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Comparison of Active Power Filter and Passive Power Filter in Harmonic Mitigation in Power System Network

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Abstract: The power quality of an electrical system is greatly impacted by harmonics, which are undesirable voltage and current waveforms that distort the sinusoidal waveform of the fundamental frequency. Harmonics, if not filtered, can damage electrical equipment, raise electric bills, and impair product quality and productivity. This can result in inefficiencies and cost losses, especially in industrial buildings. Passive and active power filters are two types of devices that can be used to mitigate harmonics in a power system. This study aims to compare the performance of passive and active power filters in mitigating harmonics in a power system. The study includes a literature review of the principles of harmonics, passive and active power filters, and their performance in harmonic mitigation. It includes simulation results of the performance of both types of filters in a power system with different levels of harmonic distortion. The results show that both passive and active power filters are effective in mitigating harmonics; however, active power filters have a higher level of performance and flexibility in terms of harmonic mitigation. The APF proves to be more effective in keeping the harmonic content within the permissible limits set by the IEEE 519-1992 standards, which is 5%.

Keywords: active and passive filter, harmonic, voltage, current

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1. INTRODUCTION

Harmonics are a sort of waveform distortion that occurs in power systems when the voltage or current deviates from a pure sine wave. Non-linear loads, such as electronic gadgets and power supplies, demand current in pulses rather than in a steady state, producing them. These pulses create additional frequency components, known as harmonics, which are integer multiples of the fundamental frequency. The usage of non-linear loads, such as electronic devices and power supply, is the most prevalent cause of harmonics in power systems. In order to convert AC power to DC power, these devices often employ switching circuits such as diodes and transistors. These circuits' switching operation generates current pulses, which generate harmonic frequencies [1].

The impact of harmonics on power quality are another key topic in harmonic theory in power systems. Harmonics can lead to a number of power quality issues, including voltage flicker, power factor, and neutral current. These issues can cause equipment interruptions, damage to power system components, and decreased system efficiency. Several measures, including Total harmonic distortion (THD), Voltage harmonic distortion (VHD), and Current harmonic distortion (CHD), can be used to assess power quality. The presence of harmonics results in an increase in the amount of apparent power that must be supplied, which exceeds both the active and reactive power by a significant margin, ultimately leading to a decrease in the power factor [2]. Therefore, it is important to mitigate harmonics in a power system to ensure the quality of the electrical power supply.

There are two main types of devices that can be used to mitigate harmonics in a power system: Passive Power Filters (PPF) and Active Power Filters (APF). Passive filters are passive electronic components that are designed to resonate at the harmonic frequencies to absorb and filter out the harmonics from the electrical power system. They are simple and inexpensive, but have limited performance in terms of harmonic mitigation and can only be used in low power systems. Active filters, on the other hand, are active electronic devices that use power electronic switches to generate a counteracting current to cancel out the harmonics. They have a higher level of performance in terms of harmonic mitigation and can be used in high power systems, but are more complex and expensive.

This study aims to compare the performance of passive and active power filters in mitigating harmonics in a power system. The study includes a literature review of the principles of harmonics, passive and active power filters, and their performance in harmonic mitigation. The results of the study will provide insights into the effectiveness and limitations of passive and active power filters in mitigating harmonics in a power system.

2. HARMONICS

2.1 Harmonics Standard IEEE 519-1992

IEEE 519-1992 specifies principles for reducing harmonic distortion in power systems. Harmonic distortion levels for various types of equipment and systems are specified in the standard. For different harmonic frequencies, the standard sets harmonic distortion restrictions in terms of total harmonic distortion (THD) and individual harmonic distortion. As per IEEE 519-1992 guidelines, the total harmonic distortion (THD) for voltage and current is restricted to 5% for system that below 69kV which is used in this project.

2.2 Nonlinear Load

A nonlinear load is a type of electrical load that does not have a linear voltage-current relationship. This indicates that the current flowing through the load is not directly proportional to the applied voltage. A non-linear load's impedance fluctuates with the applied voltage, resulting in a non-sinusoidal current draw when the applied voltage is high [3]. Devices such as rectifiers, inverters, and electronic devices that utilize switching power sources are examples of nonlinear loads. This project will cover two types of rectifiers: three phase full bridge diode and three phase thyristor rectifiers. Figure 1 shows the circuit connection that will be applied in this project.

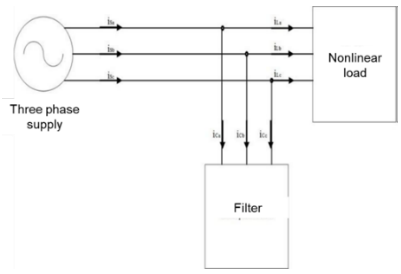

Figure 1. Circuit Connection

2.3 A Rectifier is a Type of Nonlinear Load

Rectifiers generate harmonic distortion because they utilize a non-linear component, such as a diode, to convert alternating current (AC) to direct current (DC) [4]. Since the diode only permits current to flow in one direction, a pulsing DC waveform with a fixed amplitude but changing width will be developed. The present waveform's nonlinearity causes harmonic distortion in the output.

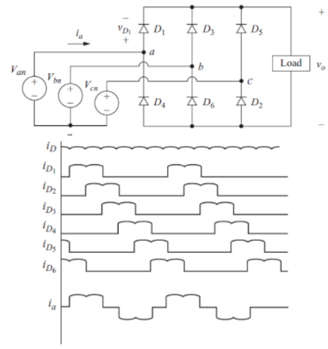

Figure 2. Waveforms of The Bridge Rectifier Circuit

2.4 Passive Power Filter

A passive power filter's operation is based on the usage of passive components such as inductors and capacitors to filter out harmonic currents. When harmonic currents are present in the system, they flow through the passive filter circuit and are absorbed by the inductors and capacitors. This minimizes the amplitude of the harmonic currents and raises the system's power factor. Passive power filters, on the other hand, have certain restrictions, such as the fact that they can only filter out harmonic frequencies that are within the filter's specified range, and they may not be effective in systems with extremely high levels of harmonic distortion [5].

2.5 Active Power Filter

An active power filter (APF) is a device that filters out undesired harmonic currents in an electrical power supply using electronic circuitry. Power electronic devices, such as thyristors or IGBTs, are used in APFs to inject a compensatory current into the power system that is opposite in phase to the harmonic current [6]. An APF's basic building component is a power electronic converter, often a voltage-source inverter (VSI), which generates compensatory current [7]. The instantaneous reactive power theory is one of the most often utilized APF control algorithms (IRPT). Overall, the APF operates by continually monitoring the power supply for harmonic distortion and creating compensatory current through the use of power electronic devices and control algorithms.

3. RESEARCH METHODOLOGY

Simulink MATLAB R2021b software was used for the simulation. The rectifier circuit is design as a nonlinear load. In this project, the rectifier will employ two components: a diode and a thyristor. The passive filter will then be designed depending on the system's output characteristics. Shunt single tuned and shunt double tuned filters are among the passive filters used in this research. Finally, the passive filter will be replaced with a shunt active filter. The THD for voltage and current was measured using the Power Gui's Fast Fourier Transform (FFT) Analysis. In order to monitor harmonic in the system, only current waveform and its THD is concentrated harmonics greatly influences it. Figure below show the overall circuit in MATLAB Simulink.

A three-phase schematic diagram with line impedance and source impedance has been constructed. Both three phase rectifiers will be connected to the R-L load shown above. The system parameters have been determined and are presented in the Table 1.

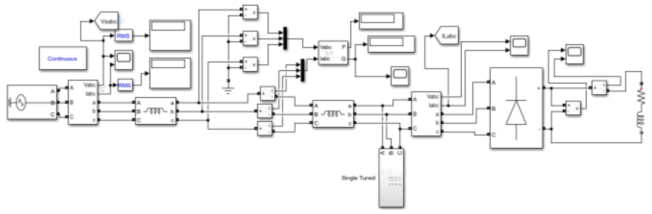

Figure 3. Overall Circuit

Table 1. Parameter Value for The System

Component	The value of a parameter
Voltage Source (Line-Line)	240V
Source Impedance	Ls = 1mH
Line Impedance	Lb = 1mH
R-L Load	R = 15Ω, L = 75mH

3.1 Diode Rectifier Design

For the first section the full wave bridge rectifier is used in the construction of rectifier circuits. In the simulation, an ideal diode is used because this project is utilizing a three-phase system, a 6-pulse diode rectifier. Harmonics are produced using a 6-pulse diode rectifier.

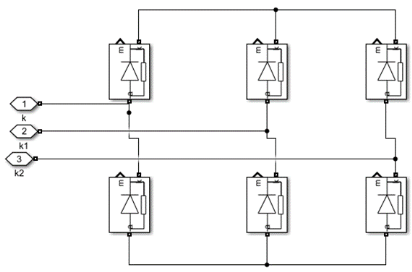

Figure 4. Six-pulse Diode Rectifier

3.2 Thyristor Rectifier Design

The Universal Bridge block represents the thyristor bridge rectifier. The thyristor functions as a power electronic switch, allowing control over the output voltage through an adjustable firing angle. One of the primary reasons for the increased harmonics is the non-linear switching characteristics of thyristors. The abrupt switching action causes steep voltage and current transitions, resulting in high-frequency components in the output waveform. The control signal for thyristor switching is obtained directly from the pulse generator block, which is supplied by a phase locked loop block and a signal from the supply voltage.

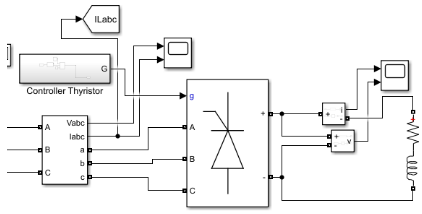

Figure 5. Thyristor Rectifier

3.3 Single Tuned Filter

A single tuned passive filter is a sort of electrical filter that filters out certain frequencies from an electronic signal using passive components (such as resistors, capacitors, and inductors) [9]. The filter is called "single tuned" because it has just one resonant frequency at which it may pass or reject signals.

The formula for determining the resonant frequency in the case of a single frequency tuning is represented by the following equation.

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

The relationship between reactive power and capacitive reactance may be represented as follows:

$$Q_c = \frac{V^2}{X_c} \tag{2}$$

Capacitance is computed as follows for single tuned filters:

$$C = \frac{1}{2\pi f\ X_c} \tag{3}$$

Equation (4) can be used to calculate filter resistance, where Q is the quality factor, R is the resistance, L is the inductance, and C is the capacitance value. Additionally, f represents the natural frequency, and v is the system voltage. The resistance of the filter is used to calculate the sharpness of the tune. The typical value of the quality factor for a regular distribution system ranges from 20 to 100 [12].

$$R = \frac{\sqrt{\frac{L}{C}}}{Q} \tag{4}$$

In the circuit configuration without any filtering, the system in this project requires approximately 3800 VAR of reactive power for the diode rectifier and 4900 VAR for the thyristor rectifier. The quality factor for the filter is set to 25. Using this data and circuit parameters, the filter configuration can be calculated and shown in the table below.

Table 2. Parameter of Single Tuned Filter for Diode Rectifier Load

Harmonics	Inductance, L (mH)	Capacitance, C (µF)	Resistor, R (Ω)
$5^{th} harmonic$	1.608	174.99	0.121
$7^{th} harmonic$	0.8206	174.99	0.0867
$11^{th} harmonic$	0.3323	174.99	0.0551
$13^{th} harmonic$	0.2379	174.99	0.0466

Table 3. Parameter of Single Tuned Filter for Thyristor Rectifier Load

Harmonics	Inductance, L (mH)	Capacitance, C (µF)	Resistor, R (mΩ)
$5^{th} harmonic$	1.247	225.66	94.03
$7^{th} harmonic$	0.636	225.66	67.15
$11^{th} harmonic$	0.258	225.66	42.77
$13^{th} harmonic$	0.185	225.66	36.22

The single tuned filter block will be added to the main circuit after all of the parameters are obtained.

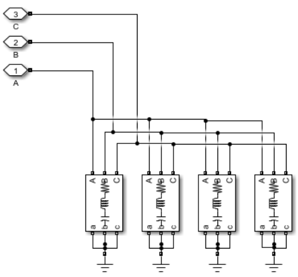

Figure 6. Single Tuned Filter

3.5 Double Tuned Filter

A double-tuned passive power filter consists of two tuned circuits that are designed to target specific harmonic frequencies. The filter is called "double-tuned" because it is designed to attenuate two specific harmonic frequencies simultaneously. Each tuned circuit consists of an inductor and a capacitor connected in series or parallel, creating a resonant circuit. To determine the parameters of a double-tuned filter, it is necessary to have knowledge of the parameters of the single-tuned filter since they are interconnected with each other.

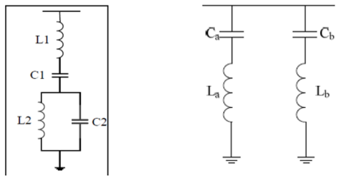

Figure 7. Double Tuned Filter

Series resonance circuit (L1, C1) and parallel resonance circuit (L2, C2) respectively have resonance frequency ωs and ωp. They can be expressed as

$$\omega_s = \frac{1}{\sqrt{L_1 C_1}} \tag{5}$$

$$\omega_p = \frac{1}{\sqrt{L_2 C_2}} \tag{6}$$

Two parallel single tuned filters resonance frequencies can be expressed as

$$\omega_a = \frac{1}{\sqrt{L_a C_a}} \tag{7}$$

$$\omega_b = \frac{1}{\sqrt{L_b C_b}} \tag{8}$$

Two parallel single-tuned filters are identical to a double-tuned filter; thus

$$\omega_a \omega_b = \omega_s \omega_p \tag{9}$$

C1 is determined using two capacitors with two order harmonics, Ca and Cb:

$$C_1 = C_a + C_b \tag{10}$$

L1 can therefore be determined as follows:

$$L_1 = \frac{1}{C_a {\omega_a}^2 + C_b {\omega_b}^2} \tag{11}$$

The series resonance frequency ω_s and parallel resonance frequency ω_p may be determined using L1 and C1:

$$\omega_s = \frac{1}{\sqrt{L_1 C_1}} \tag{12}$$

$$\omega_p = \frac{\omega_a \omega_b}{\omega_s}$$

L2 and C2 parameters may be determined as

$$L_2 = \frac{(1-\frac{{\omega_a}^2}{{\omega_s}^2})(1-\frac{{\omega_a}^2}{{\omega_p}^2})}{C_1 {\omega_a}^2} \tag{13}$$

$$C_2 = \frac{1}{L_2 \omega_p{}^2} \tag{14}$$

Table 4. Parameter of Single Tuned Filter for Diode Rectifier Load

Harmonics	Inductance , L1 (mH)	Capacitance , C1 (mF)	Inductance , L2 (μH)	Capacitance , C2 (mF)
5^{th} & 7^{th}	0.5433	0.35	63.82	3.329
11^{th} & 13^{th}	0.1390	0.35	3.90	12.760

Table 5. Parameter of Single Tuned Filter for Thyristor Rectifier Load

Harmonics	Inductance , L1 (mH)	Capacitance , C1 (mF)	Inductance , L2 (μH)	Capacitance , C2 (mF)
5^{th} & 7^{th}	0.421	0.4513	49.65	4.281
11^{th} & 13^{th}	0.1077	0.4513	3.001	16.66

3.6 Active Power Filter

The PQ theory is used to design the APF. The PQ theory decomposes the total power drawn by a load into two components: active power and reactive power. In the PQ theory, the computation of the reference current signal is based on measuring the three-phase voltages and currents of the three-phase power system. These measurements are then transformed into α-β coordinates Transformation as follow:

$$\begin{bmatrix} V\alpha \\ V\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix} \tag{15}$$

$$\begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} \tag{16}$$

The instantaneous active (p) and reactive (q) power will be defined by these phase voltages and currents on the $\alpha\beta$ axis, as illustrated in equation

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V\alpha & V\beta \\ V\beta & -V\alpha \end{bmatrix} \begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} \tag{17}$$

To isolate the varying components of the real and reactive power, a low pass filter is employed. The compensating currents in α-β coordinates are then computed in the following manner:

$$\begin{bmatrix} ic\alpha \\ ic\beta \end{bmatrix} = \frac{1}{V\alpha^2 + V\beta^2} \begin{bmatrix} V\alpha & V\beta \\ V\beta & -V\alpha \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} \tag{18}$$

Lastly, the currents represented in α-β coordinates are transformed into a-b-c coordinates using the following method:

$$\begin{bmatrix} ica \\ icb \\ icc \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} ic\alpha \\ ic\beta \end{bmatrix} \tag{19}$$

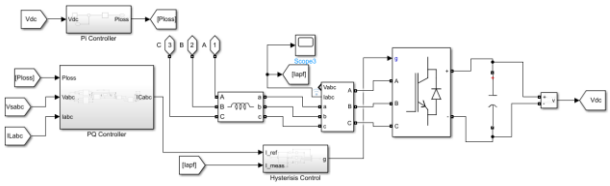

Figure 8. Active Power Filter

4. RESULT AND ANLYSIS

This section provides the Simulink model and the corresponding results. After constructing and simulating the circuit in MATLAB, the simulation results are as expected, containing a harmonic. The supply waveform and the FFT have been gathered for observation and analysis.

4.1 Uncompensated Circuit

The figure provided illustrates an uncompensated simulation model that generates harmonics in both the source voltage and current. This project involves two distinct nonlinear loads, specifically a diode and a thyristor. It is evident that both waveforms exhibit the presence of harmonics and distortion caused by the rectifier. Notably, the current waveform appears to be the most significantly affected.

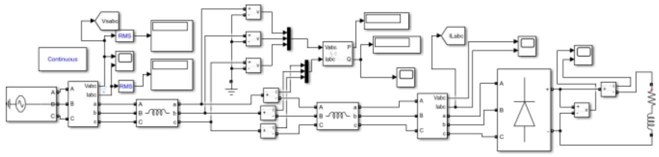

Figure 9. Uncompensated Circuit

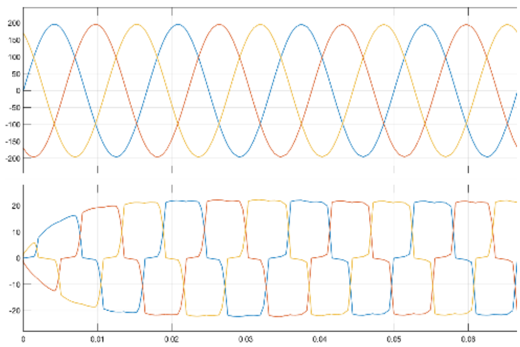

Figure 10. Supply voltage and current waveform before filtering

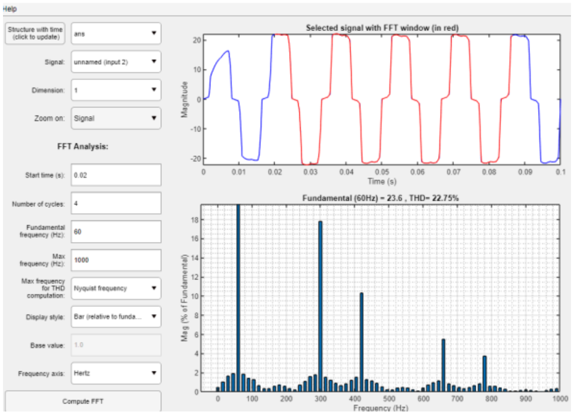

Figure 11. FFT analysis for THDi before filtering

The diagram depicts the existence of harmonic components in the source waveform. It is clear that the nonlinear properties have a substantial impact on the current waveform. The FFT Analysis findings, shown in the following figures, show that the Total Harmonic Distortion (THD) for the voltage (THDv) is 0.44%, while the THD for the current (THDi) is 22.75% for diode rectifier. However, for the thyristor bridge rectifier, the THDv is significantly reduced to 0.09% while the THDi increases to 26.87%.

Table 5. THD for Uncompensated Circuit

Parameter	Diode Rectifier	Thyristor Rectifier
THDv (%)	0.44	22.75
THDi (%)	0.09	26.87

4.2 Compensated with Single Tuned Filter

The figures below demonstrate the source current and voltage generated by the system after a single tuned filter was applied. When compared to the system without any filter, the current waveform with Single Tuned Filter is more sinusoidal and has lower THD. The FFT analysis revealed that the harmonic values are clearly falling, with STF improving THDv and THDi.

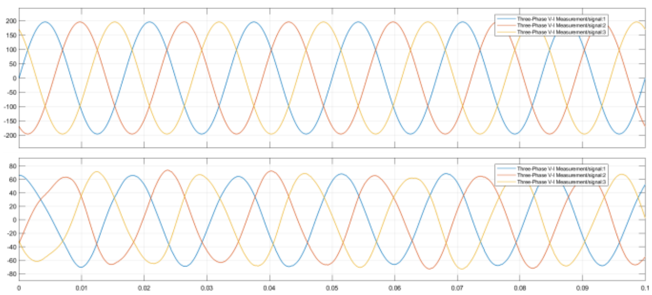

Figure 12. Supply voltage and current waveform with Single Tuned

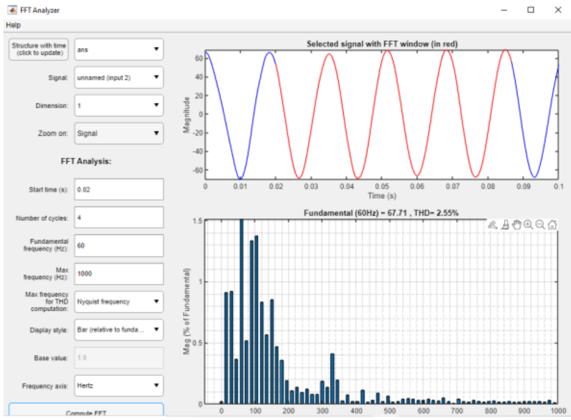

Figure 13. FFT analysis for THDi with Single Tuned Filter

4.3 Compensated with Double Tuned Filter

The following simulation results were obtained when the system was connected to the Double Tuned Filter in both nonlinear circuits. The subsequent figures illustrate the source current and voltage waveforms generated after the implementation of the double tuned filter in the system. As both are classified as passive filters, the waveform and THD value are essentially identical same with a single tuned filter.

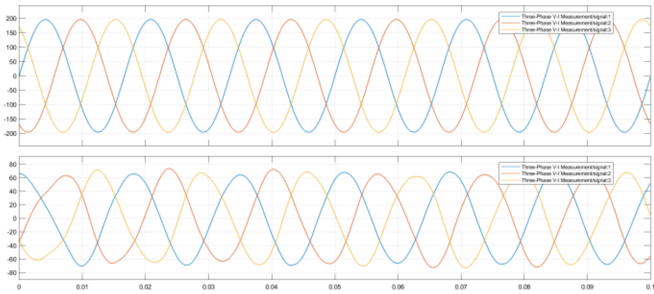

Figure 14. Supply voltage and current waveform with Double Tuned

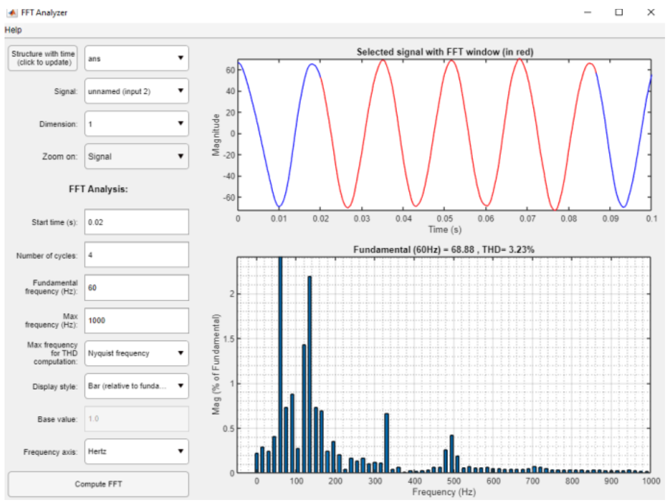

Figure 15. FFT analysis for THDi with Double Tuned Filter

4.4 Compensated with Active Power Filter

Through a 1mH coupling inductance, the active filter is coupled to a three-phase power supply. As a result, the three-phase load current will appear as shown in the figures and will be approximately sinusoidal. As anticipated, the THD level for both nonlinear diodes are significantly lower when compared to the passive power filter.

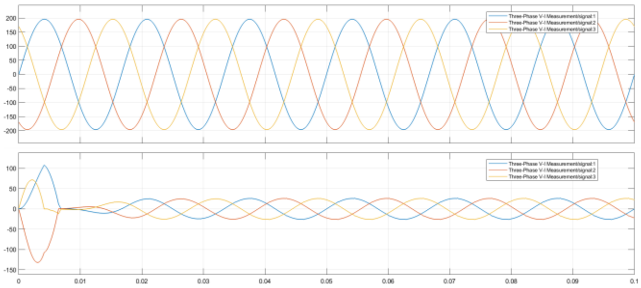

Figure 16. Supply voltage and current waveform with Active Filter

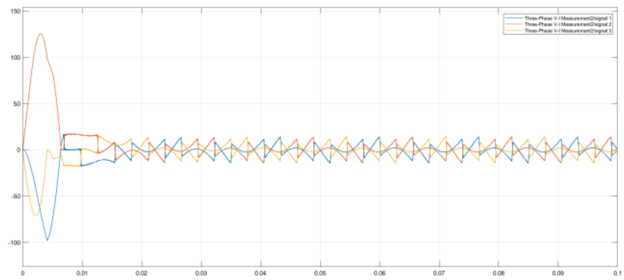

Figure 17. Compensated current fed by active filter

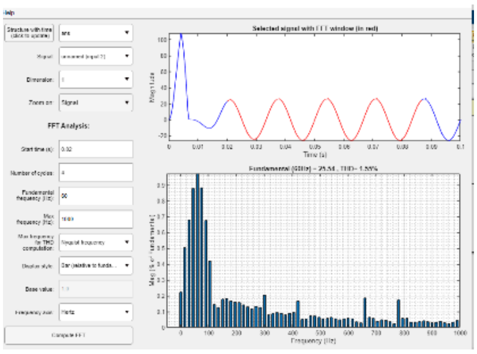

Figure 18. FFT analysis for THDi with Active Filter

Table 6. Comparison value of THDi with Several filter

Type of Rectifier	Single Tuned	Double Tuned	Active Filter
THDi (Diode)	2.55%	3.23%	1.55%
THDi (Thyristor)	5.11%	6.96%	4.24%

Based on the simulation results and FFT analysis, both filters demonstrate effective performance in compensating for harmonics. However, it is evident that the Active Power Filter (APF) outperforms the Passive Power Filter (PPF) in terms of harmonic compensation. The APF proves to be more effective in keeping the harmonic content within the permissible limits set by the IEEE 519-1992 standards, which is 5%.

5. CONCLUSION

The main goal of this project is to examine the THD and waveform to determine the influence of harmonics induced by nonlinear load on voltage and current in a power system. The used of passive and active filter to mitigate the harmonics distortion has proved.

The simulation results have showed that both filters can effectively mitigate harmonics. It has been demonstrated that the active filter is more compatible and flexible in meeting the standard regulations for harmonic control.

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