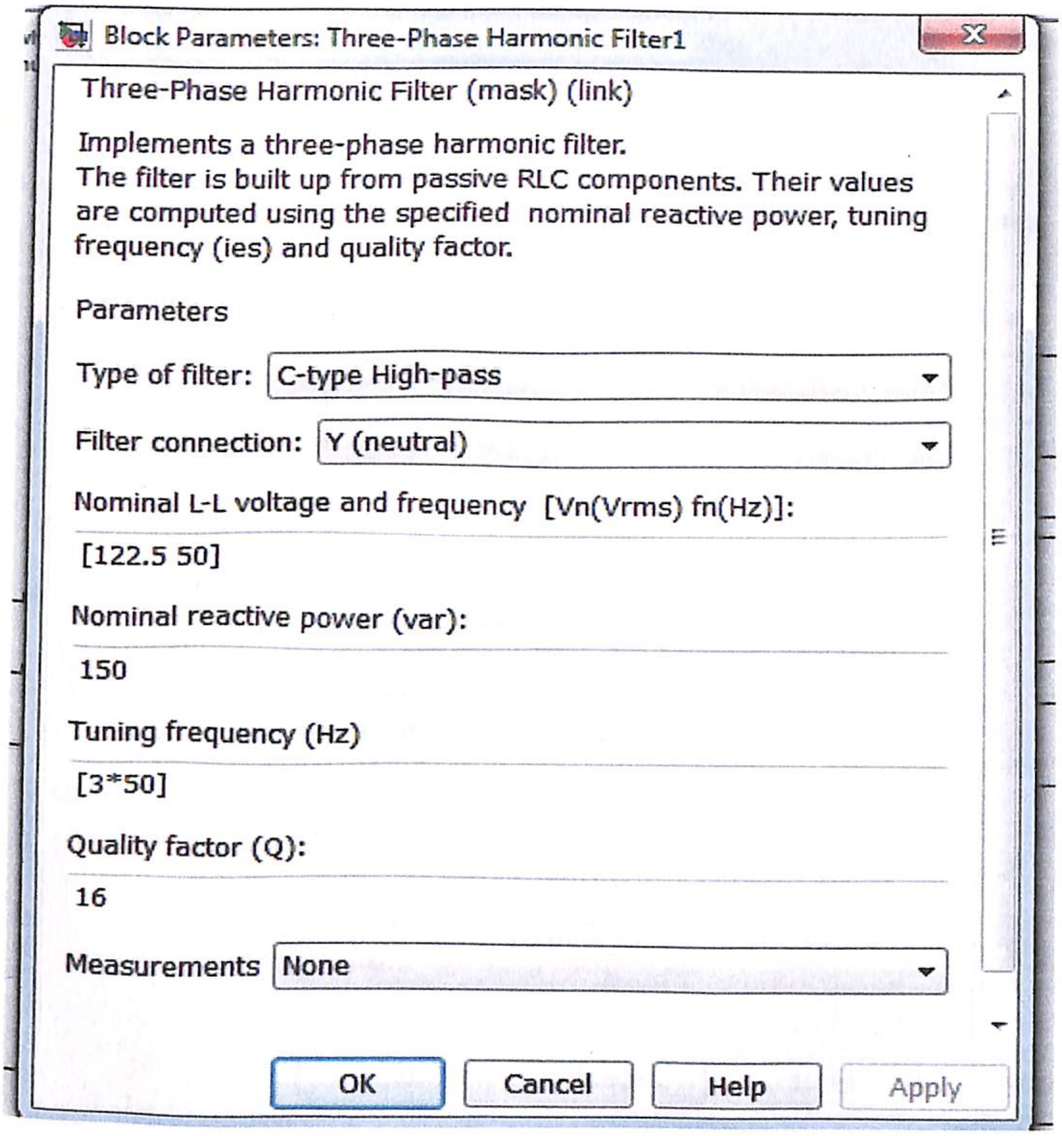
model 5: model for gating signal



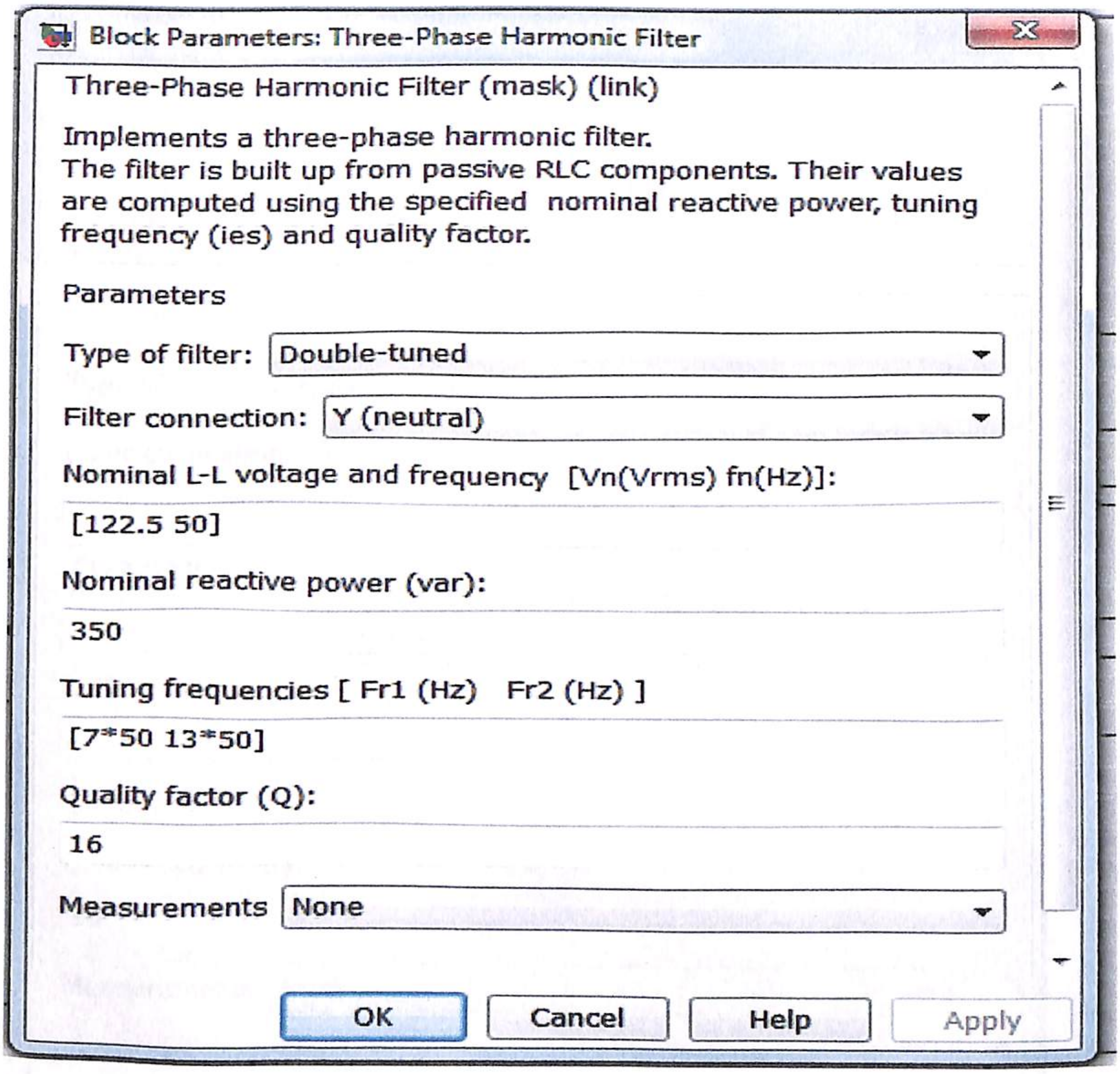
Model 6 : Switching angle and PWM frequency



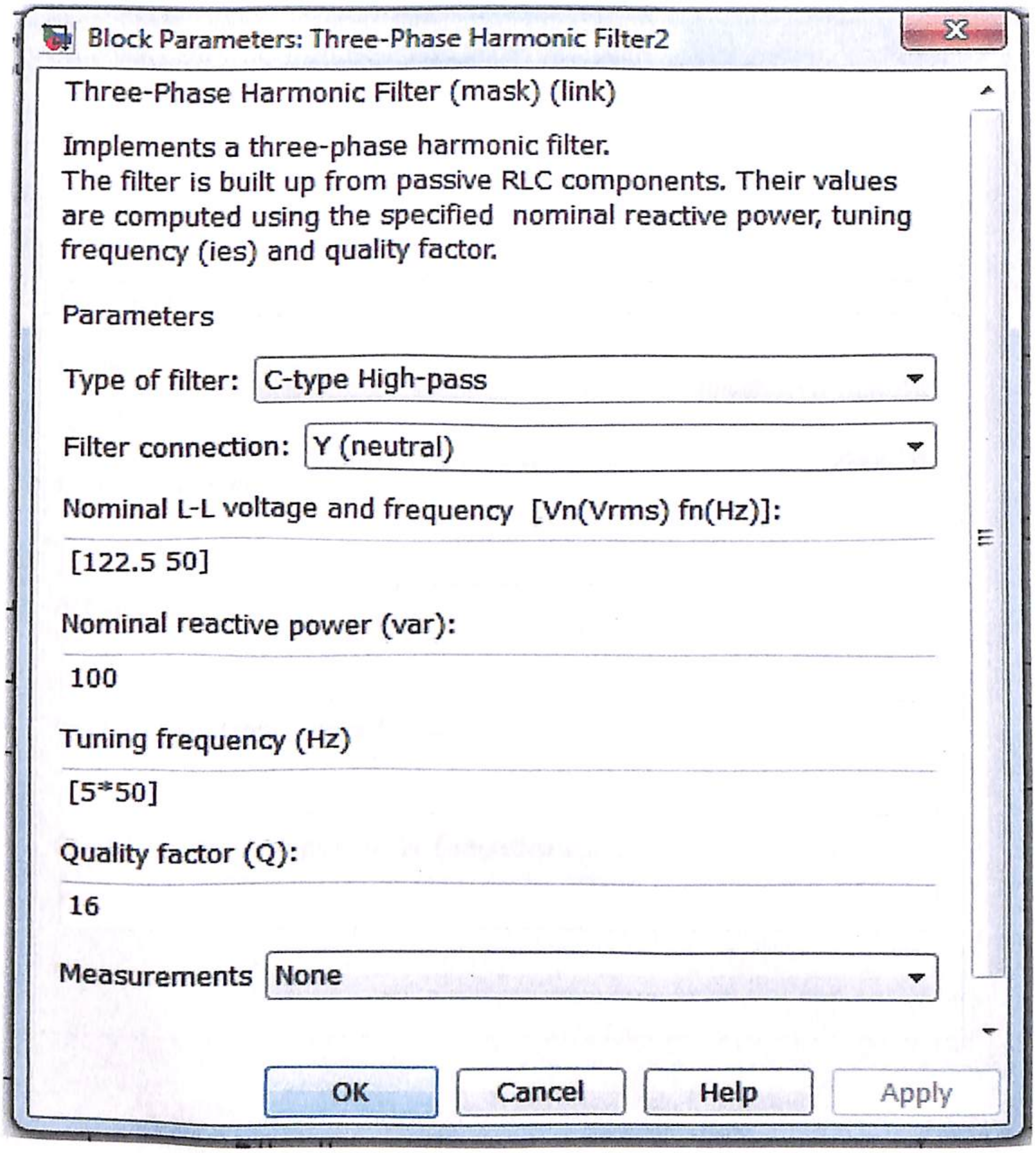
Model 7: Three phase harmonic filters connected to the system



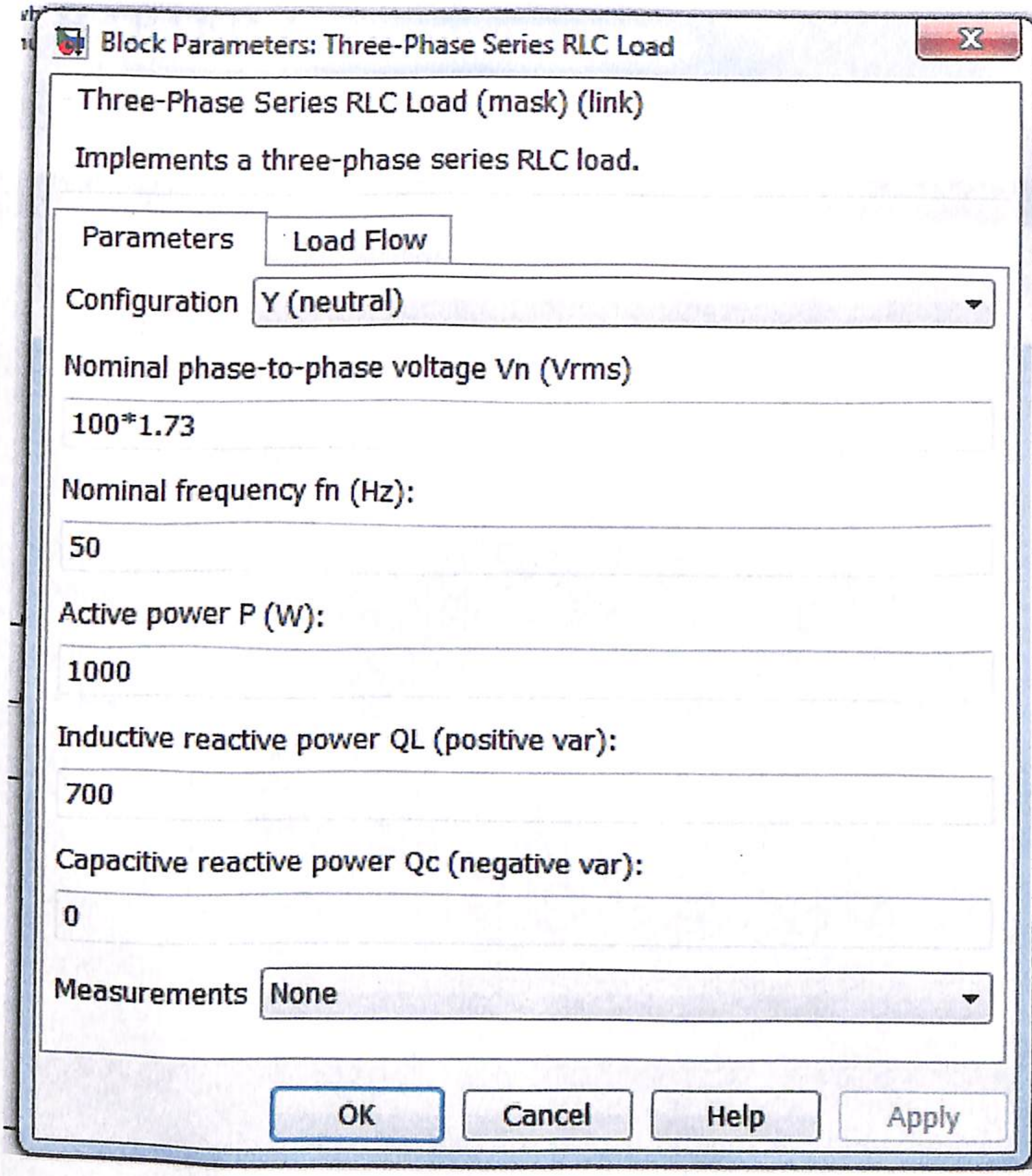
Parameter block 1 : Three phase harmonic filter (C- type High- Pass) to filter third harmonic



Parameter block 2 : Three phase harmonic filter (Double tuned) to filter seventh harmonics and thirteenth harmonics



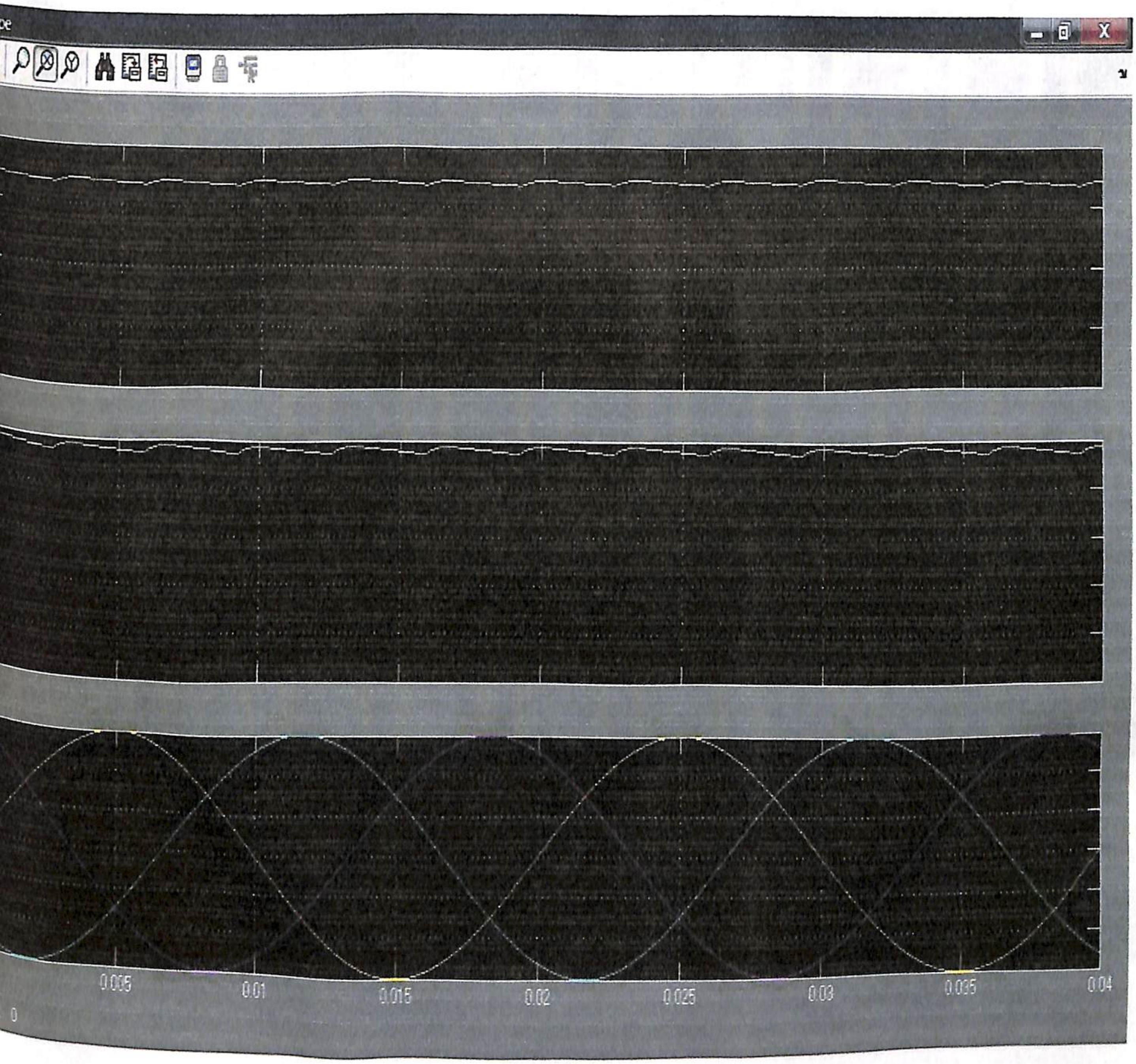
Parameter block 3 : Block parameters of Three phase harmonic filter (C – Type High Pass) to filter Fifth harmonics



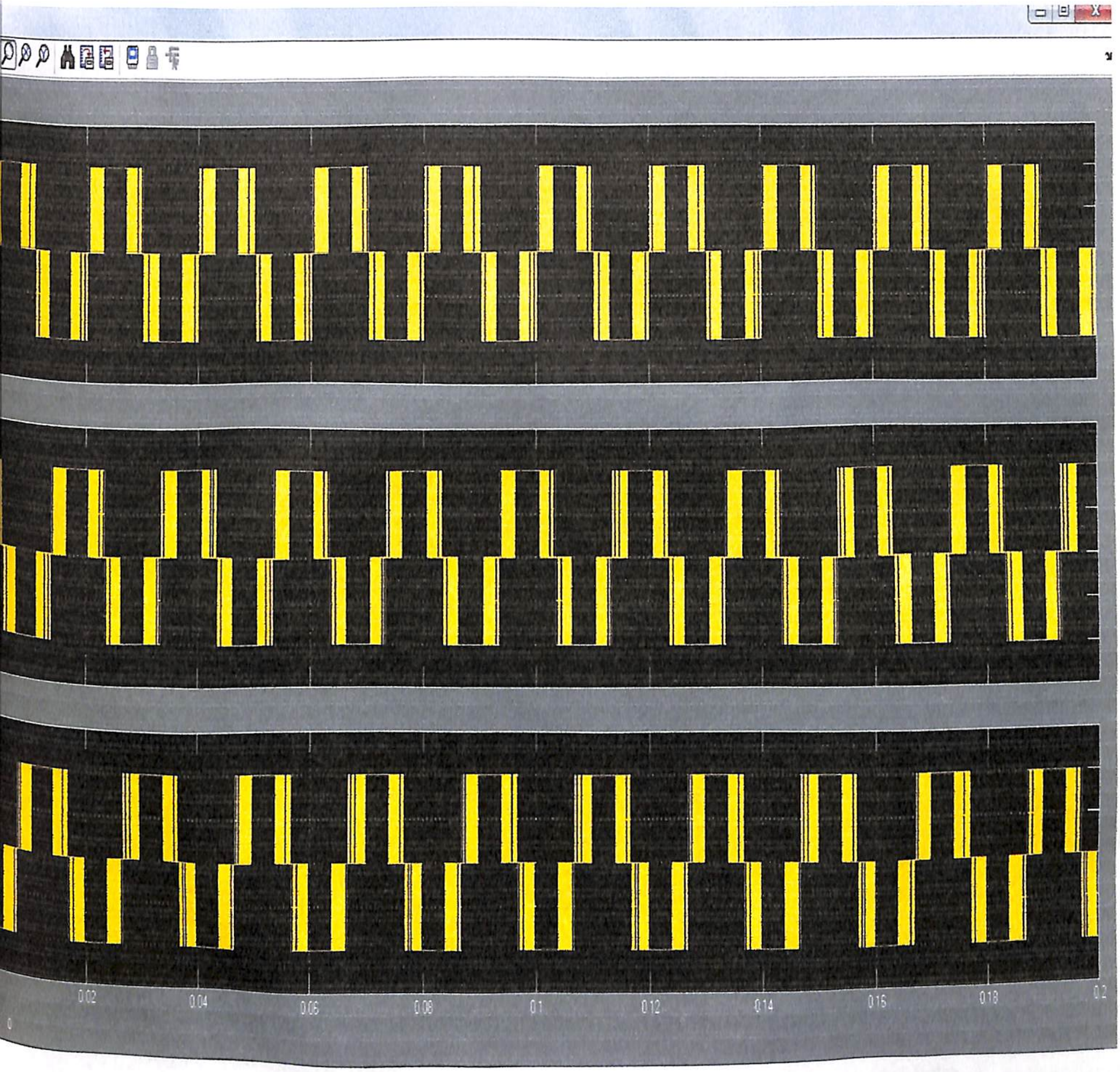
Parameter block 4 : Block parameters three phase RL load

CHAPTER 4

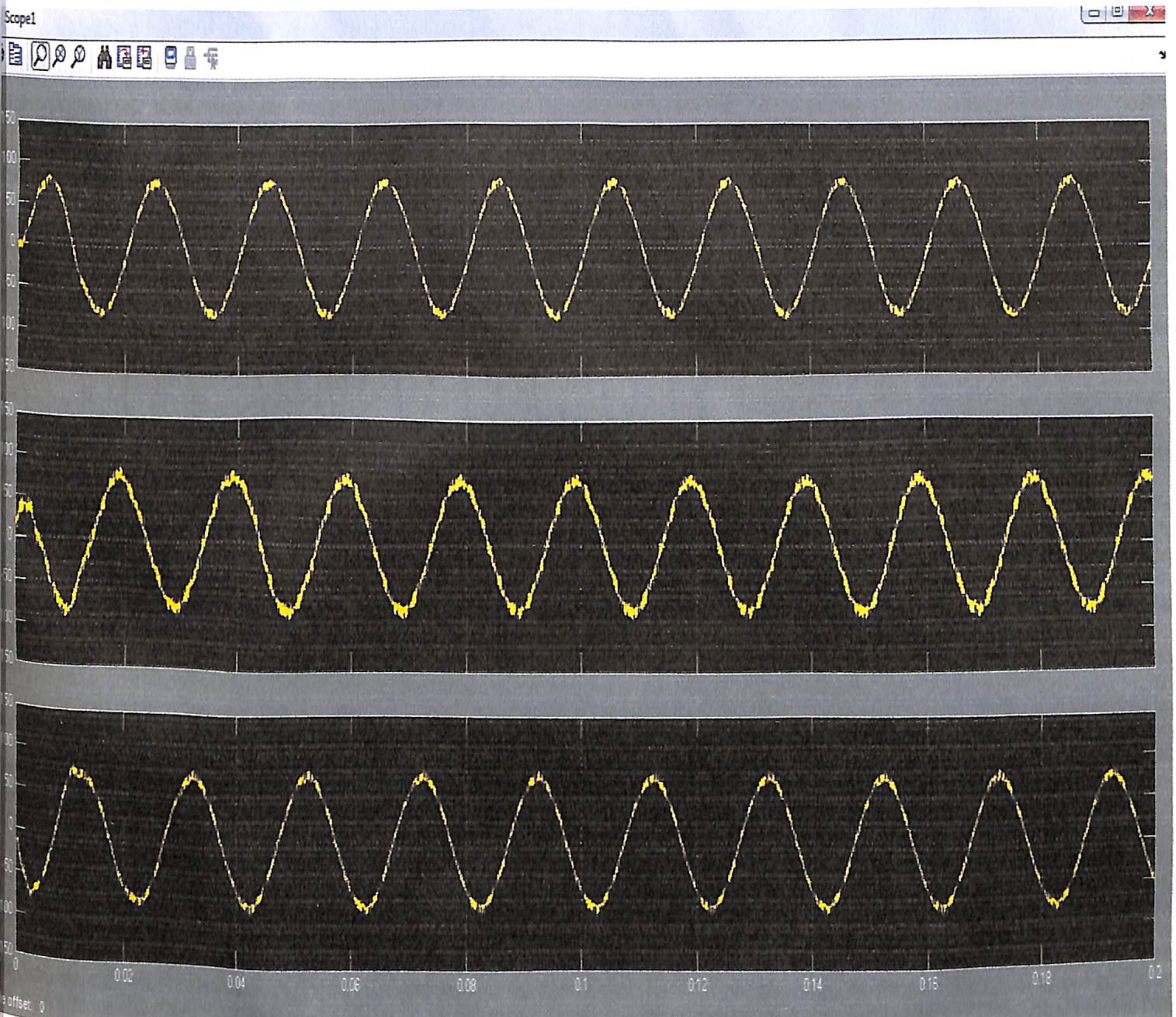
RESULTS AND GRAPHS :



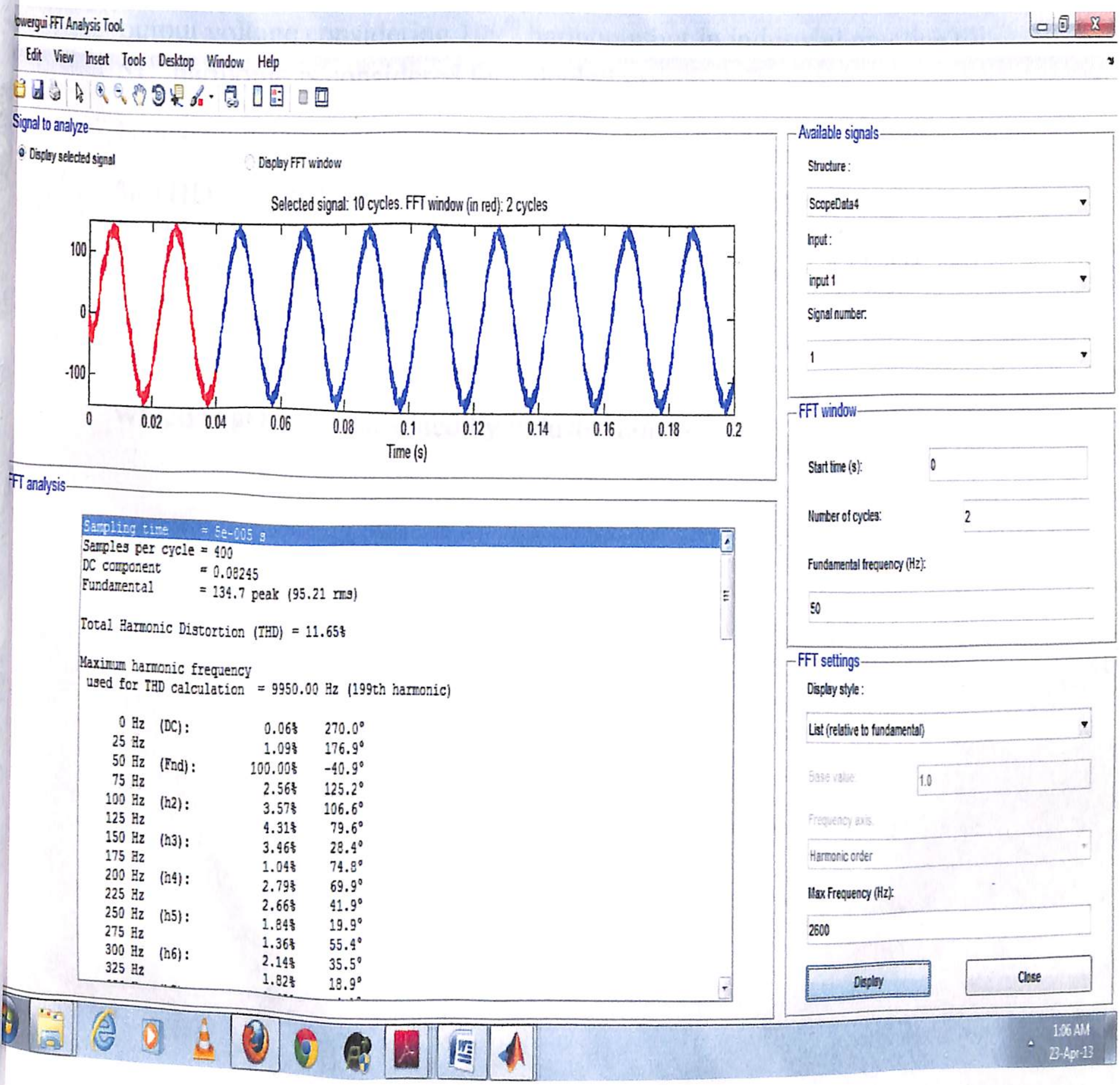
Graph 1: Waveform of three phase full wave uncontrolled rectifier



Graph 2: output three level waveform (with 100 volt amplitude) of PWM inverter



Graph 3 : output voltage waveform which is fed to the load after filtering the three phase harmonics



Result 4 : FFT analysis of the output to the RL load

By FFT analysis it displays 11 % THD(total harmonic distortion) in the output voltage considering 199th harmonic but in industrial practice till 51th harmonic is considered for calculation.

Hence on calculating manually

$$\% \text{ THD} = Sqrt(V_5^{\,2} + V_7^{\,2} + \ldots\ldots\ldots\ldots\ldots + V_{49}^{\,2})/ V_1 * 100$$

This comes out to be when manually calculating using MATLAB THD data

Sqrt(3.1084)/1 = 1.763 % only

Which is generally accepted by industry norms.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS:

After completion of modeling and simulation it can be suggested that by using PWM inverter and Harmonic filters a strong stationary stand alone generating unit can be made for remote applications. It will save non – renewable sources and generate a non pollutant efficient generating unit. Fuel cell also have one added advantage that it need not to be charged unlike batteries rather it just need pure hydrogen and oxygen to generate DC output. Fuel cell can be connected in stacks and generate electricity.

The only problem with fuel cell system is generating pure hydrogen. The processing unit of pure hydrogen is very huge and it makes fuel cells very costly. In addition to this in this thesis main focus was given to electrical system hence it can be extended to realize the model of fuel cell and its response to the changing load conditions.

The main recommendation after working on this thesis is to increase the use of renewable resource by hybridizing fuel cells with wind energy and solar energy systems. Hybrid systems and their application and response can be realized and analyzed by using MATLAB.

For example Wind energy has a very fluctuating nature due to ever changing nature of wind speed. Hence the output of the wind system is not balanced. Due to this variation power generation will not balance the power demand sometimes. In order to solve this problem fuel cell system can be integrated with the wind generating system and can be analyzed. Hence it is recommended to extend this study of fuel cell for further study and explore multiple dimensions of its applications.

In addition to this performance of various fuel cell should be studied so that we can use the best available option and utilize the resources to the maximum extend.

CHAPTER 6

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