Received: 8 September 2021 | Revised: 5 October 2021 | Accepted: 10 October 2021
DOI: 10.37917/ijeee.17.2.23 Vol. 17| Issue 2| December 2021

Open Access

Iraqi Journal for Electrical and Electronic Engineering
Original Article

Ant Colony Algorithm (ACO) Applied for Tuning PI of Shunt Active Power Filter (SAPF)

Raheel Jawad[*1], Rawaa Jawad[2], Zahraa Salman[1]
[1]Electromechanical Department, University of Technology, Baghdad, Iraq
[2] Electrical and Electronic Department, University of Technology, Baghdad, Iraq

Correspondence
*Raheel Jawad
Electromechanical Department,
University of Technology, Baghdad, Iraq
Email: eme.51262@uotechnology.edu.iq

Abstract
In the present-day decade, the world has regarded an expansion in the use of non-linear loads. These a lot draw harmonic non-sinusoidal currents and voltages in the connection factor with the utility and distribute them with the useful resource of the overall performance of it. The propagation of these currents and voltages into the grids have an effect on the electricity constructions in addition to the one of various client equipment. As a result, the electrical strength notable has come to be critical trouble for each client and distributor of electrical power. Active electrical electricity filters have been proposed as environment splendid gear for electrical power pinnacle notch enchantment and reactive electrical strength compensation. Active Power Filters (APFs) have Flipped out to be a possible wish in mitigating the harmonics and reactive electrical electricity compensation in single-phase and three-phase AC electrical energy networks with Non-Linear Loads (NLLs). Conventionally, this paper applied Ant Colony Algorithm (ACO) for tuning PI and reduce Total Harmonic Distortion (THD). The result show reduces THD at 2.33%.

KEYWORDS: ACO, APF, PID, THD, Nonlinear, Control, p-q Theory.

I. INTRODUCTION

In an ideal power system, power should be transferred from the source to the customer as pure sine waves for voltages and currents. But in practice, which does not happen for existence of non-linear load for example power electronic converters which add a wide range of harmonic distortion into utility grid.

Power electronic converters act as non-linear loads due to the switching operation which occur within them. Inserting these converters lead to generating random harmonics into the utility grid, which causes a poor power quality. Furthermore, utilizing power electronic converter with high inductive loads lead to decrease the power factor level [1], [2]. These poor power quality problems add unnecessary losses to utilities, and can cause electrical hazards in electrical equipment, such as transformers, underground cables and meters.

- To mitigate power quality problems, which are mainly high Total Harmonic Distortion (THD) with reduced power factor, two main solution is proposed:
- (i) Passive filter
- (ii) Active power filter.

These filters are still in optimization process and the new trends focus on implementing multilevel inverters in Active Power Filters with different control techniques.

Installation of various types of power electronic converters and nonlinear load for example AC/DC rectifiers, variables frequency drive and soft starters, is the major cause of PQ problems (high THD%, poor power factor and different types of transients). Therefore, it is crucial to evaluate new solutions in order to increase the quality of the electrical services utilizing reducing the harmonics distortion, correcting the power factor and reducing the losses.

Recently, a tremendous research focused on delivering real power to the loads, in addition to mitigating harmonics and increasing the power factor up to unity, which may cause problems associated with resonance and stability. APFs become the most effective solution in eliminating different types of harmonics (inter-harmonics and sub-harmonics) due to their advantages such as; fast response to grid variations, ability to compensate random harmonics and high control accuracy [3]. In practice, APF injects a compensating current or voltage into the Point of Common Coupling (PCC) equal but opposite in its direction to the grid's harmonics in order to cancel a wide range of harmonics which affect the system, also it generates / absorbs reactive power into PCC in order

to correct grid's power factor (PF). Furthermore, APF keeps the grid system balance and stable with load variations and grid transients. Fig. (1) shows the general operating concept of APF [4].

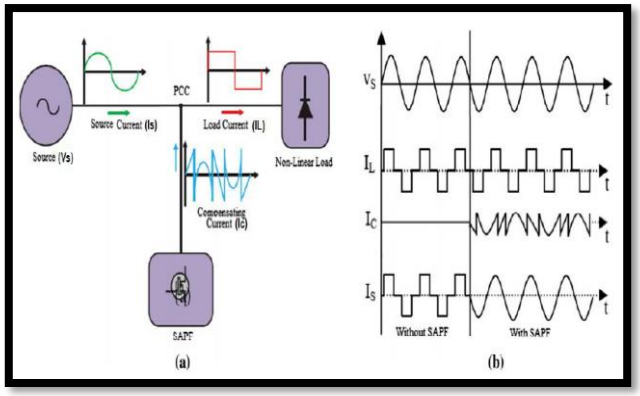

Fig. 1: General working concept of Active Power Filters; (a) block diagram of SAPF and (b) respective waveforms [4].

Many researches study active power filter and reduced Total Harmonic Distortion (THD) as: **Seema Agrawal, et.al (2018) [5]:** This research paper addresses current harmonics mitigation using shunt active power filter. Due to excessive use of power electronic converters (PECs) and non-linear loads it is observed that power system voltage and current responses become non sinusoidal and thus produce waveform driven power quality issues like voltage harmonic and current harmonic.. The proposed system is simulated using MATLAB/Simulink. An effective compensation solution with defined harmonic limit is obtained to improve power quality as per electrical regulatory commission and standards such as IEEE 519-1992. **Shikha Gautam, et.al (2019) [6] :** present design of shunt active power filter for minimizing total harmonic distortion, power quality enhancement using population based sine cosine algorithm. In this paper instantaneous p-q theory is used as control active filter technique that reduces the lower order harmonics. This method recovers supply side current quality. PI controller is used as a control strategy to control DC link voltage in the system. Parameters of the PI controller are chosen by a rule that intuitively tunes them. It is identified that THD is reduced by selecting optimal value of gain parameters. Therefore, adjusting the PI controller is very necessary. Applied Sine cosine algorithm (SCA) for tuning PI controller gain parameters i.e. Kp, Ki for improving dynamic execution of shunt active power filter. The simulation is done in MATLAB SIMULINK SOFTWARE under varying load and supply voltage conditions. **S.M. Imrat Rahman, et.al (2019) [7]:** proposes the design of an instantaneous power theory based 3-phase 2-level Shunt Active Power Filter (SAPF) for compensating current harmonics and reactive power using C-codes. The application of Finite Set Model Predictive Control (FS-MPC) for generating the compensating currents is also investigated in this paper. Additionally, the design of a High Pass Filter to extract oscillating component of active power and a controller to balance the dc link voltage is presented. The entire active power filter has been designed using C-codes which allows it to be directly implemented in a real time system. Furthermore, a MATLAB/SIMULINK model has been designed to inspect the operation of the developed active filter. Comparison this study with literature review.

TABLE 1
COMPARISON THIS STUDY WITH LITERATURE REVIEW

Author	Methods	THD
Seema Agrawal,et.al(2018)[5]	PI	2.77%
Shikha Gautam,et.al(2019)[6]	Sine Cosine Algorithm	2.92%
S.M. Imrat Rahman,et.al(2019)[7]	Model Predictive Control	13.24%
This study	PI with ACO	2.33 %

The contribution of this paper is reduce Total Harmonic Distortion (THD) of shunt active power filter by applied Ant Colony Algorithm (ACO) for tuning PI.

II. Control Techniques

A. PID Controller

The genuine – considered PID manipulate approach has been found to be a good method due to its low cost, loads masses lots plenty much less renovation in addition reachable in manipulate design. Essentially, the PID controller variables consist of three parameters: proportional reap (kp), critical accumulate (ki) and spinoff reap (kd). Dynamic response of a machine improved utilizing means of way of way of a brilliant inserting of these variables, give up overshoot, and steady-state error, as properly as adorn the steadiness of the laptop [8].The current day block structure of a PID control device is hooked up in Fig.(2). The set problem is changed, then error calculated between the set aspect and actual output. The error signal, E(s) is processed with the recommended aid of from integral, proportional and spinoff motion with ensuing signal weighted and sum to manipulate signal, U(s), comply with to a best model. Then reap new output signals. This new suited signal will be transferred to the controller and as soon as higher the error signal will be calculated. New manipulate signals, U(s), will be dispatched to the plant. This technique run consistently to achieve everyday unite state error techniques zero [9-10].

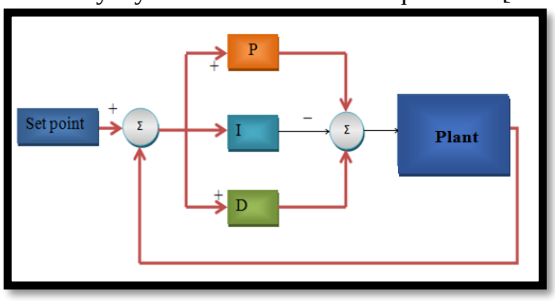

Fig. 2: PID control system.

B. Ant Colony Optimization

Ant colonies, and more generally social insect societies, are distributed systems that, in spite of the simplicity of their individuals, present a highly structured social organization. As a result of this organization, ant colonies can accomplish complex tasks that in some cases far exceed the individual capabilities of a single ant [11].

Ant colony optimization (ACO) is based on the cooperative behavior of real ant colonies, which are able to find the shortest path from their nest to a food source via a form of indirect communication. The method was developed by Dorigo and his associates in the early 1990s [12,13]. The ant colony optimization process can be explained by representing the optimization problem as a as shown in Fig. (3), where the Kp, Ki tuning using ACO. Flow chart of ACO show in Fig. (4).

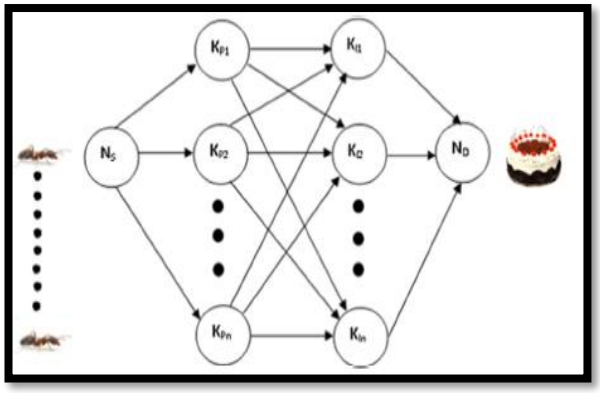

Fig. 3: PI tuning using ACO.

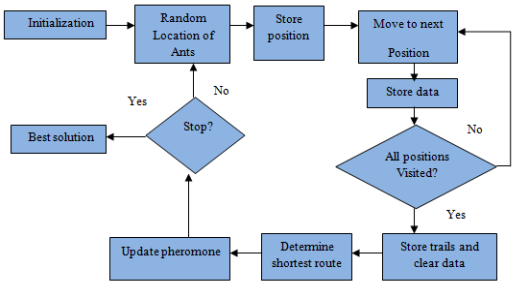

Fig.4: Flow chart of ACO

C. Hysteresis Control Method

The existing day manipulate technique performs a quintessential attribute in unexpectedly response existing day managed inverters such as the lively electrical energy filters. The hysteresis current manipulate method is the most regularly proposed manipulate approach in time domain. This strategy affords straight away employer new corrective response, pinnacle accuracy and unconditioned steadiness to the system. Besides which, this technique is noted to be the most exquisite answer for current managed inverters.

Hysteresis contemporary manipulate is approach of controlling a voltage furnish inverter so which an output present day is generated which follows a reference current day waveform.

The frequent form of PWM voltage supply inverter with hysteresis controller is hooked up in Fig. (5). The hysteresis manipulate approach ambitions to preserve the managed modern-day day indoors a described rejoin spherical the liked reference current. The attention of the switches is determined in accordance to the error. When the present day is growing and the error exceeds a extremely good tremendously proper value, the recognition of the switches changes and the brand new day starts off evolved to forestall until the error reaches a immoderate extraordinarily appropriate horrible value, then the switches center of interest changes as quickly as increased [14].

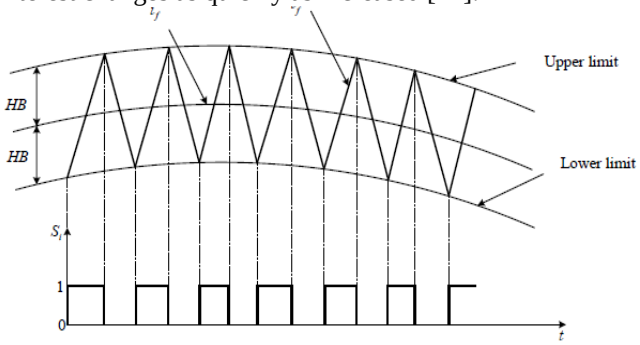

Fig. 5: Hysteresis control principle [14].

III. P-Q Method Mathematical Modelling

The relative between loads voltage and current for power system three phase and orthogonal coordinate (α-β-0) systems expressed utilizing Clarke's transformations which show

As following formula 1 and 2 [15-18].

$$\begin{bmatrix} V\alpha \\ V\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -0.5 & -0.5 \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} I\alpha \\ I\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -0.5 & -0.5 \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} Ia \\ Ib \\ Ic \end{bmatrix} \quad (2)$$

In orthogonal coordinate systems instant power may be establish out as simple multiply current instantaneous with instantaneous voltage. Three phase coordinates systems (a-b-c) equally orthogonal is nature, as well as establish out instantaneous power as 3:

$$p = v_a i_a + v_b i_b + v_c i_c \quad (3)$$

From formulas above, instantaneous reactive and active power in matrix as:

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V\alpha & V\beta \\ V\beta & -V\alpha \end{bmatrix} \begin{bmatrix} I\alpha \\ I\beta \end{bmatrix} \quad (4)$$

The instantaneous reactive power produce an opposite vector with 180°phase shift for reduces harmonic components in the current line, yield 5.

$$\begin{bmatrix} Is\alpha^* \\ s\beta^* \end{bmatrix} = \frac{1}{V\alpha^2 + V\beta^2} \begin{bmatrix} V\alpha & -V\beta \\ V\beta & V\alpha \end{bmatrix} \begin{bmatrix} Po + Ploss \\ 0 \end{bmatrix} \quad (5)$$

Current compensating of each phase will be derive utilizing inverse Clarke transformations as show in 6.

$$\begin{bmatrix} Ica^* \\ Icb^* \\ Icc^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -0.5 & \frac{\sqrt{3}}{2} \\ -0.5 & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} Is\alpha^* \\ Is\beta^* \end{bmatrix} \quad (6)$$

IV. Simulink Model of Shunt APF

The simulation model achieve utilizing MATLAB/Simulink environments utilizing Toolbox Sim-power system. Fig. (6) shows model of The *p-q* theory. Model of Hysteresis controller shown in Fig (7) also Model of Shunt APF with p-q method show in Fig (8) as well as non-linear loads show in the Fig.(9). Fig. (10). Show a model of shunt APF Nonlinear load. The output is three phase current reference which send of current hysteresis control anywhere this current is compare with actual current for active filter for getting the driving pulses for inverter.

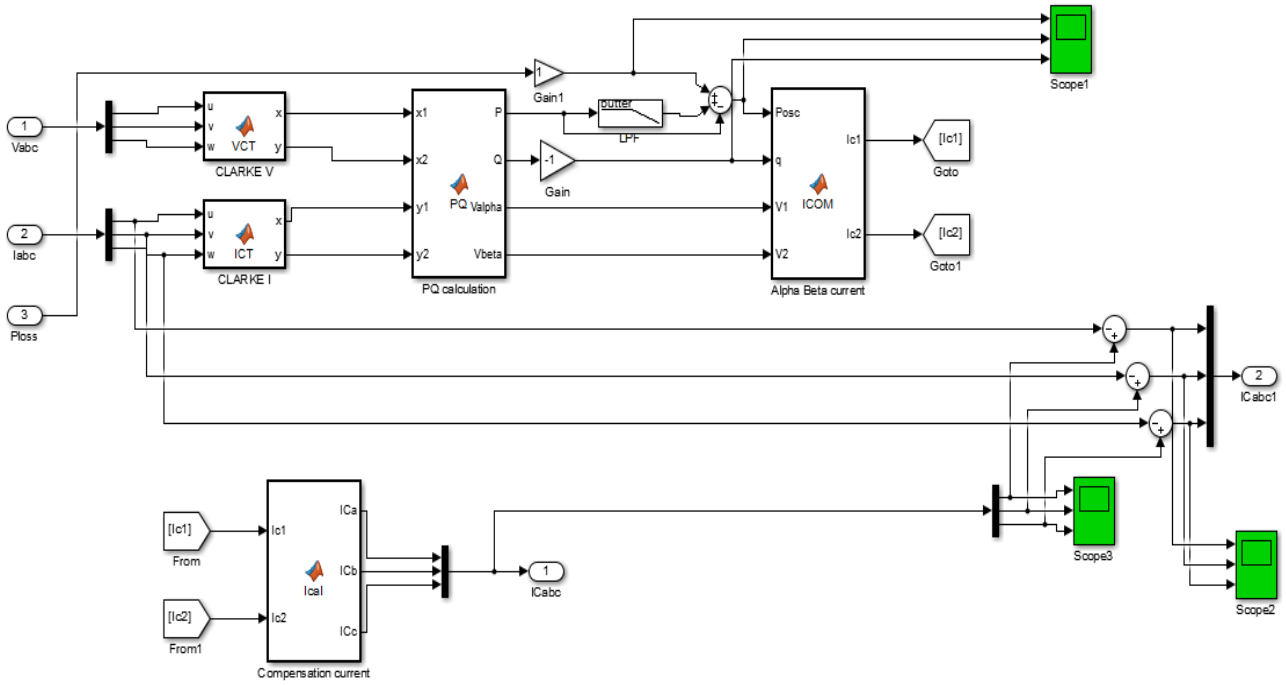

Fig. 6: Model of The *p-q* theory

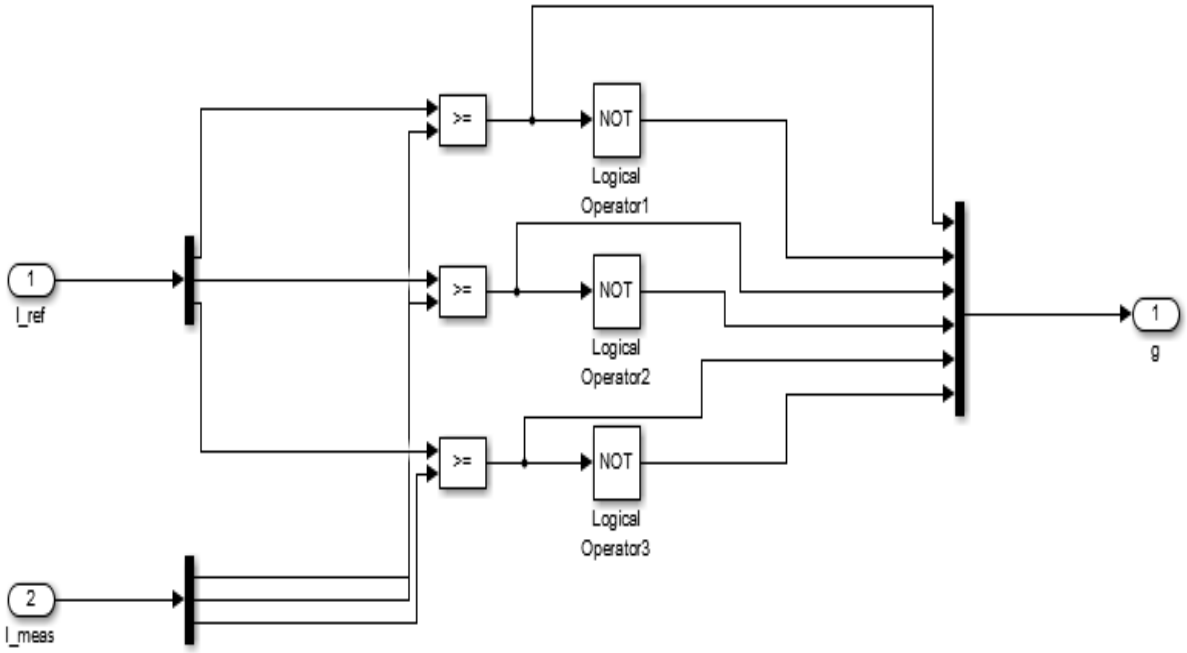

Fig. 7: Model of Hysteresis controller

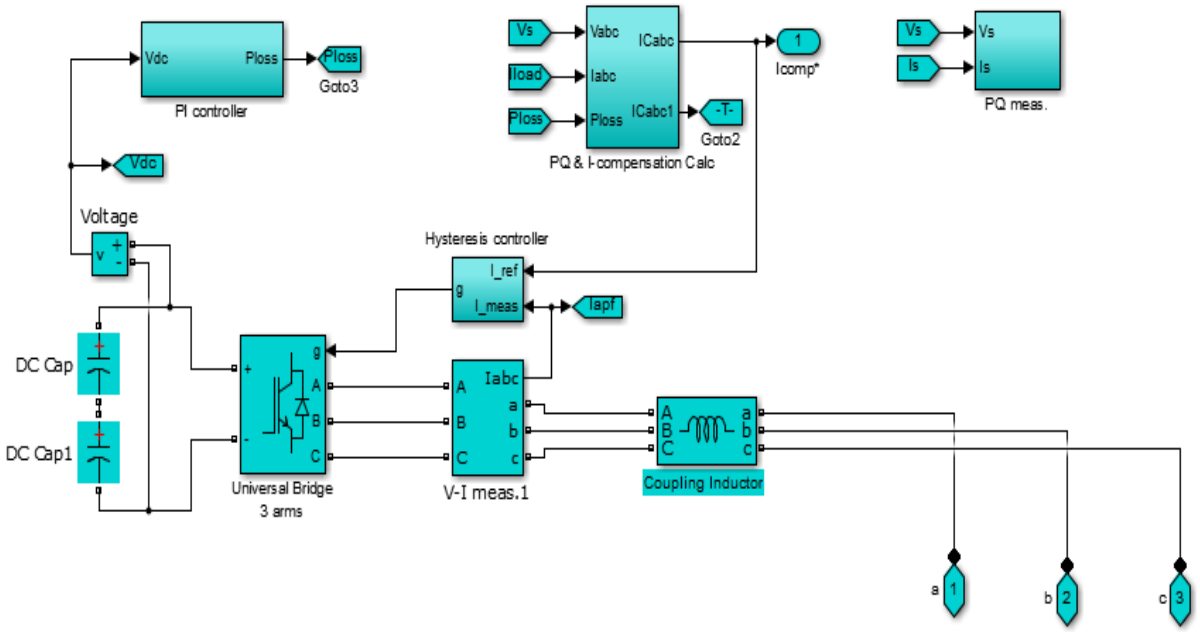

Fig. 8: Model of Shunt APF with p-q method

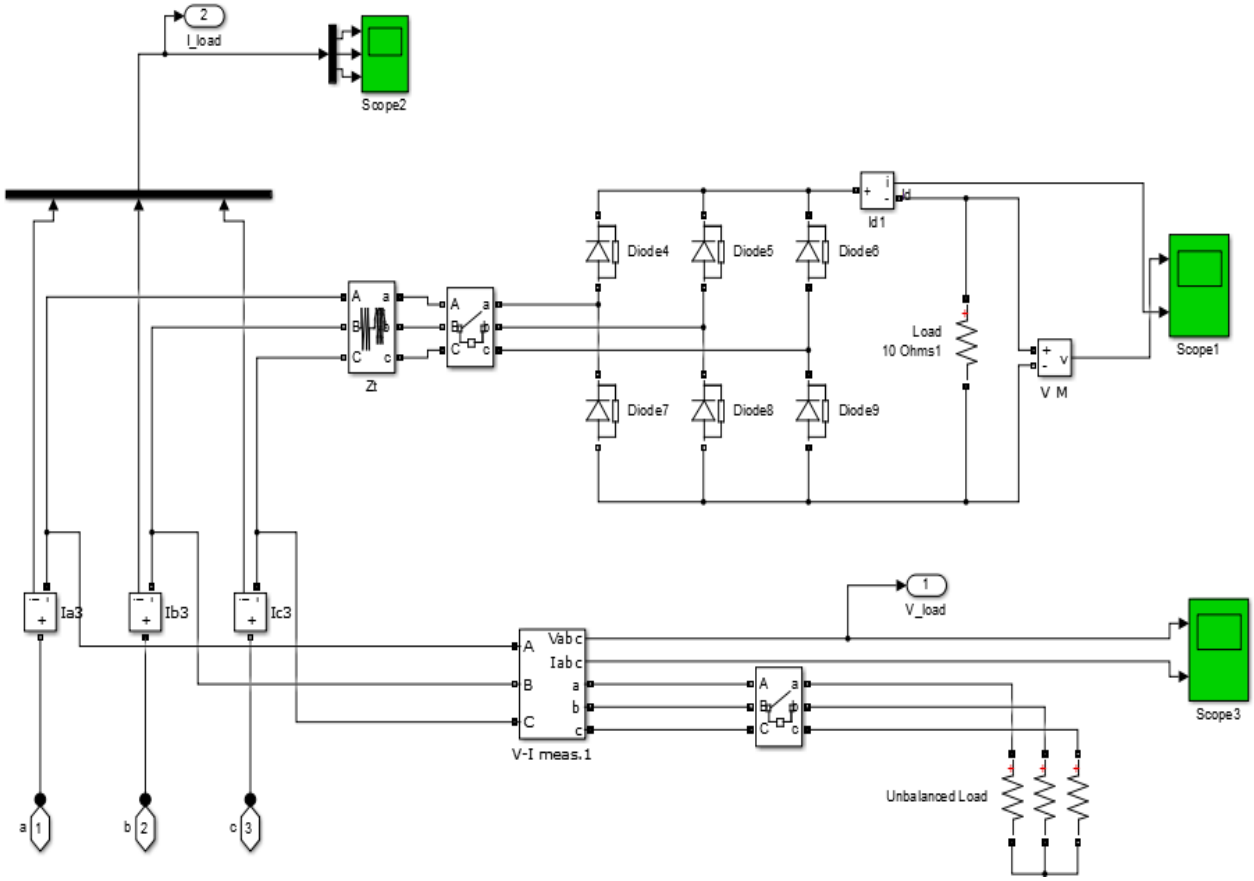

Fig. 9: Model of Nonlinear load

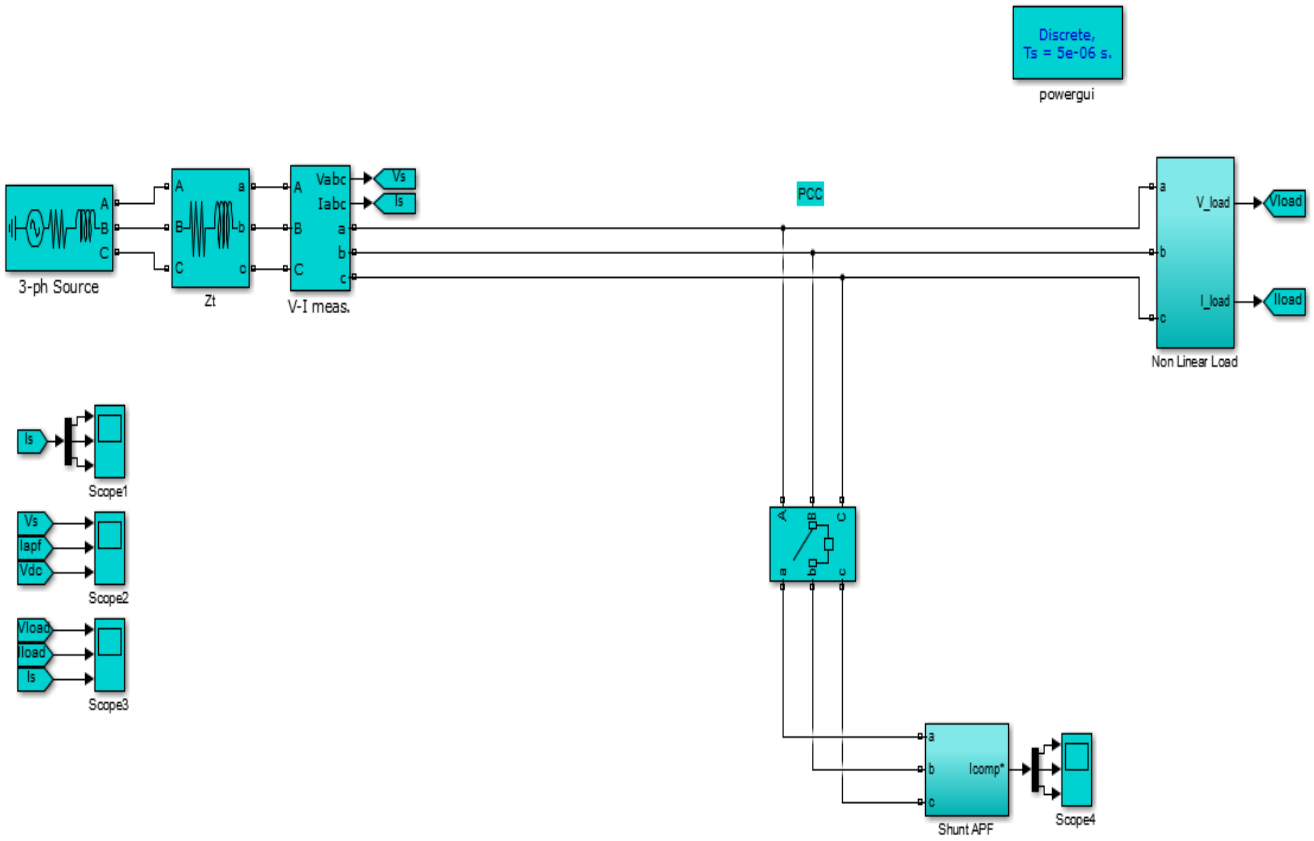

Fig. 10: Model of shunt APF Nonlinear load

V. Design Parameter of Matlab Simulation

Simulations are performed on balanced Non-Linear Loads consist of R-L loads and bridge rectifier as show in Table (2) and Table (3):

System Parameter

TABLE 2
SYSTEM PARAMETER SPECIFICATION

Source Voltage (r.m.s)	400 Volt
System Frequency	50 Hz

Active power Filter (APF) Parameter

TABLE 3
SAPF PARAMETER SPECIFICATION

Coupling Inductance	1mH
Coupling Resistance	0.01Ω
Dc link capacitance	1100μF
Source inductance	0.05mH
Source resistance	0.1Ω

PI Tuning

TABLE 4
PARAMETERS OF KP AND KI TUNING

Methods	KP	KI	THD
PI only	7.2343	0.61654	5.66%
PI with ACO	4.8741	0.1435	2.33%

VI. Simulink Result and Discussion

The simulation result achieve utilizing MATLAB/Simulink environments utilizing Toolbox Sim-power system of current source and compensation current. Fig. (11). illustrated current source, voltage source, current load with current of APF. Fig. (12) Show Harmonic of Source current of three-phase nonlinear load and source voltage of SAPF.

VII. Conclusion

The enchantment used to be as quickly as efficaciously achieved with the aid of the utilization of imparting an desire pathway for the distorted existing day which complementary to the nonlinear current. All electrical electricity switches in the APF had been properly managed the utilization of the lively PWM signal and the pulse generator to attribute blanketed commutation operation. The proposed immediate

real-power controller makes use of diminished computation for reference trendy calculations in massive big difference to massive approach. The proposed inverter switching signs are generated the utilization of triangular-sampling current controller; it gives a dynamic set up sizable prevalent average performance underneath transient and regular unit state conditions. On the groundwork of the simulation, to discover out harmonic wave and reactive load present day efficiently, compensate the load current day effectually with the really useful beneficial aid of reshaping the provide cutting-edge to which related to sine wave and reducing the THD rate to below 2.33%. The compensation large frequent extensive normal overall performance of the simulation supply up supply up give up cease result affords a sensible method to the groundwork of APF & utilized to Induction Drive to take a appear at the large famous ordinary overall performance characteristics.

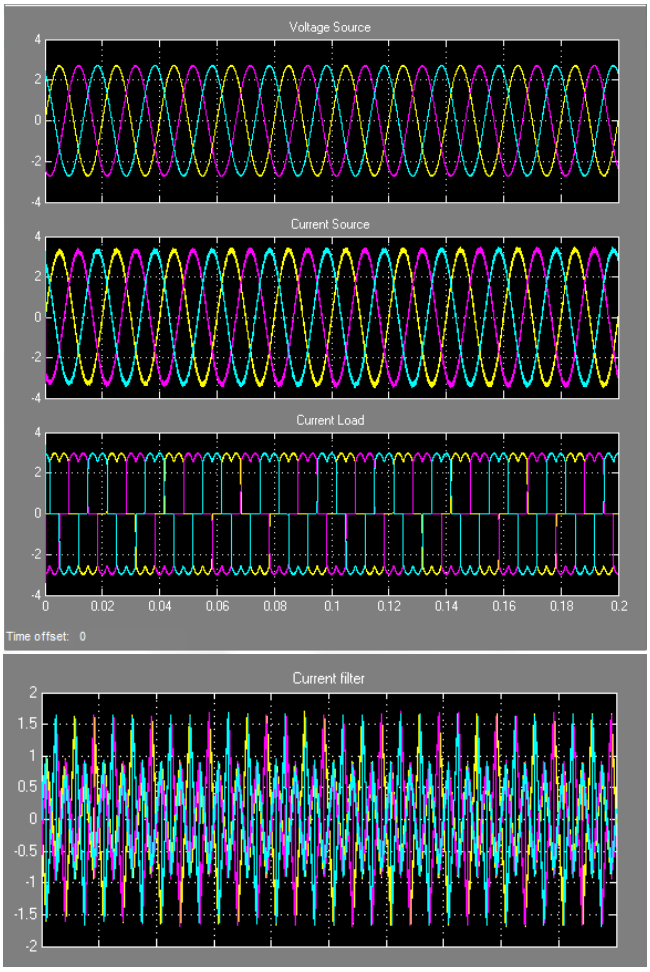

Fig. 11: Voltage source, current load, current source and current filter.

CONFLICT OF INTEREST

The authors have no conflict of relevant interest to this article.

REFERENCES

[1] A. Baggini. Handbook of power quality. John Wiley & Sons, 2008.

[2] S. Mukhtiar, et al. "Grid interconnection of renewable energy sources at the distribution level with power-quality improvement features," IEEE transactions on power delivery, vol. 26, no.1, pp. 307-315, 2011.

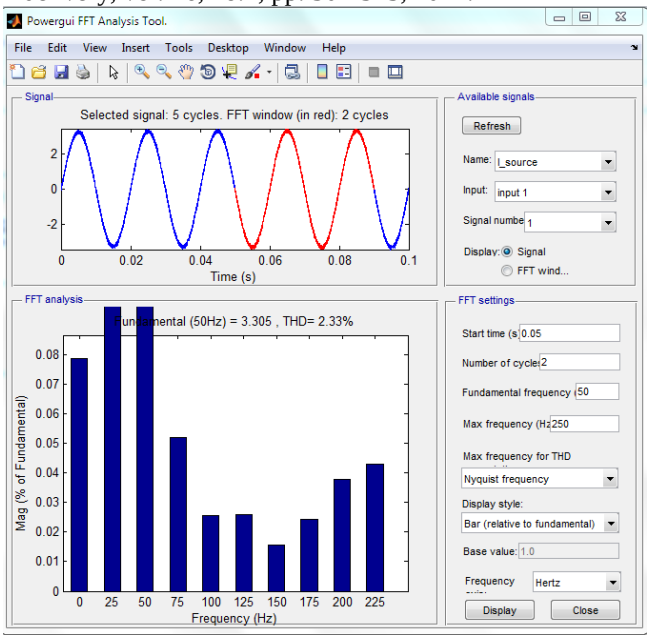

Fig. 12: Harmonic of source current of SAPF

[3] M. Moftah, Amin, G. El-Saady, and A. Ibrahim. "Active Power Filter for Power Quality Enhancement of Photovoltaic Renewable Energy Systems," Smart Grid (SASG), 2016 Saudi Arabia. IEEE, 2016.

[4] S. Elango, and M. Venugopal. "On Design and Implementation of Three Phase Three Level Shunt Active Power Filter for Harmonic Reduction Utilizing Synchronous Reference Frame Theory," International Journal of Electrical Power & Energy Systems vol. 81, pp. 40-47, 2016.

[5] S. Agrawa, V. Kumar Gupta, D. K. Palwalia and R. K. Somani" Performance Analysis of Shunt Active Power Filter based on PIDA Controller," IEEE , 2018 2nd International Conference on Micro-Electronics and Telecommunication Engineering 2018 .

[6] Sh. Gautam, "Sine Cosine Algorithm Based Shunt Active Power Filter for Harmonic Compensation," Proceedings of the Third International Conference on Electronics Communication and Aerospace Technology.

[7] S.M. Imrat R. Md. A. Abdulla Samy,Sh. Saha "C-code Implementation of a Shunt Active Power Filter Based on Finite Set Model Predictive Control" 2019 International Conference on Robotics,Electrical and Signal Processing Techniques (ICREST).

[8] Roland S. Burns, "Advance Control ", Butterworth-Heinemann, Published, 2001.

[9] M. Mohammed Matrood, A. Ahmed Nassar, "Modeling and Control of Torsional Vibration in Rotating System Using Dual Loop Controllers", Iraqi Journal for Electrical

and Electronic Engineering, vol. 17, Issue 1, pp.1-5, 2021. DOI: 10.37917/ijeee.17.1.2.

[10] B. Nasser Abdul- Samed and Ammar A. Aldair, "Design Tunable Robust Controllers for Unmanned Aerial Vehicle Based on Particle Swarm Optimization Algorithm", Iraqi Journal for Electrical and Electronic Engineering, vol. 15, Issue 2, 2019.

[11] M. Dorigo and T. Stuzel, “Ant Colony Optimization”, the MIT Press, 2004.

[12] A. Colorni, M. Dorigo, and V. Maniezzo,"Distributed optimization by ant colonies, in Proceedings of the First European Conference on Artificial Life", F. J. Varela and P. Bourgine, Eds., MIT Press, Cambridge, MA, pp. 134-142, 1992.

[13] M. Dorigo, V. Maniezzo, and A. Colorni, “The ant system optimization by a colony of cooperating agents”, IEEE Transactions on Systems, Man, and Cybernetics-Part B, vol. 26, no. 1, pp. 29–41, 1996.

[14] M. Mohapatra, B.Chitti Babu, “Fixed and Sinusoidal-Band Hysteresis Current Controller for PWM Voltage Source Inverter with LC Filter”, IEEE Student‟s Technology symposium 2010.

[15] I. Ali, V. Sharma, P. Chhawchharia, "Control Techniques for Active Power Filter For Harmonic Elimination & Power Quality Improvement," International Journal of Electrical, Electronics and Data Communication, vol. 4, Issue 10, 2016.

[16] Boualem Boukezata, Abdelmadjid Chaoui, Jean-Paul Gaubertb and Mabrouk Hachemi, "Implementation of Predictive Current Control for Shunt Active Power Filter," Proceedings of the 6th International Conference on Systems and Control, University of Batna 2, Batna, Algeria, May 7-9, 2017.

[17] G. Deep Srivastava, D. Rajendrakumar Kulkarni, "Design, Simulation and Analysis of Shunt Active Power Filter utilizing Instantaneous Reactive Power Topology," IEEE 2017 International Conference on Nascent Technologies in the Engineering Field (ICNTE-2017).

[18] K. Mini Namboothiripad, Minarti Mane, "PWM based Sliding Mode Controller for ShuntActive Power Filter," IEEE, 2017 International Conference on Nascent Technologies in the Engineering Field (ICNTE-2017).