Design and Implementation of a High-Performance Active Filter for Harmonic Mitigation in Inverters

Sonu Sen[#1], Chirag Gupta[*2], Abhimanyu Kumar[#3]

[#]M.Tech Scholar & Dept of Electrical & Electronics Engineering & RKDF University, Bhopal, India

Associate Professor & Dept of Electrical & Electronics Engineering & RKDF University, Bhopal, India

Assistant Professor & Dept of Electrical & Electronics Engineering & RKDF University, Bhopal, India

[1]sonusenecpcrt@gmail.com

[2] cgupta.011@gmail.com

[3] ies.abhi@gmail.com

Abstract: Harmonic distortion is a form of electrical noise. One type of electrical noise is harmonic distortion, which happens when signals combine at multiples of their fundamental frequency. As large power electronic systems become more common, harmonic distortion increases, leading to lower power quality and reduced system stability. This paper introduces an active power filter designed for three-phase systems with nonlinear loads. The active filter utilizes a three-phase inverter equipped with six controllable switches. Connected in parallel with other nonlinear loads, the inverter's AC side is linked through a filter inductance. On the DC side, a filter capacitor is connected. This shunt active filter manipulates the current flowing through the filter inductor, ensuring the line current aligns with the input voltage in both phase and shape. Computer simulations demonstrate the filter's effectiveness in significantly reducing injected harmonics, ultimately improving system efficiency and power factor. It's important to note that within an inverter, DC voltage is transformed into an AC output.

Keywords — *Active Power Filters, Power Quality, Control techniques, VSI, THD.*

I. Introduction

The quality of electric power is becoming an increasingly critical concern due to advancements in power system components. Over the past decade, there has been a notable shift in power system components from primarily linear to partially nonlinear in nature. According to an estimate by the Electric Power Research Institute (EPRI) in 1992, approximately 15 to 20 percent of the total load on a utility system was nonlinear, with projections suggesting that this figure could rise to between 50 and 70 percent by the year 2000. This shift has heightened the sensitivity of equipment to disturbances, making power reliability a significant issue [1]. To ensure system reliability, continuous monitoring of power quality is essential. Extensive research has been conducted on monitoring and analyzing power quality, with numerous studies discussed in the literature review section of this paper. In an ideal scenario, power quality refers to the purity of the voltage and current waveforms, ideally in a perfect sinusoidal form. Maintaining high power quality is crucial for commercial and industrial power system designs [2]. Any deviation from the ideal sinusoidal waveform, resulting in distortion, is referred to as harmonic distortion. Harmonic distortion can arise from various factors and has become a major focus for engineers seeking to mitigate it. In the past, when power system designs were simpler and more conservative, harmonic distortion was minimal. However, with the increasing complexity of modern designs, harmonic distortion has also become more prevalent [3]–[5].

This paper explores the impact of harmonics on power systems and outlines strategies for mitigating these effects. It addresses how harmonic distortion, a major concern related to power quality, can cause various disruptions within power systems. The paper discusses techniques for reducing harmonics to enhance power quality, supported by relevant simulations. Additionally, it examines the different types of inverters used in power systems, focusing on how harmonics influence power quality during the conversion from DC to AC. The detailed analysis will illustrate how reducing harmonic distortion can lead to significant improvements in power quality [6]–[8].

II. Literature Review

Programmed-waveform pulse width modulated (PWM) waveforms, which are relevant to AC-DC and DC-AC converters, are synthesized and analyzed based on various structural parameters. Through sensitivity studies and heuristic methods, optimal PWM structures are identified and compared. The findings demonstrate how total harmonic performance varies with switching levels, waveform types, commutations per cycle, and filter bandpass characteristics [9], [10].

Grid-connected voltage source converters (VSCs) are central to numerous applications where power quality is a significant concern, primarily due to their ability to control reactive power. However, a major challenge is their sensitivity to grid disturbances. Additionally, when VSCs are deployed in distributed generation (DG) applications, they can be highly susceptible to voltage unbalance, which may lead to protection systems tripping due to current unbalance or overcurrent conditions. This paper presents the development of a vector current controller for a VSC connected to the grid via an LCL filter, with the primary goal of ensuring symmetrical and balanced currents during unbalanced voltage dips. The implementation of this controller prevents the VSC system from tripping during such voltage dips [11], [12].

Active power filters are presented in this paper for single-phase power systems characterized by multiple non-linear loads. The operat-ional principles of the filter, specifics of the power circuit, details of control design, representative waveforms and spectra performance figures for an active filter working as a 384 W AC controller/yet a 900 W uncontrolled bridge rectifier, are covered. The findings from experiments indicate that typically active filters consume about 3% or less than average load power which suggests that employing such filters in parallel can lead to greater effectiveness in compensation. The spectral performance shows how the active filter guarantees that the system is in agreement with IEC-555 standards for decision frequencies above 30 kHz. Also, an alternative single-phase active filter using two controllable switches based on half-bridge topology has been discussed in the paper. [13]–[15]

This paper introduces a novel method for achieving nearly sinusoidal line current rectification of three-phase utility voltages through DC link current modulation. This approach offers several key advantages: it requires only two transistor switches, provides a regulated DC voltage at the output, thereby simplifying the design of the remaining power electronics equipment, and automatically balances the output DC voltage, even when it is quite large, across two series-connected capacitors. Additionally, it avoids the typical drawbacks associated with passive filters. This method can be applied to a wide range of power electronics equipment with three-phase utility inputs and is particularly suitable for interfacing generation systems using renewable energy sources such as wind and solar power.

Harmonic distortion, a type of electrical noise, occurs when signals that are multiples of the fundamental frequency overlap. The greater usage of large power electronic systems has resulted to increased harmonic distortion which impacts negatively on the quality of power and stability of the systems. In this paper, a neural-based proportional-integral (PI) control technique for active power filters in mono-phase systems with multiple non-linear loads is proposed. A single phase inverter with four variable switches operating as an ordinary H-bridge inverter is used by the active filter [16], [17]. The inverter's alternating current (AC) side is associated in parallel to other loads that are nonlinear using filter inductor, whereas its direct current (DC) side is interconnected using filter capacitor. The neural proportional–integral (PI) controller is developed to adjust the current flowing through the filter inductor such that it is always in phase and assimilates to the line current. The simulation results indicate a notable decrease of injected harmonics, hence enhancing the efficiency of the system and power factor [18], [19].

III. Research Methodology

The primary goal of a power system is to generate and deliver electrical energy to end users. Alongside power generation, the concept of power quality has gained significant attention, to the extent that it is now regarded as a distinct area within power engineering. The emphasis on power quality stems from several factors, one of the most important being that consumers are increasingly aware of issues such as interruptions, voltage sags, and switching transients. Additionally, the interconnected nature of modern power systems means that a failure in one part of the network can lead to adverse effects across the entire system. Furthermore, with the advent of microprocessor-based controls, protective devices have become more sensitive to power quality variations compared to those used in previous generations.

Transients: In power systems, transients are undesirable variations or disturbances that disrupt normal operation. Typically, transients are oscillatory and are damped by the system's RLC (Resistor, Inductor, Capacitor) network. While newcomers might use the term "surge" to describe transients, especially those resulting from lightning strikes and managed by surge arresters, experienced engineers usually distinguish between "transients" and "surges," reserving the latter for specific cases. Transients are generally classified into two types: oscillatory transients, which involve oscillations that diminish over time, and impulsive transients, characterized by sudden, short-duration disturbances.

Oscillatory Transient: An oscillatory transient occurs when voltage or current values rapidly alternate polarity. This type of transient arises from sudden changes in the power system, such as shifts from positive to negative polarity or non-power frequency changes, disrupting a previously steady state.

Impulsive Transient: Lightning strikes are usually the source of impulsive transients. Impulsive transients differ from oscillatory transients in that they result from a quick, one-way modification of non-power frequency during a stable configuration of voltages as well as currents. Additionally, impulsive transients can excite the natural frequency of a power system, potentially generating oscillatory transients.

Variations in Voltage

Voltage variations are classified into two categories:

- short-duration
- long-duration.

Short-Duration Voltage Variations

Faults within the power system generally cause these variations. They include phenomena such as sags, which result from system conditions and faults, leading to voltage drops, rises, or even interruptions. The impact of these faults is usually short-lived. Protective devices are employed to address these faults, but the resulting voltage changes are of brief duration.

Interruptions

When there are major drops in the level of voltage or current supply, an interruption can occur. sThey can result from various issues, including power system faults or equipment failures

Sagging

A specific type of short-duration voltage variation is sagging, which is characterized by a temporary drop in RMS voltage between 0.1 to 0.9 per unit (pu). The magnitude of sagging is often determined by the lowest RMS value recorded during the event. Sagging generally maintains a constant RMS value during its deepest part, with the lowest value being a useful approximation of the sagging magnitude.

Long-Duration Voltage Variations

These variations include both overvoltage and undervoltage conditions, which are caused by changes in the power system rather than faults. The long-term voltage fluctuations signify the steady-state conditions of the alternative current (AC) voltage's root mean square (RMS) during a very long time frame. They are categorized into interruptions, overvoltage, and under voltage.

Under Voltage

This occurs when the RMS AC voltage drops below 90% of its nominal value for a certain period. Causes of under voltage include load switching, capacitor bank activation or deactivation, and system overloads.

Over Voltage

In contrast, overvoltage is when the RMS AC voltage exceeds 110% of its nominal value for some time. Common causes include the deactivation of loads and the energization of capacitor banks.

Harmonics

Harmonics are significant issues in power systems, causing distortion in current and voltage waveforms and degrading power quality. They involve frequencies that are integer multiples of the fundamental frequency and are produced by non-linear loads. Analyzing and controlling harmonics has been a major focus over the years due to their complex nature and impact on the power system.

Linear time-invariant loads are characterized by their response to sinusoidal voltage with a sinusoidal current flow. These loads exhibit a constant impedance when subjected to a sinusoidal voltage, meaning that current and voltage are directly proportional. For example, incandescent lighting operates as a linear load. Even though transformers and rotating machines might not always have sinusoidal flux waves, they generally conform to this definition under normal loading conditions. Transformers are minimally harmonic distorted when supplied with sinusoidal voltages from linear loads that may contain both odd and even harmonics including DC.

In contrast, non-linear loads do not produce sinusoidal currents when subjected to sinusoidal voltages. These loads can draw discontinuous currents and generate significant harmonic distortion. Harmonic filters are used to isolate and mitigate these harmonics, protecting electrical equipment and improving power factor. Harmonic distortion can lead to various issues such as timing errors in electronics, increased heating in equipment, and capacitor overloads. There are two main types of filters used to reduce harmonic distortion: active and passive. Active filters, equipped with components like IGBT transistors, are designed to eliminate undesirable harmonics by injecting counteracting harmonics and are typically used in low voltage networks. In various voltage levels, there are a lot of passive filters that are more often used than active ones given their suitability to its applications.

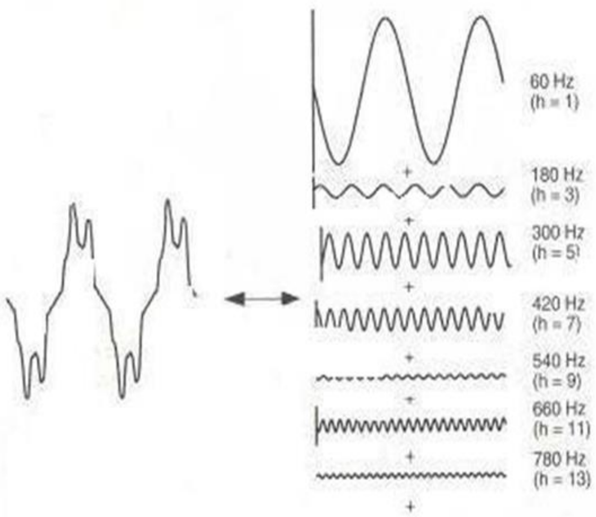

Figure 1 : Fourier series representation of a distorted waveform

Causes

Non-ideal sinusoidal waveforms were once produced by synchronous generators, but modern generators are now equipped with advanced control systems that allow for the production of nearly perfect sinusoidal waveforms. Despite these advancements, transformer saturation continues to contribute to harmonic distortion in systems, with non-linear loads being the primary source of harmonics. Non-linear loads draw currents that deviate significantly from a sinusoidal waveform, exacerbating the issue. With the advancement of power electronics, harmonic problems have become increasingly severe across power systems. Common causes of harmonics include:

1. Fluorescent Lighting
2. Arc Furnace
3. Power Supplies and Converters
4. Adjustable Speed Drives
5. Cycloconverters.

Roles of Filters in Power Systems

- Passive Filters

- Active Filters

Passive filters are designed to protect power systems by providing a low impedance path to restrict harmonic currents from entering the system. These filters typically consist of resistors, inductors, and capacitors. They work by creating a resonant circuit that cancels out specific harmonic frequencies, thereby reducing their impact on the power system.

Active filters are used primarily in distribution networks to address issues such as voltage sags, flickering, and harmonics in both current and voltage. These filters actively inject counteracting currents to neutralize the harmonics and improve power quality. They are particularly effective in dynamic and complex environments where harmonics and other disturbances fluctuate. Both types of filters utilize capacitors to help reduce harmonic distortions, contributing to overall improved power quality. Additionally, there is a third category of filtering media: the hybrid filter. Both passive and active filters are components of hybrid filters.

Figure 2 illustrates a single-phase representation of a distribution system featuring a nonlinear load and a passive shunt filter.

Passive Filters:

Passive filters, composed of resistors, inductors, and capacitors, are a cost-effective solution for mitigating harmonic currents in power systems. They function by providing a low impedance path for specific harmonic frequencies, thereby minimizing the impact of harmonics caused by nonlinear loads. Typically, passive filters are placed close to the source of harmonic generation to achieve optimal performance. By positioning them near nonlinear loads, such as rectifiers or inverters, these filters effectively reduce harmonic distortion.

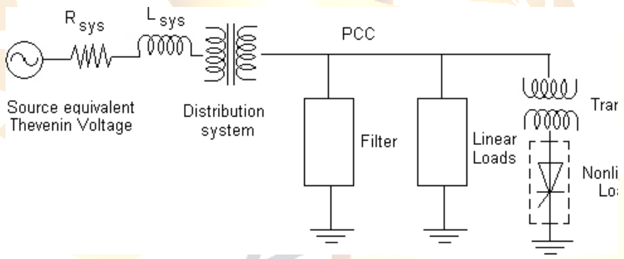

Figure 2 : Single-Phase Diagram of Nonlinear Load with Passive Shunt Filter for Harmonic Mitigation

When installing passive filters in a power system, it is crucial to ensure that each filter is matched to the specific harmonic orders that need to be addressed. For example, if a filter is designed to target the 3rd harmonic, it should only be implemented after a filter for the 1st harmonic has been installed. This sequential approach is essential because each filter is designed to address a particular harmonic frequency, and the effectiveness of higher-order harmonic filters depends on the successful reduction of lower-order harmonics.

Passive filters work by creating a resonance frequency that should ideally be distinct from the harmonic frequencies generated by nonlinear loads. To achieve effective harmonic mitigation, passive filters are typically calibrated to operate slightly below the target harmonic frequency.

DC-AC Inverter:

DC to AC inverters, which are devices that can change current directly into alternating flow, perform this function. These inverters can produce AC output with either fixed or variable magnitude and frequency, depending on their design. They are capable of generating single-phase or three-phase AC voltages ranging from 110 to 380 V, with frequencies of 50 Hz, 60 Hz, or 400 Hz. One of the primary applications of inverters is in Uninterruptible Power Supplies (UPS), where they provide continuous AC power during outages by utilizing batteries and a rectifier for recharging when the main power is restored. Inverters are also the most important parts of Variable Frequency Drives (VFDs); they provide voltage and frequency levels for motors which then affect how fast or efficient the motors run. Additionally, inverters are used to adjust the frequency of the AC output in induction motors, allowing for precise control of motor speeds according to varying operational demands. These functions highlight the essential role of inverters in enhancing power reliability and efficiency in various electrical systems.

Types of Inverters:

There are three types of Inverters

Single Phase Inverters
Three Phase Inverters
Multilevel Inverters

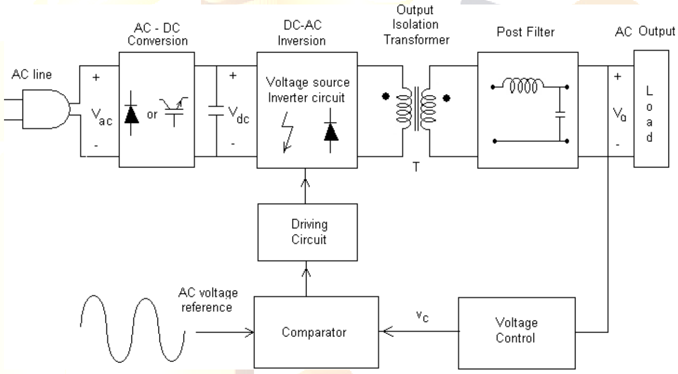

Figure 3: Power Electronic Circuit with DC-AC inverter

Block Diagram of DC-AC Inverter:

As talked about in preceding sections, harmonics can crop up in every arrangement - this includes arrangements involving inverters. While the primary goal of an inverter is to convert a DC source into an AC output, the practical reality often involves distortions that result in non-sinusoidal waveforms due to the presence of harmonics. Consequently, inverters are employed to generate output waveforms that are as close to sinusoidal and distortion-free as possible.

A DC-AC inverter circuit with filters created to reduce harmonic effects and produce a clean, sine wave AC signal is illustrated in Figure 4.10. The front section of the circuit has AC to DC converters which communicate through lines for switching purposes and operate on line frequency. After this, DC to AC inverters control power switching devices but their output frequency is independent of the line frequency. The diagram further shows a voltage control system where variable frequency drives help adjusts motor speeds and output voltages. With such a complicated arrangement, efficiently controlling inverter circuits calls for accurate control signals so as to get the intended AC output voltage. Moreover, a filter circuit that reduces harmonics has been illustrated in this diagram, as well as a comparator circuit which compares the resulting AC voltage signal against a reference one. If such is the case, it means that the filter circuits should be reactivated to ensure that what comes out of them is a clean sine wave AC voltage.

Pulse Width Modulation Technique:

Figure 4 shows a single phase inverter block diagram with a high frequency filter that is used in order to remove the harmonics from the output waveform. Here, V_O is the ac output while v_{in} is the input dc voltage.

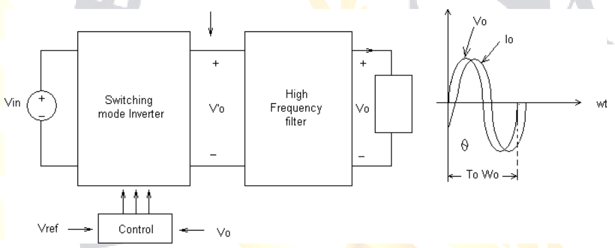

Figure 4: Single Phase Inverter with Filter

In a single-phase inverter, the output voltage is controlled by varying the width of the output pulses, a technique known as Pulse Width Modulation (PWM). PWM helps in reducing harmonics and controlling the inverter's output.

There are two primary techniques for implementing PWM:

- Non-Sinusoidal Pulse Width Modulation
- Sinusoidal Pulse Width Modulation.

IV. Simulation And Results

This section deals with the elimination of harmonics in inverters employing the Pulse Width Modulation (PWM) methodology, particularly by point out nonlinear equations that aid in determining angle of switching with an aim at achieving desired output of inverter using selected switches' angles. Specific angles are important for enabling a certain output or eliminating particular harmonics thus their elimination from power systems.

In this case, you set the fundamental part for a desired output, while all other harmonics remain to be zero. In the simulations, the switching angles were computed for 5th, 7th and 11th harmonics. This method provides an output with fewer unwanted harmonics.

The harmonic content in the inverter's output can be assessed and reduced by calculating the Total Harmonic Distortion (THD) of its output voltage and current. The formula for percentage of Total Harmonic Distortion is given by: [9]

$$\%THD = \left[\frac{1}{a^2_1} \sum_{n=5}^{\infty} (a^2_n) \right] \times 100$$

$$\text{Where } n = 6i \pm 1 (i = 1, 2, 3 \ldots.)$$

Using the methods presented in the images and ensured simulation codes, the switching angles needed to attain the required Total Harmonic Distortion (THD) are calculated. Precisely how to determine these angles is detailed by these codes to minimize harmonic distortion in an inverter's output.

Simulink model

The Shunt Active Filter is an advanced solution for mitigating harmonic distortion in power systems by employing power electronic devices to counteract harmonics produced by nonlinear loads. A shunt filter or parallel filter (active, as it is known) is a device that is usually connected in parallel to the load needing compensation. The primary aim here is that the source supplies an undistorted sinusoidal current even when subjected to harmonics from non-linear loads.

From what we have seen in figure 5.1, it is clear that when doing harmonic current cancellation using a voltage source inverter to produce harmonic current components which will neutralize the undesired harmonics from the non-linear load is the basic principle of this process. The inverter in the active filter uses DC capacitors as its power source, switching at high frequencies to produce signals that neutralize the harmonic distortions. This approach allows the active filter to address harmonics without providing real power, as it primarily handles reactive power associated with the harmonic currents. By reducing the harmonic currents flowing through the source impedance, the active filter decreases the overall harmonic voltage distortion.

The DC capacitors and filter components should be properly rated based on the corresponding reactive power of the harmonics and current waveform requirements for effective harmonic cancellation. In a current-controlled mode, the voltage source inverter uses an interfacing filter to smoothen out and isolate high-frequency components. This filter ensures that the current waveform required for harmonic cancellation is accurately produced by controlling the switching of insulated gate bipolar transistors (IGBTs) within the inverter.

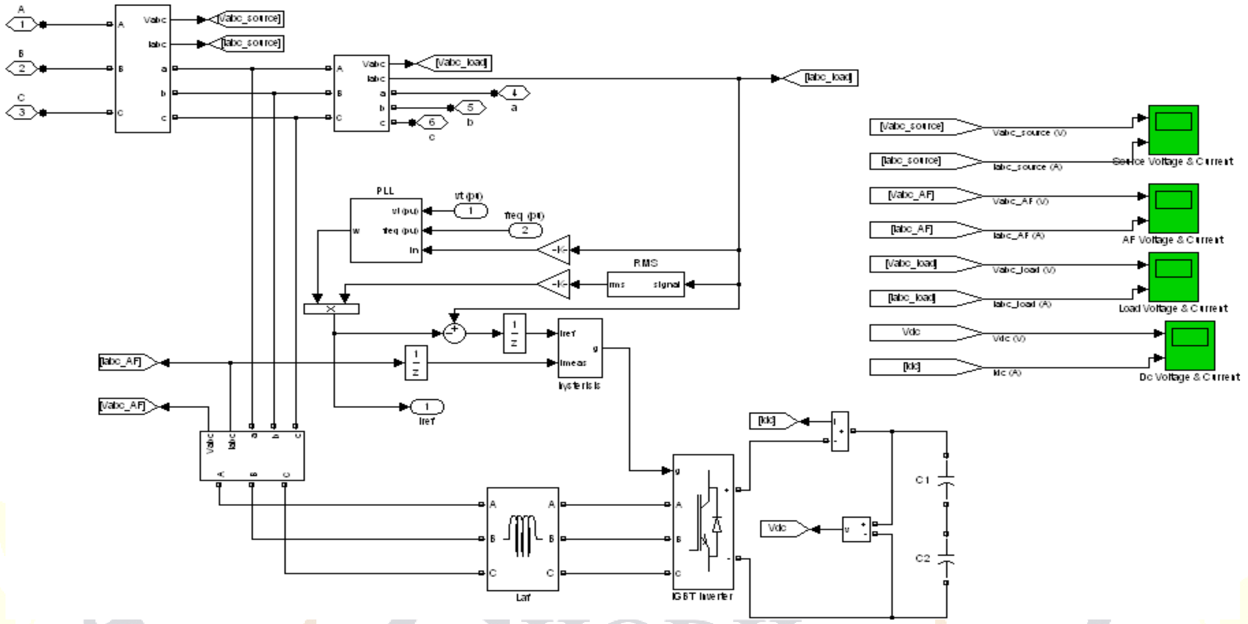

Figure 5: MATLAB Simulink model of parallel connected three phase inverter

Simulations were conducted to evaluate the performance of a three-phase shunt active filter for reducing harmonics generated by an inverter, using a known three-phase source and specific connected line inductance along with a nonlinear load. The parameters for the Pulse Width Modulation (PWM) AC voltage controller in this simulation study were set as follows: an input voltage of 4160 Vrms, with a line inductance of 1 mH. The nonlinear load was represented by a bridge snubber circuit with a resistor of 1 MΩ and a capacitor of 1 µF.

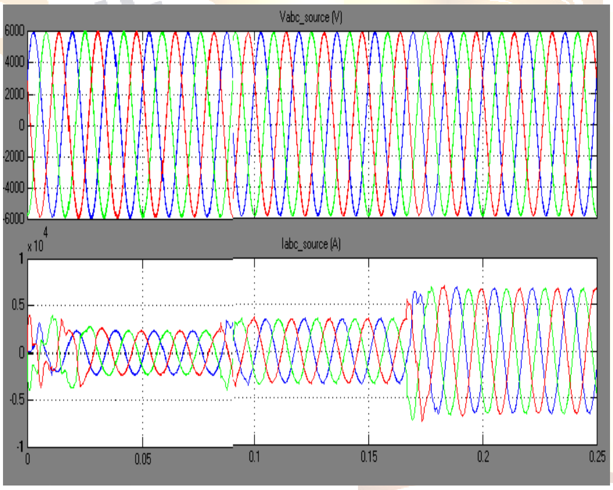

Figure 6: Source Voltage and Current for three phase source

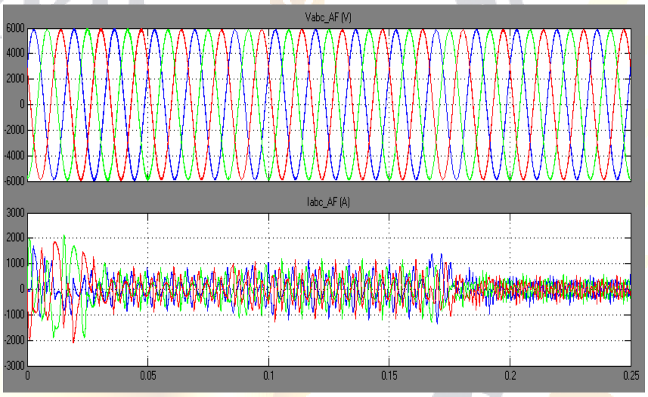

Figure 7: Shunt active filter three phase Voltage and Current waveform

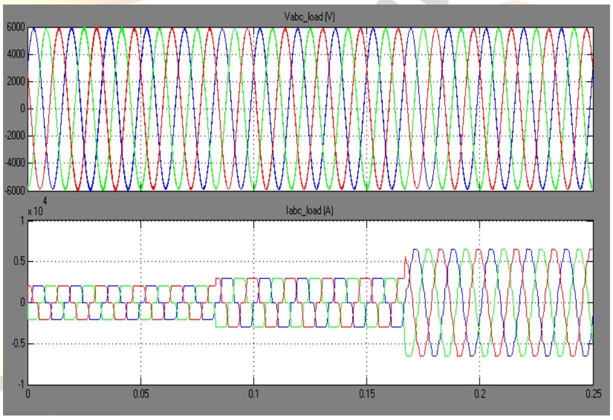

Figure 8: Three phase Voltage and Current for load side

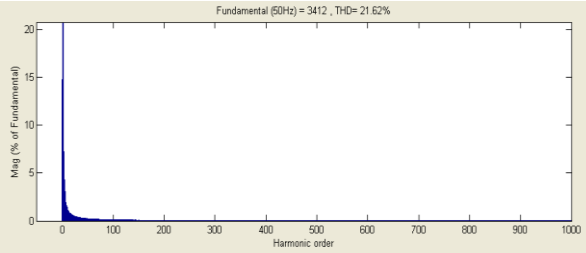

Figure 9: Total Harmonic Distortion (THD) of after shunt active filter current

V. CONCLUSION

The power electronic devices can very much elevate the level of harmonic pollution in power transmission and distribution systems. Various researchers in the field of power systems and automation have looked into many ways to solve this problem. One effective method is the use of harmonic compensation through shunt active filters. This paper focuses on the analysis of harmonics in power systems, the inverter circuit, and the implementation of shunt active filters in a three-phase circuit. In order to come up with a good shunt active filter that mitigates harmonics it is important to model it using MATLAB Simulink software. Thus, we can conclude that THD measurement is one of the primary parameters used to value how effective an active filter is in terms of its performance.

The shunt active filter (Shunt AF) has been developed for the purpose of balancing and unbalancing nonlinear load currents in a 4-wire system where the neutral wire links up with a capacitor's midpoint. This filter can dynamically adjust to compensate for harmonic currents and reactive currents as needed. It adapts within one fundamental period to accommodate unexpected variations in load current, providing a responsive solution for harmonic mitigation and reactive power compensation.

REFERENCES

[1] A. Hadi, E. Thjeel, and A. Nahar, "A Review of Control Technique Applied in Shunt Active Power Filter (SAPF)," Eng. Technol. J., vol. 40, no. 8, pp. 140–149, 2022, doi: 10.30684/etj.v40i8.2116.

[2] P. Suresh and G. Vijayakumar, "Shunt Active Power Filter with Solar Photovoltaic System for Long-Term Harmonic Mitigation," J. Circuits, Syst. Comput., vol. 29, no. 5, pp. 1–23, 2020, doi: 10.1142/S0218126620500814.

[3] C. B. Singh, A. Kumar, C. Gupta, S. Cience, T. Echnology, and D. C. Dc, "Comparative performance evaluation of multi level inverter for power quality improvement," vol. 12, no. 2, pp. 1–7, 2024.

[4] C. Gupta and V. K. Aharwal, "Optimizing the performance of Triple Input DC-DC converter in an Integrated System," J. Integr. Sci. Technol., vol. 10, no. 3, pp. 215–220, 2022.

[5] A. Kumar and S. Jain, "Critical Analysis on Multilevel Inverter Designs for," vol. 14, no. 3, 2022, doi: 10.18090/samriddhi.v14i03.22.

[6] C. Gupta and V. K. Aharwal, "Design of Multi Input Converter Topology for Distinct Energy Sources," SAMRIDDHI, vol. 14, no. 4, pp. 1–5, 2022, doi: 10.18090/samriddhi.v14i04.09.

[7] C. Gupta and V. K. Aharwal, "Design and simulation ofMulti-Input Converter for Renewable energy sources," J. Integr. Sci. Technol., vol. 11, no. 3, pp. 1–7, 2023.

[8] A. Kumar and S. Jain, "Enhancement of Power Quality with Increased Levels of Multi-level Inverters in Smart Grid Applications," vol. 14, no. 4, pp. 1–5, 2022, doi: 10.18090/samriddhi.v14i04.07.

[9] A. Raj, A. Kumar, and C. Gupta, "Shunt Active Filters : A Review on Control Techniques II . Shunt Active Power Filter," vol. 05, no. 02, pp. 78–81, 2022.

[10] P. Verma and M. T. Student, "Three Phase Grid Connected Solar Photovoltaic System with Power Quality Analysis," pp. 111–119, 2018.

[11] S. Jain, Control strategies of shunt active power filter. Elsevier Inc., 2018. doi: 10.1016/B978-0-12-814568-5.00002-8.

[12] M. O. Mahmoud, W. Mamdouh, and H. Khalil, "Source current harmonic mitigation of distorted voltage source by using shunt active power filter," Int. J. Electr. Comput. Eng., vol. 10, no. 4, pp. 3967–3977, 2020, doi: 10.11591/ijece.v10i4.pp3967-3977.

[13] V. Meena and C. Gupta, "A Review of Design , Development , Control and Applications of DC − DC Converters," no. 2581, pp. 28–33, 2018.

[14] S. Khan, C. Gupta, and A. Kumar, "An Analysis of Electric Vehicles Charging Technology and Optimal Size Estimation," vol. 04, no. 04, pp. 125–131, 2021.

[15] R. Kumar and C. Gupta, "Methods for Reducing Harmonics in Wind Energy Conversion Systems : A Review I . Introduction II . Wind Energy Conversion System III . Harmonic Mitigation Methods," vol. 04, no. 02, pp. 1–5, 2021.

[16] P. Verma and C. Gupta, "A Survey on Grid Connected Solar Photovoltaic System," Int. Conf. Contemp. Technol. Solut. Towar. fulfilment Soc. Needs, pp. 106–110, 2018, [Online]. Available: https://www.academia.edu/37819420/A_Survey_on_Grid_Connected_Solar_Photovoltaic_System

[17] A. K. Singh and C. Gupta, "Controlling of Variable Structure Power Electronics for Self-Contained Photovoltaic Power Technologies," vol. 05, no. 02, pp. 70–77, 2022.

[18] R. Kumar and H. O. Bansal, "Shunt active power filter: Current status of control techniques and its integration to renewable energy sources," Sustain. Cities Soc., vol. 42, pp. 574–592, 2018, doi: 10.1016/j.scs.2018.07.002.

[19] Y. Hoon, M. A. M. Radzi, M. K. Hassan, and N. F. Mailah, "Control algorithms of shunt active power filter for harmonics mitigation: A review," Energies, vol. 10, no. 12, 2017, doi: 10.3390/en10122038.