

---

## POWER QUALITY IMPROVEMENT IN DISTRIBUTION NETWORK USING SHUNT ACTIVE POWER FILTER

---

**\*Damina, Vuwah Sunday, A.L. Amoo, E.C. Anene**

---

Department of Electrical and Electronic Engineering, Abubakar Tafawa Balewa University  
Bauchi, Bauchi State, Nigeria.

Article Received: 24 April 2026, Article Revised: 14 May 2026, Published on: 04 June 2026

**\*Corresponding Author: Damina**

Department of Electrical and Electronic Engineering, Abubakar Tafawa Balewa University Bauchi, Bauchi State,  
Nigeria.

DOI: <https://doi-doi.org/101555/ijarp.5415>

### ABSTRACT

The needs for electricity are increasing at a faster rate in this modern society. For electrical equipment to function properly and effectively on power distribution network, a constant supply of high-quality power is required. The most common type of power quality degrading factors includes; variation in voltages and frequency, power interruption, power sag, voltage swell, under voltage, voltage spike or surges and harmonics etc. The used of non-linear loads such as computers, printers, UPS, Variable-speed drive etc are the major causes of harmonics into the supply distribution network. The existence of harmonics is the primary causes of the problems that lead to the breakdown of insulation, excessive heating of conductors and shortened the lifespan of electrical equipment. In addition to this high THD in electrical distribution network may cause the energy meter to give false readings. Shunt active power filter is an economic solution use to reduce losses caused by harmonics distortion. This research work provides an in- depth look into the application of this filter for harmonics compensation. By performing simulations with the MATLAB/Simulink software, it has been determined that using shunt active power filter reduces the total harmonics distortion (THD)of the current by 90% significantly resulting into better quality and energy conservation. The IEEE standard 519-1992 was used as a reference when making this determination. This research work presents the design of shunt active power filter for mitigation of power quality problems introduced by nonlinear loads. A shunt active power filter in parallel with the load has been investigated to improve the power quality. The control

strategy has been simulated using MATLAB software and the results to verify the effectiveness of the algorithm were presented.

**KEYWORDS:** Power quality, Harmonics, THD, IEEE, MATLAB.

## A. INTRODUCTION

With global electricity demand growing, power quality (PQ) has become a critical issue in energy systems and a significant concern. The increasing use of IT and power electronics-related electronic devices, such as variable frequency drives (VFDs), energy-efficient lighting systems, and programmable logic controllers (PLCs), has led to power load fluctuations, which are considered a major cause of degraded PQ (Temerbayev and Dovgun, 2014). The nonlinearity of these loads distorts voltage and current waveforms. With technological advancements and the global economy, profitability is declining across various processes (Rahmani et al., 2013). With the increasing sensitivity of processes in industry, residential housing, and the service sector, power quality (PQ) has become a key concern across all business sectors, making it a key determinant of energy availability. Key industries impacted by power quality include continuous processes, industrial processes, and IT services. In recent years, various approaches have been proposed to address power quality issues. Some approaches to improving power quality include air conditioning units and network filters (Shahalami et al., 2017).

Passive filters traditionally suppress harmonic distortion in industrial power systems but face drawbacks like resonance issues and performance dependence on system impedance. Salmeron and Litran (2010) indicate that active power filters were introduced to address these problems by injecting harmonic voltages or currents to eliminate harmonics in nonlinear loads. Despite their effectiveness, high initial costs and power losses limit the application of active filters, particularly at higher power ratings (Jou et al., 2005).

Filters are used to reduce harmonics and improve power quality. Filters connected to the system must be effectively controlled to achieve the desired response characteristics. Among various filter configurations, this study employs a shunt active power filter. The control method for a shunt active power filter aims to compensate for harmonics using the current it provides.

This study aims to improve power quality in a distribution network using active shunt power filters. The research system uses historical power quality data acquired from the Distribution Network Engineering Complex at the Yelwa Campus of Abubakar Tafawa Balewa

University, Bauchi. The system loads derived from this historical data will be used as potential nonlinear loads in the design of the active shunt filter.

Harmonics are a major cause of power quality degradation, known as harmonic distortion, particularly in three-phase distribution systems where low-order odd harmonics (third, fifth, seventh) prevail. These harmonics can lead to voltage drops, causing data loss, overheating, and equipment failures. Addressing harmonic content in grid current is crucial, yet nonlinear electronic devices contribute to this issue, further degrading power supply waveforms (Ramya and Arpita, 2013). These loads can cause distortion of the sinusoidal current. Harmonics in the power supply can be represented by measuring or calculating the total harmonic distortion (THD) of the current, as shown in Equation (1).

$$\text{current THD} = \frac{1}{I_{fund.}} \sqrt{\sum_{i=3,5,7, \dots}^{50} I_i^2} \quad \dots (1)$$

Where  $I_{fund.}$  = current reference value,  $I_i$  = Amplitude of odd harmonic current IEEE standard recommends noise reduction methods, such as pulse width modulation (PWM), selective harmonic suppression (SHE), and harmonic filters, to mitigate total harmonic distortion (THD) of current. This study selects a shunt active power filter to enhance power quality.

## B. LITERATURE REVIEW

### 2.2.1 Filter Classification

The various filters described in the literature can be divided into three main categories: passive filters, active filters, and hybrid filters. Each type has its own subcategories. Figure 1 shows a detailed classification of filters.

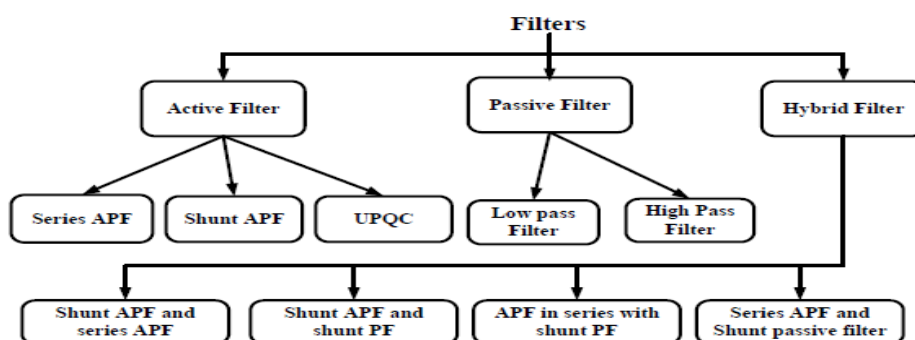
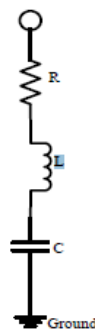


Figure 1: Filter Classification (Singh et al., 1999)

### 2.2.2 Passive power filter

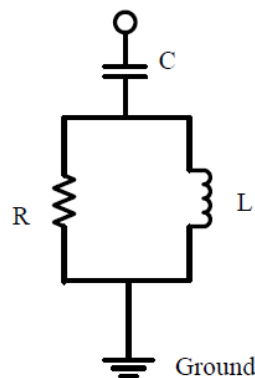
These filters consist of passive components such as capacitors, inductors, and resistors. They are widely used due to their low cost and ease of control. In addition to filtering out harmonics, passive filters can also provide reactive power. Their effectiveness depends largely on the system impedance. There are two types of filters: low-pass and high-pass.

i. **Low-pass filter:** A low-pass filter is an optimized LC circuit that provides low impedance to specific harmonic currents. This type of filter is also used for power factor correction. In power systems, they are typically used to filter out the fifth and seventh harmonics. Figure 2 shows the basic schematic of a low-pass filter.



**Figure 2: Low-pass filter. (Singh et al., 1999)**

ii. **High-pass filter:** A high-pass filter is made of passive components like inductors and capacitors, which allow harmonic currents above a certain cutoff frequency to pass while removing lower harmonics. These filters can be categorized into first-, second-, or third-order types, with second-order filters being the most common. Figure 3 shows a basic schematic diagram of a high-pass filter.



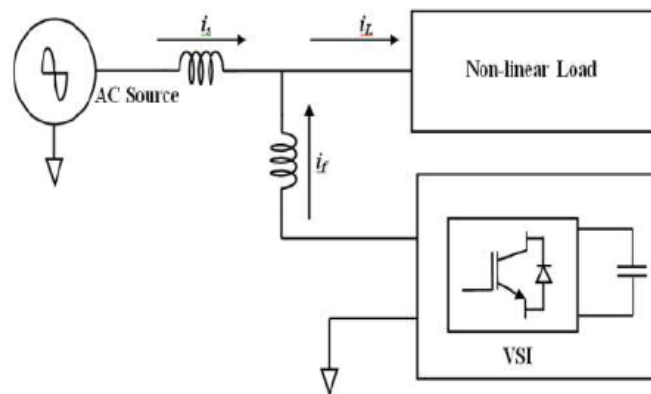
**Figure 3: High-pass filter (Singh et al., 1999)**

### 2.2.3 Active Power Filter (APF)

Active compensation using an active power filter (APF) can overcome the shortcomings of passive filters. An APF is a voltage source inverter (VSI) that provides compensating current or voltage, depending on the power system configuration. APFs were first proposed in the 1970s, but with advances in power electronics (Al-Haddad et al., 1999) and the publication of instantaneous active and reactive power theory in 1983, APFs have been applied to harmonic suppression in recent years.

APF filters represent the latest solution for harmonic compensation. Their advantages include high-speed switching elements, low power consumption, high-speed digital processors, and affordability (depending on the circuit configuration and functionality). There are three types of APF filters, each of which is discussed in detail below.

**i. Active Power Shunt Filter:** Shunt filters for automatic frequency control (AFC) using voltage source inverters function similarly to static synchronous compensators (STATCOMs). They connect to the PCC point of the shunt resistor, generating in-phase, equal-magnitude currents that counteract harmonic currents, acting as a harmonic current source for various loads and improving power factor. However, their high cost makes them unsuitable for large systems.



**Figure 4: Parallel active power filter circuit diagram (Al-Haddad et al., 1999).**

**ii. Series active power filter:** These filters, connected in series with the power supply through a matching transformer, provide a compensation voltage to address fluctuations in supply voltage. They are mainly utilized for loads with voltage-sensitive components. However, their practical use is limited due to the requirement to withstand high current ratings, which leads to increased size and losses.

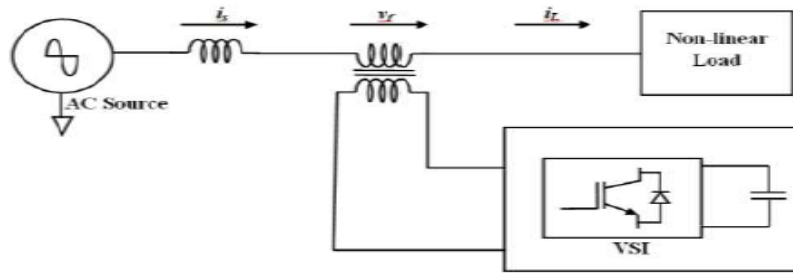


Figure 5: Series active power filter circuit diagram (Singh et al., 1999)

iii. **Integrated Power Quality Controller (UPQC):** The UPQC filter integrates a series active power filter and a shunt active power filter, leveraging their benefits to effectively compensate for voltage and current harmonics and address various power quality issues in the power grid (Axente et al., 2010). Figure 6 shows a schematic diagram of a power system using the UPQC filter.

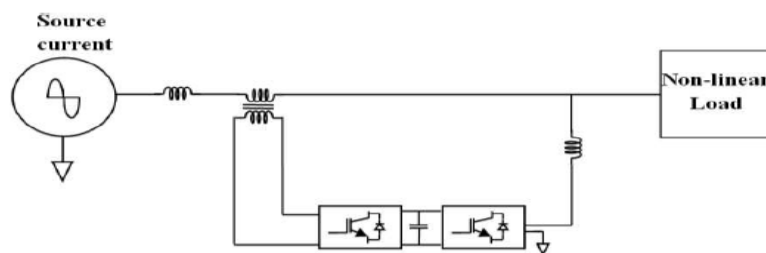


Figure 6: Schematic diagram of using UPQC (Axente et al., 2010)

iv. **Hybrid Power Filter:** Hybrid power filters have emerged as an effective solution for improving power quality by combining the benefits of active and passive power filters, addressing the high power demands of active filters. Their designs vary based on circuitry and layout.

Upadhyay A Singh (2020) proposed a method of f.orUse SPF to improve energy quality. This study proposes a shunt active power filter (SAPF) control method to eliminate current harmonics and improve power quality. The shunt active power filter utilizes various controllers, notably a proportional-integral (PI) controller, to minimize harmonic currents and improve power quality. The system's effectiveness is demonstrated through comparisons of total harmonic distortion (THD) with and without the filter, confirming its optimal performance in reducing THD. Simulations in MATLAB/SIMULINK show that even with nonlinear loads, the filter converts non-sinusoidal mains current into a sinusoidal waveform. Limitations include high implementation costs, the complexity of control algorithms, and potential instability under specific grid conditions.

Narkhede et al. (2021) developed a method to improve power quality using shunt active power filters. This study introduces a method to enhance power quality in the distribution layer of a microgrid using shunt active power filters. It focuses on developing a suitable pulse generation method to boost the filter's compensation performance, primarily through controlling the DC link capacitor voltage. An adaptive hysteresis current control method is proposed to replace traditional fixed methods. The performance is validated under various operating conditions via MATLAB/SIMULINK simulations, demonstrating improvements in compensating for harmonic currents, reactive power, neutral current, unbalanced current, and harmonics, thereby significantly enhancing overall power quality.

Nemmadi and Manjula (2023) proposed a shunt active power filter using fuzzy logic controller (FLC) to improve the power quality of distribution system. This study proposes a shunt active power filter (APF) utilizing a fuzzy logic controller (PLC) to mitigate total harmonic distortion (THD) caused by nonlinear loads in integrated distribution and generation systems, specifically photovoltaic (PV) systems. While traditional APFs with proportional-integral (PI) controllers are straightforward to implement, they struggle with nonlinearity. The fuzzy logic controller approach enhances power quality in PV systems, offering superior performance over PI controllers. However, challenges regarding implementation complexity and real-time operational efficiency may arise.

Tandon et al. (2023). Development of a Shunt Active Power Filter and Its Application in Power Quality Improvement: A Comparative Study Based on FFT Analysis. This research paper introduces a filter-based harmonic mitigation method using a harmonic current filter (HAPF) to correct the gate sequence for an IGBT inverter. It emphasizes the necessity of harmonic compensation in power systems, particularly through a shunt active power filter (SAPF). The paper discusses the current control strategy of SAPF and evaluates its performance via instantaneous active and reactive power (pq) theory. The method effectively generates filter reference currents to compensate for reactive power and harmonic components, with FFT analysis from MATLAB/SIMULINK models illustrating the active shunt filter's success in mitigating harmonics. However, the absence of a gate driver board and data acquisition board limited the validation of the experimental setup and simulation results.

Zaro, F. (2023) published a study on improving power quality in industrial parks using active power shunt filters. This study discusses the use of an active power shunt filter (APF) within an industrial park smart grid, designed using MATLAB/SIMULINK to manage nonlinear loads and harmonics from photovoltaic inverters. The APF, along with its hysteresis current

control method, effectively reduces total harmonic distortion (THD) and improves grid voltage and power factor. Nonetheless, its implementation is challenged by complex control systems and high costs.

### C. MATERIALS AND METHODS

#### 3.1 Materials

The materials used include the historical power quality data from the Fluke 453 Power Quality Analyzer, MATLAB software, Personal computer (laptop), Filter circuit model and active power shunt filter model, and a comprehensive load model of the power grid of the ATBU Engineering Complex at the Gerva Campus.

Figure 7 shows the distribution lines connecting the Engineering Complex, the ATBU Yerba Campus grid, the faculty and staff housing, and the Girls Day Care Center. Historical data was obtained by storing power quality measurements from the substation in a Fluke 435 data warehouse.

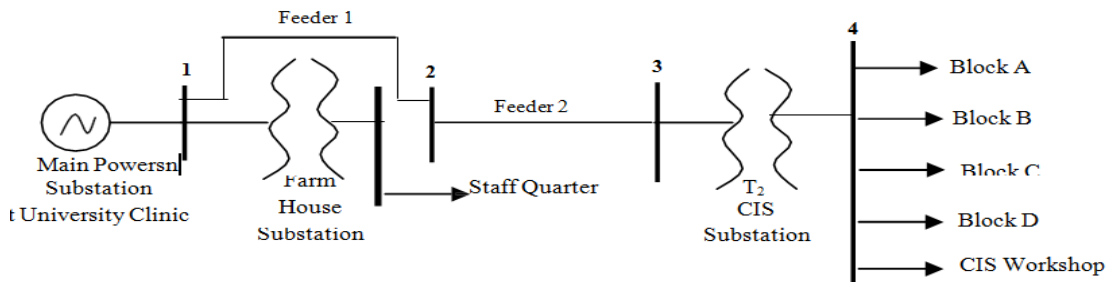


Figure 7: ATBU Engineering Complex, Yerva Campus Power Distribution Network.

The ATBU engineering composite load was modified according to the method developed by Sukhendar et al. (2015) using active shunt filters as shown in Figure 8.

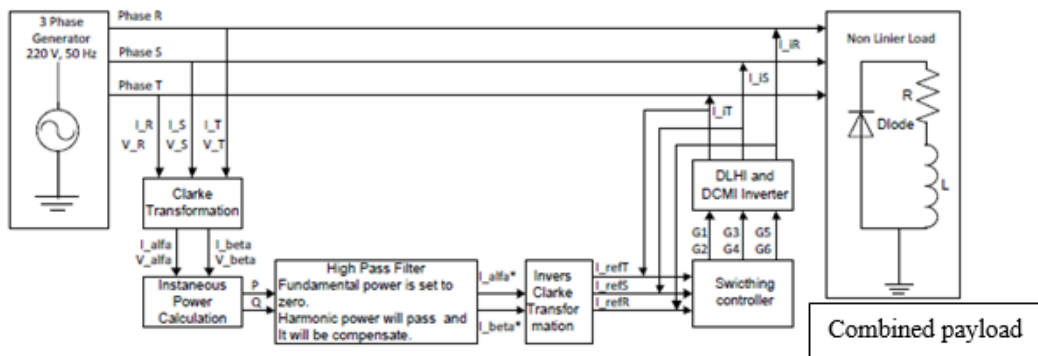


Figure 8: Active shunt filters are provided for search systems.

### 3.2.4 Filter circuit model

The filter circuit models shown in Figures 3 and 4 include a passive filter and an active shunt filter, respectively, and are developed in the MATLAB/Simulink environment.

### 3.2.5 ATBU combined load model

The parameters shown in Table 2 were collected based on the historical data of the ATBU engineering complex and converted into a constant load model using formula (2).

$$Z = \frac{V^2}{P - jQ} \quad \dots (2)$$

Where:

Z— Impedance,  $V$ — System voltage (volts),  $P$  Effective power (kW).

**Table 1: ATBU (Farmer) Project Substation 200 kVA, 11/415 V.**

Measurement scenario	Real power (kilowatt)	Reactive power (kilowatt)	Voltage (kilovolts)	impedance Omega
Phase A	36.57	7.28	0.4430	0.0052+j0.0010
Phase B	37.11	7.41	0.4328	0.0051+j0.0010
Stage C	38.27	7.72	0.4436	0.0049+j0.0010

The impedance values obtained from Table 1 are then converted into resistance R and inductance L, which are then converted into the simulation model.

## 3.3 Methods

Here we describe in detail the methods used to achieve specific goals and objectives.

### 3.3.1 Improving Power Quality by Bypass Control of Active Power Filters

The active filter control strategy is based on the method proposed by Singh (1999) and is as follows:

**Phase 1:**In the first stage, the required voltage and current signals are detected through current transformers (CTs), current transformers (CTs) and Hall sensors.

**Phase 2:**In the second stage, the compensation command signal is derived from the current or voltage level equations depending on the control strategy and active filter configuration.

**Phase 3:**In the final stage, a pulse width modulation hysteresis control scheme is employed to generate the control signals for the solid-state active filter device.

### 3.3.2 Active Power Shunt Filter

Shunt filters used to improve power quality are implemented using voltage inverters (V1). They can be three-phase or single-phase. V1 is connected to the source resistor via a shunt. Figure 9 shows the design of an active power filter.

It is based on the Clarke transform and the iterative application of the PQ theory outlined in equations (4)–(17).

### 3.3.3 Building an Active Power Shunt Filter Model in MATLAB

Modeling a shunt active power filter (ASPF) is crucial for filter control. This study models a shunt active power filter (a three-phase voltage source inverter) in a stationary 2-φ (α-β) coordinate system. Therefore, the Clarke transformation is used to transform the three-phase quantities (voltage and current vectors) into the α-β coordinate system.

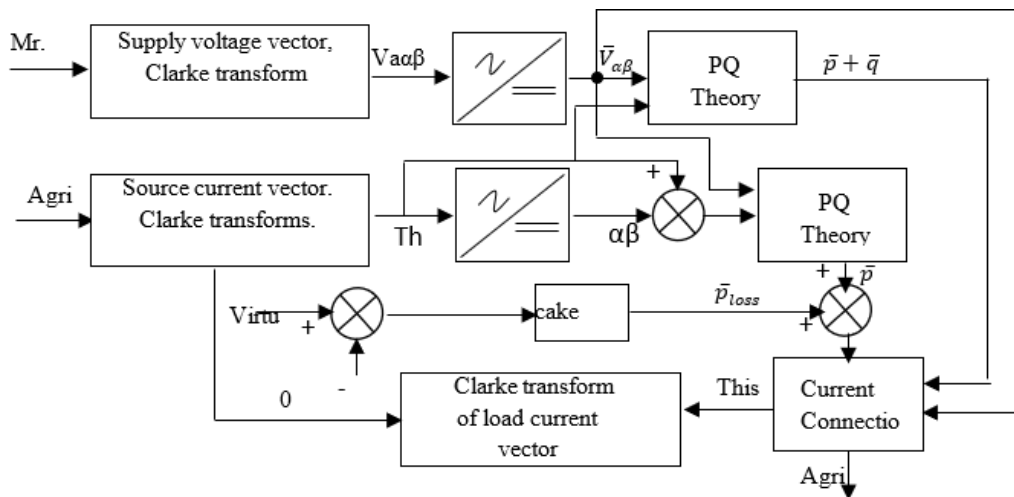


Figure 9: Design of active shunt filter based on instantaneous reactive power control.

In a three-wire 3-φ system, the voltage and current vectors are expressed by equations (3) and (3), respectively.

$$v_{abc} = [v_a v_b v_c]^T \quad \dots (3)$$

$$i_{abc} = [i_a i_b i_c]^T \quad \dots (4)$$

Here, the voltage and current vectors are transformed into two-phase systems using Clarke transformation matrices, as shown in Equations (5) and (6), respectively.

$$\begin{bmatrix} v_\alpha \\ v_\beta \\ v_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ \sqrt{2}/2 & \sqrt{2}/2 & \sqrt{2}/2 \end{bmatrix} \begin{bmatrix} v_{La} \\ v_{Lb} \\ v_{Lc} \end{bmatrix} \quad \dots (5)$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \\ i_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ \sqrt{2}/2 & \sqrt{2}/2 & \sqrt{2}/2 \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \quad \dots (6)$$

Therefore, the instantaneous value of active power in the 0- $\alpha$ - $\beta$  coordinate system can be calculated according to formula (8).

$$p + p_0 = (v_\alpha i_\alpha + v_\beta i_\beta) + v_0 i_0 \quad \dots (7)$$

In formula (8),  $v_0$  and  $i_0$  represent the voltage and current of the image component, respectively. Multiplying these two values yields the power  $p_0$  of the image component. Therefore, formula (7) can be rewritten as formula (8).

$$p_{3\phi} = p + p_0 \quad \dots (8)$$

Where  $p$  is the instantaneous active power, expressed as:

Power can be expressed as a vector real number through the dot product. Therefore, active power can be expressed in vector form as shown in formula (9).

$$\bar{P} = \bar{i}_{\alpha\beta}^T \cdot \bar{V}_{\alpha\beta} \quad \dots (9)$$

Here, the current vector transposed into the  $\alpha$ - $\beta$  coordinate system is the voltage vector in the  $\alpha$ - $\beta$  coordinate system, which is given by equations (10) and (11), respectively.

$$\bar{i}_{\alpha\beta} = [i_\alpha \ i_\beta \ 0]^T \quad \dots (10)$$

$$\bar{v}_{\alpha\beta} = [v_\alpha \ v_\beta \ 0]^T \quad \dots (11)$$

In a three-phase three-wire system, the Miller component power is zero, so the  $p_0$  term in formula (9) can be ignored. The instantaneous imaginary power can be calculated according to formula (13) as follows:

$$q = (v_\alpha i_\beta - v_\beta i_\alpha) \quad \dots (12)$$

Equation (13) can be expressed in vector form as Equation (13).

$$\bar{q} = \bar{i}_{\alpha\beta\perp}^T \cdot \bar{V}_{\alpha\beta} \quad \dots (13)$$

Where:

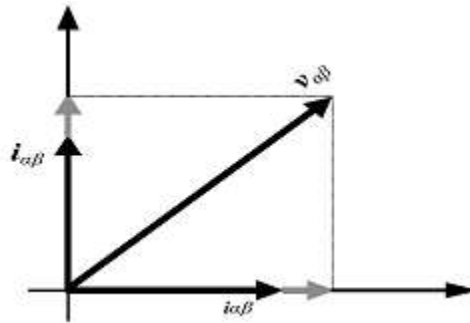
$\bar{i}_{\alpha\beta\perp}$ — The transposed current vector is perpendicular and is given by equation (14).

$$\bar{i}_{\alpha\beta\perp} = [i_\beta \ -i_\alpha]^T \quad \dots (14)$$

The instantaneous active power and reactive power of formula (12) and formula (13) can be expressed in matrix form as formula (14).

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} \bar{i}_{\alpha\beta}^T \\ \bar{i}_{\alpha\beta\perp}^T \end{bmatrix} \bar{v}_{\alpha\beta} \quad \dots (14)$$

As shown in Figure 10, the voltage vector can be resolved as an orthogonal projection onto the current vector axis.



**Figure 10: Stress vector decomposition.**

Using the current vector and the real and imaginary instantaneous powers, the voltage vector can be expressed as Equation (15).

$$\bar{v}_{\alpha\beta} = \frac{P}{|\bar{i}_{\alpha\beta}|^2} \bar{i}_{\alpha\beta} + \frac{q}{|\bar{i}_{\alpha\beta}|^2} \bar{i}_{\alpha\beta\perp} \quad \dots (15)$$

For a three-phase four-wire system, an additional term corresponding to the zero-phase component of the current is added to equation (15).

### 3.3.4 Control Strategy

The block diagram in Figure 11 illustrates this control strategy. The shunt power filter (APF) must control the injected current to compensate for harmonics in the system and improve power quality. To achieve this, the APF's output voltage must be controlled. To do this, a reference voltage is first generated. This reference voltage, when injected into the APF, achieves the desired output voltage. Next, a PI controller regulates the actual output voltage of the APF connected to the shunt filter, ensuring that the resulting output voltage equals the reference value. The overall block diagram of this control strategy is shown in Figure 11.

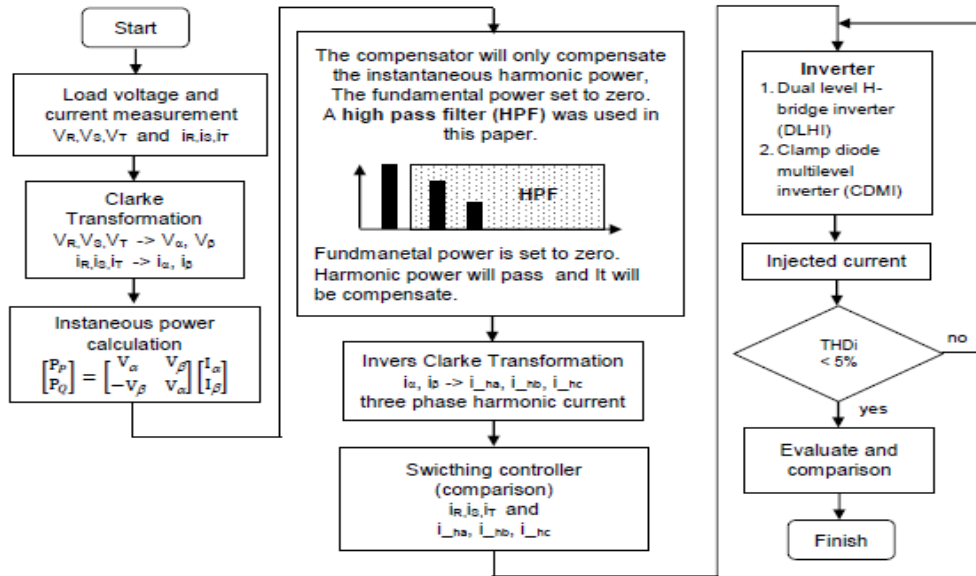


Figure 71: SAPF control strategy implementation flow chart.

Based on the PQ theory, a shunt active power filter (APF) was designed, combined with a high-pass filter (HPF) to compensate for current harmonics, as shown in Figure 11. This APF was applied to a 220 V, 50 Hz three-phase power system. Based on this approach, a nonlinear load system was designed using MATLAB/SIMULINK.

### 3.3.5 Implementing Active Power Shunt Filters Using MATLAB/Simulink

The implementation of the model equations (2)–(15) is done in the MATLAB/Simulink environment, as shown in Figure 12. This is expected to improve the power quality of the PCC network, which is the logic subroutine in the M-file code.

#### 3.3.5.1 Shunt active power control

In this study, we employed a system topology based on the methodology developed by Adam et al. (2011) that encompasses the characteristics of the power system, distribution lines, and load devices. The goal was to validate the current research methodology and apply it to the Advanced Utility Unit (ATBU) research system. Table 3 shows the data for the system used.

Table 2: Power System Data for Active Shunt Filter Design.

Load Balancing		Unbalanced load		Source Features	Voltage
Resistive load	30 ohms	resistance Load (Ra)	50 ohms	Single-phase voltage source <i>X 3 sets of</i>	220 volts
Inductive load	30 meters <i>H</i>	Capacitive load (Ca)	1000 $\mu F$	rupee	0.01 ohm
		resistance Load (Rb)	50 ohms	LS	10 microhenries
		Inductive	20	System frequency	50 Hz

		load (Lb)	millihenries		
		resistance Load (Rc)	50 ohms		

Source: Adam et al. (2011)

**RESULTS AND DISCUSSION**

**4.2 Historical data on the quality of the ATBU engineering complex.**

The power quality data collected by the ATBU engineering complex are presented.

Tables 3 through 5 show the historical power quality data collected by the Fluke 435 II and recorded as log data.

**Table 3: Historical power quality data summary, and Historical data on power quality of the ATBU engineering complex.**

Serial number	PQ data	sample	Counter settings (Fluke 430)	Serial number	PQ data	sample	Meter Setup (Fluke 430 Series II)
				1	<i>continue</i>		6 hours
1	continue		8 hours	2	Rated voltage		230 volts
2	Rated voltage		230 volts	3	Rated current		1A
3	Rated current		300A	4	Nominal frequency		50 Hz
4	Nominal frequency		50 Hz	5	RMS record count		1785
5	RMS record count		2878	6	Frequency		1785
				7	<i>Number of Harmonies</i>		1785
6	Frequency records		2878	8	Number of electricity records		1785
7	Unbalanced number of records		2878	9	Record energy figures		1785
8	Number of electricity records		2878	10	Number of flashing entries		1785
9	Record energy figures		2878	11	Number of screens		1

*Sauce:* ATBU project integrated power distribution network

**Table 4: ATBU PQ Engineered Composites Historical Data.**

Parameter	Phase A	Phase B	Stage C
	<i>Minimum</i>	average	Maximum
Phase-to-phase voltage RMS (V)	443.01	432.8	443.6
Current (A)	147.3	149.6	154.3
Frequency (Hz)	50,391	50,407	50.4
Total harmonic distortion (V%)	1.65	1.67	1.79
Kenny (A%)	6	6.12	6:35
KA coefficient	1.06	1.07	1.07
activation energy		105	
Reaction energy		21VARCH	
Apparent energy		107 Bar	
Active power	36.52 kW	37.11 kilowatts	38.27 kilowatts
Harmonic distortion	0	1.93 kVA	2.64 kVA
Reactive power	7.28 kg bar	7.41 kg bar	7.72 kg bar
Power Factor	0.98	0.98	0.98

*Sauce:* Historical data on the power quality of the ATBU engineering complex

Tables 3-5 provide an interesting overview of the storage library's power quality (PQ) data. While a 6–8-hour period is suitable for power quality studies, longer periods can also be used to detect intermittent issues. The loggers generated a consistent number of records for all metrics, indicating good synchronization of monitoring events. The number of data points in Tables 5 and 6 is 2,878 and 1,785, respectively. Data consistency is crucial for consistent power quality analysis. Table 7 contains the following key findings:

The three-phase system operates efficiently with stable phase-to-phase voltages and steady currents, reflecting good load distribution. Operating frequency is near the standard 50 Hz, ensuring high power quality. Voltage total harmonic distortion (THD) is low, but current THD exceeds 5%, indicating a need for monitoring and potential harmonic filtering. A low K-factor implies minimal transformer overheating risk, and power factor measurements show efficient energy use at 0.98. This system demonstrates effective performance and stability, though current harmonic levels require attention for sensitive equipment reliability.

#### 4.2.2 Waveform Past PQ data

Figures 17-20 show waveforms obtained from historical power quality (PQ) harmonic distortion data from ATBU Engineering. Figures 12, 13, 14, and 15 show the detected power factor (PF) and total harmonic distortion (THD) (1st, 3rd, and 5th THD, respectively). They also display the 3rd, 5th, 7th, and 9th harmonics and THD for all three phases over an 8-hour period. Eight composite graphs are shown, covering the A, B, C, and neutral voltages. The

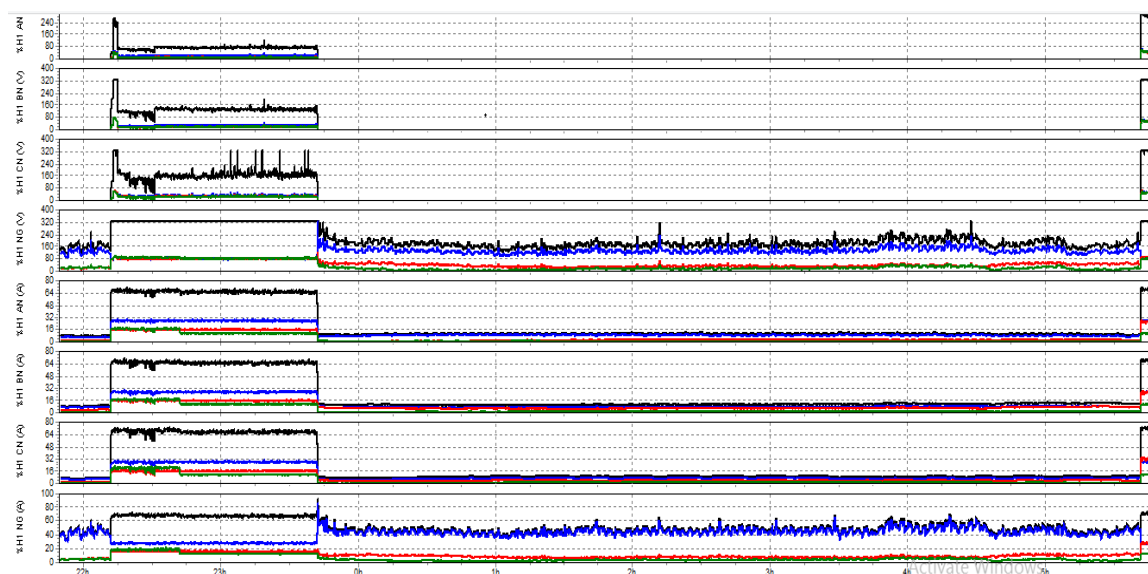
collected data shows that the PQ values remained fairly stable, with only sharp increases at approximately 4 and 7.5 hours.

The blue color on the waveform represents the third harmonic, the red color represents the fifth harmonic, the green color represents the seventh harmonic, and the black color represents the total harmonic distortion (THD).



**Figure 128: Power factor index (Historical data from the ATBU PQ Engineering Complex)**

The power factor values above show that there were five hours without power during the day, and nearly six hours with a power factor close to 1. This indicates that there are more stable devices or loads in the distribution network of the ATBU engineering complex.



**Figure 13: THD index (Historical power quality data from the ATBU engineering complex)**

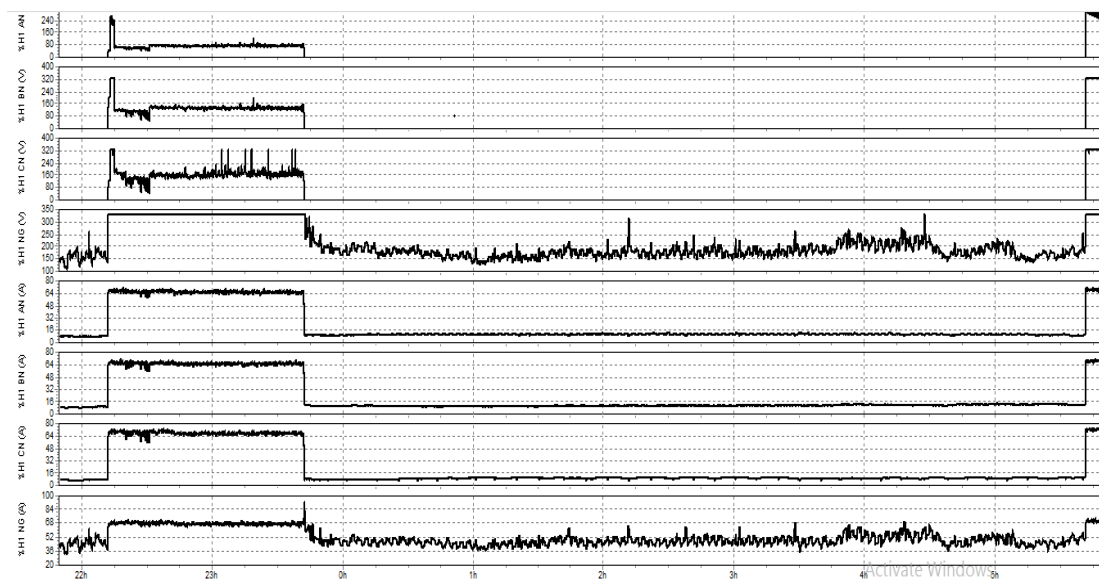


Figure 14: THD index (ATBU Engineering Complex power quality historical data).

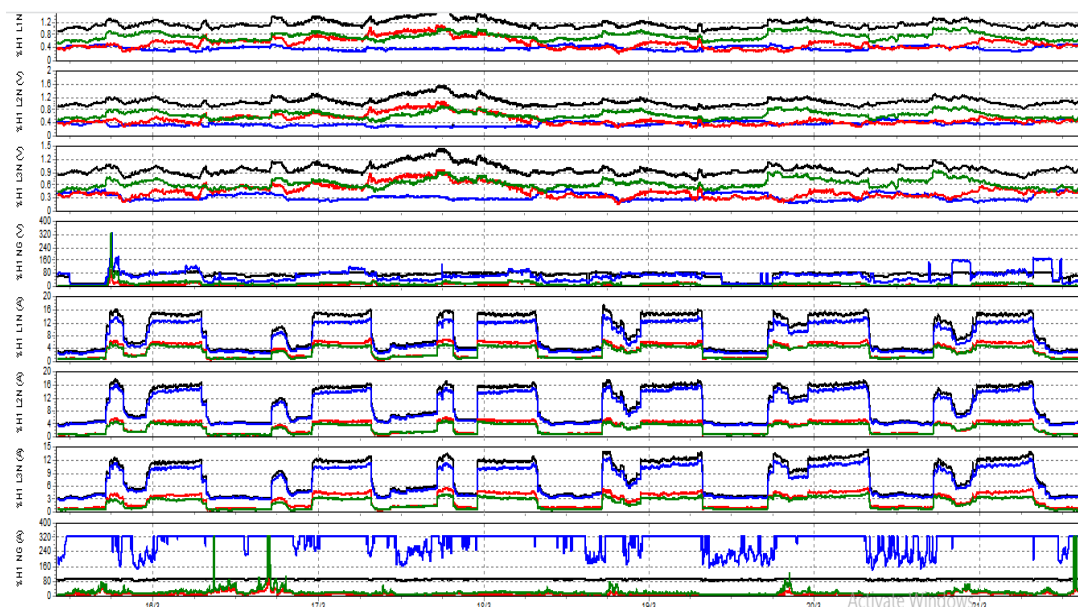


Figure 15: The THD index (Historical data on the quality of the ATBU engineering complex)

### 4.3. Engineering Combined Load Model (ECLM)

The parameters shown in Table 7 were collected from historical data of the Bauchi ATBU Engineering Complex and converted to a constant load model using equation (3) and the impedance series shown in Table 8.  $Z \Omega$

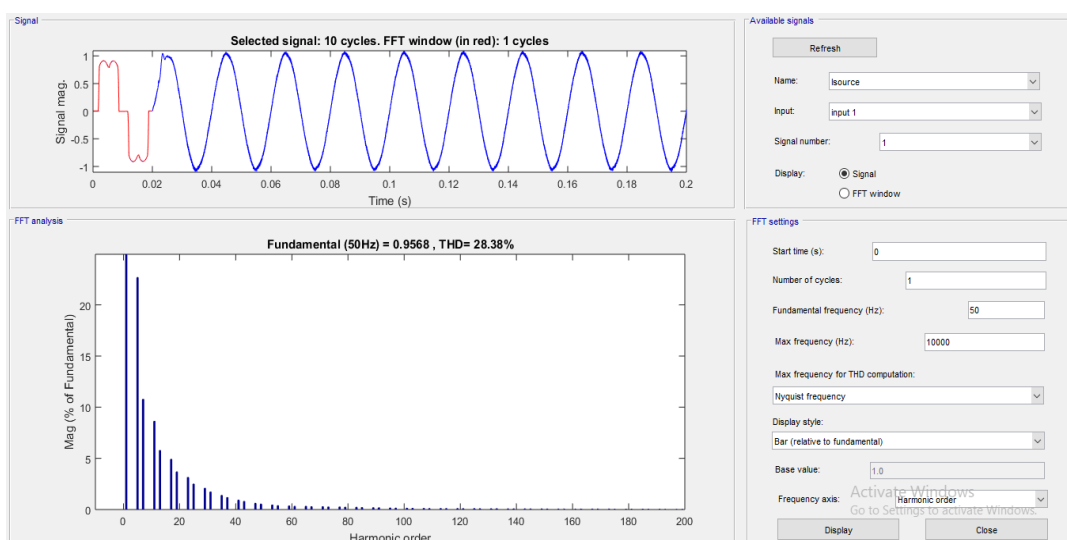
**Table 5: ATBU, Bauchi, Engineering Complex System Resistance, 200 kVA, 11/415 V.**

Measurement scenario	Effective power (kW)	Reactive power (Thousands of pounds) of	Voltage (kV)	Impedance $\Omega$
Substation (Phase A)	36.57	7.28	0.4430	0.0052+j0.0010
Substation (Phase B)	37.11	7.41	0.4328	0.0051+j0.0010
Substation (Phase C)	38.27	7.72	44,360	0.0049+j0.0010

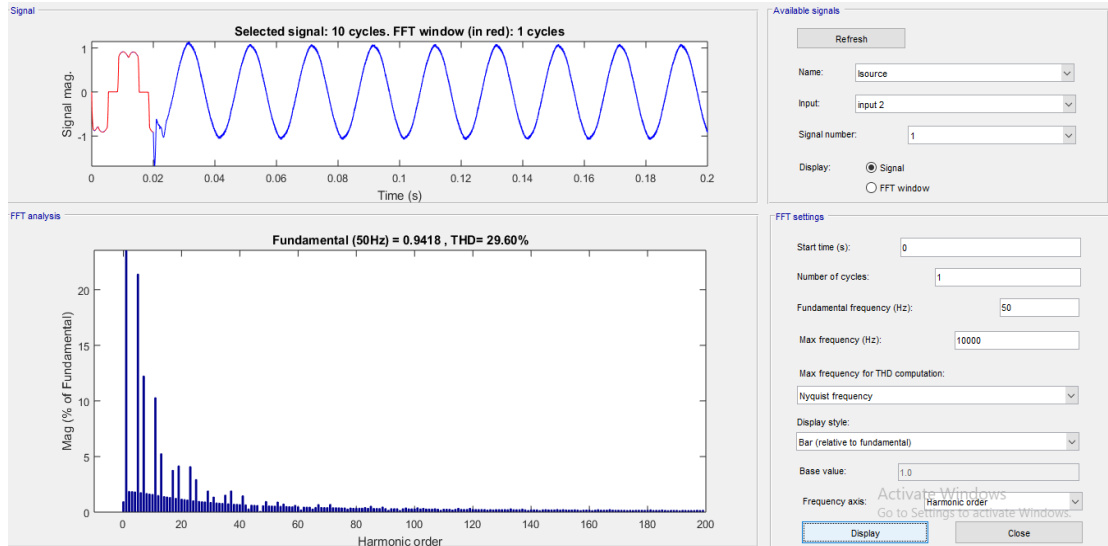
Then, the model Eqn. (3) was converted into resistive  $R$  and inductive  $L$  which was inserted into Simulink model.

#### 4.4 Simulation of the Power Systems Using Shunt Active Filter

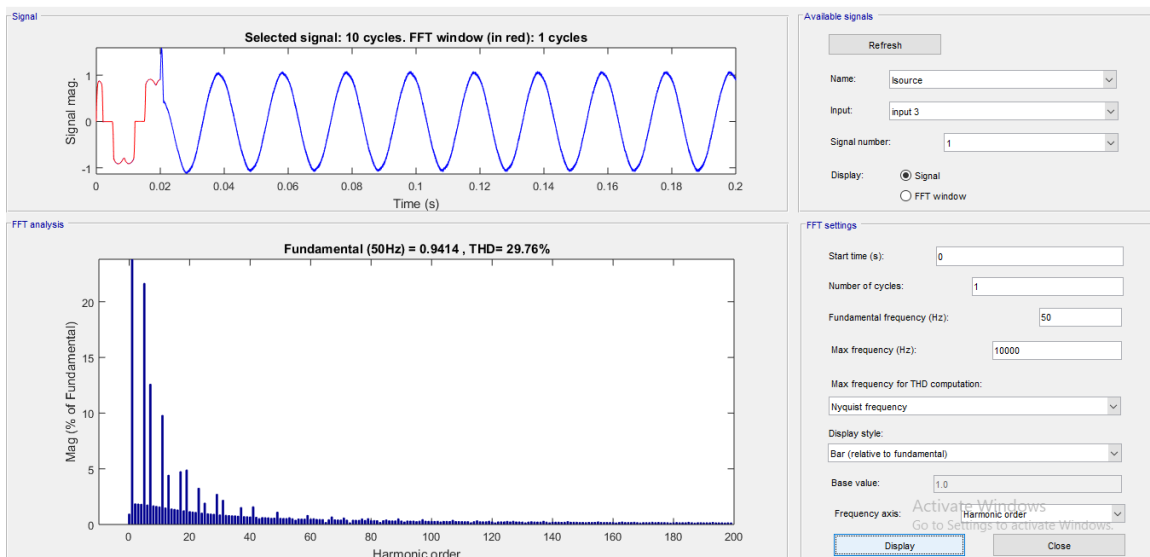
Figures 21 to 24 show the simulation results obtained in the harmonic distortion analysis of the load current, without shunt active filter. FFT analysis and waveform plots of the source current for Phases A, B and C current with/without the filter are shown from Figures 16 to 18. In Figures 16 and 17, phases A, B and C have THD of 28.83%, 29.6% and 29.76% respectively without filter. These are extremely high over the recommended limits of 5%. Figure 20 shows the load current waveform with/without filter for



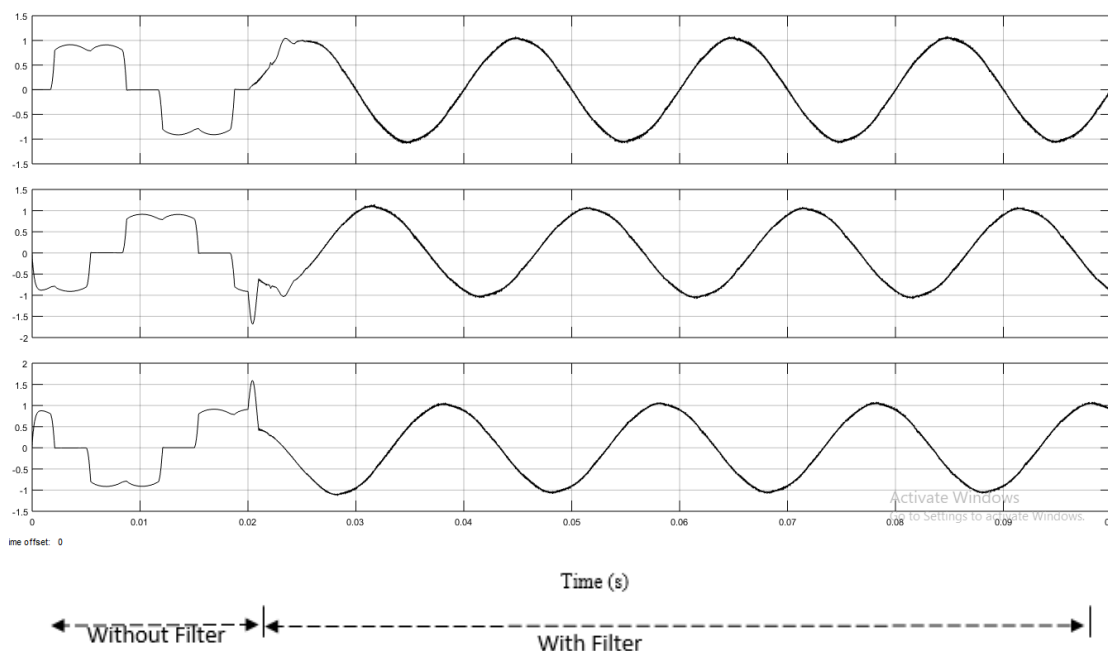
**Figure 179: FFT Analysis of source current: Phase A without filter, THD =28.83%, fundamental current= 0.9568 A.**



**Figure 1810: FFT Analysis of Source Current of Phase B without filter, THD= 29.60%, fundamental current= 0.9418 A.**



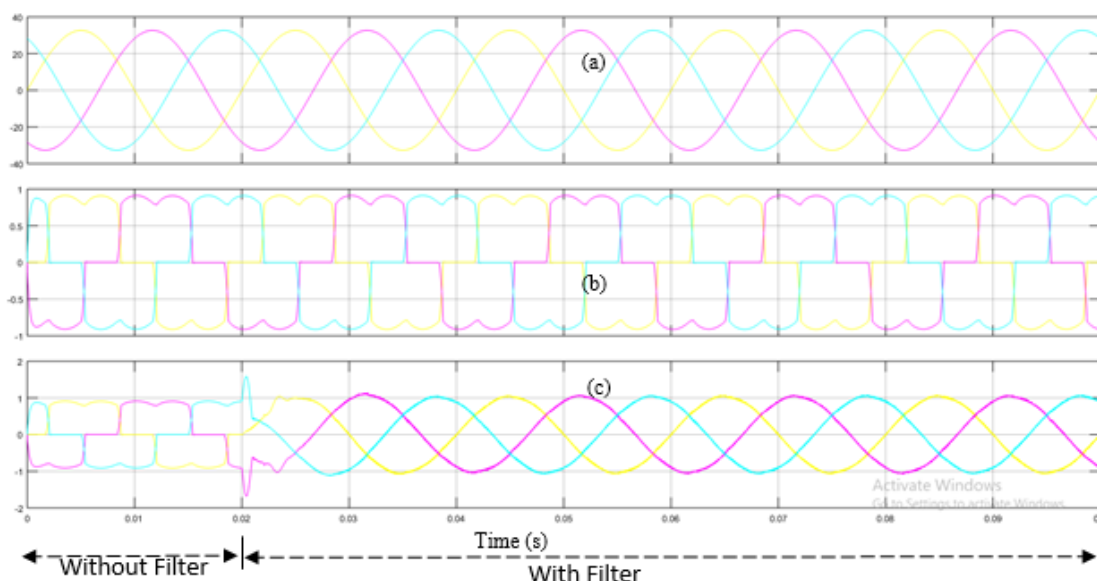
**Figure 19: FFT Analysis of Source Current of Phase C without filter, THD= 29.76%, fundamental current= 0.9414 A**



**Figure 20: Waveform plots of Phases A, B and C current using unbalanced Resistive Loads with/without filter.**

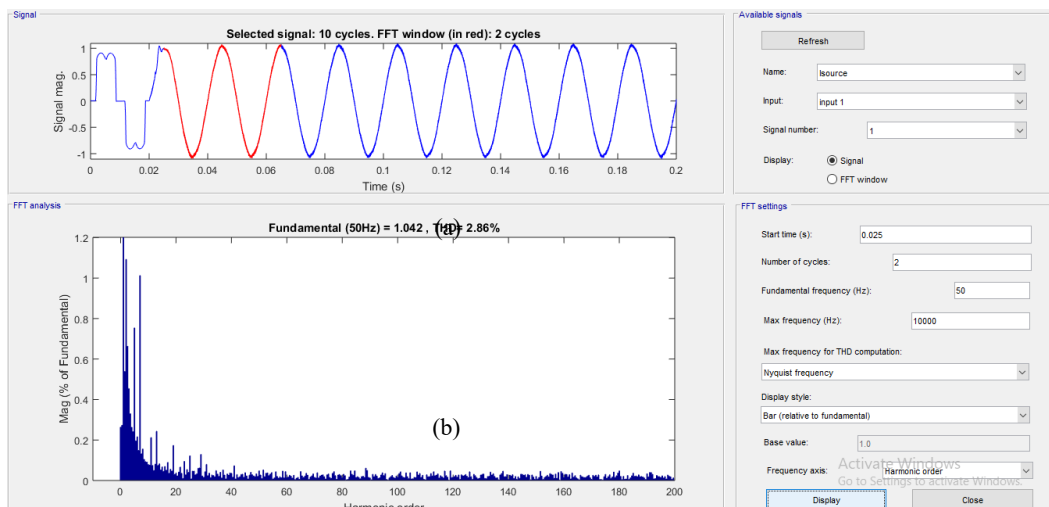
#### 4.5 Simulation of Network with Shunt Active Filter

Figures 25 through 34 illustrate the simulation results obtained from the harmonic distortion analysis of the system incorporating a shunt active filter. Figure 25 illustrate the load voltage and current waveforms as well as source current for Phases A, B, and C with/without the filter put in place, under both nonlinear and unbalanced linear load conditions.

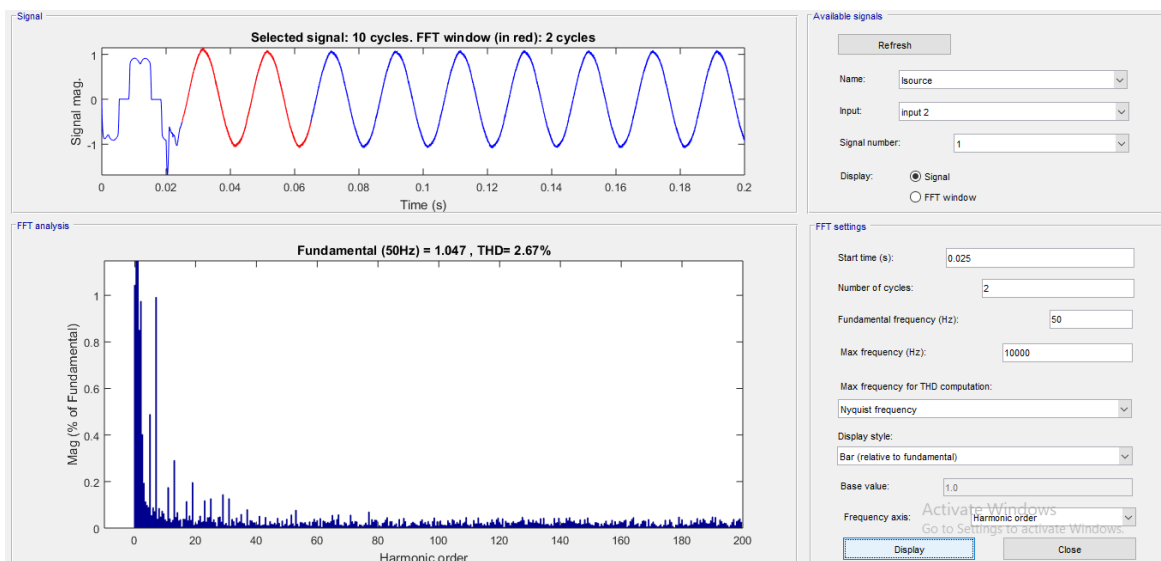


**Figure 21: Waveform plots (a) load voltage of phases A,B and C (b) Load current (c) Source current with/without filter.**

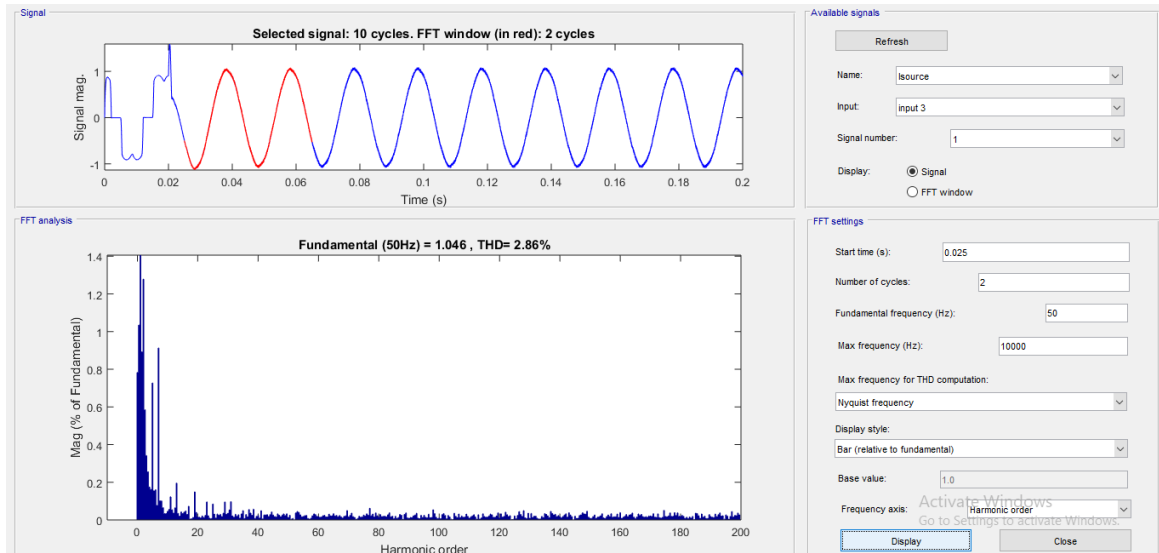
The results also include FFT analyses as well as waveform plots for the window portion of the signal analyzed with FFT tool of the Graphical user interface (GUI). Recall that, without the filter, Phases A, B and C exhibited Total Harmonic Distortion (THD) levels of 28.83%, 29.60% and 29.76%, respectively. These levels are significantly higher than the recommended limit of 5%. However, with the application of a shunt active filter, the THD was effectively reduced to 2.83%, 2.67% and 2.86% for Phases A, B and C, demonstrating substantial improvement in harmonic mitigation. Figures 22 to 30 show the FFT window and the results for phases A, B and C.



**Figure 22: FFT Analysis of source current: Phase A without filter, THD =2.83% fundamental current= 1.042 A.**



**Figure 23: FFT Analysis of source current: Phase B with filter, THD =2.67% fundamental current= 1.047 A**



**Figure 24: FFT Analysis of source current: Phase B with filter, THD =2.86% fundamental current= 1.046 A.**

Table 6 presents the summary of percent improvement with the application of SAPF for mitigation.

**Table 6: Improvement in Mitigation with SAPF.**

Phase	THD (%) without SAPF	THD (%) with SAPF	Percent improvement
PHASE A	28.83	2.83	90.18
PHASE B	29.6	2.67	90.98
PHASE C	29.76	2.86	90.39

#### 4.6 SAPF Performance for Balanced/Unbalanced Load with 3-phase Bridge Rectifier

It is intended in this section to comparatively study the performance of the designed shunt active filter under different types of balanced and unbalanced loads having a nonlinear load of 3-phase full bridge rectifier.

##### 4.6.1 Harmonics of Composite non-linear and unbalanced linear loads

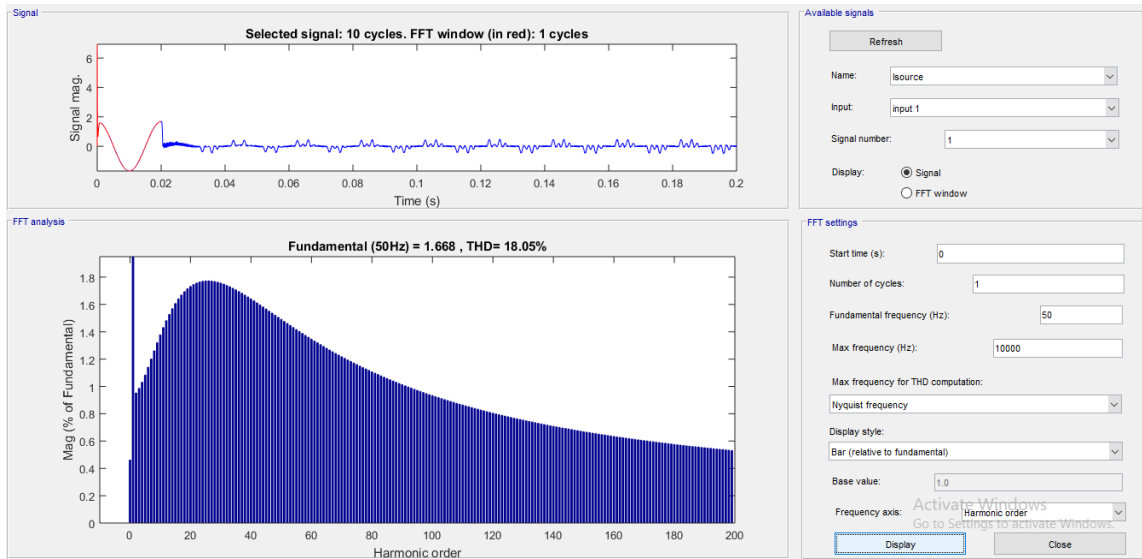
The previous section presents the impact of 3-phase bridge rectifier RL loads excluding the linear loads connection. This subsection considered the composite of non-linear and unbalanced linear loads. Although, the breaker helps in the selection of the desirable loads for analytical purposes, yet it creates switching transient current which might contribute in aggravating the harmonic distortion. The load parameters are presented in Table 10 as well as useful comments of the results. It is apparent from the results that when there is no harmonic producing load, the returned high THD. The THD obtained are 18.05% and 96.33% for RC load (scenarios 1 and 2) respectively. Similarly, for RL load (scenarios 3 and 4), with non-

linear load switched off, THD obtained are 15.84% and 9.61% respectively. These distortions are coming from the breaker switching transient. In the case of scenario 2, which recorded higher THD when there is filter could be attributed to additive of harmonic components, while for scenario 4, there could be high probability of harmonic phasor components cancellation.

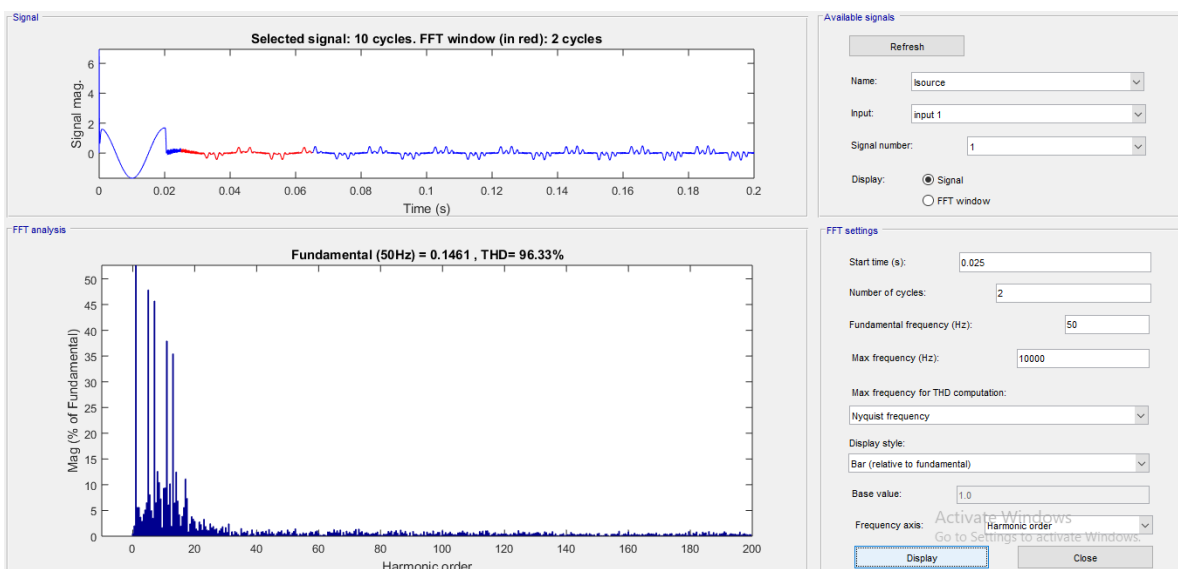
By engaging both non-linear and unbalanced linear loads, the THD normalizes to steady state values. The THDs are found higher when the filter is disconnected but would be set within the IEEE 519-2014 limits when the filter is engaged. This is apparent in scenarios 5 to 8.

**Table 71: Load Models of the Shunt Active Filter.**

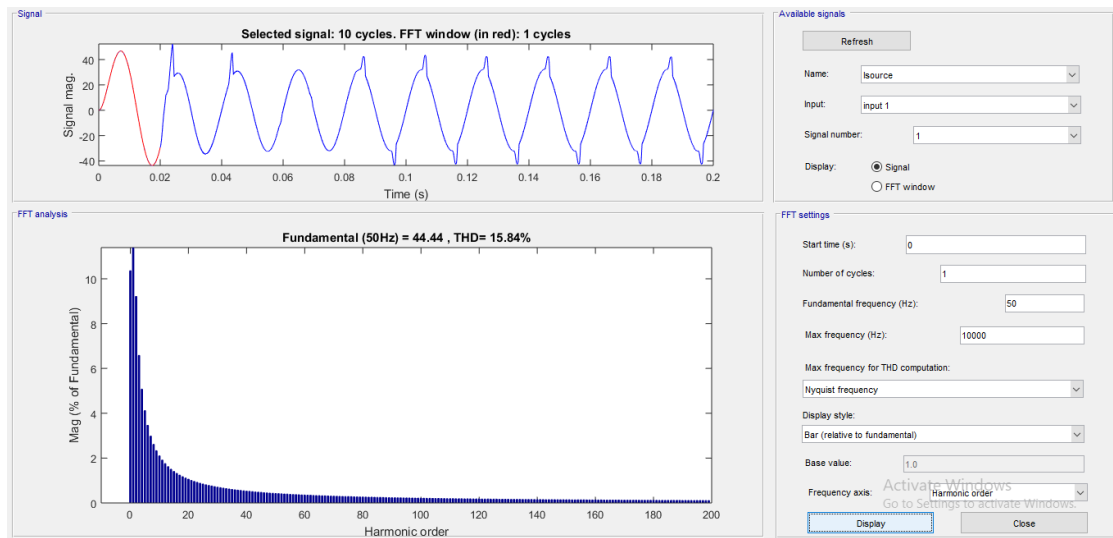
Scenario	Non-linear Load 3-phase Bridge Rectifier/Load		Linear Load		Linear Load		Comment
	R ( $\Omega$ )	L(mH)	R( $\Omega$ )	C( $\mu$ F)	R( $\Omega$ )	L (mH)	
1	-	-	2, 4, 6	10	-	-	Without filter THD: 18.05% due breaker switching harmonic transient
2	-	-	2, 4, 6	10	-	-	With filter, high THD, due to additive harmonic components
3	2, 4, 6	10			-	-	Without filter high THD due breaker switching harmonic transient
4	-	-	2, 4, 6	10	-	-	Filter reduces THD due to harmonic phasor cancellation
5	60	30	2, 4, 6	10	-	-	Without filter THD: 27.98%
6	60	30	2, 4, 6	10	-	-	With filter THD: 5.551%
7	60	30	-	-	2, 4, 6	10	Without filter THD =14.05%
8	60	30	-	-	2, 4, 6	10	With filter THD =4.57%



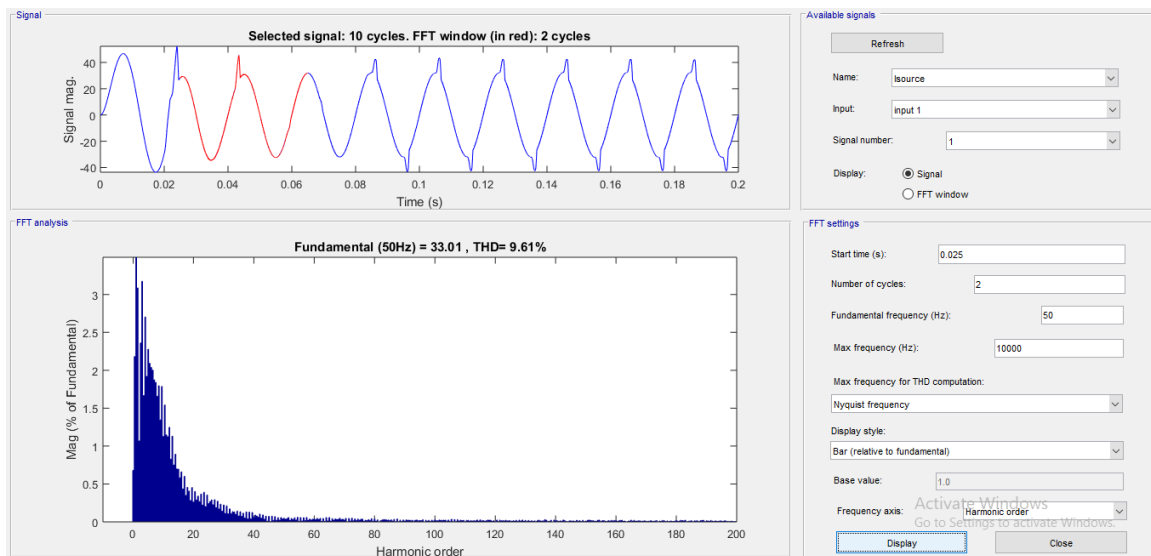
**Figure 25: FFT Analysis of source current: Phase A, THD =18.05% fundamental current= 1.668 A (Transient harmonics) without filter (Scenario 1)**



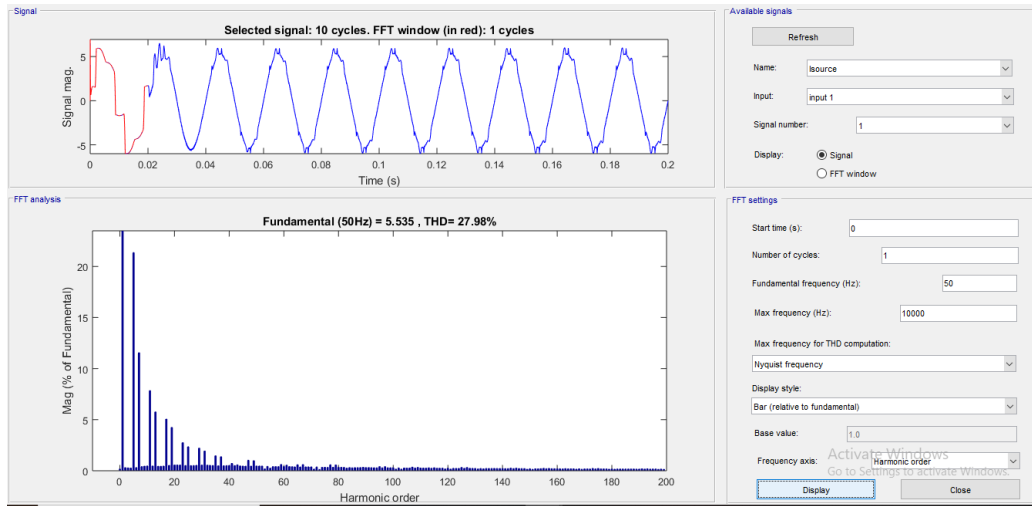
**Figure 26: FFT Analysis of source current: Phase A, THD =96.33% fundamental current= 0.146 A (Transient harmonics) with filter (Scenario 2)**



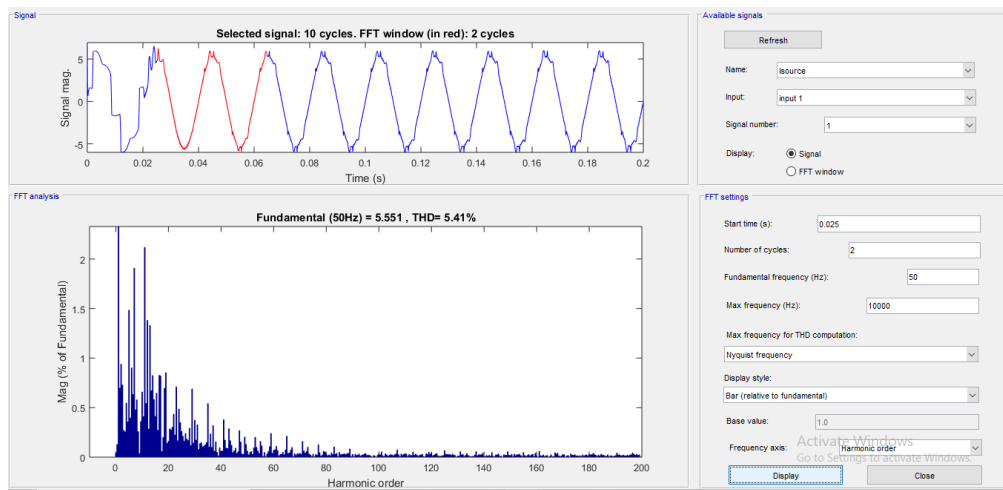
**Figure 27: FFT Analysis of source current: Phase A THD =15.84% fundamental current= 44.44 A (Transient Harmonics) without SAPF(Scenario 3)**



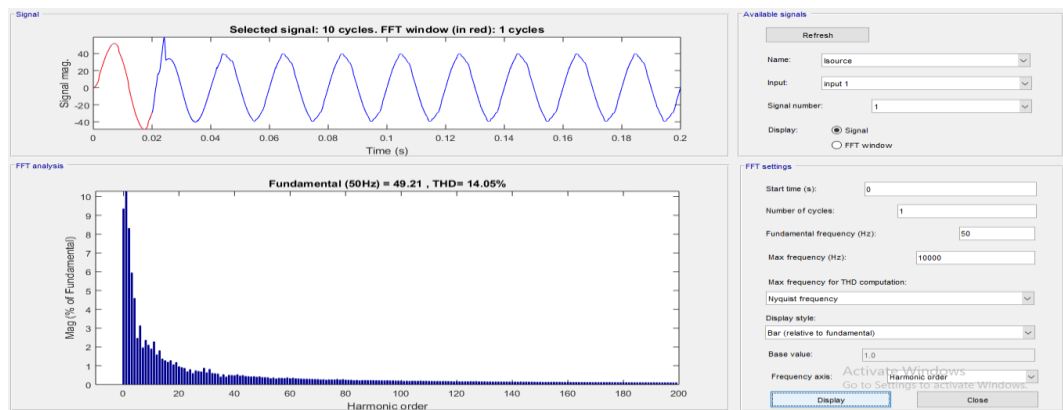
**Figure 28: FFT Analysis of source current: Phase A, THD =9.61% fundamental current= 33.01 A (Transient harmonics) with SAPF(Scenario 4)**



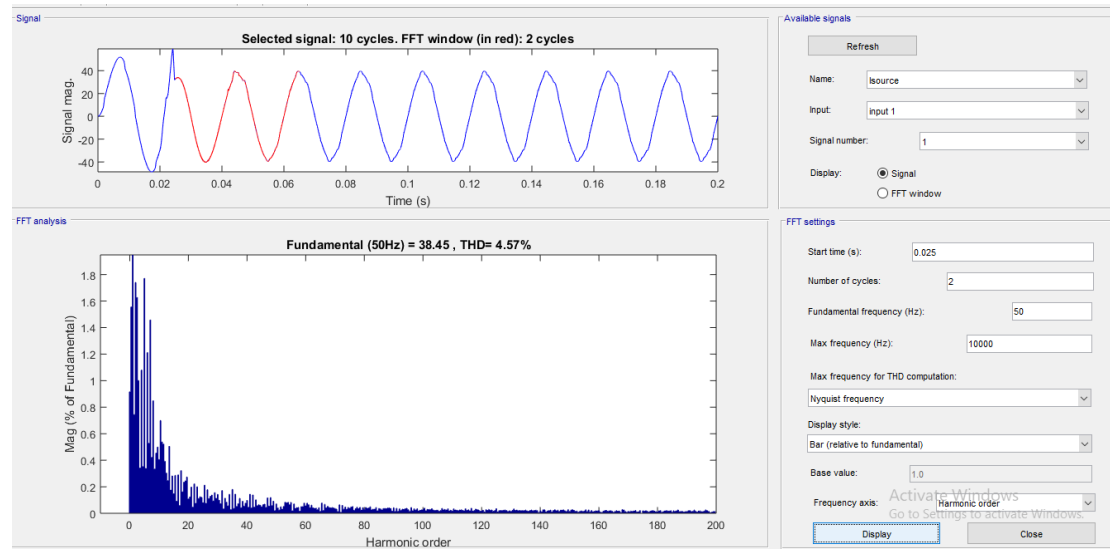
**Figure 29: FFT Analysis of source current: Phase A, THD =27.98% fundamental current= 5.335 A without filter(Scenario 5)**



**Figure 30: FFT Analysis of source current: Phase A, THD =5.41% fundamental current= 5.551 A withfilter (Scenario 6)**



**Figure 31: FFT Analysis of source current: Phase A, THD =14.05% fundamental current= 48.21 A without SAPF(Scenario 7)**



**Figure 32: FFT Analysis of source current: Phase A, THD =4.57% fundamental current= 38.45 A withSAPF (Scenario 8)**

## CONCLUSION

Based on the objectives set forth in this research, the following are the conclusion drawn for the outcomes of the work:

The ATBU Engineering Complex PQ data produced uniform number of recordings across all metrics showing there was good synchronization in the monitored events. The data uniformity is crucial for coherent PQ analysis.

1. The recorder captured minimum, average and maximum voltage. Voltage across phases is relatively well-balanced with minimal variation (~2.5%).
2. Frequencies are very close to the standard 50 Hz, indicating good supply stability.
3. Voltage THD is low but current THD is slightly above the commonly recommended limit of 5%, which might need monitoring or filtering depending on the system sensitivity.
4. RL loads in residential, commercial and industrial distribution systems. Notice, that the study system, ATBU, Bauchi is an educational set-up that has workshops, and laboratories where there are myriads of experimental modules of electric motors, pumps and ICT equipment. Thus, Abubakar Tafawa Balewa University, Bauchi might be categorized as commercial distribution system. The waveform with RL is highly distorted as observed.
5. The current injected by SAPF compensates for the load current harmonics.

6. The SAPF achieved harmonic reduction because there is an improvement in the designed SAPF performance by 90%.
7. The composite loads used in the network give rise to transient harmonics, even though have lower magnitude but could be the source of higher THD over broadband.
8. The SAPF significantly reduces the THD within the 5% recommended limits.

## REFERENCES

1. Afshin, B., Dinkhah, S., Shahabi, F., Herrera, M., & Yao Lung Chuang, Y.L. (2022). A review on multilevel inverter topologies. *Emerging Science Journal*. 185-200.
2. Al-Gahtani, S.F., Elbarbary, Z.M.S., & Irshad, S.M. (2024). IA Developed DQ Control Method for Shunt Active Power Filter to Improve Power Quality In Transformers. *doi:journal.pone.0299635*
3. Bhattacharya, S. & Dewangan, V. (2017). Improvement Of Power Quality Using Multilevel Inverter Based Shunt Active Power Filter. *International Journal Of Engineering Sciences & Research Technology*. 6(3)
4. Bhukya, A. & Koley, C. (2017). A Comparative Study on Multilevel Inverters for Shunt Active Power Filter. *International Journal of Engineering and Management Research*.
5. Boukadoum, A., Bouguerme & Bahi, T. (2023). Performance Improvement Of Shunt Active Power Filter With Voltage Sensor Failure. *International Journal Of Energistica (IJECA)*. pp 38-43
6. Das, N. & Mude, S. (2017). Power Quality Improvement of Three Phase System using Shunt Active Power Filter. *International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering*.
7. Ghoudelbourk, S., Azar, A. T., & Dib, D. (2021). Three-level (NPC) Shunt Active Power filter Based on fuzzy Logic And Fractional-order PI Controller. *International Journal of Automation and Control*. 15(2), 149-169.
8. Khan, M.A. & Awale, R.N. (2022). Fuzzy Based Power Quality Improvement using Active Power Filter. *International Journal of Research Publication and Reviews*. pp 3225-3236
9. Krishna, D., M. Sasikala, & V. Ganesh, V. (2022). Adaptive FLC-based UPQC in Distribution Power Systems for Power Quality Problems. *International Journal of Ambient Energy*. 1719–1729.
10. Krishna, D., M. Sasikala, & Ganesh, V. (2019). Fractional Order Fuzzy Logic Based UPQC For improvement of Power Quality in Distribution Power System. *International Journal of Recent Technology and Engineering (IJRTE)*. 1405–1410.

11. Krishna, D., M. Sasikala, M., & Kiranmayi, R. (2022). FOPI and FOFL Controller Based UPQC for Mitigation of Power Quality Problems in Distribution Power System. *Journal of Electrical Engineering & Technology*. 1543–1554.
12. Muhammad, A., & Awale, R. N., (2022). Fuzzy Based Power Quality Improvement using Active Power Filter. *International Journal of Research Publication and Reviews*. pp 3225-3236.
13. Narkhede, K. M., Harkut, A. V., & Jawale, P. R. (2021). Improvement of Power Quality using Shunt Active Power Filter. *International Journal of Creative Research Thoughts (IJCRT)* 2320-2882
14. Nemmad, J. i & Manjula, M. (2023) Shunt Active Power Filter For Power Quality Enhancement Of Distribution In Power System Using Fuzzy Logic Controller In Second International Conference On Emerging Trends In Engineering (ICET) (pp. 548-556) Atlantis Press.
15. Ravinder, K., Bansal, H. O., & Agrawal, H. P. (2019). Development of fuzzy logic controller for photovoltaic integrated shunt active power filter. *Journal of Intelligent And Fuzzy System*. 6231–6243.
16. Saad, F., Gahtani, A., Elbarbary, Z. M. S., & Shaik, M. I., (2024). A developed DQ Control Method For Shunt Active Power filter To improve Power Quality in Transformer. <https://doi.org/10.1371/journal.pone.0299635>
17. Sah, S. & Rizvi, T. (2019). A Review on Power Quality Improvement using Shunt Active Filter with Multilevel Inverter. *International Research Journal of Engineering and Technology (IRJET)*. 2395-0072
18. Shahbudin, S., Mohamad, Z. F., Suliman, S. I., Kassim, M., & Mohamad, R. (2017). Classification of power quality disturbances at transmission system using support vector machines. *Indonesian Journal of Electrical Engineering and Computer Science*, 6(2), 310-317.
19. Shivam, T., & Durgesh, V., (2018). Shunt Active Power Filter to Enhance Power Quality. (A Review). *International Journal Of Scientific Progress And Research (Ijspr)*. 2349-4689,
20. Suhendar, S., Firmansyah, T., Maulana, A., Zuldag, Z., & Dewanto, V. (2017). Shunt active power filter based on PQ theory with multilevel inverters for harmonic current compensation. *Telkomnika*, 15(4), 1632-1640

21. Tandon,A.K.,Gupta,V.P.&Singh.M.(2023).Shunt Active Power Filter For Power Quality ImprovementAnd Comparative Study With FFT Analysis. *International Research Journal of Modernization in Engineering Technology and Science*. 2582-5208
22. Tiwari,S.&Vishwakarma,D.(2019). Shunt Active Power Filter to Enhance Power Quality. ( A Review). *International JournalOf Scientific Progress And Research (IJSPR)*.
23. Upadhyay,A.&Singh,P.(2020). Power Quality Improvement using Shunt Active Power Filter. *International Journal of Trend in Scientific Research and Development (IJTSRD)*. 2456 – 6470
24. Vinothkumar, V. &Kanimozhi,R.(2022). Power Quality improvement By PV integrated UPQC Using Multi-level inverter With Resilient Back Propagation Neural Network Approach. *Journal of Intelligent & Fuzzy Systems Preprint* . 1–18.
25. Yavari,M.Sayyed,H.E,& Seyed, A.T.(2018). A non-linear controllerdesign for UPQC in distribution systems. *Alexandria engineering journal*.3387-3404.
26. Zaro,F.(2023). Power Quality Improvement Using Shunt Active Power Filter. An Industrial Zone Case Study.*A Journal Of Applied Science And Development*.