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Design And Performance Evaluation Of Active Power Filter For Micro Grid Connected Distribution System

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Abstract - In this work, a new control mechanism for three-phase power converters operating in parallel that allows for the equitable distribution of linear and nonlinear loads without the need for inter converter communication is described. Harmonics can be mitigated with the help of many controllers, which is why active power filters exist. The level of harmonics is evaluated by measuring the overall harmonic distortion at the point of origin. When applied to nonlinear loads, the Active Power Filter (APF) concept uses power electronic switching to generate harmonic components that cancel out the nonlinear loads' equivalent harmonic currents. Harmonic currents are blocked from entering the supply by devices like these, which convert DC to AC currents that are out of phase with the load and inject them into the AC line. A comparative analysis has been done by comparing the Simulation results of PI controller method and ANN method. Based on the analysis, the better harmonic reduction controller technique is suggested. Simulations and comparisons of the PI method and ANN method are performed in MATLAB Simulink.

Keywords - PI Controller, Artificial Neural Network (ANN), Active Power Filter (APF), Shunt Active Power Filter (SAPF)

1. Introduction

Since the 1980s, active power filters (APF) have already been utilised to enhance electrical supply. Their common coupling point serves as the connection point where they are in parallel to the load (PCC). The APF's primary roles are reactive power compensation, source current balancing, and harmonics correction from nonlinear loads. [1]. Many power quality problems have arisen as a result of the increasing prevalence of non-linear, inductive, & unbalanced workloads in the distribution system. Switched-mode power supply, computers, refrigerators, televisions, etc., are just a few examples of the types of sensitive equipment that have seen tremendous growth in demand as their use has spread throughout industrial, commercial, household, and traction applications. Utilization requires a regulated power source, which is why power electronic converters are used. Sinusoidal voltage is produced by the generators, but distorted and unbalanced currents are drawn by such loads. When this happens, the voltage on the feeder drops, which might cause problems for any loads that share that line[2]. Power electronics components are a sensitive device which must be provided by a voltage which has constant frequency and magnitude in order to achieve high efficiency in industry, which is a necessity for many developing countries. Because of their extreme vulnerability to electromagnetic interference, electronic devices necessitate high-power quality components such as those used in power electronics. Voltage sag, flicker, voltage instability, interruption, and harmonic distortion are all examples of poor power quality that can be caused by this kind of malfunction [3]. Due to the growing presence of nonlinear loads & renewable energy sources in the electric grid, power quality (PQ) research has emerged as a topic of interest for utilities and end users alike. Harmonic currents injected by non - linear loads into distribution system are the primary cause of power quality issues. Distributed- system equipment would be hampered by the harmonics that these harmonics would cause to the system voltage. These PQ instabilities spread to consumers' devices via the common coupling point (PCC) [4]. Despite its invisibility, electrical energy is a global commodity that is widely available and increasingly seen as a necessity for modern life. Solar, solar thermal, wind, and other RESs are utilised to supplement conventional power generation. Power system performance is halted as a result of stability concerns brought on by the intermittent nature of RESs, harmonics, & reactive power issues. In order to improve distribution grids' reactive power compensation, power quality, voltage stability and FACTS devices have become popular. But FACT devices also modify transmission & distribution system parameters in other ways. The power grid is made up of several interconnected components: generators, transmission lines, and distribution substations from which electricity is distributed to various consumers. When varying power is given to the load, power quality becomes increasingly important in the power system. Because of this, residential and commercial customers with sensitive loads are negatively impacted by the low power quality. While there are many different kinds of loads on the distribution side, the ones most vulnerable to poor power quality are the ones that require the most careful handling [5]. Because of the rising need for electricity and the expanding human population, many specialists in the field are exploring alternative, sustainable methods of generating the necessary amount of power. Due to their availability, technological advancement, lower installation cost, and eco-friendly nature, solar array based distributed generators have become increasingly popular for regulating power reliability and power quality [6]. There is a growing number of power-sensitive loads, making issues with electric power quality (PQ) an urgent concern. End user equipment fails or malfunctions due to power quality issues like voltage, current, or frequency variation. However, harmonic distortion is just one source of power quality issues [7]. Passive L and C filters, which have been used for decades due to their low cost and ease of installation, can be used to economically compensate reactive power, reduce harmonic components to acceptable limits, and provide voltage support for key buses in the event of a power outage in the plant. However, the constant filtering method is inappropriate in some dynamic settings. Detuning and even harmonic resonance can occur with even a little shift in operating conditions. This is why many active and passive methods have been developed to enhance its performance [8]. Customers & power utility firms alike must recognise that power quality is a key factor in determining success in today's fiercely competitive marketplace. The reliability of the electricity supply is an asset for the utility. Potential harm to electrical and electronic products can result from fluctuations in voltage and other power quality problems.

Table 1. Summary of literature review

S. No	Author reference	Control technique used	Remarks
1	[1]	APF	Compensation of poor harmonic output
2	[2]	RLC-MLC with integrated PV system	Optimization of DC link voltage
3	[5]	DVR	Improvement of Power Quality
4	[6]	CEMA	Enhancing Power Quality in Hybrid Microgrids Using Solar and Batteries (HMSs)
5	[8]	TIFS	The Enhancement of the DC Power Supply System for Industrial Use
6	[11]	PI, ANN, FUZZY	Improving Power Quality in a Solar-Fed, Multi-Level Inverter System
7	[12]	OCC	Power Quality enhancement in multilevel inverter for smart grid
8	[14]	Dq0	Removes current harmonics, voltage fluctuations, load imbalance and phase-angle deviation as well as other power quality issues plaguing the power grid.
9	[15]	PI	Harmonic Distortion
10	[16]	MFMP, EFO, HS	Optimization of PI controller gain scheduling
11	[17]	LMS-LMF	Resolution of Power Quality

			Issues brought on by Increasing Use of Solid-State Devices
12	[18]	FLPID-MCCF-MSOGI-FLL	Reduction of voltage and current harmonics
13	[3], [4], [7], [9], [13], [19], [20]		Reviews

2. Power Quality Improvement Using Active Filters

Electrical components like capacitors and inductors are used to store energy in active power filters (APFs). Instantaneous reactive power compensators, active power quality conditioners, and active power lines are all names for the same thing (IRPC). Active filters are designed to compensate utilities for voltage harmonics and voltage unbalance, and customers for current harmonics & current unbalance. In medium power applications, these active power filters efficiently reduce voltage and current harmonic disturbances, as well as notch voltage, distort voltage on the fly, and smooth out transient fluctuations. Three-wire (three-phase sans neutral), Two-wire (single phase) and four-wire (phase plus ground) designs are the most common types of APFs (three-phase with neutral). The APF topologies fall into three broad categories: series, shunt, and hybrid, depending on the nature of the connections to the supply systems. To accommodate nonlinear loads' need for harmonic current, this is applied. This APF design has the problem of requiring ac power capacitors with larger values than is typically used. To get rid of voltage harmonics, a matching transformer is connected to an APF in series near the load end. Also, it aids in voltage management and load terminal voltage stability. For three phase systems, it has also been employed for voltage regulation and the mitigation of negative sequence voltage.

Numerous applications, including Wiener filters, HVDC links with a frequency or sequence selective filters and modular compensating strategy in microgrids, inductive active filtering in distribution systems, back-to-back converters for matrices, DFIG wind energy systems, active harmonic filters, ESP systems, combined systems of APF and SVC in microgrids, and even a APF optimization using a bacterial foraging approach, have found success with APFs to improve power quality.

3. System under consideration

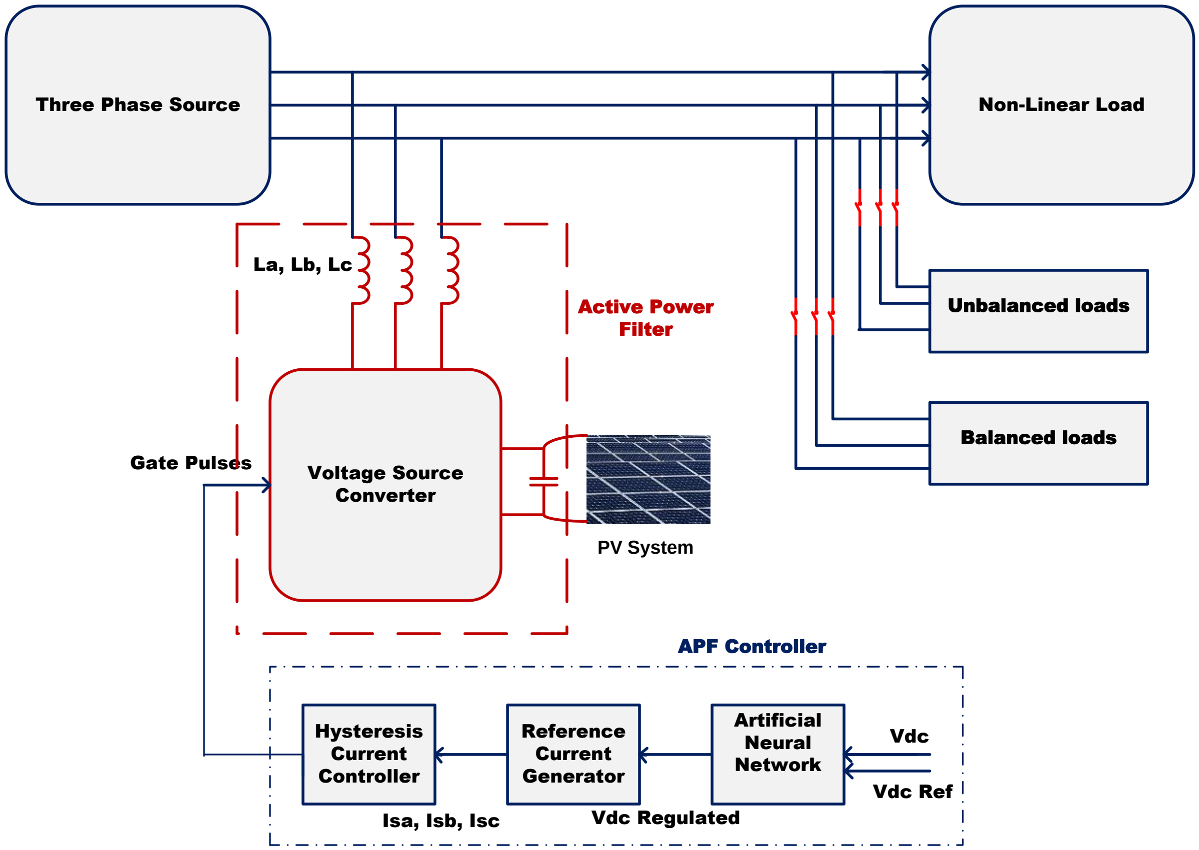

Fig. 1. The proposed system's MATLAB Simulink model

3.1. Current-Controlled Interfacing Voltage Source Inverter

As a vital component of the system, a voltage source current inverter acts as a power electronic converter of the highest order. This converter is used to change the direct current to a regulated three-phase alternating current. The grid may be used to either send or receive reactive electricity. When the inverter's output voltage is higher than the input voltage, the inverter is said to be functioning in capacitive mode. An IGBT and a diode are used to switch current in this VSCC inverter.

3.2. The control method used to connect the inverter to the shunt APF

The instants at which inverter switches are turned on and off should be chosen such that the demand and the linked RES look to the system as a balanced load. Continuous monitoring of the DC link capacitor's output after it has been filtered by a low-pass filter (LPF) is required for this form of control. A voltage regulator will take the difference between these voltages and output an active component, I. Multiplying this maximum value (Im) by the three-unit sine vectors (Ua, Ub, and Uc) that are in phase with the three source voltages yields the reference current templates (Ia*, Ib*, and Ic*). The three measured line-to-neutral voltages are used to calculate these unit sine vectors. As the instantaneous total of the balanced grid currents, the neutral current (In*) of the reference grid is zero. The phase locked loop (PLL) grid synchronizing angle can be used to create a unity vector template.

$U_a = Sin\Theta$ (1)
$U_a = Sin(\Theta - 2\prod/3)$ (2)
$U_a = Sin(\Theta + 2\prod/3)$ (3)

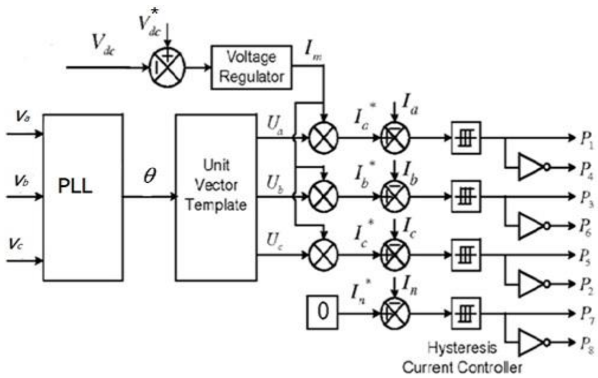

Fig. 2. Inverter control block schematic with grid connection

Using these deviations, the hysteresis current controller creates switching pulses for the inverter's six IGBTs that interface with the grid (Figure 2).

3.3. The Hysteresis Current Regulation Method

The hysteresis current control method is implemented in this study to regulate the VSI's functioning. First, in 1985, Novotny and Brod presented this HCC method. This hysteresis current controls the gates of the interface inverter, which acts as an active shunt filter to smooth out current harmonics. Figure 3 depicts the waveforms generated by a hysteresis current controller in a closed loop control system.

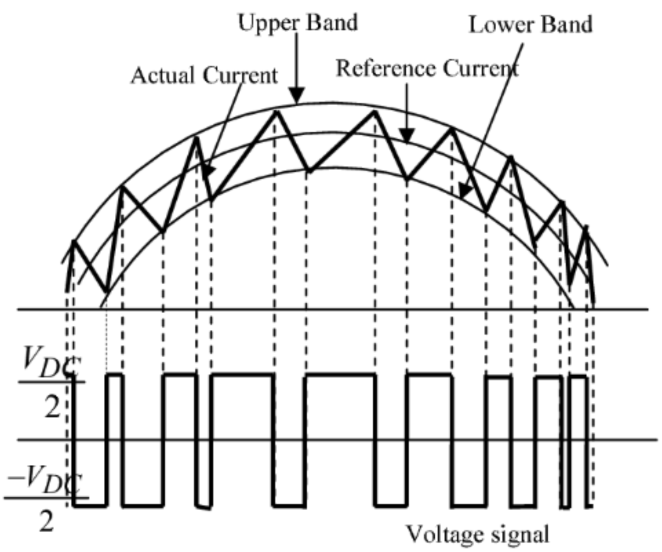

Fig. 3. Hysteresis current regulation waveform

One that suggests a mistake has occurred. In a voltage source inverter, Iaerr activates the switches. The error is equal to the difference between Ia, the necessary current, and Ii, the current actually inserted by the inverter. When the error level climbs beyond the hysteresis band's upper limit, the inverter's top arm switches off and the lower arm switches on. This results in a progressive drop in the current. When the error goes below the hysteresis band's minimum, the inverter's lower switch is deactivated and the upper switch is triggered. This causes the current to climb and return to the hysteresis range. The error signal ranges from a minimum of emin to a maximum of emax. The amount of ripple in the VSI's output current is exactly proportional to the range of the error signal, emax – emin.

4. Artificial Neural Networks

As electronic models, Artificial Neural Networks are based on the brain's neural structure but are still somewhat simplistic. Learning takes place in the brain mostly through exposure to new situations. These results demonstrate naturally that problems that are too difficult for today's computers to tackle can be solved by compact, low-power devices. Further, the use of brain models to create artificial solutions holds the promise of simplifying the process for developers. One of the next big things in computing is expected to be methods based on biology. The simplest animal brains can perform tasks that computers can't even begin to approach. Computers excel at routine tasks like maintaining an accounting system or calculating sophisticated financial calculations. But computers struggle to recognize even the most basic patterns, let alone generalize previous actions into future actions.

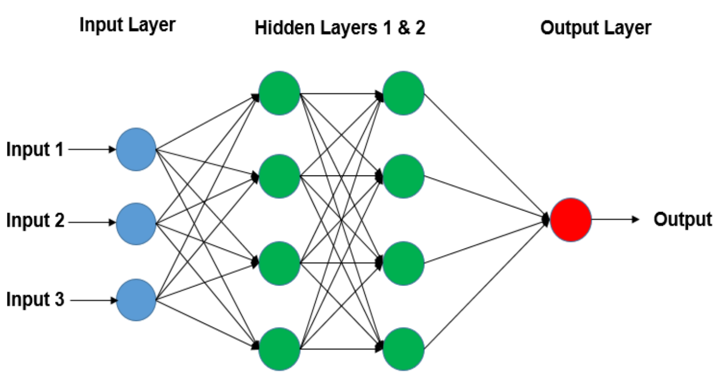

Fig. 4. Artificial Neural Network

The human brain is made up of biological neural networks, and the phrase "artificial neural network" is taken from this concept. Artificial neural networks, like the wiring of the real brain, consist of several layers of linked neurons. In other contexts, neurons may be called nodes. Dendrites comprise input, cell nuclei represent nodes, synapses represent weights, and axons represent output in ANNs built after real-world neural networks.

5. Simulation Results

The suggested work's simulation was performed in MATLAB/SIMULINK. The effectiveness of the suggested system is evaluated under a variety of load scenarios.

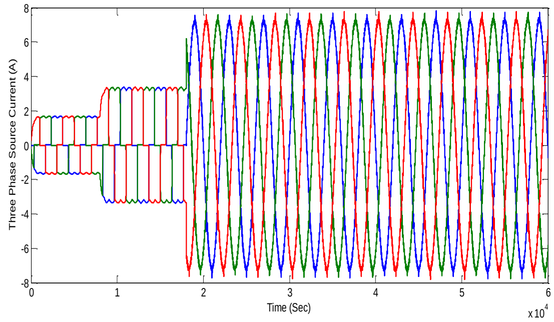

Fig. 5. Three Phase Source Current

Figure 5. Represents the three-phase source current of the system. However, single phase current is considered for the purpose of analysis.

5.1. Without shunt APF

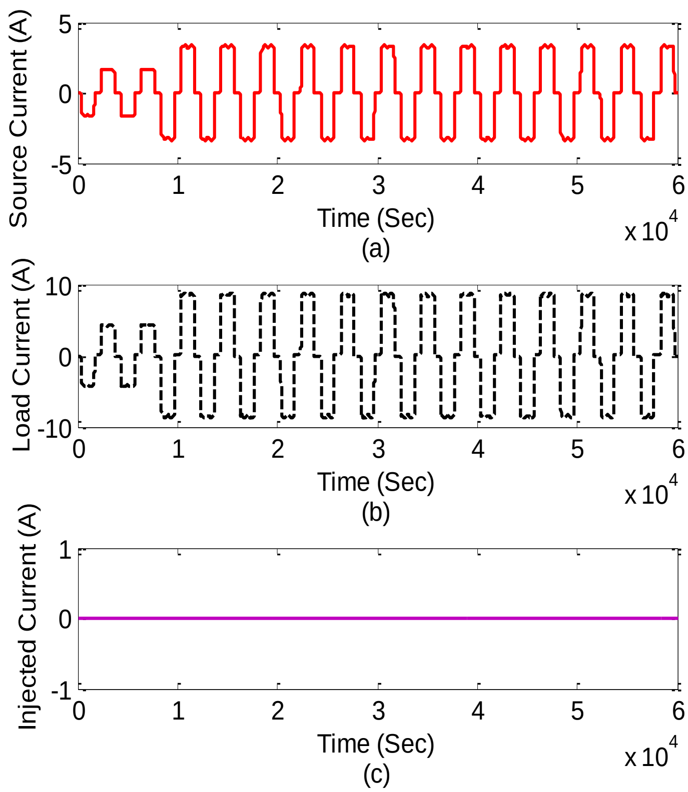

Figure 6. Simulation results of Non- Linear Load (a) Source Current (b) Load Current (c) Injected Current

Figure 6 (a) shows that the source current does not have a sinusoidal waveform because of the nonlinear load. In Figure 6 (b) and Figure 6 (c), we can see the load current and the injected current.

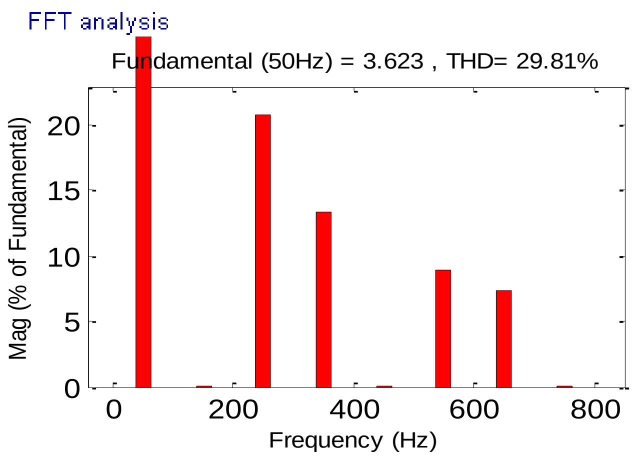

Fig. 7. THD of Source Current

5.2. With shunt APF with PI controller

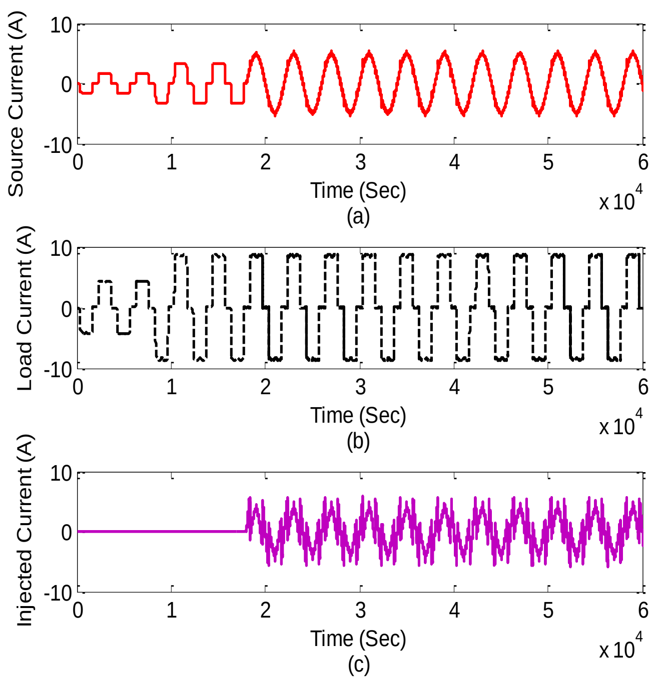

Fig. 8. Simulation results with APF (a) Source Current (b) Load Current (c) Injected Current

The SAPF causes the source current to have a sinusoidal waveform, as seen in Figure 8 (a). The Load and Injected currents re shown in Figures 8 (b) and 8(c).

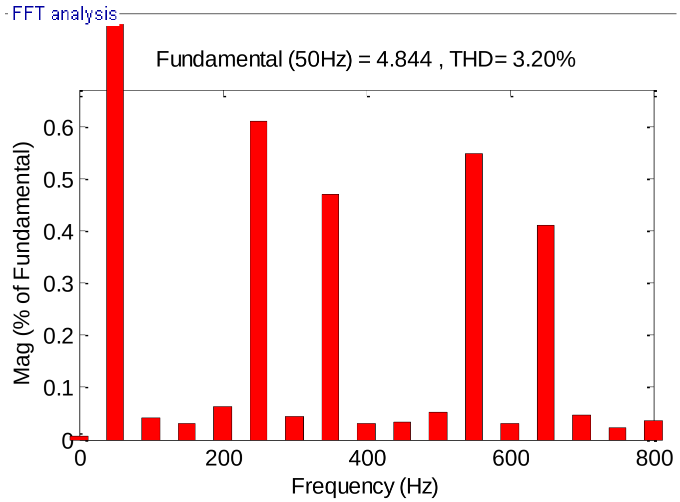

Fig. 9. THD of Source Current

From FFT analysis THD of Source Current is 3.20%.

5.3. With Shunt APF with ANN Controller

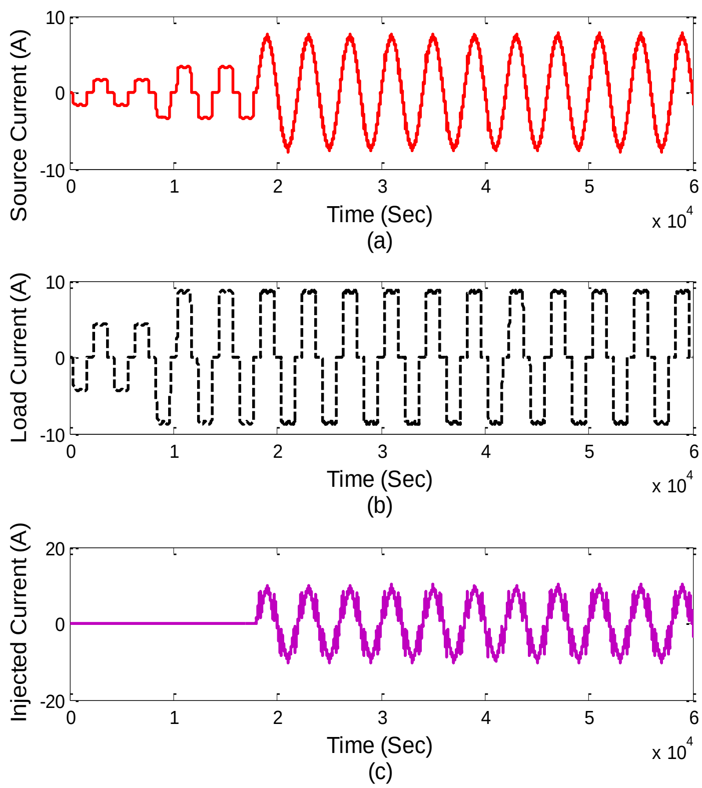

Fig. 10. Simulation results with APF (a) Source Current (b) Load Current (c) Injected Current

If one examines Figure 10, they will see that the source current waveform is sinusoidal because of SAPF. Figure 10 (b) and Figure 10 (c) depict the load current and injecting current, respectively.

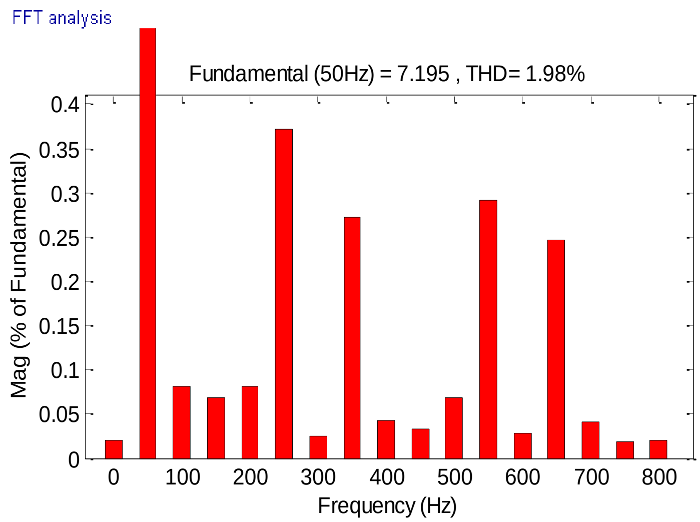

Fig. 11. THD of Source Current

From FFT analysis THD of Source Current is 1.98%.

5.4. With Shunt APF with Combination of Unbalanced load (PI Controller)

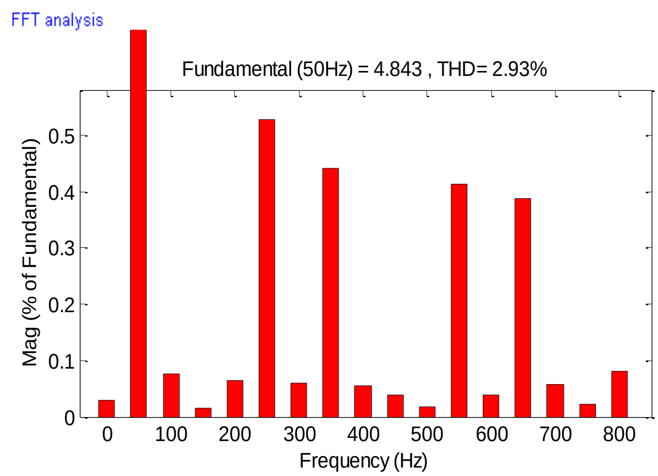

Fig. 13. THD of Source Current

From FFT analysis THD of Source Current is 2.93%.

5.5. With Shunt APF with Combination of Unbalanced load (ANN Controller)

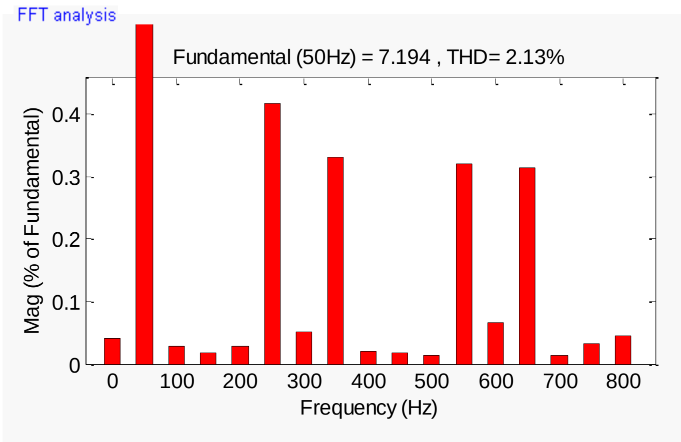

Figure 15. THD of Source Current

From FFT analysis THD of Source Current is 2.05%.

Table 2. Load values for both ANN and PI controller techniques

Type of Load	**Load**	**Load value**
Unbalanced Load	Resistance	15Ω, 6Ω, 8Ω
	Inductance	8e-3H, 4e-3H
Balanced Load	Resistance	7Ω
	Inductance	10H

Table 3. Simulation test results of distribution system under nonlinear loading

Operating Conditions	**THD % with PI controller**	**THD % with ANN controller**
Without Shunt APF	29.81	29.81
With Shunt APF	3.20	1.98
With Shunt APF with Combination of Unbalanced load	2.93	2.13
With Shunt APF with Combination of Balanced load	3.77	2.53

With Shunt APF with Combination of Unbalanced and Balanced load	4.09	2.55
With Shunt APF with Combination of Balanced Highly Inductive load	3.14	2.05
With Shunt APF with Combination of Balanced Highly Inductive load and Unbalanced load	3.19	2.08

When the active power filter is not connected to the system, the THD of the source current is the same for the PI controller approach and the ANN controller technique, as shown in Table 3. It is also clear that the THD values of the source current are reduced when an APF equipped with an ANN controller is connected to the system, as compared to the case where an APF equipped with a PI controller is used.

6. Conclusion

An inverter is used to link a modelled shunt active power filter to a simulated three-phase, four-wire power distribution network. Based on the findings, we can say that the grid-interfacing inverter serves both the inverter and the Active Power Filter roles. The grid-interfacing inverter is able to keep the source current sinusoidal by lowering the THD of the supply voltage under a wide range of load situations. Inverter current regulation is handled using a PI and ANN controllers. From the table 3, it can be seen that the THD of source current is same for both PI controller technique and ANN controller technique when the active power filter is not connected to the system. When the APF with PI controller and ANN controller without any load (except non-linear load) is connected individually to the system, then it can be observed that the THD value of source current with ANN controller is less when compared to THD value of source current with PI controller. The same can be observed when different types of loads like Unbalanced Load, Balanced Load, combination of both Balanced and Unbalanced Load, Balanced Highly Inductive Load, combination of Balanced Highly Inductive load and Unbalanced Load etc., are connected additionally and individually to the system. By comparing the THD values of source current while using ANN controller and PI controller technique, it was suggested that the usage of ANN controller technique gives better results compared to PI controller technique. This indicates that the usage of ANN controller technique will reduce the current harmonics and helps in enhancement of Power Quality

Appendix 1

S. No	Abbreviation	Description
1	APF	Active Power Filter

2	ANN	Artificial Neural Network
3	PI	Proportional Integral
4	OCC	Optimized Current Control
5	TIFS	Transformer Integrated Filtering System
6	CEMA	Centralized Energy Management Approach
7	DVR	Dynamic Voltage Restorer
8	THD	Total Harmonic Distortion
9	PQ	Power Quality

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