HARMONICS MITIGATION ON VARIABLE FREQUENCY DRIVE USING SINGLE PHASE SHUNT ACTIVE POWER FILTER CONTROLLED BY ARTIFICIAL NEURAL NETWORK A CASE STUDY OF KILN UNIT OF DANGOTE CEMENT PLANT OBAJANA

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AUGUST, 2017

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A DISSRTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIA, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE (M. Sc) DEGREE IN POWER SYSTEM ENGINEERING

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

AHMADU BELLO UNIVERSITY,

ZARIA

AUGUST, 2017

DECLARATION

I, hereby declare that the work in this dissertation entitled "**Harmonics mitigation on Variable Frequency drive using single phase shunt active filter controlled by Artificial Neural Network. A Case Study of Kiln Unit of Dangote Cement Plant Obajana**was carried out by me in the Department of Electrical and Computer Engineering, under the supervision of Prof.B. Jimoh and Dr. Y.S. Haruna as part of the Requirements for the Award of Degree of Master of Science in Power System Engineering. Information derived from literature has been duly acknowledged in the text and a list of references provided. To the best of my knowledge, no part of this dissertation was previously presented for another degree or diploma at this or any other institution.

Lawal Idogu UMAR _____ _____

Signature Date

CERTIFICATION

This dissertation titled "**Harmonics mitigation on Variable Frequency drive using single phase shunt active filter controlled by Artificial Neural NetworkA Case Study of Kiln Unit of Dangote Cement Plant Obajana** by Lawal Idogu Umar Meets the requirements for the award of degree of Master of Science (M.Sc.) in Power System Engineering by Ahmadu Bello University, Zaria and it is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This dissertation is dedicated to my Late Father Mall. Umar Idogu, my mother Hajyia Umar Fulani Bilikisu Yarwa, and Late Alhaji Muhammed Ali Ogedengbe,Hafizul Quran for their parental guidance during my study at Ahamadu Bello University, Zaria. Also to my amiable wife Madam Sefi Shaibu Ochangudu Lawal, as well as my children Muhammad Adeiza, Ha'diya Onize, Shafa'at Oiza, and Mardiya Omayioza for their patience and support rendered to me during my study.

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In the Name of ALLAH,The compassionate, Omnipotent, The most merciful**.** I referenced His gift of life, knowledge, good health and special provision for my needs throughout the period. May His blessing and mercy be upon His Noble Prophet, Muhammad (S.A.W), Ameen.

The generosity assistance and cooperation of people directly or indirectly involved in this research work are highly appreciated.

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Lawal Umar Idogu

ABSTRACT

This research presents effect of harmonic generated by variable frequency drives (VFD).In the past, electrical power system equipment and devices were designed to produce nearly sinusoidal voltage and current waveforms. However, nowadays, with much interest and wide spreads of power electronics equipment, for industrials, commercials and residential consumers, these equipment and other electronics devices are no longer operate with an ideal current and voltage waveform, because of the non-linearity of the equipment in nature, with this trend, a Recurrent Neural Network Algorithms with active power filter (SAPF) is implemented for harmonics mitigation on Variable Frequency Drive,because of its simplicity and accuracy among the artificial intelligent family controllers. Simulations were carried out using MATLAB/SIMULINK and SIMPOWER tool box environment to analyze the harmonics distortion. The total harmonics distortions (THD %) of current was calculated using relevant equations. The simulation results are in accordance with the recommended IEEE 519-2014 harmonic standard limits. However, the distortion harmonics in feeder supplying the VFD and soft starter equipment which led to frequent replacement of the drive or out of services also led the Distribution Control System Failure (DCS). 47.17% before and after the application of filter was reduced to 1.80%.

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LIST OF ABBREVIATIONS

ANN	Artificial Neural Network
GUI	Graphical User Interface
HPF	Hybrid Power Filter
IGBT	Insulated Gate Bipolar Transistor
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
PCC	Point of Common Couple
RNN	Recurrent neural Network
SAPF	Shunt Active Power Filter
SAPF	Series Active Power Filter
VIS	Voltage Source Inverter

CHARPTER ONE

INTRODUCTION

1.1 Background of the Study

Before the advent of power electronics most of electrical equipment were operated on nearly sinusoidal current and voltage waveforms. Nowadays, with the proliferation of modern power electronics devices such as adjustable speed drives, uninterrupted power supply, switch mode power supplies, fluorescent lamps, Television set, fax machines, photocopy machines, personal computers, printers and many more non-linear devices used in industrial, commercial and residential applications, supply current and voltage waveforms are no longer sinusoidal. The non-linearity of the devices make them draw and inject harmonics current to the supply system which affects the system performance and equipment by increasing power distribution system losses (Channi and Sohal, 2012). These harmonics injection leads to power quality degradation of the distribution system causing adverse effects such as overheating low tention (LT) conductors, power losses, interference to nearby communication facilities, electromagnetic induction (EMI) and total failure of equipment, etc. Harmonics produced by non-linear loads in power system draw current in abruptly pulses than in a smooth manner (Channi and Sohal, 2012). For the past decades and up till now, power quality issues have been a worry to utilities, consumers researchers and power quality system engineers (Channi and Sohal, 2012).

Consequently, efforts have been made in order to provide remedy to these harmonics problems in order to comply with the relevant provision of the IEEE 519-2014 standard on the minimum Total harmonics distortion (THD) of current and voltage within the Power Distribution Network. Various solutions to overcome harmonics problems as earlier maintained include use of traditional passive filters, active filters, magnetic wave shaping and

network reconfiguration, etc (Fuchs and Masoum, 2008), (Emadi *et al.*, 2004), (Ranjbar *et al.*, 2009). The most popular devices among the harmonic cancellations techniques are passive and active filters. Traditionally, passive filters had been firstly introduced for the harmonic current compensation, but due to its drawbacks, such as series and parallel resonances, tuning, large in size, weight and cancellation of some selective harmonics due to the non-linear loads, that is why its operation becomes very limited nowadays. With the introduction and advancement of superior filters to the passive filters in our today's markets, active power filters are now the dynamic and viable solution for simultaneously compensation harmonics current and reactive power drawn by non-linear loads. In addition, shunt active filters have the advantages of power factor correction, cancellation of harmonics induced in the neutral conductor of three-phase four-wire system, and balancing of voltage levels in three-phase three-wire system.

However, in Kiln unit of Dangote Cement Plant Obajana with different electromechanical equipment, such as Transformers, cyclo converter, Variable frequency drives (VFD) and soft starter which is the heart of cement production is to be use as case study.

Low Voltage Distribution (LV) Line diagram for the Research work (Kiln substation of Dangote Cement Plant) is presented in figure 1.1 which feed power to various electric motor, from 11KVA substation (S/S) to 415Vol and 240Volt.

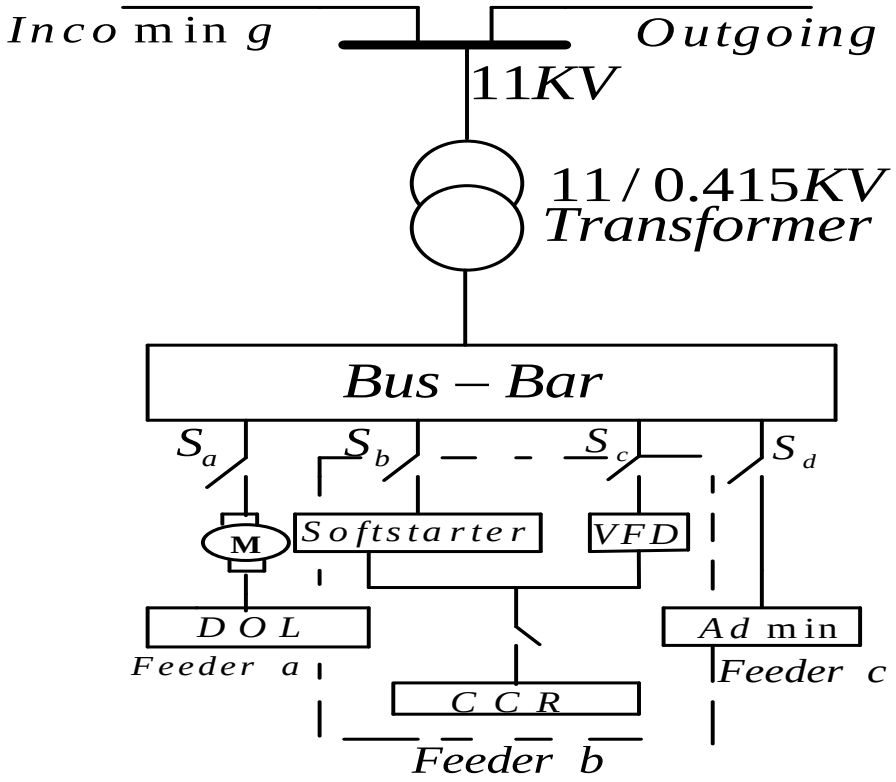


Figure 1.1 Line Diagram of the system network (Dangote kiln unit)

Parameters in the diagram are as follows

a) S/S (Substation)

b) CCR (Central control Room)

c) Sa, Sb, Sc & S_d (Molded case circuit breaker (MCCB)

d) M (Electrical motor)

e) DOL (Direct online starter)

f) VFD (Variable Frequency Drive

It was observed that among the feeders (A B C), feeder B frequently tripped and result in constant replacement of the drive as a result of the harmonics distortion present on the feeder. (Variable Frequency Drive & soft starter drive) which result in Distribution Control System (DCS) failure.

However, the need to mitigate the harmonic effects with the shunt active power filter(SAPF) based on application of RNN become important.

Kiln is a furnace that heats up powdered material (lime stone, clay, and laterite) at $1600C^0$ that flow through it to produce clinker which would be mill in to cement. (Dangote kiln unit productionManual) Kiln substation is the substation that distribute power to various electrical motors that caused the kiln to rotate at a preset frequency, such as kiln main drive (900KW, 900A, 997rpm, 690V *pf* 0.86) kiln induced drafted fan (IDF), Electrostatic precipitator (EP) etc, all these drives are variable frequency drives (VFD) controled by central control room. (Dangote kiln unitproduction Manual) Each has a control feeder that contained VFD module that generate current harmonics due to the nonlinear load that make up the module, also the feeder is incorporated with communication link Protocol Field Bus called (profibus) that provide feedback information about the status of the motor in the field to the central control room.

However, the first step of a pulse width modulation (PWM) VFD (the rectifier) generates distortion of the AC line as the rectifier charges a capacitor bank called the DC bus. Current is drawn from the AC supply line only when the rectified voltage exceeds the voltage level to which the capacitor is charged. Severe harmonic distortion can have several detrimental effects as earlier stated (A Bagini 2008). VFD controls the speed of an AC motor by varying the frequency supplied to the motor, it also regulates the output voltage in proportion to the output frequency to provide a relatively constant ratio of voltage to frequency V/F as required by the characteristic of the Ac motor to produce adequate torque. The output voltage is turned on and off at high frequency, with duration of on-time, or width of the pulse, controlled to approximate a sinusoidal waveform. In addition, the electronic circuit diagram is at appendix B. Also the network configuration at pcc is shown at appendix C

The figure 1.2 shows the power circuit with the bridge inverter and ANN controller.

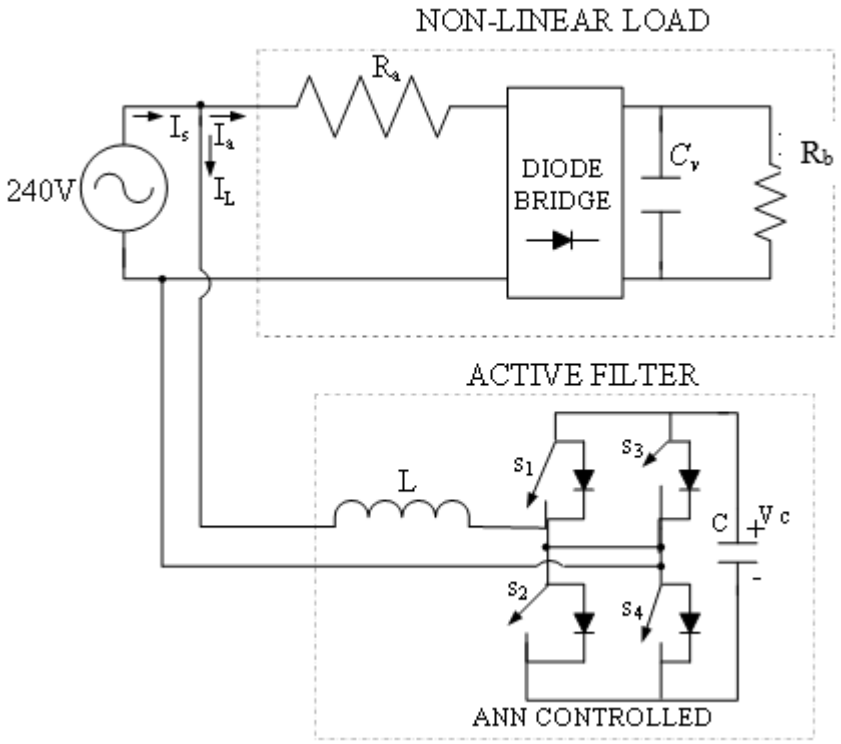


Figure 1.2: Feeder Network Schematic Diagram at PCC. (Dangote kiln unit low voltage power circuit)

1.2 Problem Statement

Harmonics studies in power system networks has been one of the disturbing issues militating utilities, industries, commercial and local consumers due to the wide spread of power electronic devices that drawn non-linear loads. As of now, harmonics cannot be completely eliminated but can be reduced to acceptable level, as imposed by the IEEE 519-2014 standard on minimum current and voltage THD level. A lot of researches on how to remedy effects of harmonics have been ongoing by researchers.

It is observed that among the feeders (A B C), in figure 1.1 feeder B frequently tripped as a result of the harmonics distortion generated by VFD module present on the feeder and replacement of the drive, it also results in the failure of Distribution Control System (DCS). This caused total production stoppage.

However, the need to mitigate the presence of this harmonic with the SAPF and application of Recurrent Neural Network (RANN) based become important.

1.3 Aim and Objectives

The aim of this research is the modeling and simulation of single-phase shunt active power filter using recurrent neural network for harmonics reduction in Variable Frequency Drive.

The objectives of this research work are summaries as follows:

1. Data collection for the power quality problems at Kiln unit of Dangote Cement Plant Obajana.
2. To model the line parameters of non-linear load of VFD module at kiln unit using MATLAB/SIMULINK software environment.
3. To model and simulate single phase shunt active power filter using Artificial Neural Network (ANN) controller by MATLAB/SIMULINK Software environment.
4. To compare the simulation results with imposed harmonic standard limit of IEEE 519-2014.

1.4 Significance of the research

A lots of research works have been done on improving the power qulity both utility and consumer on mitigation of harmonics. Various control strategies were employed. However, the significance of this research study are as follows:

I. Development of Recurrent Neural Network for harmonic detection and extraction

II. Development of Analytical table for harmonic distortion using FFT

III. Selection of Alpha perfectly march for any value and optimal result was obtained.

1.5 Dissertation Organization

The organization of this research work is as follows: Chapter one presents the general background of the study. Chapter two, reviewed the fundamental concepts of this work, and detailed review of similar related works were presented. In Chapter three, the details

explanation of methods and materials used were presented. Chapter four outlined the simulation results and discussion. Finally, Chapter five is the conclusions and recommendations with the references quoted in this work as well as appendix A, B and C used in SIMULINK simulation.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

In this chapter, the literature review which includes the review of fundamental concepts and the review of similar works are presented.

2.2 Review of Fundamental Concept

This section presents the review of the main research work, including power quality, harmonic distortion in power system, shunt active power filter and its topology and artificial neural network controller.

2.2.1 Power Quality

Electrical Power Quality (EPQ) Problems, is any problem on power system which leads to current, voltage or frequency deviations that resulted in the failure or malfunction of consumer's equipment or devices within the consumer's specification. Electrical power quality is a term that refers to maintaining the nearly sinusoidal waveform of power distribution bus voltages and current at rated magnitude and frequency level (Surajit *et al.* 2011). Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE1100 defines power quality as "the concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment." As appropriate as this description might seem, the limitation of power quality to "sensitive electronic equipment" might be subject to disagreement. Electrical equipment susceptible to power quality or more appropriately to lack of power quality would fall within a seemingly boundless domain. All electrical devices are prone to failure or malfunction when exposed to one or more power quality problems. The electrical device might be an electric motor, a transformer, a generator, a computer, a printer, communication equipment, or any household electrical appliance. All of these devices and others respond adversely to power quality issues, depending on the severity of problems. A

simpler and perhaps more concise definition might state: “Power quality is a set of electrical boundaries that allows a piece of equipment to function in its intended manner without significant loss of performance or life expectancy.” This definition embraces two things that we demand from an electrical device: performance and life expectancy. Any power-related problem that compromises either attribute is a power quality concern. In light of this definition of power quality, this chapter provides an introduction to the more common power quality terms, along with definitions of the terms and also attempts to explain how power quality factors interact in an electrical system.

2.2.2 Frequency Variation

Operational characteristic of power system is determined by frequency, also an important index in measuring alternating voltage, defined as continuous frequency of fundamental voltage profile measured over a specific time interval of 10s (Baggini, 2008).

The frequency deviation Δf allows evaluation of slow frequency variation

$$\Delta f = f - f_r \qquad (2.1)$$

$fr =$ Rated frequency (50Hz to 60Hz), $f =$ real frequency

$$\varepsilon f(\%) = \frac{f - f_r}{f_r} \times 100 \qquad (2.2)$$

Relative frequency deviation.

Integral deviation allows clock synchronized to electrical network for a day.

$$If = \int_0^{24} \Delta f . \Delta t \qquad (2.3)$$

However, the effect of harmonics in our rotating machine or transformers is that a magnetic circuit operating in a certain reduced configuration of frequency leads to increase in magnetic flux, the system becomes non-linear load as it is shown in the equation.2.4

$$\phi_{\mu} \cong \frac{\sqrt{2 \times \nu}}{2\pi f \omega} \tag{2.4}$$

Where $\theta\mu$ = magnetic flux.V= Applied voltage, f = frequency,ω = number of coil (Baggini, 2008).

Power quality problem, is any problem on power system which leads to current, voltage or frequency deviations that resulted in the failure or malfunction of consumer's equipment or devices within the consumer's specification. The quality of power is very important to both the utility and the consumer, because most of the supply current and voltage were supplied to the consumers by the utility in nearly sinusoidal wave forms. The deterioration of the power system quality originates from the consumer's side, due to the use of non-linear loads such as adjustable speed drives, uninterrupted power supplies, rectifiers etc, that draws harmonics on the equipment and the devices. Moreover, power quality problems can be found in many ways within the utility or consumer's sides, such as voltage sags, voltage flicker, noise, frequency variations, notches DC offset and harmonics. Each of this type of power quality problem can be mitigated with different harmonic suppression techniques, depending on the type of the problem encountered by the utility.

Classification of power system disturbance (Surajit *et al.* 2011)

1 Interruption, under voltage, overvoltage

2 Voltage current unbalanced.

3 Transient

4 Voltage sag

5 Voltage swell

6 Harmonics

7 Notches in supply voltage main

Harmonic power quality problems due to non-linear loads are the main study throughout in this research, due to its severity amongst the mentioned power quality problems. Different power quality problem issues in power system network that cause serious devastating effect in the performances of power supply were studied previously by many researchers. Figure 2.1, shows the representation of sag wave form for the supply system, sag is the sudden drop in the peak value of the wave forms in either voltage or current. Voltage sag can be suppressed by dynamic voltage restorer (DVR) custom devices. Voltage sag can result in voltage drop and even cause failure to equipment or devices under operation in the consumer's network.

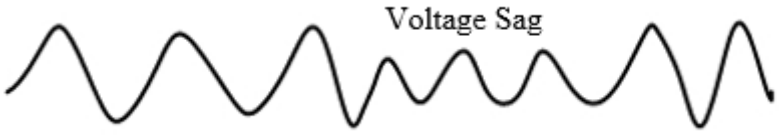


Figure 2.1Voltage Sag due to sudden drop in supply Voltage Main(Khalid and Dwivedi, 2011).

Similarly, swell is another voltage power quality problem inherent in power system supply. Voltage swell is the increase in the peak value of the supply system voltage which cause serious sudden increased in the consumer's power supply, Voltage swell in power system network can leads to the failure or even burning of the consumer's equipment or devices, as a result of the sudden increase in supply voltage. Swell means increase in voltage above the nominal value. Figure 2.2 depicts the concept of the swell in power system supply wave form.

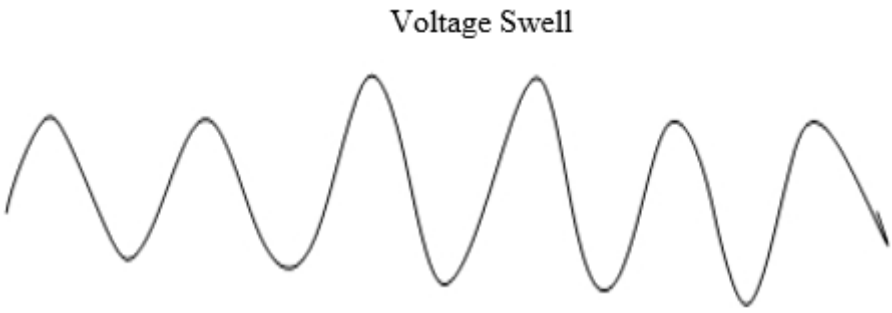


Figure.2.2 Voltage Swell due to sudden increase in Supply Voltage Main (Khalid and Dwivedi, 2011)

Another power quality problem issue is the voltage interruption on power supply voltage or current wave forms:

Voltage interruption in power system supply is the drop of voltage or current to zero level for a short period duration, during the power supply operation. An interruption in power system network can cause power system failure during the period of the sudden drop of the voltage or current within the utility system during power system operation. Figure 2.3, shows the supply waveform phenomena of an interrupt in power system. During power interruption, both the supply voltage and current are zero.

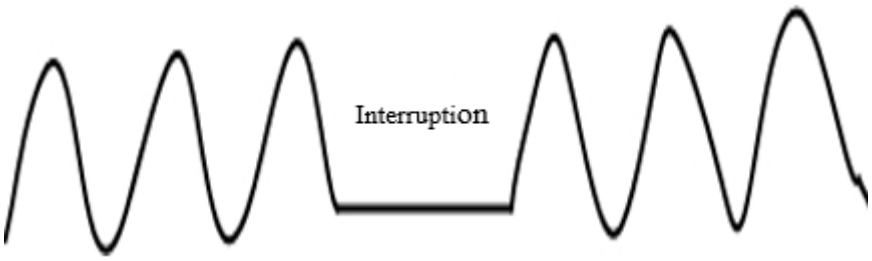


Figure 2.3: Voltage Interruption of Power Supply (Joseph Seymour 2001).

Notches are other power quality problems that are encountered during power supply system operation. Notches occur in some segments parts of the voltage or current wave forms, as depicted in Figure 2.4

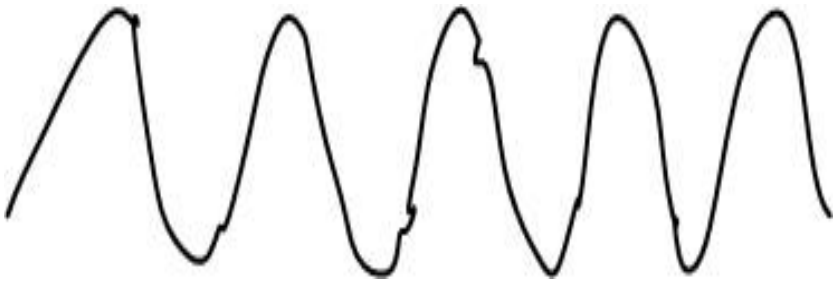
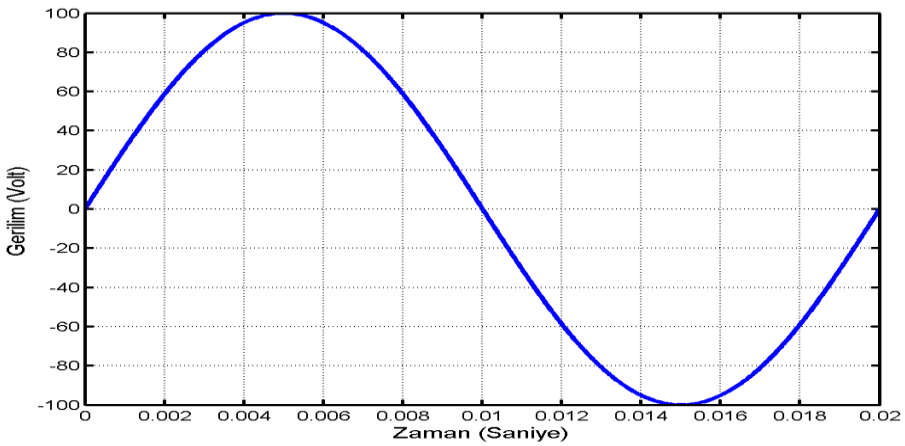


Figure 2.4: Notches in Supply Voltage Main (Singh *et al.*, 2012).

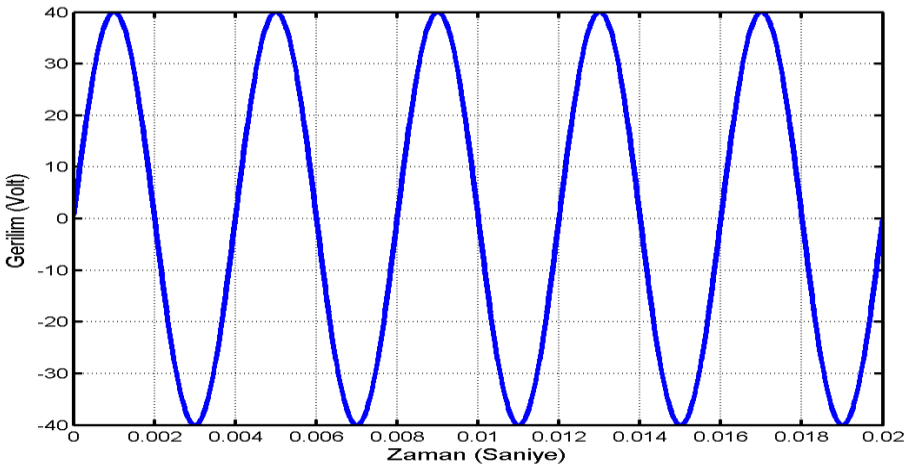
2.2.3 Harmonics

Any current or voltage waveform that are integer multiples of the system fundamental frequency (50Hz or 60Hz) are called harmonics. With the system fundamental frequency of 50HZ which is the first fundamental harmonic. This fundamental harmonic, cannot be changed even with FFT analysis because 50Hz when multiplied by1, it will still be 50Hz, that is why for any FFT analysis the first harmonic which is the fundamental frequency does not change and remained constant. In this regard the 2^{nd}, $3^{rd,}$ 4^{th}, 5^{th}, 6^{th}, 7^{th} harmonics and so on will be 100Hz, 150Hz, 200Hz, 250Hz, 300Hz and 350Hz respectively. Figure 2.5, shows the fundamental frequency with 5^{th} and 7^{th} harmonics frequencies together with the summations of the two

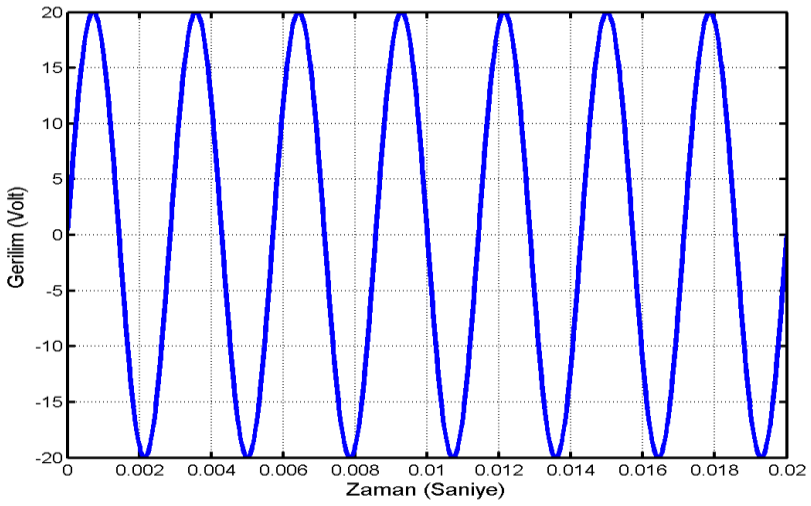


harmonics frequencies.

(a)



(b)



(c)

Figure 2.5: (a) Fundamental frequency (b) 5thHarmonic frequency & (c) 7th Harmonic frequency(Arrillaga and Watson, 2003)

Effect of the 5th and 7th harmonics frequency is shown in figure 2.6b while figure 2.7 shows the combined frequencies fundamental frequency,5th and 7th harmonic sum.

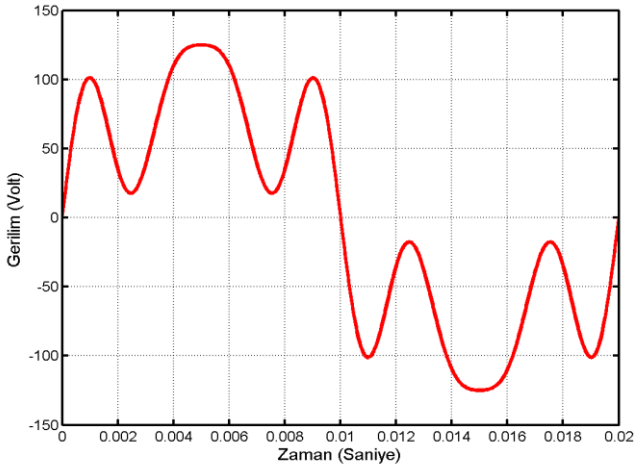


Figure.2.6d: Resultant Harmonic Frequency component signal (Arrillaga and Watson, 2003)

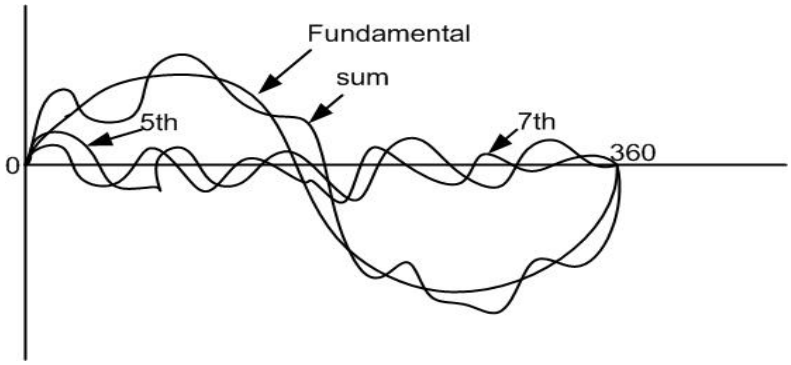


Figure 2.7: fundamental and sum of 5th and 7th order harmonics (Kumar, 2011)

In harmonic analysis, the odd harmonics are the ones to be considered in mitigating current and voltage due to the non-linear loads. In this analysis, harmonics current are the most distorted waveforms that suffered than the voltage waveforms in the system. While the even harmonics cancelled themselves in the analysis of the FFT which becomes zero, and does not have any effect to the system. Today, in typical practical equipment and devices, harmonics can be measured up to 63rd order, and in distribution system, harmonics orders from 3rd to

25th can also be measured and considered (Arrillaga and Watson, 2003). Figure 2.8, shows a simple concept of current distortion due to a single nonlinear resistor connected to a purely sinusoidal supply voltage. Ideally, the source voltage is purely sinusoidal before insertion of the resistor, as the source voltage is increased gradually; the source current wave form gradually becomes distorted. The V-I characteristic curve of Figure 2.8b, shows a non-linear curve, this is due to the non-proportionality of the current and voltage, i.e. current and voltage are anti phase.

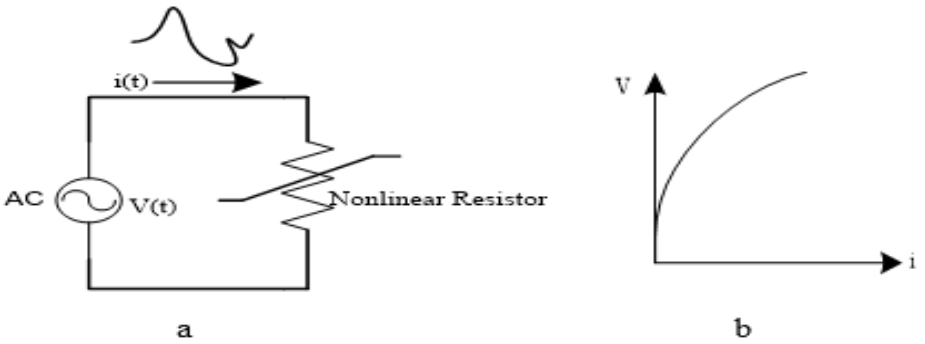


Figure 2.8: (a) Circuit diagram for Non-linear resistive load (b) Graph of nonlinear resistive Load (Amran, 2010)

2.2.4 Causes of harmonics

Harmonics are typically caused by industrial, commercials and residential consumers' equipment or devices that draw non-linear currents. Such drives are:

i. Adjustable speed drives, arc furnace, cyclo-converters and welding machines etc for (industrial applications).
ii. Personal Computers photocopier machines, fax machines, lather printers, TV set, fluorescent lamps, air conditioners, UPS, and switch mode power supplies etc. (commercial/residential applications).

Harmonics are produced from application of semiconductor and electromagnetic devices such as transformer and rotating machines, it is also based on the properties

and materials used in constructing them. The sources can be grouped into the following: Magnetization nonlinearities of transformer, rotating machines, Arcing devices and semiconductor based power supply system, inverter fed A.C. drives, Thyristor controlled reactor, phase controllers and A.C regulators (Surajit et al 2011).

2.2.5 Effect of harmonics

The adverse effects of power quality of supply system due to the harmonics current drawn by the non-linear loads, which also affect supply system efficiency include: Electrical power losses in the system, low power factor, electromagnetic induction (EMI), overheating in the system cables and conductors, constant tripping of sensitive devices,(like circuit breakers), accelerated life spans of equipment that affect system, total system failure and interference in nearby communicating facilities etc. Harmonics effects are still the militating issues that are continually disturbing power system.

However, harmonics are not desirable and have adverse effect in our equipment and operation. The following are some of the effect: Resonance, poor damping, effect on rotating machines, transmission line, measuring instrument, power system protection, capacitor banks, and consumer equipment.

The effect on rotating machine is losses of voltage and current in stator and rotor circuit and their lamination. Cogging and crawling, the resultant effect is copper and iron losses overheating and poor efficiency of the machine. Also, the poor damping effect is that the small negative impedance supply by variable frequency drive (V.F.D) decrease the current then rise the voltage, hence the result is the poor performance in our control and measuring instrument (Surajit *et al.* 2011).

But up till now, researches are still on the way forward in order to get a lasting solution to these devastating power quality problems. At present, active power filters are still the

dynamic and viable solution for compensating harmonics current and reactive power drawn by the non-linear loads.

2.2.6 Load model

These are electrical loads that are utilized for commercial, residential and industrial applications. In linear loads, the supply voltage is directly proportional to the system supply current. That means, the voltage is in phase with the current, linear loads obey ohms' law. Examples of linear loads include incandescent lamp, electric stove, motors, and boiling rings etc. Figure 2.9, depicts the relationship between the supply voltage and supply current.

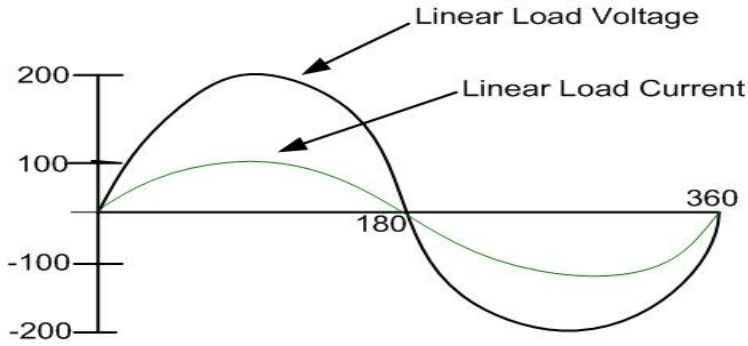


Figure 2.9: Graph of Voltage against Current (De Almeida *et al.*, 2003)

2.2.7 Non-Linear Loads

Non-linear loads are electrical loads that also employed for commercial, residential and industrial applications. In non-linear loads, current is not directly proportional to the system applied voltage, they are in anti-phase to each other. Non-linear loads are the source of harmonics problems associated with power system supply, due their non-linearity in nature. Examples of non-liner loads in today's applications are, television, personal computer, uninterruptable power supply, (UPS, switch mode power supply (SMPS), half and full bridge rectifier, electric arc welding machines e.t.c. Figure 2.10, shows the relationship between the supply voltage and the supply current.

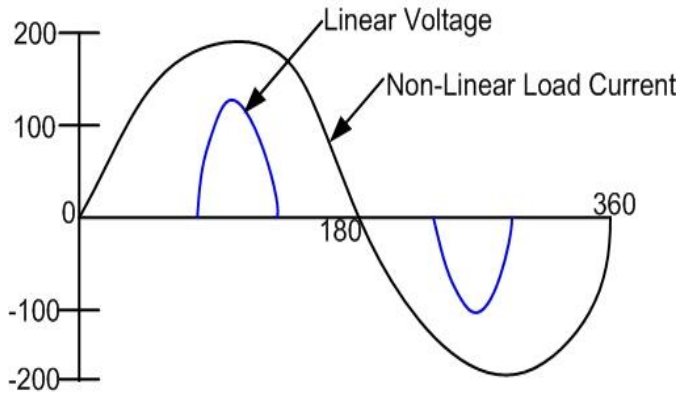


Figure 2.10: Graph of Voltage against Current Due to Non-Linear Loads (Joseph Seymour 2011)

2.2.8 Fourier series Analysis

In 1822 Joseph B. J. Fourier suggested that any continuous function say f (t) in the time interval T can be represented by its fundamental sum and series of its high order of harmonic frequencies that are integer multiples of its fundamental frequency (IEEE, 1993). Fourier series analysis gives the mathematical analysis for the level of fundamental and other odd/even harmonics orders with respect to its sine and cosine functions. Fast Fourier transform (FFT) are normally used to represent the level of odd/even harmonics order together with the main fundamental frequency in order to see the level of harmonics current drawn by non-linear loads. For a given function i_L (K) as in equation 2.5 (Kumar, 2011).

$$i_{L(k)=} \sum_{n=1,2,3...}^{N} [a_n \sin(n\omega t) + b_n \cos(n\omega t)] = a_1 \sin\ n\omega t\ + b_1 \cos\ n\omega t\ + \sum_{n=2,3....}^{N} [a_n \sin(n\omega t) + b_n \cos(n\omega t)] \quad (2.5)$$

(Where, the coefficients a_n and b_n are the amplitudes of the sine and cosine of the Fourier equation, where n is the harmonic order. While the n_{th} harmonic vector is given by $A_n<\phi_n$ in polar coordinate, and a_n+jb_n in complex real and imaginary coordinates respectively). The imaginary equation is transformed by Pythagoras theorem which gives the magnitude as in equation 2.6

$$A_n = \sqrt{a_n{}^2 + b^2{}_n}$$

(2.6)

And the corresponding phase angle as $\phi_n = \tan^{-1}(b_n / a_n)$. Further calculations by integrating equation 2.5 and the coefficients a_n and b_n can be evaluated.

2.2.9 Harmonic Indices

Harmonic distortions for current and voltage wave forms in power quality studies measurement can be analyzed by various harmonics indices as recommended by IEEE 519 harmonic standard, among the indices are: telephone influence factor (TIF), K-Factor, THD and TDD etc. But the most commonly and widely used harmonic indices are, Total harmonic distortion (THD) and Total demand distortion (TDD). All the two indices are measures of the effective value of a wave forms. (Baggini 2008)

2.2.10 Total Harmonic Distortion (THD)

This is one of harmonic indices for measuring harmonic distortion levels in current or voltage waveforms. Total harmonic distortion (THD) is the ratio of the square root of the squaresum of all the harmonics components to the fundamental component of either voltage or current wave forms multiply by 100%. (Baggini 2008)

$$THD_V = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \ldots V_n^2}}{V_1} \times 100\% \qquad (2.7)$$

Where V_2 , V_3 and V_4 are the harmonic voltages, while V_n is the numbers of harmonic orders. However, the THD_I of current is obtained as:

$$THD_I = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + \ldots I_n^2}}{I_1} \times 100\% \qquad (2.8)$$

Where I_2 , I_3, and I_4 are the harmonic currents, and I_n is the number of harmonic currents.

2.2.11Total Demand Distortion (TDD)

This is another harmonic index that is applied in the measurement of current harmonic wave form of a power system as recommended by IEEE 519-1992 harmonic standard. TDD is simply defined as the ratio of the square root of the square sum of the entire harmonics current component to the maximum demand load current (Duffey and Stratford, 1989). Where I_L is the load current of the system. (Baggini 2008)

$$TDD_I = \frac{\sqrt{I_2{}^2 + I_3^2 + I_4^2 + ...I_n^2}}{I_L} \times 100\% \quad (2.9)$$

2.2.12 Imposed IEEE 519-2014 Harmonic Standard Limits

The serious wide spread of modern power electronics to consumers, that inject harmonic currents due to the non-linear loads has resulted in non-sinusoidal current and voltage waveforms to the supply system.

There is various power quality IEE standard tables. Such as surge standard, notches standard, voltage swell standard, harmonic standard etc.

An imposed IEEE 519-2014 harmonic standard limit was used in this research for the total harmonic distortion (THD) that was caused by these non-linear loads at the point of common coupling (PCC).Table1.1 Shows' the Harmonic Current limits by IEEE 519-2014 Standard at the point of common coupling (PCC)Current distortion limits for systems rated 120V through 69 kV(Ramos Jr, 1999).

Table 2.1IEE Harmonic Standard Table (519-2014).

Maximum Harmonic Current Distribution in percentage of Fundamental I_L						
Individual Harmonic order (odd Harmonics)[a,b]						
I_{SC}/I_L(SCR)	**3≤h≤11**	**11≤h≤17**	**17≤h≤23**	**23≤h≤35**	**35≤h≤50**	**THD**
<20	4.0	2.0	1.5	0.6	0.3	5

20-50	7.0	3.5	2.5	1.0	0.5	8
50-100	10.0	4.5	4.0	1.5	0.7	12
100-1000	12.0	5.5	5.0	2.0	1.0	15
>1000	15.0	7.0	6.0	2.5	1.4	20

Even harmonics are limited to 25% of the odd harmonic limits above Current distortions that result in a dc offset, example, half-wave converters, are not allowed. All power generation equipment is limited to these values of current distortion, regardless of actual *I*sc to *I*L ratio.

Where

*I*sc = maximum short-circuit current at PCC.

*I*L = maximum demand load current (fundamental frequency component) at the PCC under normal load operating conditions.

2.2.4 Filter

Filter is an electrical device, which select a combination of frequencies from group of frequency signal and block all other higher frequencies order in an electrical network. In this research, active power filter is considered as the dynamically and viable solution for harmonic current cancellation and reactive power compensation due to current drawn by non-linear loads. Basically, there are two types of filters, passive and active filter.

A. Topologies of Active power filter

As the solution to harmonics problem in power system, active power filter topologies can be categorized in to three as follows:

B. Shunt or parallel active power filter

Shunt active power filter which also called parallel active power filter, is the most widely spread type of filter used for current harmonics mitigation and compensation of reactive

power drawn by non-linear loads. Shunt active filter gained interest due to its known topology, simplicity in design, non-causes of series or parallel resonances, capable of cancellation of barely all harmonics orders than the traditional passive filter (Salam *et al.*, 2006). Shunt active filter design is achieved based on either voltage source inverter (VSI) or current source inverter (CSI).The voltage source inverter (VSI) is the most widely used filter in cancellation of current harmonics and compensation of reactive power, because of its well known in topology type and simple in installation technique (Salam *et al.*, 2006).

Shunt active power filter mainly consist of power semiconductor switching devices, like IGBTs or MOSFETs, filter inductor to reduce ripple, DC side capacitor which charges and maintain the DC voltage in steady state condition, and also served as energy storage device which supply difference of the real power between the source and load during short fault duration period (Kumar, 2007). Shunt active power filter work on the principle of compensating current, this filter is controlled to draw/supply compensating current from/to power supply utility (PCC), so that the harmonics on the AC current drawn by non-linear loads can be cancelled and give reactive power required by the load side (Sahu and Gadanayak, 2012). As mentioned earlier, these APF topologies can be implemented for both single-phase and three-phase systems. Figure 2.11 shows Voltage Source Inverters (VSI) based shunt active power filters type that is commonly employed for current harmonics suppression due to the generated harmonics by the full bridge rectifier circuit (Singh *et al.*, 2012).

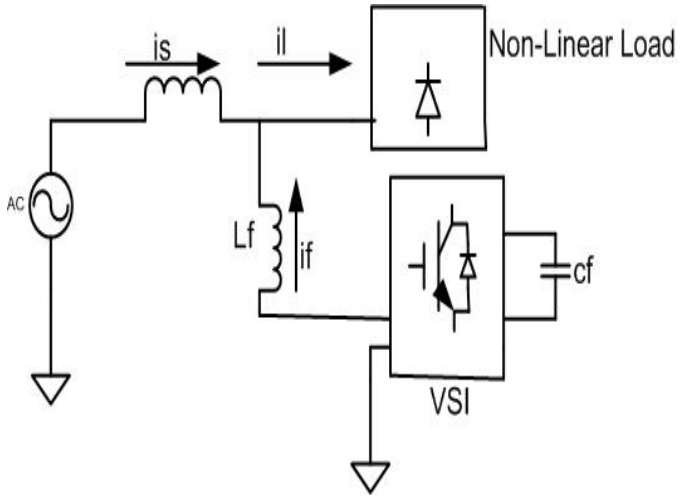


Figure 2.11: General block diagram of SAPF based on VSI (Moran and Joos, 1998).

C. Series Active Power Filter

This type of active power filter, behave like shunt active power filter, the only different with this filter is the coupling transformer as against the shunt active power filter which has a coupling inductor. In this type of compensating device, the current is mitigated due to the non-linear loads by applying a high impedance path with the harmonic current that forces very high frequency currents to flow through the passive LC filter connected in parallel with the non-linear load (Moran and Joos, 1998). Series active power filter work on the principle of harmonic voltage injection (V_f) on the coupling interfacing transformer. These injected harmonic voltages are sum/deducted to/from the main supply voltage in order to obtain a perfectly and purely sinusoidal voltage waveform on the non-linear load (Singh *et al.*, 2012). This type of active power filter handles high current capability than it counterpart SAPF. Barely series active filters are purposely aimed at suppression harmonics voltage drawn by non-linear loads and compensating reactive power. That is why; most of the utilities employed the use of series active power filters for sensitive devices such as protective relays in compensating voltage level profiles of the equipment. With these qualities of SAPF, the quality of supply voltage profile is improved (Salam *et al.*, 2006). Figure 2.12 shows the configuration of series active power filter.

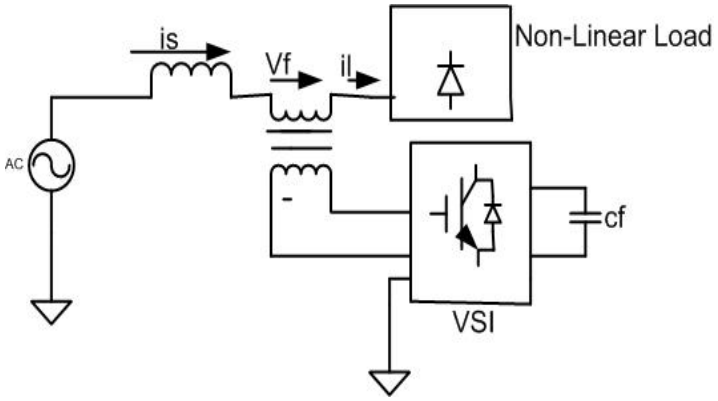


Figure 2.12: General Block diagram of Series APF based on VSI (Singh *et al.*, 2012)

D. Hybrid active Power Filter

Hybrid active power filter is the third among the active filter configurations, it is the combination of shunt and series active power filters. With the emergence of fast semi-conductors switching devices like, IGBTs and MOSFETs which are employed in SAPF for harmonics mitigation, which caused high frequency noise in the mitigated current source which becomes one of the SAPF limitations in compensating current harmonics due to non-linear loads in a system. Moreover, with the introduction of digital controllers, such as digital signal processor (DSPs), also the limitation of this controller becomes a burden in smooth current compensation with active power filters, because of the sampling rate in real time application of the DSP device. With these limitations of the digital controller and the SAPF, the application of hybrid power filter in cancellation of harmonics current and compensation of reactive power drawn by the non-linear loads becomes necessary. Hybrid filter are therefore for mitigating high orders of harmonics than its counterpart SAPF which can cancell lower order harmonics. Different hybrid power filters exist, but the most popular and widely used are, the shunt active power filter plus passive power filter, series active power filter plus shunt passive power filter. Figure 2.13 shows one of such types (Litrian *et al.*, 2009).

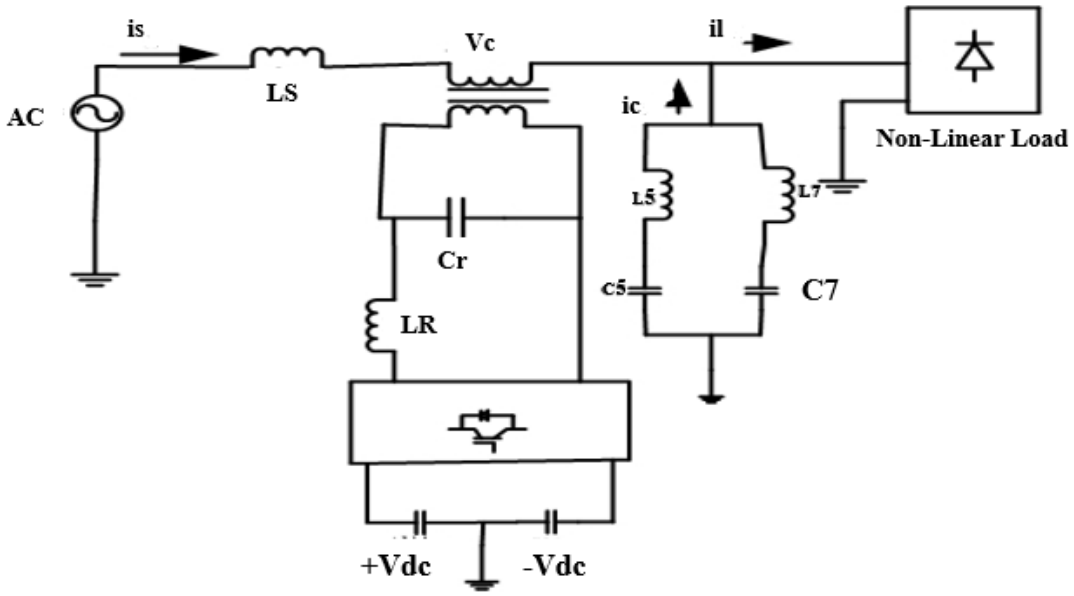


Figure 2.13: Hybrid power filter, combination of series active and shunt active power filters

(Litrian *et al.*, 2009)

E. Control Algorithms for Shunt Active Power Filter

Control algorithms for active power filters play vital roles in generating the gating signal for the semi-conductors switching devices. Various control techniques exist in different literatures; the dynamic performance of active filter is seriously important in selecting the gating signal of the control algorithms. With this, it is so important to select a control algorithm that best suit the dynamic solution to particular harmonics current and reactive power compensation. Active power filter control strategies are: instantaneous reactive power theory (p q), dead beat control, synchronous reference frame, PI controller, fuzzy logic controller, neural network, genetic algorithm and expert system. Due to complexity of frequency or time domain control algorithm by involving complex mathematical modeling, the application of digital controllers is very important in real time hardware implementation of these control algorithms.

F. Active Power Filter Digital Controllers

Here we are, with the advancement in digital controllers' technology, the application control of active power filters has led to another direction. Active power filters have found itself in new trend in its control strategies; by introducing digital signal processors (DSPs), Field programmable Gate arrays (FPGAs) both for hardware implementation of various control algorithms. Some of the controllers that can be implemented with these digital controllers are traditional proportional integral (PI), artificial intelligent family, like Fuzzy logic controller, neural network controller, the famous reactive power theory. (Janpong, *et. al*, 2011)

G. Wiring configurations of Active Power Filters

Basically, there are three modes of wiring configuration of active power filters.

1. One-phase two wire system, for low voltage connections.
2. Three-phase three wire systems, for voltage at medium voltage level with balanced system.
3. Three-phase four wire system with neutral conductor for medium voltage and for mitigatingharmonics current in the neutral conductor.

As it shown in the figure 2.14 where reference current and filter current are determined by application of Khrichoof current law. (KCL)

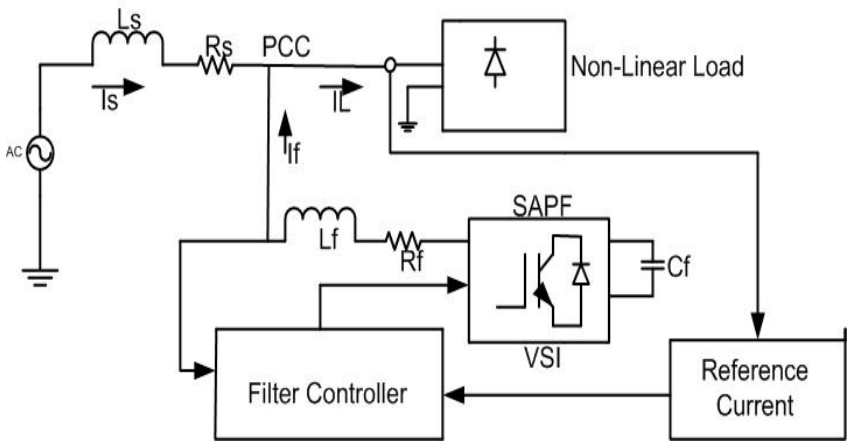


Figure 2.14: Single Phase Shunt APF Configuration for the research work. (Singh *et al.*, 2012)

Applying khrichoof current law (KCL) at the point of common couple (PCC)

$$I_s(t) + i_c(t) - i_l(t) = 0$$

(2.11)

$$I_s(t) = i_l(t) - i_c(t) \quad (2.12)$$

2.2.5. Artificial neural network

Artificial neural network is a family of artificial intelligent**,** is a computing system made up of a number of simple, highly interconnected processing elements, which process information by their dynamic state response to external input. In most cases an ANN is an adaptive system that changes it structure based on the external or internal information that flows through it network (Zilouchian, 2001)

2.2.6 Neural network architecture

The architecture of an artificial neural network defines how it's several neurons are arranged, or placed, in relation to each other. These arrangements are structured essentially by directing the synaptic connections of the neurons. The topology of a given neural network, within a particular architecture, can be defined as the different structural compositions it can assume. In other words, it is possible to have two topologies belonging to the same architecture, where the first topology is composed of 10 neurons, and the second is composed of 20 neurons. Several neural networks architectures are available from simple Boolean networks (perceptrons) to complex self-organized networks (Kohonen networks). Other networks Hopefield networks, puls networks, Radial –Basis function networks, etc (Zilouchian, 2001)

2.2.7. ANN topology

In general, an artificial neural network can be divided into three parts, named layers, which are known as:

(a) Input lay.

This layer is responsible for receiving information (data), signals, features, or measurements from the external environment. That is input layer of source nodes that projects directly onto neurons of output layer (Ziloychain, 2001).

(b) Hidden, intermediate, or invisible layers

These layers are composed of neurons which are responsible for extracting patterns associated with the process or system being analyzed. These layers perform most of the internal processing from a network. (Zilouchain, 2001)

(c) Output layer

This layer is also composed of neurons, and thus is responsible for producing and presenting the final network outputs, which result from the processing performed by the neurons in the previous layers. (Zilouchain, 2001)

The main architectures of artificial neural networks, considering the neuron disposition, as well as how they are interconnected and how its layers are composed, can be divided as follows: (i) single-layer feedforward network,(ii) multilayer feedforward networks, (iii) recurrent networks

1. Single-Layer Feedforward Architecture

This artificial neural network has just one input layer and a single neural layer, which is also the output layer. It has n inputs and m outputs. The information always flows in a single direction which is from the input layer to the output layer. These networks are usually employed inpattern classification and linear filtering problems

2. Multiple-Layer Feedforward Architectures

This type of networks architecture has one or more hidden layer, the intermediate layers receiving data from input and then processes it to the network output. They are employed in the solution of diverse problems, like those related to function approximation, pattern classification, system identification, process control, optimization, robotics (Rezaul, 2004)

3. Recurrent or Feedback Architecture

In these networks, the outputs of the neurons are used as feedback inputs for other neurons. The feedback feature qualifies these networks for dynamic information processing, meaning that they can be employed on time-variant systems, such as time series prediction, system identification and optimization, process control. One of its output signals is fed back to the middle layer. Then, using the feedback process, the networks with this architecture produce current outputs also taking into consideration the previous output values. As shown in the Figure 2.16

Recurrent Neural Network is widely used in controlling or extraction of generated compensation signal, where harmonics are generated from non-linear load current.

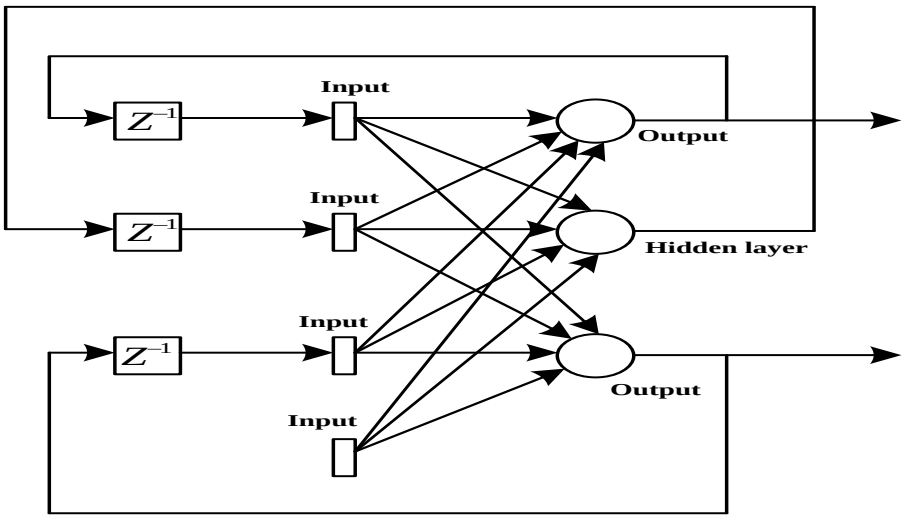


Figure 2.15 Recurrent ANN Structure (Zilouchian, 2001)

The output of each neuron is a function of its inputs. In particular, the output of the ***j***th neuron in any layer is described by two sets of equations:

$$U_j = \sum X_j . W_{ij}$$

(2.13)

$$Y_j = F_{th}\ U_j + t_j \quad (2.14)$$

For every neuron, ***j***, in a layer, each of the ***i*** inputs, $\boldsymbol{X}_i$, to that layer is multiplied by a previously established weight, $\boldsymbol{w}_{ij}$. These are all summed together, resulting in the internal value of this operation, $\boldsymbol{U}_j$. This value is then biased by a previously established threshold value, $\boldsymbol{t}_j$, and sent through an activation function, $\boldsymbol{F}_{\text{th}}$. This activation function is usually the sigmoid function, which has an input to output mapping as shown in Figure 2.15 the resulting output, $\boldsymbol{Y}_j$, is an input to the next layer or it is a response of the neural network if it is the last layer. Neuralyst allows other threshold functions like to be used in place of the sigmoid described here.

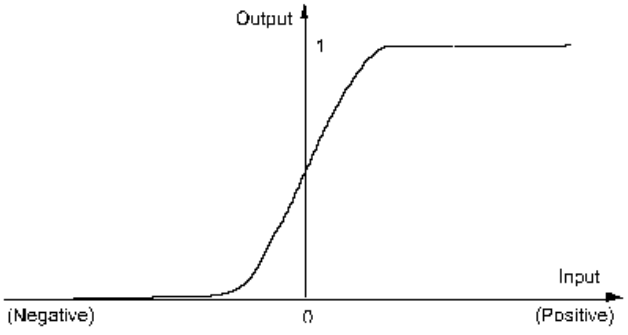


Figure2.16: Sigmoid Function (Bird, 2014)

In essence, Equation 2.13: was used to implement the combination operation of the neuron and Equation 2.14 was used to implement the firing of the neuron.

From equations (2.13) and (2.14) a predetermined set of weights, a predetermined set of threshold values and a description of the network structure (that is the number of layers and the number of neurons in each layer), it is possible to compute the response of the neural network to any set of inputs.

Y= $$\frac{1}{1+e^{-x}}$$

(2.15)

2.3 Review of Similar Works

This part presents a review of similar works related to the present proposed work. Some of the related works are as follows:

Vazquez and Salmeron, (2003) presented a paper active power filter control using neural network technologies. In this work, they proposed pulse width modulation control (PWM) with two blocks that include neural networks. An adaptive network which estimate the reference current and a multilayer perceptron feed forward network that act as a hysteresis band was used in the study. MATLAB- SIMULINK was utilized in the simulation study. Training process was not elaborated.

Garrido and Revuelta (2006) Presented a paper Control of active Power Filter using dynamic neural networks. In their study, a dynamic multilayer perceptron (MLP) neural network has been applied to the control algorithm of shunt active power filter. Simulation was performed using MATLAB environment. Simulation results with this method, shows a good dynamic performance of the ANN control algorithm.Selection of learning rate was not detail.

Janpong *et al.* (2011) presented a paper on Neural Network Application for Shunt Active Power Filters. In this work, a review of ANN to shunt active power filter for suppression of current harmonics distortion was studied. The research article shows the advantages of using ANN to the most three parts of shunt active power filters such as harmonic detection component, compensating current control and DC bus voltage control.

Sarasvathi and Rajalakshmi (2013) Studied the performance analysis of shunt active power filter using different controller were presented. In the proposed study, they used Fuzzy logic

controller and compared the results with PI controller in order to see the differences in the controller's algorithms. Simulations were performed for both Fuzzy and PI controller using MATLAB environment, Simulation results for Fuzzy logic controller was more accurate as compared with PI controller techniques. Both simulation results for the two algorithms are within the tolerable IEEE limit. The research could not elaborate the alpha rate selection.

Fei and Wang (2013) presented a paper Adaptive Neural Sliding Mode Control of Active Power Filter. In this research work, a radial basis function (RBF) neural network adaptive sliding mode control was used. Sliding surface coordinate function and sliding mode controller are also utilized as the input and output of the radial basis function (RBF) neural network. Simulation results of the proposed algorithm shows a serious reduction of current harmonics distortion produced by non-linear load. The Fast Fourier Transform (FFT) analysis of the current harmonics distortion obtained to be 24.71% THD before compensation, while a THD of 2.56% were obtained after applying shunt active power filter. The simulation results after compensation found to be within the IEEE 519-1992 harmonics standard limit.

Aliyu sabo *et al.* (2013) Presented a paper modified Artificial Neural Network (ANN) Algorithm to Control Shunt Active Power Filter (SAPF) for Current Harmonics Reduction.The research work described contamination effect of harmonic on distribution network, adopting a modified mathematical algorithm Delta rule weight-updating with suitable alpha value. The research work was not detailed in selection of alpha and specific network.

Arthy and Marimuthu (2014) Describes "Review of Digital Control schemes for Active Power Filters". In this study, different control algorithms such as p-q theory, Synchronous reference frame (SRF) theory, Synchronous detection method (SDM), Sliding mode controller, Pulse width modulation, Hysteresis current control (HCC) were presented.

However, in the proposed paper, they presented digital control algorithms like Digital signal processor (DSP), Field Programmable Gate Array (FPGA) which are used for implementation of proto type hard ware of shunt active power filter. In another vein, the paper highlights different topologies of shunt active power filter.The paper only described simulation and experimental validations using various digital control algorithms, experimental detail is required.

Venkata *et al.* (2014) Presented a paper on design of Shunt Active Power Filter for Implementation of Power Quality with Artificial Intelligence Techniques. In the work, shunt active power filter controlled with traditional PI controller was compared with Artificial neural network (ANN) based PI and particle swarm optimization (PSO) based PI controller was highlighted in the study. However, a new method of hysteresis band current controller (HBCC) was utilized for the generation of the gating signal of the voltage source inverter (VSI) circuit. Simulation results of the particle swarm optimization (PSO) has proven to be a viable and dynamic solution for current harmonics compensation produced by non-linear load as compared with (ANN) and PI controllers. Simulation results of the three controllers are all within the IEEE standard limit, but PSO method found to be more accurate than the other two control algorithms.

Sathish and Joshi (2015) Presented a paper Artificial Neural Network Controlled Shunt Active Power Filter for Power Quality Improvement. In this research work, the authors compared PI controller with ANN algorithms in order to see the performances of the two controllers. Simulation was performed with MATLAB because of its simplest and easy implementation of simulation process. Simulation results of the two controllers' shows that ANN is more viable solution in mitigating current harmonics produced by non-linear load. Moreover, the THD% obtained with ANN was found to be 1.77% as compared to that of PI controller which amounted to be 2.12% THD. These simulation results of the two proposed

algorithms are all within the harmonics standard limit.Incomprehensive back propagation algorithm.

Dey and Mekhilef (2015) Presented a paper on the technical review of shunt active power filter for mitigating current harmonics distortion produced by non-linear loads. The presenters show choices and implementation of the current regulator which was more important for acquiring a desired satisfactory performance level. The proposed work also gave room for the researchers to select a proper control method for various applications of active power filter. The paper however, highlighted different compensation techniques such as: Hysteresis – band current control, sliding mode control, negative sequence current component control, dead beat control, predictive control, space vector modulators, Delta Modulation Control (DMC), Triangle-comparison (TCPWM) control, Repetitive control, one-cycle control, soft computing algorithms, fuzzy control, artificial neural network, genetic algorithm, particle swarm optimization and wavelet theory. But this work did not give details of artificial neural network algorithm.

(Victor & Alberto,) (2015) Presented a paper entitled improved injection current controller in single phase shunt active power filters. They used new method using digital predictive algorithm which satisfied the current harmonics compensation of load due to nonlinear loads. Simulation and experimental validations of the proposed control algorithm was also presented in the work. Both simulation and experimental results were within the IEEE 519-1992 harmonics standard limit. The research work lacks the harmonic detection technique.

2.4 Summary of Research gap

So far from the research journals and papers consulted they could not elaborate the learning rate selection which is more of concern and pratical implementation of ANN is not well developed to targed the research works with a network that generates harmonics to justify the

harmonic distortion. The wider range of selection of alpha bridge the research gap between the various research group.

CHAPTER THREE

MATERIALS AND METHOD

3.1 Introduction

This section described the step by step approach involve in the simulation and modeling to archive the set objectives as stated in section 1.4

3.2 Methodology

The following describe the step by step approach involved in the simulation model for the research work.

1. To model the line parameters of non-linear load of VFD module at kiln unit using MATLAB/SIMULINK software environment.
2. To Model and simulate single phase shunt active power filter
3. FFT analysis to the determined system load characteristic
4. Modeling of Artificial Neural Network algorithm with MATLAB Comparison of the simulation results with the imposed IEEE-519-2014 Harmonics standard limits.

3.3 Data collection

1. The line parameters of nonlinear load of variable frequency drive were meseaured using digital multimeter at kiln unit.
2. Modeling of nonlinear load at kiln unit. using Matlab tools software GUI
3. Performing Fast Fourier analysis to determine the state of harmonics distortion in the VFD feeder.

3.4 Artificial Neural Network (ANN)

Artificial neural network controller (ANN) is one of the current control techniques to detect and compensate harmonic current, and equipped with adaptive and self-organization capacity

for nonlinear load modeling and can monitor the non-linear relationship based on input and output without the detail mathematical model. Normally ANN control can be classified into feed forward neural networks, feedback neural network, local approximation neural networks and fuzzy neural network based on structure.

3.5 Mathematical Modeling of ANN

The GUI was developed for modeling artificial neural intelligent (ANN) Algorithm for harmonics extraction. The flowchart in the Figure 3.1 show the implementation of the method used to developed the algorithms for weight readjustment to obtained a satisfactory result that comply with IEEE Standard for harmonic mitigation.

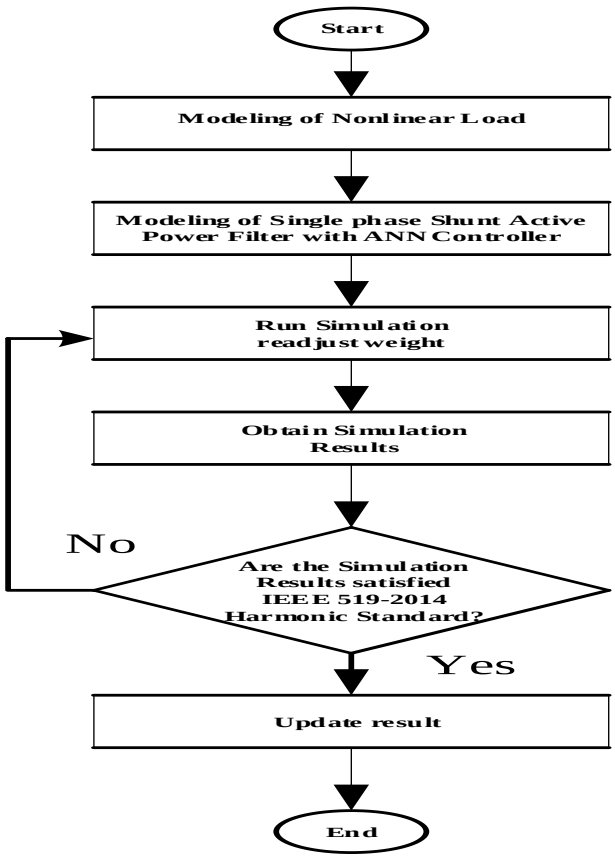


Figure 3.1: A modified flow chart of single phase shunt active power filter using RANN.

3.2 Line Parameters for the development of Non-Linear Load

The simulation of the complete non-linear load at the kiln VFD without shunt active power filter was developed using full bridge diode rectifier which fed parallel RC load of values 500-μF and 150Ω respectively. The non-linear load with the rectifier is the components that resulted in non-linearity of the load current due to the point of common coupling (PCC). Table 3.1. Gives the parameter values for the development of the non-linear load. Figure 3.2 depicts the simulation diagram.

Table 3.1 Simulation parameters for the development of non-linear load

Parameter	**Value**
Voltage source	240V
Capacitor	500μF
Resistor	150Ω
Frequency	50Hz
Line resistor	120Ω

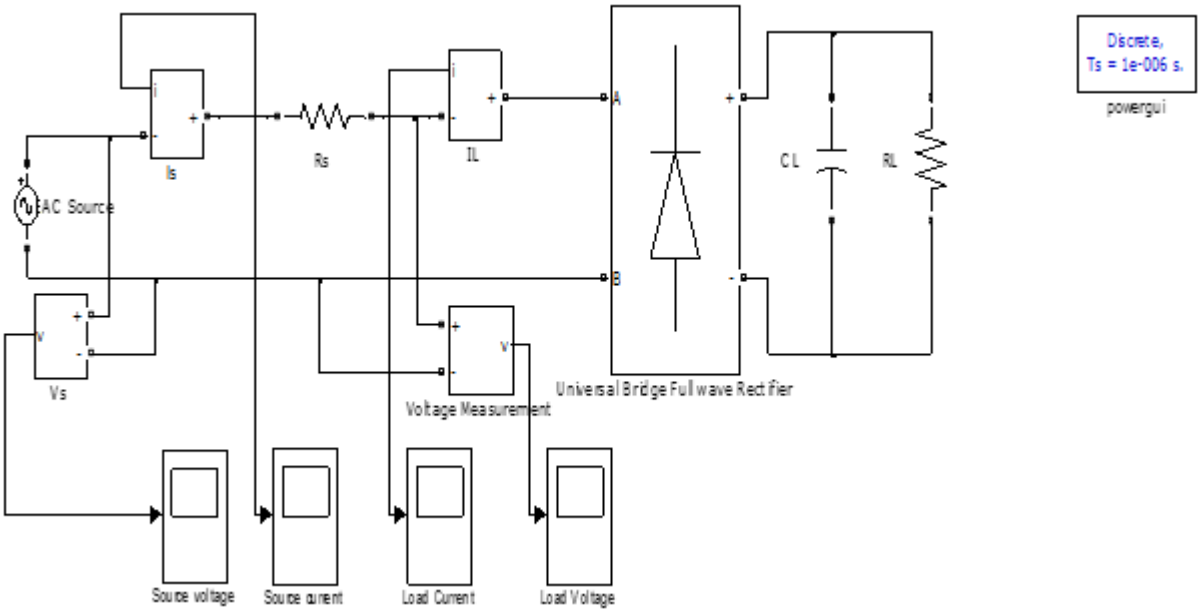


Figure 3.2: Complete Simulation Model of the Non-Linear Load without Filter

i Performing Fast Fourier analysis

References to Figure 2.10, the following characteristics are noted:

(i) The mean value is zero since the area above the θ axis is equal to the area below it. Thus the constant term, or d.c component, $a_0 = 0$.

(ii) Since the wave form is symmetrical about the origin the function I is odd, which means that there are no cosine terms present in the Fourier series.

(iii) The waveform is of the form as in equation 3.1 which means that only odd harmonics are present.

$$f(\theta) = -f(\theta + \pi) \qquad (3.1)$$

Investigating wave form characteristics has thus saved unnecessary calculations and in this case the Fourier series has only odd sine terms present in equation

$$i = b_1 \sin\theta + b_3 \sin 3\theta + b_5 \sin 5\theta + b_7 \sin 7\theta + \ldots + b_{(2n-1)} \sin(2n-1)\theta \qquad (3.2)$$

The expression, without the 'sine terms' columns and without the 'even sine' columns is shown in table 3.2 Up to and including, the fifth harmonic from which the Fourier

coefficients b_1, $b_3$and b_5 can be determined. Twelve coordinates are chosen and labeled as y_1, y_2, y_3, y_4…..y_{12} as shown in table 3.2

Table 3.2: Fourier series Analytical table

Ordinate	θ^0	i	$\sin\theta$	$i\sin\theta$	$\sin 3\theta$	$i\sin 3\theta$	$\sin 5\theta$	$i\sin 5\theta$
y_1	30^0	2	0.5	1	1	2	0.5	1
y_2	60^0	7	0.866	6.06	0	0	-0.866	-6.06
y_3	90^0	10	1	10	-1	-10	1	10
y_4	120^0	7	0.866	6.06	0	0	-0.866	-6.06
y_5	150^0	2	0.5	1	1	2	0.5	1
y_6	180^0	0	0	0	0	0		0
y_7	210^0	-2	-0.5	1	-1	2	-0.5	1
y_8	240^0	-7	-0.866	6.06	0	0	0.866	-6.06
y_9	270^0	-10	-1	10	1	-10	-1	10
y_{10}	300^0	-7	-0.866	6.06	0	0	0.866	-6.06
y_{11}	330^0	-2	-0.5	1	-1	2	-0.5	1
y_{12}	360^0	0	0	0	0	0	0	0

This calculation analytically justified the level of distortion caused by nonlinear load of the VFD injected into the network before the application of filter.

$\sum_{k=1}^{12} i_k \sin\theta_k$ = 1+6.06+10+6.06+1+0+1+6.06+10+6.60+1+0=48.24

$\sum_{k=1}^{12} i_k \sin 3\theta_k$ =2+0+-10+0+2+0+2+0-10+0+2+0=-12

$\sum_{k=1}^{12} i_k \sin 5\theta_k$ =1-6.06+10-6.06+1+0+1-6.06+10-6.06+10+0=-0.24

Where:

$b_n \approx \frac{2}{p}\sum_{k=1}^{p} y_k \sin nx_k$ or $bn \approx \frac{2}{p}\sum_{k=1}^{p} i_k \sin n\theta_k$ Where P=12 hence

$b_1 \approx \frac{2}{12}(48.24) = 8.04$ $b_3 \approx \frac{2}{12}(-12) = -2.00$ And $b_5 \approx \frac{2}{12}(-0.24) = -0.04$

Thus the Fourier series for current **i** is given by:

$i = 8.04\sin\theta - 2.00\sin 3\theta - 0.04\sin 5\theta$

$$THDI = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + I_5^2 + I_6^2 + ... + I_n^2}}{I}$$

Since it is only an odd harmonic then this becomes:

$$THDI = \frac{\sqrt{I_3^2 + I_5^2 + I_7^2 + I_9^2 + I_{11}^2}}{I_1}$$

$$THD_I = \frac{\sqrt{(10)^2 + (2)^2 + (-2)^2 + (-10)^2 + (-2)^2}}{31}$$

$$THD_I = \frac{\sqrt{212}}{31} \times 100 = 47.7\%$$

In ANN algorithm, the sum of the sine and cosine with coefficient attached to each component to present any periodic signals are used. K is the sampling in its digital operation with sampling time Δt and its fundamental frequency ω the non-linear load current iL is always represented by a fundamental component and a harmonic component as given in equations

$$i_L\ k\ = \sum_{n=1,2,3,\ldots}^{N} \left[w_{1n} \sin\ nk\omega\Delta t\ + w_{2n} \cos\ nk\omega\Delta t\ \right]$$

$$= w_{11} \sin\ k\omega\Delta\ + w_{21} \cos\ k\omega\Delta t\ + \sum_{n=2,3,\ldots..}^{N} \left[w_{1n} \sin\ nk\omega\Delta t\ \right] + w_{2n} \cos\ nk\omega\Delta t$$

(3.3)

Where w_{1n} and w_{2n} are the amplitudes of the sine and cosine parts of the measured non-linear load current and n is the order of harmonic, to N maximum order if required. In vector form:

$$\bar{i}_L\ k\ = \bar{w}^{T} \bar{X}\ k$$

(3.4)

And weight matrix is given by the equation below

$$w^{-t} = w_{11} w_{21} \ldots.. w_{1N} w_{2N} \qquad (3.5)$$

Sine and cosine can be evaluated as

$$\bar{X}\ k = \begin{bmatrix} \sin\ k\omega\Delta t \\ \cos\ k\omega\Delta t \\ . \\ . \\ . \\ \sin\ Nk\omega\Delta t \\ \cos\ Nk\omega\Delta t \end{bmatrix}$$

(3.6)

The ANN algorithm is used to train $\bar{w}^{T}$ to generate the right value of $i_L\ k$ predicted in Figure 3.3 The main brain of this research algorithm –extraction circuit is the weights updating algorithm. In this research, recurrent ANN was used for its ability to extract fundamental harmonic from distorted harmonics.

Between the actual measured signal iL (K) and the estimated signal i_{est} (K) which is given as:

$$\bar{w}\ k+1 = \bar{w}\ k + \frac{e\ k}{X\ k\ \bar{X}^{T}\ k}\bar{X}\ k \qquad (3.7)$$

Here, $e\ k = i_L\ k - i_{est}\ k$ and $\bar{X}^{T}\ k\ \bar{X}\ k$ is the square of the vector $\bar{X}\ k$ the proposed ANN algorithm's modified version.

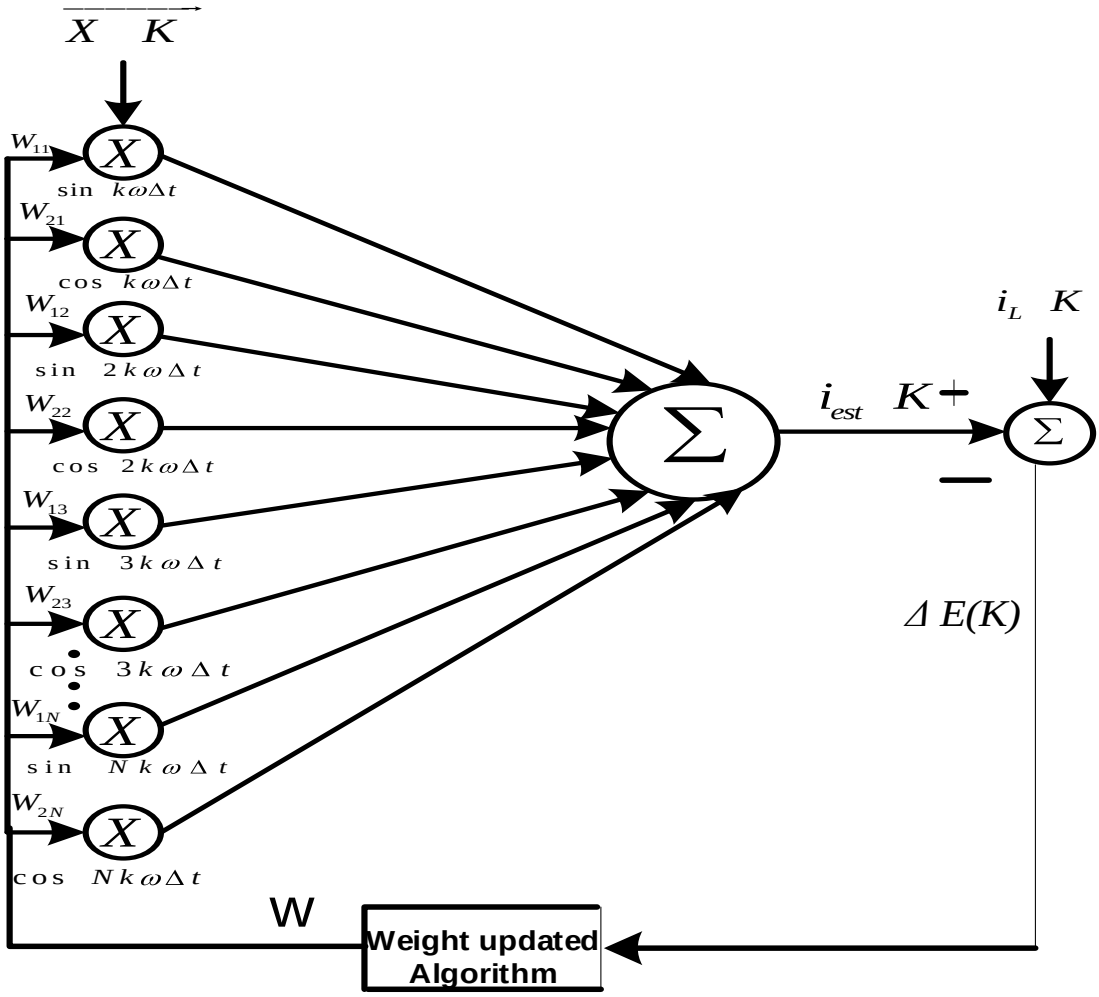


Figure.3.3 ANN Harmonics Extraction (Sabo *et al.*, 2013)

Moreover, the measure of the weight matrix $\bar{w}^{T}$ is always updated according to the number of harmonic orders N with a simplified algorithm expressed as (Tey *et al.*, 2005)

$$\bar{w}\ k+1\ = \bar{w}\ k\ + \frac{\alpha e\ k\ \bar{Y}\ k}{\bar{Y}\ k\ \bar{Y}\ k} \qquad (3.8)$$

$$\bar{w} = \ w_{11} w_{21}\ \ \bar{Y} = \begin{bmatrix} \sin\ k\omega\Delta t \\ \cos\ k\omega\Delta t \end{bmatrix}$$

(3.9)

α Is the Learning rate of the algorithm.

To determine a suitable learning rate must be explored for optimal operation of the modified ANN algorithm. Equation (3.8), the square of the vector $\bar{Y}\ k$ is 1, as it contains only the fundamental component. However, the learning rate is to be less than $\frac{1}{N}$ in order to ensure an optimum algorithm's performance. A suitable learning rate helps the algorithm to have an optimal fundamental part of the load current from both the sine and cosine parts that helps in acquiring the compensation signal. The harmonic current i_H (k) can also be found from the load current using equation 3.10

$$i_H(k) = i_L(k) - \omega_{11}\sin(k\omega\Delta t) \qquad (3.10)$$

3.4 Developing the ANN Model

The ANN model was developed using data collected from line parameter of the VED at the Kiln unit of Dangote cement plant. Model involves the following steps: creating, configuring, training and testing of the ANN model using Neural Net Graphical User Interface (GUI) in matlab.

i. Creating the ANN

The input data and target data were imported from matlab workspace and used in the Neural Network/Data manager (nntool) as depicted in Figure 3.4

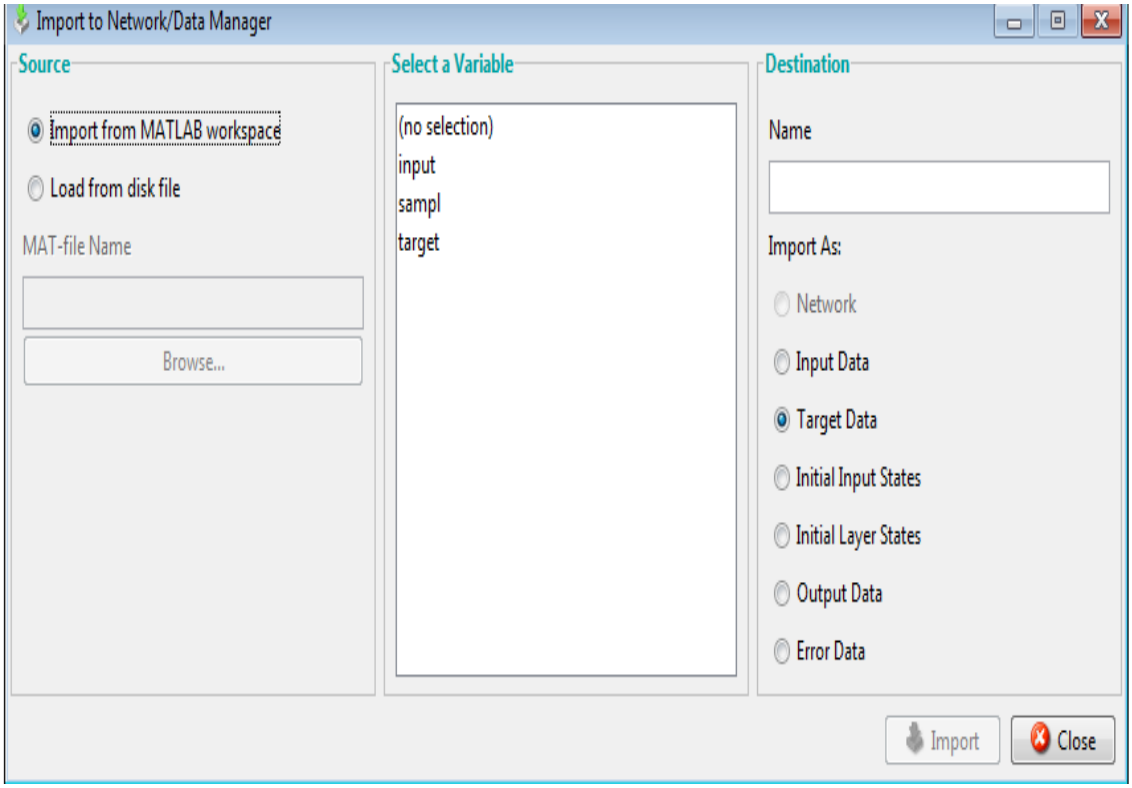


Figure 3.4 Neural Network/Data Manager Interface

The network was created as shown in Figure 3.5 by entering the harmonic parameters under the “network name” and set the “network type” to recurrent layers using “traingdm” (training algorithm with gradient decent momentum) for training function, “learningdm” (learning algorithm with gradient decent momentum) for adaptation learning function.

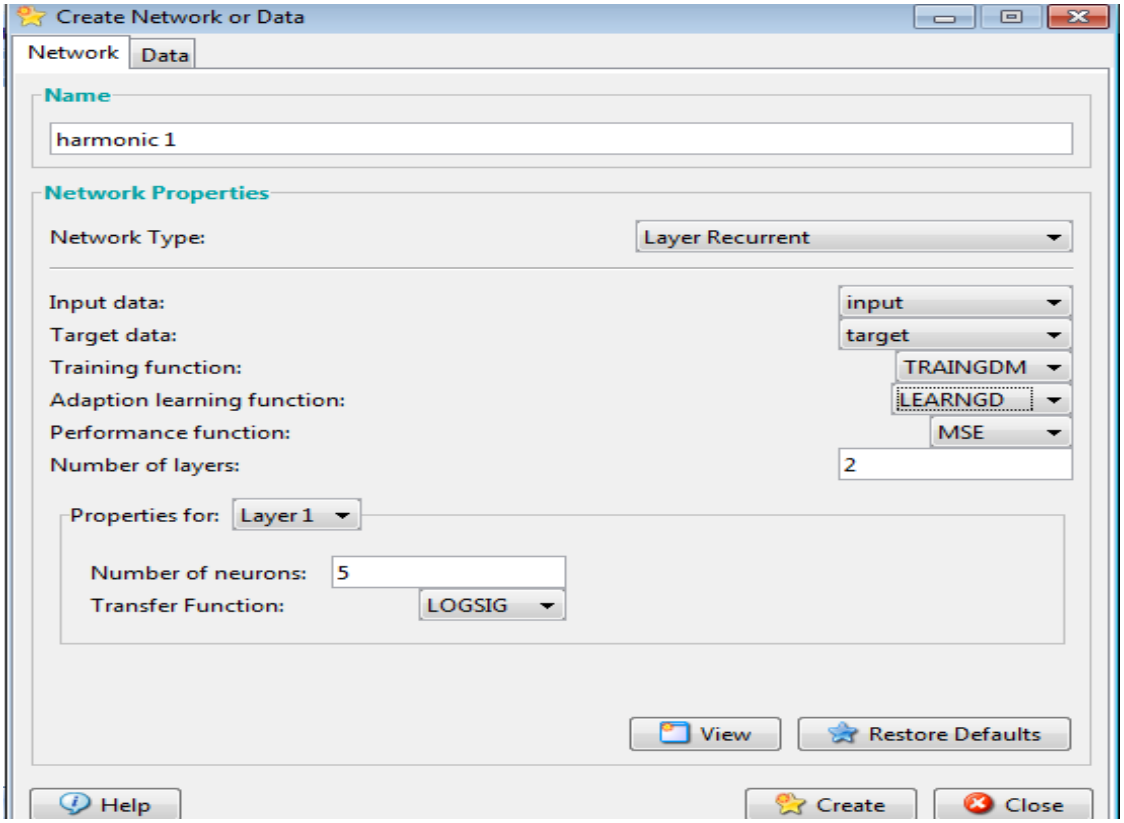


Figure 3.5 Network Creation

ii. Neural Network Training

The neural network training tool shown in Figure 3.6 represents the completed training process for the ANN. It depicts the various sections of ANN simulation process i.e. neural network system algorithms progress and plots. Neural network system comprises of various blocks showing input output and hidden layers.

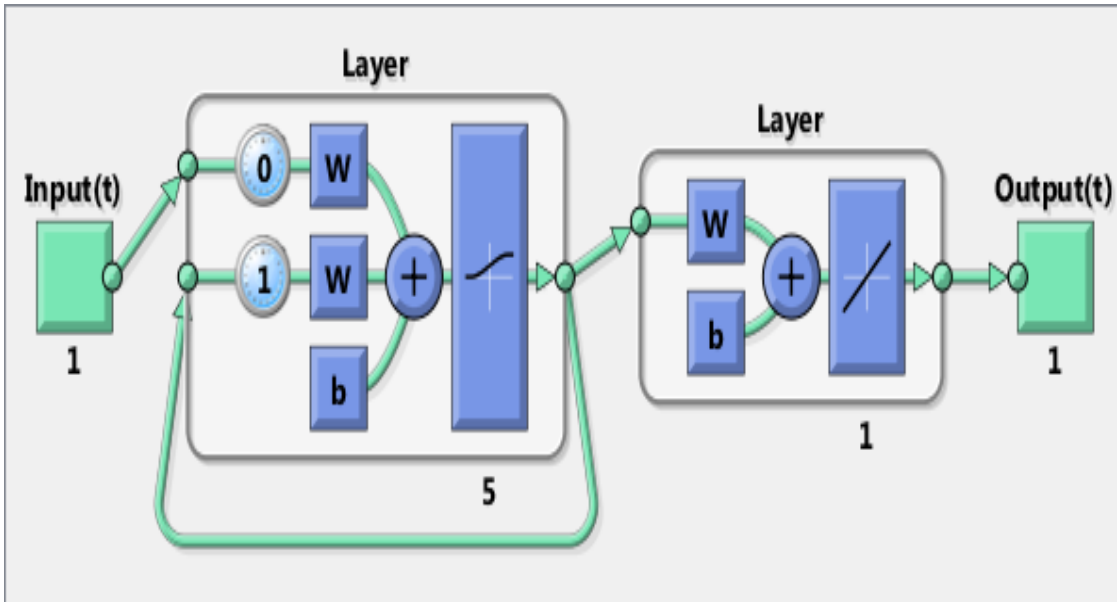


Figure 3.6 Development of Recurrent ANN Structure.

3.4 Mathematical Modeling of ANN

The figure 3.7 show the mathematical model of reference current and estimated current are determined by the algorithm using matlab Simulink library with modeling equation. (3.7)

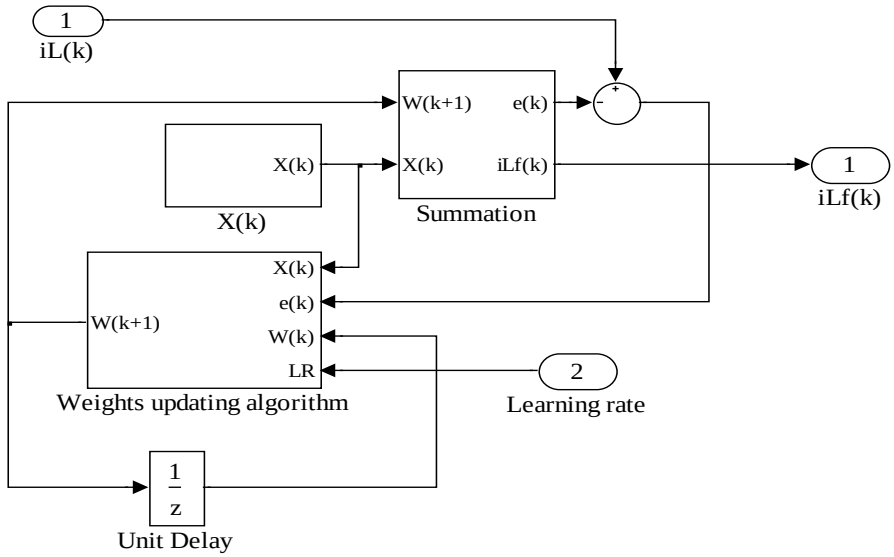


Figure 3.7 Development of Complete SIMULINK Model of ANN Algorithm

The complete mathematical model of the (ANN) control algorithm. The uses of RNN has increased the control speed and reliability by the parallel computing architecture.

Modeling equation

$$e\ k\ = i_L\ k\ - i_{est}\ k\ \ (3.7)$$

Matlab model equation for harmonic detection technic is shown in figure 3.8 for the proper selection of alpha, this determined the accuracy and stability of the network learning speed.

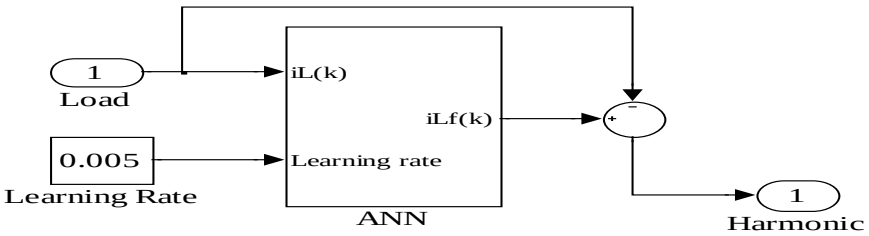


Figure 3.8 Development of Artificial Neural Network (ANN) Harmonic Detection Technique.

The Artificial Neural Network (ANN) harmonic detection technique (modified ANN technique, which provides the main controller of the shunt active power filter for suppression of current harmonics produced by non-linear loads.

$$\bar{w}\ k+1\ = \bar{w}\ k\ + \frac{\alpha e\ k\ \bar{Y}\ k}{\bar{Y}\ k\ \bar{Y}\ k} \ (3.8)$$

Figure 3.9 represent the weight updating algorithms model for the transferfunction, using Simulink library.

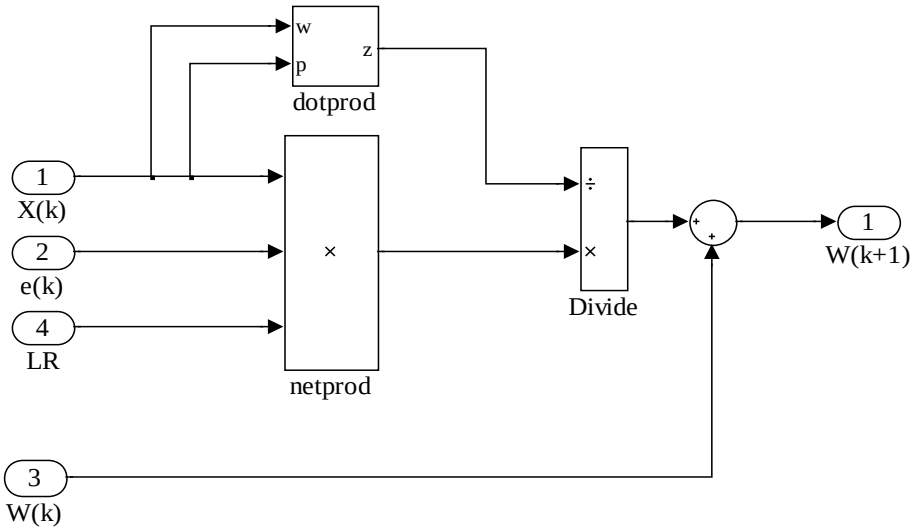


Figure 3.9 SIMULINK Model of the Weights-updating Algorithm.

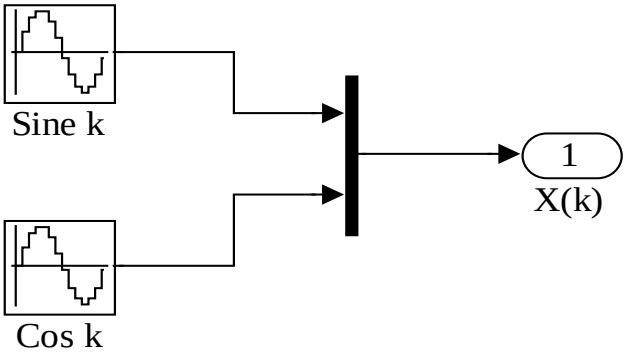


Figure 3.10 Sine and Cosine Vectors.

Figure.3.10 Depicts the sine and cosine multiplication vectors. As modeling equation in

$$i_H(k) = i_l(k) - w_{11}\sin(kw\Delta t) \tag{3.9}$$

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

In this section, the modeling and simulation of the non-linear load without filter and with the single phase shunt active power filter using MATLAB/SIMULINK software is presented. A SimPower systems block set was also used in developing the power electronic circuits. The overall system setup parameters in the simulation model Figure 4.1 shows the complete simulation model of the shunt active power filter controlled with Artificial Neural Network (ANN) for mitigation of current harmonics distortion due to non linear loads, a details block from library browser in the SIMULINK environment were modeled in the MATLAB environment as depicted in Figure 4.1.

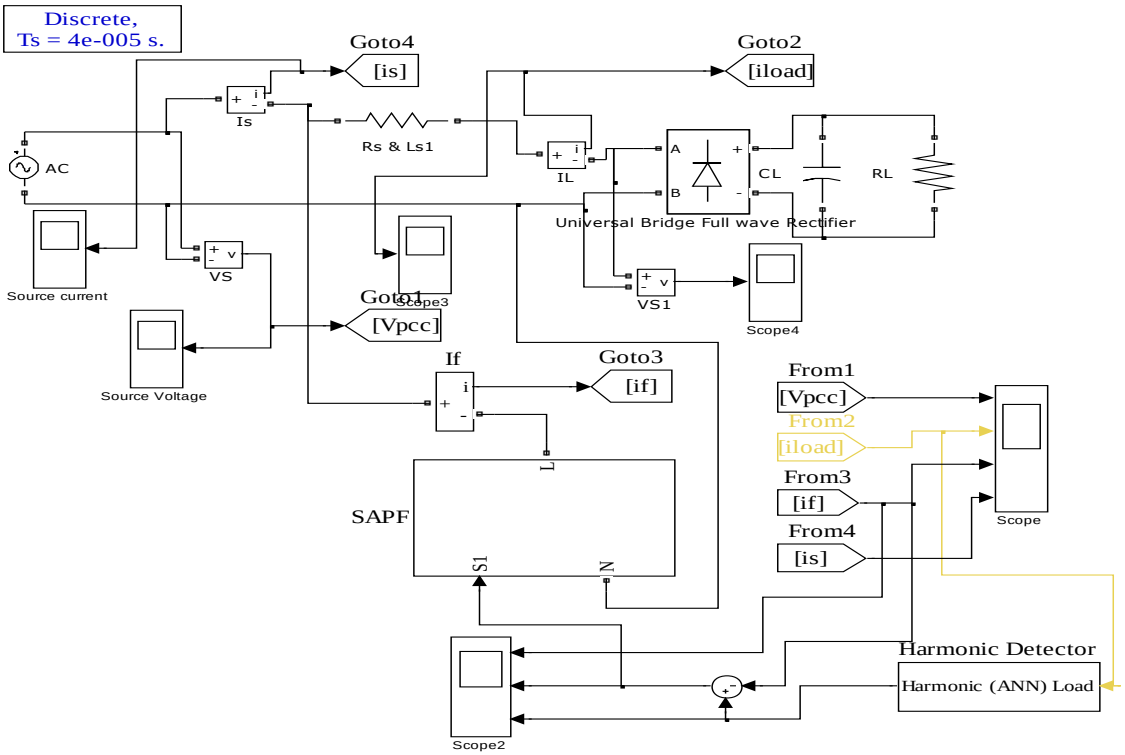


Figure 4.1: Development of Complete Simulation Model of the Shunt Active Power Filter.

4.2 Simulation of the Complete Model of Shunt Active Power Filter

Figure 4.2 shows the Development of IGBT voltage source inverter (VSI) simulation model for the control of the shunt active power filter, the configuration involved four numbers of IGBTs for the switching of the gating signal using pulse width modulation (PWM) SIMULINK block. PWM was also employed in producing switching Patten for the filter circuit. Current harmonic produced by non-linear load were observed and reduced by the application of the shunt active power filter.

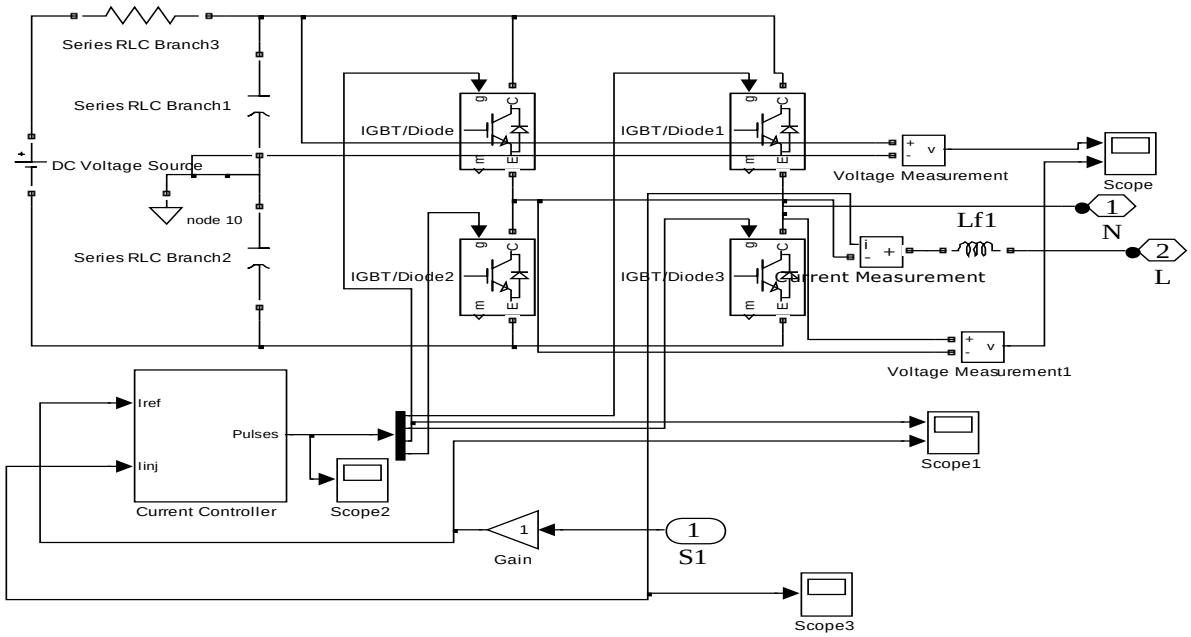


Figure 4.2: Shunt Active Power Filter Simulation Model.

A graphical user interface (GUI) was used to configure solver using discrete variable step in order to ensure the simulation's digital operation. Sampling time of 4μS was set for the solver configuration. The simulation model was run to produce related voltage and current waveforms for both without and with shunt active power filter. However, Fast Fourier Transform (FFT) analysis was displayed in order to view the harmonics order of the simulation results.

4.3 Simulation Results

In this part, the results of the modeling and simulation of the single-phase shunt active power filter controlled by Artificial Neural Network (ANN) is presented by the MATLAB/ SIMULINK blocks set tool box. IEEE 519-2014 was used to validate the simulation results and to show the effectiveness, and good performance of the control algorithm in mitigating the harmonic currents drawn by nonlinear loads.

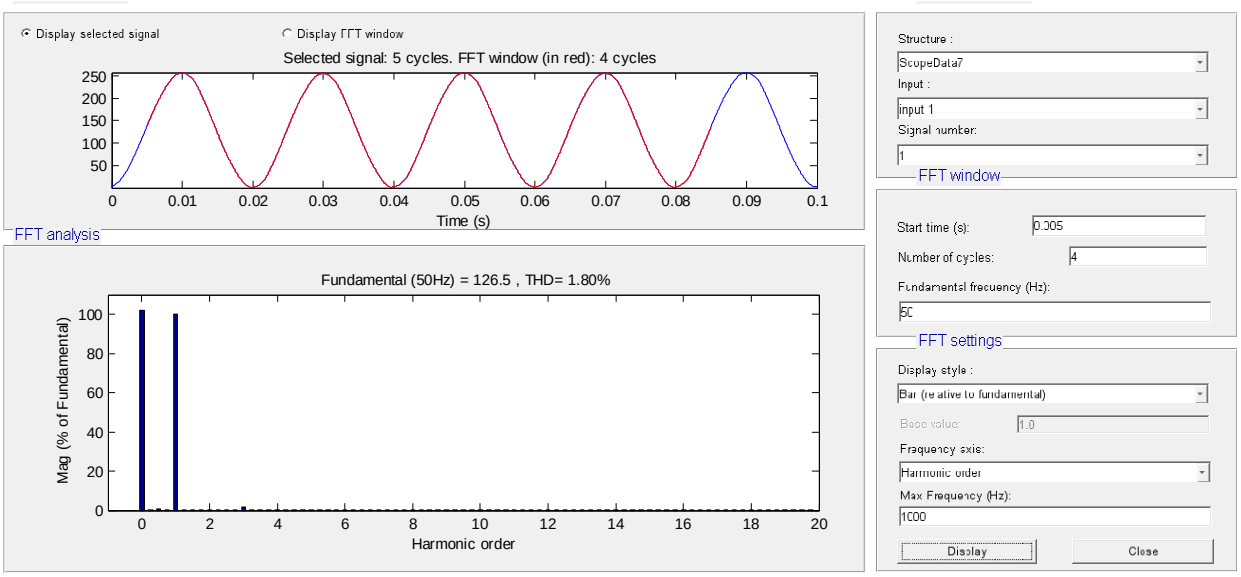


Figure 4.3: Source Current Fast Fourier Transform (FFT) Analysis with Shunt Active Power Filter. The FFT analysis of the source current after connecting shunt active power filter. The result of the THD% of Figure 4.3 shows 1.80% with shunt active power filter, this means that, the results obeyed the IEE 519-2014 harmonic standard limit.

The figure bellow shows the Aliyu *et al.*, (2013) result significantly compered the result obtained by a modified recurrent ANN performed better than Aliyu *et al.*, (2013) at alpha selection of 0.004 and THD is 3.91%.

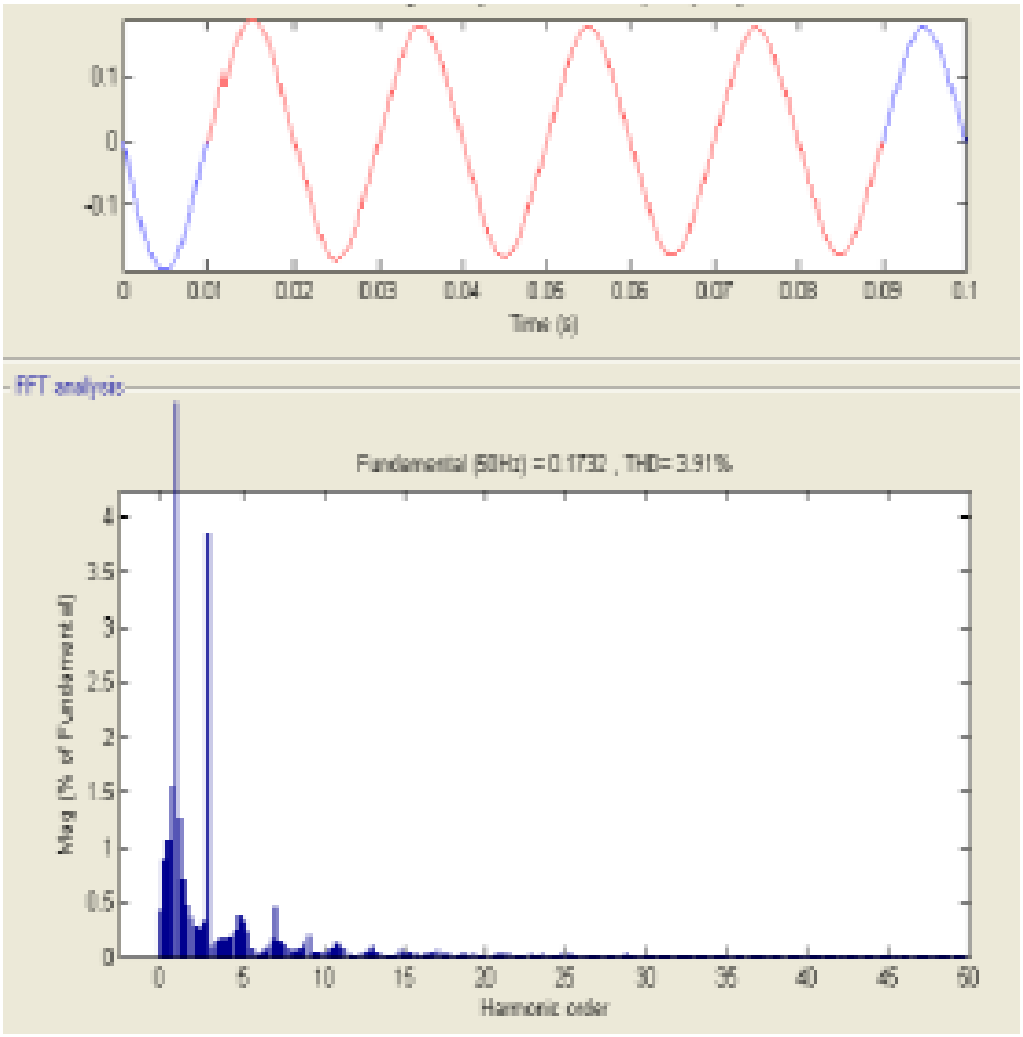


Figure 4.4: FFT spectrum of the load current after Compensation

4.4 Discussion of Results

This section discussed the simulation results for both linear load and the linear load with shunt active power filter.

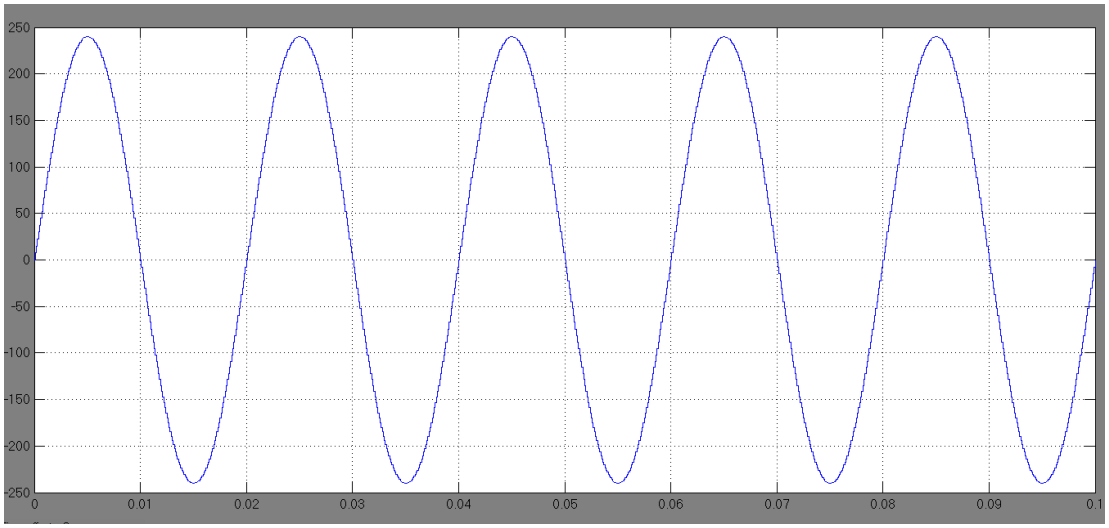


Figure 4.5: Source voltage wave based on non-linear load model.

This shows that the source voltage remains constant (i.e. No distortion) which looks purely sinusoidal in nature.

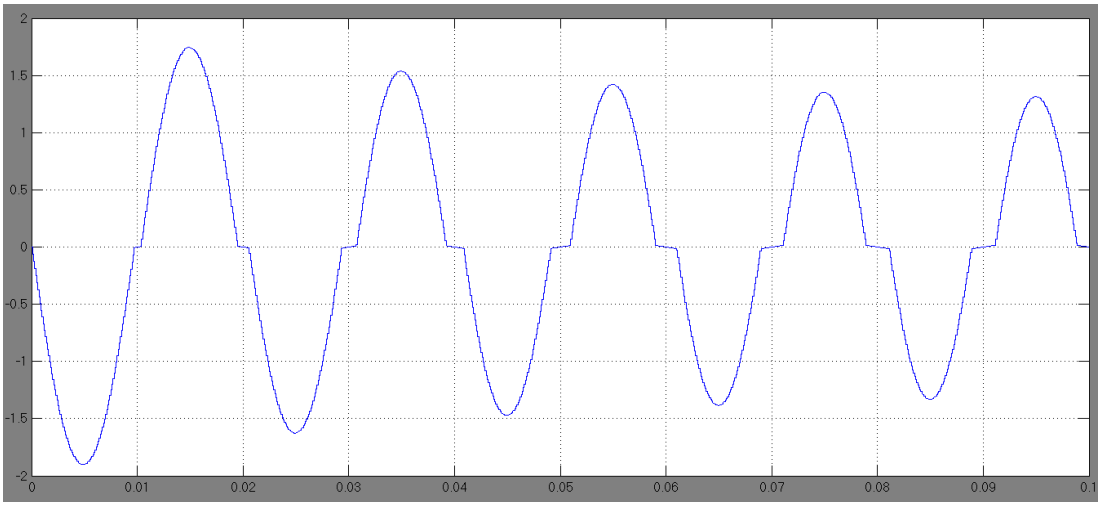


Figure 4.6: Simulated waveforms for the Source Current without Shunt Active Power Filter.

Figure 4.6 shows the simulated current wave form which is in anti phase with the source voltage because of the non linear load rectifier circuit.

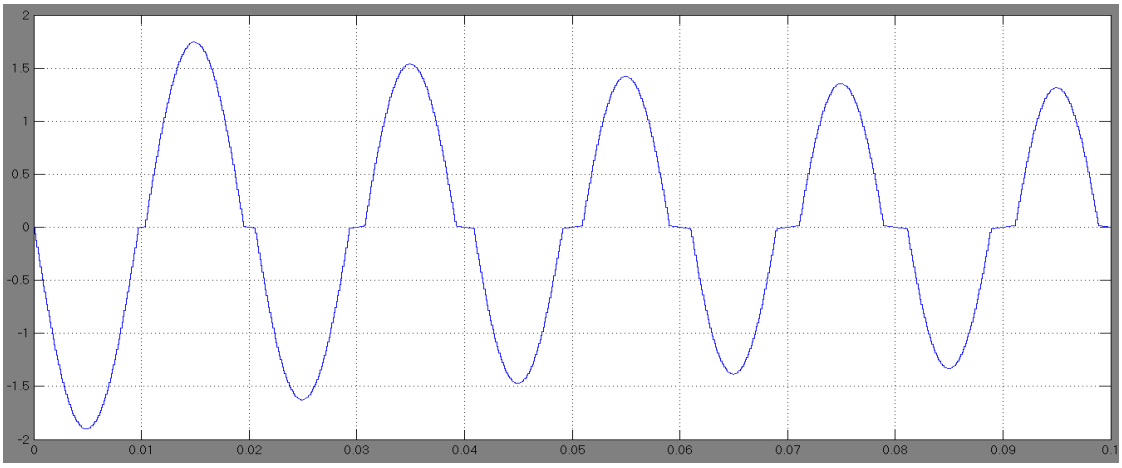


Figure 4.7: Simulated waveforms for the Load Current without Shunt Active Power Filter

However, Figure 4.7 shows the load current due to the non-linear load, this mean that, both source current and load current are in phase to each other, this is because of the harmonics drawn by non linear load.

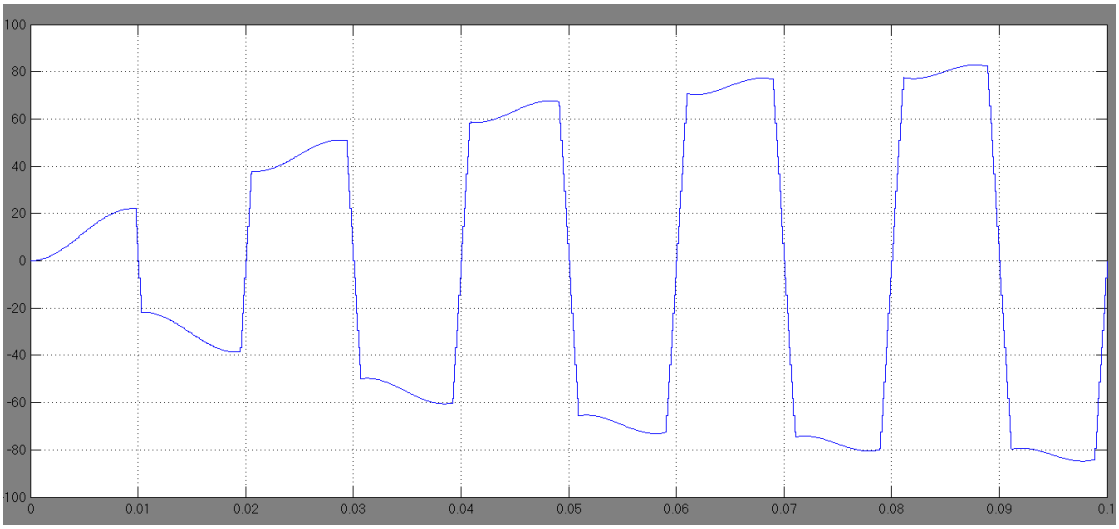
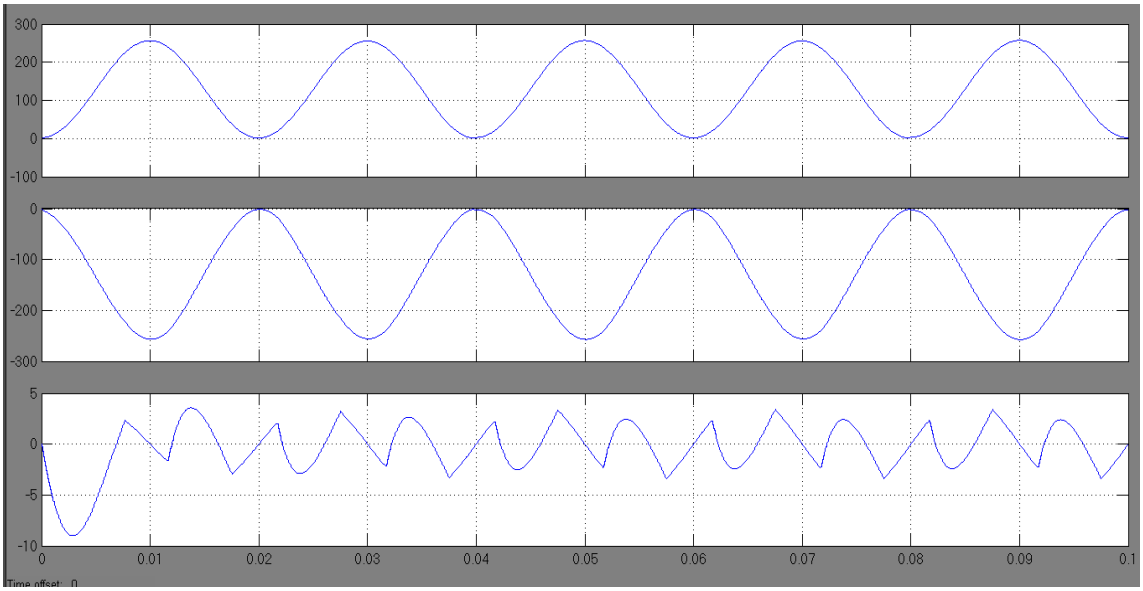


Figure 4.8: Simulated waveforms for the Load Voltage without shunt Active Power Filter.

Figure 4.8: depicts the simulated waveform of the load voltage due to the non-linear load model.



Figures 4.9: Top; Source Voltage, Middle: Source Current and Bottom: Filter Current.

Figure 4.9 shows the simulated results of the source voltage, source current and filter current respectively. It can be deduced that source voltage and source current are now in phase to each other as a result of the shunt active power filter compensation.

The figure 4.10 compared the filter current of Aliyu Sabo et al. Before application of filter.

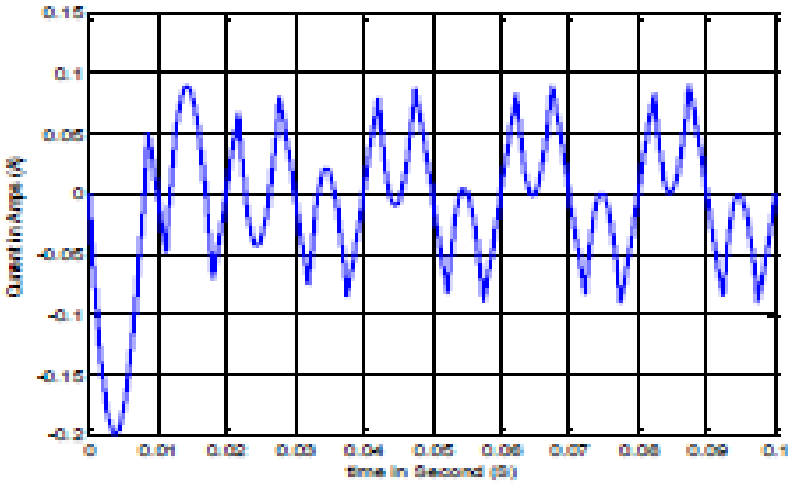


Figure 4.10 Filter current

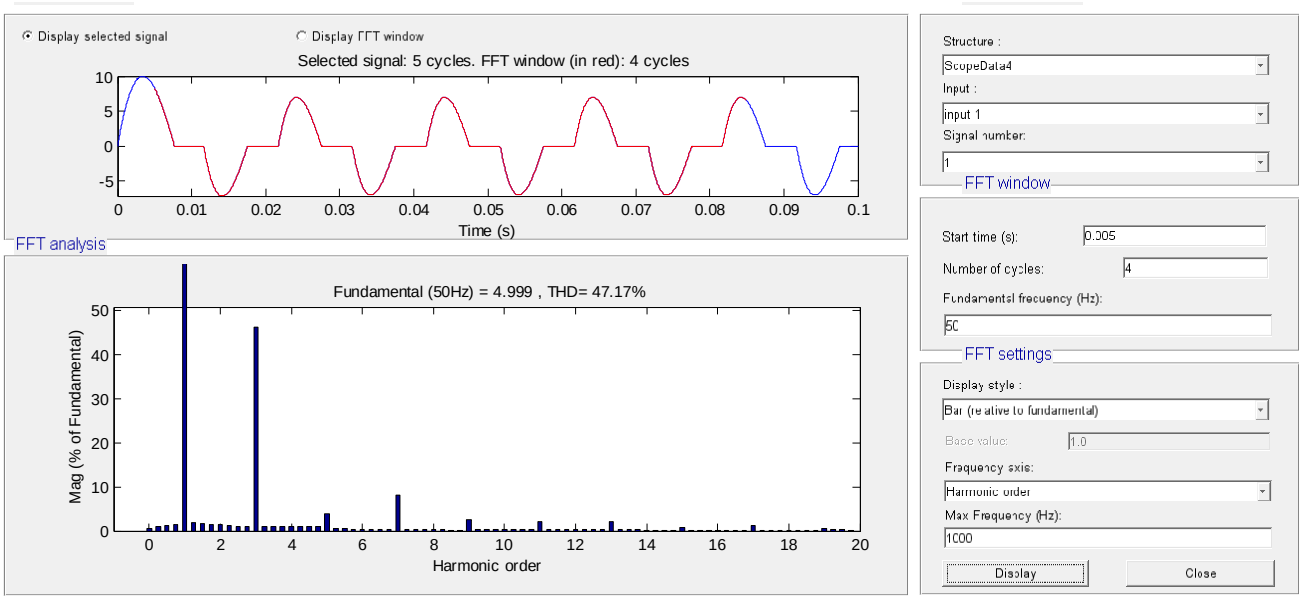


Figure 4.11: Load Current Fast Fourier Transform (FFT) Analysis with Shunt Active Power Filter.

In the same vein, Figure 4.11 depicts the Fast Fourier Transform analysis (FFT) of the load current without shunt active power filter. From the FFT result it shows that the Total harmonic distortion percentage (THD %) read 47.17% which violated the IEEE 519-2014 harmonic standard limit; this is due to the current harmonics drawn by non-linear load.

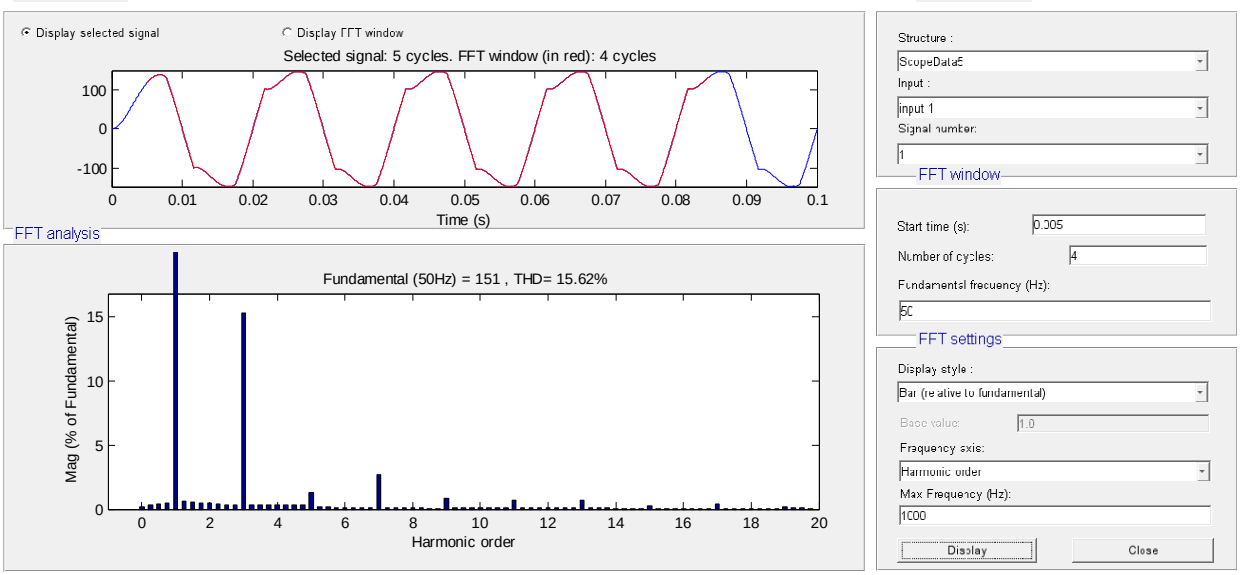


Figure 4.12: Load Voltage Fast Fourier Transform (FFT) Analysis with Shunt Active Power Filter.

Figure 4.12 shows the FFT analysis of the load voltage which also seems to disobey the harmonic standard norms. The THD% obtained by the analysis found to be 15.62%.

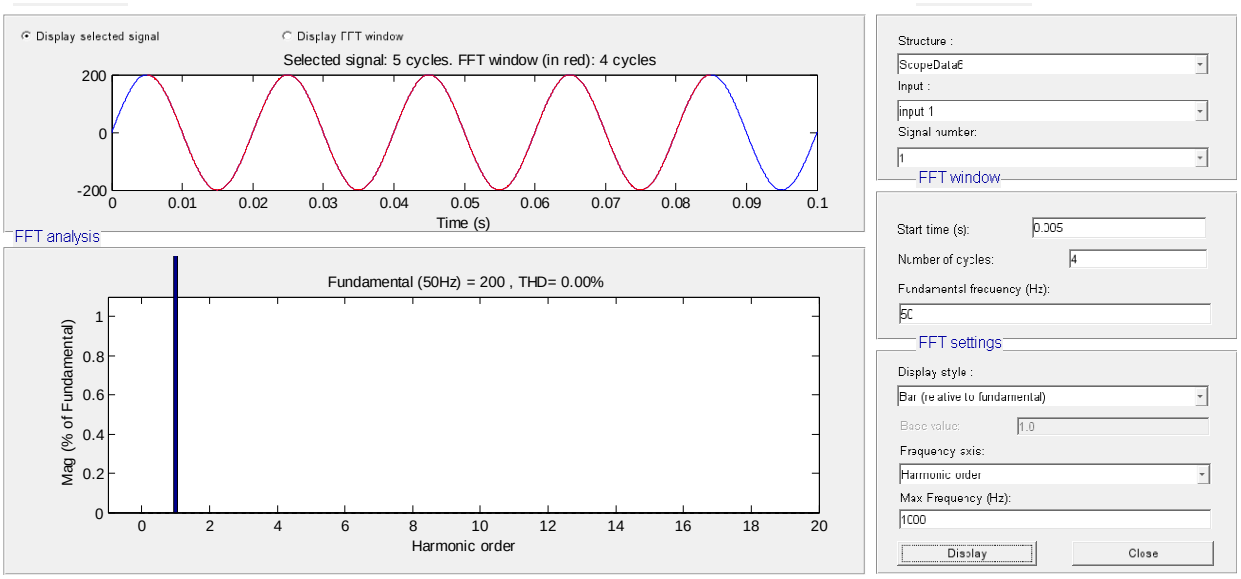


Figure 4.13: Source Voltage Fast Fourier Transform (FFT) Analysis with Shunt Active Power Filter.

Figure 4.13 indicates a THD% of 0% for the source voltage and that is how it supposed to be. (i.e No harmonics contents), this result of the source voltage shows that the source voltage without and with shunt active power filter are the same.

CHARPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Summary

The problems of power quality for both utility and consumers that militates the quality of power supply system as well as the viable solution in mitigating these problems are discussed in this dissertation work. Power quality problem is simply the deviation in voltage, current or frequency wave forms that caused consumers equipment to malfunction or failed within the supply system. In this research work, the modeling and simulation of single phase shunt active power filter controlled by Artificial Neural Network (ANN) in MATLAB/SIMULINK environment, for mitigating current harmonics produced by nonlinear loads is presented.

Simulation of shunt active power filter was conducted and was successfully simulated according to IEEE 519-2014 harmonics standard. A modified ANN was to perform the control algorithm of the shunt active power filter.

5.2 Conclusion

A modified ANN was designed in order to detect the harmonics components and PWM was also employed in producing switching Patten for the filter circuit. Current harmonic produced by non-linear load were observed and reduced by the application of the shunt active power filter. The result of the THD% due to non-linear load alone was found to be 47.17% without shunt active power filter. However, the THD% obtained with shunt active power filter found to be 1.80%, which satisfied the IEEE 519-2014 harmonics standard limit.

Moreover, through extensive work done in simulation work, for single phase shunt active power filter which proved to be a viable solution for mitigating current harmonics distortion produced by non-linear load was found to be very effective and for its ability to force supply current to be sinusoidal, that have low current harmonics and be in phase with source voltage.

5.3 Significant Contributions

The development of single phase shunt active power filter using Artificial Neural Network (ANN) controller to reduce harmonic distortions and to increase power factor was achieved.

The significant novelties of this research work are as follows:

1. Achieved a reduction of total harmonic distortion (THD) for kiln unit of Dangote Cement Plant from 47.17% to 1.8%
2. Obtained a wider range of selection of learning range from 0.001 to 0.009 as compaered to the work of Sabo et al whose rang is between 0.01 to 0.99.

5.4 Recommendations

The following are suggested and recommended for further future work as:

1. Further works, possible with the existing design are topology upgrade and control algorithms improvement of this dissertation work can be implemented.
2. Proto type of this simulation model can be implemented using digital controllers, such as Digital Signal Processor (DSP) or Field Programmable Gate array (FPGA) controllers in order to improve the controller capability.
3. Further simulation work can be done with other classical or modern controllers in order to see the flexibility of the shunt active power filter.

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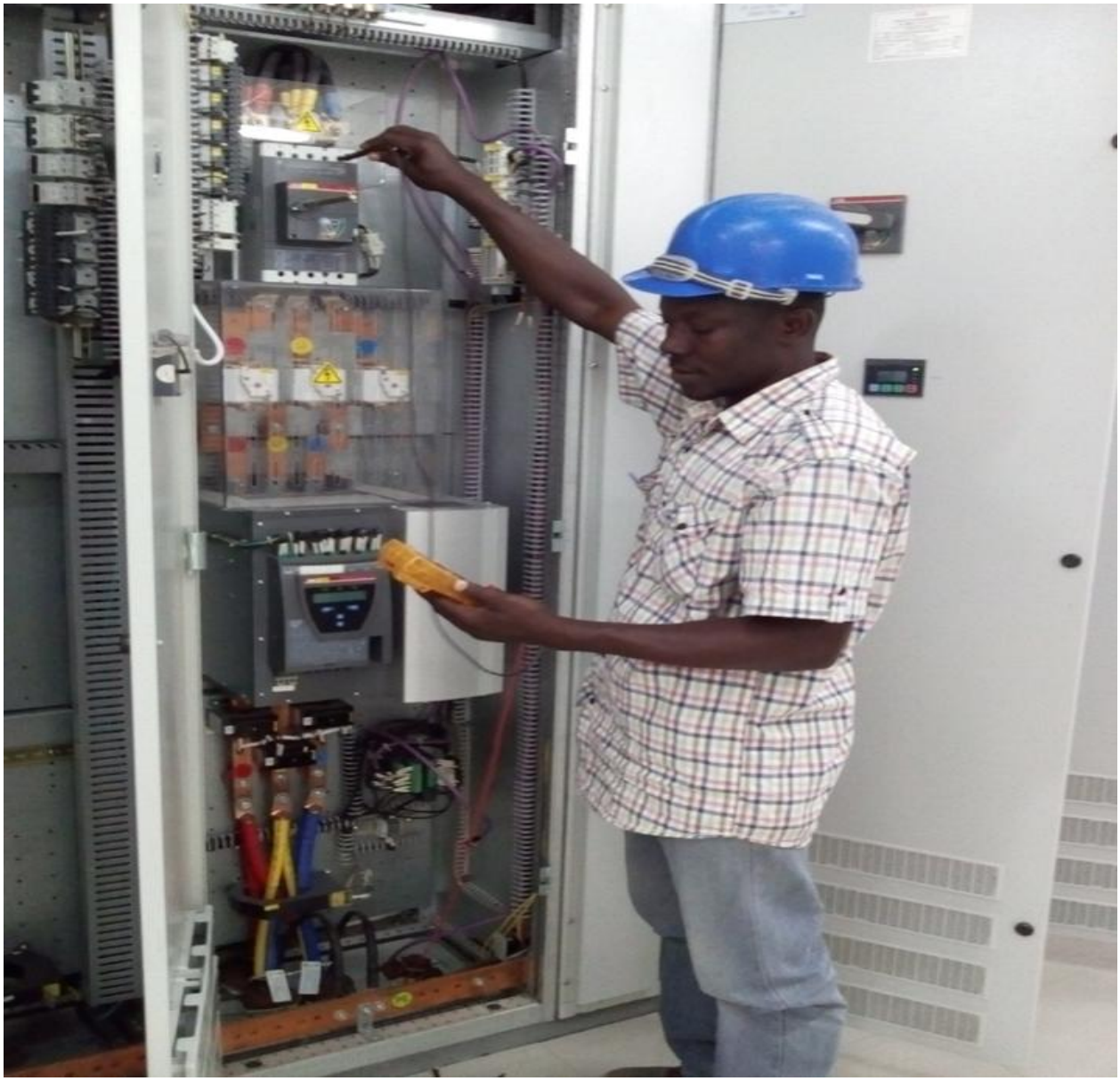
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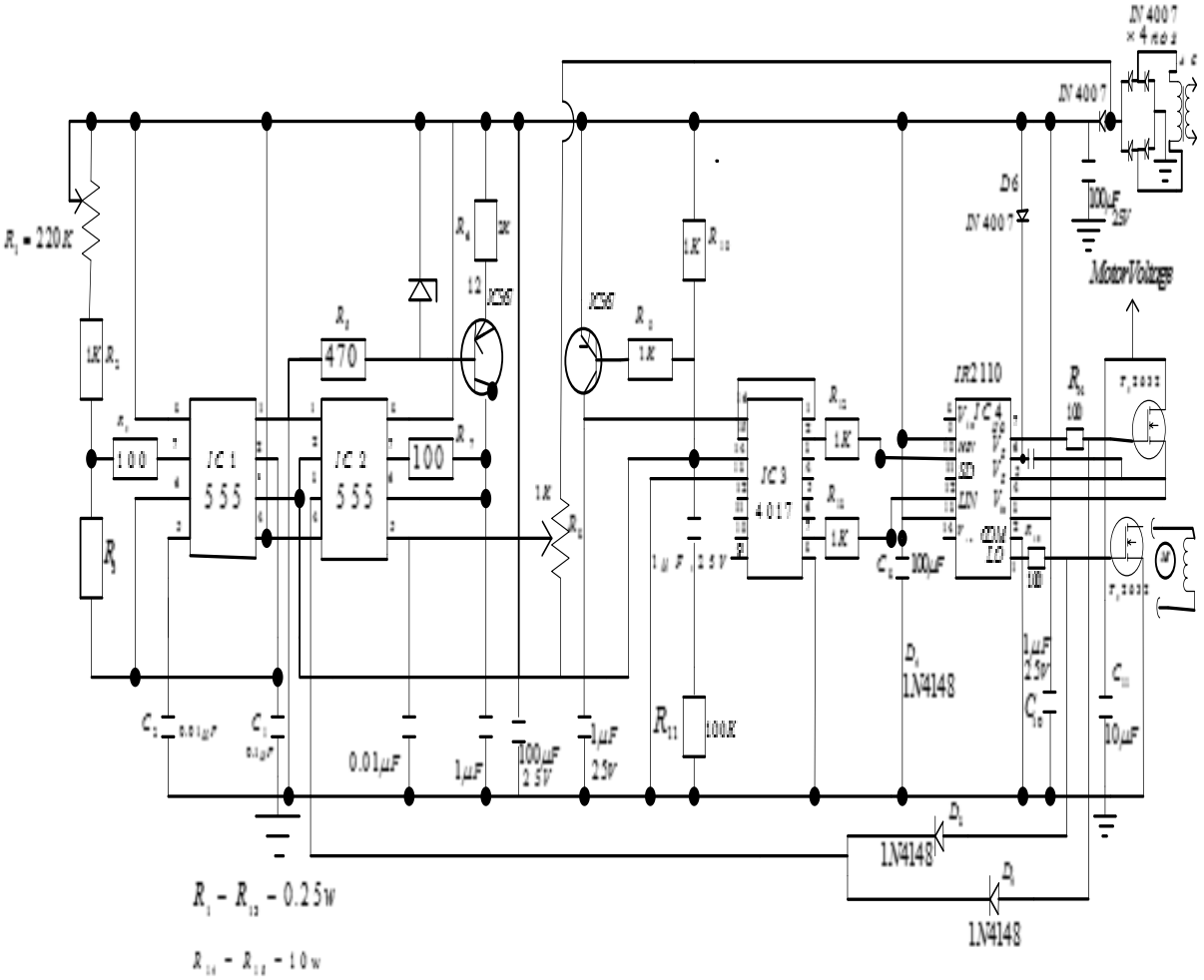
Appendix A

Measurement of the Line Parameters



APPENDIX B

Single phase VFD Electronic Circuit Diagram



APPENDIX C

Unidirectional Motor Starter with Frequency converter

Obajana cement Plant Line3

