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Reduction of Harmonics in Power Lines Using Finite Impulse Response Filter

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This work focused on reduction of harmonics in Power lines using finite impulse response filter. Since the rising usage of power electronic devices sensitive to harmonics, which has resulted in a growth in the number of adverse harmonic-related occurrences, network harmonic investigations have become a major concern in electric power systems. The problem of power quality and how to control it is becoming more of a concern. Power quality difficulties have arisen as a result of the connection of nonlinear loads in the network, resulting in widespread waveform distortion. The harmonic analysis was based on bus bar voltage solutions acquired from a power flow study on the Electricity Distribution Company's power distribution network at the Onitsha TCN work centre. The focus of this work was on the use of active power filter in reducing the harmonics by generating compensation signal by the active filter (APF) for the reduction of harmonic distortion as well as enhancing the system's power factor. A system model to reduce harmonics in power line by using FIR filter to generate compensation signals and switching pulses for the active filter was modeled and the performance of the FIR filter using Matlab/Simulink environment was compared with the performance without filter. The sending and receiving end bus bar voltages were derived from the power flow analysis and used in the simulation. Harmonic results without filter and with filter were shown and it shows that the use of FIR active filter which has improved advantages over the conventional passive filters in mitigating harmonics was able to reduce the harmonics from 17.77% to 0.87% which is 16.9% (95% reduction) thereby improving the current, voltage and power factor

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(pf) of the system. Reduction of harmonics reduced disturbances that usually cause equipment overheating and deterioration of the performance of electronic equipment; hence the performances of the electronic equipment greatly improved leading to economic benefits.

Keywords: Harmonics; filter; frequency; finite impulse; distortion.

1. INTRODUCTION

Advances in technology, particularly the advent of power electronics applications based on semiconductor switches (diode and thyristor rectifiers, electronic starters, UPS and HVDC systems, arc furnaces, and so on) have fetched many technical benefits and cost savings in recent years, but they have also introduced new challenges for power system operation.

Electric energy has become the engine that drives industrialization, technological advancement and socio economic activities, which improve communication, provide sound healthcare delivery system and assist innovation in science and technology [1]. To get the most out of an asset, it's important to keep it safe and dependable. This applies to a variety of areas of power system functioning.

Devices utilized for power conversion, such as power electronic circuitry, are classified as non-linear loads by the electrical transmission system [2].

Because of their non-ideal features, nonlinear elements in power systems create distortion. Nonlinear loads, such as uninterruptible power supplies (UPS), variable frequency drives (VFD), switched mode power supplies and adjustable speed drives (ASD), pose a unique difficulty to delivering high-quality power under all conditions. With the growing number of power electronic systems linked to the mains, supply voltage and current aberrations have become more of a concern [3].

The resonance problem that emerges between the supply inductances and capacitances, resulting in over-currents and over-voltages, is one of the numerous negative repercussions of distorted voltages and currents. Increased I^2Z heat losses in the transformer due to distorted current encourages thermal and mechanical insulation strains. Supply voltage variations caused by rapidly changing or varied industrial loads such as electric arc furnaces, welding machines, alternators, rolling mills, and motors can cause equipment to trip [4]. Alternating current power systems, both voltage and current, are ideally a pure sinusoidal wave, but the existence of non-linear loads alters the voltage and current properties from the ideal sinusoidal wave. Harmonics are a reflection of this divergence. The sinusoidal component of a periodic wave or quantity with a frequency that is an integral multiple of the fundamental frequency is known as harmonics.

However, improvements in the power supply because of the critical function of electricity in our economic lives must be given top consideration.

The purpose of an electrical power system is to generate electrical energy in ample volume at most suitable locality, transmit it in a bulk quality to a load centre, which is then distributed to the individual consumers [5]. Manufacturers have rightfully expressed their concern that any disruption in electricity supply will have a negative impact on their output. Power outages have been reported by residential electricity customers as having an impact on their electrical/electronic appliances. Small and medium-scale electricity customers have confessed that outages are the bane of their firms' smooth operations [6]. To reduce power quality issues, passive power filters (PPF) (combinations of capacitors and inductors) were commonly utilized at first. These techniques were widely utilized to filter harmonics on both the AC and DC sides in high voltage DC transmission (HVDC). This method, however, is ineffective at the distribution level because PPF can only fix certain load circumstances or states of the electrical system. These filters are unable to adapt to changes in the system. To compensate for harmonics and reactive power, the active power filter (APF) was developed [7].

The goal of this project is to employ a finite impulse response (FIR) filter to reduce harmonics distortion in distribution systems by establishing a low Total Harmonics Distortion (THD) value and enhancing the power factor of the system.

1.1 Harmonic (H) in Power Systems

Harmonic problems are not a novel occurrence in the power system (PS). Years ago, transformers were the primary generators of harmonics, and the main issue was inductive disturbance with open-wire telephone networks. Around that period, some previous work on harmonic reduction in distribution lines was done. There has been a significant shift in the application of nonlinear loads in recent years. As a result, the value of harmonic non sinusoidal currents and voltages in the system has increased dramatically. These harmonic factors have an impact on the general Power system as well as the equipment of the client. As a result, sustaining the PQ is a major concern today. Harmonics are described as sinusoidal voltages or currents with frequencies that are entire multiples of the supply system's operating frequency (50 Hz or 60 Hz). Any periodic altered waveform can be described as a summation of pure sinusoids, as shown in Figs. (1) and (2). The harmonic ratio usually refers to the frequency ratio of a harmonic component to the fundamental frequency [8].

Harmonic frequencies are integer multiples of the fundamental frequency of the waveform. The harmonic components of a 60 Hz fundamental waveform, for example, will be at 120 Hz, 180 Hz, 240 Hz, and 300 Hz, respectively. As a result of the aggregate of all these harmonic parts, harmonic distortion is the extent to which a waveform differs significantly from its perfect sinusoidal values [9].

Ripples in the force from the generator prime-mover plus current from the excitation system cause temporal harmonics in the generator flux, which vary in a non-sinusoidal fashion, starting with traditional generation based on rotating machinery. Furthermore, additional harmonics are imparted to the electrical output due to the generator's shape and the spatial distribution of the windings. The harmonic content generated then spreads across the power system to other associated loads [10].

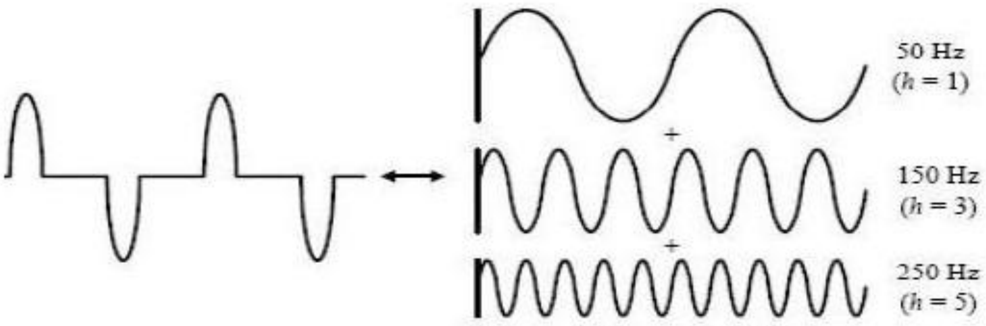

Fig. 1. Waveform with a periodic distorted pattern [8]

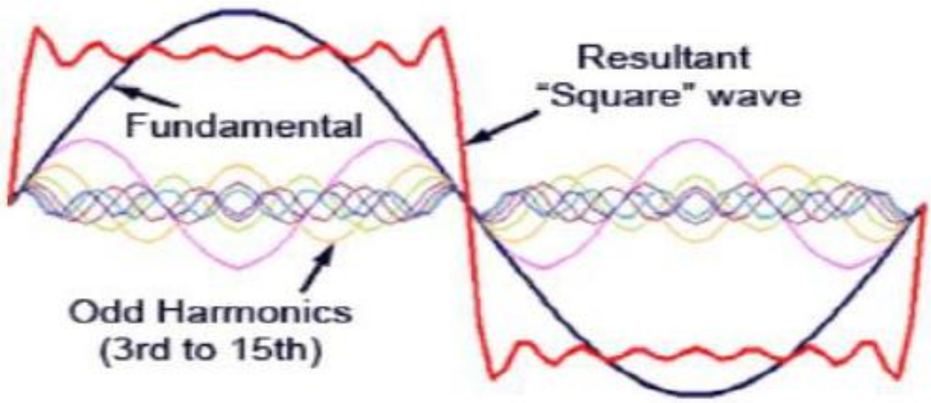

Fig. 2. Waveform with a periodic distorted pattern [8]

2. METHODOLOGY AND DESIGN

2.1 Processes of Achieving Harmonic Reduction

In this research work, finite impulse filter is implemented for removing signal harmonics using Shunt active performance filters to compensate for greater harmonic currents in non-linear loads.

The methods used in achieving the harmonic reduction were the following steps.

1. The data collected from the harmonic measurements from a power quality analyzer that was installed at the source of the distribution feeders were fully studied.
2. The sub models for voltage sags and swell without filter were separately simulated since all three active power filters have same voltage sags swells mitigation sub model.
3. The finite impulse filter model composed of sub models was simulated for harmonic compensation and power factor correction
4. Matlab/Simulink was used to simulate the harmonic compensating sub models combined with power factor correction for the harmonic reduction analysis.

2.2 Characterized Power Sources at Awada TCN Work Centre

Awada TCN Power network is made up of 330/132/33kv transmission station in Obosi, Anambra State. Okpai 330kv line from Okpai power station in Delta State is connected to Awada work centre. Awada work centre is connected to the national grid via the Benin 330kv line.TheOkpai power station was built by AGIP Oil Company which is one of the private power stations presently hooked to the National grid.

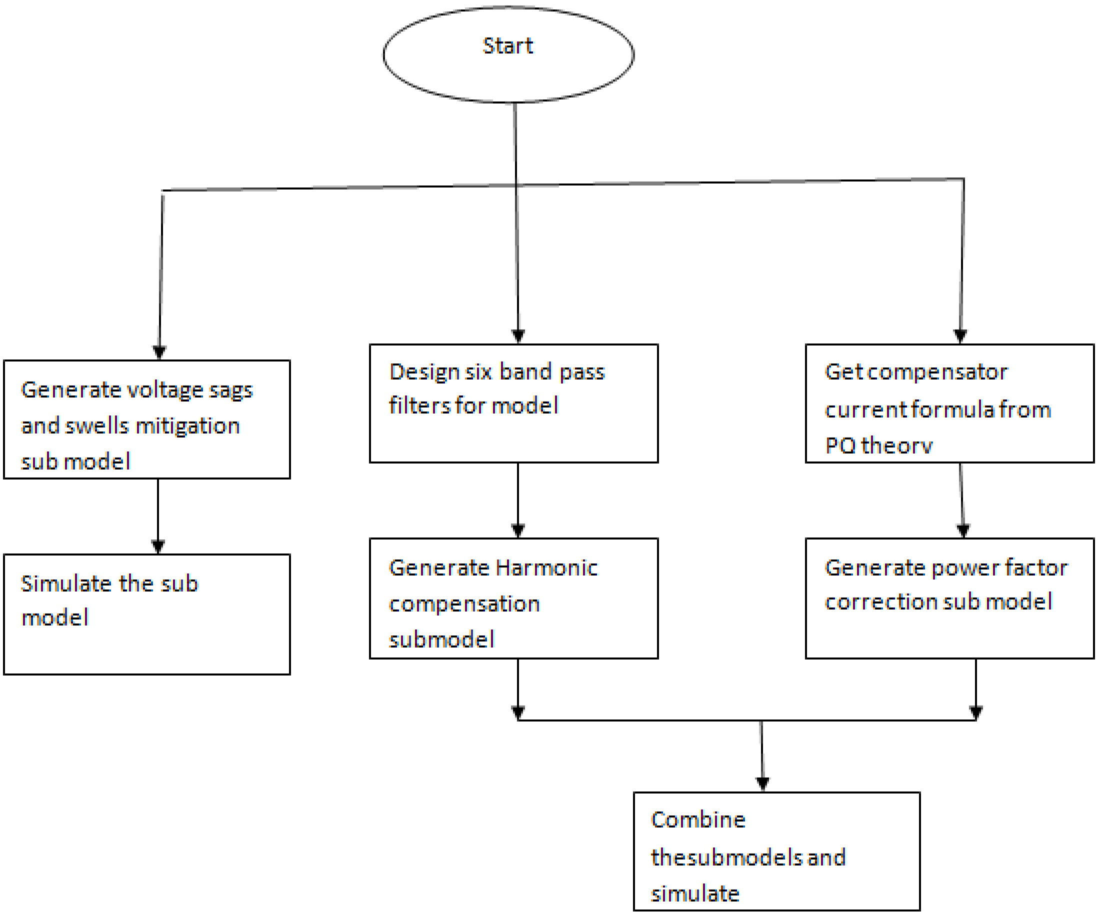

Fig. 3. Simulation process block diagram

The Benin 330kv line emanated from the interconnected systems of other generating stations tied together and controlled by the national control center (NCC), Oshogbo.

The Awada TCN primary station has eight(8) power transformers of two 330/132kv, 150MVA and one 330/132kv, 90MVA that were paralleled and stepped down to (i) 60MVA 132/33kv TR11 transformer feeding three 33kv lines of Obosi, 3-3 and Osamala (ii) 60MVA 132/33/11kv TRI 3 transformer feeding Nnewi,Nnewi industrial and Niccus 33kv feeders. (iii) 45MVA 132/33/11kv Mobitra 1 transformer feeding Umunya and Ogidi 33kv feeders with Woliwo and Nwaziki 11kv feeders; (iv) 40 MVA 132/33/11kv Mobitra 2 transformer feeding Army barracks and Awada 2, 33kv lines, and (v) 15MVA 132/11kv TRI2 transformer feeding PPI, IUNT and Ezeiweka 11kv lines.

The Awada TCN power network aside these power transformers at the TCN has twelve (12) 33/11kv injection substations which are Army Barracks 1x2, Umuoji, Awada 1x2, Akwudo, Oraifite, Uruagu, Atani, 3-3, Feggae and Ugwunwasike with associated 11kv feeders.

Army barrack injection substationhas has two 15MVA transformers with Ngbuka, Army, Minaj 1, Minaji 2, Omagba, GRA and Inland; Umuoji injection substation has a 7.5 MVA transformers with Avenco and Umuoji 11kv feeders; Awada 1x2 Injection Substations has two 15MVA transformers, one 15MVA 132/11kv transformer with Awada , Mgbemena, Okpoko , Nwaziki , Woliwo, PPI,IUNT and Ezeiweka 11kv feeders; Akwudo injection substation has one 15MVA and 7.5 MVA transformers with Mbanagu, Otolo and Nnewichi 11kv feeder ;Uruagu 7.5MVA Injection Substation has Uruagu 11kv feeder; Oraifite has 7.5 MVA transformer with Ibollo and Nkwoedo 11kv feeders ; Atani substation has two 15MVA transformers with Iweka, Water works, Industrial and Premier 11kv feeders; 3-3 Injection substation has a 15MVA and 7.5 MVA with Nsugbe, Housing and Nkwelle 11kv feeders;Feggae Injection Substation has Bida,Uga,market and housing and Ugwunwasike 15MVA Injection substation has Alben, Ogidi, Nkpor and Tollgate 11kv feeders. The line diagram of the distribution Power lines (33kv and 11kv) radiating from Awada work centre is shown in Fig. 4.

Harmonic data of the entire distribution network from power quality analyzer at Onitsha work center

The results of data collected from a power quality Analyser (PQube) that was installed at the secondary side of the distribution lines at Awada work centre during the nationwide power quality Assessment programme targeted at major industrial feeders were used for the purpose of this study as was provided on request by the Awada TCN primary substation.

The line diagram of the distribution power lines from Awada work centreshowing the power distribution network is seen in Fig. 4. The total harmonic distortion data from the PQube’s memory card that is used as a base data for harmonic analysis is seen in Table 1. and 2 for current and voltage source respectively.

2.3 Simulation of Three Phase Shunt Active Power Filter with FIR in MATLAB/SIMULINK Environment

The Matlab/Simulink software version 7.5 was used to create the system model. The performance of the proposed APF is studied using computer simulation with MATLAB. A model without FIR filter was simulated as shown in Fig. 5 and after that, as shown in Fig. 6, a three-phase harmonic filter block filters harmonic currents produced by a 12-pulse, 1000 MW AC/DC converters in a 132/33kv, 60 Hz system. The filter set consists of the four components listed below, which provide a sum of 600 Mvar

1. 1 C-type high-pass filter adjusted to the 3rd harmonic, 150 Mvar (F1)
2. One double-tuned 150 Mvar filter tuned to the 11/13th (F2)
3. A high-pass filter adjusted to the 24th harmonic of 150 Mvar (F3)
4. A capacitor bank with a capacity of 150

The key intentions of the research work is to propose intelligence based control approach based on AI techniques ,which is compared with the other control strategies, in order to increase the Shunt Active Filter's performance. Shunt Active Filter’s execution is estimated using MATLAB / SIMULINK environment using Simlink power Systems toolbox and the results demonstrate the behavior of Shunt Active Filter using simple and flexible control methods to face the different operating conditions and disturbances inherent in power transmission and distribution system

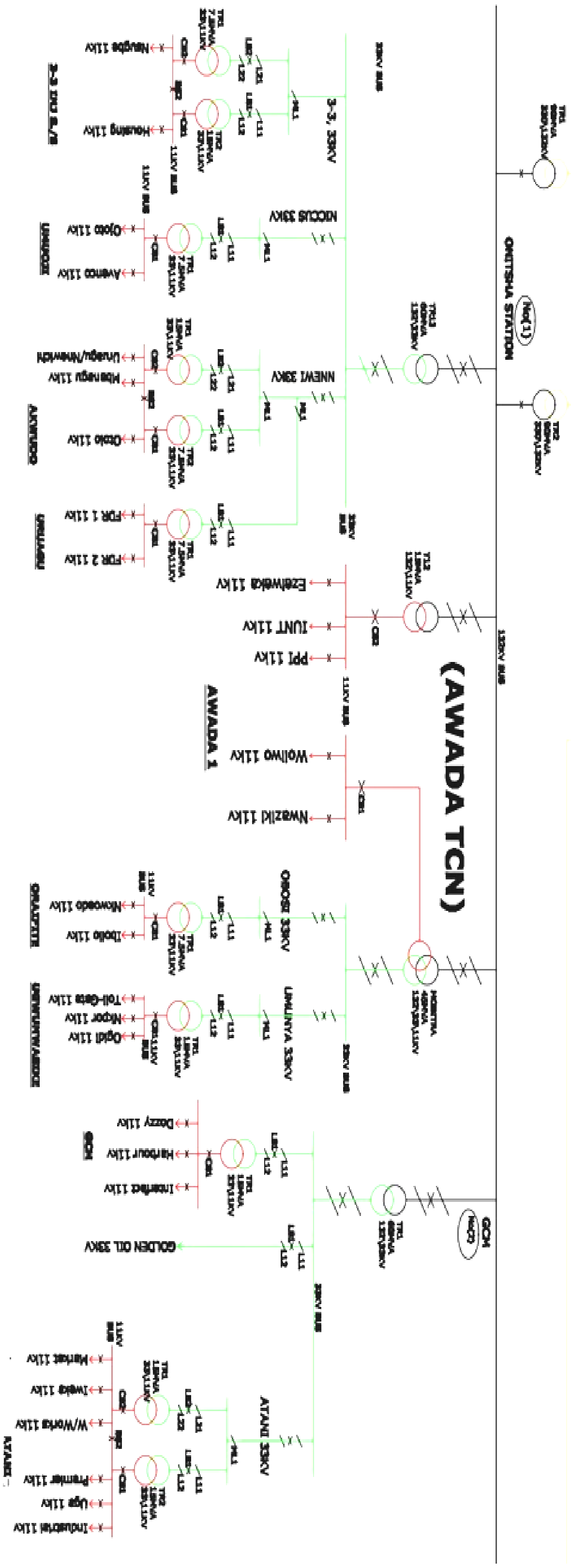

Fig. 4. Line diagram of the Awada TCN network radiating the 33kv and 11kv outgoing feeders: (source: TCN Onitsha work centre)

Table 1. VTHD showing the penetration of 3rd and 5th harmonics on the network using the current source

Bus ID	VTHD	Harmonic Order
Obosi 33kv Bus	14.94	3.00
3-3 33kv Bus	13.15	3.00
Osamala 33kv Bus	13.41	3.00
Nnewi 33kv Bus	15.14	3.00
Nnewi Industrial 33kv Bus	13.43	3.00
Niccus 33kv Bus	5.23	3.00
Woliwo 11kv Bus	5.16	5.00
Nwaziki 11kv Bus	2.44	5.00
Army barracks 33kv Bus	4.57	5.00
Awada 1 33kv Bus	3.52	5.00
Awada 2 33kv Bus	7.13	5.00
PPI 11kv Bus	6.38	5.00
IUNT 11kv Bus	7.38	5.00
Ezeiweka 11kv Bus	6.57	5.00

Source: (Transmission Company of Nigeria, Onitsha Work Center.)

Table 2. VTHD Showing the penetration of 3rd and 5th harmonics on the network using the voltage source model

Bus ID	VTHD	Harmonic Order
Obosi 33kv Bus	14.94	3.00
3-3 33kv Bus	13.43	3.00
Osamala 33kv Bus	13.41	3.00
Nnewi 33kv Bus	13.14	3.00
Nnewi Industrial 33kv Bus	15.15	3.00
Niccus 33kv Bus	5.12	3.00
Woliwo 11kv Bus	5.16	5.00
Nwaziki 11kv Bus	2.82	5.00
Army barracks 33kv Bus	4.88	5.00
Awada 1 33kv Bus	2.51	5.00
Awada 2 33kv Bus	6.15	5.00
PPI 11kv Bus	7.29	5.00
IUNT 11kv Bus	7.30	5.00
Ezeiweka 11kv Bus	7.65	5.00

Source: (Transmission Company of Nigeria, Onitsha Work Center.)

Two 6-pulse thyristor bridges are connected in series to make the HVDC rectifier. A 45-MVA Three-Phase transformer connects the converter to the system (three windings). A 0.5 H smoothing reactor connects a 1000-MW resistive load to the DC side. The filters set is made up of the powerlib/Elements library's four components:

1. A 150 Mvar capacitor bank (C1) modeled using a "Three-Phase Series RLC Load,"

2. Three filters modeled with a "Three-Phase Harmonic Filter"

(1) A C-type high-pass filter adjusted to 150 Mvar's 3rd (F1) frequency
(2) One double-tuned 150 Mvar's 11/13th (F2) frequency
(3) A high-pass filter set at 150 Mvar's 24th (F3) frequency.

The filters overall Mvar rating is therefore 600 Mvar. To link the filters on the AC bus, a three-phase breaker (Brk1) is used. The converter is open-loop regulated using the Extras/Discrete Control library's "Synchronized 12-Pulse Generator" with a constant conducting angle alpha of 19 degrees.

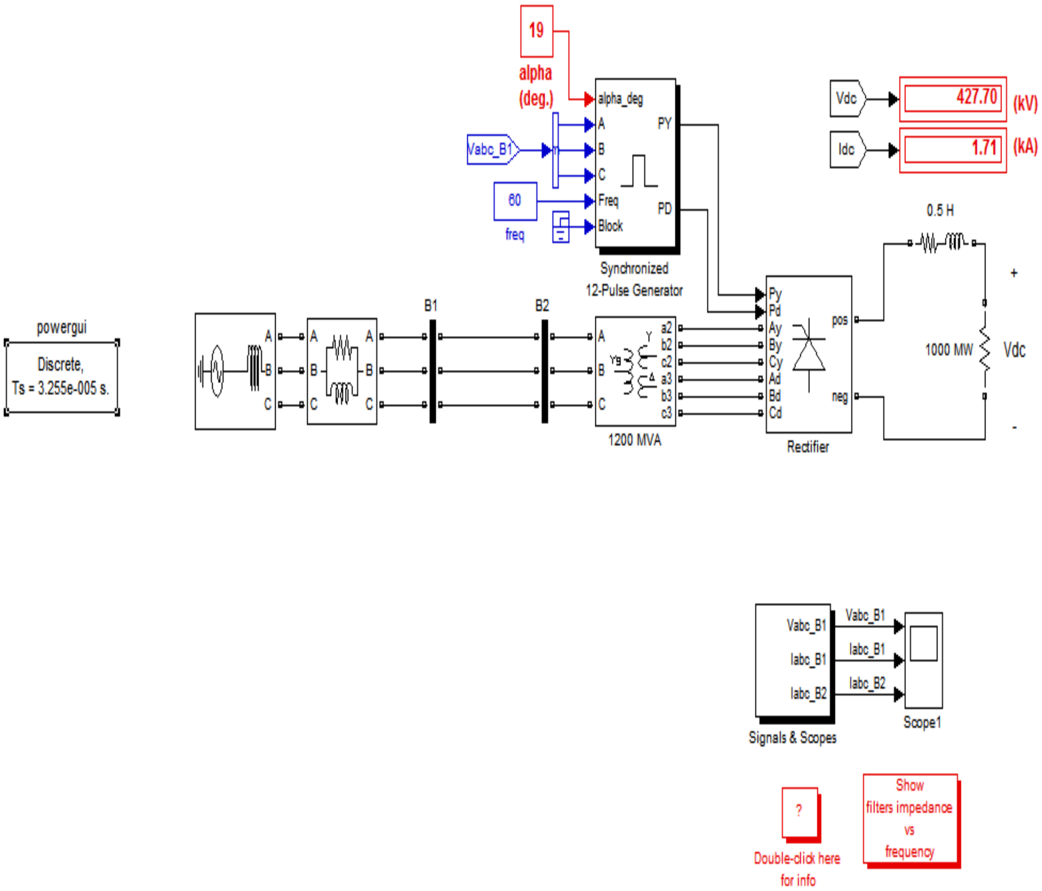

Fig. 5. Simulink model of a Power System Network without FIR filter

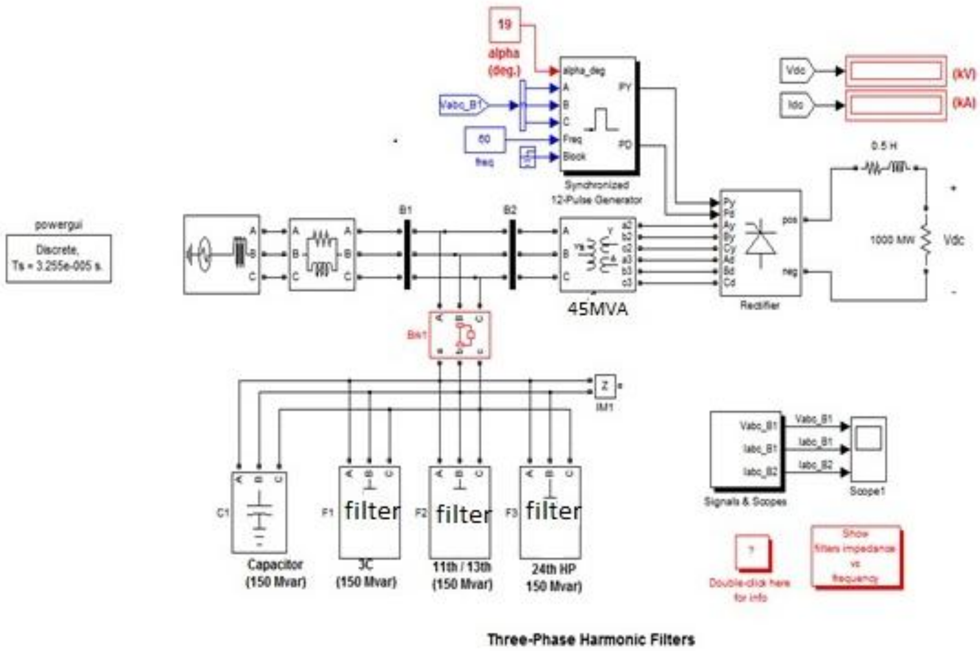

Fig. 6. Simulink model of a power system network with three-phase harmonic filter

3. SIMULATION RESULT

3.1 Simulation Result without FIR Filter

The study and simulation used a three-phase supply voltage and a linear resistive load grid - connected via a three-phase bridge rectifier. The simulation is run without the FIR filter. Fig. 7 depicts the current drawn in harmonic load and a phase of the source.

Fig. 7 depicts the grid voltage (Vs) and current (Is) for phases A, B, and C. Because the PV system compensates for all of the load's reactive power, the current and voltage are in phase. The duration of time window 0.1s was supplied for easier readability of executed tests. Single phase waveforms are colored differently: phase A is blue, phase B is yellow, and phase C is pink.

3.2 Simulation Result with FIR Filter

A shunt active filter is installed in the three-phase 3-wire system with a non-linear load to reduce current harmonics. FIR is used to control a shunt active filter for normal and increased load under balanced and unbalanced source voltage conditions. The case study and simulation used a three-phase voltage and a nonlinear resistive load to the grid via a 3 diode-bridge rectifier. Now, the simulation is carried out with the help of a FIR filter. Fig. 8 depicts the current drawn in harmonics load and a phase of the source.

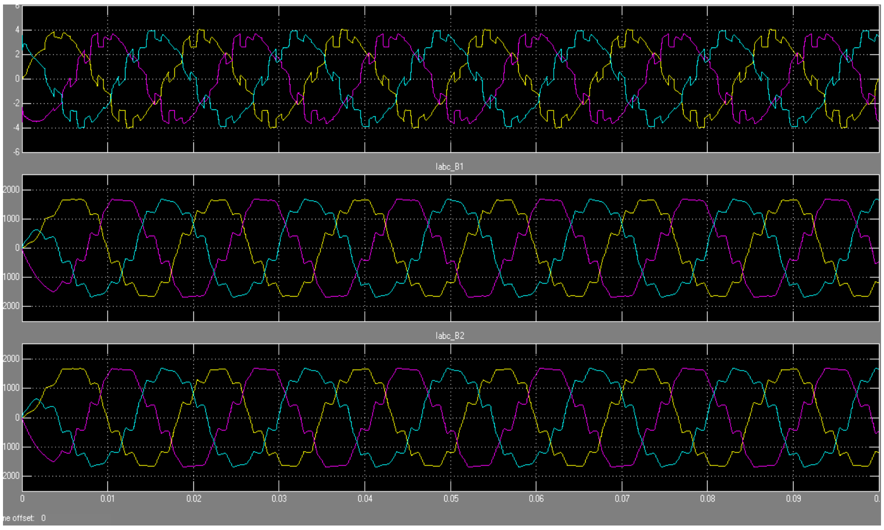

Fig. 7. Graph of Voltage and Current before compensation

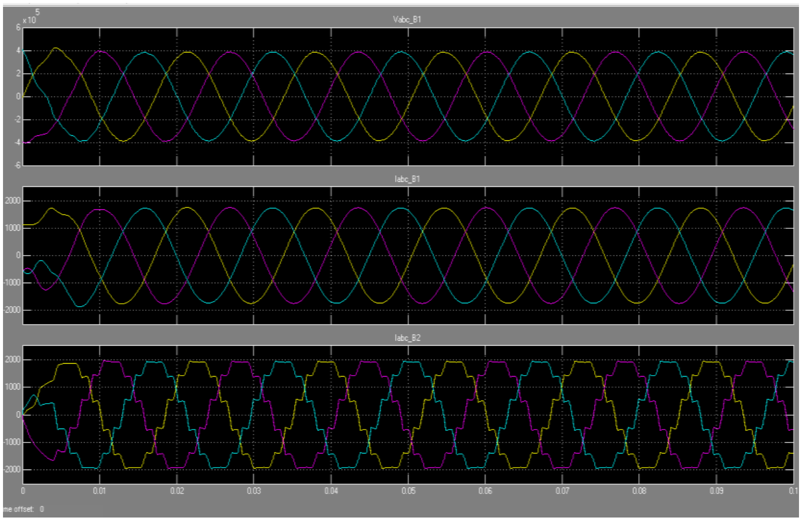

Fig. 8. Graph of voltage and current

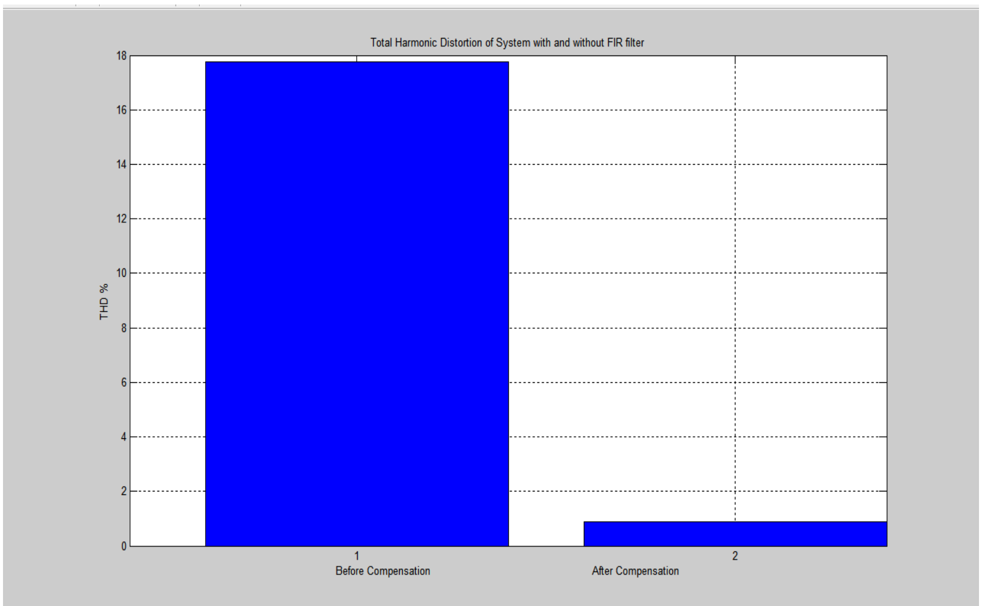

Fig. 9. Comparative graphical analysis between system without and with filter

Table 3. Total Harmonic Distortion of System with and without FIR filter

System without FIR Filter	System with FIR filter
17.77%	0.87%

Fig. 8 depicts the grid voltage and current for phases A, B, and C. Because the FIR filter method compensates for all of the load's reactive power, both current and voltage are in phase.

The comparative analysis between system without FIR filter and with FIR filter using current control method based on FFT analysis is shown in Table 3 Fig. 9 shows the Total Harmonic Distortion (THD) of the system before and after using filter. As seen from the graph, the system with FIR filter gives the better result of 0.87% as compare to the system without filter with resulted in 17.77%.

4. DISCUSSIONS

The FFT analysis of the MATLAB/SIMULINK circuit model with and without filter clearly demonstrates that the harmonic component present in the source is compensated with the use of FIR filter. Further it is also seen that harmonic is compensated to a greater extent while using FIR filter i.e. the THD of source current is almost reduces drastically by more than 90%. The comparative analysis between system without FIR filter and with FIR filter using current control method based on FFT analysis is shown in Table 3 .Fig. 9 depicts the system's Total Harmonic Distortion (THD) before and after utilizing the filter. As seen from the graph, the system with FIR filter gives the better result of 0.87% as compare to the system without filter with resulted in 17.77%.

5. CONCLUSION

The major purpose of this project is to use a FIR filter system to manage active power and compensate for harmonics and reactive power of non - linear loads, as well as to increase the power factor of the power system. The proposed method's performance allowed the power system to be controlled to function at its maximum power point, and the FIR filter was able to adjust for harmonics and reactive current. In addition, the current's THD reduces considerably.

Based on the simulated results achieved in this research effort, it can be concluded that the Shunt Active Filter is a viable instrument for damping harmonic resonance, reactive power compensation, and load balancing in the developing power quality challenges.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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