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FACULTY OF ELECTRICAL AND ELECTRONICS TECHNOLOGY AND INFORMATION AND COMMUNICATION TECHNOLOGY (DEPARTMENT OF ELECTRICAL AND ELECTRONICS TECHNOLOGY)

DESIGN AND ANALYSIS OF PROPORTIONAL-RESONANT CONTROLLER WITH THYRISTOR CONTROLLED SWITCHED CAPACITOR FOR MITIGATION OF HARMONIC DISTORTION IN THREE-PHASE SYSTEM

A thesis submitted to the school of graduate studies, Ethiopian Technical and Vocational Training Institute in partial fulfillment of Master of Science

In

Electrical automation and control technology (control)

By,

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Supervisor,

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AUGUST 2022

Addis Ababa, Ethiopia

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In partial fulfillment for the Degree
MASTER OF SCIENCE *in* ELECTRICAL AUTOMATION AND CONTROL TECHNOLOGY MANAGEMENT

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DECLARATION

I, the undersigned pure that the work being obtainable during this theory entitled “Design and Analysis of Proportional-Resonant Controller with Thyristor Controlled Switched Capacitor for Mitigation Harmonic Distortion in Three-Phase System” is one in every of my very own styles of works and has not been presented for the degree during this or another school, and every one wellsprings of materials used for the idea are totally perceived.

Name: ENATNESH ASRAT (MTR/527/13)

Signature: - ________________________

Place: Addis Ababa

Date of Submission: - _________________

This thesis has been submitted with my approval as a university advisor

Dr. BISRAT GEZAHEGN	-----------------------	30/08/2022 --------------
Advisor name	Signature	Date

TECHNICAL AND VOCATIONAL TRAINING INSTITUTE (TVTI)

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Name of Chairperson Signature Date

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ABSTRACT

The quality of electrical power has been a growing source of concern for both electric providers and end customers. It serves as a general term for a variety of distinct types of grid disruptions. In this paper design and analysis of a proportional-resonant controller with thyristor controlled switched capacitor for mitigation of harmonic distortion and style procedure for a digital Proportional-Resonant (PR) current controller mechanism is to boost power quality by reducing total harmonic distortion (THD) in three-phase system voltage source inverter is implemented in MATLAB/Simulink. The planning process provides a scientific explanation of how to calculate the proportional and resonant gains in addition to the coefficients for the digital resonant route. Additionally, a developed digital PR controller that is designed and tested at 50 Hz is subjected to a frequency domain analysis. The investigation of this three-phase harmonic distortion mitigation has been disbursed by minimizing the harmonics filter as well as improving the general power quality of the three-phase filters within which filter harmonics were joined in parallel. A suitable way to reduce harmonics at various frequency ranges is revealed by the designing of Active Power Filters for Harmonics Mitigation using MATLAB Simulink. Fast Fourier Transform (FFT) is used to evaluate the total harmonic distortion (THD) of the converters with and without filters, which aids in this filter's ability to suppress higher order harmonics.Basedon the source current, the harmonics distortion mitigation reduced from 80.31% to 3.10% with out and with compensation respectively. Therefore, the proposed control and topology have a promising effect on power utility as well as the customer. The three-phase harmonic filter's visual appearance and simulation were completed using MATLAB Simulink. Three-phase filter types were also briefly examined. The outcome of this thesis demonstrates that the system was shielded from both high- and low-frequency harmonics by the filtering of voltage and current sources.

Key word: - **Harmonic Distortion, Active Power, Filter, MATLAB, Simulink**

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ABBREVIATIONS

AC	Alternating current
APLC	Active Power Line Conditioner
CPU	Central Process Unit
DC	Direct current
EPQ	Electric Power Quality
FFT	Fast Fourier Transform
HAPF	Hybrid Active Power Filter
HD	Harmonic Distortion
HZ	Hertz
IEC	Institute of Electrical Commission
IEEE	Institute of Electrical Electronics Equipment
IGBT	Insulated Gate Bipolar Transistor
IMP	Internal Model Principle
PCC	Point of Common Coupling
PR	Proportional Resonant
RMS	Root Mean Square
SVC	Static Var Compensator
THD	Total Harmonic Distortion
TSC	Thyristor Switched Capacitor
VSD	Variable Speed Drives

CHAPTER ONE

1. INTRODUCTION

1.1. BACKGROUND

Today, majority electrical utilities are distributed electricity to consumers in the form of AC voltage at 50/60Hz frequency. The utilities enforce strict control on the setup and usage of the transmission and distribution instruments so that the power and frequency sent to their customers are constantly kept within tight confinement limits. But regrettably, every one of the available electronic converters is encountering a rising number of nonlinear loads that pump distorted currents into the network when coupled to our power systems, producing harmonic voltage waveforms. Harmonics are sinusoidal currents or voltages that have integer multiples of the frequency that the availability system is designed to operate at (referred to as the elemental frequency; often 50 or 60 Hz)[2].The widespread use of power electronic systems and other nonlinear loads is one among the most causes of skyrocketing harmonic distortion, which worsens the standard of electrical systems [2].As a result, effective reporting of the standard of their electrical product is becoming increasingly crucial for power distribution firms of these factors, taken together, necessitate the efficient use of energy via sophisticated electronic and control technologies, yet because the improvement of power quality. In systems using electric drives, there's plenty of room to enhance energy efficiency. The THD (Total Harmonic Distortion) value is that the most significant measurement for analysis and measurement. The quality of IEEE 519-2014is considered a benchmark for the identification of Harmonic problems within the Process Industry [3].The foremost cost-effective and technically good solution for this problem is decided by the user's goals; the severity of harmonics, and therefore the costs and advantages of the assorted technologies in use at that location [4].Today's developments in power electronics are fundamentally changing people's expectations for power quality. The standard of electrical power has been significantly impacted by the increase of power electronics-based technology supply. Power electronics has given us many new ways to provide services, manufacture products, and utilize energy. These converter-based systems are nonlinear. The nonlinear loads change the sinusoidal nature of the ac power current (and consequently the ac voltage drop) leading to the f1ow of harmonic currents within the power grid [1].Harmonic currents result in distorted voltages and currents, which can negatively affect the operation of the system in a number of ways. The functioning and longevity of other equipment, which may not be owned or operated by the same corporation, may be impacted by harmonic voltages. Both high-power industrial loads and household loads can contribute to harmonics in the system voltages. Moreover, a large portion of the problematic technology is susceptible to harmonic distortions. Harmonics can be problematic in equipment that uses an explicit voltage undulation to calculate. When several single-phase distorting loads exist across three phases and the neutral current exceeds the active line current, harmonics like these can occur in commercial buildings. The following extreme levels are where harmonics may be possible [5].

- ✓ Overheating the neutral conductor might cause the loss of the conductor and a hazardous fireside
- ✓ Interfering with the local area network and technological products if the grounding system is poor
- ✓ When the temperature in the coils rises, the insulation quickly deteriorates and loss of life
- ✓ Overheating of transformers results in a discount in their durability life
- ✓ When the temperature rises of the dielectric of transformers with a possibility of explosion
- ✓ Overheating of service kit and reduction in their service life [5].

The power quality is plagued by many problems which occur within the gear mechanism and distribution systems. Harmonics, transients, abrupt switching operations, voltage fluctuations, frequency changes, etc. are a few of them [6].The term "maintaining power quality" refers to preserving the nearly sinusoidal waveform of voltages and currents on power distribution buses at the designated magnitude and frequency (EPQ).As a result, wattage quality is widely used to represent other qualities such as voltage, current, service reliability, power supply quality, etc. Consumer-driven issues with energy quality are characterized as[7].Any power issue that results in equipment failure or improper performance for customers, whether it manifests as a voltage, current, or frequency variation. Different disciplines of EPQ research are developing to address various power quality-related problems. The phases of these branches are separated. The essential notion sources of effects Analyses and Models Instrumentation Solution.

1.1.1. Fundamental concepts

Different in proportion to their rated magnitude, the parameters and their degrees of importance are recognized by EPQ. This is the primary cause of the decline in the standard of electrical power.

1.1.2. Sources

The areas, sites, and events that result in the unintended alteration of these characteristics are the sources. It is quite challenging for the facility engineers to identify the precise causes of power quality-related disruption in the ever-complicated network.

1.1.3. Effects

The system and consumer equipment experience the impacts of low power quality as a result of numerous disruptions.

1.1.4. Analysis and Modeling

Challenges are attempted to construct the disturbance, origins, its occurrence besides consequences in modeling and analysis, primarily supporting the mathematical foundation.

1.1.5. Instrumentation

Continuous measurement and "instrumentation" of the electrical parameters is required for EPQ monitoring.

1.1.6. Solution

It is nearly impossible to provide a complete solution, that is, to deliver pure power to the patron side. Our goal is to lower the likelihood that disruptions will develop and to lessen the effects of EPQ issues.

1.1.7. Description of Harmonic Distortion

The sources of poor power quality are categorized into two groups:

(I). Actual loads, equipment, and components.

(II). Subsystems of transmission and distribution systems

Poor quality is generally caused by cable disturbances like impulses, notches, voltage sag and swell, voltage and current unbalances, momentary interruption, and harmonic distortions [7]. The foremost contributors to poor power quality are harmonics and reactive power. Solid state control of ac power using high-speed switches is the main source of harmonics whereas different non-linear loads contribute to excessive drawl of reactive power from supply. It results in catastrophic consequences like long production downtimes, malfunction of devices, and shortened equipment life.

1.2. Valuation of Electric Power Quality

The general knowledge that numerous systems and equipment suffer from the negative impacts of electrical power of poor quality. Furthermore, when electrical power quality deteriorates, so do facility stability, continuity, and dependability [7]. It's critical to constantly evaluate the quality of electricity supplied to a customer in order to prevent such impacts.

1.2.1. Types of Power System Disturbances

Problems with power quality are caused by many types of electrical disturbances. The majority of EPQ disruptions depend on either amplitude, frequency, or both. Depending on how long EPQ disruptions have been present, incidents can be classified as short, medium, or long kinds. These issues are mostly categorized as[1].

1.2.1.1. Interruption/under voltage/over voltage

The voltage level of a chosen bus completely drops to zero after a power outage. The interruption might last for a medium, short, or long time. Lower voltage and overvoltage are the rise and fall in a particular bus's voltage levels relative to the standard bus voltage. Such disruptions result in an increase in the reactive power a system draws or delivers, insulation issues, and voltage stability.

1.2.1.2. Voltage/Current unbalance

Unbalance in the producing system or gear, as well as uneven loads, can lead to voltage and current imbalance. Negative sequence components show up during imbalance. It impairs voltage stability and system performance.

1.2.1.3. Harmonics

Harmonics are sinusoidal voltages or currents having frequencies that are integer multiples of the frequency at which the provisioning system is intended to control (termed the basic frequency; usually 50 or 60 Hz). Periodically distorted waveforms may be decomposed into a sum of the elemental frequency and therefore the harmonics. Harmonic distortion originates because of the nonlinear characteristics of devices and loads on the facility system. Integer harmonics, sub harmonics, and inter harmonics are the different categories for harmonics. Inter harmonics and integer harmonics have frequencies that are higher than fundamental frequencies, while sub-harmonics and integer harmonics have frequencies that are lower than harmonic frequencies. Time harmonics and spatial (space) harmonics are two different categories for harmonics. A crucial factor in the installation application is the monitoring of harmonics with pertinent fundamentals.

1.2.1.4. Transients

Signals can abruptly increase at any time, either from within the same system or from outside it Dc transients and ac transients are the two different types of transients. Utility capacitor transient switching is shown in Figure 2.1.

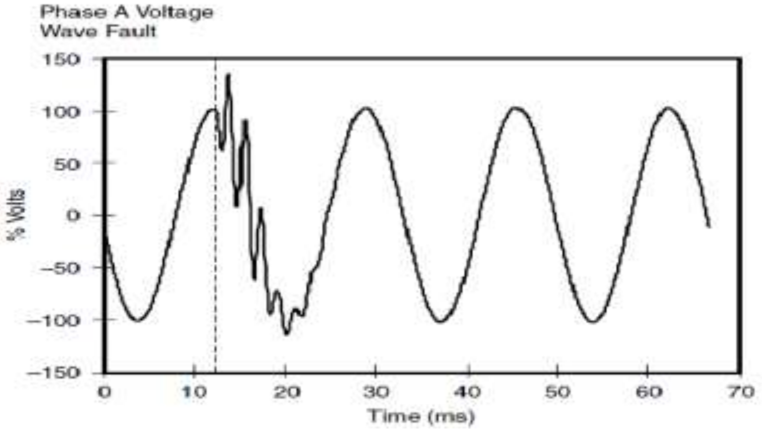


Figure 1.1: shows utility capacitor-switching transient [7].

1.2.1.5. Voltage Sag

This disruption only lasts a short while. RMS voltage briefly drops to a completely low level during voltage sag. It is a lessening in RMS voltage throughout the range of 0.1-0.9 pu during a time period longer than 10 ms but less than 1 s.

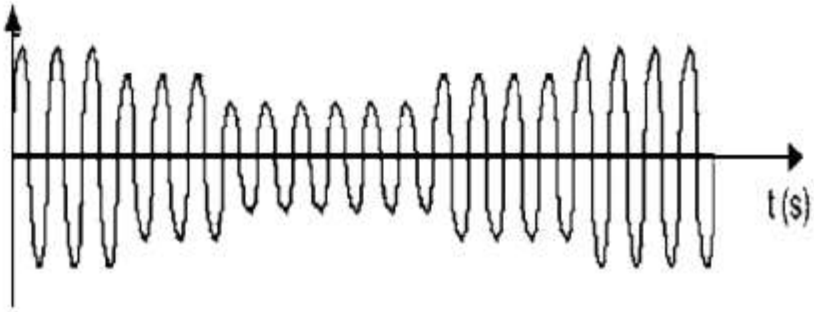


Figure 1.2: voltage sag[8]

1.2.1.6. Voltage Swell

This disruption only lasts a short while. RMS voltage rises to a high level for a brief period of time during voltage sag. It is an increase in RMS voltage throughout a range of 1.1 up to 1.8 P u lasting longer than 10 ms but less than 1 s.

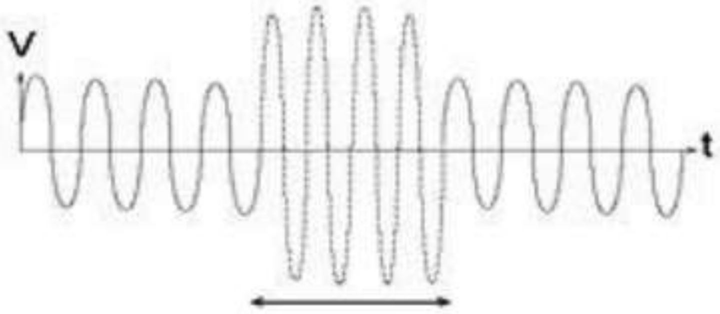


Figure 1.3: Voltage Swell[8]

1.2.2. Power Quality

Value is the main factor driving our interest in power quality. There are financial repercussions for utilities, their clients, and load equipment providers. Numerous industrial users may have an immediate economic effect due to the electricity standard [7].These disruptions are connected by a bundle. The economic effect of equipment sensitivity to transient voltage sags in the semiconductor production sector led to the creation of an entirely new standard for equipment ride-through. The electrical utility is also concerned about problems with power quality. Strong motivators include exceeding client expectations and preserving consumer trust. A utility's financial situation might be severely impacted by the defection of a dissatisfied customer to a rival power provider.

A pure poly-phase device is anticipated to own simply sinusoidal waveforms of electricity and voltage at a same frequency. However, the situation in 000 departs from this virtue. The waveforms of the actual current and voltage are altered. They are commonly referred to as non-sinusoidal waveforms. The combination of several sine waves with different frequencies results in the non-sinusoidal waveform. As a result, genuine grid signals have both fundamental and harmonic components. The nonlinear equipment at the facility causes harmonic distortion. A nonlinear device's present is not proportional to the applied voltage. A waveform may be expressed as the sum of pure sine waves when it doesn't change from one cycle to the next waves, where each sinusoid's frequency is an integer multiple of the wave's fundamental frequency. The term "harmonic of the elemental" is used to describe this multiple, therefore the topic's name. The Fourier series, named for the kind mathematician who discovered the idea, is the sum of sinusoids.

Harmonic component order n current may be expressed as:

$$I_{n}=I_{n} sin2\pi ft \tag{1.1}$$

where, I_n is the amplitude of the nth harmonic section.

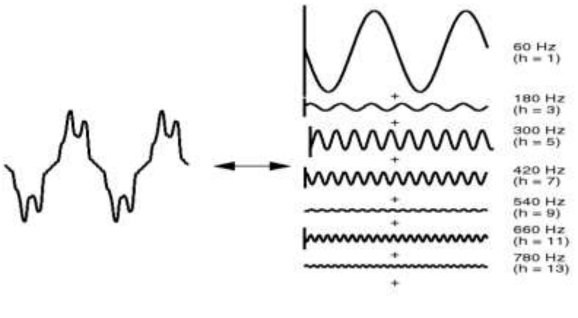


Figure 1.4: Sum of distorted any period waveform sinusoids [9]

Figure 1.4illustrates that every deformed periodic waveform may be represented as the sum of sinusoids

1.3.1. Types of Harmonics

Odd harmonics and even harmonics are two types of integer harmonics [9].

1.3.1.1. Odd Harmonics

Integer harmonics with frequencies that are an odd integer multiple of the fundamental frequency are known as odd harmonics. Ase might be used to indicate odd harmonics [9]:

$$I_{n=}I_{n}sin2\pi ft \tag{1.2}$$

Where n = 3, 5, 7... and the amplitude of the harmonic component of order n is in.

2.3.1.2. Even Harmonics

With frequencies that are even integer multiples of the fundamental frequency, even harmonics are integer harmonics. Harmonics may also be stated as[9].

$$I_n = I_n \sin 2\pi nft \tag{1.2}$$

Where, n = 2, 4, 6 . . . etc. andI_n is the amplitude of the harmonic component of order n.

1.3.2. Sources of Harmonics

The main sources of harmonics in wattage systems will be categorized as [9].

- ✓ Magnetization nonlinearities of transformer
- ✓ Rotating machines
- ✓ Arcing devices
- ✓ Semi-conductor-based power supply
- ✓ Inverter fed A.C drives
- ✓ Thyristor controlled reactors
- ✓ Phase controllers
- ✓ A.C regulators

As mentioned above, initial considerations because the main source of the waveform distortion since they use magnetic materials that are operated near - and infrequently in - the nonlinear region for economic purposes. However, the event of technology over decades, especially the expansion of the utilization of switched power semiconductor devices has resulted in the rapid proliferation of harmonics within the ability systems, specified the harmonics introduced by rotating machinery are nowadays considered negligible compared to those introduced by power electronic devices. Harmonics and inter-harmonics of a waveform are often defined in terms of its spectral components within the quasi-steady state over a spread of frequencies. For general purposes the harmonic sources are often divided into three categories [10].Several distributed nonlinear components with low rating (i.e., mass goods) are made up mostly of single-phase diode bridge rectifiers, low voltage appliance power supply (SMPS in TV sets, PCs, and other IT devices), and gas discharged lamps. Large static power converters and power electronic devices at the gear mechanism level Static Power Converters (SPC) are increasingly being utilized to manage loads. SPCs come in numerous variations, including rectifiers, inverters, cyclo-converters, single-phase, three-phase, twelve-pulse, and six-pulse, but they all share the same properties. They are all nonlinear and introduce non sinusoidal current into the capability system. Nonlinear loads that is large and randomly variable. This mostly refers to electric metal-melting arc furnaces with power ratings in the tens of megawatts that are linked to a transmission network. Because the carbon electrodes attached to iron have differing impedances between positive and negative current flows, the furnace arc impedance changes arbitrarily and is exceptionally symmetrical. Resistance welding has the same features, except that the copper electrodes, and therefore the steel being welded, have different impedances between the positive and negative current flows.

1.3.2.1. Harmonic Producing Loads

To comprehend the injection of harmonic currents into the power distribution network, one must first discuss the general characteristics of nonlinear loads. Even when supplied by a sinusoidal voltage or current waveform, nonlinear loads introduce harmonic currents or harmonic voltages into the distribution network. Nonlinear loads are widely classified into two types: Loads using alternating current sources Loads powered by harmonic voltage sources Thyristor-controlled loads, such as those used in DC drives, current-source inverters (CSIs), and so on, are examples of harmonic current source loads. [7].These loads generate harmonic currents on the alternating current supply side of the rectifier in order to operate, similar to induction motors, which need reactive currents. In contrast, diode rectifiers with dc side capacitors constitute harmonic voltage source type loads. These loads produce voltages on the ac side of the rectifier to control and are getting prevalent because of their use in domestic equipment; variable speed drives (VSDs), etc. Harmonic currents within the supply result in thanks to harmonic voltages and are determined by the ac side impedance. As a result, harmonic current source loads are frequently described by a simple current source or Norton equivalent circuit as shown in Figure 1.5.

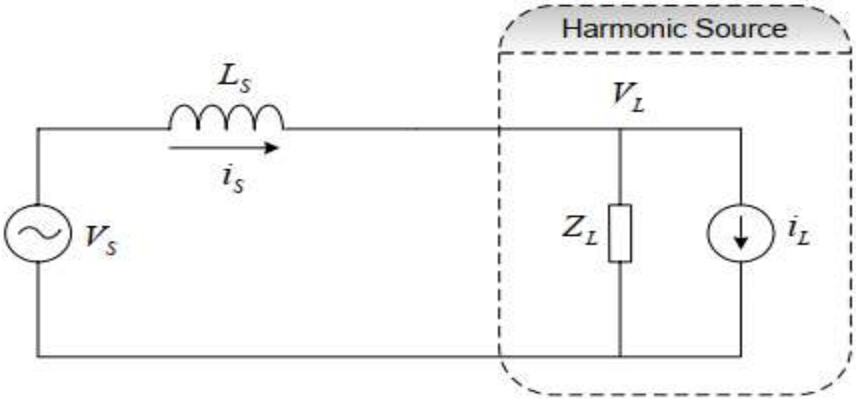


Figure 1.5: Norton equivalent circuit for harmonic current source type load [10]

Similarly, harmonic voltage source loads are represented by a simple voltage source or the venin equivalent circuit as shown in Figure 1.6.

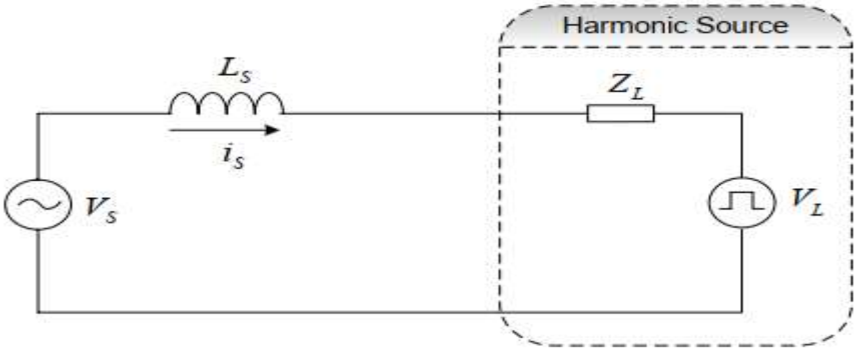


Figure 1.6: The ven in equivalent circuit for harmonic voltage source type load [10]

These basic Norton and hence venin equivalent circuit models should be used with caution, however, because they do not adequately describe the harmonic sources in particular cases like as resonance conditions.[11].

1.4. EFFECTS OF HARMONICS

Harmonics aren't desirable in most applications and operations of the power system; therefore, it's wide adverse effects on the system. The results of harmonics are also classified as [11]: [24]

1.4.1. Resonance and Effect on Capacitor Banks

When the frequency of the circuit impedance's equal capacitive and inductive reactances occurs, resonance occurs. A series quality has low impedance whereas a parallel resonance has high impedance at the echoing rate. Harmonic resonances cause issues with the operation of power factor correction capacitors [11]. Due to harmonic frequencies, capacitors employed for power factor adjustment produce system resonances. This results in an abnormally high current, which may cause capacitor damage. Changes in harmonic content can occasionally cause reactive power to exceed manufacturer specifications.

1.4.2. Poor Damping

In the presence of harmonics, the undesired fluctuation in damping degree affects the operation of numerous measuring and controlling equipment [10].

1.4.3. Harmonic Effects on Rotating Machines

Harmonic currents and voltages cause overheating and efficiency loss inside the stator windings, rotor circuit, rotor and stator insulation. Harmonic currents present in an AC machine's stator generate induction motoring action, which generates shaft torques in the same direction as the harmonic field velocities, so that each positive sequence harmonic will generate shaft torques aiding shaft rotation, whereas negative sequence harmonics will have the opposite effect, significantly affecting the speed/torque characteristic[11].

1.4.4. Effects on Transformer

Harmonic Voltage increases the core losses in laminations and stresses the insulation, while harmonic current increases copper losses. They also cause a rise in core vibrations.

1.4.5. Effects on Transmission Lines

Harmonics tend to extend Skin and Proximity Effects since both are frequency dependent. Harmonic currents reduce the ability transmitting capacity by increasing copper losses and generating drops in harmonic voltage across various circuit impedances Therefore, a stiff system with low impedance has high fault levels but lower voltage disturbances, in contrast to a weak system with large impedance that has low fault levels but greater voltage disturbances. Harmonic voltages lower cable dielectric strength by increasing dielectric losses[10].

1.4.6. Harmonic Interference through Power System Protection

Harmonics impairs the protecting relays' ability to function. Sample data and nil crossing moments are issues for several digital relays and algorithms. In such procedures, harmonic distortion causes mistakes. Harmonics increase di/dt at zero crossings, decreasing thermal magnetic breakers' ability to detect current, and altering the trip point owing to extra solenoid heating [10]. Current harmonic alteration has an impact on the ability of circuit breakers and fuses to interrupt power.

1.4.7. Effects of Harmonics on Customer Equipment

A substantial amount of study has been done on this topic by the IEEE Task Force on the Effects of Harmonics on Equipment. The final outcome is as follows.

1.4.7.1. Television Receivers

TV picture size and brightness are affected by harmonics. Inter harmonics change how the basic frequency is modulated. For instance, the beam tube image can periodically become magnified and then less magnified at levels as low as 0.5% inters harmonic level.

1.4.7.2. Mercury Arc and Fluorescent Lighting

A resonant frequency is produced by the capacitors used in these lighting applications in conjunction with the inductance of the ballast AND circuit. It results in excessive heating and operational failure. Harmonic voltage distortion results in the production of audible noise.

1.4.7.3. Computers

Harmonics cause issues with display and CPU operation. Harmonic rate (geometric) in vacuum must be less than 3% (Honeywell, DEC) or 5%. (IBM). The CDC requires that the peak to effective voltage ratio of the provision voltage be 1.41±0.1.

1.5. HARMONICS REDUCTIONS IN POWER ELECTRONICS

Harmonic distortion was not a major concern in the past since power system designs were basic. Harmonic distortion has risen in recent years due to the use of complicated designs in the industry. Harmonic distortion in relation to power quality has received a lot of attention. DC power is transformed to alternating current (AC) at an inverter input. Harmonics have an effect on ability quality during this conversion [10]. The next sections show how harmonic reduction can assist to improve ability quality.

1.5.1. Harmonics reduction techniques

The amount and assortment of harmonics qualification strategies presently obtainable succeed difficult to choose the simplest acceptable option. Some of the strategies rely on the system condition to function, while others need substantial system study. These methods are categorized into different groups within this section.[7].

1.5.1.1. Frequency Domain Techniques

Harmonic detection methods in frequency domain approaches rely heavily happening the Fourier convert method. There are three phases in these detecting techniques:

- ✓ Change the time-domain distorted current or voltage to the frequency domain,
- ✓ Separate the harmonic from the elemental component in the frequency domain., and
- ✓ Rebuild the compensatory signal.

1.5.1.2. Time domain techniques

Time domain methods for harmonic detection are applicable in power systems.

Filter Based Methods

Since they produce a number of issues including hotness and temperature increases in generators, harmonics in nonlinear loads are a significant difficulty in power systems. These consequences may create device damage. Filters are commonly used to solve harmonics problems. Filters are commonly employed in power systems for harmonic reduction as nonlinear loads increase. For nonlinear loads linked to the facility system, installing a filter helps to reduce harmonics. There are two types of filters: active and passive filters. These filters are electric devices that remove unwanted distorted signals and harmonics from the system [7]. Active filters use active mechanisms such as IGBT transistors, which operate at small voltages. Passive filters, on the other hand, are made up of passive components like inductors, capacitors, and resistors that are used at dissimilar voltage levels. A hybrid filter is a sort of third filter that combines passive and active filters. The use of filters would result in dramatically improved power quality.

- The passive filters

As previously stated, there are passive filters employed for a variety of voltage stages. A resistor, inductor, and capacitor are linked in parallel or series with the passive filter. A parallel passive filter can accept current, but a series filter can accept voltage. Furthermore, around the resonant frequency, the filter gives maximum attenuation [7]. The passive filter reduces or eliminates the harmonic by attenuating its frequency. The lowered harmonic frequency must be greater than the circuit's resonant frequency; consequently, the network's impedance and the filter's low impedance remove the harmonic current. Passive filters are well-known for reducing harmonic currents inside an installation by eliminating harmonics caused by nonlinear loads. As a result, passive filters give superior results in terms of decreasing the influence of the harmonic. A single-phase distribution system with a nonlinear load and a passive shunt filter is shown in Figure 1.7. One desirable harmonic can only be removed by a passive filter. A passive filter designed to delete the third harmonic, for example, will only eliminate this harmonic instruction. The resonance frequency of the passive filter must be lower than the frequency of the harmonic to be eliminated in order to prevent a shift in the frequency of the filter caused by changes in the filter parameters.

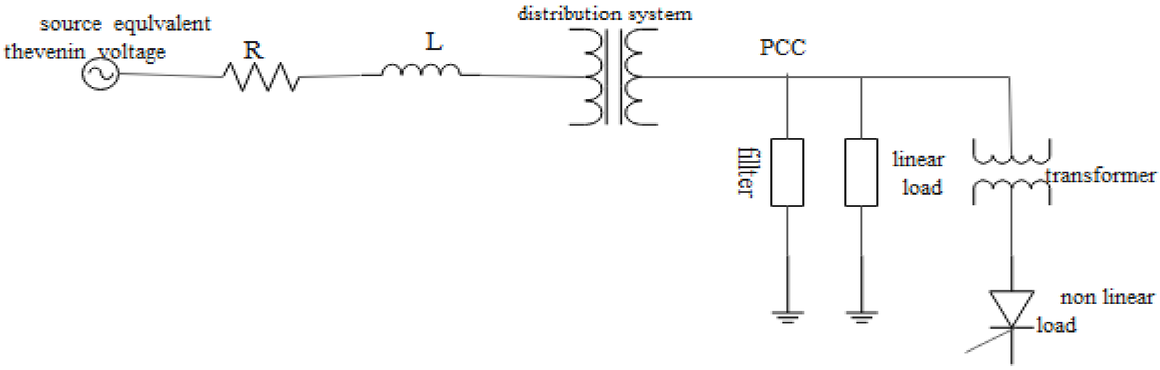


Figure 1.7: Single phase representation of supply system with nonlinear load and passive shunt

- Types of Passive Filters
    - Shunt passive filters
    - Series passive filters

For single-phase and three-phase power systems, both shunt and series passive filters are utilized. In addition, many shunts and a series of passive filters are frequently utilized in conjunction with and without one another during a structure. The differences between series passive and shunt filters include the following:

- ✓ Series passive filters carry the whole load current, whereas shunt passive filters only carry a portion of it.
- ✓ The shunt passive filter is less expensive than the series passive filters, so they are more commonly castoff.

Figures, 1.8 and1.9shunt and series designs of three phases of three wire passive filters, respectively.

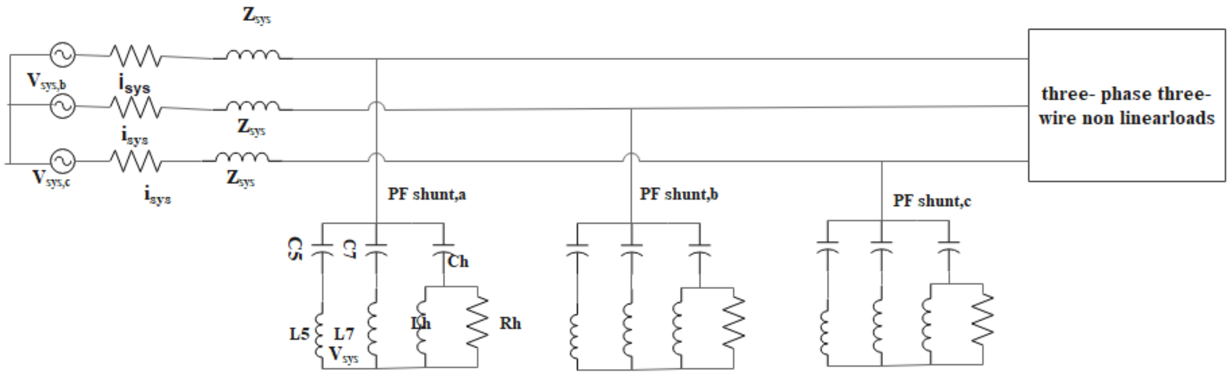
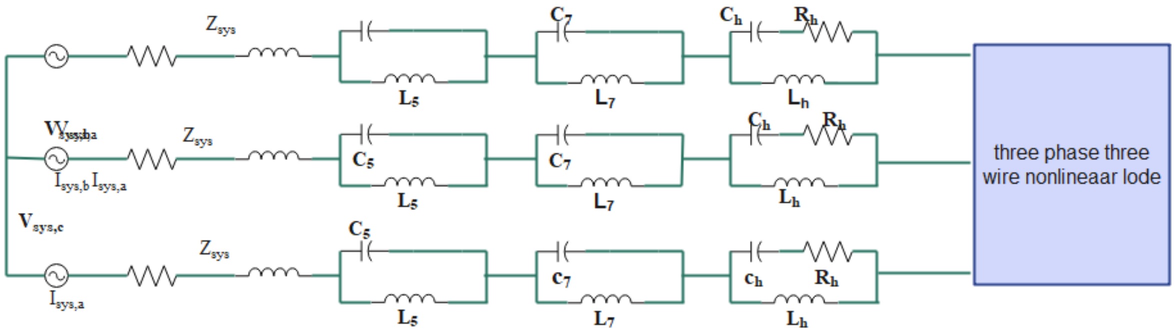


Figure1.8: Three Phase-Three Wire Passive Filter for Shunt Configuration



Figure,1.9: Passive Filter with Three Phases and Three Wires for Series Configuration

In an overachieving system, three or more filters are often coupled to reduce harmonics. The primary two filters are coupled so that a high pass filter is used to reduce the impact of effective harmonics.

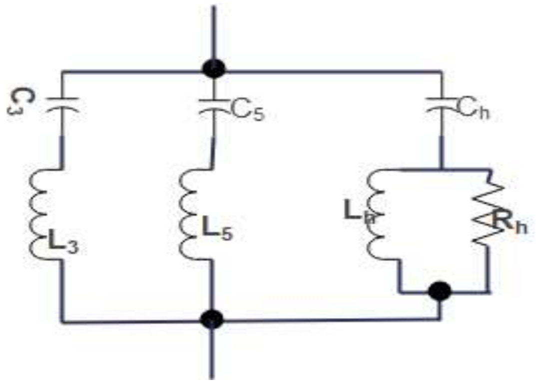


Figure 1.10: Shunt Passive Filter

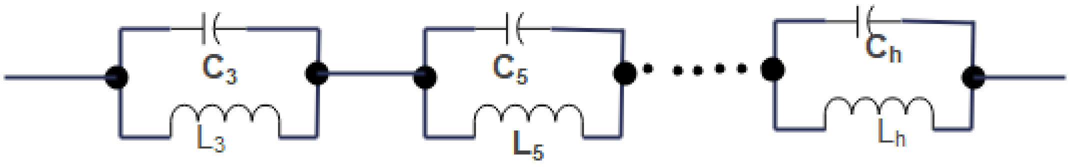


Figure 1.11: Series-Passive Filter

1.6. Thyristor Switched Capacitor

A kind of SVC shunt to the road might be a thyristor switched capacitor (TSC) system. Figure 2.12 illustrates the single phase, which consists of numerous back-to-back coupled thyristor pairs serial to a capacitor and a reactor. The number of branches in a phase is determined by the required level of reactive power accuracy. SC is favored in various application areas because to its many advantages, which include simple design and installation. Supply voltage support, reactive power adjustment, harmonics filtering, etc. are a few of them that are frequently cited. Reactive power correction is the most prevalent application area for TSC. The most electricity that TSC supply is capacitive reactive power, which lowers or eliminates the large industrial loads' need for reactive power.

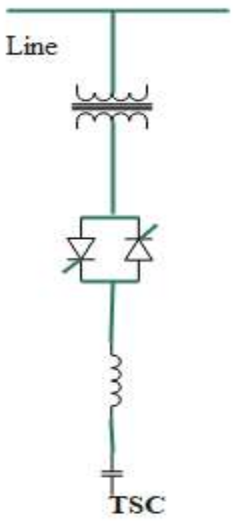


Figure 1.12: General structure of TSC

Supply voltage support, reactive power adjustment, harmonics filtering, etc. are a few of them that are frequently cited. Reactive power correction is the most prevalent application area for TSC. The most electricity that TSC supplies are capacitive reactive power, which lowers or eliminates the large industrial loads' need for reactive power.

1.6.1. Definition and Principles of TSC

TSC could be a frequently employed compensation tool in industrial settings. It serves as a primary reactive power control method due to its ease of development and therefore dependable functioning. Additionally, its use isn't just restricted to controlling reactive power. It is frequently employed for harmonic filtration, terminal voltage control, big induction motor starting, and other purposes with careful engineering. The next part will provide a quick explanation of these ideas. Figure 1.13 depicts possible TSC setups. A ideal design would have a capacitor and back-to-back coupled thyristors that are not parallel. Each phase features a parallel combination of switched capacitors for more practical operation, allowing the reactive power to be frequently raised or lowered step-by-step by turning on/off the appropriate number of capacitors in each phase at a time (Figure 1.14). The outcome is improved switching performance and smooth voltage and current waveforms.

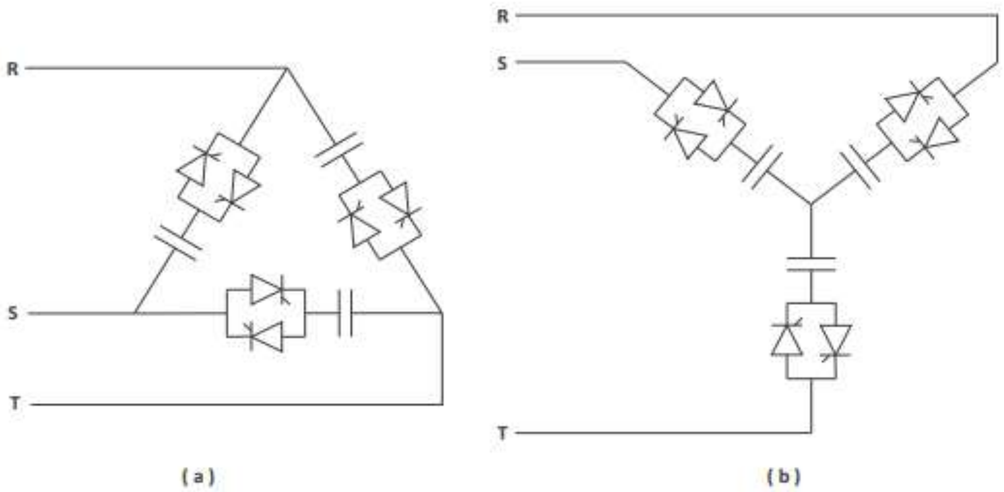


Figure 1.13: Various configurations of Thyristor Switched Capacitor Circuit

(a)Delta Connection, (b) Wye Connection

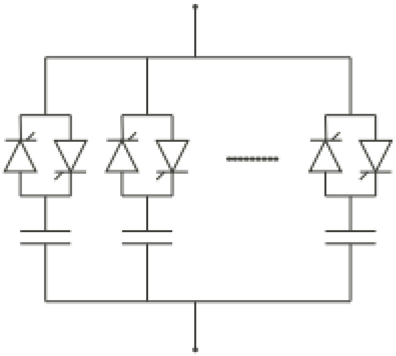


Figure 1.14: Representation of an ideal TSC branch

To increase the reactive power variation, each phase may contain multiple thyristor/capacitor combinations. The required reactive power determines how many branches are needed.

1.7. STATEMENT OF THE PROBLEM

Power electronic devices play an important role in the enhancement of technology. In particular, thanks to its small size, controllability, and programmability, it brings a dramatic change in the field. On the contrary, power electronics technology has significantly contributed to the development of power quality issues. Generally, these harmonics may be categorized into current source type and voltage source type harmonics. These current-or voltage-type harmonics are increasing the distribution system. These nonlinear loads may be found in home appliances, renewable energy interfaces, entrainment, office equipment, industrial devices, medical facilities, etc. These increases in non-linearity, unstable, distorted loads result in operational and life problems for other equipment similarly. As a result, the following widespread use of electronic applications, harmonics have become a main concern for this research. The main intention of this thesis is to unravel this problem by employing a shunt compensator for the present type of harmonic and thyristor control for the voltage-type harmonic source. As a result of this, both these and voltage type harmonic sources are often mitigated from the distribution feeder.

1.8. OBJECTIVES

1.8.1. General Objective

The general objectives of this thesis is design and analyze the proportional-resonant controller and thyristor controller switched capacitor for mitigation of harmonic distortion in an exceedingly three-phase distribution power grid using MATLAB/Simulink.

1.8.2. Specific Objective

- ✓ To build a mathematical model of the proportional-resonant controller and thyristor controller switched capacitor with a three-phase facility mitigation harmonic distortion
- ✓ To design PR controller and TSC controller for three-phase power grid harmonic distortion mitigation
- ✓ To simulate and analyze the designed model of three-phase facility harmonic mitigation using MATLAB /Simulink.

1.9. SIGNIFICANCE OF THE STUDY

The contribution of this thesis is more important in industrial application, electric utility, residential, & commercial for electrically operated machines. It’s useful for the reduction of the price of electrical energy for purchasers and loss of service for utility. It also avoids harmonic interference with nearby communication networks and medical centers. Generally, it also can be a baseline for other researchers who have an analogous inters within the field.

1.10. SCOPE OF STUDY

The scope of this research focuses on the facility quality and its issues with utility interface, concentrating more on harmonics effects within the three-phase distribution system and its mitigation techniques. Using the proposed controller design of power quality and its issues with utility interface concentrating more on harmonics distortion within the three-phase system and mitigation techniques operations are indicated employing a simulation working environment of using MATLAB/Simulink. Among the various techniques used to reduce harmonic distortion in a three-phase system, this study focuses on active filter compensation with applicable control methods.

1.11. THESIS STRUCTURE

This paper work report is split into six sections. This thesis is to explain and prove the proportional-resonant controller with thyristor controller switched capacitor for harmonic distortion designs which may fit best for the application. MATLAB software design and analysis, as well as comparison of various characteristics finally, the thesis ends with a chapter about the conclusions and future work. The chapters are organized as follows:

Chapter 1: Introduction: - This chapter includes the planning and analysis of the proportional-resonant controller with thyristor controller switched capacitor for harmonic distortion mitigation in three-phase installation objectives, an announcement of the matter, the importance of the study, and the scope of the study.

Chapter 2: Literature Review: -This chapter explains and discusses the look and Analyzing of a proportional-resonant controller with thyristor-controlled switched capacitor for mitigation of harmonic distortion research, another research consistent with this thesis, and the material utilized in this thesis.

Chapter 3: Theoretical Background and Modeling of Harmonic distortion Mitigations: -This chapter explains about theoretical background modeling of harmonic distortion mitigation techniques to realize the look and analysis of proportional-resonant controller with thyristor controlled switched capacitor for harmonic distortion mitigation and the way the thesis work task is completed.

Chapter 4: Controller Design: - This chapter designed and modeled a simulation of the look and Analysis of a proportional-resonant controller with thyristor controlled switched capacitor for mitigation of harmonic distortion in three-phase installation design, other research per this thesis, and therefore the controller design utilized in this thesis.

Chapter 5: Simulation and Result Analysis: -This chapter shows the planning and Analysis of a proportional-resonant controller with thyristor controlled switched capacitor for mitigation of harmonic distortion during a three-phase installation to induce the objectives of this thesis and the way the thesis simulation is analyzed and simulated.

Chapter 6: Conclusion, Recommendation and Future Work: -This chapter concludes and recommends future work on the planning and Analysis of a proportional-resonant controller with a thyristor-controlled switched capacitor for mitigation of harmonic distortion in three-phase facility research work to create sure it meets the objectives of the thesis goal and recommendation.

CHAPTER TWO

2. LITERATURE REVIEW

Many academics and engineers interested in using active filters in real applications have examined them since their fundamental compensation concepts were first suggested about 1970.The widely used instantaneous reactive power theory in ac networks was proposed in [12] in 1983. The principle of instantaneous reactive energy, or p-q, is another name for it. The 3-stage cable, 4-stage wire, and 1-stage networks are all covered by this theory. The main step in p-q theory entails changing the three-phase voltages and currents from alphabets A-B-C to alphabets-0 algebraically. It takes Clarke's metamorphosis to complete this task. The axes a, b, and c are secure on the same plane. They are 120° apart. They are 120° apart. The beta and alpha axes are at a 90degree angle. Passive filtering was often the industry standard in [13] for compensating for harmonic and reactive power. The ease and precise control of active filtering are taken into account with developments in power electronics. Some active and passive filter network topology were given in this work. In order to create simulation models, passive and active filter topology of mathematical models were proposed & utilized in the artificial language. This condition of active filters is discussed in [14], together with the author's thoughts and predictions, which support the chances for cutting-edge electronic power technology in the tenth era. The term active filter swill imply far more in the near future than it did in the 1970s. As active filters' capabilities rise, their function will be expanded to include power quality enhancement for power distribution systems in addition to voltage flicker compensation and voltage regulation.

In [15] develops a novel three-phased power filter control computation based on the space vector idea. The low pass filter classes are further decreased, the multiplication and addition times are computed, and amount of speed is frequently enhanced in addition to any or all of the benefits. The compensation efficiency could be increased and a reduced harmonic current could be provided if this kind of filter is used through the same circuit parameter. The simulation's output demonstrates that the values are fantastic in terms of static, complicated compensatory and functional aspects. This three-phase active power filter incorporates a fundamental regulating concept and is backed by the widely accepted theory of instantaneous reactive power. It may effectively simplify the current estimate of the instructions. An improved dynamic output shunt active power (APF) filter is defined in [16]. When the value of the load current fluctuates quickly, the APF transition reaction is just too sluggish, causing the road current to become distorted. The road current's time-dependent harmonic content can be increased as a result of this modification. The APF current's behavior is influenced by the inverter time output, which consists of the inductance at the APF output and, as a result, the load and grid impedance that go along with it. The non-causal predictive current correction improved efficiency in the transient circuit of the proposed APF. The second option makes use of an updated output inverter. In [17], an improved dynamic output shunt active power filter is deliberated (APF). When the value of the load current fluctuates fast, the APF transition reaction is just too sluggish, and the road current suffers from a fancy distortion. This disturbance allows the road current to prolong its time-dependent harmonic content. The inverter time output, which includes the APF output inductance as well as the ensuing load and grid impedance, determines the APF current dynamics. on-causal predictive current compensation improved efficiency in the proposed APF transient circuit.

Power electronics systems emerged in [18] and are now employed in a variety of applications. Electricity efficiency may be a key issue for the consumer and distribution side. APF that boosts output while compensating for reactive power. The harmonic issue produced by the nonlinear load is discussed in this study. In [19], the definition and simulation of numerous nonlinear a lot of a single-phase shunt active power filter's harmonic and power factor correction are shown. An uncontrolled corrector and an ac controller with an energetic filter that compensates for the harmonic current produced by the load make up the device in MATLAB Simulink.

The AC controller takes care of the nonlinear load. The active filter is constructed on a three-phase inverter for complete bridges. The availability current's spectrum analysis demonstrates that the active filter successfully canceled out load harmonics. Altering the switching frequency further presents the impact on the active filter's output .In [20] extends the facility output on the ability supply side by using active filters. Frequently, this is a two part simulation. 1) Employing the hysteresis control technique to reduce the third harmonic on the load side.2) Use MOSFET AND circuit driver models to decrease 3rd harmonics on the load side. The utilization of nonlinear loads will result in significant losses from harmonics on the load side, and the power factor will therefore reduce costs per unit. Applying both of the aforementioned methods will reduce losses as the third harmonics in this system are inadequate. In[21] Ethiopia is one of the African countries with the most underutilized energy resources, as evidenced by the fact that major energy demands are still fulfilled by traditional means. Currently, the country's final term energy consumption is around 40,000 GWh, of which around 92% is consumed by residential appliances, 4% by the transportation sector, and three by industry [22]. According to [22], industrialization is taking place in Ethiopia. Electric motors fed by a converter-inverter; heaters, frequency converters with renewable energy sources, and so on are common components of emerging industries, resulting in nonlinearity and power quality issues. Simultaneously, there is a profusion of PQ-sensitive equipment throughout the country in industry, residential, and commercial structures. Customers employ personal computers, buildings, and industrial automation systems that are powered by power electronic systems and are sensitive to power quality [23].

In [24]Propose that power quality relates to non-standard voltage, current, or frequency deviation that fails in end-user equipment. In this paper, power quality issues, their effects on the electrical kinds of equipment, and so the methods to reduce them. The system verification of the mitigation of power quality problems is critical where it's harmful to the operation of the equipment. In[25]have reviewed the possible research direction within the sphere of power quality, the authors mainly focused on voltage magnitude variation, harmonic emission, and harmonic resonance and discussed along with the terminology and various issues related to power quality. In[26] Propose Power quality standards required to limit the entire harmonic distortion within a satisfactory range caused by power electronic-based devices, during this paper, design of hybrid active filter to cut back current disturbances produced by power electronics-based devices, the simulation result performed to entails the usefulness of the HAPF which compensates the harmonic currents of the source current effectively. In[27]2014 IEEE Standards, propose Harmonic Control in wattage Systems Industry Application Society identified the sources, effects, measurement procedure, standards, and control procedures of harmonics. During this paper, harmonic control and reactive power compensation of such converters are addressed.

In [28]propose improving proportional-resonant controllers for unbalanced voltage and frequency variation grid, during this paper, a replacement controller supported by the PR configuration has been developed to spice up the system capable of an influence converter under frequency variation conditions. The new method has not only extended the frequency range of the previous work to the negative value but also significantly reduced the dependence between controllers within the 2 stationary frames. The introduced controller is love and preserves all advantages of the normal PR method. Simulation results have verified great improvements from the proposed method compared with the quality PR controller in terms of frequency variations. In[29] propose an Analysis, Design, and Implementation of a Multi-Quasi-Proportional-Resonant Controller for Thyristor-Controlled LC-Coupling Hybrid Active Power Filter, during this paper the analysis, design, and implementation of the MQPR controller with gain scheduling algorithm for the TCLC-HAPF, which can improve the steady-state performance with lower steady-state error, lower output current ripple and noise under both inductive and capacitive loads, as compared with the hysteresis current controller and QPR controller .In[30] Present a Three-Phase Grid-Tied Converter Controller Structure with Finite-Gain Proportional-Resonant Controls. In this study, the P+R controller outperformed the PI regulator in terms of operating dynamics. The supply voltage discrepancies were even rather substantial in favor of the P+R controller. The changes weren't as noticeable in the case of reactive power control, when the system performed a second function in compensating for reactive power, but the P+R controller was nonetheless distinguished by superior operating dynamics. It will be determined that the resonant section of the suggested P+R controller offers higher dynamic performance because both controllers had a comparable proportional gain.

2.1.1. Identified Gap

Based on the above-reviewed document I got the subsequently identified gaps in my thesis work:

- ✓ There is not any related appropriate model and controller design of harmonic distortion mitigation techniques for a three-phase power grid shunt active power filter by using thyristor switched capacitor controller design and proportional-resonant controller. To support those gaps, I proposed the proportional-resonant controller thyristor controller switched capacitor controller and style of PR controller for a three-phase installation for a shunt active power filter grid harmonic distortion mitigation by using MATLAB /Simulink.

CHAPTER THREE
3. MODELING OF HARMONIC DISTORTION MITIGATIONS

3.1. INTRODUCTION

The mathematical modeling of harmonic distortion reduction in an extremely three-phase system is the main topic of this chapter. This three phase system is being converted in to three distinct single phase systems, each of which may be much easier to study. This technique is frequently used to examine how the system reacts to harmonic currents, but it must be utilized carefully to avoid upsetting the fundamental assumptions. Any unbalanced phase voltages or currents may be converted into balanced sets using this procedure.

Three sinusoidal waveforms that are 120 degrees out of phase with one another are present in each positive sequence. The A-B-C sequence's phases are the most commonly utilized conventional phase (0, 120, and 120 degrees).The waveform of the negative sequence is additionally moved 120 degrees in phase. Being a negative sequence, these sets have the other phase notation A-C-B. In a perfect balanced three phase system the harmonic sequences will be determined by multiplying the traditional positive sequence with the harmonic number h. example for the 2nd harmonic of magnitude h = 2, we'll have 2 X (0, 120, 120), (0, 120, 120) which is able to yield the negative sequence. These phases are identical hence they're going to cancel one another out because the harmonic component is an excellent number 2, phase sequence for all other harmonic components is found using the identical method as a distorted waveform has only odd harmonics [31]. The list below provides an overview of odd harmonic phase sequences.

- ✓ The sequences of harmonics of order h = 5, 11, and 17 are all negative.
- ✓ The Triplons (those who are multiples of 3) h=3, 9, and 15 are known as the zero sequence.
- ✓ The sequences of harmonics of order h = 1, 7, and 13 are all positive.

3.1.1. Fast Fourier transform (FFT)

The Fourier Transform expression is defined below by well-known mathematicians and scientists. Studying the Fourier series served as the inspiration for the Fourier transformation. Because the sum of simple waves is represented mathematically by sins and cosines, sophisticated yet periodic functions are produced in the study of series. The Fourier transform arises from lengthening and allowing the amount of the depicted function to approach infinity, which is an extension of the Fourier series[32]. In essence, the Fourier Transform is a mathematical technique for breaking a symbol down into sine and cosine components. Figure 3.1 In its simplest form, the Fourier transform involves determining the sine and cosine components of a symbol. The modified signal is shown as a function of frequency in the findings, whilst the input signals are shown as a time function.

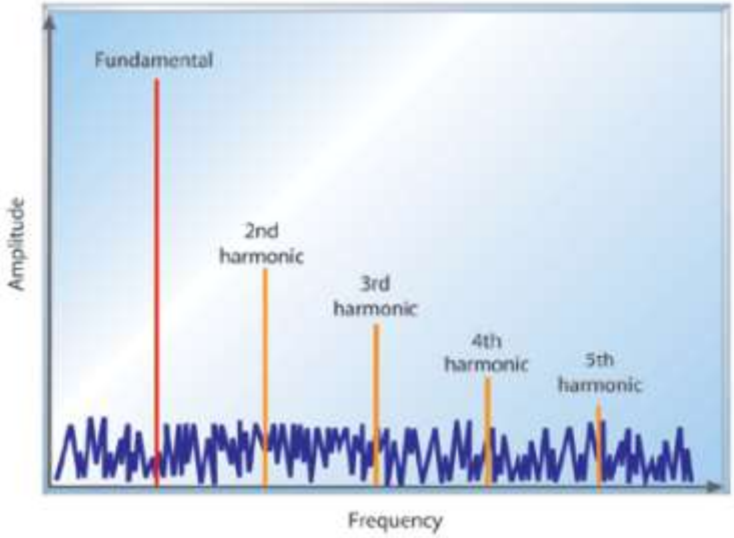


Figure 3.1: Fourier transform of harmonics

3.1.2 Harmonic Indices

The whole harmonic distortion (THD) and the total demand distortion are the two metrics most frequently employed to assess the harmonic content of waveforms.

3.1.2.1. Total Harmonic Distortion

The distortion of all harmonics occurs because the summation of all harmonic values (apart from the elemental component) is divided by the elemental component. THD is frequently defined as such. The main goal is to keep voltage and current harmonics under a certain threshold. In power quality and harmonic standards, it is fairly prevalent.[33]. In the equation below, THD is calculated for both current and voltage waveforms.

$$\boldsymbol{THD_V} = \frac{\sqrt{\sum_{h=2}^{\infty} \boldsymbol{V_h^2}}}{V1} \tag{3.1}$$

$$\boldsymbol{THD_I} = \frac{\sqrt{\sum_{h=2}^{\infty} \boldsymbol{I_h^2}}}{I1} \tag{3.2}$$

This indicates that the total harmonic distortion defines the relationship between the values of current and voltage to their respective fundamentals (THD). When looking at waveforms for the purpose of common coupling PCC, harmonics are most obvious. This PCC is occasionally found at the meters of shoppers and may represent the majority of client wants. When placed adjacent to their rated current, weak sources with a high current demand will exhibit more waveform distortion. Although there are many situations where the THD might be very helpful, it is important to be aware of its limits. It can give a good indication of how much more heat will be generated when a distorted voltage is placed across a resistive load. Additionally, it may indicate any additional losses brought on by this running via a conductor. However, since the voltage stress within a capacitor is related to the height value of the voltage waveform rather than its heating value, it is not a reliable indicator of that stress. Most typically used to describe voltage harmonic distortion is the THD index. Harmonic voltages almost always relate to the waveform's elemental value at the time of sampling due to basic voltage variations

3.1.2.2. Total Demand Distortion (TDD)

A THD value may be used to describe the current levels of distortion, although this number is frequently deceptive. Despite having a high THD, a very little current poses no danger to the system. For instance, after running at flaring loads, Many adjustable speed drives will display significant total harmonic distortion values for the input current. This is often not necessarily a big concern because the magnitude of the harmonic current is low, while its relative current distortion is high. Some analysts have attempted to avoid this difficulty by referring THD to the basic of the height demand load current instead of the basic of this sample of always a meaningful number. The criteria in IEEE Standard 519-1992, Recommended Practices and Requirements for Harmonic Control in Power Systems, are based on the concept of total demand distortion. It's explained as follows[33]: The demand or load of current IL over an observable period is what total demand distortion (TDD) is based on.

$$TDD = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{IL} \tag{3.3}$$

Where the maximum demand loads is current measured at the point of common coupling (PCC)for the fundamental frequency component

3.2. THREE- PHASE HARMONIC FILTER

An arrangement of parallel components called a three-phase harmonic filter is used in a facility to reduce voltage distortion and optimize the ability factor. Electronic converters that create both harmonic currents and voltages simultaneously are examples of harmonic elements. The ability system is given these distortions. This might eventually result in a distorted current flow across the system's impedance, which could cause an assembly of harmonic voltage distortion. By directing the harmonic currents to the tail where there is comparatively low resistance, harmonic filters, whether single phase or three phases, are known to lessen this distortion [33].Harmonic filters can be used to generate reactive power that converters may need for power factor adjustment since they are capacitive at the bottom or first harmonic. Numerous filter banks—the most often utilized of those filters—are typically linked in parallel to achieve a suitable distortion limit.

3.2.1. Band pass filters

Low-order harmonics like the 5th, 7th, 11th, and 13th are frequently filtered using these filters. These filters may be found in single-tuned and double-tuned varieties. A single-tuned filter operates at a single frequency, whilst a double-tuned filter operates at two.

3.2.2. High pass filters

As their name suggests, these filters are used to filter high harmonic frequencies. The C-type filter, a unique form of high pass filter, was used in this thesis to provide reactive power and prevent parallel resonance. It permits the filtering of the third harmonic, which is of very low order, while maintaining zero losses at the low frequency.

3.2.3. Three-phase harmonic filters

The RLC components used in this filter's construction. These RLC values are calculated using the following parameters from the filter's form.[34]:

- ✓ Reactive power when the voltage is nominal
- ✓ Frequency of tuning
- ✓ A quality-related factor

The four types of filters that can be used in conjunction with the three-phase harmonic filter are illustrated below. The single tuned filter, which uses only one frequency to operate, is the best type of these filters. Figure 3.2 illustrates the standard factor and formulae for calculating the reactive and active powers, respectively. The Q=nXl/R filter's standard factor and, consequently, the reactance at the tuning frequency are the same and are denoted by and respectively. The tuning frequency's sharpness is measured by the bandwidth B, which is indicated by the standard factor Q.

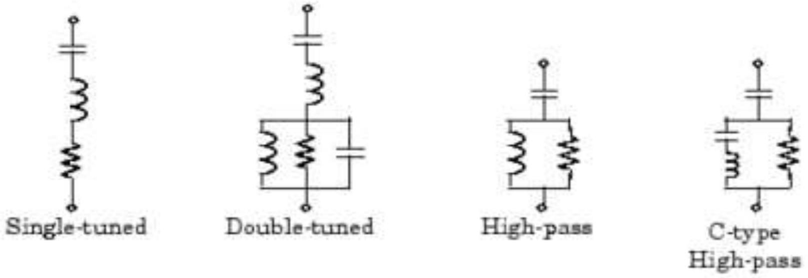


Figure 3.2: Different types of three-phase RLC harmonic filter[34]

3.3. HARMONICS CONTROL

Harmonic distortion may be found across the whole power system. Fundamentally, harmonics should only be controlled if they pose a threat. Three common factors lead to harmonic issues:

- ✓ Harmonic currents have a source that is simply too big.

- ✓ Electrically speaking, the currents' path is just too lengthy, which might result in excessive voltage distortion or phone interference.
- ✓ One or more harmonics are amplified by the system's reaction to a higher extent than is acceptable.

The following are the most important options for reducing harmonics when a problem arises:

- ✓ Change the system's Frequency response by adding filters, inductors, or capacitors
- ✓ Add filters to the system to remove harmonic currents, prevent harmonic currents from entering the system or locally provide harmonic currents.
- ✓ Reduce the load's harmonic current output.

3.3. PLACE OF HARMONICS CONTROL

The methods for reducing harmonic distortion issues vary a little depending on the area. The following methods can be used to reduce harmonic distortion on both the end-user power grid and the utility distribution feeder.

3.3.1. On Utility Distribution Feeders

On distribution feeders, harmonic issues frequently only appear at low loads. The distribution transformers have to deliver more harmonic currents as a result of the increased voltage, and there is also less load to attenuate resonance. The problem can be resolved by frequently turning down the capacitors' current. One instance of a filter mounted on an overhead distribution feeder is shown in Figure 3.3. This reduces the harmonic free fall inside the lines and shortens the common route or the harmonic currents, potentially lowering phone interference.

Figure 3.3: Utility Distribution Feeders

3.3.2. In End-User Facilities

The first thing to do when harmonic issues occur in an end user facility is to determine if the reason is resonance with Power Factor capacitors there. Use of a certain capacitor size would be a simple solution if this were the case. Filters are typically easier and more cost-effective to install on end-user low-voltage systems than on utility supply systems. Both the prerequisites for Filter installation and the accessibility of filtering equipment on the market have improved.

3.4. MODELLING OF THYRISTOR-SWITCHED CAPACITOR

The TSC Configuration-Figure 3.4 is made up of many banks of shunt capacitors of various sizes that are turned on and off by two anti-parallel thyristors. Any rating of capacitance from zero up to the whole spectrum of ratings is swapped in or out with a graduation of one unit since the bank size is set up with a progression of 1, 2, 4, 8, etc. When the capacitor current approaches a natural zero current, which also corresponds to the capacitor voltage capable of the highest ac system voltage, the reactive power through the capacitor quickly comes to an end by suppressing thyristor gate pulses. The harmonic production is very minimal since the currents are switched at zero crossing locations. However, the capacitor's dc voltage increases while the thyristor is conducting.

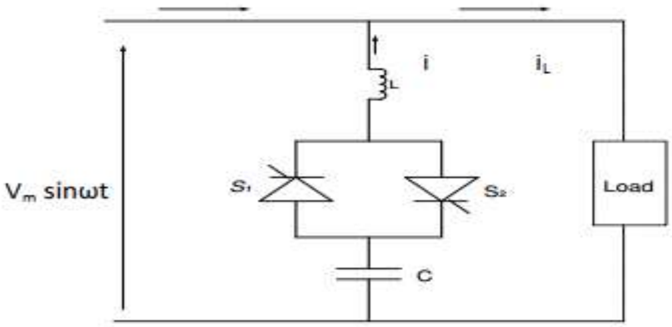


Figure 3.4: Thyristor-switched capacitor (TSC)

A three-phase bank can be created by joining three single-phase branches in a star or delta pattern, as shown in Figure 3.5.

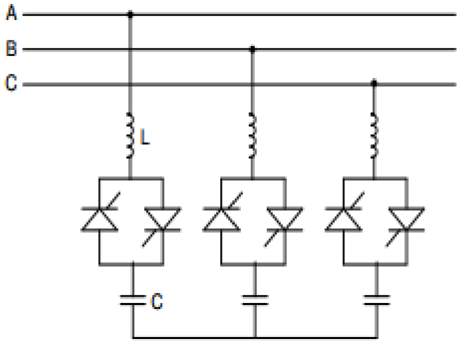


Figure 3.5: three-phase bank

The inductor is a small part of the TSC. Its purpose is to prevent resonance with the network and to restrict the rate of increase of current through the thyristors.

3.5. SYSTEM MODELING

The novel design model of a proportional resonant controller for three-phase linked applications will be the main topic of discussion in this section. On the other hand, because of the nonlinear and unbalanced loads, the output voltage waveform is affected by the negative and zero sequence and current harmonics. The 3-power system linked VSI is the target audience for the PR control technique mentioned in this study. A schematic representation of a three-phase power system coupled VSI and its control loop configuration is shown in Figure 3.6. The Pulse Width Modulation (PWM) technology is used to regulate the inverter, which is linked to the grid by an L-filter. One or more units share a DC connection with the VSI DC supply voltage (s). The VSI's linear control model was obtained by using various [6]. These presumptions include that the DC link voltage will remain constant and that the switching frequency of the inverter will be high enough to have minimal impact on the dynamics of the control loop.

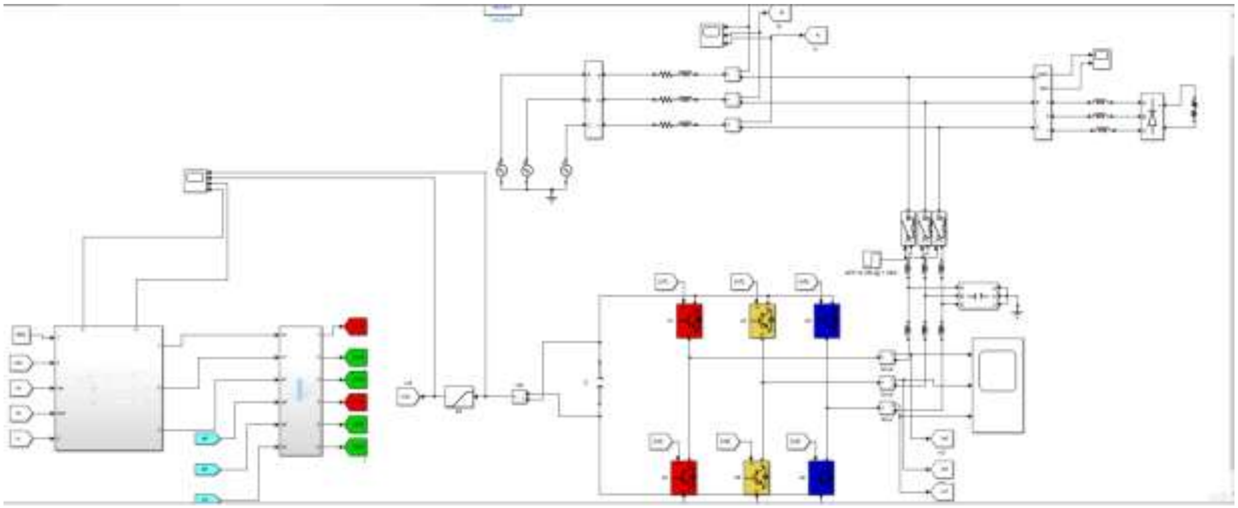


Figure 3.6: Schematic diagram for a three-phase power system PR controller of VSI

From Figure 3.6 the mathematical equations for the voltages and currents are written as follows:

$$L\frac{di(t)}{dt} + Ri(t) = Vin(t) - Vgn(t) \tag{3.3}$$

Where v n(t) is the inverter's output voltage, n = a, b, and c designate the phase, in (t) is the AC flowing through the L-filter into the grid, Vgn (t) is the grid voltage, and R-L is the interface inductor and its equivalent series resistance. Using the observed AC and grid voltage, the outer power control loop calculates the grid's active (P) and reactive (Q) power and compares it to the reference power signals P*ref and Q*ref. The facility equations (3.5) and (3.6) are used to facilitate the calculation of P and Q separately.

$$P(t) = Va(t)ia(t) + Vb(t)ib(t) + Vc(t)ic(t) \tag{3.5}$$

$$Q(t) = {}^{1}\!/_{\sqrt{3}}\,[Vab(t)ic(t) + Vbc(t)ia(t) + Vca(t)ib(t)] \tag{3.6}$$

The PI controllers for the outer power control loop are built with a slower dynamic reaction time requirement than those for the inner current control loop. The actuating power outputs of the PI controllers are used to determine the reference currents for the inner control loop. Frequently, this is accomplished by modifying the d-q frame P and Q power equations [4.1][5]. The calculations for the reference currents id ref and iq ref in the d-q frame are shown in equations (3.7) and (3.8).

$$\mathrm{i_{dref}(t) = 2xP_c(t)/V_{gd}} \tag{3.7}$$

$$\mathrm{i_{qref}(t) = 2xQ_c(t)/V_{gd}} \tag{3.8}$$

Where PC(t) and QC(t) are the PR controllers that, respectively, act on the active and reactive power outputs The PC(t) and QC(t) frame power equations presented in [1] might be used to directly determine the reference currents. But it was discovered that doing so had a significant influence on the dynamics of the control loop.

3.5.1. PROPORTIONAL RESONANT MODEL

In order to comply with the international standards IEEE-519, this controller's goal is to deliver inverter output sinusoidal voltage with low Total Harmonic Distortion (THD) even with nonlinear loads and give an honest transient response for the abrupt change in load. The MATLAB/SIMULINK software is used to model the system. The inner Model Principle has been supported by resonant controllers [35]. Which claims that when the closed loop is in stable condition, excellent tracking for a reference or a rejection for disturbance signals is guaranteed? One of its primary features is the introduction of infinite gain at a particular resonant frequency, which should coincide with the periodic reference signal frequency.

CHAPTER FOUR

4. PR CONTROLLER AND HARMONIC DISTORTION DESIGN

4.1. INTRODUCTION

The paper focus on the appearance of a three-phase grid harmonic distortion mitigation filter design in this chapter. Since the filter designs for three-phase power systems were so straightforward, it had not been a major problem. As more complicated designs are used in the industry today, harmonic distortion has developed. Harmonic distortion as it relates to power quality has received a lot of attention. DC voltage is changed into AC output at an inverter's input. Harmonics have an impact on the facility's quality during this changeover. The next subsections will show how harmonic reduction may be used to improve ability quality.

4.1.1. HARMONICS

A symptom or wave that is harmonic has a Frequency that is an integer Multiple of the elemental frequency [36]. In addition to the fundamental frequency f, the sign may also contain harmonics with frequencies of 2f, 3f, 4f, and so forth. If all of the energy is contained at the elemental frequency, the signal can be a perfect wave. The signal isn't a pure sinusoidal waveform if some energy is present in the harmonics; instead, it has a shape like a triangle, square, or saw tooth [36]. A network also has numerous internally connected power systems. Due to the combination, the entire system is impacted if one of the inner networks fails.

Harmonic distortion is mostly caused by nonlinear loads. A load is referred to as nonlinear if it draws a non-sinusoidal current while being coupled to a sinusoidal voltage. Electrical equipment is shielded from harm by harmonic voltage distortion by harmonic filters that separate the harmonic current. These filters additionally raise the ability quality. Power quality has drawn a lot of attention since intermission, sagging, and switching transients are issues that many consumers are worried about [36]. A network also contains several internally linked power systems. Due to the combination, the entire system is impacted if one of the inner networks fails.

4.2. PR CONTROLLER DESIGN

The PR controller, which results in the perfect controller transfer function GAC(s) given in, is essentially a combination of a proportional kp and resonant controller (equation 4.1).

$$G_{AC}(s) = Kp + \frac{K_i S}{S^2 + \omega^2} \tag{4.1}$$

Where K i is a carefully chosen constant that may be used to shift the amplitude response of the controller vertically[5], [7]. The finest PR controller lacks phase shift, has gains at other frequencies, and has an infinite gain at the AC frequency. Due to practical restrictions of the signal processing systems that implement it, a non-ideal transfer function GAC(s) (eq. 4.1) is used instead of an ideal transfer function because the controller's infinite gain may cause stability issues (eq 4.2).

$$G_{AC}(s) = Kp + \frac{K_i S}{S^2 + 2\omega_c S + \omega^2} \tag{4.2}$$

The finest PR controller lacks phase shift, has gains at other frequencies, and has an infinite gain at the AC frequency. Due to practical restrictions of the signal processing systems that implement it, a non-ideal transfer function GAC(s) (eq. 4.1) is used instead of an ideal transfer function because the controller's infinite gain may cause stability issues (eq 4.2).[5].

4.2.1. PR Controller with TCS Controller Design

The inner Model Principle has been supported by resonant controllers (IMP)[37],which claims that if the closed loop is stable, effective tracking for a reference or a rejection for disturbance signals is guaranteed. One of its primary features is the introduction of infinite gain at a particular resonant frequency, which should coincide with the periodic reference signal frequency. The PR current controller GPR(s) is represented as in the transfers function of this controller with the sinusoidal internal model (equation 3.4). IMP states that the resonant controller defined in (4.1) guarantees zero steady-state error for sinusoidal tracking (disturbance rejection) at a frequency if the closed-loop stability is assured. The Bode diagram demonstrates that the PR controller described by has theoretically infinite gain at frequency r, allowing it to confirm zero steady-state error only at this frequency while introducing no gain or phase shift at other frequencies. This controller is regarded as a perfect controller and has theoretically infinite gain at frequency r. This best controller's infinite gain may make it challenging to implement with analog or digital systems. Additionally, it would be unable to select the optimal gain and width for this controller, which would reduce its flexibility and cause stability problems. Therefore, it is preferable to utilize the non-ideal variation of the controller, which has a limited gain but still exhibits reasonably good permanently tracking capability to prove zero steady-state error, rather than the ideal variety of the controller mentioned above. The non-ideal PR control Bode plot is depicted by (equation 3.5).

4.3. THREE-PHASE HDMITIGATION CONTROLLER DESIGN

4.3.1. Harmonic Filters

A filter is any set of passives (R, L, C) and/or active (transistors, op-amps) components intended to select or reject a range of frequencies. Because certain electrical equipment or signals are nonlinear in nature, filters are frequently used to filter out any undesirable frequencies. One of the correctives (remedial) methods used to address harmonic issues and maintain them within acceptable bounds is the use of filters. They are referred to as tuned (resonant) circuits because they provide a coffee impedance channel or "trap" to a harmonic to which a filter is tuned. The tuning technique seeks to tune the circuit to the resonance frequency, or f-r, at which the response is or is at its maximum. This indicates that the circuit is at an extremely high level of resonance. Three different types of filters exist[38].

1. Passive filters

2. Active filters

3. Hybrid filters

It will be managing only Passive Filters as these are the most apprehension of this thesis work. a brief description of active and hybrid filters is additionally provided in what follows:

4.3.2. Passive Filters

In order to achieve the appropriate harmonic suppression, passive filters are mostly topologies or arrangements of R, L, and C components coupled in various combinations. By tweaking the weather to produce resonance at a certain frequency, they are used to either Shunt the Harmonic currents off the road or to stop their flow between different components of the system. Additionally; they compensate the system's reactive power, which raises the capability level. The performance of a passive filter is mostly dependent on the system source impedance due to the drawback that they may interact negatively with the power system. However, they are employed for the removal of a particular harmonic frequency, and the number of passive filters rises as the number of harmonics in the system rises. They will be divided into[38]:

1. Passive shunt filter

2. Passive series filter

The emphasis of this thesis's research is passive shunt filters, which are ably addressed here while a poignant idea about series filters is put out.

4.3.2.1. Passive Shunt Filters

They are classified as shown in figure 4.1 below:

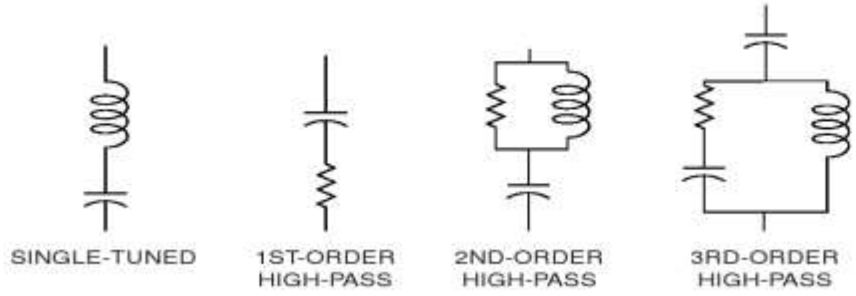


Figure 4.1: schematic diagram of series tuned filter[38]

Single Tuned Filter**:**

The single tuned "notch" filter is the most popular kind of passive Filter. this is the most affordable form and is typically enough for the task. The ‘notch’ filter is shunt-connected and series tuned to sometimes offer impedance to a Particular Harmonic Current. with the system of abilities. As a result, harmonic currents are redirected through the filter from their usual flow pattern on the road. Harmonic suppression and power factor adjustment are both capabilities of notch filters [38].Power Factor Correction capacitors could also be wont to make single-tuned filters. Additionally, single-tuned filters might be made using power factor adjustment capacitors. Low harmonic frequencies are used for tuning. The capacitor and reactor have identical reactance at the tuned harmonic, but the filter just has resistive impedance. Figure 4.1 displays a generic schematic representation of the series-tuned filter. Figure 4.2 depicts the impedance V s frequency curve for this filter.

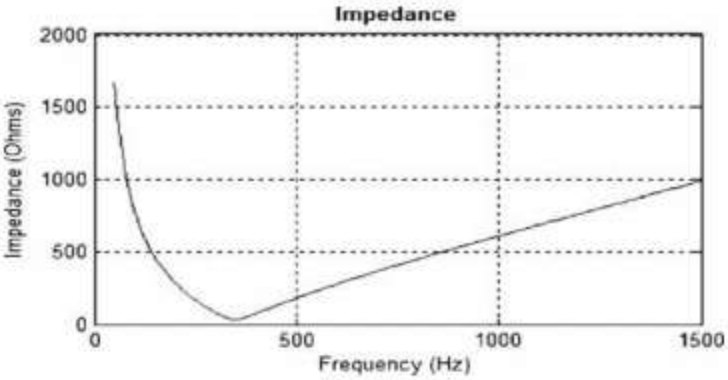


Figure 4.2: impedance V_s frequency curve[38]

Double Band Pass Filters:

A series configuration of the most capacitors, reactors, and tuning device consisting of a tuning capacitor and tuning reactor coupled in parallel could result in a double band pass filter. Such a filter has low impedance at two tuned frequencies.

Damped Filters:

They can be of the first, second, or third order. The second order is the most prevalent. A parallel combination of the actor and a resistor, along with an asynchronous capacitor, make up a second-order damped filter. For a somewhat wide range of frequencies, it has low impedance. A damped filter is referred to as a high pass filter when used to remove high order harmonics (17th and above), offering a lower impedance for primary frequencies while blocking low ones. Typically, dampened filters are adjusted to an hr, which is 10.7, 16.5, and so forth. Figure 4.3 depicts the Second-Order High Pass Filter's Impedance vs. Frequency graph.

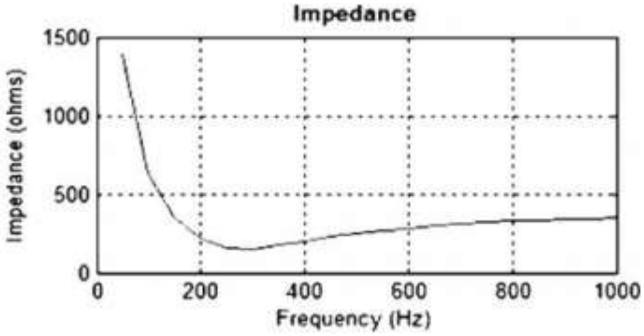


Figure 4.3: Impedance Vs Frequency curve of Second-Order High Pass Filter[37]

4.3.2.2. PASSIVE SERIES FILTER

As contrast to a notch filter, which is connected in shunt with the capability system, a series passive filter is connected asynchronously with the load. The inductance and capacitance are modified and connected in parallel to provide high impedance at a certain harmonic frequency. [37].As a result, only harmonic currents at the tuned frequency may flow due to the high impedance. The elemental current would be able to flow with very little additional resistance and losses if the filter was designed to have low impedance at harmonic frequencies. Figure 4.4 depicts a series filter in a common arrangement. When it is impossible to take advantage of zero-sequence characteristics in a single-phase circuit, series filters are employed to block one harmonic current (such as the third harmonic). Series filters can only be used to stop currents with plenty of harmonics. For each harmonic current, a series filter tuned to it harmonically is required. This arrangement might lead to significant losses at the fundamental frequency.

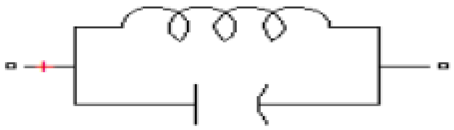


Figure 4.4: series filter[37]

4.3.3. ACTIVE FILTERS

Active filters are a relatively recent type of harmonic cancellation technology. They are significantly more costly than passive filters and supported complex power electronics. They do require the clear advantage, though, that they do not connect with the system. They will function regardless of the system impedance properties [39].They will thus be used in extremely challenging situations when passive filters cannot effectively work due to resonance issues with parallel lines. Additionally, they will handle 1 harmonic at a time and address additional power quality issues as in flicker. for large distorted loading from somewhat vulnerable spots on the facility system they are very helpful.

4.4. HYBRID FILTERS

Due to their high rating and extremely high switching frequency of PMW (Pulse Width Modulator) converters, APFs (Active Power Filters) topologies are not cost-effective for high power appliances. Therefore, harmonic filtration of such substantial nonlinear loads is accomplished by LC PPFs (Passive Power Filters). However, passive filters have several drawbacks. For instance, the system's fluctuating impedance has an impact on their performance, and when used with a utility system, series and parallel resonances may also be formed, which leads to the extension of current harmonics in the supply[39].As a result, the HAPF (Hybrid Active Power Filter), another harmonic mitigation method, has been introduced. Combining the benefits of APF and PPF, PDF does away with their drawbacks. These topologies offer well-filtering performance and are cost-effective solutions to high-power power quality issues.

4.5. STANDARD LIMITS OF HARMONIC DISTORTION

This subsection, which is solely based on the harmonic distortion mitigation study, presents the limitations of acceptable voltage and current harmonics distortion specified by IEEE and IEC. These standards include recommendations for power quality practices and usages [40].

4.5.1. Voltage Harmonic Distortion Limits

Table 4.1: ANSI/IEEE 519 voltage distortion limits [41]

Bus voltage at PCC	Each$\boldsymbol{V_h}$, %	Voltage THD, %
V<69KV	3.0	5.0
69≤V<161KV	1.5	2.5
V≥161KV	1.0	1.5

Table 4.2: IEC 61000-2-2 voltage harmonic distortion limits in public low-voltage network[41]

Odd harmonics		Even harmonics		Triplen harmonics	
H	% V_h	H	% V_h	H	% V_h
5	6	2	2	5	
7	5	4	1	9	1.5
11	3.5	6	0.5	15	0.3
13	3	8	0.5	15	0.3
177	2	10	0.5	≥21	0.2
19	1.5	≥12	0.2		
23	1.5				

Table 4.3: IEC 61000-2-4 voltage harmonic distortion limits in industrial plants[41]

		Even harmonics		Triplen harmonics	
H	% V_h	H	% V_h	H	% V_h
5	6	2	2	3	5
7	5	4	1	9	1.5
11	3.5	6	0.5	15	0.3
13	3	8	0.5	15	0.3
17	2	10	0.5		
19	1.5	≥12	0.2		
23	1.5				
25	1.5				
≥29	x				

Table 4.4: IEC 61000-22-4 class 3[41]

Odd harmonics		Even harmonics		Triplen harmonics	
H	%,V_h	H	%,V_h	H	%, V_h
5	8	2	3	3	6
7	7	4	1.5	9	2.5
11	5	≥6	1	15	2
13	4.5	21	1.75		
17	4	≥27	1		
19	4				
23	3.5				

4.5.2. Current Harmonic Distortion Limits

Table 4.5: Table 4.5-IEC 61000-3-2 maximum permissible harmonic currents for class D equipment [41]

H	3	5	7	9	11	13	15………… 39
Max $\mathbf{I}_h$	2.3	1.14	0.77	0.40	0.33	0.21	0.15……… $15/h$
Equipment input current ≤ 16 A per phase							

Table 4.6: IEEE 519 current distortion limits [41]

Isc/IL	$\mathbf{I}_h$/ IL, % ---- general distribution systems (120V-69KV)					TDD
	h<11	11≤h<17	17≤h<23	23h≤h<35	h≥35	
<20	4.0	2.0	1.5	0.6	0.3	5
20-50	7.0	3.5	2.5	1.0	0.5	8
50-100	10	4.5	4.0	1.5	0.7	12
100-1000	12	5.5	5.0	2.0	1.0	15
>1000	15	7.0	6.0	2.5	1.4	20
ISC/IL	$\mathbf{I}_h$/ IL, % ---- general sub transmission systems (69-161KV)					TDD
	h<11	11≤h<17	17≤h<23	23≤h<35	h≥35	
ISC/IL	$\mathbf{I}_h$/ IL, % ---- general transmission systems (>161KV)					TDD %
	h<11	11≤h<17	17≤h<23	23≤h<35	h≥35	
<50	2.0	1.0	0.75	0.3	0.15	2.5
≥50	3.0	1.5	1.15	0.45	0.22	3.75

CHAPTER FIVE

SIMULATION AND RESULT ANALYSIS

5.1. MATLAB SIMULATION SETUP

This chapter focuses on the simulation and results in the analysis of nonlinear loads without and with active power filter Harmonic compensation. The proposed harmonic compensation mechanisms are analyzed and compared its total harmonic distortion THD with the system model without compensation and standards for harmonic compensation up to the target harmonic frequency. The compared result is displayed in the percentage to demonstrate the compensation distortion measured in the output. The complete schematic diagram of the shunt APF is shown in Figure 5.1.

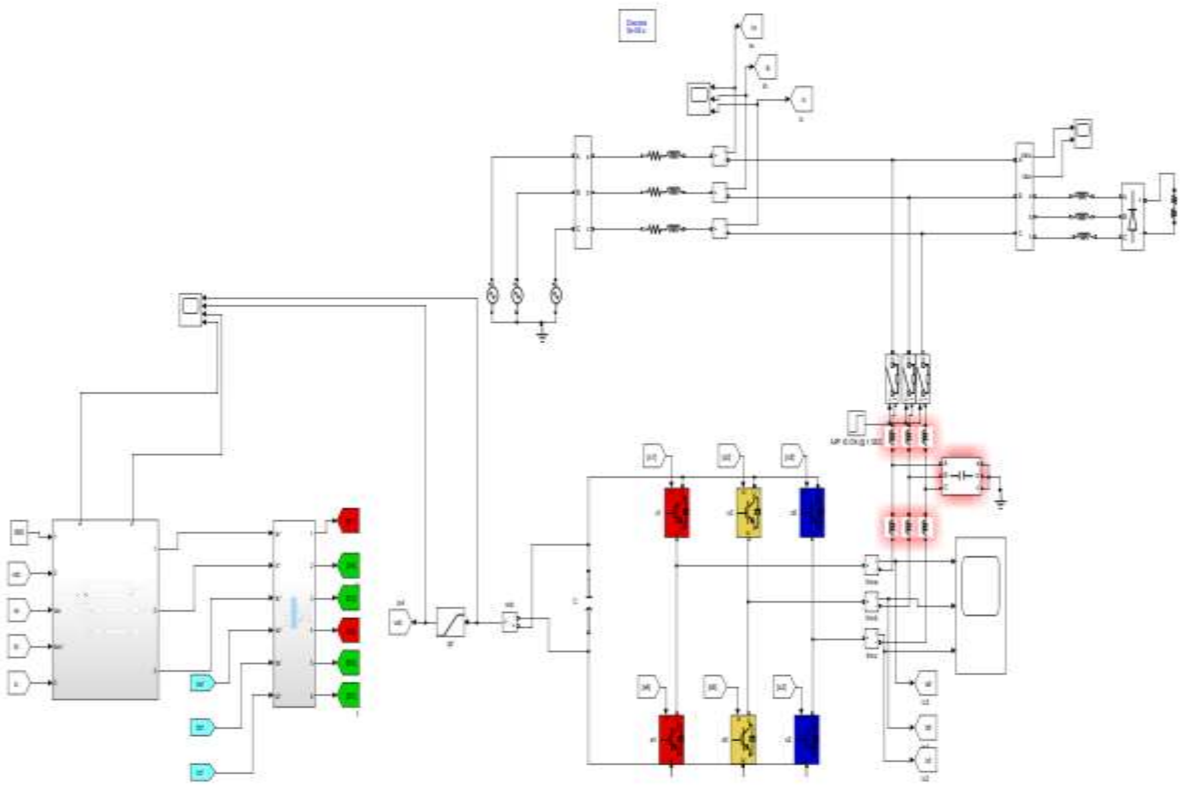
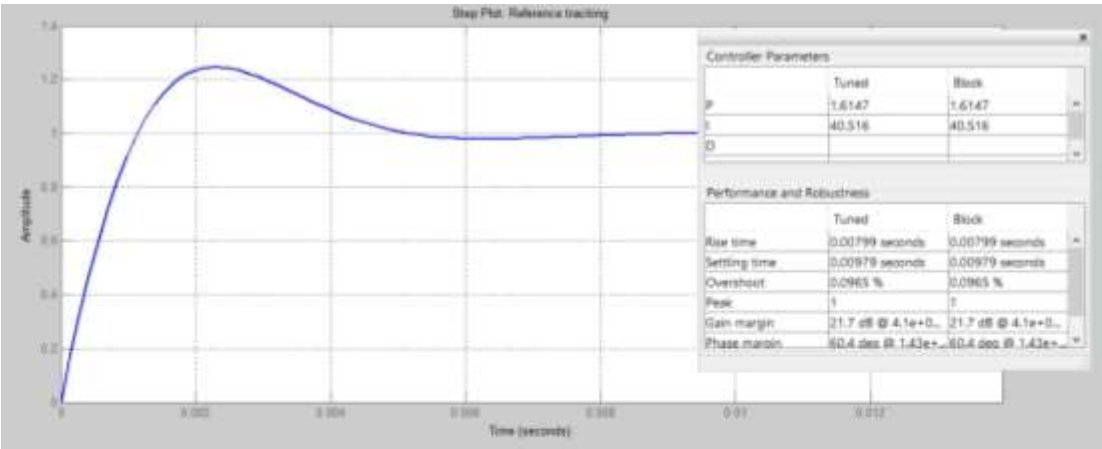


Figure 5.1: Complete schematic diagram of the shunt AFP

A three-phase ac voltage source is connected to the three-phase voltage and current measurement block. The source currents are measured, and output is shown in the data acquisition scope1. On the other side non-linear load is connected to the three-phase voltage and current measurement block. The output current and voltage of non-linear load are seen in scope6. Shunt APF is connected to the wires of source currents and the current of APF is measured in scope2. Capacitor voltage (Vdc) connected to APF is seen in scope 3. S1 to S6 are six IGBT/diodes connected anti parallel to each other to form APF circuitry.

The system model is composed of the current controller, voltage controller, three-phase inverter, and power circuit with the nonlinear load. The actual capacitor voltage is compared with a set reference value. The dc-link voltage is sensed from the capacitor and compared with the reference DC-voltage 680 V. The voltage error is regulated by the PI controller. The output of the voltage controller PI acts as the reference current for the PR current controller. The three-phase currents are sensed from the line current and compared with the reference current. The error is regulated by the proportional resonant controller.



Controller Parameters

	Tuned	Block
P	1.6147	1.6147
I	40.516	40.516
D		

Performance and Robustness

	Tuned	Block
Rise time	0.00799 seconds	0.00799 seconds
Settling time	0.00979 seconds	0.00979 seconds
Overshoot	0.0965 %	0.0965 %
Peak	1	1
Gain margin	21.7 dB @ 4.1e+0...	21.7 dB @ 4.1e+0...
Phase margin	60.4 deg @ 1.43e+...	60.4 deg @ 1.43e+...

Figure 5.2: PID Tuner with PI controller

Knowing where to start and where to go can be challenging when tuning a PID controller. Finding values that satisfy the requirements and offer the desired control is more crucial than finding the "perfect" values. Make sure the control device is mechanically sound first. Most of the time, when trying to "tune" PID values to address a problem; people are actually trying to address a physical problem rather than an automation problem. We can begin programming once everything has been validated. There are many different PI controllers available, and in some cases, this is all that is needed. But you must identify the effective value if your application might profit from the derivative's dampening effects. Once you've established a stable PI controller, gradually increase the derivative value, alter the set point, and give the controller some time to settle.PR controller is similar to PI controller. PI controller is used for dc (d-q parameter) and PR is used for ac (alpha-beta, abc) kind of system. The suggested way to tune the PR controller is to replace PR by PI and tune the PI controller. Further replace the PI by PR with the same parameter gains and it will work. A tuning method of the zigle-Nichols type of their tunings.

5.2. OUTPUT FILTER

The conventional output filters can be an RL circuit. However, for better harmonic compensation an LCL filter is used to restrict the flow of harmonic current in the converter as shown in Fig.5.2

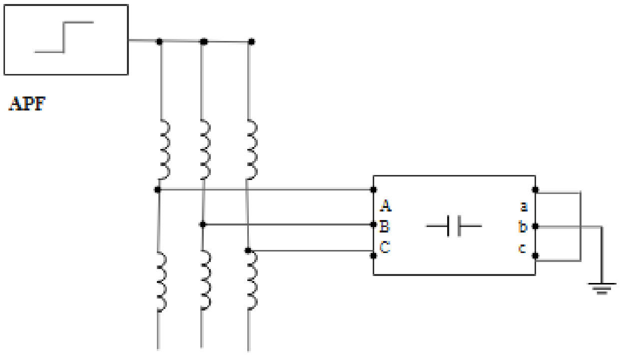


Figure 5.3: LCL filter

The LCL filter is design with L1= 1.8mH, L2 = 0.01mH andC_f = 60 microfarad.

5.3. PR CONTROL SCHEME

The conventional PI controller is insufficient to compensate for the ac signal. The nonlinear load injects high harmonic content into the system which is difficult to compensate for with this conventional PI controller. Therefore, a proportional-resonant controller for each phase is applied to regulate the current harmonic up to the 11th order (550 Hz). The block diagram of the PR controller is displayed in figure 5.4. The proportional gain for PR is 15.

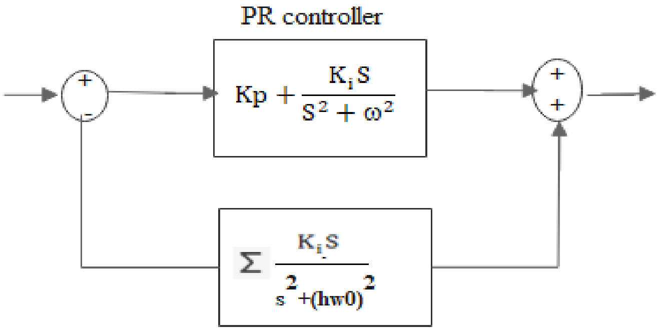


Figure 5.4: PR control scheme

Figure 5.5 Simulink model of three-phase harmonic distortion mitigation based VSI model is designed in MATLAB software. In this model, IGBTs are ON in pairs and for 180-degree conduction. IGBT inverter is modeled in MATLAB. For modeling the Simulink model Sim power sys toolbox is used. IGBT is used in inverters as switches.

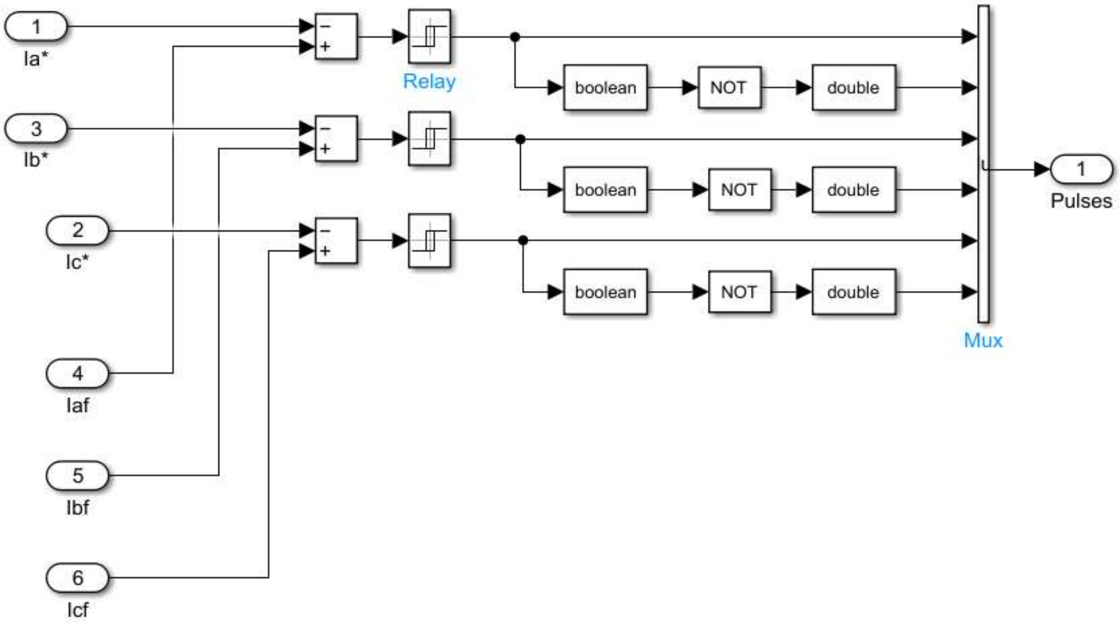


Figure 5.5: Hysteresis Current regulator

These reference currents and actual currents are given to subsystem1. The difference between reference current and actual current decides the operation of switches. These switching signals after proper isolation and amplification are given to the switching devices. Due to these switching actions, current flows through the filter inductor Lc to compensate for the harmonic current and reactive power of the load, so that only active power is drawn from the source.

5.4. SIMULATION RESULTS

5.4.1. Case-1 Simulation Results Without Compensation

The complete active power filter system model run without compensation with a three-phase source, a nonlinear load, a voltage source converter, and a PR controller. All these components are modeled separately to simulate the system. The spectrum of different source current and voltages and load current and voltages are shown below respectively. The overall system is simulated without compensation for up to 1 second. In Y and X –axis indict current (Amp)and time in second.

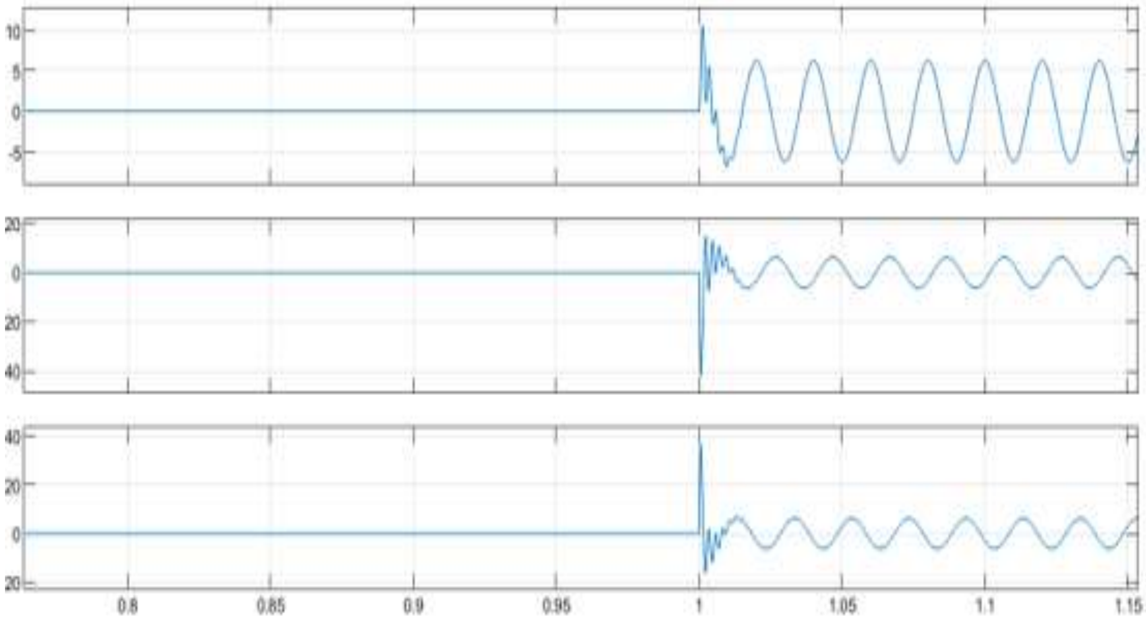


Figure 5.6: Three-phase source current without nonlinear load

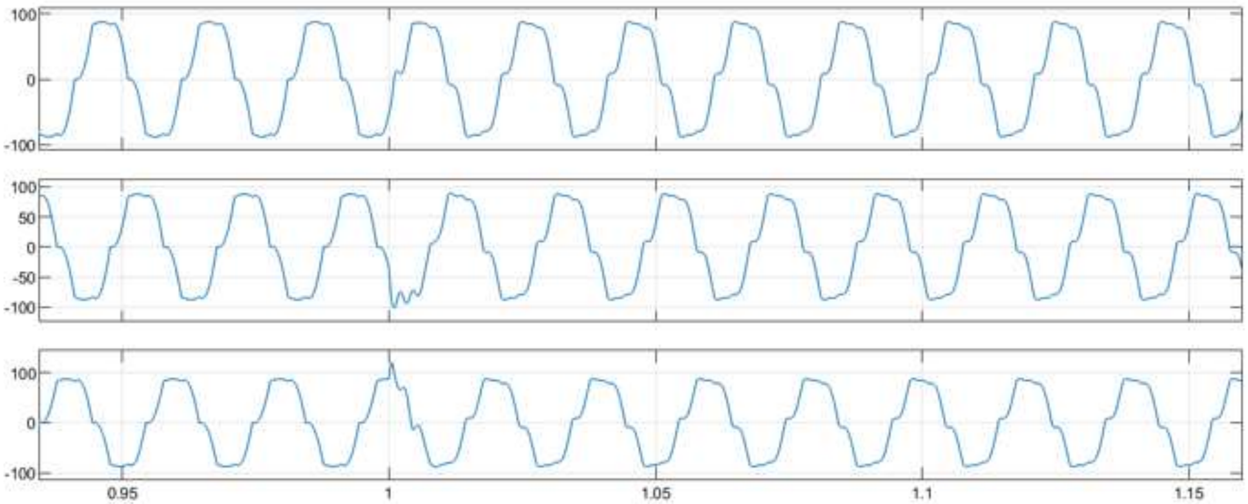


Figure 5.7: Three-phase source current with nonlinear load

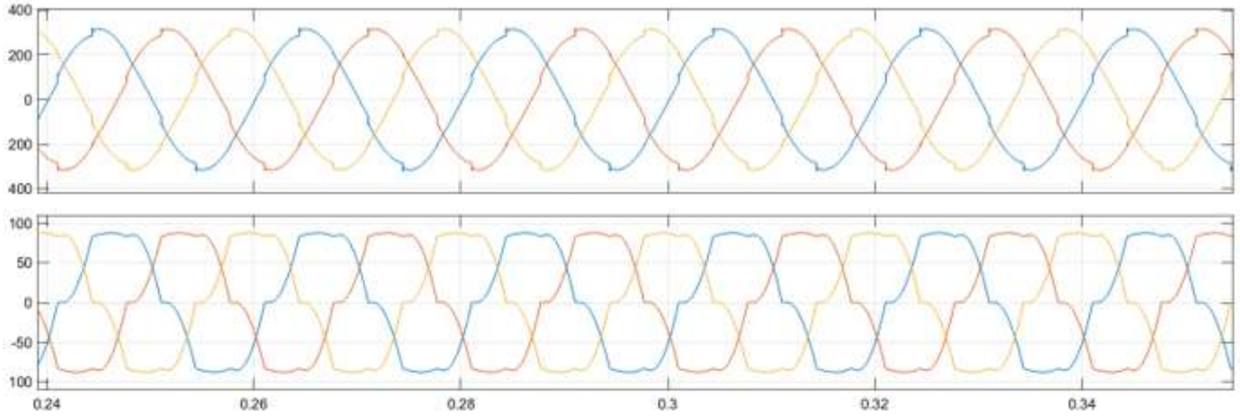


Figure 5.8: Three-phase load current and voltage

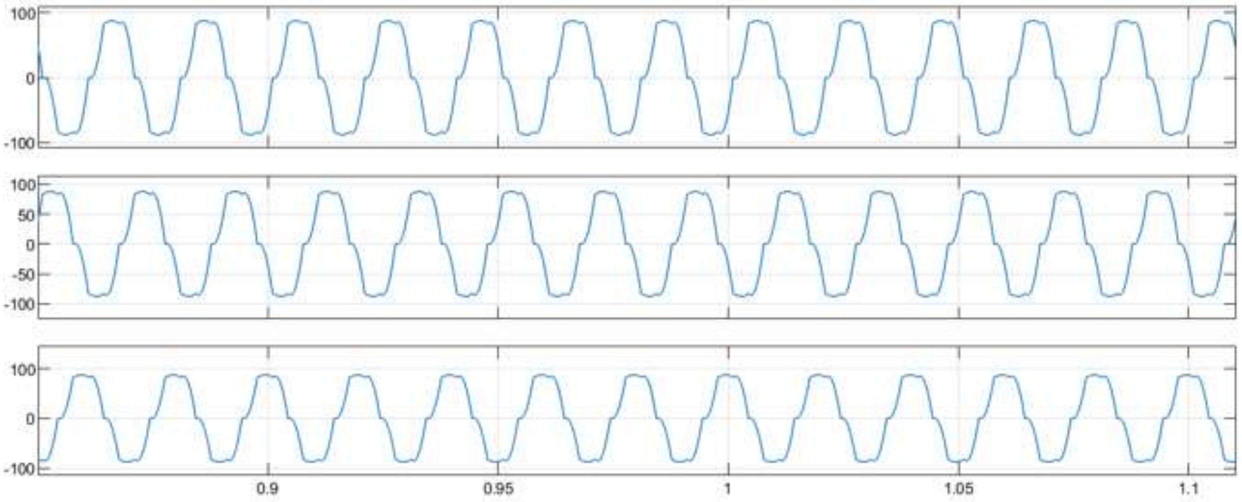


Figure 5.9: Source current without compensation

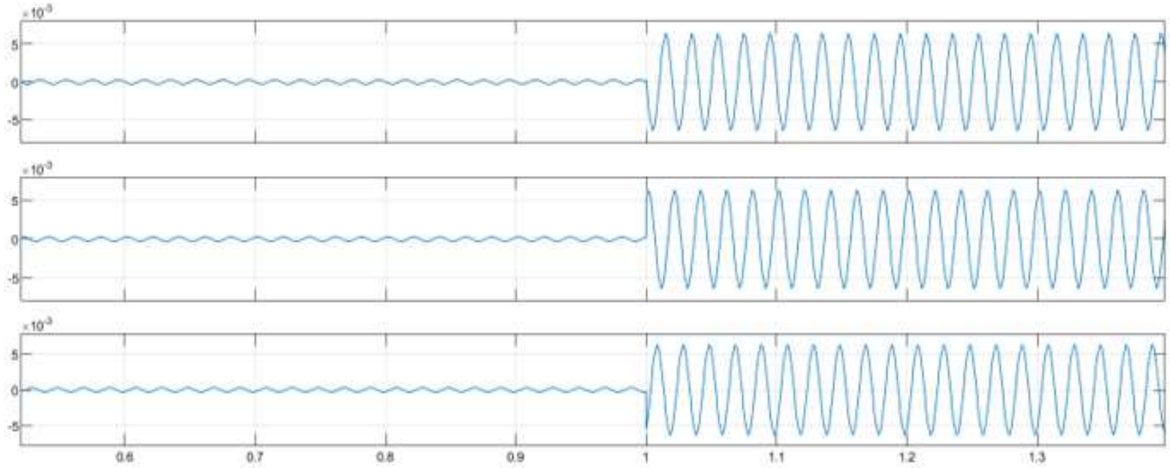


Figure 5.10: Filter current without Compensation

5.1.2. Case-2 Simulation Results Without Compensation

The whole system is simulated with the proposed controller and output filter. The output voltage and current signal are captured from the Simulink simulation**.** The overall system is simulated with compensation after 1 second. In Y and X –axis indict current (Amp)and V(volt) and time in second.

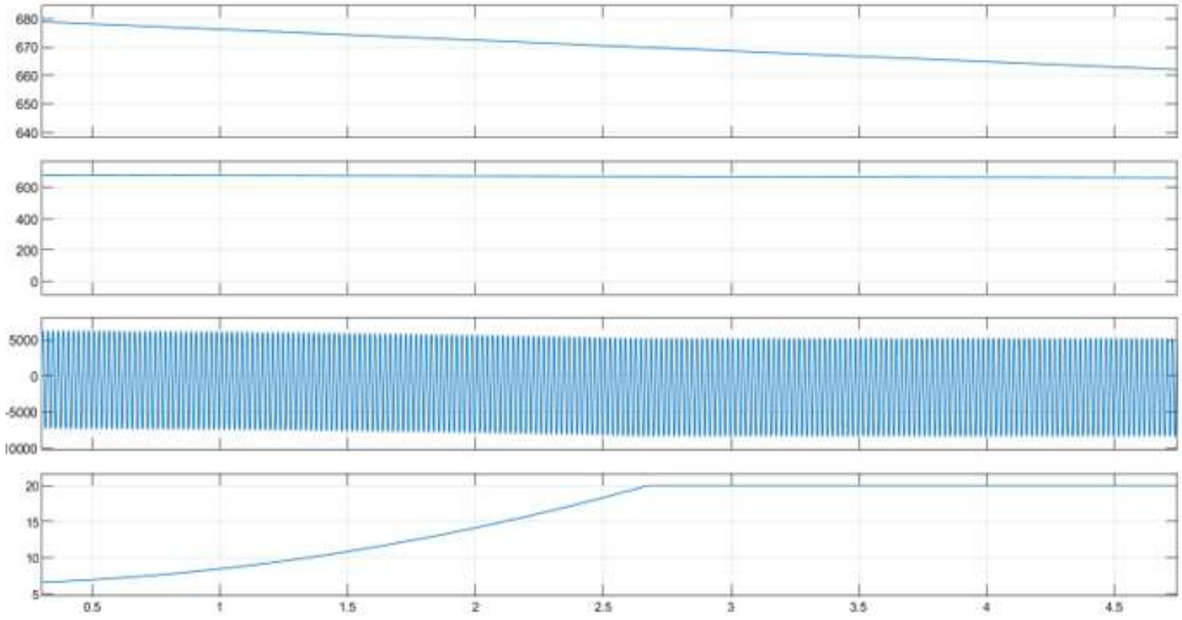


Figure 5.11: Three-phase compensated Current and Voltage

In Yand X –axisindict current (Amp)and V(volt) and time in second.

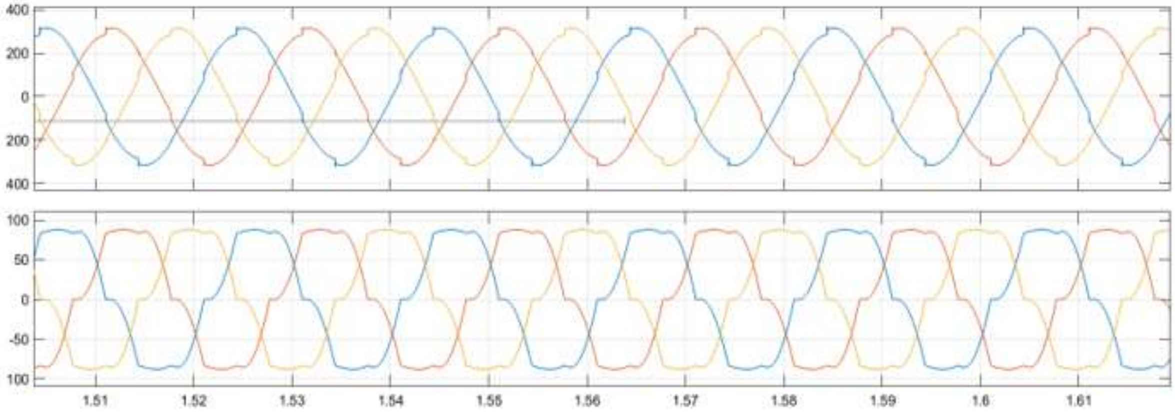


Figure 5.12: Three- phase compensation load current

By using FFT analysis overall THD of the output voltage is calculated. Here, by using the fundamental frequency 50Hz is used. The value of THD is varied and the modulation index is observed in Figures 5.13 and figures 5.14 respectively here.

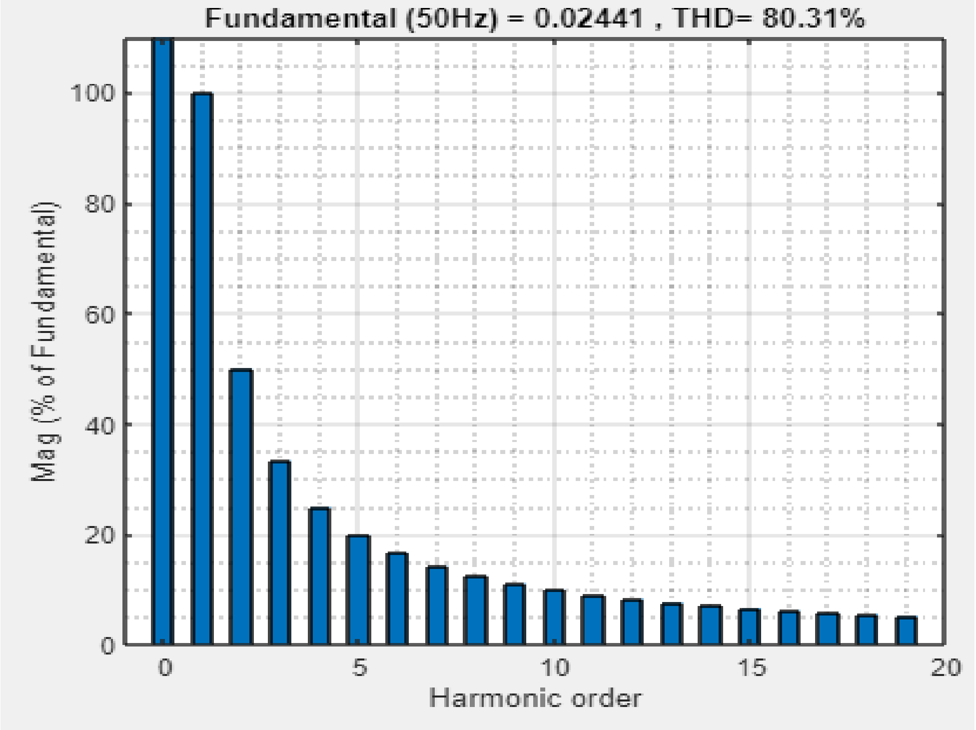


Figure 5.13: FFT analysis without harmonic filter

The bar diagram is also given describing the various orders of THD. Figure 5.13 shows the FFT analysis of load current without APF connected to the system. Harmonics come out to be 80.31% in the source current.

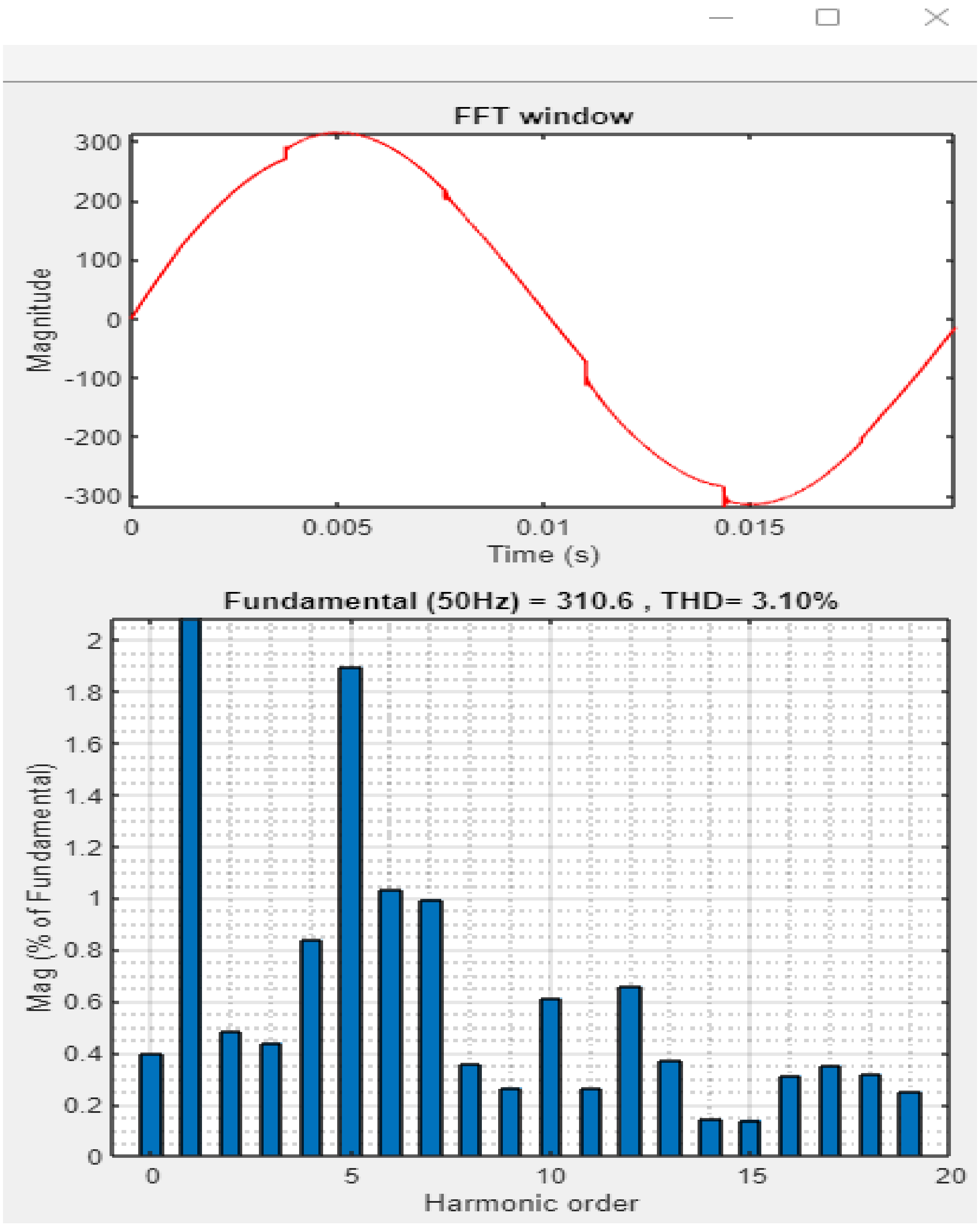


Figure 5.14: FFT analysis with harmonic filter

The bar diagram is also given describing the various orders of THD. Figure 5.14 shows the FFT analysis with APF connected to the system. It is clearly seen that the THD in source current is reduced to 3.10% only.

5.1.3. Case-3 Simulation Results with Compensation

An anti-parallel SCRs with a capacitor to compensate for the line voltage is shown in Fig .5.12. Similarly, the overall system with Anti-parallel SCRs with a capacitor to compensate for the line voltage is shown in fig. 5.13. The whole system is simulated with the proposed controller, anti-parallel SCR, and output filter. The output voltage and current signal are captured from the Simulink simulation**.**

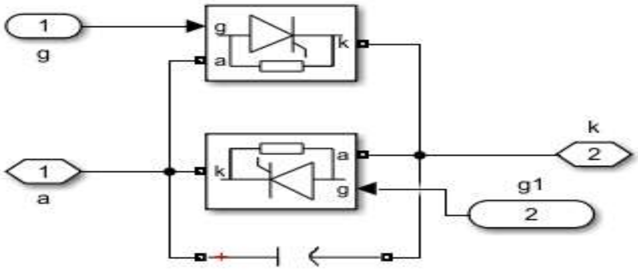


Figure 5.16: Anti-parallel SCRs with a capacitor to compensate for the line voltage.

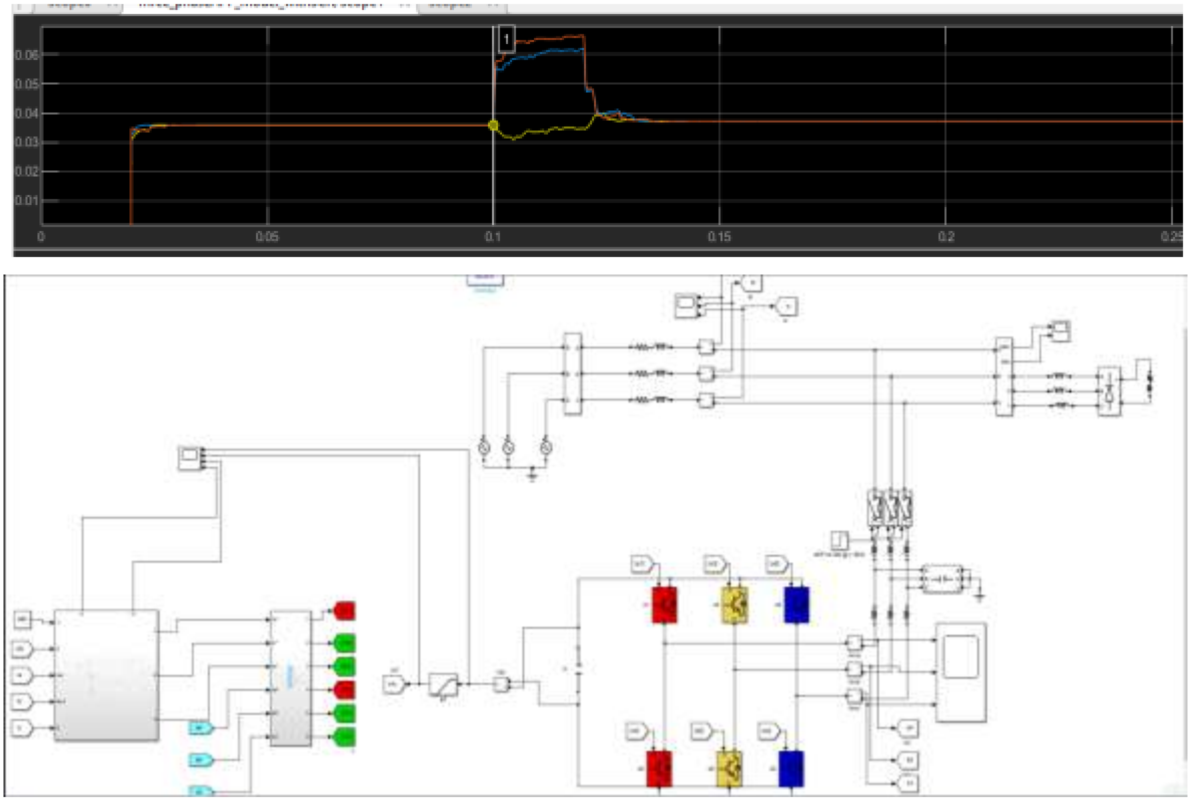


Figure 5.17: System Model with Anti-parallel SCRs with a capacitor to compensate for the line voltage

A three-phase capacitive load is added to verify the effectiveness of the proposed controller for the anti-parallel controller. The linear reactive load with excessive voltage harmonic is added to the system and the controller is designed to interact at the simulation time of 0.1 seconds. The proposed anti-parallel controller compensates the system harmonic from 80.31% THD to3.10% THD and 77.21% power quality is improved. Therefore, both the PR and Anti-parallel comparing control works in a complementary fashion to minimize the cost of APF controller design.

CHAPTER SIX

CONCLUSION AND FUTURE WORK

6.1. CONCLUSION

To reduce harmonic distortion and improve power quality, the proposed shunt Active compensator controller with the power Filter model has been investigated and analyzed in MATLAB Simulink. Harmonic compensation of the non-linear load is achieved by implementing a PR controller and anti-thyristor parallel connected switched capacitor controller-based Shunt active power filter. The SIMULINK model from the MATLAB toolbox is used to simulate the overall system and design the controller. According to simulation studies, the shunt active power filters improve the power quality of the power system by removing harmonics and reactive current from the nonlinear load current, transforming it into a sinusoidal current that is in phase with the source voltage. The FFT analysis of load current without and with APF attached to the system is shown in the FFT windows bar diagram that is presented while detailing the various orders of THD. Based only on the source current, the harmonics distortion mitigation reduced from 80.31% to 3.10% with out and with compensation respectively. Therefore, the proposed control and topology have a promising effect on power utility as well as the customer.

6.2. FUTURE WORK

Harmonic evaluations are widely used and becoming more prevalent in our nation today. The harmonic measurements and analysis used in the current work have produced several intriguing and unique results that require more in-depth research. The existence of non integral harmonics in the electrical network can be detected by measuring inter-harmonics with high-resolution instruments. Lab VIEW may be used for harmonic simulation to create a better user experience with visual programming capabilities.

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