PRE-PROJECT REPORT

ON

SHUNT ACTIVE POWER FILTERS

AND

ANALYSIS OF IMPROVED POWER QUALITY CONVERTERS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

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CERTIFICATE

It is to certify that the contents of the report entitled "**SHUNT ACTIVE POWER FILTERS AND ANALYSIS OF IMPROVED POWER QUALITY CONVERTERS**" is a bonafide work carried out by **Mr. HAKIM SHAIQ HUSSAIN (19207145029)**, **Ms. RIZWANA RAMZAN (19207145025)**, **Ms. FILZA SHAH (19207145032)** and **Mr. MUHAFIZ BILAL KHAN (19207145053)** under my supervision and guidance in partial fulfillment of the requirements for the award of the degree of Bachelor of Technology in Electrical Engineering. The contents of the report have not been submitted earlier for the award of any other degree or certificates and I hereby commend the work done by them in this connection.

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CERTIFICATE OF APPROVAL

This project titled "**SHUNT ACTIVE POWER FILTERS AND ANALYSIS OF IMPROVED POWER QUALITY CONVERTERS**" carried out by **Mr. HAKIM SHAIQ HUSSAIN (19207145029)**, **Ms. RIZWANA RAMZAN (19207145025)**, **Ms. FILZA SHAH (19207145032)** and **Mr. MUHAFIZ BILAL KHAN (19207145053)**, is hereby approved as the creditable study of technology in Electrical Engineering and is presented in a satisfactory manner.

It warrants its acceptance as a prerequisite in fulfillment of the requirements for the award of the degree of Bachelor of Technology in Electrical Engineering at National Institute of Technology Srinagar, J&K.

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CANDIDATE'S DECLARATION

We hereby certify that the work which is being presented in the Project entitled "**SHUNT ACTIVE POWER FILTERS AND ANALYSIS OF IMPROVED POWER QUALITY CONVERTERS**" by "**HAKIM SHAIQ HUSSAIN**", "**RIZWANA RAMZAN**", "**FILZA SHAH**" and "**MUHAFIZ BILAL KHAN**" in partial fulfilment of requirements for the award of degree of B.Tech. (Electrical Engineering) submitted to the Department of Electrical Engineering at INSTITUTE OF TECHNOLOGY, ZAKURA CAMPUS, UNIVERSITY OF KASHMIR is an authentic record of our own work carried out during a period from 3rd April, 2023 to 6th June, 2023. The matter presented in this project has not been submitted by us in any other University / Institute for the award of B. Tech Degree.

1.___________

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We would like to articulate our sincere gratitude towards all those who have contributed their precious time and helped along in our project work. Without them it would have been a tough job to complete and understand this project work.

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Abstract

This report introduces various methods of mitigation of power quality issues caused due to the production of harmonics in source currents and reactive power. Use of power electronic converters with nonlinear loads produces harmonics in source currents and reactive power. Previously passive filters were used to mitigate the harmonics and power capacitors were used to compensate the reactive power. But they provide fixed compensation and detuning because of ageing**.** In recent years there has been considerable interest in the development and applications of active filters, at both distribution and consumer levels, and the need to control reactive power and voltage stability at transmission levels. Active power filters are the emerging devices, which can perform the job of harmonic elimination more effectively. The active power filters are used to filter out higher as well as lower order harmonics in the power system.

This report presents a review of passive and shunt active power filters. The unit voltage template control technique is used to get the reference signals and hysteresis control method is used to get the required signals to inverter (for shunt active power filter). The report presents the PI controller-based shunt active power filter which is extensively verified with non-linear loads and is demonstrated through MATLAB based simulation results.

Table of Contents

List of Tables

List of Figures

CHAPTER 1
POWER QUALITY: AN INTRODUCTION

The term electric power quality (PQ) is generally used to assess and to maintain the good quality of power at the level of generation, transmission, distribution, and utilization of AC electrical power. Since the pollution of electric power supply systems is much severe at the utilization level, it is important to study at the terminals of end users in distribution systems. There are a number of reasons for the pollution of the AC supply systems, including natural ones such as lightening, flashover, equipment failure, and faults (around 60%) and forced ones such as voltage distortions and notches (about 40%). A number of customer's equipment also pollute the supply system as they draw non-sinusoidal current and behave as nonlinear loads. Therefore, power quality is quantified in terms of voltage, current, or frequency deviation of the supply system, which may result in failure or mal operation of customer's equipment. Typically, some power quality problems related to the voltage at the point of common coupling (PCC) where various loads are connected are the presence of voltage harmonics, surge, spikes, notches, sag/dip, swell, unbalance, fluctuations, glitches, flickers, outages, and so on. These problems are present in the supply system due to various disturbances in the system or due to the presence of various nonlinear loads such as furnaces, uninterruptible power supplies (UPSs), and adjustable speed drives (ASDs). However, some power quality problems related to the current drawn from the AC mains are poor power factor, reactive power burden, harmonic currents, unbalanced currents, and an excessive neutral current in polyphase systems due to unbalancing and harmonic currents generated by some nonlinear loads.

These power quality problems cause failure of capacitor banks, increased losses in the distribution system and electric machines, noise, vibrations, overvoltage and excessive current due to resonance, negative-sequence currents in generators and motors, especially rotor heating, derating of cables, dielectric break-down, interference with communication systems, signal interference and relay and breaker malfunctions, false metering, interferences to the motor controllers and digital controllers, and so on [1].

State of the Art on Power Quality

The power quality problems have been present since the inception of electric power. There have been several conventional techniques for mitigating the power quality problems and in many cases even the equipments are designed and developed to operate satisfactorily under some of the power quality problems. However, recently the awareness of the customers toward the power quality problems has increased tremendously because of the following reasons:

• The customer's equipment has become much more sensitive to power quality problems than these have been earlier due to the use of digital control and power electronic converters, which are highly sensitive to the supply and other disturbances. Moreover, the industries have also become more conscious for loss of production.

• The increased use of solid-state controllers in a number of equipment with other benefits such as decreasing the losses, increasing overall efficiency, and reducing the cost of production has resulted in the increased harmonic levels, distortion, notches, and other power quality problems. It is achieved, of course, with much more sophisticated control and increased sensitivity of the equipment toward power quality problems. Typical examples are ASDs and energy-saving electronic ballasts, which have substantial energy savings and some other benefits; however, they are the sources of waveform distortion and much more sensitive to the number of power quality disturbances.

• The awareness of power quality problems has increased in the customers due to direct and indirect penalties enforced on them, which are caused by interruptions, loss of production, equipment failure, standards, and so on.

• The disturbances to other important appliances such as telecommunication network, TVs, computers, metering, and protection systems have forced the end users to either reduce or eliminate power quality problems or dispense the use of power polluting devices and equipment.

• The deregulation of the power systems has increased the importance of power quality as consumers are using power quality as performance indicators and it has become difficult to maintain good power quality in the world of liberalization and privatization due to heavy competition at the financial level.

• Distributed generation using renewable energy and other local energy sources has increased power quality problems as it needs, in many situations, solid-state conversion and variations in input power add new problems of voltage quality such as in solar PV generation and wind energy conversion systems.

• Similar to other kinds of pollution such as air, the pollution of power networks with power quality problems has become an environmental issue with other consequences in addition to financial issues [1].

Causes of Power Quality Problems

There are a number of power quality problems in the present-day fast-changing electrical systems. The main causes of these power quality problems can be classified into natural and man-made in terms of current, voltage, frequency, and so on. The natural causes of poor power quality are mainly faults, lightening, weather conditions such as storms, equipment failure, and so on. However, the man-made causes are mainly related to loads or system operations. The causes related to the loads are nonlinear loads such as saturating transformers and other electrical machines, or loads with solid-state controllers such as vapor lamp-based lighting systems, ASDs, UPSs, arc furnaces, computer power supplies, and TVs. The causes of power quality problems related to system operations are switching of transformers, capacitors, feeders, and heavy loads.

The natural causes result in power quality problems that are generally transient in nature, such as voltage sag (dip), voltage distortion, swell, and impulsive and oscillatory transients. However, the man-made causes result in both transient and steady-state types of power quality problems.

However, one of the important power quality problems is the presence of harmonics, which may be because of several loads that behave in a nonlinear manner, ranging from classical ones such as transformers, electrical machines, and furnaces to new ones such as power converters in vapor lamps, switched-mode power supplies (SMPS), ASDs using AC–DC converters, cycloconverters, AC voltage controllers, HVDC transmission, static VAR compensators, and so on [1].

Effects of Power Quality Problems on Users

The power quality problems affect all concerned utilities, customers, and manufacturers directly or indirectly in terms of major financial losses due to interruption of process, equipment damage, production loss, wastage of raw material, loss of important data, and so on. There are many instances and applications such as automated industrial processes, namely, semiconductor manufacturing, pharmaceutical industries, and banking, where even a small voltage dip/sag causes interruption of process for several hours, wastage of raw material, and so on.

Some power quality problems affect the protection systems and result in mal operation of protective devices. These interrupt many operations and processes in the industries and other establishments. These also affect many types of measuring instruments and metering of the various quantities such as voltage, current, power, and energy. Moreover, these problems affect the monitoring systems in much critical, important, emergency, vital, and costly equipment.

Harmonic currents increase losses in a number of electrical equipment and distribution systems and cause wastage of energy, poor utilization of utilities' assets such as transformers and feeders, overloading of power capacitors, noise and vibrations in electrical machines, and disturbance and interference to electronics appliances and communication networks [1].

Classification of Mitigation Techniques for Power Quality Problems

In view of increased problems due to power quality in terms of financial loss, loss of production, wastage of raw material, and so on, a wide variety of mitigation techniques for improving the power quality have evolved in the past quarter century. These include passive components such as capacitors, reactors, custom power devices, a series of power filters, improved power quality AC–DC converters, and matrix converters.

However, the power quality problems may not be because of harmonics in many situations such as in distribution systems where problems of poor voltage regulation, low power factor, load unbalancing, excessive neutral current, and so on are observed. Some of these power quality problems such as poor power factor because of reactive power requirements may be mitigated using lossless passive elements such as capacitors and reactors. Moreover, the custom power devices such as DSTATCOMs, DVRs, and UPQCs are extensively used for mitigating the current, voltage, or both types of power quality problems.

In the presence of harmonics in addition to other power quality problems, a series of power filters of various types such as active, passive, and hybrid in shunt, series, or a combination of both configurations in single-phase two-wire, three-phase three-wire, and three-phase four-wire systems are used externally as retrofit solutions for mitigating power quality problems through compensation of nonlinear loads or voltage-based power quality problems in the AC mains. Since there are a large number of circuits of filters, the best configuration of the filter is decided depending upon the nature of loads such voltage-fed loads, current-fed loads, or a combination of both to mitigate their problems.

Power quality improvement techniques used in newly designed and developed equipment are based on the modification of the input stage of these systems with PFC converters, also known as IPQCs, multipulse AC–DC converters, matrix converters for AC–DC or AC–AC conversion, and so on, which inherently mitigate some of the power quality problems in them and in the supply system by drawing clean power from the utility. There are a large number of circuits of the converters of boost, buck, buck–boost, multilevel, and multipulse types for unidirectional and bidirectional power flow with and without isolation in single-phase and three-phase supply systems to suit very specific applications. These are used as front-end converters in the input stage as a part of the total equipment and in many situations they make these equipment immune to power quality problems in the supply system [1].

CHAPTER 2

SINGLE PHASE FULL BRIDGE AC-DC CONVERTERS

A phase-control thyristor is turned on by applying a short pulse to its gate and turned off due to natural or line commutation; in the case of a highly inductive load, it is turned off by firing another thyristor of the rectifier during the negative half-cycle of input voltage. AC-DC converters are used to convert AC to DC voltage across the load. The circuit arrangement of a single-phase full converter is shown in Figure 2.1. During the positive half-cycle, thyristors T1 and T2 are forward biased; when these two thyristors are turned on simultaneously at $\omega t = \alpha$, the load is connected to the input supply through T1 and T2. Due to the inductive load, thyristors T1 and T2 continue to conduct beyond $\omega t = \pi$, even though the input voltage is already negative. During the negative half-cycle of the input voltage, thyristors T3 and T4 are forward biased; the turning on of thyristors T3 and T4 applies the supply voltage across thyristors T1 and T2 as reverse blocking voltage. T1 and T2 are turned off due to line or natural commutation and the load current is transferred from T1 and T2 to T3 and T4.

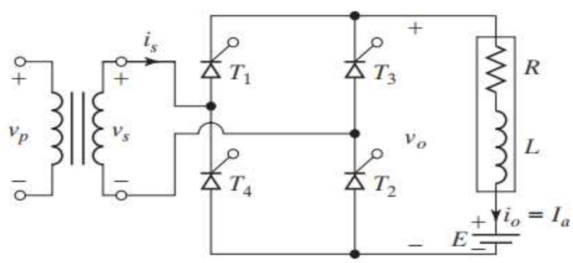

Figure 2.1

During the period from α to π, the input voltage v*s* and input current *is* positive, and the power flows from the supply to the load. The converter is said to be operated in *rectification* mode. During the period from π to $\pi + \alpha$, the input voltage v*s* is negative, and the input current *is* is positive, and reverse power flows from the load to the supply. The converter is said to be operated in *inversion mode*. But the net flow of power is from source to load [2].

Fourier Analysis of Input Current

This investigation into the harmonic distortion begins with a Fourier analysis of the fundamental component of the input current. Figure 2.1 shows a simplified schematic of the controlled rectifier circuit. In it four thyristors are connected in a full bridge configuration with an AC input and a resistive load output. The firing angle (α) of the thyristors can be controlled through their gates to chop the input current on the positive and negative cycles.

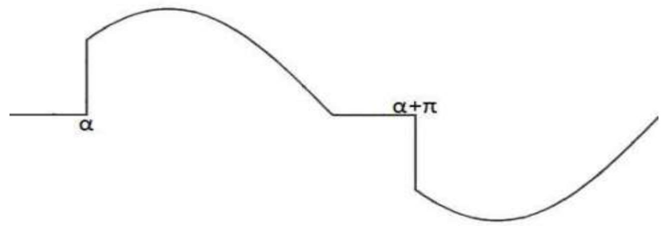

Figure 2.2

Using Figure 2.2, which shows the input current waveform, the Fourier series component can be expressed as:

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

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

Since in determining the THD this analysis is only concerned with the fundamental component (n = 1), the above equations must only be used for n equal to one. The derivation of a1 and b1 is summarized below.

$$\pi a_1 = \int_\alpha^\pi sin(\omega t)\cos(\omega t)\, d(\omega t) + \int_{\pi+\alpha}^{2\pi} sin(\omega t)\cos(\omega t)\, d(\omega t)$$

$$= \frac{sin^2(\omega t)}{2}\Big|_\alpha^\pi + \frac{sin^2(\omega t)}{2}\Big|_{\pi+\alpha}^{2\pi}$$

$$2\pi a_1 = -2sin^2(\alpha)$$

$$\boxed{\boldsymbol{a_1 = -\frac{1}{\pi}sin^2(\alpha)}}$$

$$\pi b_1 = \int_\alpha^\pi sin(\omega t)\sin(\omega t)\, d(\omega t) + \int_{\pi+\alpha}^{2\pi} sin(\omega t)\sin(\omega t)\, d(\omega t)$$

$$2\pi b_1 = \int_\alpha^\pi (1-\cos(2\omega t))\, d(\omega t) + \int_{\pi+\alpha}^{2\pi} (1-\cos(2\omega t))\, d(\omega t)$$

$$= t - \frac{\sin(2\omega t)}{2}\Big|_\alpha^\pi + t - \frac{\sin(2\omega t)}{2}\Big|_{\pi+\alpha}^{2\pi}$$

$$= \pi - \alpha - \frac{\sin(2\pi)}{2} + \frac{\sin(2\alpha)}{2} + 2\pi - \pi - \alpha - \frac{\sin(4\pi)}{2} + \frac{\sin(2\pi+2\alpha)}{2}$$

$$\boxed{\boldsymbol{b_1 = 1 - \frac{\alpha}{\pi} + \frac{\sin(2\alpha)}{2\pi}}}$$

Since both a1 and b1 are magnitudes and at the same frequency they must be changes to rms values and their geometric mean must be calculated.

$$f_{1(rms)} = \sqrt{\frac{a_1^2 + b_1^2}{2}}$$

The total rms value is calculated from:

$$f_{tot(rms)} = \sqrt{1 - \frac{\alpha}{\pi} + \frac{\sin(2\alpha)}{2\pi}}\frac{1}{\sqrt{2}}$$

while the THD can be shown as:

$$THD = \frac{\sqrt{f_{tot(rms)}{}^2 - f_{1(rms)}{}^2}}{f_{1(rms)}}$$

[3]

Simulation

Following the Fourier analysis of the source current, a computer simulation using MATLAB/SIMULNK was formed. The schematic is shown in figure 2.3. The simulation modelled actual phase controlled single phase full bridge AC-DC converter. The firing pulse of Thyristors was given through pulse generators. The model had following parameters:

Source voltage Vs=100V (peak)

Frequency fs=50Hz

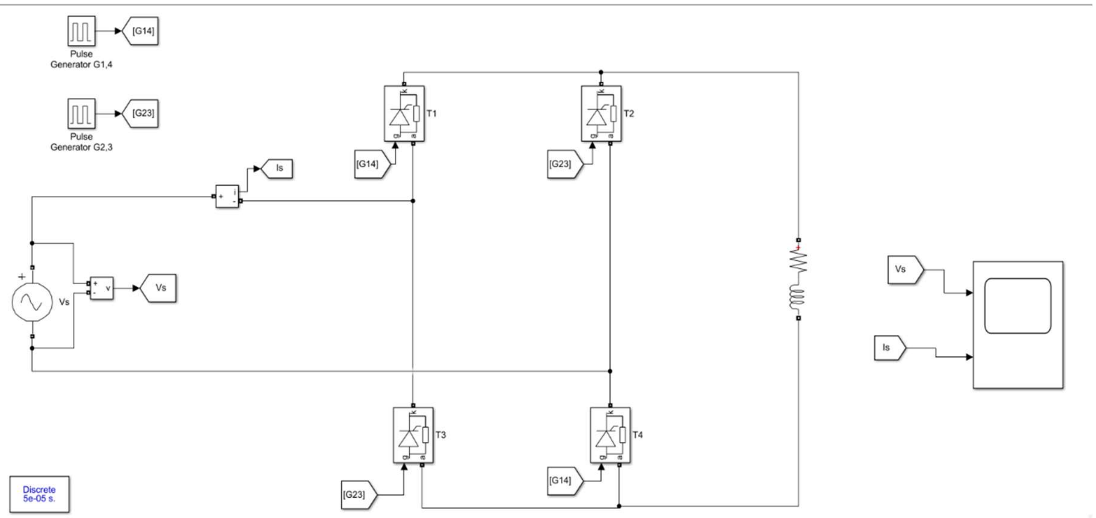

Figure 2.3

Simulation Results

On running the simulation shown in Figure 2.3, we got the following waveforms. Note that these waveforms have been taken for RL load for firing angle of α=0°.

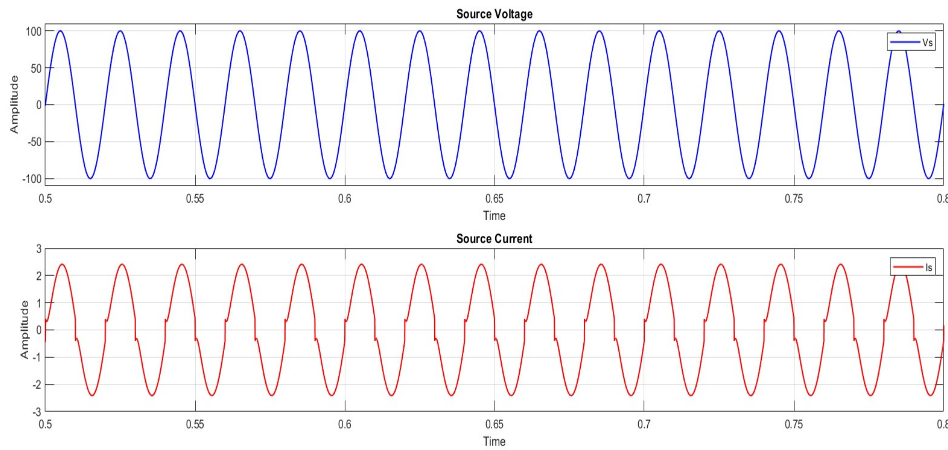

Figure 2.4

The FFT analysis of the source current is shown in Figure 2.5:

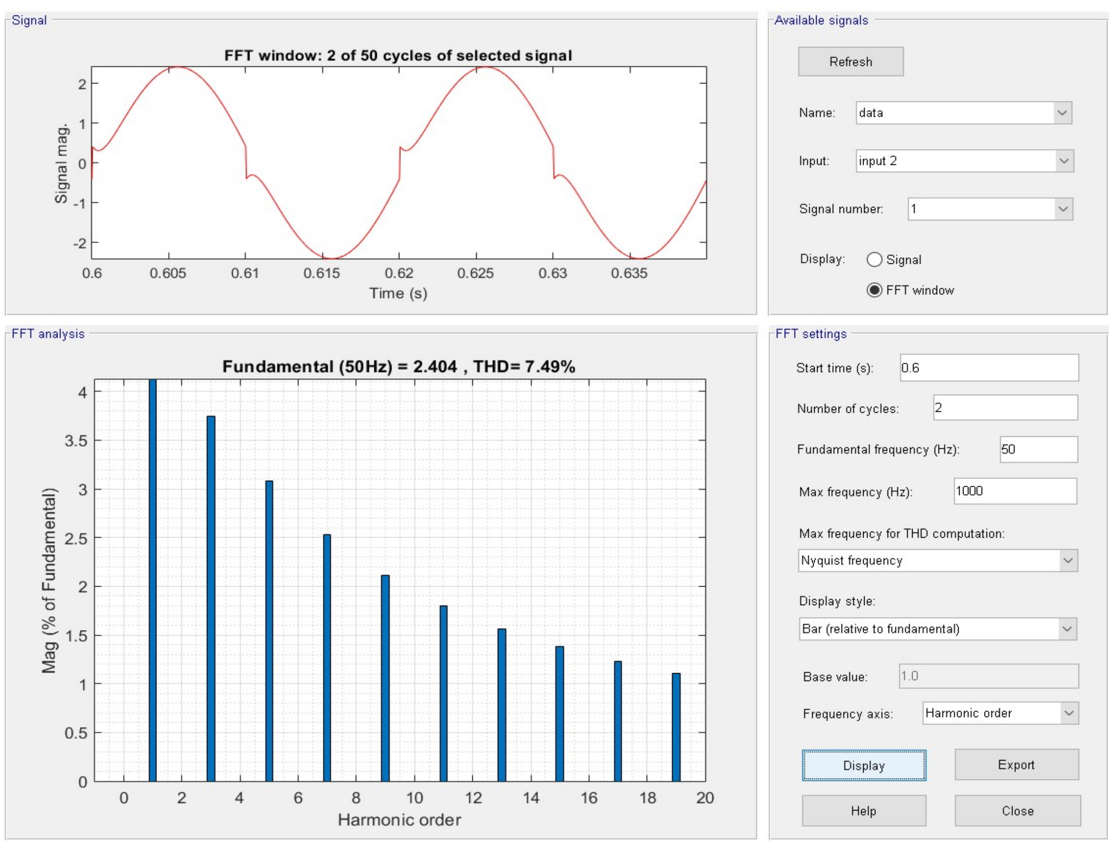

Figure 2.5

The THD for different firing angles is shown in Table 2.1.

Firing Angle	**%age THD**
0°	7.49
15°	2.32
30°	10.41
45°	19.56
60°	30.20
75°	41.73
90°	53.65

Table 2.1

Conclusion

Power converters using thyristors and other semiconductor switches are widely used to feed controlled electric power to electrical loads such as adjustable speed drives (ASDs), furnaces, and large power supplies. Such solid-state converters are also used in HVDC transmission systems, AC distribution systems, and renewable electrical power generation. As nonlinear loads, the solid-state converters draw harmonics and reactive power components of current from the AC mains. The injected harmonic currents, and reactive power burden, cause low system efficiency and poor power factor. They also result in disturbance to other consumers and protective devices and interference to nearby communication networks [1]. On examining the waveform as in Figure 2.4, we see that the source current is far from being sinusoidal. Table 2.1 shows the %THD of source current and we see that the THD is far greater than 5%. Hence this degrades the performance of power systems by increasing losses, overloading in neutral conductors, premature ageing of generators and transformers and these harmonics must be mitigated. Various techniques are used for this purpose, and we shall discuss one such technique that makes use of filters to mitigate the harmonics in rectifiers. Moreover, the phase shift between source voltage Vs and source current Is can also be made 0 by supplying the reactive power requirement from VAR compensators like Shunt Active Power Filters. So, the source will only supply active power to the load making its power factor equal to unity.

CHAPTER 3

FILTER TECHNIQUES USED FOR POWER QUALITY IMPROVEMENT

Two types of filters used in harmonic mitigation will be discussed in this report. They are as follows:

1. Passive Filters
2. Shunt Active Power Filters

Passive Filters

Traditionally, passive power filters (PPFs) are used to reduce harmonics and capacitors are generally employed to improve the power factor of the AC loads. We will be discussing a passive series filter in this report. Passive series filters are connected in series with these harmonic currents do not enter supply systems and are confined to flow in the local passive circuits preferably consisting of parallel connected lossless passive elements such as is a simple parallel LC circuit as in Figure 3.1 [1].

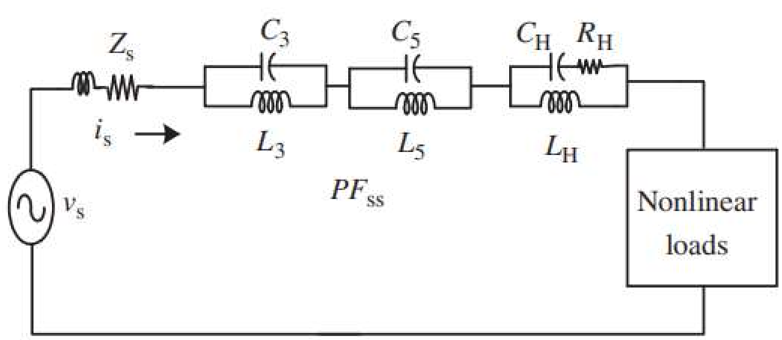

Figure 3.1

The LC circuits shown are to be tuned to each harmonic frequency. So, we need to install 'n' number of these LC circuits to block 'n' number of harmonic frequencies. Each LC circuit offers a high impedance to the frequency it is tuned to (resonant frequency) and, hence blocking that frequency. The impedance offered to fundamental frequency is very small thereby allowing the fundamental current to pass with negligible voltage drop and losses.

Simulation

Following the discussion on Passive filters, a MATLAB/SIMULINK model was formed of the same with a single-phase AC-DC converter as our nonlinear load. The schematic of the model is shown in Figure 3.2:

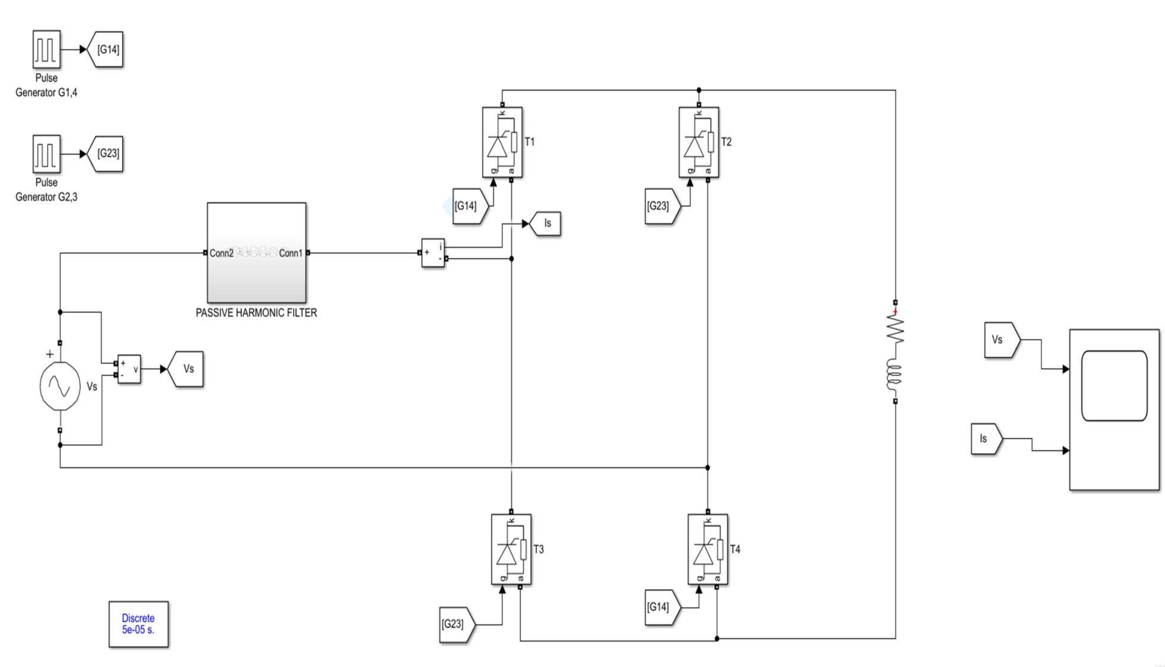

Figure 3.2

The source voltage Vs=100V(peak) and fundamental frequency is 50Hz.

The passive filter schematic is shown in Figure 3.3 as:

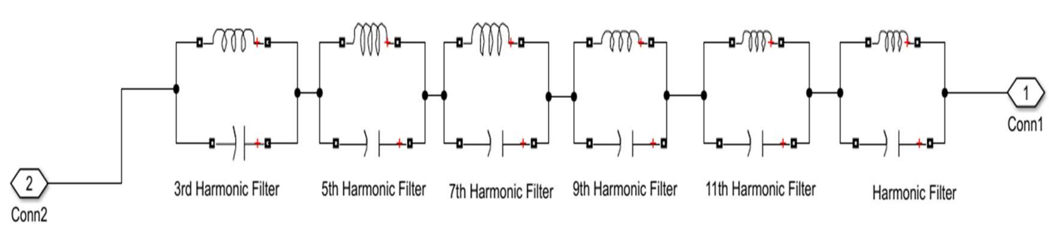

Figure 3.3

We had constructed six filters for the elimination of six odd harmonic frequencies i.e.,150Hz, 250Hz, 350Hz, 450Hz, 550Hz and 650Hz. The values of L and C taken are shown in Table 3.1

L (mH)	**C (µF)**	**Resonant Frequency (Hz)**
10	112.57	150
10	40.52	250
10	20.67	350
10	12.50	450
10	8.37	550
10	5.99	650

Table 3.1

Simulation Results

After running the simulation shown in Figure 3.2, we got the following waveforms and results. Note that these waveforms have been taken for firing angle α=0° for thyristors.

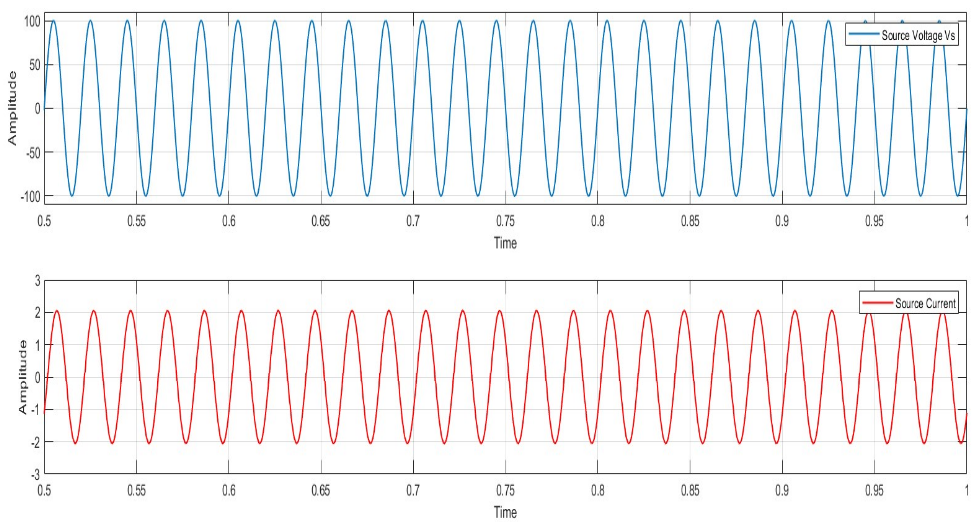

Figure 3.4

We observed that the source current waveform was more sinusoidal as compared to what we saw in Figure 2.4. For α=0°, the THD is shown in Figure 3.6. The FFT analysis of the source current at α=0° showed that the source current waveform had a THD of 1.54% after a passive filter was connected contrary to what we saw in Table 2.1 where the THD came out to be 7.46% for the same firing angle.

Notice in Figure 3.5 that the bar graph showing the magnitude of different frequencies relative to fundamental frequency is almost insignificant for the odd ordered frequencies up to 13^{th} harmonic (650Hz) as we have installed passive filters up to this frequency only.

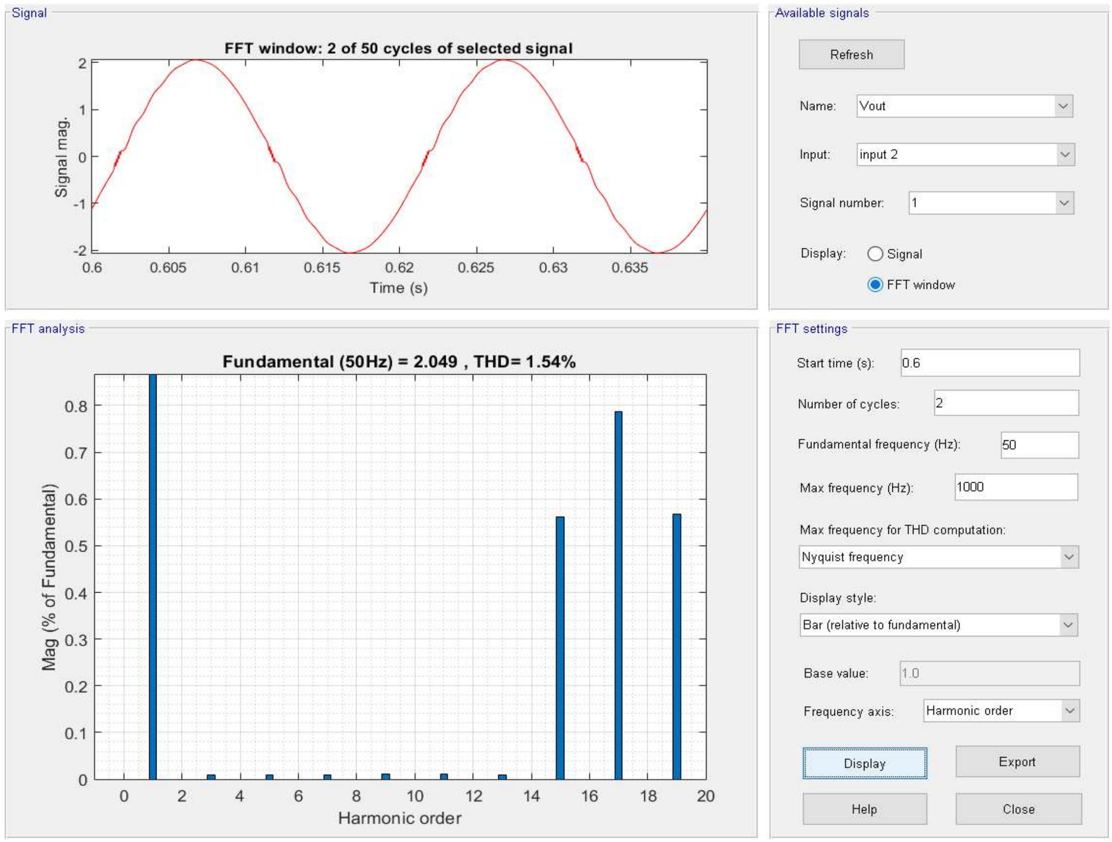

Figure 3.5

The THD for other firing angles is shown in the following table:

Firing Angle	%age THD before passive filter is installed	%age THD after passive filter is installed
0°	7.49	1.54
15°	2.32	1.54
30°	10.41	1.72
45°	19.56	4.69
60°	30.20	12.87
75°	41.73	24.39
90°	53.65	44

Table 3.2

So, the use of passive filters in systems with nonlinear loads decreased the THD of source current as seen in Table 3.2. But to eliminate harmonics, we must install a separate LC filter for each harmonic frequency. Moreover, the inductor used in the LC filters a quite bulky due to their iron cores and the components are prone to ageing. Also, the passive filters are not adaptable to changes in the system. So due to these reasons, we use Shunt Active Power Filters.

Shunt Active Power Filters

The main objective of shunt active power filters is to mitigate multiple power quality problems in a distribution system. SAPF mitigates most of the current quality problems, such as reactive power, unbalanced currents, neutral current, harmonics, and fluctuations, present in the consumer loads or otherwise in the system and provides sinusoidal balanced currents in the supply along with its DC bus voltage control. In general, a SAPF has a VSC connected to a DC bus and its AC side is connected in shunt normally across the consumer loads or across the PCC. F. The VSC used as SAPF is normally controlled in PWM current control mode to inject appropriate currents into the system. The SAPF also needs many passive elements such as a DC bus capacitor, AC interacting inductors etc.

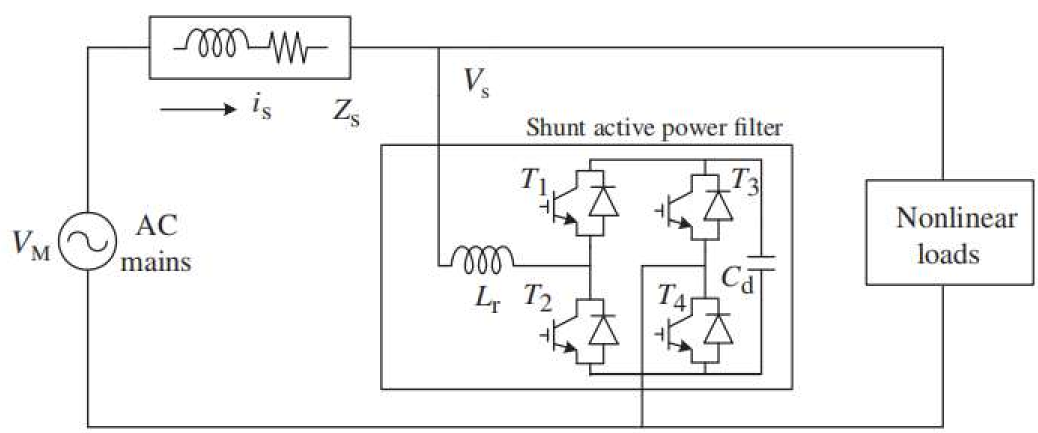

Figure 3.6

Using a control algorithm, the reference APF currents are directly controlled by estimating the reference APF currents. However, in place of APF currents, the reference currents may be estimated for an indirect current control of the VSC. The gating pulses to the APF are generated by employing hysteresis (carrier less PWM) or PWM (fixed frequency) current control over reference and sensed supply currents resulting in an indirect current control. Using SAPF, the supply current harmonics compensation, reactive power compensation, and unbalanced currents compensation are achieved in all the control algorithms [1].

Control of Shunt Active Power Filters

Reference current signals for the control of SAPF must be derived accordingly and these signals may be estimated using several control algorithms. One such method is the UVT (Unit Vector Template) based control technique. In this method, reference supply current is derived using sensed AC voltages (at PCC) and the DC bus voltage of the APF as feedback signals. PI voltage controllers are used to estimate the amplitude of reference supply current.

Simulation

The MATLAB/SIMULINK model for a two-wire SAPF with a voltage source converter is shown in Figures 3.7 to 3.9.

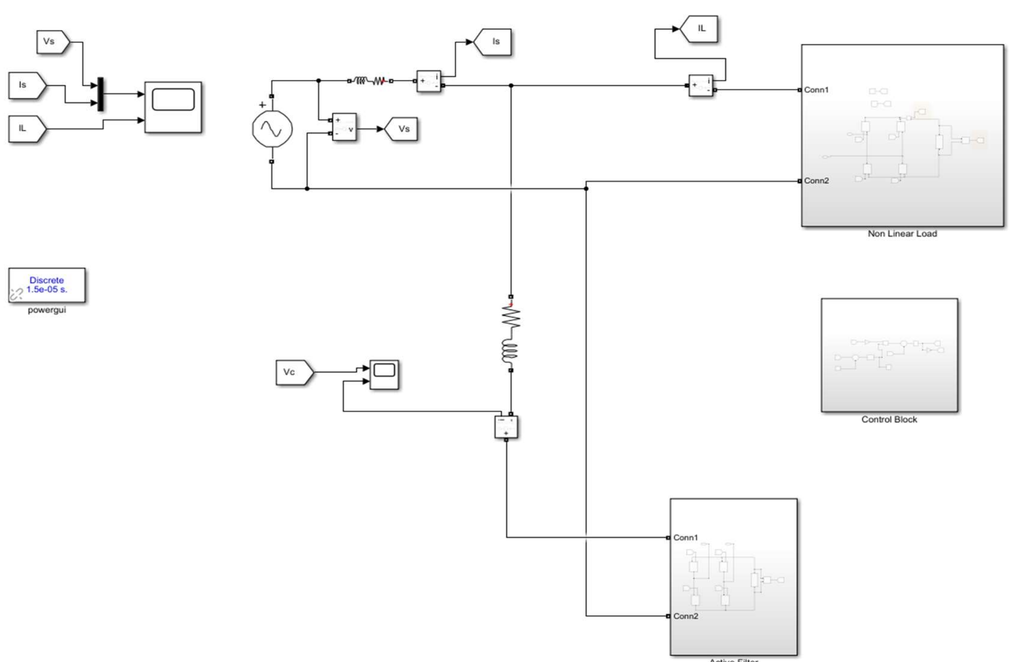

Figure 3.7

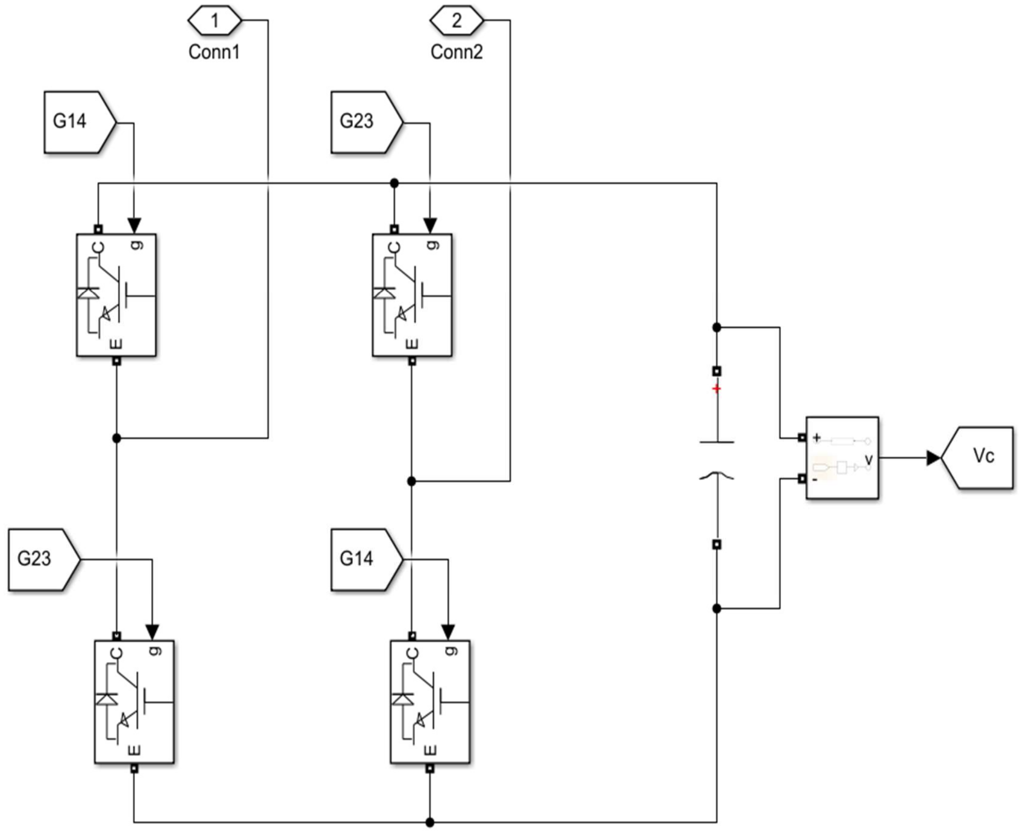

Figure 3.8

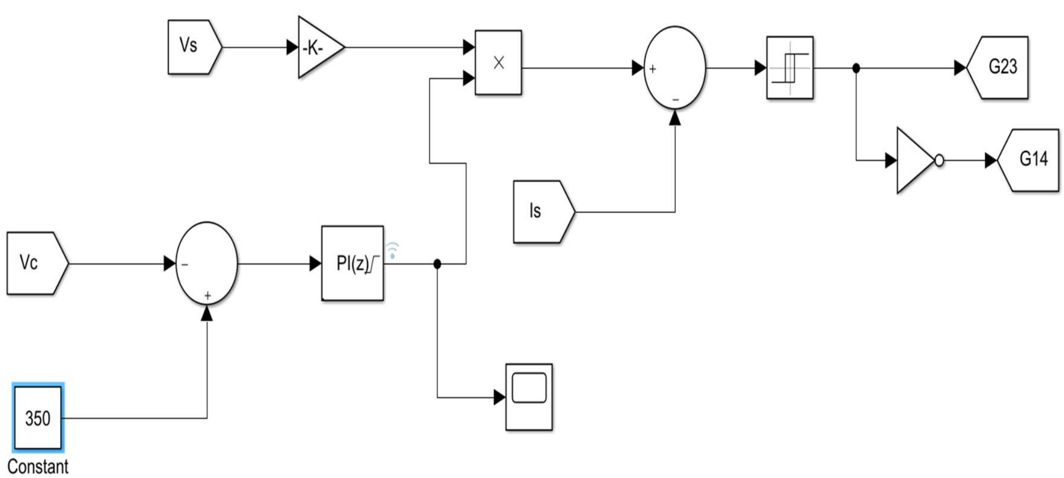

Figure 3.9

The different parameters of the model are as follows:

System Parameter	Value
Supply Voltage (Vs)	100V (peak)
Frequency	50Hz
Source Impedance (Zs)	0.01Ω, 3mH
Filter Impedance	0.001Ω, 3mH
DC link Capacitor (C)	550μF
DC reference voltage (Vdc)	350V
Proportional Gain (Kp)	0.05
Integral Gain (Ki)	5

Table 3.3

In Figures 3.7 to 3.9, showing the control circuit of the SAPF modelled, we saw the source voltage Vs was measured using a voltage measurement block and the measured signal was passed through a gain block having a gain of 1/100 as 100 was the maximum value of the supply voltage thus generating a unit template which was a pure sine wave i.e., sin ωt. On the other hand, DC voltage across the capacitor that acted like a DC source to the inverter was measured and compared with a reference DC voltage of 350V thus producing an error signal that went into the PI controller. The PI controller produced a maximum value of reference current Im*. This Im* was given as an input to a product block with the other input being the unit template signal. The product block generated our reference current Im* sin ωt.This reference current was compared with actual source current Is and then the resulting signal was passed through a relay block that acted as a hysteresis current controller. The output of our hysteresis current controller acted as the firing pulse of T2 and T3 and its NOT signal acted as a firing signal to T1 and T4. The inverter after getting these set of pulses produced a compensating current Ic that constituted of harmonic currents and reactive power currents which were injected into our system at the point of common coupling (PCC) hence eliminating the need for the source to supply harmonic currents and reactive power. Moreover, the capacitor voltage Vc settled at 350V as these lines connected to PCC also served to charge the DC capacitor after it discharged and voltage across it fell below 350V.

Simulation Results

On running the simulation, we saw that for α=0°, the waveforms and FFT analysis as shown in Figures 3.10 to 3.12:

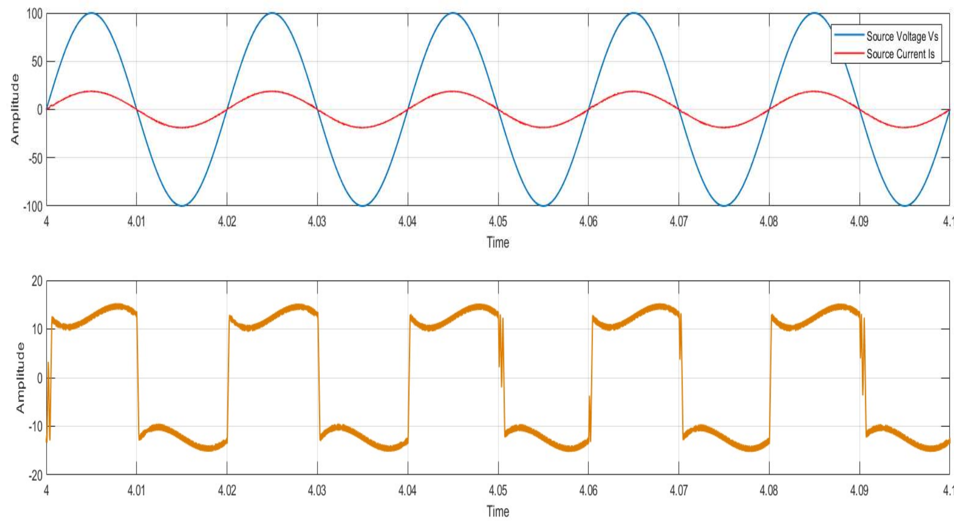

Figure 3.10

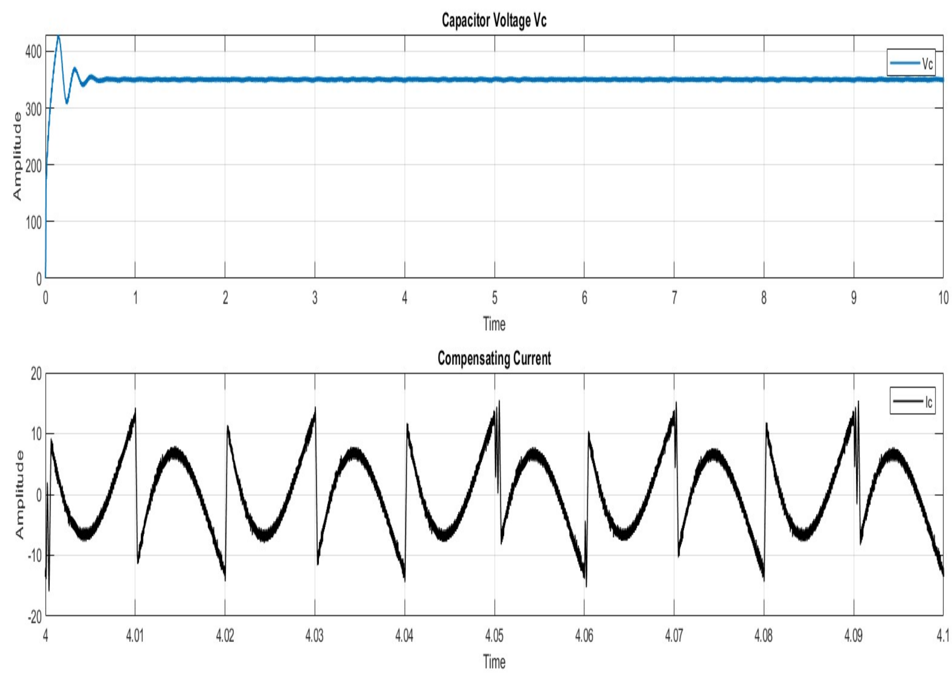

Figure 3.11

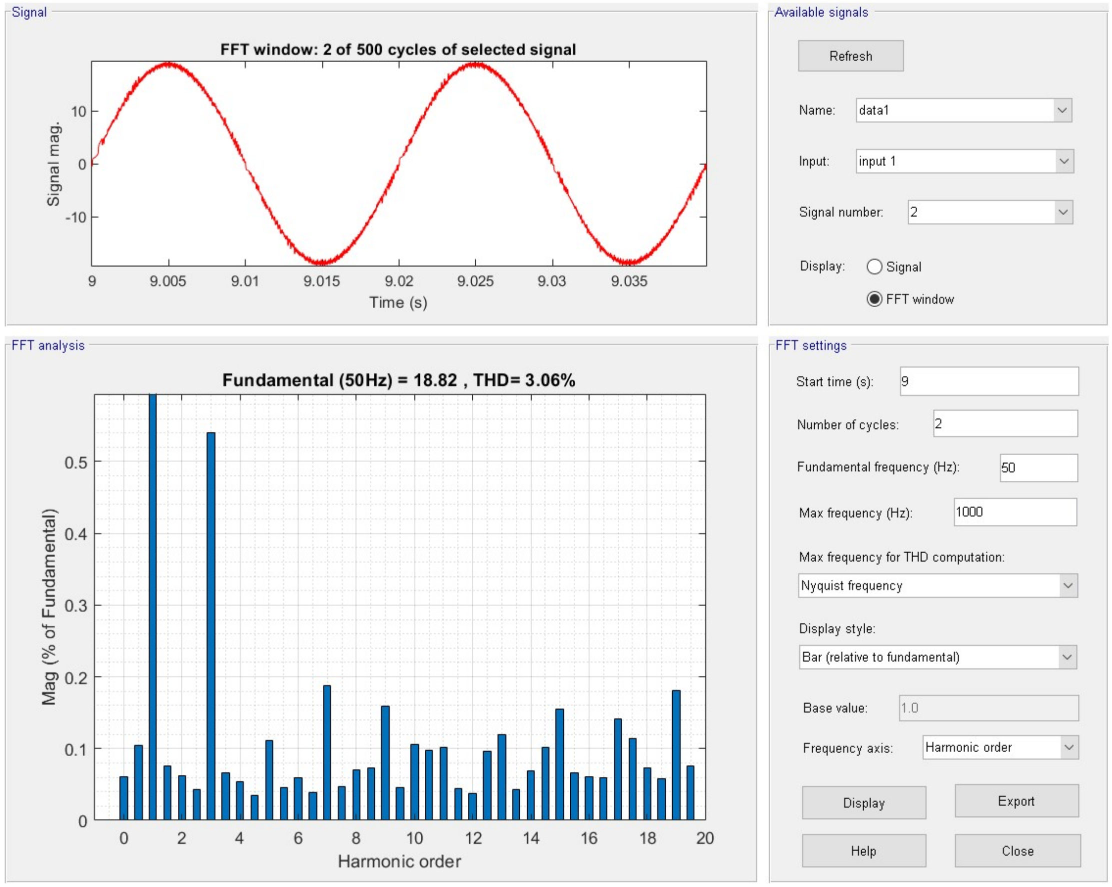

Figure 3.12

We noted that the THD for source current waveform Is from Figure 3.11 came out to be 3.06% which was less than 5%. Moreover, on analyzing the source voltage Vs and source current Is, we observed that the phase angle between Vs and Is was 0° and thus the power factor was unity. The THD and power factor for different conduction angles is shown in Table 3.4:

Firing angle	%THD		Power Factor	
	Before SAPF	After SAPF	Before SAPF	After SAPF
0°	25.11	3.06	0.8679	1
15°	25.33	3.18	0.8438	1
30°	23.24	3.77	0.7607	1
45°	16.90	4.94	0.6351	1

Table 3.4

Conclusion

The utilization of power electronic converters is often accompanied by power quality issues such as harmonics and reactive power. To address this concern, passive filters and power capacitors have been employed in the past; however, these solutions are no longer recommended due to their fixed compensation and their tendency to lose effectiveness over time. As a remedy, active filters have been introduced to provide automatic compensation by supplying variable capacitance through an inverter. The inverter is driven by the latest feedback from the source voltage, currents, and dc side voltage. Simulation results demonstrate that the active power filter controller effectively reduces harmonics in the source current, particularly in cases where the load demands non-sinusoidal current, and regardless of whether the load is static or fluctuating. This approach yields superior outcomes in comparison to alternative solutions.

REFERENCES

[1] Bhim Singh, Ambrish Chandra and Kamal Al-Haddad, *Power Quality Problems and Mitigation Techniques,* The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, United Kingdom: Wiley, 2015.

[2] Muhammad H. Rashid*, Power Electronics: Devices, Circuits, and Applications,* Fourth Edition, USA: Pearson, 2014.

[3] Michael McCarty, Taufik Taufik, Andre Pratama, Makbul Anwari, "Harmonic Analysis of Input Current of Single-Phase Controlled Bridge Rectifier", IEEE ISIEA, October 4-6, 2009.