DEVELOPMENT OF A TOOL TO DESIGN AC HARMONIC FILTER FOR HVDC TRANSMISSION SYSTEM

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A thesis submitted in fulfillment of the

requirement for the award of the degree of

Bachelor of Electrical Engineering

Faculty of Electrical and Electronic Engineering

University Malaysia Pahang

NOVEMBER 2010

UNIVERSITI MALAYSIA PAHANG

BORANG PENGESAHAN STATUS TESIS♦

DEVELOPMENT OF TOOL TO DESIGN AC HARMONIC FILTER FOR HVDC TRANSMISSION SYSTEM

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I declare that this thesis entitled *"Development of a Tool to Design AC Harmonic Filter for HVDC Transmission System"* is the results of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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To my mother and father

For your infinite and unfading love, sacrifice, patience, encouragement and

Best wishes

ACKNOWLEDGEMENT

All praises and thanks be to God who has guided us to this.

Words cannot express my gratitude towards my supervisor, one of the best lecturer UMP Mohd Redzuan Bin Ahmad for suggesting the problem and for providing guidance and assistance during the entire period of this project withpatience, humble supervision and fatherly advice received from him in the course of his project.

Also I would like to heartily thank lecturers Nurul Wahidah, Faradila and Fairuz Rizal for being helping hands during my laboratory sessions and of course to the rest of the staff, academic and non-academic wise.

ABSTRACT

The conversion of power from AC to DC and from DC to AC constitutes the central process of High Voltage Direct Current (HVDC) transmission. Therefore, it is important to real world to understand the principles, which harmonic filters are needed on the HVDC converter station to absorb the harmonics current generated by the HVDC converter. Hence, decrease the impact of the harmonic on the connected AC systems such as AC voltage distortion and telephone interference. Moreover, compensate the demand of the converter station from supply reactive power. The objective of this work is to develop a tool for AC harmonics filter design. This work will implement the technique of designing an AC harmonic filter connected to HVDC converter bus. MATLAB software is used as a simulation tools for this project. This technique capable to perform reliable analysis of studies with fulfilling the filter parameter desired.

ABSTRAK

Pernukaran kuasa dari arus ulang alik ke arus terus dan dari arus terus ke ulang alik merupakan pusat penghantaran proses bagi arus terus voltan tinggi. Oleh kerana itu, adalah penting untuk memahami prinsip-prinsip yang diperlukan oleh penapis harmonik pada stesen penukar arus terus voltan tinggi untuk menyerap arus harmonik yang dihasilkan oleh penukar arus terus voltan tinggi. Seterusnya, mengurangkan kesan harmonik pada sistem arus ulang alik seperti gangguan voltan arus ulang alik dan gangguan telefon. Selain itu, ianya juga dapat mengimbangi permintaan kuasa reaktif pada stesen penukar. Tujuan kajian ini adalah untuk membangunkan sesuatu kaedah untuk merekacipta penapis harmonik arus ulang alik. Kerja ini akan menerapkan teknik merancang sebuah arus ulang alik penapis harmonik terhubung ke bas penukar arus terus voltan tinggi. Perisian MATLAB digunakan sebagai alat simulasi untuk projek ini. Teknik ini mampu melakukan kajian mengenai pelbagai jenis analisa kepekaan untuk memenuhi parameter penapis yang dikehendaki.

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LIST OF SYSMBOLS

Ia   -   Line Current

I1   -   Fundamental current

Id   -   Direct current

Ir   -   Current through resistor

IL   -   Current through inductor

Ic   -   Current through capacitor

Ih   -   Harmonic current

If   -   Current through filter

Is   -   Current through system

| Ir | -   Absolute value of current through resistor

Irms   -   RMS current

IT   -   Harmonic current factor

(IL)h   -   Inductor current at harmonic loading

Vs	-	Voltage supply
VL	-	Line voltage
V1	-	Fundamental voltage
Vh	-	Harmonic voltage
VLh	-	Worst harmonic voltage
Vc	-	Voltage across capacitor
VL	-	Voltage across inductor
Vr	-	Voltage across capacitor
Z	-	Impedance
ZS	-	System impedance
Zf	-	Filter impedance
Zt	-	Total impedance
Zst	-	Single tuned filter impedance
Zhp	-	High-Pass filter impedance
Ys	-	System admittance

Yf	-	Filter admittance
Yt	-	Total admittance
Yst	-	Single tuned filter admittance
Yhp	-	High-Pass filter admittance
Zf5	-	The 5th filter impedance
Zf7	-	The 7th filter impedance
Zf11	-	The 11th filter impedance
Zf13	-	The 13th filter impedance
Zhp	-	The high pass filter impedance
Yf5	-	The 5th filter admittance
Yf7		The 7th filter admittance
Yf11	-	The 11th filter admittance
Yf13	-	The 13th filter admittance
Yhp	-	The high pass filter admittance
YFA3	-	The total filter admittance of the 3th harmonic

YFS3   -   The system filter admittance of the 3th harmonic

YT3   -   The network filter admittance

V3   -   The 3th harmonic voltage

I1   -   The fundamental frequency current

I3   -   The 3th harmonic current

CHAPTER 1

INTRODUCTION

1.1   Project Background

Electrical power is generated as an alternating current (AC). It is also transmitted and distributed as AC and, apart from certain and industrial drives and processes, it is consumed as AC. Nowadays, it is economically and technically advantageous to introduce direct current (DC) links into the electrical supply system. In such situation, it may be the only possible method for the power transmission. When two AC systems cannot be synchronized or when the distance by land or cable is too long for stable or economic AC transmission, DC transmission is used. At one converter station the AC is converted to DC, which is then transmitted to a second converter station, converted back to AC, and fed into another electrical network. In back-to-back HVDC schemes the two converter station are bought under the same roof, reducing the DC transmission length to zero.

HVDC transmission application fall into four broad categories and try scheme usually involved a combination of two or more of these. The categories are;

i)   Transmission of bulk power where AC would be uneconomical, impracticable or subject to environment restrictions.

ii) Interconnection between systems which operate at different frequencies, or between non-synchronized or isolated systems which, although they have the same nominal frequency, cannot be operated reliably in synchronism.

iii) Addition of power in feed without significantly increasing the short circuit level of the receiving AC system.

iv) Improvement of AC system performance by the fast and accurate control of HVDC power.

The AC harmonic filter reduces the amplitude of one or more fixed frequency harmonic currents and voltages. Generally consists of one or more L-C tuned circuits. R-L-C circuits constitute a special type of damped harmonic filters. These filters, in additional to filtering the harmonic currents or voltages, can also reduce either overshoot or rate of rise of a transient current or voltage.

By definition, a filter F is a function of

$$F = f [Zs , Xt , Ih , Cf , P , Qt] \qquad [1]$$

Where

Zs = system impedance

St = converter transformer reactance

Ih = harmonic current at harmonic h

Cf = filter capacitor

Qt = total reactive power demanded of converter

P = active power transmitted by converter

AC harmonic filter design is an integral and important part of HVDC converter station design. The AC filter constitutes about 15% [3] of the total cost of the converter station. The AC harmonic filter at an HVDC converter station Figure 1 shown as the designed to control the converter generated level of AC harmonic which are injected into the AC system, in addition to providing reactive power for the converter
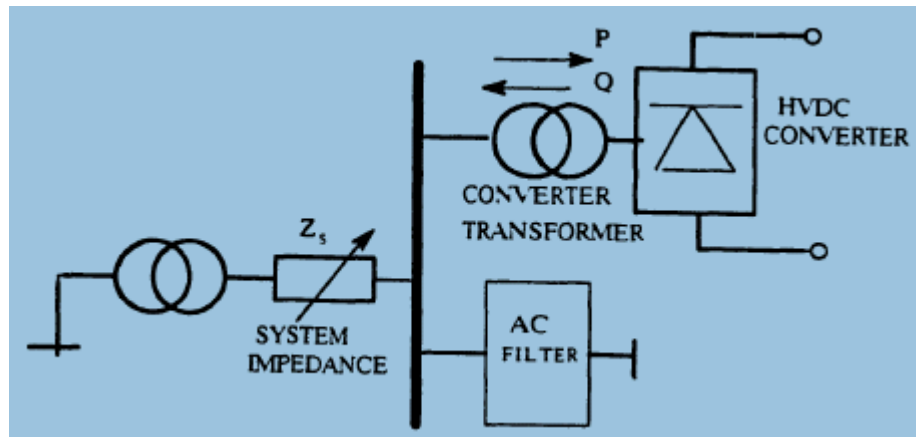
Figure 1: Layout of HVDC converter station

1.2   Problem Statements

The need to reduce the voltage and current waveform distortion to acceptable levels has been a problem in power system design from the early days of alternating current. In high voltage direct current, serious problem need to be undergo for avoiding hazardous to the electrical systems. The matters that need to be encounter are:

1)   To reduce or eliminate the harmonic voltages and currents by the filter.

2)   The trial-and-error approach consume a lot of time to compute the parameters required.

1.3   Research Objective

To design an AC harmonic filters at a HVDC converter bus that should systematically compute the filter parameters while simultaneously satisfying the filter performance requirements.

1.4   Project Scope

This project is to design an AC Harmonic Filter near the HVDC transmission line. As an AC Filter it is important to filter the unwanted signal in the HVDC transmission line systems. Therefore, the focuses in this project are;

1)   Design and stimulate the approach technique
2)   Studies on MATLAB software on GUI feature

1.5 Thesis Outline

Ideally electrical power systems operate at a fixed frequency (typically at 50 or 60 Hz) and at a constant voltage level. The problem of voltage regulation and its control is the subject matter of considerable power system research and analysis. The problem of voltage waveform distortion involved in many emissions of harmonics from various sources and devices.

Chapter 2 deals with high voltage direct current application on the understanding of AC Switchyard and characteristic of harmonics generated by an HVDC converter station. The general expressions for harmonics of a 6-pulse and 12-pulse converter are given. Various other sources which generate harmonics are also listed. The adverse effects on electrical equipment due to the injection of harmonic frequency voltages and currents are discussed.

The literature review of thesis on design of AC harmonic filters in previous chapter is classified into four sections: a) General filter design, b) self-tuned filters, c) Filter performances estimation, d) Specification of filters.

The chapter concludes with the introduction of the method to design an AC harmonic filter.

Chapter 4 deals with the method that will be used to applied on this project. Many implementations will involve such that various aspects of the AC filter design at an HVDC converter bus. Various types of AC harmonic filters are discussed. Generalized impedance expressions for two specific type of filter (of second order) are classified into two parts: a) Basic filter design and b) Filter performance specifications. Basic filter design requires consideration of current source, filter and system admittances and harmonic voltages, besides such

quantities as filter Quality Factor (Q) and AC system Frequency Deviation (∂). The performances specification requires consideration of Total Harmonic Distortion (THD), Telephone Interference Factor (TIFF).

CHAPTER 2

HARMONIC OF HVDC TRANSMISSION SYSTEM

2.1   Introduction

A simple representation of a HVDC interconnection is shown in Figure 2.1. AC power is fed to a converter operating as a rectifier. The output of this rectifier is DC power, which is independent of the AC supply frequency and phase. The DC power is transmitted through a conduction medium such as overhead line, a cable or a second converter. This second converter is operated as a line-commutated inverter and allows the DC power to flow into receiving AC network.
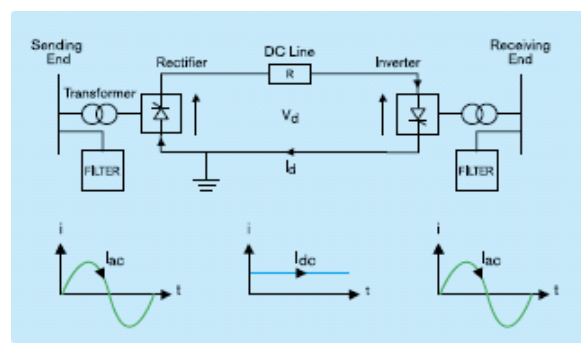
Figure 2.1: Basic HVDC transmission

Conventional HVDC transmission utilizes line-commutated thyristor technology. Figure 2.2 shows a simple thyristor circuit. When a gate pulse (*ig*) is applied while positive forward voltage is imposed between the anode and cathode (*Vthy*), the thyristor will conduct current (*iL*). Conduction continues without further gate pulses as long as current flows in the when the current tries to reverse. Hence, a thyristor '*turn-off*' takes place only when the current requires an existing alternating AC voltage (*Vac*) in order to operate as an inverter. This is why the thyristor based converter topology used in HVDC is known as a line-commutated converter (*LCC*).
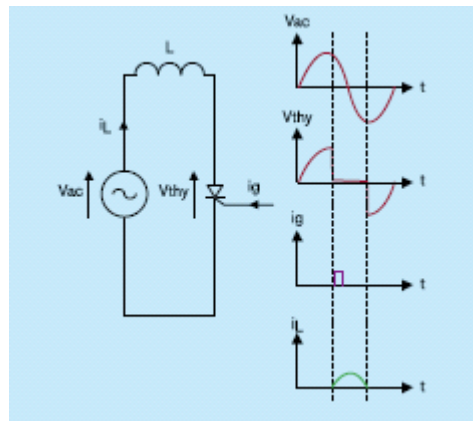
Figure 2.2: The gating and commutated of a thyristor

Electrical power systems are operate at a fixed frequency (typically at 50 or 60 Hz) and at a constant voltage level. The emission of harmonics from various sources and devices is a matter of concern to power system engineers. The identification of these harmonic sources and development of effective methods of controlling the power system and other electrical devices are part of engineering design tasks. In this case, various sources which generate harmonics are listed. The adverse effects on electrical equipment due to the injection of harmonic frequency voltages and currents are discussed.

This chapter deals in particular with harmonics generated by an HVDC converter station. The characteristic harmonics generated by the converter are briefly discussed. The general expression for the 6 and 12-pulse converter harmonics are given.

2.2 High Voltage Direct Current (HVDC)

HVDC transmission systems can be configured in many ways to take into account cost, flexibility and operational requirement. The basic system configuration will be discussed on more detail based on the order of increasing complexity.

2.2.1 Single Line Diagram of one end of a HVDC Bi-pole Converter

Figure 2.3 shows a typical layout for a single line diagram of one end of a HVDC Bi-pole converter and gives a clear indication of the relative space taken up by the various plant components. The major proportion of the space is taken by external plant, particularly the capacitors used in the form of harmonic filters and for voltage support. It is better to be explained by referring the figure 2.3 showing the complete circuit which fully equipped to conducting the HVDC system.
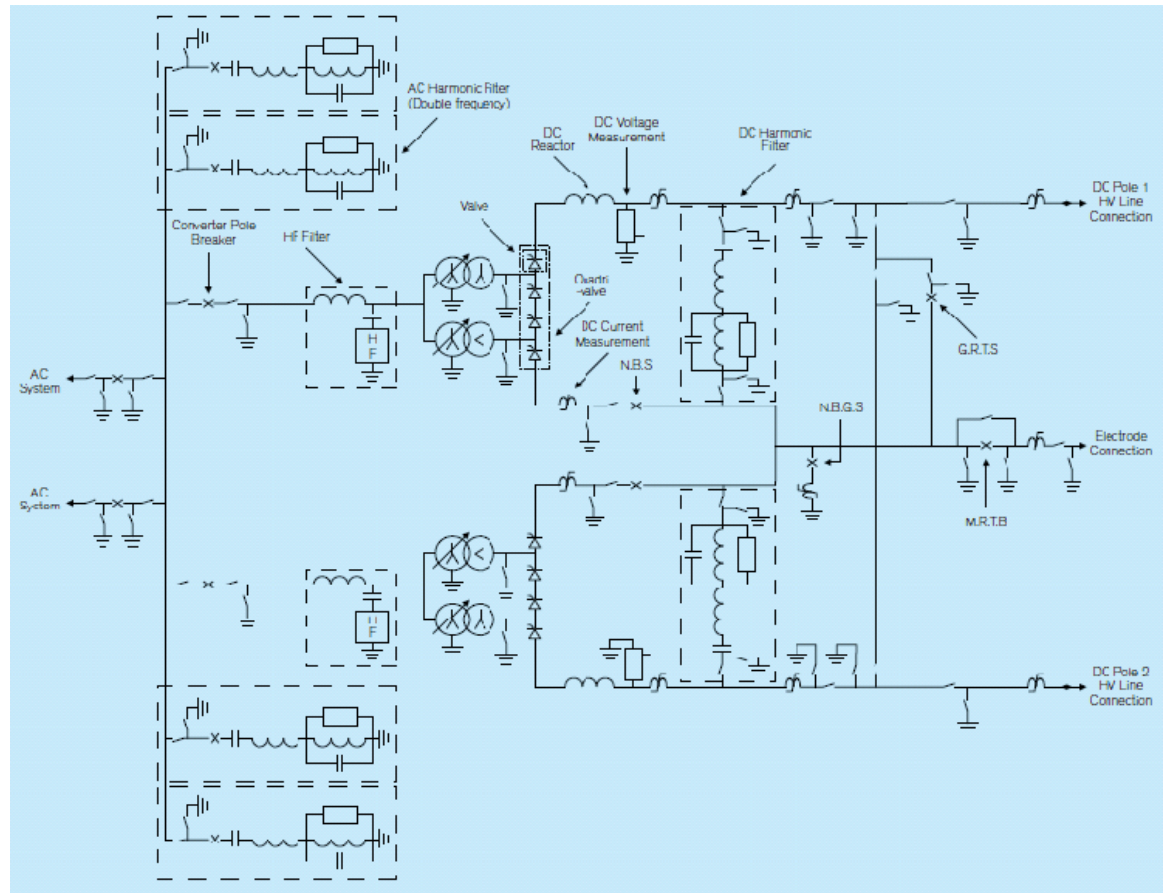
Figure 2.3: Shows a typical SLD of one end of a bi-pole overhead transmission line HVDC converter station.

2.2.2   AC Switchyard

The AC system connects to a HVDC converter station from a converter bus, which is simply the AC bus-bar to which the converter is connected. The AC connection, the HVDC connections along with connections to AC harmonic filters and other possible loads such as supply transformer, additional reactive power equipment, and so on, can be arranged in several ways normally dictated by reliability or redundancy requirements, protection and metering requirements, the number of separately switchable converters and local practice in AC

substation design. Figure 2.4 shows a selection of AC connection arrangements that can be used in HVDC converter stations starting with (a) a simple, single, 3-phase bus-bar with one switchable connection to the AC system and the switchable AC harmonic filters connected directly to it. In such arrangements, it is not possible to use the AC harmonic filters for reactive power support of the AC system without having the converter energized as the AC system connection is common [11]. Figure 2.4(b) shows a scheme comprising two converters and includes an additional circuit breaker dedicated to each converter. In this arrangement, the AC harmonic filters can be used for AC reactive power support without energizing the converter.

However, in common with Figure 2.4(a), a bus-bar fault will result in the complete outage of the converter station. To provide some additional redundancy a double bus-bar arrangement can be used as shown in Figure 2.4(c). In Figure 2.4(c) an AC bus-bar outage will result in those loads connected to that bus-bar being disconnected until the disconnectors can be arranged to re-connect the load to the remaining, 'healthy' bus-bar. Disconnected rearrangements will typically take in the order of ten seconds to complete and in some cases such as outage may not be acceptable, hence the arrangements shown in Figure 2.4(d) can be used, where each load is connected via a dedicated circuit breaker to each bus-bar, allowing for fast disconnection and reconnection in the event of a loss of a bus-bar typically around 300ms. A disadvantage of the arrangement shown in Figure 2.4(d) is the large number of AC circuit breakers requires. In order to reduce the number of circuit breakers, the arrangement shown in Figure 2.4(e) can be used. In Figure 2.4(e) two loads can be individually switched between two three-phase bus-bars via three circuit breakers, hence, this configuration is commonly known as a 'breaker-and-a-half' arrangement [11]. Many other arrangements of AC switchyard configuration exist and have been used in association with existing HVDC schemes.
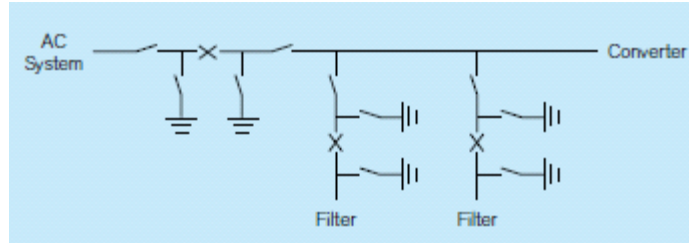
Figure 2.4(a): Single bus-bar
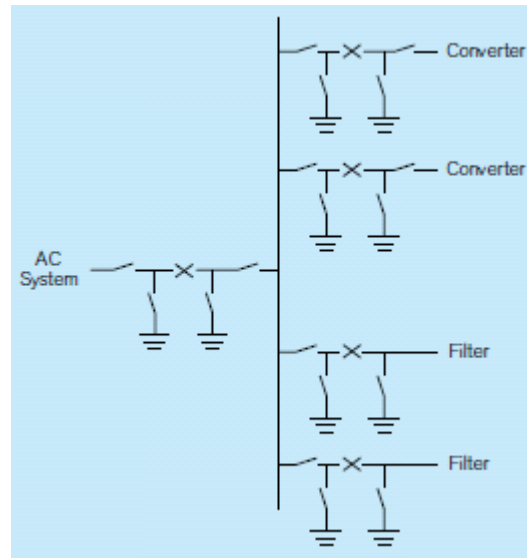
Figure 2.4(b): Single bus-bar with separate

converter breaker
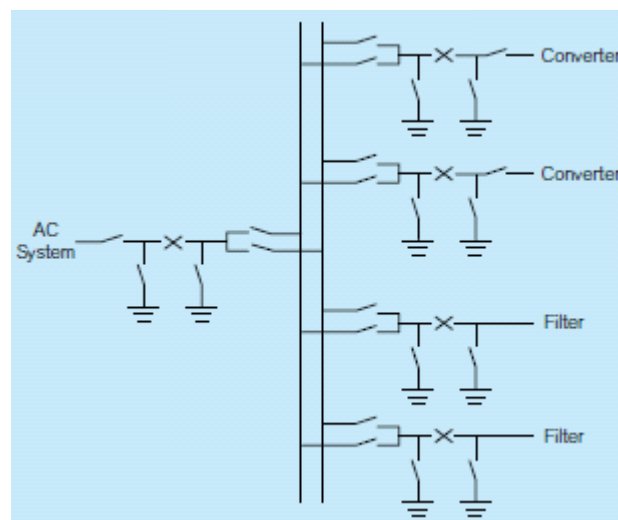
Figure 2.4(c): A double bus-bar
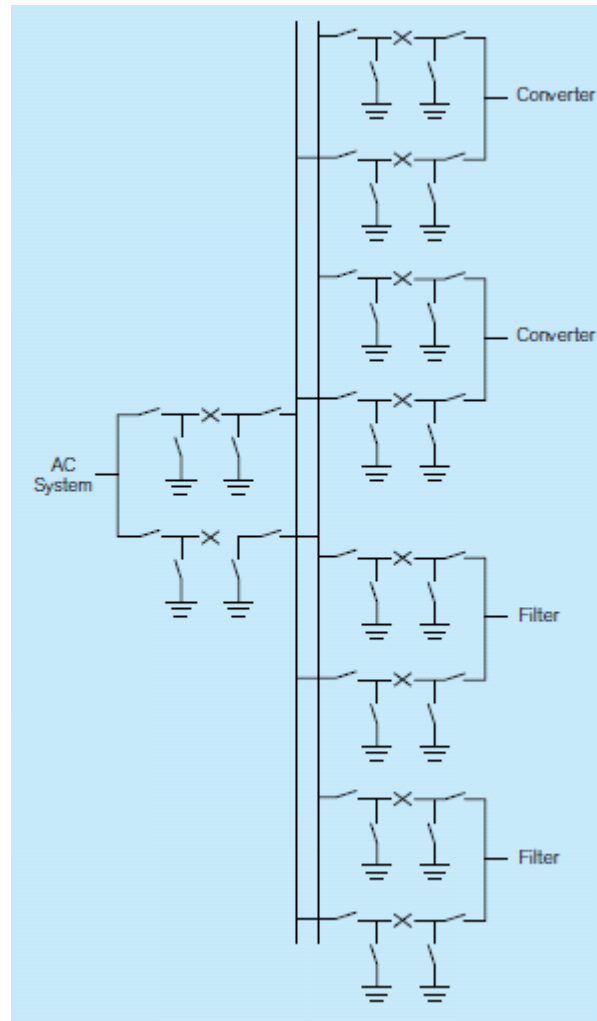
Figure 2.4 (d): A double bus-bar, double breaker
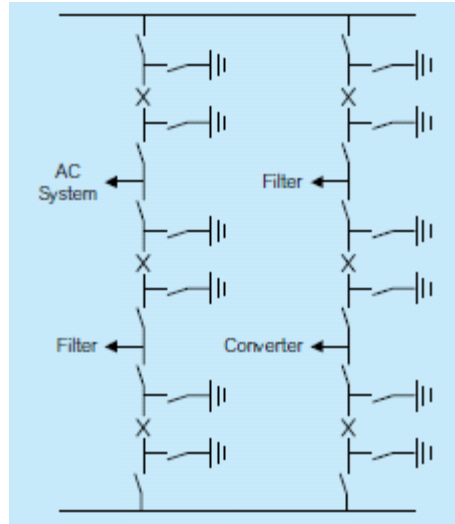
Figure 2.4 (e): A breaker and a half

2.3 Harmonic in Power System (HVDC)

The term harmonics is used to define the sinusoidal components of a repetitive waveform and these consist exclusively of frequencies which are exact multiples which are the harmonics orders of the basic repetition frequency that is the fundamental. The harmonic involved in power system are been a tedious problem in this few century. Therefore, lot of development on researching has been done to investigate the cause of the harmonic. Hence, there are some important roles that need to be considered and the discussion will be explained in detail on the next session

2.3.1 Harmonic Sources

Static converter is one of the major sources of harmonic generation, but there are other sources within power systems which generate harmonics [1]. These are:

a) Non-linear loads using power electronic switches.

b) Synchronous machines when suffering sharp variations in the load and air gap.

c) Rectifiers, inverters, arc furnaces, solid state voltage controllers, frequency converters and so on.

d) Inter-connection of wind and solar power converters.

The potential use of direct energy conversion devices such as magneto-hydro dynamics may increase power harmonics. Most of the sources mentioned, they share the common technology of solid state power devices.

2.3.2 Harmonics in AC Power systems

All equipment that includes a non-linear element and is connected to a power system can result in the generation of harmonics as a consequence of either its design or its operation. The figure 2.5 shows a typical background harmonic distortion on an 11 KV network. Examples of harmonics sources within a power system are:

i) Power converter (HVDC, SVC, drives)

ii) Domestic electronic (television, video, personal computers)

iii) Non-linear devices

- Transformers
- Voltage limiters

iv) Fluorescent lights

v) Rotating Machines

vi) PWM converters
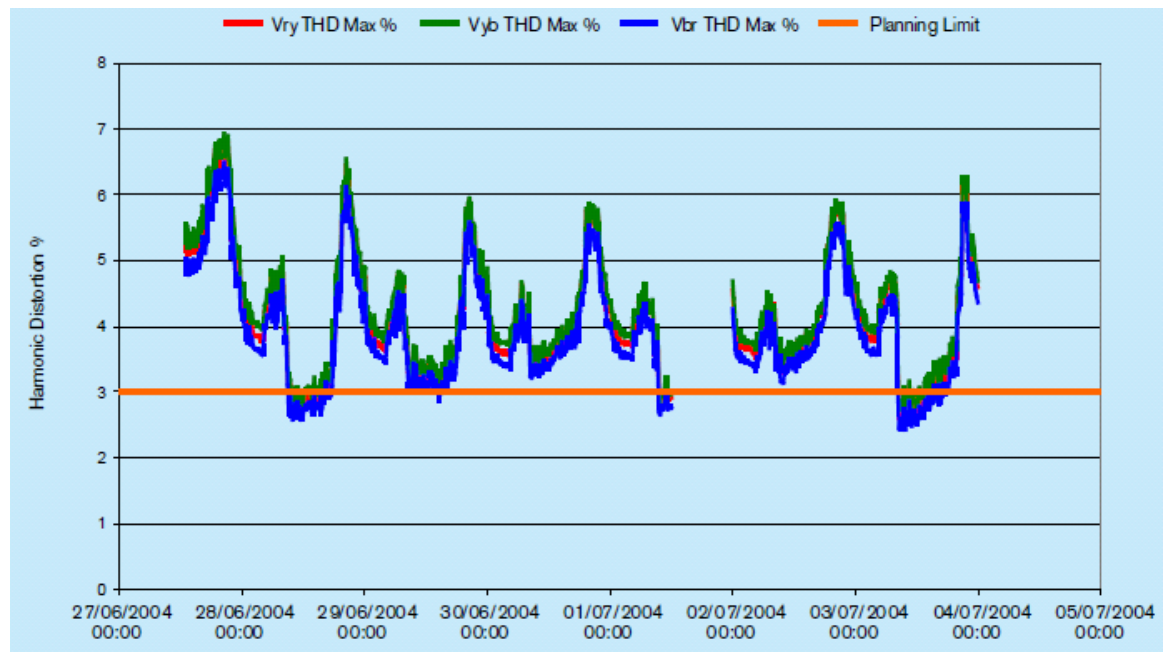
Figure 2.5: An example of excessive background harmonic distortion on an 11KV network

2.3.3 Harmonics Caused by Converter

The AC/DC converter is a source of harmonics. This is because the converter only connects the supply to the load for a controlled period of a fundamental frequency cycle and hence the current drawn from the supply is not sinusoidal. From the AC side, a converter can be considered as a generator of current harmonics (Figure 2.6 (a)), and from the DC side a generator of voltage harmonic (Figure 2.6 (b)). The actual level of harmonics generated by an AC/DC converter is a function of the duration over which a particular phase is required to provide unidirectional current to the load. Therefore, the higher the ' Pulse Number' of the converter, which means the more switching between phases within a cycle, the lower the harmonic distortion in both the AC line current and the DC terminal voltage [11].

*I_h = Sinusoidal current at harmonic 'h'
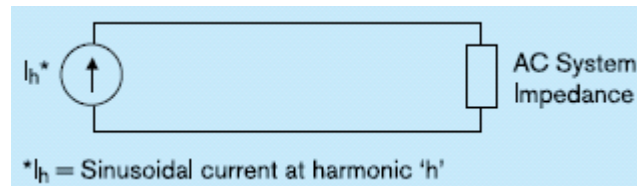
Figure 2.6(a): AC/DC converter represented as AC harmonic
current source on AC side

*V_h = Sinusoidal voltage at harmonic 'h'
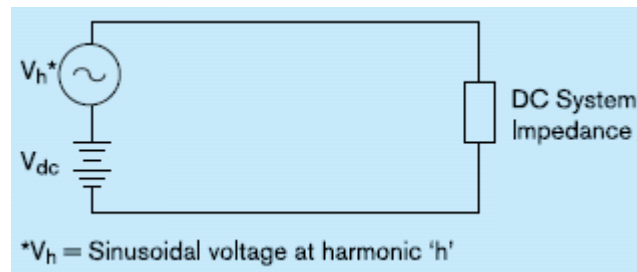
Figure 2.6 (b): AC/DC converter represented as AC harmonic
voltage source on DC side

2.3.4 Harmonic Generated by an HVDC Converter

The converter acts as a harmonic current source on the AC side, and a harmonic voltage source on the DC side. A converter of pulse number "p" generates harmonics principally of orders h [1].

$$h = pq \text{ (on DC side)} \qquad\qquad 2.1$$
$$h = pq \pm 1 \text{(on AC side)} \qquad\qquad 2.2$$

Where q is an integer

In general the amplitude of the harmonics decreases with increasing harmonic order. For example, if the AC current at fundamental is $I1$, then the current at order h is $I1/h$.

The harmonics generated can be classified either as characteristic or non-characteristic harmonics. Characteristic harmonics are those defined in equations 2.1 and 2.2. Non-characteristic harmonics are those of other orders. The pulse number p of a converter is the number of non-simultaneous commutation/cycle of fundamental alternating voltage. The "order of a harmonic" h is the ratio of its frequency to the fundamental frequency. In mathematical derivation of characteristic harmonics based on the pulse number is available in [8]. Based on the definition and assumptions in [8], the line current of a 6-pulse converter is

$$
\begin{aligned}
I_a = \left(2.\sqrt{3}/\pi\right)I_d[\cos(\theta) - 1/5.\cos(5\theta) + 1/7.\cos(7\theta) - \\
1/11.\cos(11\theta) + 1/13.\cos(13\theta) - 1/17.\cos(17\theta) + \\
1/19.\cos(19\theta) - ......]
\end{aligned}
\qquad 2.3
$$

This contains only harmonics of order 6q ± 1, where *Id* is the value of the direct current [1]. The crest value of the fundamental frequency current is

$$I_1 = \left(2.\sqrt{3}/\pi\right)I_d = 1.103 I_d \qquad 2.4$$

and its effective (RMS) value is

$$I_{rms} = I_1/\sqrt{2} = \left(1.103/\sqrt{2}\right)I_d$$
$$= 0.780 I_d \qquad 2.5$$

The effective value of the hth harmonic is

$$I_h = I_1/h \qquad 2.6$$

Similarly the line current of a 12-pulse converter [1] is

$$I_a = 1.103 I_d [\cos(\theta) - 1/11.\cos(11\theta) + 1/13.\cos(13\theta) - 1/23.\cos(23\theta) + 1/25.\cos(25\theta) -] \qquad 2.7$$

This contains only harmonics of order 12q ± 1

2.3.5   Effects of Harmonics on Electrical Apparatus

The injection of harmonic frequency voltage and currents into power systems can produce many adverse effects [17] in equipment connected to or adjacent to that system. The most important of these effects are:

2.3.5.1 Additional losses and Heating in Machines

The absence of harmonic currents in machines causes heating of the winding and directly reduces the maximum torque available. Harmonic voltages at the maximum of power factor correction capacitor produce a disportionate increase in the current in the capacitor which has to be derated to compensate for the increased di-electric loss and hence internal heating [1].

2.3.5.2 Overvoltage Due to Resonance

A small harmonic voltage appeared at one point in a system may result in a very much larger voltage appearing elsewhere in the system due to series resonance. For example, resonance between an intermediate transformer on an AC line and a power factor correction capacitor [1].

2.3.5.3 Interference with Ripple Control Systems

Some electric power utilities sell power at especially reduced rates for off-peak loads and control the hours of usage transmitting audio frequency tones over the power network to control contactors in series with customer's apparatus [1]. Harmonics from converter may cause undesired of such equipment.

2.3.5.4   Interference with Converter Controls

The addition of voltage harmonics of the fundamental frequency voltage wave may cause a shift in the voltage zero crossover points, which in some control systems are used as a reference for firing pulses especially for thyristors. The firing of the valves which in turn generates non-characteristic harmonics, the resulting distortion may seriously affect converter operation [1].

2.3.5.5   Apparatus Effected by Harmonics

The frequency range used in voice transmission is approximately 200 to 3500 Hz and this range includes many harmonics of the fundamental power frequency. There is a great difference between the power levels of the telephones circuits and power lines and when power lines are placed in close proximity to telephone lines, there is a great potential for inducing unwanted voltages and currents in the telephone lines.

The following equipment or devices are effected by harmonics:

    -Transformers
    -Rotating machines
    -Capacitor banks
    -Switchgear
    -Protective relays
    -Metering devices
    -Electronics equipment
    -Lightning devices

System studies are needed to define the combined effect of distributed sources of harmonic in an integrated power system.

2.3.6   Effects of Harmonics in AC Power Systems

Harmonics within a power system are defined as the modulation of the voltage or current of an integer multiple of the fundamental frequency. Hence, for example, on a 50 Hz system, the presence of 5th harmonic voltage means that there is an additional 250 Hz component added to the voltage waveform which will distort the voltage waveform as shown in Figure 2.7(a) and 2.7 (b) [11].

The presence of harmonics in the power system can result in some undesirable effects on connected power system equipment, for example, the presence of harmonics can result in;

i)   Overheating of capacitor banks

ii)   Overheating of generators

iii)   Instability of power electronic devices

iv)   Interference with communication systems
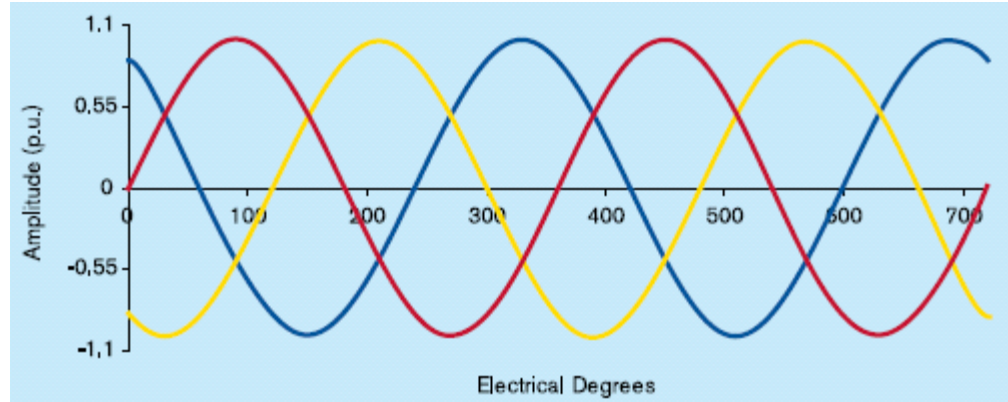
Figure 2.7 (a): Three phase fundamental frequency sine wave
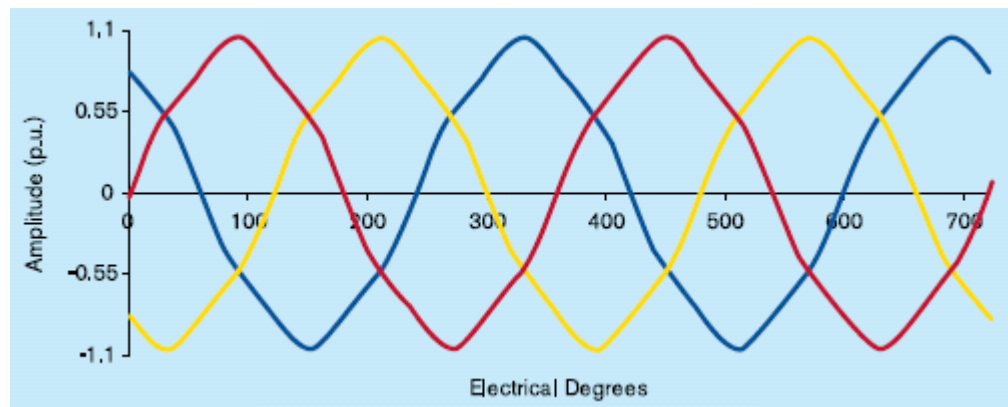
Figure 2.7 (b): Example of 5% 5th harmonic distortion on a three phase AC waveform

2.4   Harmonic Filter

The harmonic filter can be classified to a few categories to investigate the type of filter involved. Firstly, there some purpose need be exposed for the duties of filter such as absorb harmonic current generated by the HVDC converter and thus to reduce the impact of the harmonics on the connected AC systems, like AC voltage distortion and telephone interference and also to supply reactive power for compensating the demand of the converter station. Therefore, further discussion will be on the next session.

2.4.1   AC Harmonic Filter

Converter operation results in both generations of AC current harmonics and the absorption of reactive power. In order to limit the impact of these AC harmonic currents and the absorbed reactive power, the converter station normally includes shunt connected switchable AC harmonic filters, either connected directly to the converter bus-bar or connected to a filter which, in turn, is connected to the converter bus-bar [11].

The AC harmonic filters are automatically switched-on and off with conventional AC circuit breakers when they are needed to meet harmonic performance and reactive power performance limits. The AC harmonic filters are typically composed of a high voltage connected capacitor bank in series with a medium voltage circuit comprising air-cored air-insulated reactors, resistors and capacitor banks [11]. These components are selected to provide the required

performance from the AC harmonic filter and to ensure that the filter is adequately rated.

2.4.2 DC Filter

Converter operation results in voltage harmonics being generated at the DC terminals at the converter, that is, there are sinusoidal AC harmonic components superimposed on the DC terminal voltage. This AC harmonic component of voltage will results in AC harmonic current flow in the DC circuit and the field generated by this AC harmonic current flow can link with adjacent conductors, such as open-wire telecommunication systems, and induce harmonics current flow in these other circuits. In a back-to-back scheme, these harmonics are contained within the valve hall with adequate shielding. However, with open-wire DC transmission it may be necessary to provide DC filters to limit the amount of harmonic current flowing in the DC line. The DC filter is physically similar to an AC filter in that it is connected to the high voltage potential via a capacitor bank; other capacitors along with reactors and resistors are then connected to the high voltage capacitor bank in order to provide the desired tuning and damping.

2.4.3 Need to Eliminate the Harmonics

The previous sections dealt with the adverse effects of harmonics on electrical equipment in the power systems. These harmonics have to be eliminated or drastically reduced to minimize their effects on a wide range of power apparatus harmonic filters that are commonly used to eliminate or reduce effects of these harmonic on the system and apparatus.

2.5 Filter Design technique

The technique to design a filter which compensates the fundamental frequencies revolved the basic of understanding on the filter applications. Therefore, the technique will indicate several types of filter and besides, the performance specification also will be discussed in detail for the next session.

2.5.1 General Filter Design

Parker [1] has presented a set of design procedures for a unique filter configuration taking into account the types of filters, filter efficiency, reactive power compensation and point of connection. His highlight principle was to design a filter with reactive power compensation as the governing criteria. This criterion determined the number of single-tuned filters and high-pass filters.

Double-tuned filter design procedure was carried out by using single-tuned filters with conversion to compound type being affected in the final design stage.

Filter efficiency was specified to be the limit of the total harmonic voltage appearing at the AC system terminals. The reactive power generation was important since it played a vital role in the final form of the filter design. Komaragiri M.K, [1] also talked about point of connection of filters, that is, connection of filters to the primary side of converter transformer or to a tertiary winding of the same transformer.

Brewer, Clarke and Gavrilovic [3] suggested that harmonic filter be considered in an overall system study as reactive power generating units besides providing filtering. Komaragiri M.K, [1] pointed out that reactive power consumed by a converter varies with load. At low load, the filter will overcompensate and the excess reactive power will be fed into the system. If the system cannot accept this excess, then the filter size has to be reduced. Komaragiri M.K, [1] also stressed that a minimum cost filter normally supplies only part of the total reactive power required by the converter and that the capacitor amounts to about 60% of the cost of the filter.

The characteristic of the AC system have a considerable influence on the design and cost of the harmonic filter. This was considered in terms of the harmonic voltage distortion appearing at the converter AC terminals. If the required distortion was low, then the number of filter arms or the size of the arms may have to be increased.

The impedance of the network to harmonic frequency currents influenced the most of a filter from the both current magnification and harmonic voltage distortion. Mohamed and Swift [14] have investigated the transient performance of the interconnected AC/DC power system for filter design. Simulation studies

done by them showed that fixed-tuned filters are better than self-tuned filters from system performance point of view.

Morand, Erikson, and Morias [15] studied the impact of the bus-bar inductance on the AC filter performance. They considered the impedance of the connecting elements in filter design analysis. However, it was observed that the steady state currents and voltages on each filter component calculated with bus-bar inductances are not expected to be larger than if the bus-bar inductances were ignored. Komaragiri M.K, [1] felt that designing the AC filter taking into account the bus-bar inductances was at least time consuming and may prove to be unnecessary.

2.5.2   Self-Tuned Filters

Clark and Johnson-Brown [2] suggested a methodology for designing self-tuned filters. Self-tuning was achieved by adjustment to the inductor, resulting in small frequency deviation, ∂ and therefore higher filter quality Q and filter efficiency. This in turn resulted in lower R values and losses. The frequency deviation was monitored by the control circuit, and necessary control action initiated. They stated that a self-tuned filter will always have better performance than conventional harmonic filters, with respect to lower harmonic voltage. A filter arm can go off-tune due to component changes caused by (a) changes in the ambient temperature, (b) the temperature rise due to current, and (c) due to changes in the system frequency. Initial mistuning must also be considered. As a filter goes off-tune, the impedance of the arm was given approximately by

$$Z = R(1 + jQ2 \partial]……[1]$$

Where

∂ is the per unit effective frequency detuning from nominal due to all causes, and

Z and *R* are filter impedance and resistance respectively.

They also added that, where de-tuning was small or where the required fundamental frequency reactive power of the filter arm was high, self-tuning may offer no cost advantage. For minimum harmonic voltage, the values of capacitance, *C* and reactive power, *Q* should be as high as possible. The capacitor accounts for about 60% of the total filter cost depending largely on the total VAr rating. A high value of *C* meant a large fundamental rating and high cost. As *Q* is increased the required capacitor VAr rating is also increased. To obtain reasonable ratings and also adequate filtering, a compromise between *C* and *Q* must be found.

Moreover, they stated that, the economic advantages of using self-tuned versus fixed-tuned filters will vary with each application. The indication was that the higher the converter rating the more economic self-tuned filters frequency and temperature variation are small or where high reactive power generation at fundamental frequency was required, and then fixed-tuned filters may still be preferred.

2.5.3 Filter Performance Estimation

Brewer [5] adopted a simple method for estimating harmonic performance by using the impedance locus approach to describe the system harmonic impedance in terms of two parameters:

1) *RL*, radius of the system harmonic impedance locus, and
2) ϕ_m , maximum cut-off harmonic impedance angle.

Brewer observed that the value of *RL* varies from 10 ohms in 11KV networks to several hundred ohms in 400 KV networks. The impedance angle of the system was always above 75̊. Brewer also suggested that ϕf the detune angle of the filter, caused by drift in component values has a common value used by filter designers. The maximum detune angle of ϕ_f = 45̊ is obtained when 2QS = 1.

Where Q = quality factor of the filter arm and
        S = equivalent frequency deviation.

He also stated that the maximum harmonic voltage distortion at the filter and the system terminals occurred when the combined admittance the harmonic source was essentially constant current. In this condition, the admittance of the filter was determined and the minimum total admittance *Yt* was obtained.

If *Ih* is the harmonic current generated at the *hth* harmonic, the corresponding harmonic voltage is

Vh = Ih / Yt

The current flowing into the filter is

If = Vh ×Yf

$\quad$ = Ih ×[Yf / Yt]

The current flowing into the whole of the system including the other filter arms is

Is = Vn Ys = In ×[Ys / Yt]

$\qquad$ It is important to take note that the ratio of *(Yf / Yt)* is greater than unity [8], and therefore the harmonic current into the filter is greater than that produced by generated harmonic current due to partial resonance. For this reason, filters are often rated for the worst condition of the system impedance angle of 90 degrees to ensure that they are properly rated at maximum detune. Brewer's paper [5] provides an approximate guide to the performance of tuned harmonic filters.

2.5.4 Specification of Filters

$\qquad$ Fletcher and Clarke [16] state that the lower order harmonics such as 5th, 7th, 11th and 13th which have large harmonic magnitudes should have separately tuned filters. The 17th and higher harmonics can be absorbed by high-pass filters. In addition to the harmonics mentioned above, other harmonics are also produced by the converter and, although relatively small in magnitude, must be considered in filter design.

$\qquad$ The effectiveness of the filters to limit the harmonics was called the total harmonic voltage distortion (THD), telephone interference factor (TIF) on the AC bus at the converter station, and the IT factor, which was a measure of

harmonic current flowing into the AC system. The AC system harmonic impedance must be considered in order to calculate the performance parameters.

The ratings of the components of the filter have to be adequate for all stages of converter station expansion up to one bi-pole, including when the situation where any one valve group could be out of service. The choice of the components was based on meeting the performance requirements.

Komaragiri M.K, [1] state that a self-tuned filter has one advantage over a conventional filter; with a variable reactance capability, the possibility of resonance between the filter arm and the rest of the system can be minimized.

2.6   Summary

In this chapter a brief description of harmonics generated by an HVDC converter is provided. Various other harmonic sources with power systems are identified. Finally, the adverse effect of these harmonics on electrical apparatus and the need to eliminate them is discussed.

CHAPTER 3

THE DESIGN OF AC HARMONIC FILTER FOR HVDC TRANSMISSION SYSTEM

3.1   Introduction

This project method will begin with require of frequency that encounter. The figure 3.1 shows the method flow of the project. The steps involved in the maps are set of frequency has to be considered, compute for filter impedance and worst harmonic voltage. This two element need to be considered first before enter the next procedure. Therefore, all frequencies must be considered otherwise the whole process need to repeat again. After the frequencies are considered, compute the total distortion. This element needs to be considered before to compute the three main parameter RLC. Therefore, same as previous step, repeating will occur if the solution is not optimal.

This chapter deals with design of various types of AC filter at an HVDC converter bus. General impedance expressions for two specific types of filters, they are single-tuned and high-pass of second order, are developed. Design of any filter is classified into two parts:

a) Basic Filter design: Basic filter design requires consideration of current source, filter and system admittance and harmonic voltages, besides such quantities as filter Quality factor *(Q)* and AC system frequency deviation (∂).

b) Performance Specification: The performance specification requires consideration of such as Total Harmonic Distortion (THD), Telephone Interference Factor (TIF). After the basic design is completed, the performance specifications are to develop the final filter design.

```
                    ┌─────────┐
                    │  Start  │
                    └────┬────┘
                         ↓ ←─────────────────────────┐
          ┌──────────────────────────┐               │
          │  Insert selected Reactive │               │
          │      power demand         │               │
          └──────────────┬───────────┘               │
          ┌──────────────────────────┐               │
          │   Insert fundamental      │               │
          │ frequency and line voltage│               │
          └──────────────┬───────────┘               │
          ┌──────────────────────────┐               │
          │    Insert nominal tuned   │               │
          │ frequency and phase angle │               │
          └──────────────┬───────────┘               │
                         ↓                            │
                  ◇───────────────◇    ┌────┐         │
                 ╱   All data has   ╲   │ No │─────────┘
                ╲    been kev in    ╱   └────┘
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                         │ ┌─────┐
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                         ↓ └─────┘ ←──────────────────┐
          ┌──────────────────────────┐               │
          │      Compute R, L and C   │               │
          └──────────────┬───────────┘               │
          ┌──────────────────────────┐               │
          │     Compute tuned and     │               │
          │  damped filter impedance  │               │
          └──────────────┬───────────┘               │
          ┌──────────────────────────┐               │
          │    Compute the harmonic   │               │
          │     voltage distortion    │               │
          └──────────────┬───────────┘               │
                         ↓                            │
                  ◇───────────────◇    ┌────┐         │
                 ╱     Is the       ╲   │ No │─────────┘
                ╲     solution      ╱   └────┘
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                         │ ┌─────┐
                         │ │ Yes │
                         ↓ └─────┘
          ┌──────────────────────────┐
          │     Result R, L, and C    │
          └──────────────┬───────────┘
                         ↓
                    ┌─────────┐
                    │   End   │
                    └─────────┘
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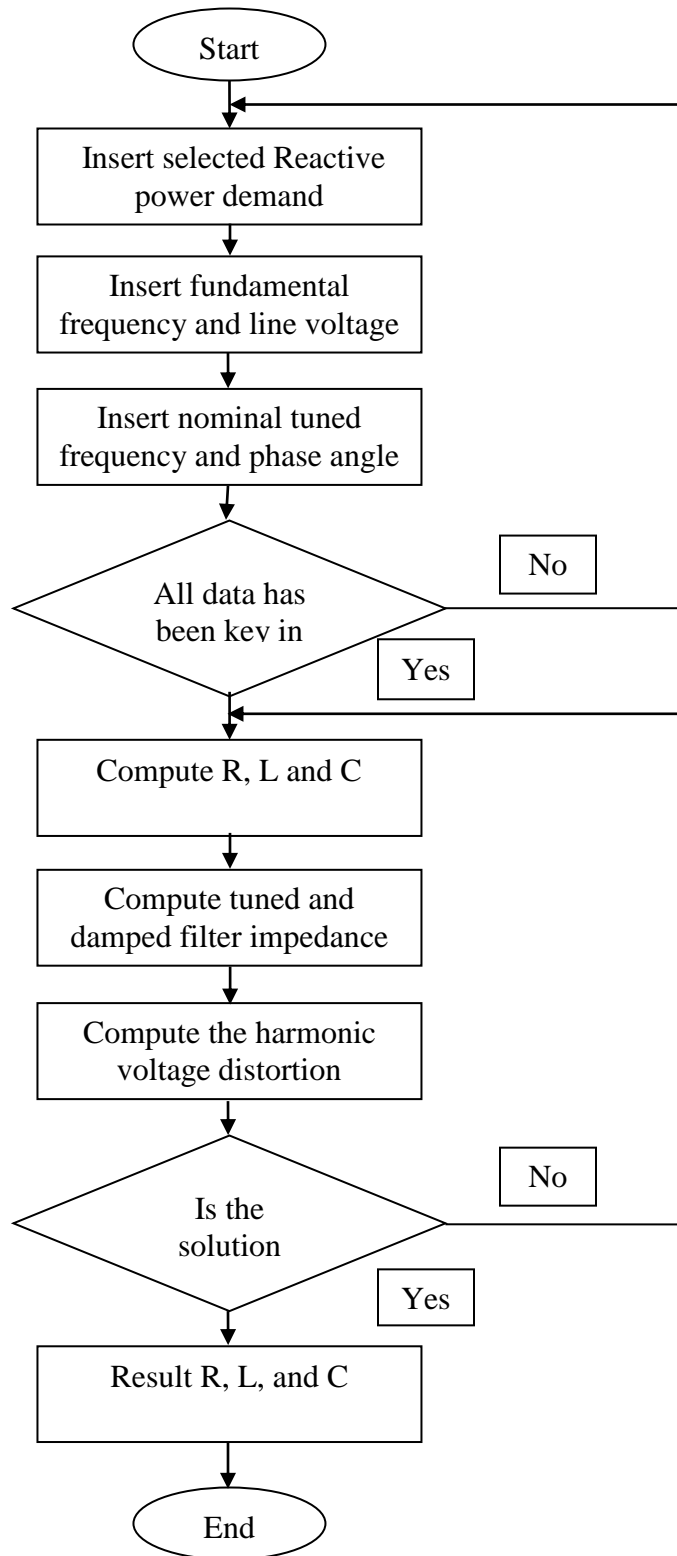
Figure 3.1: The flow of method

3.2 Types of Harmonic Filter

There are two categories of filters required by an HVDC converter: 1) AC filters and 2) DC filters. This thesis is directed towards AC filters only, although similar techniques could be applied to the DC filter design also. The AC filters at a converter station may be categorized according to the functions they perform. A filter may be tuned to a specific frequency (Single-tuned filter, Figure 3.2(a)) or a filter may be designed to cover a broad range of frequencies (High-pass filter, Figure 3.2(b)).
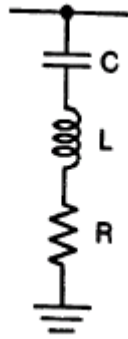
Figure 3.2(a): Single-tuned filter   Figure 3.2(b): High-pass
              filter
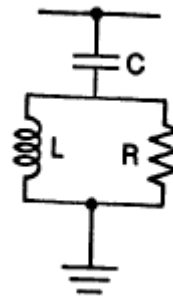
Tuned-filter meant single, double or even triple-tuned filters. A single-tuned filter is responsive to one single frequency. Two single-tuned filters may be combined to form a double-tuned filter which is responsive to two frequencies.

Various types of high-pass filters exist such as;
a)   second order (Figure 3.3(a)),
b)   third order (Figure 3.3(b)),
c)   C-type (Figure 3.3(c)).

The discussion will be limited to high pass type filters only. The other types of filters are left for future development.
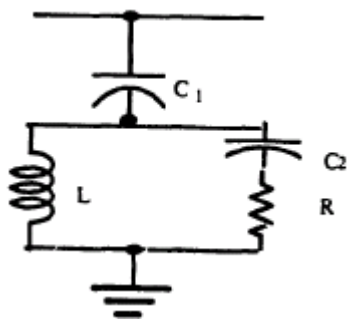
Figure 3.3(a): Second Order
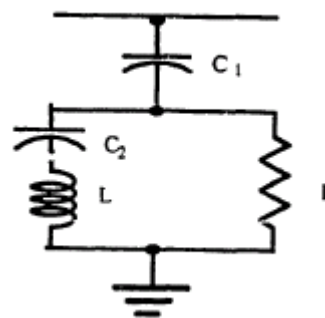
Figure 3.3(b): C-Type
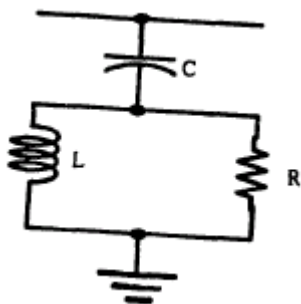
Figure 3.3(c): Third Order

3.2.1 Single Tuned Filter

A single-tuned filter is a series RLC circuit (Figure 3.2(a))
The impedance of the filter is expressed as

$$\omega_n = 1/\sqrt{L.C} \qquad\qquad 3.1$$

At the resonant frequency fn, the impedance has a low resistance, R. Its passband (PB) is bounded by frequency $f1$ and $f2$ at which $|Zf| = \sqrt{2}.R$. at these frequencies the net reactance equals the resistance, and the impedance angle is $\pm$ 45°.

Now at tuned frequency angular frequency (rad/sec) is expressed as

$$\omega_n = 1/\sqrt{L.C} \qquad\qquad 3.2$$

and ∂, the deviation (per unit) of frequency from the tuned frequency as

$$\partial \cong (\omega - \omega_n)/\omega_n \qquad\qquad 3.3$$

and $X0$ reactance of inductor or capacitor in ohms as

$$X_0 = \omega_n.L$$
$$= 1/\omega_n.C$$
$$= \sqrt{L/C} \qquad\qquad 3.4$$

The quality factor of the filter or sharpness of tuned filter can be expressed as

$$\mathbf{Q} = \mathbf{X_o}/\mathbf{R} \tag{3.5}$$

Rewriting from the equation 3.3 yields

$$\omega = \omega_n(1+\partial) \tag{3.6}$$

Rewriting from the equation 3.4 and substituting for $X0$ from equation 3.5 yields an expression for capacitor *C*.

$$\mathbf{C} = 1/(\omega_n.\mathbf{X_0})$$
$$= 1/(\omega_n.\mathbf{R.Q}) \tag{3.7}$$

Similarly Inductor L can be expressed as

$$\mathbf{L} = \mathbf{X_0}/\omega_n$$
$$= \mathbf{R.Q}/\omega_n \tag{3.8}$$

Substituting equation 3.6, equation 3.7 and equation 3.8 into the equation 3.1 yields

$$Z_{st} = \mathbf{R}\left(1 + j.Q.\partial.\frac{(2+\partial)}{(1+\partial)}\right) \tag{3.9}$$

If ∂ is too small, that is, $\partial \ll 1$ then

$$Z_{st} = \mathbf{R}(1 + j.2.\partial.Q) \tag{3.10}$$

3.2.2   High Pass Filter

The high-pass damped filter (Figure 3.2(b)) has capacitive reactance at fundamental frequency, and low, much more resistive, impedance over a wide of higher frequencies (Figure 3.4)
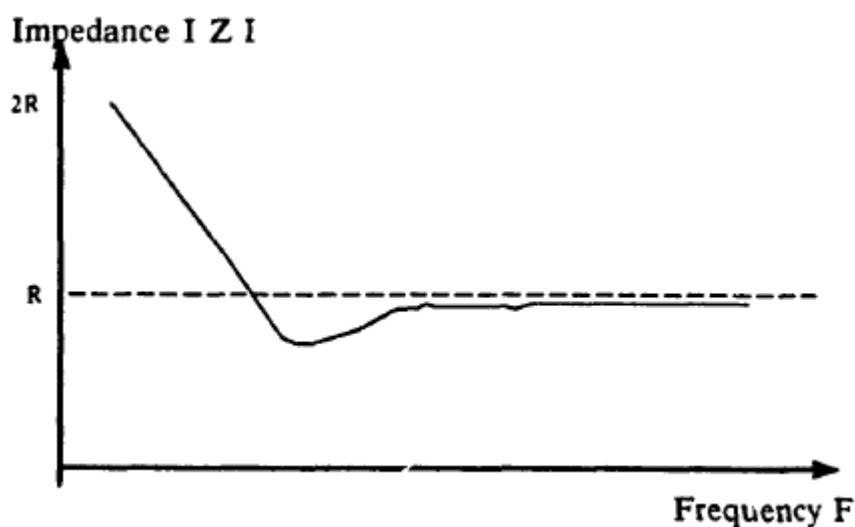
Figure 3.4: High-Pass filter impedance vs. frequency.

The advantages of using a high-pass filter are:

a)   Its performance and loading is less sensitive to temperature variation, frequency deviation, component manufacturing tolerances, loss of capacitor elements.

b)   It provides a low impedance for a wide spectrum of harmonics without the need for subdivision of parallel branches with increased switching and maintenance problems,

c)   The use of tuned filters often results in parallel resonance between the filters and the system admittance at a harmonic order below the lowest tuned filter frequency or in between tuned frequencies. In such cases, the use of one or more damped filters is more adequate approach.

The main disadvantages of a high-pass filter are:

a)   By achieve a similar level of filtering performance, the damped filter needs to be designed for higher fundamental VA ratings, for most cases a good performance can be obtained within the limits required for power factor correction.

b)   The losses in the resistor and reactor are generally higher. When designing a damped filter, the *Q* is chosen to give the best rating over the required frequency band and there is no optimal *Q* as with tuned filters. The behavior of damped filters has been described by Ainsworth [9] with the help of two parameters; these are

$$f_o = 1/2\pi CR \qquad\qquad 3.11$$

$$M = L/R^2 C \qquad\qquad 3.12$$

Where *f0* = *N* * fundamental frequency (*N* is the starting frequency of the high-pass filter)

   M = damping factor, normally varies between 0.5 and 2

Rewriting from the equations 3.11 and 3.12 in terms of *R* and *L* yields

$$R = \frac{1}{2.\pi.f.C} \qquad\qquad 3.13$$

$$L = M.R^2.C \qquad\qquad 3.14$$

The high pass filter impedance is

$$Z_{hp} = (1/j.\omega.C) + [j.R.\omega.L/(R + j.\omega.L)]$$ 3.15

Substituting for *R* and *L* from equation 3.13 and 3.14 respectively results in

$$Z_{hp} = \frac{1}{j\omega C} + \frac{j\omega M}{2\pi f_0 C(2\pi f_0 + j\omega M)}$$ 3.16

3.3   Design Consideration For A Filter

The general objective of a filter is to reduce or eliminate the amplitude of the harmonic currents and voltages. In additional, it should also provide all or part of the reactive power consumed by the converter, and meets other performance specification, such as THD, TIF and so on. Theoretically, a filter can be designed for a very high quality factor (*Q*) that is, very sharply tuned to a specific frequency. However, a slight deviation of the AC system frequency will de-tune the filter, resulting in increased harmonics into the AC system.

Another consideration in the filter design is the AC system impedance. AC system network topology changes due to various loading conditions. Any change in the network topology, brings changes in the AC network impedance. AC harmonic filter design depends on the AC network impedance. Data of the network impedance expressed in terms of network impedance radius *RL* and network impedance phase angle $\pm\phi_m$ are taken into consideration to design an AC harmonic filter [1].

AC system frequency deviation (∂), which is built into the impedance expression (equation 3.9), is another requirement to be considered for the filter design. Single-tuned filter, which is tuned to a specific frequency, is sensitive to AC system frequency deviation (∂). For a high-pass filter, starting frequency, f_0 which is referred to as high-pass tuning frequency, along with the damping factor M is to be considered for filter design (equation 3.16). The limits on harmonic voltages and currents flowing into the AC systems are also considered as requirements for filter design.

Practically, filter design is carried out in two parts, a) Basic filter design and b) Design for meeting performance specification.

3.3.1   Basic Filter Design

In the basic filter design, four design parameters require specific consideration:

1)   Harmonic Current, *Ih*
2)   Filter admittance, *Yf*
3)   System admittance, *Ys*
4)   Harmonic voltage, *Vh*

3.3.2   Harmonic Current, *Ih*

The harmonic current generated by a converter depends on its pulse number and operating firing angle, as explained in section 2.3.4, that is ,if a 6-pulse converter is used, then the AC current is contain of harmonics of order 6q± 1, where q is an integer. Similarly the converter firing angle value determines the magnitude of the harmonic currents [8]. Normally, harmonic current orders up to 50 are considered for the filter design. This assumes that the current magnitudes of higher order harmonics are very small and can be ignored.
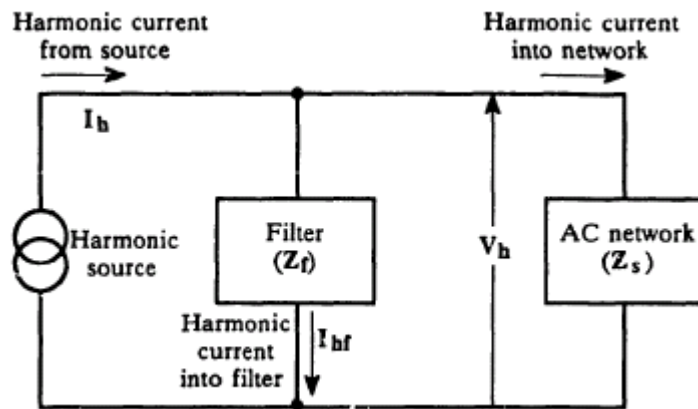
Figure 3.5: Current source

3.3.3   Filter Admittance, *Yf*

Filter admittance is a function of the filter parameters that are *R, L* and *C* (section 3.2). The parameters that affect the filter admittance are: a) Quality factor *Q* of the filter or sharpness of tuning of the filter, and b) Frequency de-

tuning, ∂. The filter parameters R, L and C are expressed by Q, ∂ and ω, such that the final filter admittance will be a function of these terms.

3.3.3.1 Quality Factor (Q)

The quality factor of a filter determines the sharpness of tuning and filters may either be high Q or low Q type. The high Q filter is sharply tuned to one of the lower harmonic frequencies (equation 5^{th}) and its typical Q values is between 30 and 90 [1]. The low Q filter, typically has a Q value in the range of frequencies. The low Q filter, typically has a Q value in the region of $0.5 - 5$, and also has a low impedance over a wide range of frequencies. The high-pass filter is of this type. Normally, Q is expressed as

$$Q_{opt} = \frac{1+\cos(\phi_m)}{2\delta_m \sin(\phi_m)} \qquad\qquad 3.17$$

or

$$Q = X_0/R$$

Where *X0* is the reactance of the filter at the tuned frequency, R is the filter impedance, δm is maximum frequency deviation and φ is maximum phase angle

3.3.3.2 Filter de-tuning,(∂)

The filter de-tuning from the nominal tuned frequency is represented by a factor ∂. Normally, a filter is not always tuned exactly to the harmonic frequency that it is intended to eliminate. De-tuning is also caused by:

1) Variation in the filter capacitance, *C* and inductance, *L*. The capacitance changes more because of ageing and changes in the temperature and self-heating.
2) Variation in the power system frequency causing harmonic frequency to change proportionally.
3) Initial off-tuning caused by manufacturing tolerances and finite size of tuning steps.

A change of *L* or *C* of 2% [8] causes the same detuning as a change on system frequency of 1%. The overall de-tuning in per-unit of the nominal tuned frequency is

$$\partial \cong \left(\omega - \omega_n\right)/\omega_n \qquad 3.18$$

Where ω_n is the tuned angular frequency (rad/sec).

The total de-tuning ∂ or equivalent frequency deviation is given as [8]

$$\partial \cong \delta F/F_n + 1/2\left[\delta L/L_r + \delta C/C_n\right] \qquad 3.19$$

3.3.4 Systems Admittance, *Ys*

The reactive components of system impedance and of the impedance of the resonant filters can give rise to parallel resonance [6] that tend to amplify harmonic voltage and currents in the network impedance at the various harmonic frequencies is one of the important factors in the rating of the components of resonant filters as well as in calculating filter performance. Figure 4.6 and 4.7 shows plots of the system impedance for various frequencies for two different topologies. These figures illustrate the dynamic nature of the AC system impedance.

The maximum amplification of the harmonic current in the filter for large frequency and temperature variations depends on both the system impedance and the Q factor. A high Q filter suffers from a greater risk of amplification but, on the other hand, smaller losses and smaller harmonic voltages when the filter is correctly tuned [8].

The methods of computing the system impedance [6] are fairly involved. Figure 4.6 and 4.7 illustrate system
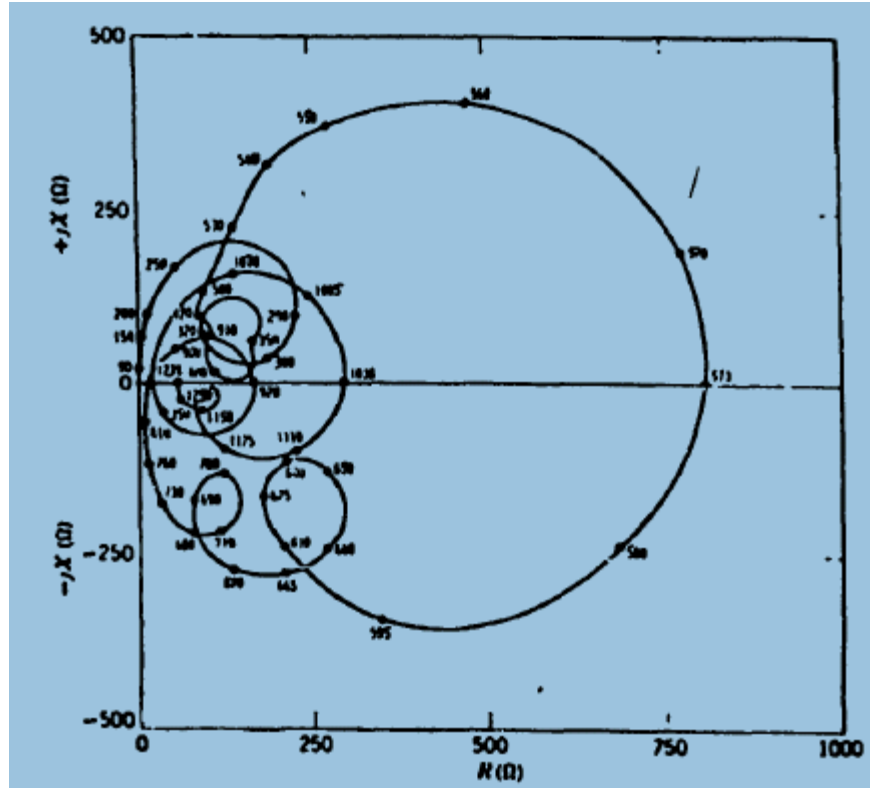
Figure 3.6: Calculated Impedance of 220 kV Network at Minimum Load with One Line Disconnected
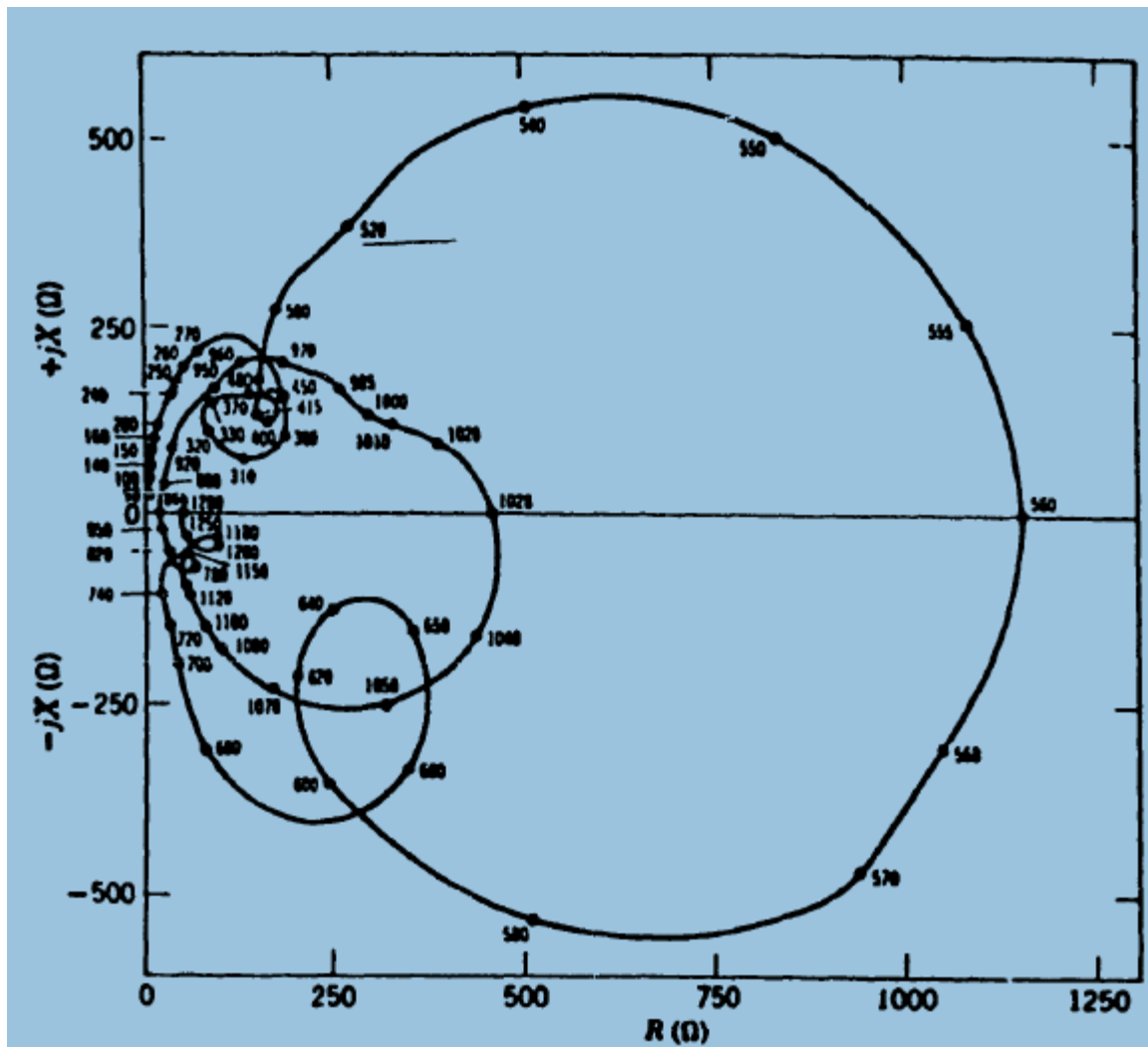
Figure 3.7: Calculated Impedance of 220 kV Network at Minimum Load with Two Lines Disconnected

Impedance for the different frequencies, figure 3. 6 represent system with one line disconnected, while Figure 3.7 represents the system with two lines disconnected. System topology varies with the changing structure of the network under various load conditions. however, all impedances of this kind can nevertheless be circumscribed in a part of the R-jX plane and with two straight lines at an angle from the origin as shown in Figure 3.8, which is a modified version of Figure 3.6, where

Φm – maximum phase angle of the AC system impedance

Rl – AC system operating radius which circumscribed all possible load considerations of the region.
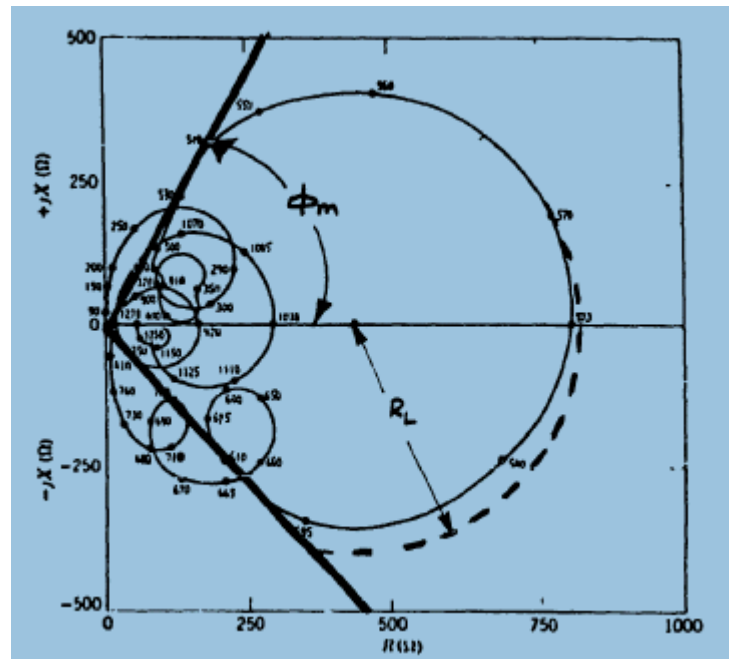
Figure 3.8: Circumscribing a Network Plot

The maximum phase angle ± ϕm of the system impedance is limited to a value below 90 degrees and generally decreases with increasing frequency. Further restrictions to the circumscribing locus can be applied when the limits of individual harmonic impedance are known.

Figure 3.8 can be simplified further and redrawn using only ϕm and RL to define system admittance as shown in Figure 3.9.
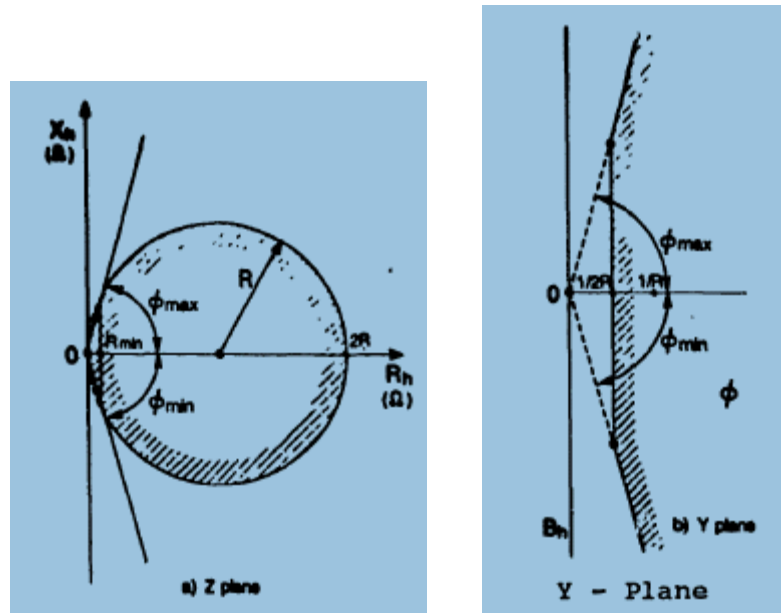
Figure 3.9: Circumscribed System Impedance/Admittance

3.3.5   Harmonic Voltage, *Vh*

In practical filter design includes minimizing harmful telephone interference commonly expressed by the harmonic current or harmonic voltage or both. In order to obtain the maximum voltage distortion it is required to compute the minimum total equivalent admittance *(Ys + Yf)* of both filter and system (Figure 3.5) at each frequency. Once harmonic voltage is computed, the basic design of the filter is complete. The harmonic voltage, *Vh* at the filter bus-bar is

$$V_h = I_h / Y_t \qquad\qquad 3.20$$

Where *Ih* is source harmonic current and

$$Y_t \text{ is } Y_s + Y_f$$

To minimize the harmonic voltage it is necessary to increase the overall admittance of the filter in parallel with the AC system.

All the parameters mentioned above such as source harmonic current Ih, filter admittance Y_f, system admittance Y_s, and so on. Form part of the basic filter design.

3.4   Performance Specification

The basic filter design does not satisfy all the system performance requirements such as

1)   Total Harmonic Distortion THD,
2)   Telephone Interference Factor TIFF,
3)   Harmonic Current Factor IT and
4)   Reactive Power Requirements.

The final filter design is a product of these additional filter design. These performance specifications are discussed in the following sections.

3.4.1 Total Harmonic Distortion, THD

Some limits are placed on the effective distortion of the AC voltage wave. This being a root-sum-square (R.S.S) value of the distortion produced by all harmonics [17], it is defined as

$$\text{THD} = (1/V_1)\left[\sum_{h=2}^{m}(V_h^2)\right]^{1/2}$$

3.21

Typically this limit varies from 1% to 5%. The harmonics considered are all the characteristic harmonics from 2^{nd} to the 50^{th} harmonic.

3.4.2 Telephone Interference Factor, TIF

The telephone interference factor is a dimensionless value used to describe the influence of a power transmission line on a telephone line without taking into account detailed geometric aspects of coupling, and is given as

$$\text{TIF} = \frac{\left[\sum_{h=2}^{m}(K_h P_h V_h)\right]^{1/2}}{\left[\sum_{h=2}^{m}(V_h)^2\right]^{1/2}}$$

3.22

Where Kh is the coupling co-efficient and is equal to, by definition to $5h$.

Ph is the weighting factor of the harmonic in question with a maximum value of 1 at 1000 Hz called the C-message weighting factor

M highest number of harmonic number considered.

3.4.3   Harmonic Current Factor, IT

The factor IT provides a similar measure of the influence of a power line on a telephone line. IT factor is a root-sum-square combination of products of currents (in Amperes) of various frequencies, each multiplied by the corresponding *Kh* and *Ph* factors, that is

$$\text{IT} = \left[\sum_{h=2}^{m} (K_h P_h I_h)^2 \right]^{1/2}$$

3.23

Where *Ih* is the harmonic current flowing into the system. Typical values of **IT** are between 10k – 20k.

3.4.4   Reactive Power Requirement

The major function of the filter is to absorb the harmonic currents generated from the converter source and therefore eliminate them from entering the power system. Since the filter is composed of reactive elements of capacitor,

C and inductor, L, they naturally generate reactive power. The converter consumes reactive power which can be supplied by any combination of four different sources:

1)   Filter bank including shunt capacitor,
2)   Synchronous condenser,
3)   Static VAr compensator, and
4)   Power system

About reliability and economics of VAr supply with respect to a synchronous condenser and static VAr compensator (SVC), a synchronous condenser is preferred due to its capability to supply or absorb VArs and increase the system short circuit ratio [6]. However, due to improved switching response and flexibility in terms of VAr generation, SVC's are becoming more acceptable to system engineers. Filter banks are part of converter station design to filter out the harmonic voltages and currents. Besides that, filter bank also produces reactive power. Hence, a combination of filter banks, synchronous condensers and SVC's can be effectively used to meet the dynamic need for the reactive power of the converter station.

The converter demand for reactive power is a dynamic process. This demand changes with the converter firing angle. However, the filter bank generates a fixed amount of reactive power assuming that system voltage stays constant. There are three scenarios possible:

a)   Converter VAr demand is fully met by the filter capability
In this case, there is no need for additional units such as synchronous condensers or SVC's to meet the converter demand. This case is highly idealized and is practically never realized due to the dynamic nature of the converter operation.

In normal operation, reactive power generated by the filter bank is partially meets the converter station demand.

b)   Converter VAr demand is more than the filter capability.

In this case, converter station demand for reactive power exceeds the generating capacity of the filter bank. The additional power is then supplied either by synchronous generator, SVC or the AC system.

c)   Converter VAr demand is less than the filter capability.

In this case the filter bank generates excess reactive power than required by the converter. This can occur when the converter is slightly loaded for some reason. When this happens, some of the filters in the filter banks are switched , therefore, the high harmonic currents do not enter the system.

The challenge to the filter designers is to match the VAr

generation from the filters and shunt capacitor bank throughout the converter load range and at the same time meet the performance specification for filtering purposes.

So, extensive load flow type studies are carried out to match these performance criteria.

3.4.5 Reactive Power Generation

At fundamental frequency, the filter banks are almost purely capacitive and the VAr generation of the bank is approximately equal to the VAr rating of the capacitors in the filter. But due to the presence of other reactive elements, that is, inductor, a minor decrease in the VAr generation results. This is given as

$$Q_t = \frac{(V_L)^2}{(X_C - X_L)}$$

3.24

Where Q_t - Reactive power of the filter at fundamental frequency (MVA),

V_L - AC line voltage (KV),

X_C - reactance due to capacitance at fundamental,

X_L - reactance due to inductance at fundamental.

Reactive power generation is not confined to fundamental frequency. Harmonic frequencies also contribute to the VAr generation. The reactive power at harmonic frequencies is given as

$$Q_h = \frac{(V_{1h})^2}{\sum_{h=2}^{50}(X_C(h) - X_1(h))}$$

3.25

Where Q_h - reactive power at harmonic frequencies.

V1h   - Worst harmonic voltage.

$X_C(h)$ - Harmonic reactance due to capacitor.

$X_1(h)$ - Harmonic reactance due to inductor.

Total reactive power is the sum total of the reactive power generated at fundamental and harmonic frequencies, that is,

$$\mathbf{Q_T} = \mathbf{Q_f} + \mathbf{Q_h}$$

In high-pass filters, the VAr generation decrease below the capacitor capability when harmonic components are considered. However, in case of single-tuned filters, VAr generation increase beyond the capacitor's capability.

3.5   Tools of Development

Matlab software is introduced to implement the design in this session. First and for most, Matlab is a software package for modeling, simulating, and analyzing dynamical systems. Its support linear and non-linear systems, modeled in continuous time. Systems can also be Multirate, that is, have different parts that are sampled or updated at different rates. Matlab is a high-level technical computing language and interactive environment for algorithm development, data visualization, data analysis, and numeric computation. Using the MATLAB product, you can solve technical computing problems faster than with traditional programming languages, such as C and C++. Matlab also provides a graphical user interface (GUI) for implementing "Window based" AC filter designs. The GUI developed here is relatively simple with only a few filter design options and no "user input" error checking features. The objective is to develop a Matlab GUI that will allow a user to choose AC filter design parameters such as the filter order, the filter type and the choice of window function. After choosing the

desired parameters, the user then can "click on a pushbutton" that will load and run the filter design.

3.6 Summary

Two types of filters, single tuned and high pass filters have been discussed. The impedance expressions for both have been developed. Various design consideration for a filter have been discussed. Overall filter design is classified into two parts: a) Basic filter design and, b) Design for meeting performance specification. Components which contribute to each part of the filter design have been dealt with and relevant expressions developed.

CHAPTER 4

RESULTS AND ANALYSIS

4.1   Introduction

The main focuses in this are harmonics analysis, reactive power involved in the ac system network analysis and the tool efficiency analysis. The theoretical method is used to analyze the AC current harmonics level of a certain system. Further on, the analysis being done by using MATLAB software.

The ac system network deal with reactive power demand has been performed using MATLAB GUI. The reactive power demand includes the effect of system performances and also the effect of ac system connection.

MATLAB GUI is used to speed up the iteration for the whole system. Hence, all the related parameters such as AC and DC voltages, currents, powers, phase angles and de-tuning are first initialized before to design the filter. The analysis and stimulation results will be covered in this chapter.

4.2   Project Flow

According to the optimizing method and the algorithm mentioned, a PC-based filter design procedure is implemented as shown in Figure 4.1. Stimulation program can be used, before and after the filter design, to analyze the distribution system for the behavior of harmonic and voltages as function of time, and to determine the magnitude of the various harmonic throughout the system and the voltage distortion at the distribution bus. Stimulation is also intended to verify the filter design and check the effectiveness the filter on different operating conditions, as well as the reduction of the filter effectiveness due to minor harmonics neglected in the process of filter design.
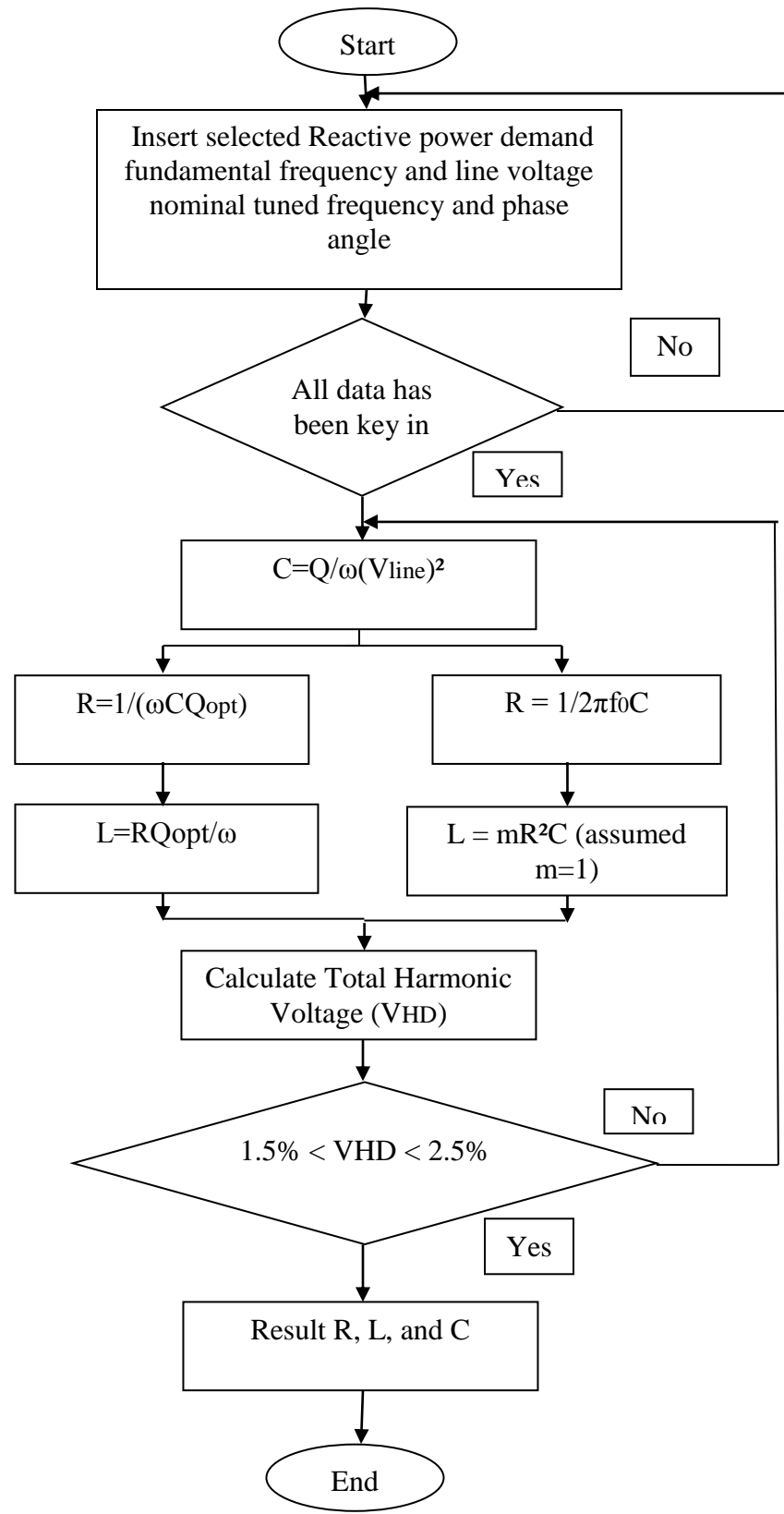
Figure 4.1: Decision flow chart Single Tuned and Damp filter design

4.3   Results and Validation

The HVDC converter from the previous section (4.2) is constructed by connecting two compact HVDC valve group model in series. It includes the six-pulse converter bridge, built in firing controls and valve blocking. In this case, the idea here is to eliminate the unwanted frequency that produces from the source. Under such conditions they produce considerable 5th and 7th harmonics as well as the characteristic 12-pulse-related orders. These are conventionally filtered by using a hybrid combination of tuned branches for the low orders, they are, 5th, 7th, 11th and 13th, and a high-pass damped filter for the 17th and higher orders.

The conventional design is best illustrated with some cases.

4.3.1   Case 1: High Distortion or a strong a.c system

A six-pulse converter bridge is rated at 100 KV, 100 MW d.c., operating at α = 15 degree. The bridge is connected to a 275 KV, 50 Hz a.c. system via a 275/83 KV converter transformer with 15% leakage reactance. The secondary fundamental current is 780 A that of the primary 236 A. the filters, to be connected to the primary side, consist of resonant arms for the 5th, 7th, 11th, and 13th harmonics, and a second-order high-pass arm.

For a total filter size of 80 MVAr, and assuming that the capacitances is to be 2.105 μF and equally divided among the filter branches, each branch requires 0.421 μF. If the capacitor temperature coefficient is 0.05% per degree Celsius,

ambient temperature coefficient 0.01% per degree Celsius, ambient temperature ±20 degree Celsius and frequency tolerance ±1%.

Then from equation (4.20)

$$\delta = (1/100)[1 + 0.5(0.05 \times 20 + 0.01 \times 20)]$$
$$= 0.016$$

Let the a.c. system impedance be of any magnitude but its phase angle restricted to $\varphi < 75$ degree at any frequency. The optimum Q that giving the lowest harmonic voltage is then obtained from equation (4.18), that is

$$Q = (1 + \text{Cos } 75) / 2(0.016)\text{Sin } 75$$
$$= 40.7$$

With Q and C known, the values of L and R of the resonant arms can then be determined.

The damped arm component are found from the equation (4.12) and (4.13) by choosing m = 1 and f0 = 17× 50 = 850 Hz. Since C has been fixed above that is 0.421µF, the resulting values of inductor and resistor are:

$$\text{Resistance, R} = 1 / (2\pi \times 850 \times 0.421\mu)$$
$$= 444.8 \ \Omega$$

$$\text{Inductance, L} = 1 \times (444.8)^2 \times 0.421\mu$$
$$= 0.0833 \text{ H}$$

Similarly, equations (4.7) and (4.8) provide the following values for the remaining branches:

5^{th}-tuned branched:

$$\text{Resistance, R} = 1 / (2\pi \times 5 \times 50 \times 0.421\mu \times 40.7)$$
$$= 37.2\ \Omega$$

$$\text{Inductance, L} = (37.2 \times 40.7) / (2\pi \times 5 \times 50)$$
$$= 0.964\ \text{H}$$

7^{th}-tuned branched:

$$\text{Resistance, R} = 1 / (2\pi \times 7 \times 50 \times 0.421\mu \times 40.7)$$
$$= 26.5\ \Omega$$

$$\text{Inductance, L} = (26.5 \times 40.7) / (2\pi \times 7 \times 50)$$
$$= 0.491\ \text{H}$$

11^{th}-tuned branched:

$$\text{Resistance, R} = 1 / (2\pi \times 11 \times 50 \times 0.421\mu \times 40.7)$$
$$= 16.9\ \Omega$$

$$\text{Inductance, L} = (16.9 \times 40.7) / (2\pi \times 11 \times 50)$$
$$= 0.199\ \text{H}$$

13[th]-tuned branched:

$$\text{Resistance, R} = 1 / (2\pi \times 13 \times 50 \times 0.421\mu \times 40.7)$$
$$= 14.3 \ \Omega$$

$$\text{Inductance, L} = (37.2 \times 40.7) / (2\pi \times 13 \times 50)$$
$$= 0.142 \ \text{H}$$

The filter branch impedances at the third harmonic are obtained by substituting $\omega 3 = 150$ Hz in the tuned and damped branch impedance equation (4.1) and (4.16). These are then inverted and added together to produce the total filter admittance, those are

Impedance, Zf5:

$$\text{Zf5} = 37.2 + j[(2\pi \times 150 \times 0.964) - 1 / (2\pi \times 150 \times 0.421\mu)]$$
$$= 37.2 - j1611.7$$

Admittance, Yf5:

$$\text{Yf5} = 0.0000143 + j0.00062$$

Impedance, Zf7:

$$\text{Zf7} = 26.5 + j[(2\pi \times 150 \times 0.491) - 1 / (2\pi \times 150 \times 0.421\mu)]$$
$$= 26.5 - j2057.5$$

Admittance, Y f7:

$$Y f7 = 0.00000626 + j0.000486$$

Impedance, Zf11:

$$Zf11 = 16.9 + j[(2\pi \times 150 \times 0.199) - 1 / (2\pi \times 150 \times 0.421\mu)]$$
$$= 16.9 - j2332.7$$

Admittance, Yf11:

$$Y f11 = 0.0000031 + j0.000429$$

Impedance, Zf13:

$$Zf13 = 14.3 + j[(2\pi \times 150 \times 0.142) - 1 / (2\pi \times 150 \times 0.421\mu)]$$
$$= 14.3 - j2386$$

Admittance, Y f13:

$$Y f13 = 0.00000251 + j0.000419$$

Impedance, Zhp:

$$Zhp = [1 / j(2\pi \times 150 \times 0.421\mu)] + [j(2\pi \times 150 \times 444.8$$
$$\times 0.0833)/(444.8 + j (2\pi \times 150 \times 0.0833)]$$
$$= 13.439 - j2444.13$$

Admittance, Yhp:

$$Yhp = 0.00000225 + j0.000409$$

The total admittances, YFA3 = Y f5 + Y f5 + Y f5 + Y f5 + Y hp

$$= 0.00002842 + j0.002363$$

The system harmonic impedance that yields the largest parallel impedance with the filter has been found to be Z3 = 444.8∟75, that is

$$ZF3 = 115.12 – j429.64$$

and $\qquad$ YFS3 = 0.000582 – j0.00217

Thus, the parallel system and filter admittance is

$$YT3 = YFA3 + YFS3$$
$$= 0.0006104 + j0.000193$$

The third harmonic voltage distortion is
$$V3 = I3 / YT3$$

Where *I3* is the maximum expected level of injected third harmonic current. This is a difficult parameter to calculate, as it results from a number of different sources, among them the presence of some background third harmonic in the supply voltage, the presence of negative sequence, some unbalance in the commutation reactance and firing angle unbalance. Unbalance in the commutation reactance is the most likely cause of third harmonic generation,

which can be typically up to 0.7% of the fundamental current because the commutation reactance has been neglected [12].

The fundamental frequency current for the 275 KV connection is 236 A and assuming that the new current is inversely proportional to the voltage, the 100 KV current will be

$$I1 = 236 \times [(275) / (100)]$$
$$= 649 \text{ A}$$

Therefore,

$$I3 = (0.7 \times I1) / 100$$
$$= 4.543 \text{ A}$$

and

$$V3 = 4.543 / (\sqrt{0.000611^2 + 0.00582^2})$$
$$= 7096.4 \text{ V or } 1.34\%$$

Therefore, the Total Harmonic Distortion of the system is calculated using equation 4.22.

$$THD = (1 / V1) \left[\sum_{h=2}^{50} (V_h^2) \right]^{1/2}$$
$$= (1 / [(100/\sqrt{3}) \times 1000)] \times [(2.82^2 + 4.729^2 + 7.099^2 + 2.318^2 +$$
$$0.164^2 + 2^2 + 0.118^2 + 2.871^2 + 1.475^2 + 0.516^2 + 0.075^2 + 1.07^2 +$$
$$0.063^2 + 0.293^2 + 0.489^2 + 0.636^2 + 0.736^2 + 0.797^2 + 0.83^2 +$$
$$0.848^2 + 0.858^2 + 0.865^2 + 0.87^2 + 0.876^2 + 0.882^2 + 0.888^2 +$$
$$0.895^2 + 0.902^2 + 0.909^2 + 0.917^2 + 0.924^2 + 0.932^2 + 0.939^2 +$$
$$0.946^2 + 0.953^2 + 0.96^2 + 0.967^2 + 973^2 + 0.98^2 + 0.986^2 + 0.992^2$$

$$+0.998^2 + 1.004^2 + 1.009^2 + 1.014^2 + 1.02^2 + 1.024^2 + 1.029^2 +$$
$$1.034^2 + 1.038^2) \times 1000] \times 100\%$$
$$= 19.95 \%$$

Nth Harmonics	Resistance, Ω	Inductance, H	Capacitance, µF	THD, %
5^{th}	37.2	0.9640	0.421	
7^{th}	26.6	0.4910	0.421	
11^{th}	16.9	0.1990	0.421	19.99
13^{th}	14.3	0.1420	0.421	
17^{th}	444.8	0.0833	0.421	

Table 4.1: The theoretical calculation

Nth Harmonics	Resistance, Ω	Inductance, H	Capacitance, µF	THD, %
5^{th}	37.2037	0.96445	0.420115	
7^{th}	26.5741	0.49206	0.420115	
11^{th}	16.9108	0.19926	0.420115	19.3973
13^{th}	14.3091	0.14267	0.420115	
17^{th}	445.633	0.08343	0.420115	

Table 4.2: The result achieved from the stimulation.

Hence, figure 4.2 below illustrated the MATLAB GUI interface stimulation figure of popup window for the result shown in table 4.2. Besides, to have a clearer view of each parameter that will be situated in the proper order which in branches, therefore, figure 4.3 shown the typical AC filter designed.
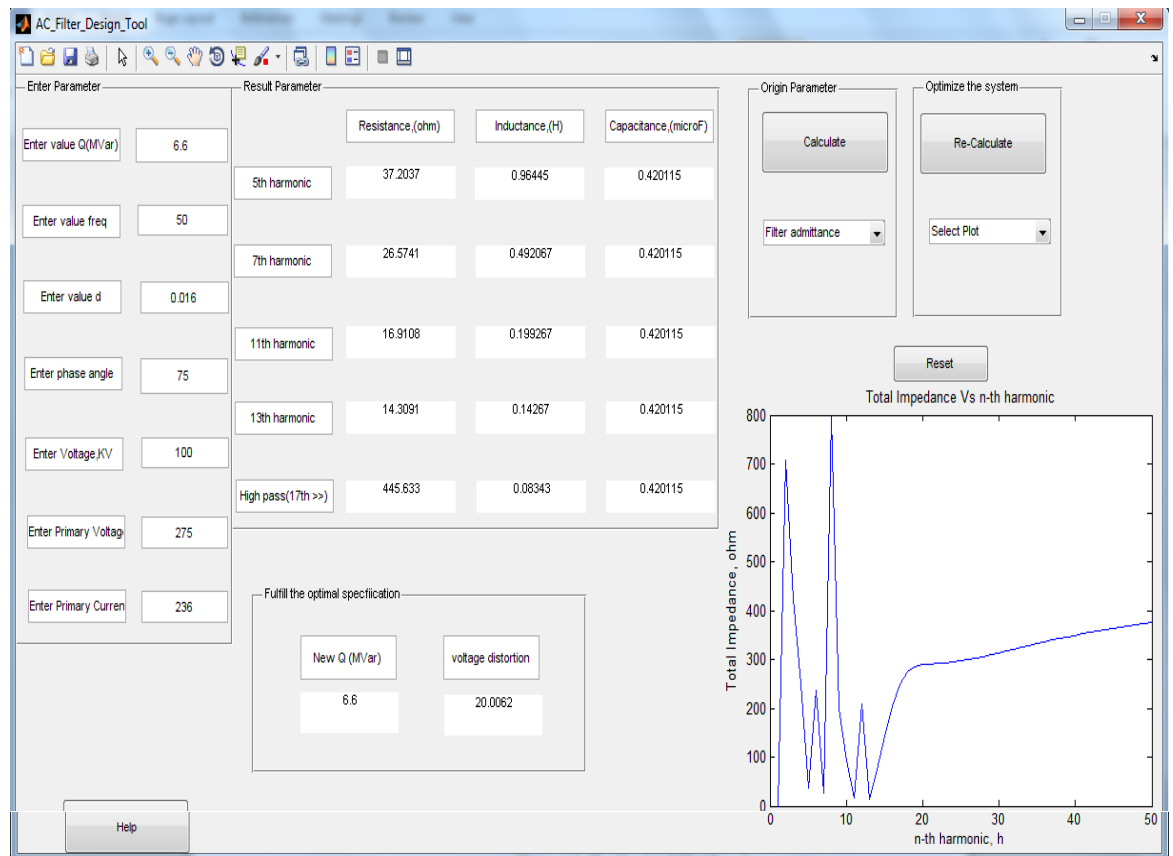
Figure 4.2: The Graphical User Interface
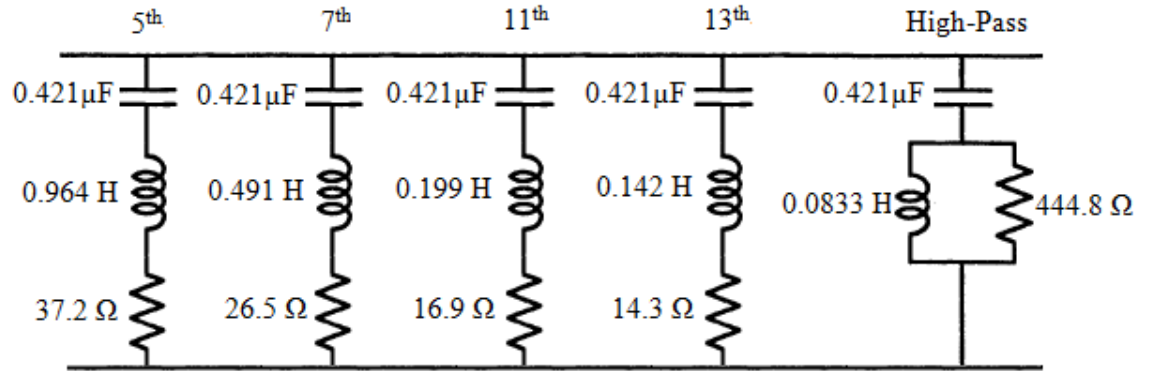
Figure 4.3: The AC Filter Design

4.3.2 Case 2: Low Distortion or a weak a.c system

Let us now consider the possible connection of the converter of the test system described above to a 110 KV instead of 275 KV network and assess whether the filters are effective at all harmonic. Let us further assume that the system third harmonic impedance may lie between 70 and 100 Ω, while the phase angle remains at 75 degree.

The total filter capacitance is

$$C = 80 / (2\pi \times 50 \times 110^2)$$
$$= 21.045 \mu F$$

And that of the individual filter branches $C/5 = 4.209$ μF

Nth Harmonics	Resistance, Ω	Inductance, H	Capacitance, µF	THD, %
5th	3.71	0.0963	4.209	
7th	2.65	0.0490	4.209	
11th	1.69	0.0199	4.209	1.65
13th	1.43	0.0142	4.209	
17th	43.9	0.0083	4.209	

Table 4.3: The theoretical calculation

Nth Harmonics	Resistance, Ω	Inductance, H	Capacitance, µF	THD, %
5th	3.71386	0.0962763	4.20851	
7th	2.65276	0.0491205	4.20851	
11th	1.68812	0.0198918	4.20851	1.60028
13th	1.42841	0.0142420	4.20851	
17th	44.4853	0.0083284	4.20851	

Table 4.4: The result achieved from the stimulation.

4.3.3 Case 3: Reduced filter capacitance

In case 2, repeat the calculation with a total filter capacity of 50 MVar instead of 80 MVar, with the capacitance still equally divided between the various filter branches.

Below are the parameter for the new tuned and damped filter with all the impedance and admittance.

Nth Harmonics	Resistance, Ω	Inductance, H	Capacitance, µF	THD, %
5^{th}	5.94	0.1540	2.631	
7^{th}	4.25	0.07860	2.631	
11^{th}	2.70	0.03180	2.631	2.64
13^{th}	2.29	0.0228	2.631	
17^{th}	71.2	0.0133	2.631	

Table 4.5: The theoretical calculation

Nth Harmonics	Resistance, Ω	Inductance, H	Capacitance, µF	THD, %
5th	5.94218	0.154042	2.63032	
7th	4.24441	0.078593	2.63032	
11th	2.70	0.031827	2.63032	2.56044
13th	2.29	0.022787	2.63032	
17th	71.2	0.013325	2.63032	

Table 4.6: The result achieved from the stimulation.

4.4 Analysis of Results Based on Graph

Once the harmonic sources are clearly defined, they must be interpreted in terms of their effects on the rest of the system and on personnel and equipment external to the power system. Therefore, in power system the possibility amplification of harmonic levels resulting from series and parallel resonances. In this case, the consideration for this project here is parallel resonances. Hence, there are some effects that will be discussed in this following session.

4.4.1 The Effects of System Performance Deals with Total Harmonic Distortion

The system impedance deal with reactive component and resonant filters can give rise to parallel resonance. Besides, they tend to amplify harmonic voltage and current in the filters and the system. From the result that achieved from stimulation, all the figures below show plots of the system impedances for various frequencies, voltage distortion for various frequencies and the operating for each iteration due to considering the capacitance. These figures below illustrated the comparison between before and after fulfilling the filter performance specification, and the lastly was the process of iteration by considering the requirement to fulfill the filter performance specification.

The impedance system and the voltage distortion were consequently very high by referring to figures below are the previous section that has been discussed in case 1 and case 2. According to the theory and principle of harmonics, the reactive power and the de-tuning or quality factor will give a tremendously effect to the system. So to narrow down our scope that just mentioned, we take reactive power as priority to meet the performance specification. The result achieved after had met the performance specification that been verified was approximately the same as expected. Therefore, figure 4.3(b) and figure 4.4(b) are the result that illustrated a large decreased for the both character and let us investigate the changes happened that shown in figure 4.5. The total harmonic distortion is inversely proportional to the iteration of reactive power. Hence, for case 1 the reactive power is increased and case 2 is decreased due to the iteration. Further discussion on this point will be in the coming session.

Case 1

Figure 4.4(a): Before fulfill the filter performance specification

Figure 4.4(b): After fulfilled the filter performance specification
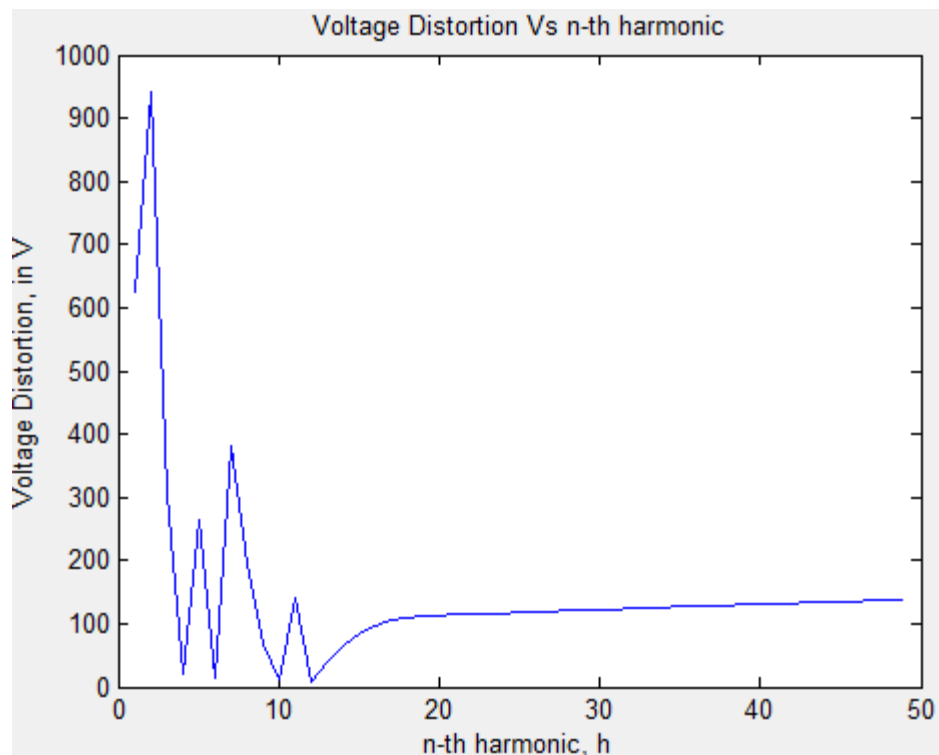
Figure 4.45(a): Before fulfill the filter performance specification
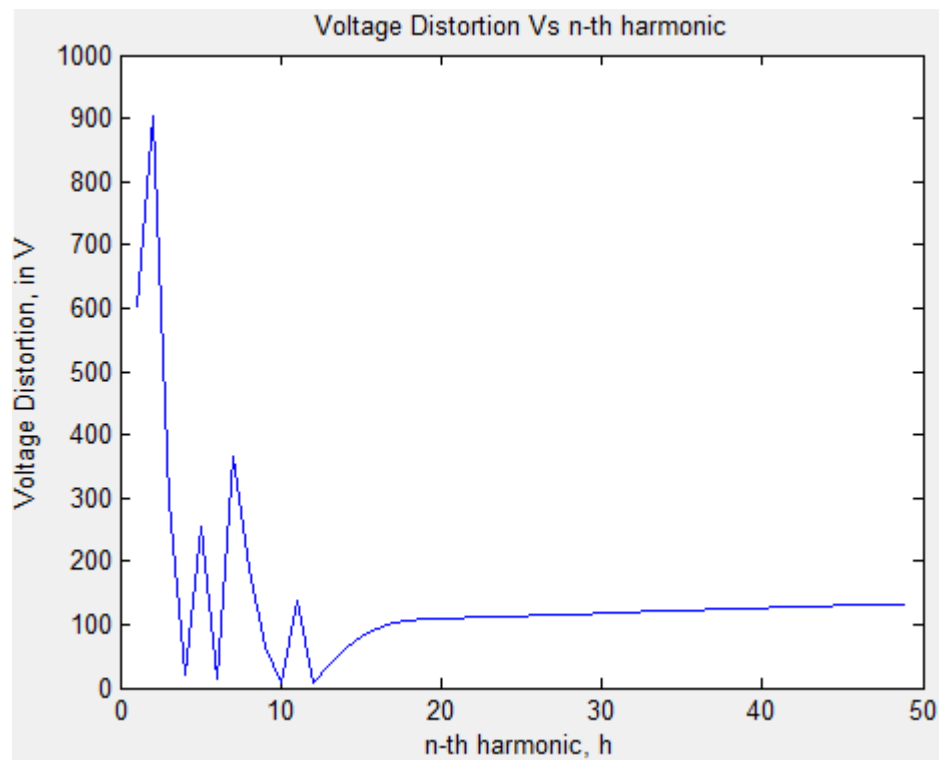
Figure 4.5(b): After fulfilled the filter performance specification
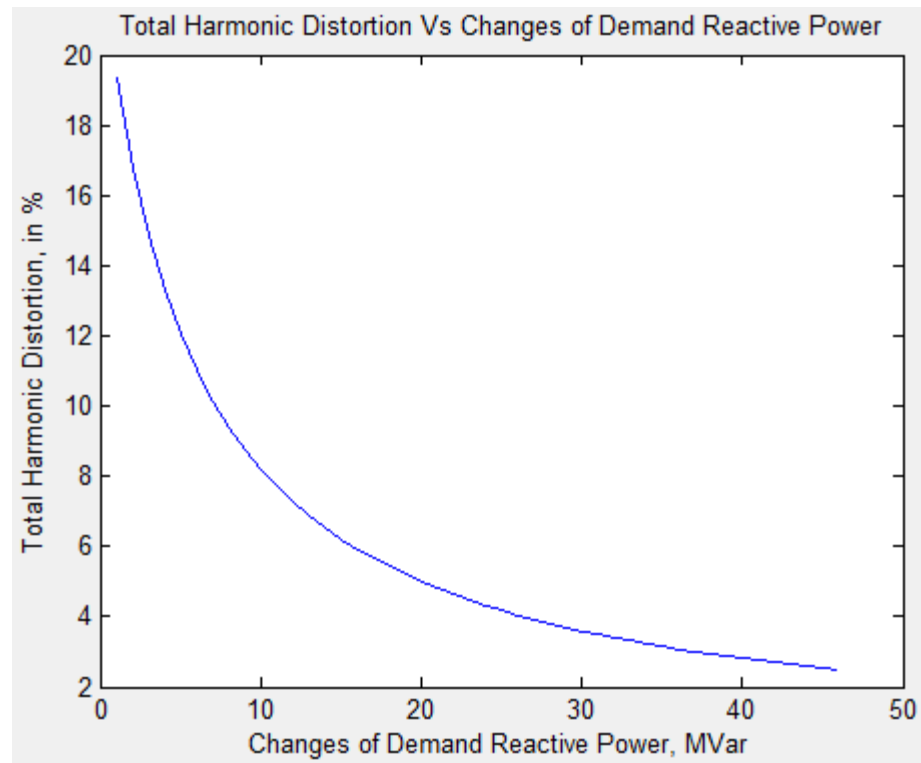
Figure 4.6: The process of iteration to fulfilling the filter performance specification.

Case 2

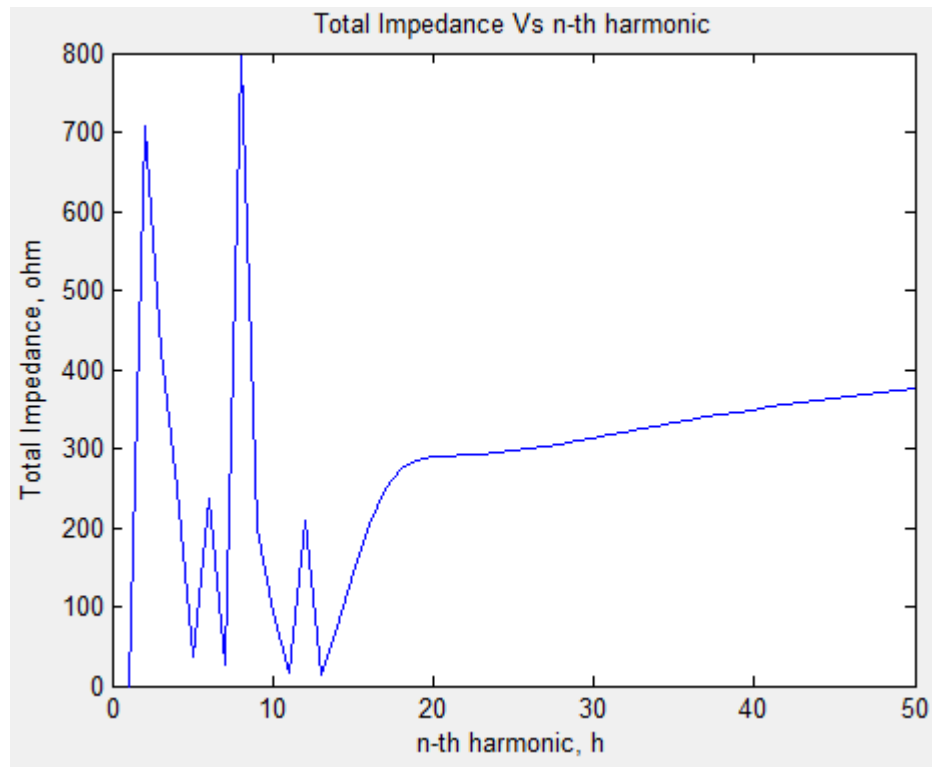
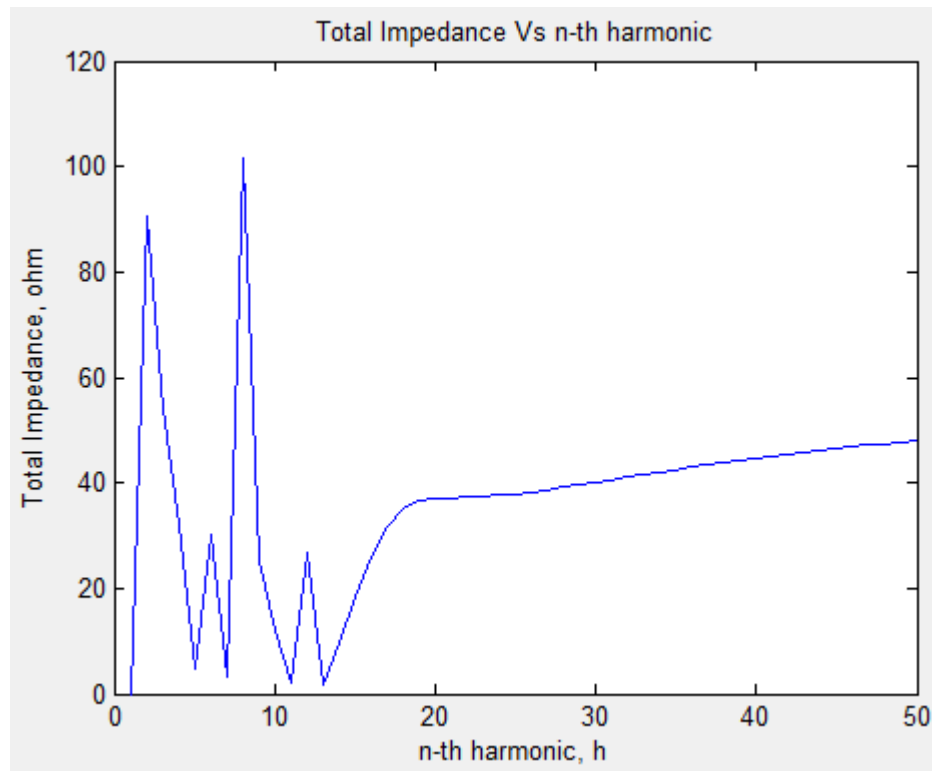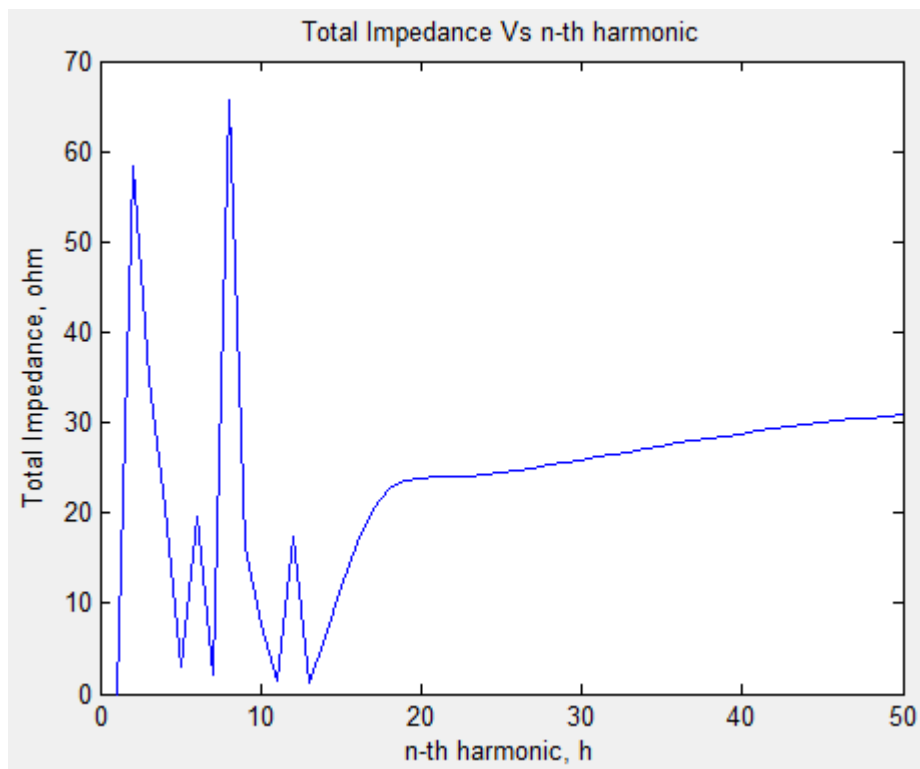Figure 4.7(a): Before fulfill the filter performance specification
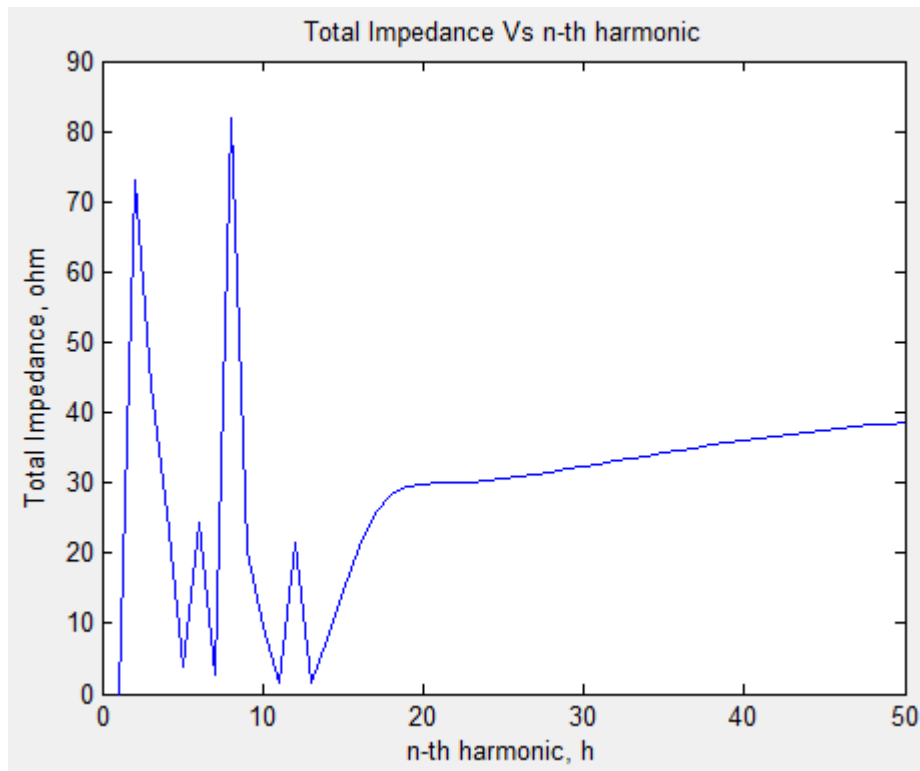
Figure 4.7(b): After fulfilled the filter performance specification
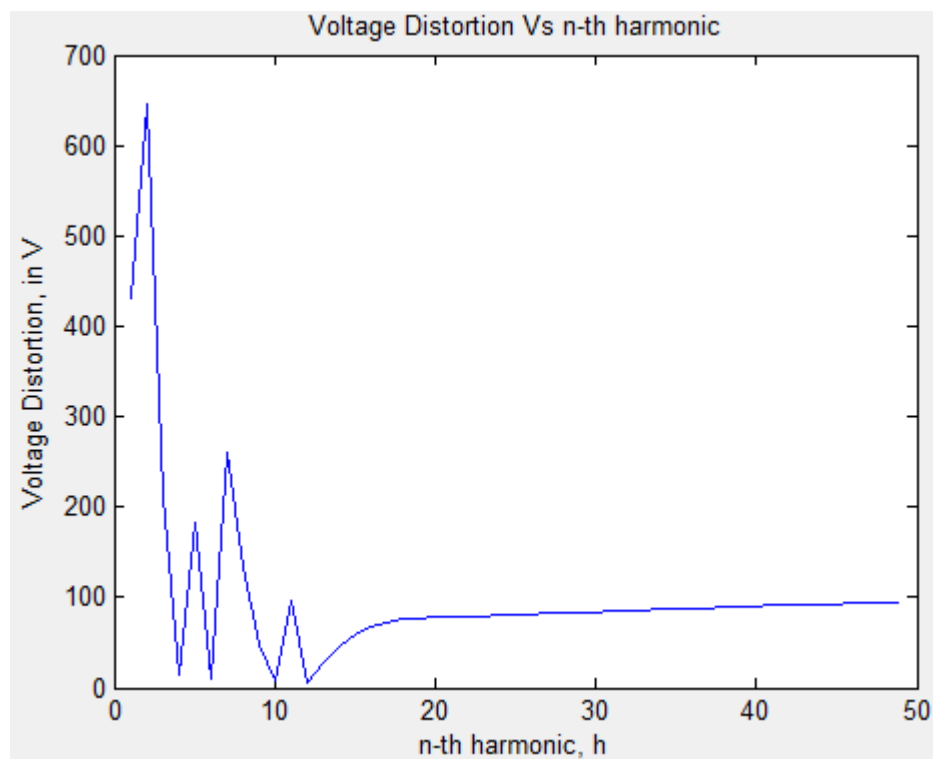
Figure 4.8(a): Before fulfill the filter performance specification
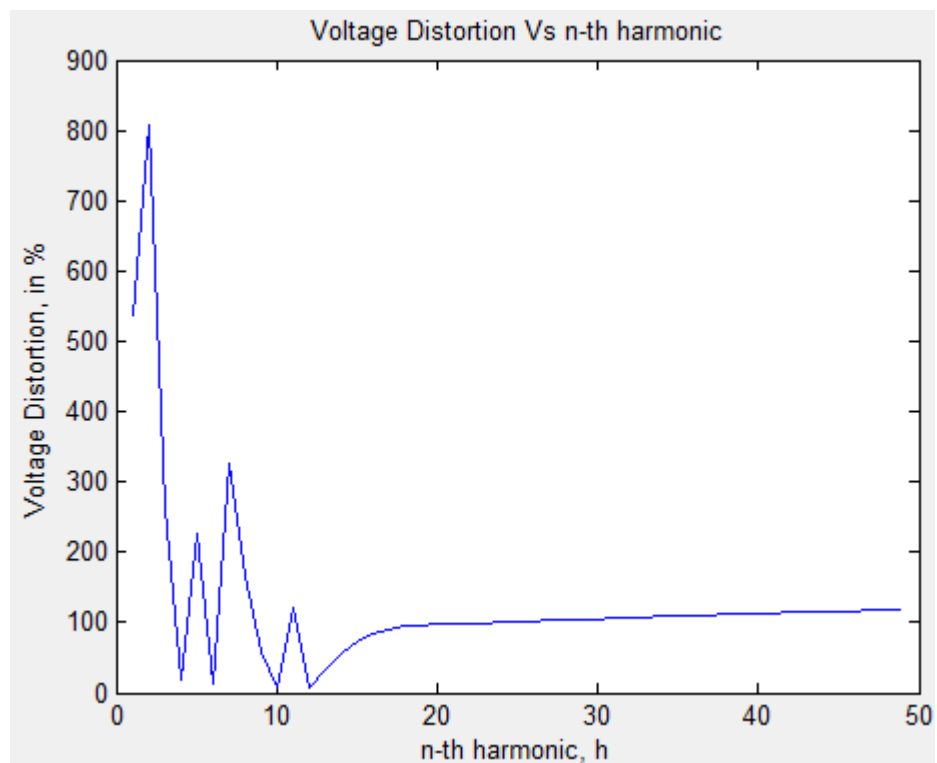
Figure 4.8(b): After fulfilled the filter performance specification
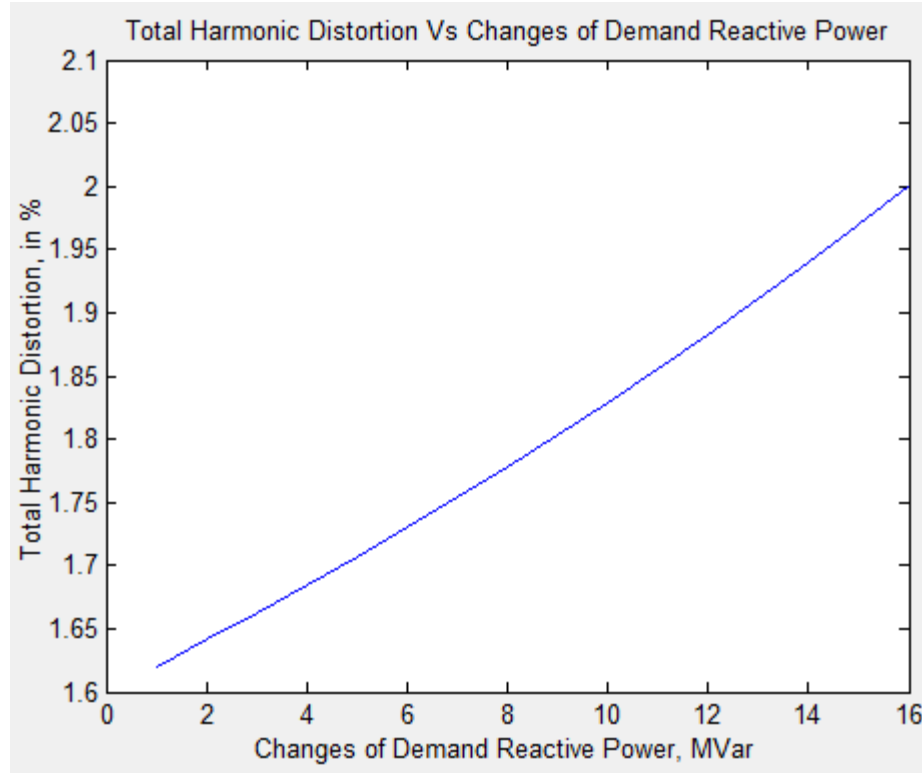
Figure 4.9: The process of iteration that fulfilling the filter performance specification that characterized based on total harmonic distortion

4.4.2 The Changes of Reactive Power Demand Against Total Harmonic Distortion

The filter performance specification that involved the total harmonic distortion was the main criteria to meet the filter requirement. The effect was obviously shown in figure 4.9(a) and figure 4.9(b). The both cases were successfully eliminate the harmonics or drastically reduced to minimize their effects on a wide range of these harmonics on the system and apparatus.

Case 1
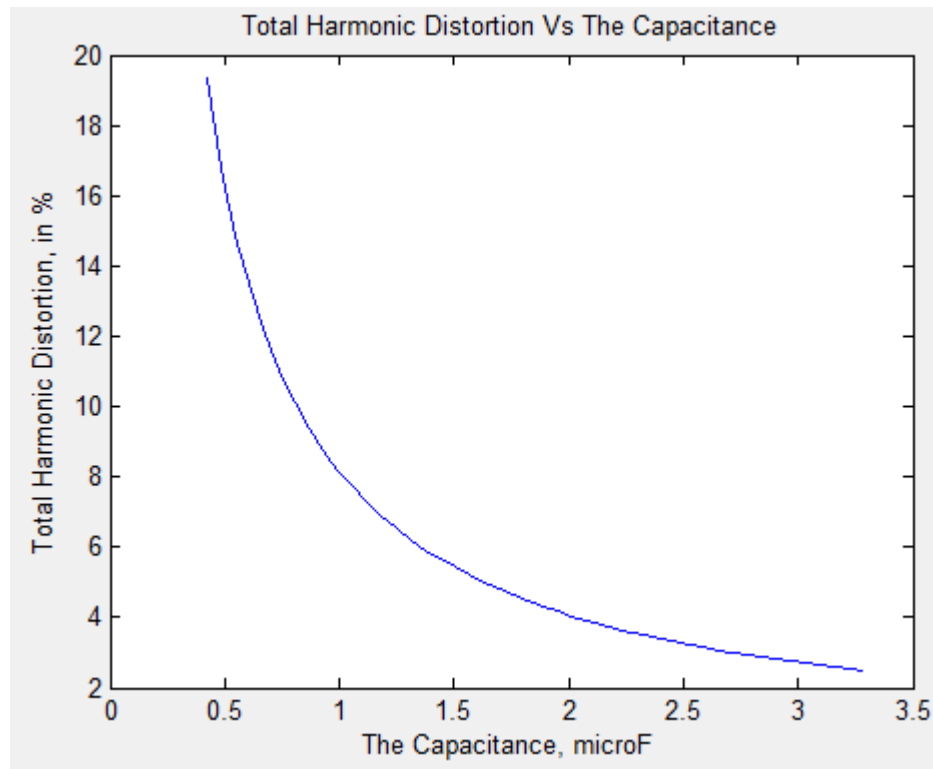
Figure 4.10(a): The process of iteration that fulfilling the filter performance specification that characterized based on capacitance and total harmonic distortion

Case 2
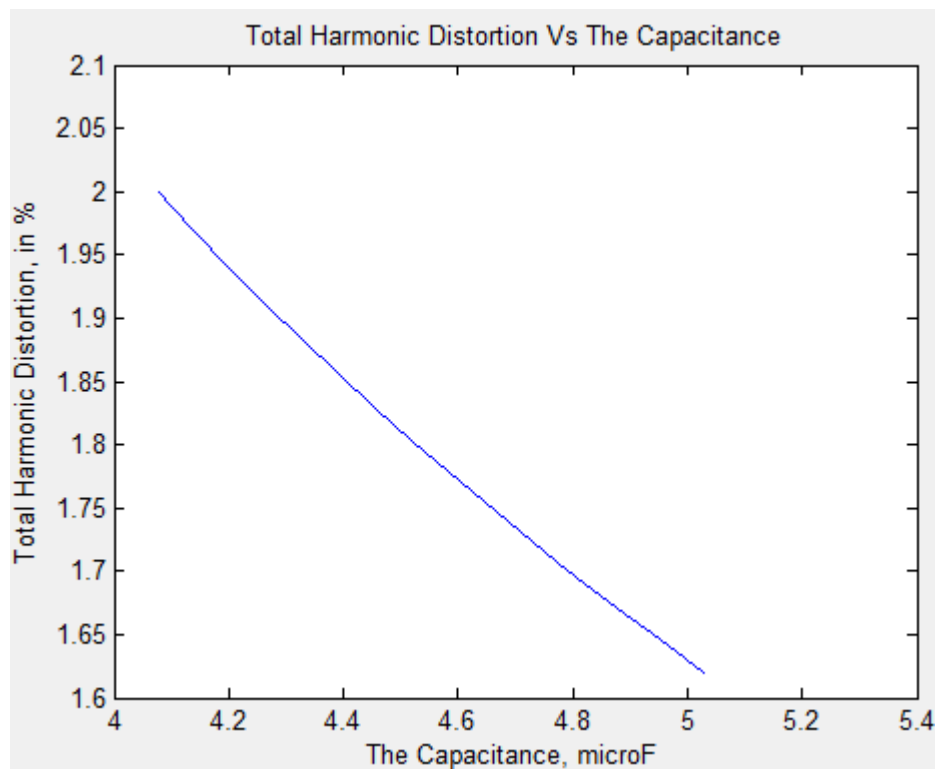
Figure 4.10(b): The process of iteration that fulfilling the filter performance specification that characterized based on capacitance and total harmonic distortion

4.4.3 The changes of Reactive Power Demand over the System

The reactive power demand plays an important role that will give serious impact to the system. According to Case 1, the reactive power demand is kept increasing until approximately stopped at the 46^{th} iteration and meanwhile for Case 2, the reactive power demand is conversely kept decreasing until reach the performance requirement and stopped at 16^{th} iteration. On the other hand, the both figure below can summarized that this techniques is proven can speeded up the design approach.

Case 1
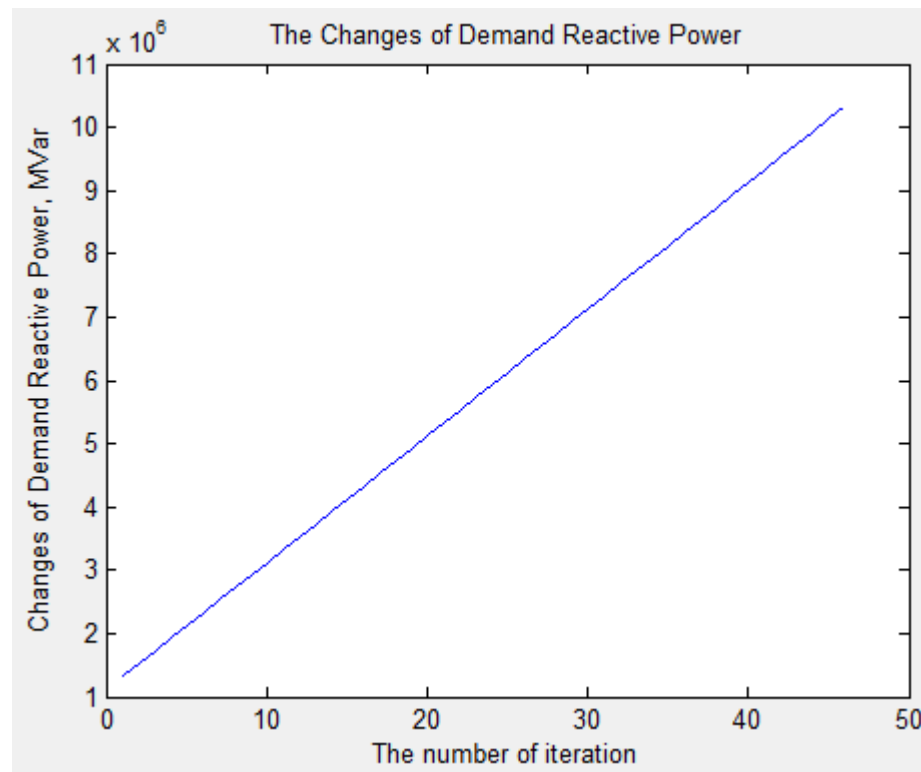
Figure 4.11(a): The process of iteration that fulfilling the filter performance specification that characterized based on capacitance

Case 2
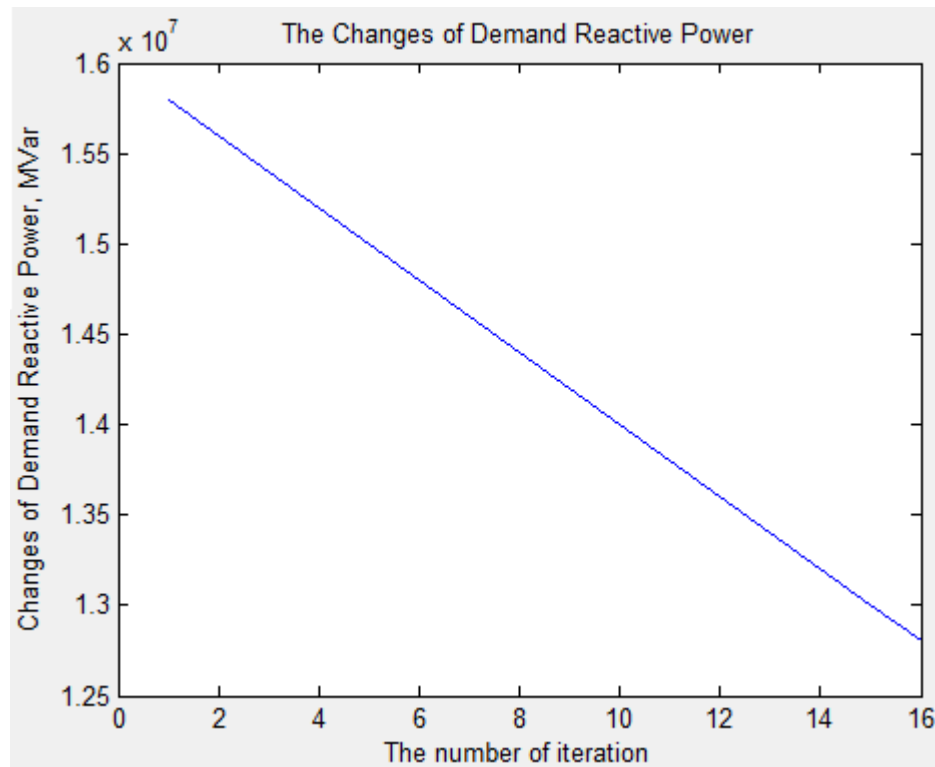
Figure 4.11(b): The process of iteration that fulfilling the filter performance specification that characterized based on capacitance

4.5   SUMMARY

The proposed method has been compared to a typical filter and has been shown to provide a similar solution. The comparison was done with two specific cases:

1. Involving very high harmonic distortion and in another words also known   strong a.c system connection.
2. Involving very low harmonic distortion and also known as weak a.c system connection.

CHAPTER   5

CONCLUSION AND FUTURE DEVELOPMENT

5.1   Conclusion

A thorough analysis of stability for the AC-HVDC power system transmission is presented in the previous chapter by illustrating various type of graph. This analysis is based on designing an AC harmonic filter with considering the system requirement.

According to this analysis, the discussed was focus on the six pulse converter bridge where involving single tuned filter and high pass filter. The discussion for the filter was applied until high pass filter only. Furthermore, the total harmonic distortion was applied to perform the filter performance specification requirement to meet the desired parameter.

The system is successfully modeled into MATLAB GUI stimulation. The designed system functioned accordingly with employing some proper step and there are several useful function available in the MATLAB GUI program such as pushbutton, text, axes, popup menu, panel and so on.

This technique to optimally design a filter has been presented and also has been compared to different ac system configuration and has been shown to provide a similar solution. The proposed technique is simple and direct optimization program to facilitate the work of the design engineer. Literature reviewed showed various methods for filter design, however these methods were based on a trial and error method and were tedious to utilize. Hence, the computerized program had successfully overcome the problem. Moreover, the application of optimization techniques to design filter is found to produce similar results with related ease. Furthermore, the ability to perform sensitivity studies greatly aides the design process.

Moreover, the programed system runs the proposed method more efficiently although many times of recalculation process are needed. Therefore, the problem of consuming a lot of time to design preferable parameter is solved. The result has shown the system is running smoothly without any other interruption such as program error or system run slowly. The trial and error approach is not a practicable apply for the design .

The proposed method addressed two major aspects of the AC harmonic filter design near a HVDC converter:

1) To keep the harmonic contents of voltages and currents at the converter bus to an acceptable level. This is achieved by filtering harmonic voltages at defined harmonic frequencies.

2) To generate required amount of reactive power to be consumed by the converter. This is achieved with the aid of reactive elements in the filter, namely the capacitor and inductor, which generates the reactive power.

The use of a general purpose non-linear optimization package has proven to be an efficient way of arriving at the required solution. The design procedure is interactive, permitting sensitivity analysis studies to be performed.

As a conclusion, based on the analysis and discussion for the few cases involved such as the strong AC system, it will generate very high voltage distortion due to the small filter size been used. This is found out by designed a filter by optimized the size of the filter and is proven that the voltage distortion has been drastically decrease to a more optimum reliability. Consequently, for the weak AC system it appeared conversely compared to the strong AC system which generate very low voltage distortion. Therefore, for this case the problem can be solved by increased the filter size and it is also proven the effect of distortion will be decreased.

In addition, since the high pass filters presents a considerable capacitive reactance at fundamental frequency, it is better to dedicate more reactive power to its capacitance to decrease both losses and resonance chance. Results show that the harmonic circumstances will be improved in this condition.

Finally, it must be considered that the algorithm can be applied for other plant and utility power systems. Selection of the HVDC converter is only for wide spectrum of harmonic frequency, which is generated by this unit. Also, the technique where are applying the algorithm for a practical system with actual data, the results will be presented on the coming development.

5.2   **Recommendation for Future Development**

At present, the proposed method of applying the technique of designing is devised only for 6 pulse converter bridge. Therefore, the further on development will involve are twelve pulse converter bridge. Moreover, the method of applying optimization techniques to design filter is only for (1) single tuned filters and (2) high pass filters of first order. For these basic filter designs, the development will be applied to double tuned filters. This extension of this work to cover high pass filters of higher order, particularly which of third order and C-type has yet to be carries out. Design of DC filters using the proposed method needs to be explored. Furthermore, applying the method of performing the filter performance specification that has been used in this design was the total harmonic distortion (THD), therefore, coming development the consideration for the other specification requirement which is been mentioned in chapter 3 (Section 3.4) will be applied in the filter design.

The application of this technique to design filters by considering the capital cost of the filter that is around 15% [3] that can keep the operating cost of the filter to a minimum level needs to be explored.

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APPENDIX

The coding for all the callback function which represent pushbutton, edit text and popup menu.

Edit text

```matlab
function Q_Callback(hObject, eventdata, handles)
Q = str2double(get(hObject, 'String'));
if isnan(Q)
    set(hObject, 'String', 0);
    errordlg('Input must be a number','Error');
end
% Save the new Q value
handles.metricdata.Q = Q;
guidata(hObject,handles)




function f_Callback(hObject, eventdata, handles)
f = str2double(get(hObject, 'String'));
if isnan(f)
    set(hObject, 'String', 0);
    errordlg('Input must be a number','Error');
end
```

```matlab
% Save the new f value
handles.metricdata.f = f;
guidata(hObject,handles)




function d_Callback(hObject, eventdata, handles)
d = str2double(get(hObject, 'String'));
if isnan(d)
   set(hObject, 'String', 0);
   errordlg('Input must be a number','Error');
end
 % Save the new d value
handles.metricdata.d = d;
guidata(hObject,handles)




function m_Callback(hObject, eventdata, handles)
m = str2double(get(hObject, 'String'));
if isnan(m)
   set(hObject, 'String', 0);
   errordlg('Input must be a number','Error');
end
 % Save the new m value
handles.metricdata.m = m;
guidata(hObject,handles)
```

```matlab
function v_Callback(hObject, eventdata, handles)
v = str2double(get(hObject, 'String'));
if isnan(v)
    set(hObject, 'String', 0);
    errordlg('Input must be a number','Error');
end
 % Save the new v value
handles.metricdata.v = v;
guidata(hObject,handles)




function pv_Callback(hObject, eventdata, handles)
pv = str2double(get(hObject, 'String'));
if isnan(pv)
    set(hObject, 'String', 0);
    errordlg('Input must be a number','Error');
end
 % Save the new pv value
handles.metricdata.pv = pv;
guidata(hObject,handles)




function pa_Callback(hObject, eventdata, handles)
pa = str2double(get(hObject, 'String'));
if isnan(pa)
    set(hObject, 'String', 0);
    errordlg('Input must be a number','Error');
```

```
end
 % Save the new pa value
handles.metricdata.pa = pa;
guidata(hObject,handles)
```

Reset pushbutton

```
% --- Executes on button press in reset.
function reset_Callback(hObject, eventdata, handles)
initialize_gui(gcbf, handles, true);
function initialize_gui(fig_handle, handles, isreset)
if isfield(handles, 'metricdata') && ~isreset
   return;
end
 handles.metricdata.Q = 0;
handles.metricdata.f = 0;
handles.metricdata.d = 0;
handles.metricdata.m = 0;
handles.metricdata.v = 0;
handles.metricdata.pa = 0;
handles.metricdata.pv = 0;
set(handles.Q, 'String', handles.metricdata.Q);
set(handles.f,  'String', handles.metricdata.f);
set(handles.d,  'String', handles.metricdata.d);
set(handles.m,  'String', handles.metricdata.m);
set(handles.v,  'String', handles.metricdata.v);
```

```matlab
set(handles.pa, 'String', handles.metricdata.pa);
set(handles.pv, 'String', handles.metricdata.pv);
set(handles.R5, 'String', 0);
set(handles.R7, 'String', 0);
set(handles.R11, 'String', 0);
set(handles.R13, 'String', 0);
set(handles.Rhp, 'String', 0);
set(handles.L5, 'String', 0);
set(handles.L7, 'String', 0);
set(handles.L11, 'String', 0);
set(handles.L13, 'String', 0);
set(handles.Lhp, 'String', 0);
set(handles.C5, 'String', 0);
set(handles.C7, 'String', 0);
set(handles.C11, 'String', 0);
set(handles.C13, 'String', 0);
set(handles.Chp, 'String', 0);
set(handles.C1, 'String', 0);
set(handles.VHD, 'String', 0);
cla(handles.axes1,'reset')
set(handles.popupmenu1,'Value',1);
set(handles.popupmenu2,'Value',1);
guidata(handles.figure1, handles);
```

Calculate pushbutton

```matlab
% --- Executes on button press in calculate.
function calculate_Callback(hObject, eventdata, handles)
for w= 1:70
f = [2:1:50];
F=[];
for k=1
   F=[F,f'];
end
HP = [];
for k=1
   HP=[HP,f'];
end
C1 =(handles.metricdata.Q + w - 1);
C5=(((handles.metricdata.Q+w-1)*1000000)
/(2*pi*handles.metricdata.f*((handles.metricdata.v)^2)))/5;
C7=(((handles.metricdata.Q+w-1)*1000000)
/(2*pi*handles.metricdata.f*((handles.metricdata.v)^2)))/5;
C11=(((handles.metricdata.Q+w-1)*1000000)
/(2*pi*handles.metricdata.f*((handles.metricdata.v)^2)))/5;
C13=(((handles.metricdata.Q+w-1)*1000000)
/(2*pi*handles.metricdata.f*((handles.metricdata.v)^2)))/5;
Chp=(((handles.metricdata.Q+w-1)*1000000)
/(2*pi*handles.metricdata.f*((handles.metricdata.v)^2)))/5;
R5=1000000/(C5*(handles.metricdata.f*5*2*3.142)*((1+cosd
(handles.metricdata.m))/(2*handles.metricdata.d*sind (handles.metricdata.m))));
R7=1000000/(C7*(handles.metricdata.f*7*2*3.142)*((1+cosd
(handles.metricdata.m))/(2*handles.metricdata.d*sind (handles.metricdata.m))));
```

```
R11=1000000/(C11*(handles.metricdata.f*11*2*3.142)*(1+cosd
(handles.metricdata.m))/(2*handles.metricdata.d*sind (handles.metricdata.m)));
R13=1000000/(C13*(handles.metricdata.f*13*2*3.142)*(1+cosd
(handles.metricdata.m))/(2*handles.metricdata.d*sind (handles.metricdata.m)));
Rhp =1000000/(Chp*2*3.142*handles.metricdata.f*17);
L5 =1000000/(C5*(handles.metricdata.f*5*2*3.142)^2);
L7 =1000000/(C7*(handles.metricdata.f*7*2*3.142)^2);
L11 =1000000/(C11*(handles.metricdata.f*11*2*3.142)^2);
L13 =1000000/(C13*(handles.metricdata.f*13*2*3.142)^2);
Lhp =((Rhp)^2)*(Chp/1000000);
Zs = Rhp*(((cosd (handles.metricdata.m)) + (sind (handles.metricdata.m))*i));
Ys = 1/complex(real(Zs),imag(Zs));
g = (F*handles.metricdata.f*2*pi*C5*0.000001).^(-1);
a = F*handles.metricdata.f*2*pi*Rhp*Lhp*i;
d = (Rhp + HP*handles.metricdata.f*2*pi*Lhp*i).^(-1);
Z5 = R5 + ((F*handles.metricdata.f*2*pi*L5)- g)*i;
Z7 = R7 + ((F*handles.metricdata.f*2*pi*L7) - g)*i;
Z11 = R11 + ((F*handles.metricdata.f*2*pi*L11) - g)*i;
Z13 = R13 + ((F*handles.metricdata.f*2*pi*L13) - g)*i;
H = a.*d;
Zhp = ((F*handles.metricdata.f*2*pi*Chp*0.000001*i).^-1) + H;
X = (Z5.^(-1)) + (Z7.^(-1));
Z = (Z11.^(-1)) + (Z13.^(-1));
W= X + Z;
G = W + (Zhp.^(-1));
Y = G + Ys;
Ytf=abs(Y);
I = handles.metricdata.pa*handles.metricdata.pv/handles.metricdata.v;
I3 = (0.7*I)/100;
v3 = I3*(Ytf.^(-1));
Yf=[];
```

```matlab
for k=1
    Yf=[Yf;v3];
end
S = (Yf.^2);
E=sum(S);
Y=sqrt(E);
vhd = Y./(handles.metricdata.v *10);
    if vhd < 2.5
        if vhd > 1.5
        break
    else
    for w= 1:70
f = [2:1:50];
F=[];
for k=1
    F=[F,f'];
end
HP = [];
for k=1
    HP=[HP,f'];
end
C1 =(handles.metricdata.Q - w);
C5=(((handles.metricdata.Q-w)*1000000)
/(2*3.142*handles.metricdata.f*((handles.metricdata.v)^2)))/5;
C7=(((handles.metricdata.Q-w)*1000000)
/(2*3.142*handles.metricdata.f*((handles.metricdata.v)^2)))/5;
C11=(((handles.metricdata.Q-w)*1000000)
/(2*3.142*handles.metricdata.f*((handles.metricdata.v)^2)))/5;
C13=(((handles.metricdata.Q-w)*1000000)
/(2*3.142*handles.metricdata.f*((handles.metricdata.v)^2)))/5;
```

```
Chp=(((handles.metricdata.Q-w)*1000000)
/(2*3.142*handles.metricdata.f*((handles.metricdata.v)^2)))/5;
R5=1000000/(C5*(handles.metricdata.f*5*2*3.142)*((1+cosd
(handles.metricdata.m))/(2*handles.metricdata.d*sind (handles.metricdata.m))));
R7=1000000/(C7*(handles.metricdata.f*7*2*3.142)*((1+cosd
(handles.metricdata.m))/(2*handles.metricdata.d*sind (handles.metricdata.m))));
R11=1000000/(C11*(handles.metricdata.f*11*2*3.142)*(1+cosd
(handles.metricdata.m))/(2*handles.metricdata.d*sind (handles.metricdata.m)));
R13=1000000/(C13*(handles.metricdata.f*13*2*3.142)*(1+cosd
(handles.metricdata.m))/(2*handles.metricdata.d*sind (handles.metricdata.m)));
Rhp =1000000/(Chp*2*3.142*handles.metricdata.f*17);
L5 =1000000/(C5*(handles.metricdata.f*5*2*3.142)^2);
L7 =1000000/(C7*(handles.metricdata.f*7*2*3.142)^2);
L11 =1000000/(C11*(handles.metricdata.f*11*2*3.142)^2);
L13 =1000000/(C13*(handles.metricdata.f*13*2*3.142)^2);
Lhp =((Rhp)^2)*(Chp/1000000);
Zs = Rhp*(((cosd (handles.metricdata.m)) + (sind (handles.metricdata.m))*i));
Ys = 1/complex(real(Zs),imag(Zs));
g = (F*handles.metricdata.f*2*pi*C5*0.000001).^(-1);
a = F*handles.metricdata.f*2*pi*Rhp*Lhp*i;
d = (Rhp + HP*handles.metricdata.f*2*pi*Lhp*i).^(-1);
Z5 = R5 + ((F*handles.metricdata.f*2*pi*L5)- g)*i;
Z7 = R7 + ((F*handles.metricdata.f*2*pi*L7) - g)*i;
Z11 = R11 + ((F*handles.metricdata.f*2*pi*L11) - g)*i;
Z13 = R13 + ((F*handles.metricdata.f*2*pi*L13) - g)*i;
H = a.*d;
Zhp = ((F*handles.metricdata.f*2*pi*Chp*0.000001*i).^-1) + H;
X = (Z5.^(-1)) + (Z7.^(-1));
Z = (Z11.^(-1)) + (Z13.^(-1));
W= X + Z;
G = W + (Zhp.^(-1));
```

```matlab
Y = G + Ys;

Ytf=abs(Y);

I = handles.metricdata.pa*handles.metricdata.pv/handles.metricdata.v;

I3 = (0.7*I)/100;

v3 = I3*(Ytf.^(-1));

Yf=[];

for k=1

    Yf=[Yf;v3];

end

S = (Yf.^2);

E=sum(S);

Y=sqrt(E);

vhd = Y./((handles.metricdata.v/sqrt(3)) *10);

if vhd > 1.5

    break

end

    end

      end

    end

    if vhd > 1.5 & vhd < 2.5

      break

    end

end


VHD=vhd;

if  vhd < 2.5 && vhd > 2

helpdlg('The Results is OPTIMAL','Is the RESULTS OPTIMAL?');
end


set(handles.C5, 'String', C5);

set(handles.C7, 'String', C7);
```

```matlab
set(handles.C11, 'String', C11);
set(handles.C13, 'String', C13);
set(handles.Chp, 'String', Chp);
set(handles.L5, 'String', L5);
set(handles.L7, 'String', L7);
set(handles.L11, 'String', L11);
set(handles.L13, 'String', L13);
set(handles.Lhp, 'String', Lhp);
set(handles.R5, 'String', R5);
set(handles.R7, 'String', R7);
set(handles.R11, 'String', R11);
set(handles.R13, 'String', R13);
set(handles.Rhp, 'String', Rhp);
set(handles.C1, 'String',C1);
set(handles.VHD, 'String',VHD);
```

Re-calculate pushbutton

```matlab
% --- Executes on button press in pushbutton.
function pushbutton_Callback(hObject, eventdata, handles)
f = [50:50:2500];
F=[];
for k=1
    F=[F,f'];
end
HP = [];
```

```
for k=1
    HP=[HP,f'];
end
C1 = (handles.metricdata.Q);
C5=((handles.metricdata.Q*1000000)
/(2*3.142*handles.metricdata.f*((handles.metricdata.v)^2)))/5;
C7=((handles.metricdata.Q*1000000)
/(2*3.142*handles.metricdata.f*((handles.metricdata.v)^2)))/5;
C11=((handles.metricdata.Q*1000000)
/(2*3.142*handles.metricdata.f*((handles.metricdata.v)^2)))/5;
C13=((handles.metricdata.Q*1000000)
/(2*3.142*handles.metricdata.f*((handles.metricdata.v)^2)))/5;
Chp=((handles.metricdata.Q*1000000)
/(2*3.142*handles.metricdata.f*((handles.metricdata.v)^2)))/5;
R5=1000000/(C5*(handles.metricdata.f*5*2*3.142)*((1+cosd
(handles.metricdata.m))/(2*handles.metricdata.d*sind (handles.metricdata.m))));
R7=1000000/(C7*(handles.metricdata.f*7*2*3.142)*((1+cosd
(handles.metricdata.m))/(2*handles.metricdata.d*sind (handles.metricdata.m))));
R11=1000000/(C11*(handles.metricdata.f*11*2*3.142)*(1+cosd
(handles.metricdata.m))/(2*handles.metricdata.d*sind (handles.metricdata.m)));
R13=1000000/(C13*(handles.metricdata.f*13*2*3.142)*(1+cosd
(handles.metricdata.m))/(2*handles.metricdata.d*sind (handles.metricdata.m)));
Rhp =1000000/(Chp*2*3.142*handles.metricdata.f*17);
L5 =1000000/(C5*(handles.metricdata.f*5*2*3.142)^2);
L7 =1000000/(C7*(handles.metricdata.f*7*2*3.142)^2);
L11 =1000000/(C11*(handles.metricdata.f*11*2*3.142)^2);
L13 =1000000/(C13*(handles.metricdata.f*13*2*3.142)^2);
Lhp =((Rhp)^2)*(Chp/1000000);
Zs = Rhp*(((cosd (handles.metricdata.m)) + (sind (handles.metricdata.m))*i));
Ys = 1/complex(real(Zs),imag(Zs));
g = (F*2*pi*C5*0.000001).^(-1);
```

```
a = F*2*pi*Rhp*Lhp*i;

d = (Rhp + HP*2*pi*Lhp*i).^(-1);

Z5 = R5 + ((F*2*pi*L5)- g)*i;

Z7 = R7 + ((F*2*pi*L7) - g)*i;

Z11 = R11 + ((F*2*pi*L11) - g)*i;

Z13 = R13 + ((F*2*pi*L13) - g)*i;

H = a.*d;

Zhp = ((F*2*pi*Chp*0.000001*i).^-1) + H;

X = (Z5.^(-1)) + (Z7.^(-1));

Z = (Z11.^(-1)) + (Z13.^(-1));

W= X + Z;

G = W + (Zhp.^(-1));

Y = G + Ys;

Ytf=abs(Y);

I = handles.metricdata.pa*handles.metricdata.pv/handles.metricdata.v;

I3 = (0.7*I)/100;

v3 = I3*(Ytf.^(-1));

Yf=[];

for k=1

    Yf=[Yf;v3];

end

S = (Yf.^2);

E=sum(S);

Y=sqrt(E);

VHD = Y./(((handles.metricdata.v)./sqrt(3))*10);

if VHD > 1.5 && VHD < 2.5

helpdlg('The Results is OPTIMAL','Is the RESULTS OPTIMAL?');

else
errordlg('The Results is NOT OPTIMAL','Is the RESULTS OPTIMAL?');

 end

set(handles.C5, 'String', C5);
```

```matlab
set(handles.C7, 'String', C7);
set(handles.C11, 'String', C11);
set(handles.C13, 'String', C13);
set(handles.Chp, 'String', Chp);
set(handles.L5, 'String', L5);
set(handles.L7, 'String', L7);
set(handles.L11, 'String', L11);
set(handles.L13, 'String', L13);
set(handles.Lhp, 'String', Lhp);
set(handles.R5, 'String', R5);
set(handles.R7, 'String', R7);
set(handles.R11, 'String', R11);
set(handles.R13, 'String', R13);
set(handles.Rhp, 'String', Rhp);
set(handles.C1, 'String',C1);
set(handles.VHD, 'String',VHD);
```

Popup menu 1

```matlab
% --- Executes on selection change in popupmenu1.
function popupmenu1_Callback(hObject, eventdata, handles)
f = [2:1:50];
F=[];
for k=1
    F=[F,f'];
end
HP = [];
```

```
for k=1
    HP=[HP,f'];
end


C1 =((handles.metricdata.Q )*1000000)/5;
C5=(((handles.metricdata.Q)*1000000)
/(2*3.142*handles.metricdata.f*((handles.metricdata.v)^2)))/5;
C7=(((handles.metricdata.Q)*1000000)
/(2*3.142*handles.metricdata.f*((handles.metricdata.v)^2)))/5;
C11=(((handles.metricdata.Q)*1000000)
/(2*3.142*handles.metricdata.f*((handles.metricdata.v)^2)))/5;
C13=(((handles.metricdata.Q)*1000000)
/(2*3.142*handles.metricdata.f*((handles.metricdata.v)^2)))/5;
Chp=(((handles.metricdata.Q)*1000000)
/(2*3.142*handles.metricdata.f*((handles.metricdata.v)^2)))/5;
R5=1000000/(C5*(handles.metricdata.f*5*2*3.142)*((1+cosd
(handles.metricdata.m))/(2*handles.metricdata.d*sind (handles.metricdata.m))));
R7=1000000/(C7*(handles.metricdata.f*7*2*3.142)*((1+cosd
(handles.metricdata.m))/(2*handles.metricdata.d*sind (handles.metricdata.m))));
R11=1000000/(C11*(handles.metricdata.f*11*2*3.142)*(1+cosd
(handles.metricdata.m))/(2*handles.metricdata.d*sind (handles.metricdata.m)));
R13=1000000/(C13*(handles.metricdata.f*13*2*3.142)*(1+cosd
(handles.metricdata.m))/(2*handles.metricdata.d*sind (handles.metricdata.m)));
Rhp =1000000/(Chp*2*3.142*handles.metricdata.f*17);
L5 =1000000/(C5*(handles.metricdata.f*5*2*3.142)^2);
L7 =1000000/(C7*(handles.metricdata.f*7*2*3.142)^2);
L11 =1000000/(C11*(handles.metricdata.f*11*2*3.142)^2);
L13 =1000000/(C13*(handles.metricdata.f*13*2*3.142)^2);
Lhp =((Rhp)^2)*(Chp/1000000);
Zs = Rhp*(((cosd (handles.metricdata.m)) + (sind (handles.metricdata.m))*i));
Ys = 1/complex(real(Zs),imag(Zs));
```

```matlab
g = (F*handles.metricdata.f*2*pi*C5*0.000001).^(-1);

a = F*handles.metricdata.f*2*pi*Rhp*Lhp*i;

d = (Rhp + HP*handles.metricdata.f*2*pi*Lhp*i).^(-1);

Z5 = R5 + ((F*handles.metricdata.f*2*pi*L5)- g)*i;

Z7 = R7 + ((F*handles.metricdata.f*2*pi*L7) - g)*i;

Z11 = R11 + ((F*handles.metricdata.f*2*pi*L11) - g)*i;

Z13 = R13 + ((F*handles.metricdata.f*2*pi*L13) - g)*i;

H = a.*d;

Zhp = ((F*handles.metricdata.f*2*pi*Chp*0.000001*i).^-1) + H;

X = (Z5.^(-1)) + (Z7.^(-1));

Z = (Z11.^(-1)) + (Z13.^(-1));

W= X + Z;

G = W + (Zhp.^(-1));

D= G.^-1;

L(F) = abs(D);

Y = G + Ys;

Ytf=abs(Y);

I = handles.metricdata.pa*handles.metricdata.pv/handles.metricdata.v;

I3 = (0.7*I)/100;

v3 = I3*(Ytf.^(-1));

Yf=[];

for k=1

    Yf=[Yf;v3];

end

S = (Yf.^2);

E=sum(S);

Y=sqrt(E);

vhd = Y./(handles.metricdata.v *10);


val=get(hObject,'Value');

str=get(hObject,'String');
```

```matlab
switch str{val}
    case 'nth harmonic Vs voltage distorted'
        axes(handles.axes1)

        plot(Yf);
        title('Voltage Distortion Vs n-th harmonic');
        xlabel('n-th harmonic, h');
        ylabel('Voltage Distortion, in V');
    case 'Filter admittance'
        axes(handles.axes1)

        plot(L);
        title('Total Impedance Vs n-th harmonic');
        xlabel('n-th harmonic, h');
        ylabel('Total Impedance, ohm');

end
```

Popup menu 2

```matlab
% --- Executes on selection change in popupmenu2.
function popupmenu2_Callback(hObject, eventdata, handles)
for w= 1:70
f = [2:1:50];
F=[];
for k=1
    F=[F,f'];
```

```
end
HP = [];
for k=1
   HP=[HP,f'];
end

C1(w)=((handles.metricdata.Q + w - 1)*1000000)/5;
C5(w)=(((handles.metricdata.Q+w-1)*1000000)
/(2*3.142*handles.metricdata.f*((handles.metricdata.v)^2)))/5;
C7(w)=(((handles.metricdata.Q+w-1)*1000000)
/(2*3.142*handles.metricdata.f*((handles.metricdata.v)^2)))/5;
C11(w)=(((handles.metricdata.Q+w-1)*1000000)
/(2*3.142*handles.metricdata.f*((handles.metricdata.v)^2)))/5;
C13(w)=(((handles.metricdata.Q+w-1)*1000000)
/(2*3.142*handles.metricdata.f*((handles.metricdata.v)^2)))/5;
Chp(w)=(((handles.metricdata.Q+w-1)*1000000)
/(2*3.142*handles.metricdata.f*((handles.metricdata.v)^2)))/5;
R5(w)=1000000/(C5(w)*(handles.metricdata.f*5*2*3.142)*((1+cosd
(handles.metricdata.m))/(2*handles.metricdata.d*sind (handles.metricdata.m))));
R7(w)=1000000/(C7(w)*(handles.metricdata.f*7*2*3.142)*((1+cosd
(handles.metricdata.m))/(2*handles.metricdata.d*sind (handles.metricdata.m))));
R11(w)=1000000/(C11(w)*(handles.metricdata.f*11*2*3.142)*(1+cosd
(handles.metricdata.m))/(2*handles.metricdata.d*sind (handles.metricdata.m)));
R13(w)=1000000/(C13(w)*(handles.metricdata.f*13*2*3.142)*(1+cosd
(handles.metricdata.m))/(2*handles.metricdata.d*sind (handles.metricdata.m)));
Rhp(w) =1000000/(Chp(w)*2*3.142*handles.metricdata.f*17);
L5(w) =1000000/(C5(w)*(handles.metricdata.f*5*2*3.142)^2);
L7(w) =1000000/(C7(w)*(handles.metricdata.f*7*2*3.142)^2);
L11(w) =1000000/(C11(w)*(handles.metricdata.f*11*2*3.142)^2);
L13(w) =1000000/(C13(w)*(handles.metricdata.f*13*2*3.142)^2);
Lhp(w) =((Rhp(w))^2)*(Chp(w)/1000000);
```

```
Zs(w)=Rhp(w)*(((cosd(handles.metricdata.m))+(sind
(handles.metricdata.m))*i));
Ys = 1/complex(real(Zs(w)),imag(Zs(w)));
g = (F*handles.metricdata.f*2*pi*C5(w)*0.000001).^(-1);
a = F*handles.metricdata.f*2*pi*Rhp(w)*Lhp(w)*i;
d = (Rhp(w) + HP*handles.metricdata.f*2*pi*Lhp(w)*i).^(-1);
Z5 = R5(w) + ((F*handles.metricdata.f*2*pi*L5(w))- g)*i;
Z7 = R7(w) + ((F*handles.metricdata.f*2*pi*L7(w)) - g)*i;
Z11 = R11(w) + ((F*handles.metricdata.f*2*pi*L11(w)) - g)*i;
Z13 = R13(w) + ((F*handles.metricdata.f*2*pi*L13(w)) - g)*i;
H = a.*d;
Zhp = ((F*handles.metricdata.f*2*pi*Chp(w)*0.000001*i).^-1) + H;
X = (Z5.^(-1)) + (Z7.^(-1));
Z = (Z11.^(-1)) + (Z13.^(-1));
W= X + Z;
G = W + (Zhp.^(-1));
D= G.^-1;
L(F) = abs(D);
Y = G + Ys;
Ytf=abs(Y);
I = handles.metricdata.pa*handles.metricdata.pv/handles.metricdata.v;
I3 = (0.7*I)/100;
v3 = I3*(Ytf.^(-1));
Yf=[];
for k=1
    Yf=[Yf;v3];
end
S = (Yf.^2);
E=sum(S);
Y=sqrt(E);
vhd(w) = Y./((handles.metricdata.v/sqrt(3)) *10);
```

```
    if  vhd(w) < 2.5
       if vhd(w) > 1.5
       break
     else
    for w= 1:70
f = [2:1:50];
F=[];
for k=1
    F=[F,f'];
end
HP = [];
for k=1
    HP=[HP,f'];
end


C1(w)=((handles.metricdata.Q - w)*1000000)/5;
C5(w)=(((handles.metricdata.Q-w)*1000000)
/(2*3.142*handles.metricdata.f*((handles.metricdata.v)^2)))/5;
C7(w)=(((handles.metricdata.Q-w)*1000000)
/(2*3.142*handles.metricdata.f*((handles.metricdata.v)^2)))/5;
C11(w)=(((handles.metricdata.Q-w)*1000000)
/(2*3.142*handles.metricdata.f*((handles.metricdata.v)^2)))/5;
C13(w)=(((handles.metricdata.Q-w)*1000000)
/(2*3.142*handles.metricdata.f*((handles.metricdata.v)^2)))/5;
Chp(w)=(((handles.metricdata.Q-w)*1000000)
/(2*3.142*handles.metricdata.f*((handles.metricdata.v)^2)))/5;
```

```
R5(w)=1000000/(C5(w)*(handles.metricdata.f*5*2*3.142)*((1+cosd
(handles.metricdata.m))/(2*handles.metricdata.d*sind (handles.metricdata.m))));
R7(w)=1000000/(C7(w)*(handles.metricdata.f*7*2*3.142)*((1+cosd
(handles.metricdata.m))/(2*handles.metricdata.d*sind (handles.metricdata.m))));
R11(w)=1000000/(C11(w)*(handles.metricdata.f*11*2*3.142)*(1+cosd
(handles.metricdata.m))/(2*handles.metricdata.d*sind (handles.metricdata.m)));
R13(w)=1000000/(C13(w)*(handles.metricdata.f*13*2*3.142)*(1+cosd
(handles.metricdata.m))/(2*handles.metricdata.d*sind (handles.metricdata.m)));
Rhp(w) =1000000/(Chp(w)*2*3.142*handles.metricdata.f*17);
L5(w) =1000000/(C5(w)*(handles.metricdata.f*5*2*3.142)^2);
L7(w) =1000000/(C7(w)*(handles.metricdata.f*7*2*3.142)^2);
L11(w) =1000000/(C11(w)*(handles.metricdata.f*11*2*3.142)^2);
L13(w) =1000000/(C13(w)*(handles.metricdata.f*13*2*3.142)^2);
Lhp(w) =((Rhp(w))^2)*(Chp(w)/1000000);
Zs(w)=Rhp(w)*(((cosd(handles.metricdata.m))+(sind
(handles.metricdata.m))*i));
Ys = 1/complex(real(Zs(w)),imag(Zs(w)));
g = (F*handles.metricdata.f*2*pi*C5(w)*0.000001).^(-1);
a = F*handles.metricdata.f*2*pi*Rhp(w)*Lhp(w)*i;
d = (Rhp(w) + HP*handles.metricdata.f*2*pi*Lhp(w)*i).^(-1);
Z5 = R5(w) + ((F*handles.metricdata.f*2*pi*L5(w))- g)*i;
Z7 = R7(w) + ((F*handles.metricdata.f*2*pi*L7(w)) - g)*i;
Z11 = R11(w) + ((F*handles.metricdata.f*2*pi*L11(w)) - g)*i;
Z13 = R13(w) + ((F*handles.metricdata.f*2*pi*L13(w)) - g)*i;
H = a.*d;
Zhp = ((F*handles.metricdata.f*2*pi*Chp(w)*0.000001*i).^-1) + H;
X = (Z5.^(-1)) + (Z7.^(-1));
Z = (Z11.^(-1)) + (Z13.^(-1));
W= X + Z;
G = W + (Zhp.^(-1));
D= G.^-1;
```

```matlab
L(F) = abs(D);
Y = G + Ys;
Ytf=abs(Y);
I = handles.metricdata.pa*handles.metricdata.pv/handles.metricdata.v;
I3 = (0.7*I)/100;
v3 = I3*(Ytf.^(-1));
Yf=[];
for k=1
    Yf=[Yf;v3];
end
S = (Yf.^2);
E=sum(S);
Y=sqrt(E);
vhd(w) = Y./((handles.metricdata.v/sqrt(3)) *10);
if vhd(w) > 1.5
    break
end
    end


        end
    end


if vhd(w) > 1.5 & vhd(w) < 2.5
    break
end
end

val=get(hObject,'Value');
str=get(hObject,'String');
switch str{val}
    case 'times Vs Vhd'
```

```matlab
    axes(handles.axes1)


    plot(vhd);
    title('Total Harmonic Distortion Vs Changes of Demand Reactive Power');
    xlabel('Changes of Demand Reactive Power, MVar');
    ylabel('Total Harmonic Distortion, in %');
case 'times Vs Q'
     axes(handles.axes1)


    plot(C1);
    title('The Changes of Demand Reactive Power');
    xlabel('The number of iteration');
    ylabel('Changes of Demand Reactive Power, MVar');
case 'nth harmonic Vs voltage distorted'
     axes(handles.axes1)


    plot(Yf);
    title('Voltage Distortion Vs n-th harmonic');
    xlabel('n-th harmonic, h');
    ylabel('Voltage Distortion, in V');
case 'Filter admittance'
     axes(handles.axes1)


    plot(L);
    title('Total Impedance Vs n-th harmonic');
    xlabel('n-th harmonic, h');
    ylabel('Total Impedance, ohm');
case 'Q Vs THD'
     axes(handles.axes1)


    plot(C5,vhd);
```

```matlab
        title('Total Harmonic Distortion Vs The Capacitance');
        xlabel('The Capacitance, microF');
        ylabel('Total Harmonic Distortion, in %');
end




Help pushbutton


% --- Executes on button press in help.
function help_Callback(hObject, eventdata, handles)
open('C:\Users\Cha\Documents\MATLAB\guide.txt');
```