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Power Quality Improvement of PV fed Grid Connected System using ANN Controlled Shunt Active Power Filter

Giriprasad Ambati[1], A. Ganga Dinesh Kumar[2], Thumu Raghu[3], B Venkata Seshukumari[4], Raja Reddy Duvvuru[5], Ch. Rami Reddy[6,7]*

[1]*Department of Electrical and Electronics Engineering, VNR Vignana Jyothi Institute of Engineering and Technology, Secunderabad-500090, India. giriprasad_a@vnrvjiet.in*

[2]*Department of Electrical and Electronics Engineering, Malla Reddy Engineering College for Women, Secunderabad- 500100, India. toganga@gmail.com*

[3]*Department of Electrical and Electronics Engineering, Anurag Engineering College, Kodad – 508206, India. thumuraghu@gmail.com*

[4]*Department of Information Technology, VNR Vignana Jyothi Institute of Engineering and Technology, Secunderabad-500090, India. seshukumari_bv@vnrvjiet.in*

[5]*Department of Electrical and Electronics Engineering, Malla Reddy Engineering College, Secunderabad- 500100, India. rajajntuacep@gmail.com*

[6]*Department of Electrical and Electronics Engineering, Joginpally B R Engineering College, Hyderabad-500075, India. crreddy229@gmail.com*

[7]*Applied Science Research Center, Applied Science Private University, Amman-11937, Jordan*

***Correspondence:** Giriprasad Ambati and Ch. Rami Reddy; *giriprasad_a@vnrvjiet.in and crreddy229@gmail.com*

ABSTRACT- Harmonics are common in integrated power systems, especially with the increasing use of nonlinear loads (NLL), such as those found in photo voltaic (PV) systems connected to the grid. Traditional LC filters Shunt active power filters (SAPF) have been developed to effectively correct harmonics and improve power quality performance. This study presents a three-phase voltage-fed SAPF implementation to mitigate harmonics using an artificial neural network (ANN) controller. The SAPF control system focuses on generating reference source currents to counterbalance the harmonic effects caused by NLL. The model's effectiveness is validated using experimental data gathered from a nonlinear load through MATLAB/Simulink simulations.

Keywords: Harmonics mitigation, shunt active power filter, instantaneous reactive power theory, Artificial Neural Networks.

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1. INTRODUCTION

In today's fast-paced world of electrical power systems, it is extremely important to maintain reliable and high-quality electricity. However, as more and more non-linear loads, renewable energy sources, and advanced electronic gadgets expand their influence into all sectors of modern life various problems caused by harmonic distortion, low power factor, and voltage fluctuations have appeared in front of us [1]. To address these difficulties now a new approach has been proposed that involves the use of the Shunt Active Power Filters. SAPF, an advanced pupil in power electronics, has always been deliberately designed to handle all sorts of undesired happenings to enhance the quality of electrical power [2]. These phenomena which include reactive power, voltage sags, swells, and harmonic waves, in addition to electric particulars can impair sensitive equipment and the overall effectiveness of the electrical distribution system likewise will disturb normal operation [3-4]. The SAPF basically is working as a control system that responds dynamically to any abnormality in electricity waveform, whether detected at the point of use or in transmission and distribution networks. Shunt Active Power Filters (SAPF) introduce controlled currents - all in phase with each other and large enough to cancel out the unwanted contributions - back into the electrical systems for them to normalize [5-6]. The problems are resolved by following a step-by-step approach that aims at getting these parameters back to their desired conditions. Unlike passive power filters, which are a static element possessing only limited compensatory ability, SAPF has an active form and instant power quality correction capability. The installation of renewable energy systems Surge protective devices, power factor correction equipment, uninterruptable power supplies, and active harmonic filters are all examples of SAPFs used to enhance power quality [7]. They play a critical role in protecting sensitive equipment and ensuring a stable and reliable electricity supply. SAPFs are becoming increasingly important as industrial and commercial systems grow more complex, leading to a rise in power quality issues. However, some control strategies belonging to VSI-based SAPFs include the following: The load current is continuously sensed for the SAPF to calculate the reference compensation current under hysteresis control. After, it gives the reference value and commands that control the switches of the inverters to maintain the current within a band of hysteresis centered on the reference value [8-9]. Proportional-integral (PI) control includes PI controllers that regulate the inverter output regarding the deviation of the set current and measured current. Proportional and integral gains are the states that give the amount for which the control response responds (how fast and accurately) concerning due time. In the current context, we cover the actual current control systems that control the compensatory current injection of a current source inverter (CSI) and control its phase and magnitude [10]. The control loop adjusts the inverter's output voltage so that it modulates the required current waveform model. It is a very sophisticated control technique used in SAPF systems, applying predictive control in order to improve compensation performance. Unlike conventional control strategies, MPC predicts the one-step-ahead future behavior of the power system and accordingly controls the compensating currents or voltages [11]. The proactive strategy mitigating the errors expected by dealing with complex and dynamic systems fits because it shows respect both for the system dynamics and the constraints themselves. The other convenient technique is repetitive control dealing with periodic disturbances, as in the case of harmonics in SAPF systems. This approach produces a compensating periodical signal for compensating the recurrent harmonic components in the load current using a repeating control algorithm [12-13]. Adaptive control techniques that will make SAPF schemes adapt to a dynamic load characteristic and system conditions become very critical. Meanwhile, these approaches operational even in dynamic context which secure the optimal compensation by continuously updating the control parameters based on real-time observations of the same. Other strategies applied to SAPF systems include fuzzy logic control [14]. It provides a stable and flexible control approach with the use of fuzzy sets and rules especially in a case where it is impossible to build an exact mathematical model. For a given SAPF type and method of control there is a certain advantage or disadvantage [15]. Thus, depending on the power quality concerns, system attributes, and performance demands, the choice of SAPF and the control approach are based on the following reasons. Efforts have been made in research and development for more advanced control strategies, which may increase adaptability and efficacy in handling power quality by the SAPF system [16-17]. A new type of Artificial Neural Network (ANN) controller for reducing the harmonic content in the source current of grid-connected PV systems is suggested in this study. Thus, a new ANN controller is developed here for the mitigation of the harmonic contents in the grid-connected PV system's source current.

The outline of the remaining part of the article is such that *section 2* denotes the test system, and *section 3* presents the proposed ANN control technique. *Section 4* presents the obtained simulation results, and the *section 5* gives the conclusions.

2. TEST SYSTEM

A grid-connected PV system with a SAPF is the main component of an electrical power system which is designed to control and reduce harmonics in current and effects of reactive power. SAPF was designed to improve the power quality of electrical distribution networks by producing compensating current to reduce the current harmonics. The main objectives of SAPF are to reduce voltage distortion, enhance power factor and compensate for harmonics. SAPF plays a major role in commercial and industrial purposes. Nonlinear loads such as variable frequency drives in the system lead to voltage distortion, overheating of windings and decrement in system efficiency which results in current harmonics. Two ways to reduce current harmonics are reactive power control and harmonic compensation. SAPF ensures the reliability and stability of power supply for various applications.

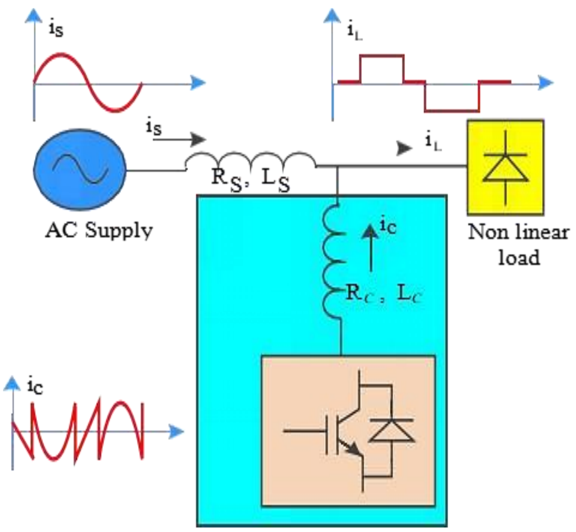

Figure 1. SAPF connected to the grid through nonlinear load

2.1 Grid-connected PV system

In this study, a two-stage PV network configuration is employed, along with a PV inverter and a DC/DC boost converter as shown in *figure 1*. The PV array block represents the PV arrays, with the main inputs being solar irradiance and cell temperature data. At its maximum power point (MPP), occurring at a cell temperature of 25°C and solar irradiation of 1000 watts per square meter, the PV system yields a voltage of 1840 volts. The system's DC bus voltage is maintained at 3700 volts. Consequently, a DC/DC boost converter is utilized to elevate the output voltage of the PV array to match the DC bus voltage level by adapting the duty cycle of the boost converter according to environmental factors, it efficiently follows the Maximum Power Point (MPP) of the PV array. Voltage Source Inverter (VSI) maintains synchronization between the PV system and the utility grid apart from converting DC electricity from PV array into AC power by keeping booster converter output voltage constant at DC link. The input DC voltage of VSI is maintained at 3700 volts which is transformed into 400 volts of three phase AC power at a frequency of 60 Hz. The LC filter reduces the excess harmonics produced by the inverter.

2.2 P&O MPPT Technique

One of the most popular Maximum Power Point Tracking (MPPT) method used in nowadays is Perturb and Observe method. This method involves gradually adjusting the voltage of the PV array and comparing the resultant power output to that of the preceding perturbation cycle. Despite its utility, the P&O algorithm has drawn some criticisms because of its slow response to rapidly changing environments. Analysing changes in voltage, current and power is crucial for analysing the duty ratio of boost converter in P&O method [13]. This algorithm figures out whether the voltage or current is increased or decreased by comparing the power levels before and after modifications in the voltage. Voltage adjustments can increase or decrease power output, with changes occurring in the opposite direction to the east of the Maximum Power Point (MPP), depending on the system's position with respect to the MPP [12- 13].

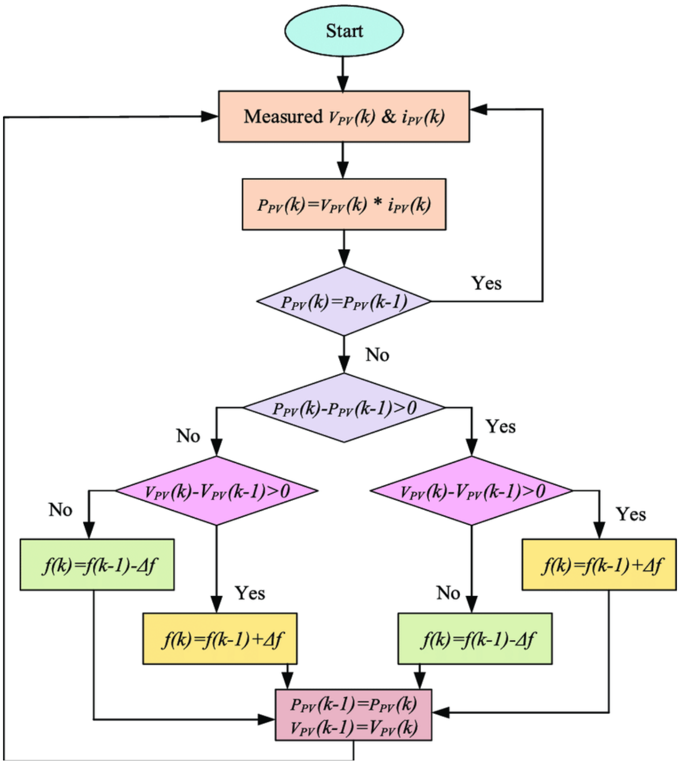

Figure 2. P&O MPPT Technique

The perturbation level stays constant when power increases, approaching the MPP, and vice versa. In stable circumstances of irradiance, P&O [12] typically operates well. But because of its poor flexibility to changes in temperature and irradiance, it suffers from power oscillations around the MPP during steady-state operation. In conclusion, by tracking power production the P&O technique maximizes solar cell performance as shown in *fig. 2*. However, there are disadvantages as well like sensitivity to changes in the environment and difficulties maintaining power stability around the MPP particularly under steady-state settings.

2.3 P&Q THEORY

Power system analysis is done using a technique called instantaneous reactive power theory, or P-Q theory as shown in *Fig. 3*. It works by using a Clarke transformation to change the stationary reference frame (*a-b-c*) into a revolving reference frame (*0-α-β*). Reactive power in three-phase systems can be more easily analyzed thanks to this transformation [15-16]. This method helps with power system control and management by providing precise instantaneous reactive power levels. This theory can be applied in MATLAB/Simulink to successfully simulate and analyze power system behavior using suitable block diagrams.

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & \sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}$$

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & \sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

Where v_a,v_b and v_c refers are three phase voltage at *a,b,c* coordinates respectively and i_a, i_b and i_c are three phase currents at *a,b,c* coordinates respectively. v_0, v_α and v_β are three phase voltages at *0,α,β* coordinates respectively. i_0, i_α and i_β are three phase voltages at *0,α,β* coordinates respectively.

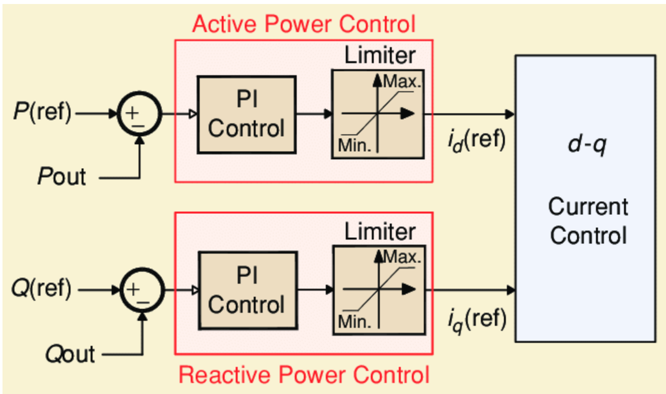

Figure 3. Block diagram of the active and reactive power theory

The instantaneous reactive power theory, which is usually known as P-Q theory, is the main principle for controlling the operation of SAPF. SAPFs are the essential parts of the electrical power systems that deal with power quality issues like harmonic distortion and reactive power imbalance. The P-Q theory states that SAPFs can differentiate the real components of reactive power (Q) and active power (P) in electrical power systems. Through precise evaluation of these components, SAPFs also evaluate the proper compensating current to address the power quality issues. SAPFs operate with in a closed-loop

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system due to the P-Q hypothesis. They monitor the power quality supplied to the electrical power system and adjust their plans as per the requirements. SAPFs will be able to provide efficient and customized compensating current by monitoring in real-time which improves power quality issues and reduces losses in the electrical power networks. P-Q theory offers a systematic approach to analysing and optimizing power quality issues in electrical power systems.

3. PROPOSED CONTROLLING METHOD

3.1 Basic Compensation Principle

The shunt active power filter's structure features a self-regulating DC bus which resembles a static compensator (STATCOM) as shown in *figure 4*. It is a device that regulates reactive power in power transmission networks. Its primary function is to compensate to counteract load current harmonics and compensating currents are injected with equal magnitudes but opposite phases. Practically, this indicates that the compensatory current is either drawn or sent to or from the utility grid for a shunt active power filter [14] to function. To properly align the source current with the source voltage, this current is carefully adjusted to offset current harmonics on the AC side. This method makes sure that the system operates continuously to reduce harmonic distortions and improve overall power quality and hence, the system will run without any interruptions.

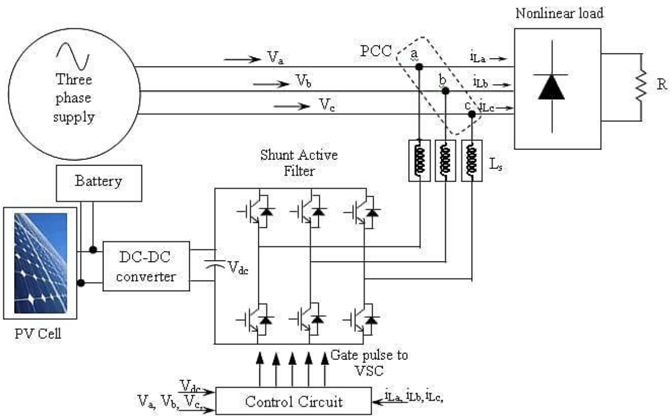

Figure 4. Grid-connected PV system through SAPF

3.2 Role of DC Side Capacitor

The DC-side capacitor is a crucial part of this system as it carries out two important tasks. At first, it ensures uninterrupted operation by maintaining constant DC voltage with minimum fluctuations in the system. Moreover, it functions as a temporary energy storage capacity by reducing the imbalance between the load requirements and the power supply. When everything runs properly, the supply from the source should meet the load requirements and additional power needs to be produced for losses in the shunt active power filter. This equilibrium maintains constant DC capacitor voltage at a predefined reference level. The DC capacitor is required to make the difference in actual power as any modifications to the load circumstances disturb this equilibrium.

3.3 Artificial Neural Networks

The reference current's peak value influences the real power taken from the source modifications to guarantee smooth operation. This interchange of real power which may be used to charge or discharge the DC capacitor compensates for variations in the real power used by the load until the DC capacitor voltage returns to the reference level. By following this process, the actual power consumed by the load and the real power provided by the source are restored to equilibrium. When it comes to addressing difficult functions with accuracy the ANN has a major advantage due to its capacity to process non-linear input as shown in *figure 5*. The system may be trained to accomplish goals by adjusting the weights throughout the layers of the neural network.

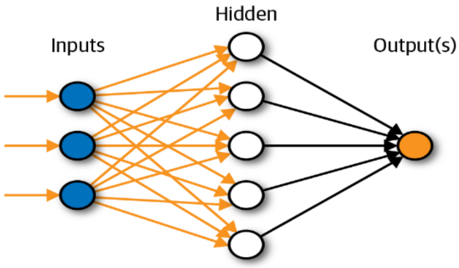

Figure 5. Feed-Forward type ANN

3.4 Implementation of ANN

The architecture and operation of biological neural networks served as the paradigm for ANN as in *figure 6*, which are mathematical constructs [17]. They use a connectionist method of information processing and are made of networked artificial neurons.

This network comprises two layers with corresponding neuron connections: the input layer with 2-neurons to receive inputs, a hidden layer with 21-neurons to process inputs, and an output layer with 1-neuron to calculate the loss power (Ploss). Activation functions, such as the TanSigmoidal function for the input layer and the Pos-Linear function for the output layer, are assigned to each layer to facilitate training to train the artificial neural network (ANN), copious amounts of DC-link voltage data for 'n' and 'n-1' intervals are collected and saved in the MATLAB workspace. The training procedure is then applied to get this data. While the number of hidden neurons greatly influences the accuracy of ANN operation, the number of neurons in the input and output layers is usually fixed to fit the given input.

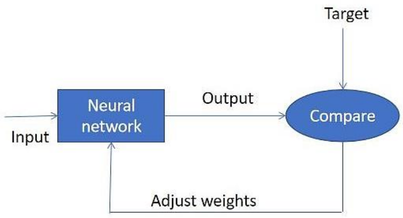

Figure 6. ANN Operational Block Diagram

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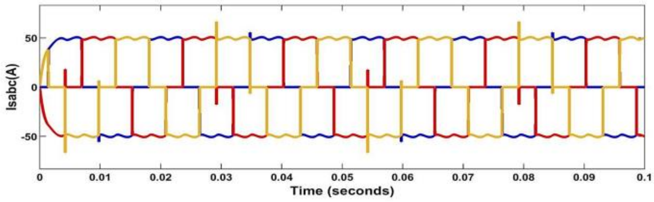
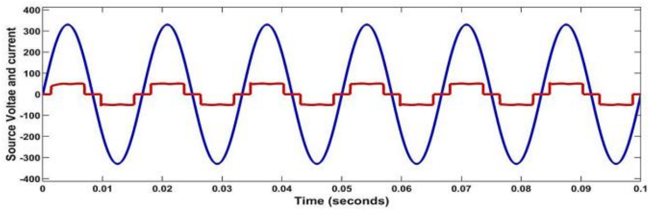
4. RESULTS

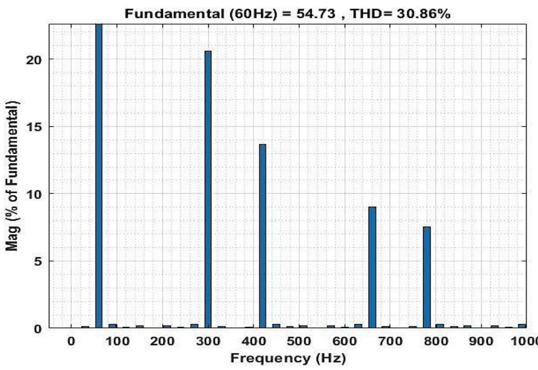
In this research, we utilized the MATLAB environment to conduct simulation experiments aimed at assessing the performance of the proposed Harmonics mitigation using SAPF controlled by ANN. Initially, we analyzed the simulation results without the SAPF implementation.



(a)



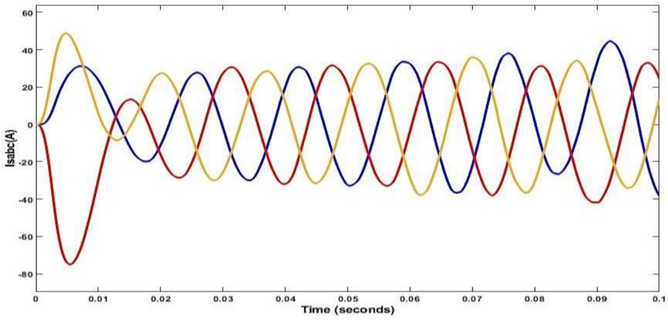
(b)



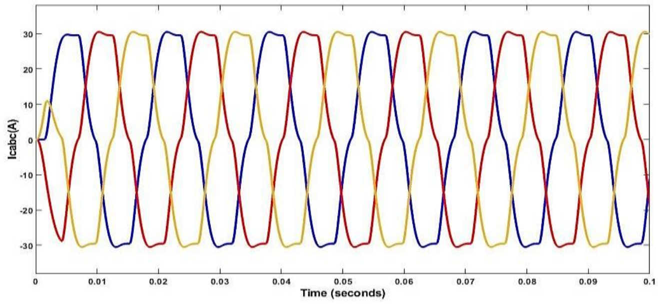
(c)

Figure 7. Without SAPF (a) Source current and (b)Source voltage (c) THD of source current

Figure. 7 (a) shows the distorted three-phase source current waveform with a nonlinear load connected. The source current is distorted due to the non-linearity behavior of the load. *Figure 7 (b)* shows the source voltage and source current wave forms where the source voltage waveform is sinusoidal and the load current waveform is distorted. The Fast Fourier Transform (FFT) analysis in *figure 7(c)* shows the THD of the source current as 30.86%.



(a)



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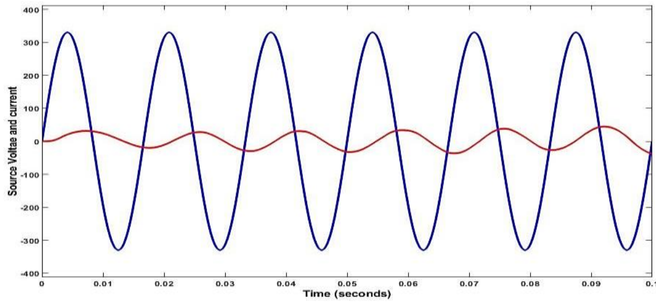
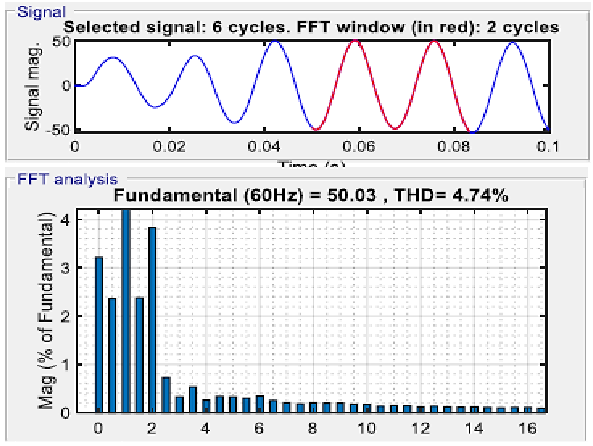


(c)



(d)

Figure 8. ANN controlled SAPF(a) Source Current, (b) Compensation Current, (c) Source Voltage (d) THD of source current

Figure 8 (a) illustrates how SAPF is used to return the source current waveform to a sinusoidal shape. The compensatory current waveform for SAPF utilizing the ANN controller is displayed in *figure 8 (b).* The source voltage and current sinusoidal wave forms are displayed in *figure 8 (c).* With an ANN acting as the controller, *figure 8 (d)* shows that the THD of the source current is decreased from 30.86% to 4.74%. The THD comparison of proposed ANN controller with PI and fuzzy controllers is presented in *table 1*, below.

Table 1. Comparison of THD results with fuzzy and PI controllers

Sl. No	Controller	THD
1	Without SHAF	30.86%
2	PI	9.46 %
3	PID	8.47 %
4	Fuzzy	6.16 %
5	ANN	4.74 %

5. CONCLUSION

Based on the simulation findings, it can be concluded that the addition of a SAPF improves the system's power quality considerably by removing reactive current and harmonics from the load. A sinusoidal load current that is in phase with the source voltage is the outcome of this transformation. Consequently, both the source voltage and current become synchronized, indicating the successful elimination of harmonics and compensation of reactive power, leading to a power factor approaching unity. The sinusoidal nature of the source current post-compensation indicates a marked improvement in power quality. The escalation of non-linearity in systems can yield undesirable consequences such as diminished system efficiency, a decline in power factor, as well as disruptions to other users and communication systems. It is expected that non-linearity effects will worsen in the upcoming years, which emphasizes how critical it is to solve these issues. Power capacitors are used to address power factor problems, but shunt passive filters—which include tuned LC filters or high-passive filters—have historically been used to reduce harmonics.

REFERENCES

[1] Jandan, Fayyaz, Suhail Khokhar, Z. Memon, and S. Shah. "Wavelet based simulation and analysis of single and multiple power quality disturbances." Engineering, Technology & Applied Science Research 9, no. 2 (2019): 3909-3914.

[2] Cheepati, K. R., Parimalasundar, E., Suresh, K., Reddy, C. R., Alqahtani, M. M., & Khalid, M. (2023). Design of Triple Tuned Passive Harmonic Power Filter—A Novel Approach Conception d'un filtre passif de puissance harmonique à accordement triple-Une nouvelle approche. IEEE Canadian Journal of Electrical and Computer Engineering.

[3] Govind, Annu, Kuldeep Jayaswal, Vijay Kumar Tayal, and Prakash Kumar. "Simulation and real-time implementation of shunt active power filter for power quality enhancement using adaptive neural network topology." Electric Power Systems Research 228 (2024): 110042.

[4] Reddy, C. R., Goud, B. S., Aymen, F., Rao, G. S., & Bortoni, E. C. (2021). Power quality improvement in HRES grid connected system with FOPID based atom search optimization technique. Energies, 14(18), 5812.

[5] Adware, Ramchandra, and Vinod Chandrakar. "A Hybrid STATCOM Approach to Enhance the Grid Power Quality associated with a Wind Farm." Engineering, Technology & Applied Science Research 13, no. 4 (2023): 11426-11431.

[6] Umadevi, A., L. Lakshminarasimman, and A. Sakthivel. "Optimal design of shunt active power filter for mitigation of inter harmonics in a grid-tied photovoltaic system." Electric Power Systems Research 220 (2023): 109232.

[7] Yarlagadda, Venu, Nireekshana Turaka, Giri Prasad Ambati, and S. Poornima. "Optimization of voltage stability-based shunt and series compensation using PSO." Design Engineering 2021, no. 7 (2021): 8679-8694.

[8] Rasul, Mohamed JMA, H. V. Khang, and Mohan Kolhe. "Harmonic mitigation of a grid-connected photovoltaic system using shunt active filter." In 2017 20th International Conference on Electrical Machines and Systems (ICEMS), pp. 1-5. IEEE, 2017.

[9] Srinivas, K., and Prashanth Kancharla. "Harmonic elimination by reference current strategy using shunt active power filter (SAPF)." In AIP Conference Proceedings, vol. 3007, no. 1. AIP Publishing, 2024.

[10] Pattan, Yusuf Khan, P. Naga Phanindra, and K. Sarada. "Enhancement of power quality by adopting a PQ and DQ current control using shunt active power filter." In AIP Conference Proceedings, vol. 2512, no. 1. AIP Publishing, 2024.

[11] Rachid, Dehini, and Berbaoui Brahim. "Challenges of ANN in Adapting to Abrupt Parameters Variations for Shunt Active Filter." International Journal 10, no. 2 (2023): 2122-2131.

[12] Rekha, R., B. Srikanth Goud, Ch Rami Reddy, and B. Nagi Reddy. "PV-Wind-Integrated Hybrid Grid with P&O Optimization Technique." In Innovations in Electrical and Electronics Engineering: Proceedings of the 4th ICE 2019, pp. 587-600. Springer Singapore, 2020

[13] Yarlagadda, Venu, G. Lakshminarayana, Giriprasad Ambati, and Garikapati Annapurna Karthika. "FFT Analysis and Power Quality Improvement in Grid Connected Solar Power Plant with MPPT Algorithm." In International Conference on Electrical and Electronics Engineering, pp. 30-43. Singapore: Springer Nature Singapore, 2022.

[14] Rasul, Mohamed JMA, H. V. Khang, and Mohan Kolhe. "Harmonic mitigation of a grid-connected photovoltaic system using shunt active filter." In 2017 20th International Conference on Electrical Machines and Systems (ICEMS), pp. 1-5. IEEE, 2017.

[15] Barva, Akash V. "Analysis of SAPF based on pq and SRF Theory for Different Supply and Load Conditions." In 2023 International Conference on Power, Instrumentation, Energy and Control (PIECON), pp. 1-6. IEEE, 2023.

[16] Hajjej, Mohamed, and Lassaad Sbita. "A New Design and Implementation of a Three-Phase Four-Wire Shunt Active Power Filter for Mitigating Harmonic Problems caused by Compact Fluorescent Lamps." Engineering, Technology & Applied Science Research 14, no. 3 (2024): 14619-14627.

[17] Geubbelmans, Melvin, Axel-Jan Rousseau, Tomasz Burzykowski, and Dirk Valkenborg. "Artificial neural networks and deep learning." American Journal of Orthodontics and Dentofacial Orthopedics 165, no. 2 (2024): 248-251.