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A Review of Control Technique Applied in Shunt Active Power Filter (SAPF)

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HIGHLIGHTS

- Study of SAPF technology for processing harmonics in the network
- The THD is summarized for a literature review.
- controller techniques: reference current generation, PWM Control, and DC voltage control
- Using optimization algorithms for the PI control system to perform well in reducing THD
- Some Highlights findings of literature review:
  - Pavitra Shukl 2020 [43]
  - Narendra Babu 2020 [47]
  - -Maciej Klimas 2021 [49]
  - Abhishek Srivastava 2018 [51]
  - P. Suresh 2020 [52]

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Keywords:
SAPF; THD; PID Control; p-q Theory; PWM.

ABSTRACT

In recent years, electronic transformers and electronic devices (nonlinear loads) have increased. These loads are the source of harmonics (non-sinusoidal and distorted waves) and the interactive force that affects the performance of the power system network. Also, it badly affects the power factor and electrical energy on the scales of efficiency and quality. For this reason, a system called "Active Power Filters" has been adopted. It provides an effective alternative to traditional LC passive power filters. It can improve network performance by treating and reducing harmonics, improving power factor and quality, avoiding resonance between the filter and the network, and reducing reactive power. This paper presents a study on the shunt active power filters device and how to connect it to the distribution network and A review of the bathing control strategies in the methods of calculating current and power, methods of controlling the PWM device, the most prominent techniques for improving the PID control system, and the most prominent algorithms applied in that to improve the safety performance of the Shunt Active Power Filter (SAPF) on the one hand and to demonstrate the ability of different systems to compensate for THD on the other hand. APF performance fluctuates from one control strategy to another. It reduced (THD) between 0.9% and 13% in several control techniques applied with PWM. The aim of this paper is to illustrate the techniques applied to control the performance of the "Shunt Active Power Filter" to reduce THD.

1. Introduction

The rapid increase in the use of non-linear loads such as electronic devices and inverters, which are the sources of harmonics and reactive power, negatively affects the system's performance. It becomes a fact beyond denial that harmonics are non-sinusoidal, in equal balance with distorted waves. This leads to distortion of the vector line voltage, current, and electromagnetic interference, leads to a decreased power factor, poor electrical quality problems of interference in communication systems, heat and low power efficiency, etc. [1-5]. Above all, the loss of electrical power in transmission and distribution becomes a matter of fact. Harmonics can be filtered and processed using power filters such as passive power filters, active power filters (both types of shunt active power filter, series active power filter), and hybrid power filters. Passive filters have several drawbacks, including resonance, electromagnetic resonance in the network, and reactive power problems. To overcome these problems, shunt active power filters SAPF, which are covered in this paper, have been used to reduce the total harmonic wave distortion THD and improve the quality and efficiency of electrical power [6-15]. The electrical power system in the research is three-phase [3]. Three-wire system consists. A three-phase voltage source for alternating current.

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Non-linear load represented by electronic devices or electronic power inverters, Shunt Active Power Filter (SAPF), and network impedance may be balanced or unbalanced, as shown in Figure 1. Active Power Filter consists of a PWM VSI voltage source inverter [20]. The (SAPF) device works on the principle of sensing harmonics in the source current wave. It generates a compensating current (If) injected into the network through a common coupling point (PCC) to reduce harmonics, eliminate unwanted frequencies, compensate the reactive power, and correct the waveform as close to the sinusoidal shape as possible [21]. The following inverter is fed from a DC source [19]. The APF is connected in parallel between the load current and the filter current, as shown in the proposed control circuit [22]. An alternating voltage source must be known and measured. It should be considered that the source current and the source voltage difference are equal to the voltage difference at the common coupling point (PCC).

The main purpose of the SAPF is to reduce THD by injecting a compensated electric current of SAPF into the network through the PCC and counter-current to the current source phase.

$$If = Il - Is \tag{1}$$

Generating and pumping the compensated current in the three-phased wire network consists of a PWM and a voltage source that uses a Cdc capacitor as a power source. This process is controlled by different control techniques, as shown in Figure 2, including current reference generation Techniques and inverter control techniques such as hysteresis PWM and DC voltage regulator control. In addition, these processes are subject to a PID balanced control system [2].

2. Current Reference Generation Techniques

Several control strategies are applied to control the SAPF device. These strategies are techniques for calculating power and current to estimate the compensated current in terms of waveform and its amount, taking into account the frequency domain and time domain use, shown in Figure3. These techniques are summarized from references [1-35]. To complete these calculations, we need to know the main current source voltage and DC link voltage values. We will discuss the methods of calculating the compensated current below, such as the pq method. These methods are valid for operating the SAPF device in the case of a transitional system or a steady-state and for the general voltage being based and synchronous detection method, which allows the SAPF device to control in real-time [2-7].

2.1 PQ Theory

For further references to any determination of currents, there are several advanced strategies as the theory of PQ that has been an active and instantaneous reactive current components and a method of simultaneous detection as shown in the block diagram of Figure 4. This strategy uses the first Clarke Transform shift current load and source voltage defined in the equations [5].

The two-phase calculation method is used to convert the three-phase measurements into a two-phase model (α & β) using Clarke transform according to Eq. (2) and (3)[5].

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

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

Both instantaneous real power (P) and instantaneous reactive power (Q) can be calculated by implementing Eq. (4)[5].

$$\begin{bmatrix} P \\ Q \end{bmatrix} = \begin{bmatrix} V\alpha & V\beta \\ V\beta & -V\alpha \end{bmatrix} \begin{bmatrix} I\alpha \\ I\beta \end{bmatrix} \tag{4}$$

Where:

$$P = \bar{P} + \tilde{P} \tag{5}$$

$$Q = \bar{Q} + \tilde{Q} \tag{6}$$

Such P- and Q-are the average components of real and reactive powers, respectively. The reference compensating currents $Ia*$ and $Ib*$ in a two-phased model can be calculated depending on Eq. (7)[5].

$$\begin{bmatrix} I\alpha^* \\ I\beta^* \end{bmatrix} = \frac{1}{V\alpha^2 + V\beta^2} \begin{bmatrix} V\alpha & V\beta \\ V\beta & -V\alpha \end{bmatrix} \begin{bmatrix} P \\ Q \end{bmatrix} \tag{7}$$

The compensating current in a three-phased model is mandatory for a three-phased inverter and can be evaluated from Eq. 7 by applying inverse Clarke transformation according to Eq. (8) [5].

$$\begin{bmatrix} Ia^* \\ Ib^* \\ Ic^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -0.5 & \frac{\sqrt{3}}{3} \\ -0.5 & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} I\alpha^* \\ I\beta^* \end{bmatrix} \quad (8)$$

2.2 DQ Theory

The d-q method makes it possible to analyze the three-phased load current into positive, negative, and zero sequences depending on the park transformation method. The current signal is synchronized with the respective source voltage [11], shown in Figure (5).

2.3 Direct testing and calculating method (DTC)

This method aims to detach the reactive power and harmonics from the load currents shown in the figure. The stream is filtered to elicit the main constituent. As the current signal is synchronized with the source voltage, this technology provides the reactive power required by the load. However, a problem with these techniques floats to the surface. It is the fluctuation of low-frequency current from the DC voltage of the active power filter, as shown in Figure (6) [34].

2.4 Synchronous reference frame method (SRF)

In this technique, real currents are converted into a synchronous reference frame. One of the advantages of this method is that the reference currents are directly derived from the real load currents without referring to the voltage source shown in Figure (7) [34].

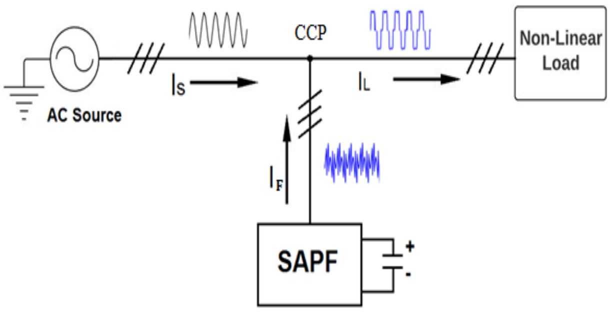

Figure 1: Shunt APF connected to the power system

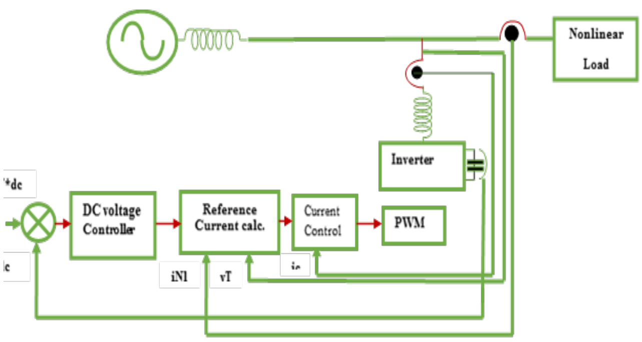

Figure 2: Block diagram of the controller of APF [7]

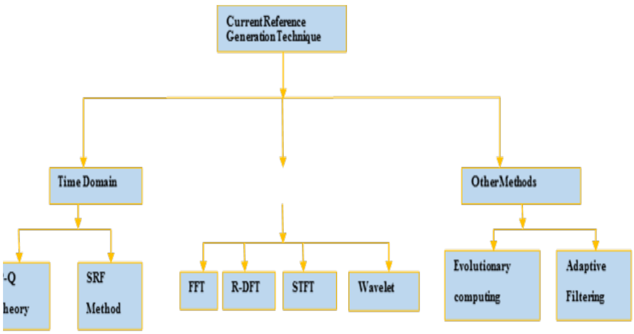

Figure 3: Control Strategies Applied to APF

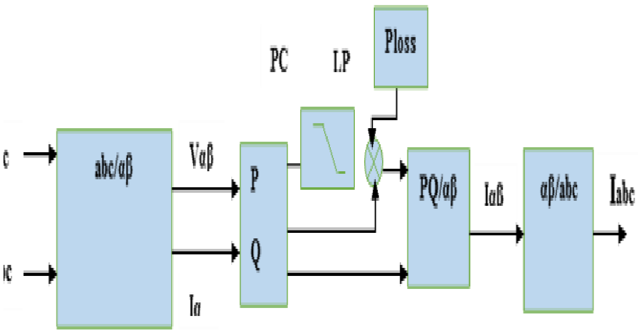

Figure 4: Block diagram of the instantaneous reactive power theory [5]

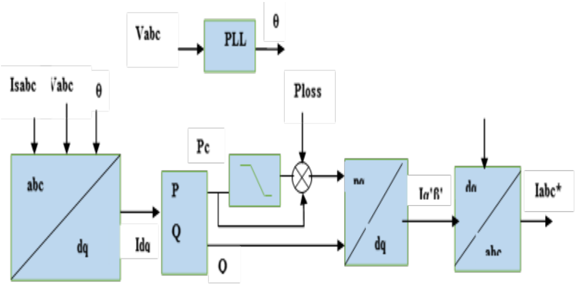

Figure 5: Block diagram of DQ theory

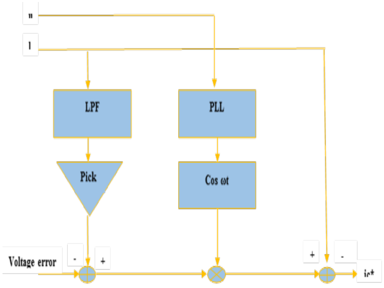

Figure 6: Direct testing and calculating method [37]

3. PWM Control Techniques

PWM control techniques have a noticeable effect on SAPF performance to obtain the deformed compensation current injected into the network. The current control must have the ability to trace the abrupt change in the wave amplitude of the source current waveform. Different control strategies are advanced in this bus-based PWM, hysteresis, control, etc. The switching pulses of the other two phases are generated, as illustrated in Figure (8).

3.1 Hysteresis Control Strategy

The hysteresis control strategy is one of the most appropriate time-domain control strategies for active filters. Its operating principle is based basically on comparing the error signal and two upper/lower bands, as shown in Figure (8). The switching pulses are generated depending on the next expressions [22]:

The upper switch is ON, and the lower switch is OFF when

$$Ia^* - Ia < HB \tag{9}$$

The upper switch is OFF, and the lower switch is ON when

$$Ia^* - Ia > HB \tag{10}$$

3.2 Space Vector PWM

The use of space bus modulation (SVPWM) technology has been recently developed as a popular method for pulse width modulation (PWM) of voltage buffer inverters due to its very good harmonic quality and linear operating range. The purpose of using SVPWM technology is to obtain suitable switches according to a specific modification scheme. The figure below shows a diagram of the SVM technology, as shown in Figure (9) [16].

3.3 Triangle-Comparison PWM Control

The principle of the triangular comparison control technique of the PWM is that the modulation signal is achieved by the current regulator from the intersection of the current signal with the triangle wave signal. The impulses obtained are to control the switches of the transformer.

4. Main external control loop with a constant voltage source

To regulate the DC-link voltage and to be able to control the active power flowing to the SAPF, the strategy of PID control is designed by the error between the reference values and the actual values instead of the error between the inputs and the outputs. This is to estimate the reference current. The closed-loop system will be stabilized if suitable parameters of PID are selected. This is the main reason why PID control is widely used. Next, the reference value is the control block diagram, which is given 1v0 as in figure(1) [54-55]. X stands for the actual values, while E stands for the error between v0 and x. These parameters of PID can be tuned by using advanced optimization algorithms such as Genetic algorithm(GA), Particle Swarm Optimization (PSO), Ant Colony Algorithm(ACO), etc. [56]. To conclude, the constants Ki and Kp's values give the best results in the PI control system. The equation below represents the relationship between the values of the constants and the error function [57].

$$K = Kp(Vdc.ref - Vdc) + Ki\int_0^1 (Vdc.ref - Vdc)dt \tag{11}$$

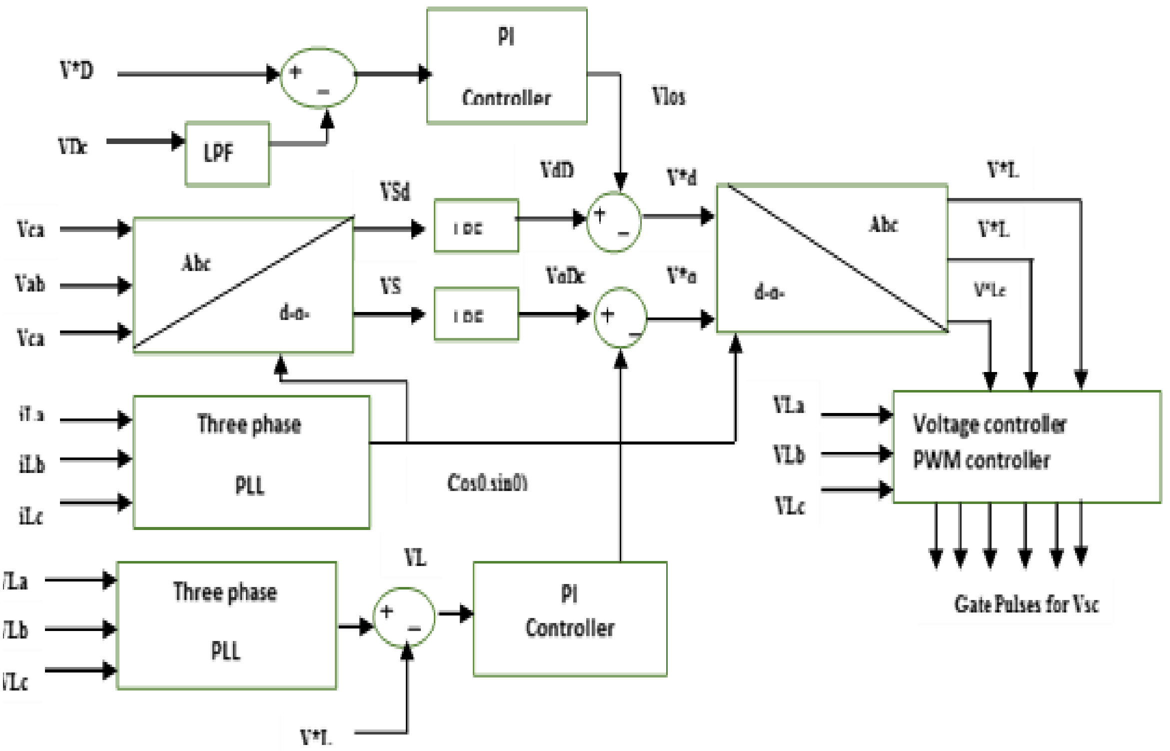

Figure 7: Synchronous reference frame method (SW) [35]

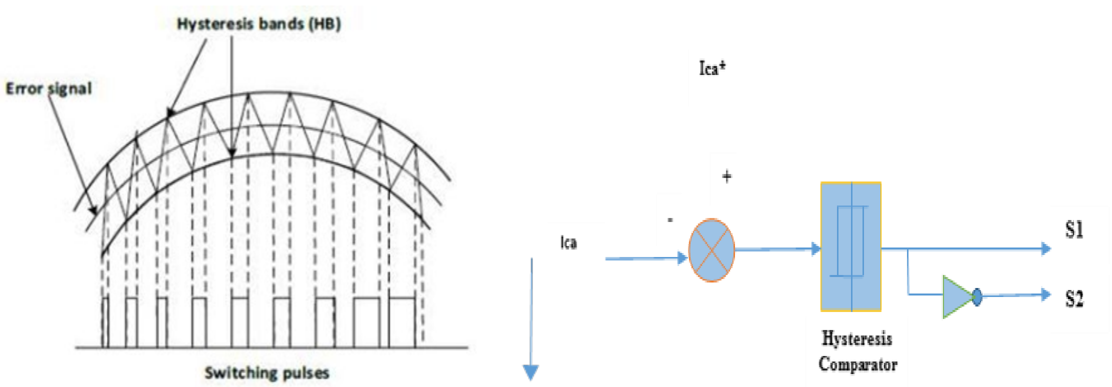

Figure 8: Hysteresis control strategy [15]

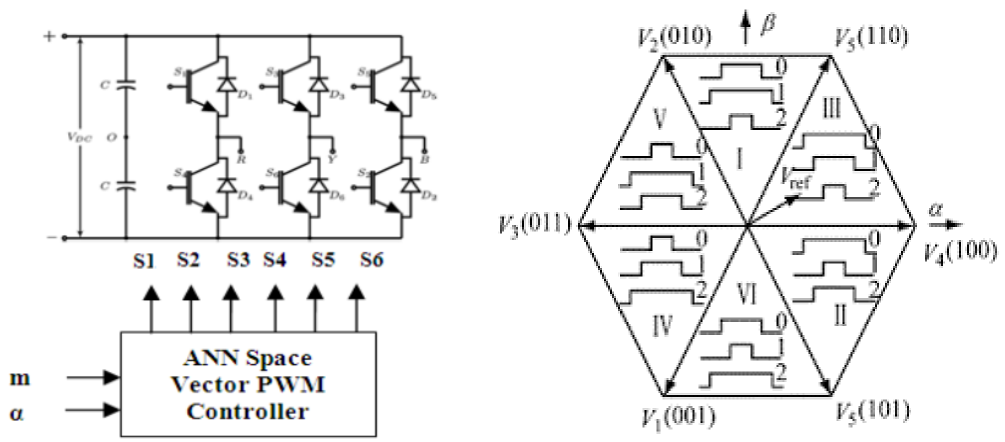

Figure 9: Space vector PWM [36]

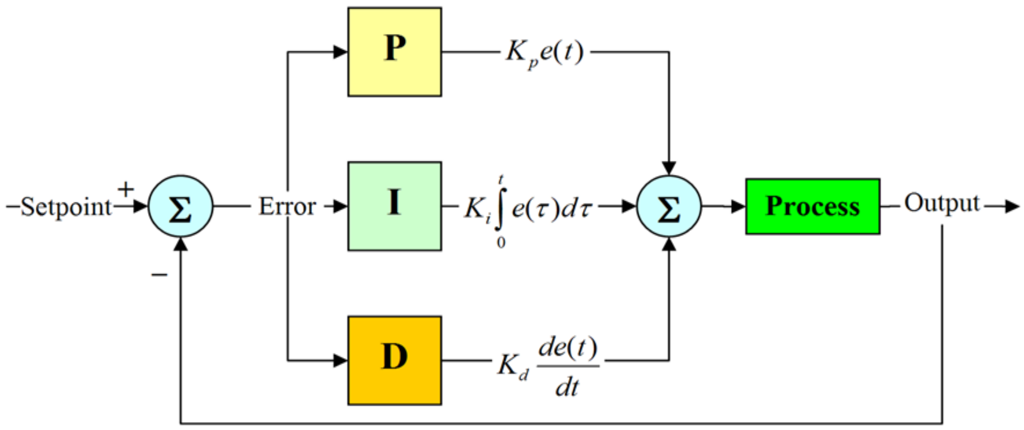

Figure 10: Structure of PID control

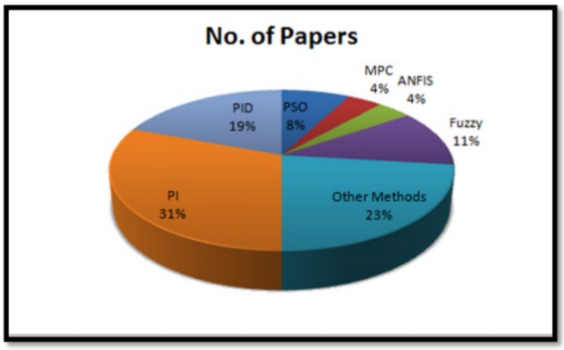

Figure 11: No. of papers with control techniques of SAPF

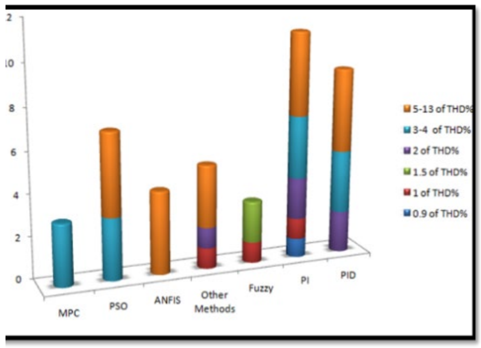

Figure 12: Control techniques of SAPF with THD

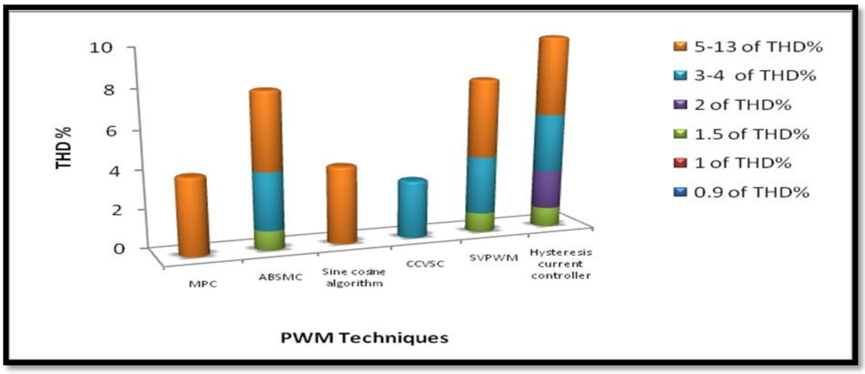

Figure 13: PWM Control techniques of SAPF with THD

5. Results and discussion

As much as other papers, this paper review has used a control of shunt active power filter using many techniques of controls such as PID, PI, Adaptive Neuro-fuzzy (ANFIS), Model Predictive Control (MPC), and PID with Particle swarm optimization (PSO). Other methods are alike. They used algorithms to improve the performance of the PI control system to find the values of Kp and Ki factors to get the best results. The result shows that many researchers used PI as 40%, PID as 25%, and 15% using fuzzy logic control, and 10%,5%, and 23% using PSO, MP, and ANFIS, respectively, as shown in Figure 11. Moreover, a control technique shows a clear reduction of Total Harmonic Distortion (THD) at different system parameters. The different techniques used in Figure12 illustrate that (THD) becomes 0.9% when using PI under specific conditions and system parameters. In the same arena (THD) ranges from (1-13) at other parameters and other control techniques used for this purpose. Using PWM control techniques such as hysteresis control, SVPWM, MPC, algorithm as shown in the Figure13 shows the relationship between PWM Control techniques of SAPF with THD.

Table 1: Summarize types of control techniques for active power filter and the results of each review

N	Authors	Current Reference GenerationTechniqs	Control Techniques	PWM Current ControlTechniques	Result THD
1	IRFAN ALI, et.al 2016	PQ	PICONTROLLER	Hysteresis current Controller Discrete PWMSVPWM	7.13%
		DQ	PI CONTROLLER		4.15%
		PQ	PI CONTROLLER		3.80%
2	SeemaAgrawal,et.al 2018	PQ	PID CONTROLLER	hysteresis current control	2.77% phase A 2.79% phase B 2.82% phase C
3	Saad Al-Gahtani,2019	DQ	DSP based D Space	Hysteresis currentcontroller	2.8%
4	Boualem BOUKEZATA a) ,et.al 2017	PQ	Predictive Current Control	Predictive currentcontrol	2.4%
				hysteresis current control	3.3%
5	Gaurava Deep Srivastava, 2017	PQ	Proportional Integral (PI) controller	General Purpose Input Output (GPIO) pin of DSP	4.41%
6	ShikhaGautam 2019	PQ	Sine CosineAlgorithm	Sine cosine algorithm	2.92 %
7	KelthoumHACHANI,et.al,2019	PQ	PI CONTROLLER	Carrier based PWM	7.1%
8	Ravinder Kumar, 2018	PQ	Adaptive neuro fuzzy inference system(ANFIS)	MPPT	4,14% 4.68%
9	Minarti Mane, 2017	PQ	Fuzzy Logic, Artificial Neural Network (ANN) and Genetic Algorithm	hysteresis current control	5.87%
10	Muneer V ,et.al 2018	PQ	PI CONTROLLER	modified feedback control circuit	2.6%
11	Shreya Parmar 2018	PQ	PI CONTROLLER	hysteresis current control	2.34%
12	S.M. ImratRahman,et.al 2019	PQ	Model Predictive Control	MPC algorithm	13.24%
13	SaritaSamal,et.al 2016	DQ	PI CONTROLLER	hysteresis current controller	2.53%
14	Seyed Abbas Taher, et.al 2017	PQ	FS-MPC	hysteresis current controller	3.58%
15	BalagaUdayaSri,et.al 2015	PQ	PI CONTROLLER	hysteresis current controller	3.75%
16	HarshaVanjani,et.al2016	PQ	fuzzylogic controller for sapf	hysteresis Current controller	1.63%
17	BhukyaNageswar Rao, ,et.al 2020	DQ	pi controller	CMI	2.4%
18	AbdelbassetKrama,et.al2018	PQ	PSO	SVPWM	3.8%
19	Ikram Ullah,et.al 2019	PQ	PI CONTROLLER	hysteresis current control	2.28%
20	ALOK KUMAR MISHRA,et.al 2020	PQ	PSO-GWOOptimized Fractional Order PID	hysteresis current control	3.52%
21	Hong Shen , Fan ,et.al2019	detect and extract harmonics	PI CONTROLLER	VI-APF	2.59%
22	Ali TETA,et.al 2018	PQ	Adaptive-fuzzy	hysteresis currentcontrol	2.53%
23	S. Kumaresan,et.al 2020	PQ	PI CONTROLLER	hysteresis current control	1.98%
24	Sabir Ouchen,et.al 2020	PQ	PI CONTROLLER	SVPWM	3.37%
25	MUHAMMAD KASHIF, 2020	synchronization phase signal.	DSPACE	hysteresis current control	3.4%
26	Anish PratapVishwakarma,2020	PQ	ACO	hysteresis current control	4.18%
27	JuntaoFeiet.al (2021)	PQ	ADAPTIVE NEURAL	hysteresis current control	1.87%
28	Boubakeur ROUABAH 2020	PQ	GSC control	hysteresis current control	3.67%
29	Kanagavel Rameshkumar 2020	PQ	Bee Colony Algorithm Optimized PI Control	hysteresis current control	3.8%
30	P. Suresh 2020	PQ	Fuzzy	hysteresis current control	2.1%
31	Krishna Viswanth K 2020	DQ	PI	hysteresis current control	4.9%
32	Tej Kiran Rangineedi 2020	PQ	OPAL-RT Real Time CONTROL	hysteresis current control	2.67%
33	Yap Hoon 2019	PQ	Predator-prey based firefly optimization	hysteresis current control	1.9%
34	Elango Sundaram 2019	PQ	Genetic algorithm based control	hysteresis current control	2.74%
35	Francis Mulolani 2020	PQ	Virtual-Flux based CONTROL	hysteresis current control	8.95%
36	Asia'u Talatu Belgore	PQ	fuzzy controller	hysteresis currentcontrol	3.9%
37	BasamaAbd El-Rahman 2020	PQ	Adaptive PLL	hysteresis current control	4.06%
		DQ	CONTROL		3.11%
38	V. Munee, Avik Bhattacharya 2020	PQ	ES-CHB-bas CONTROL	hysteresis current control	1.68%
39	Youcef Bekakra 2021	PQ	Grey wolf optimizer	SVPWM	1.57%
40	Ragam Rajagopal 2020	DQ	RLS algorithm Based control	hysteresis current control	2.53%
41	Radek Martinek 2019	DQ	Recursive Least Squares Algorithms	hysteresis current control	4.89%
42	Roman Belyaevsky 2020	PQ	Adaptive Control	hysteresis current control	4.3%
43	Pavitra Shukl 2020	PQ	predictive control	hysteresis current control	3.4%
44	Yunmei Fang and Juntao Fei 2019	PQ	Adaptive Neural Backstepping Controller Using Neural Compensator	hysteresis current control	2.96%
45	Dawid Buła 2021	PQ	combinatorial optimization algorithm	hysteresis current control	3.89%
46	Mihaela Popescu 2020	PQ	Adaptive Control	hysteresis current control	3.3%
47	Narendra Babu 2020	PQ	Adaptive Control	hysteresis current control	2.424%
48	Agata Bielecka 2021	PQ	Predictivecurrent controller	SVPWM	2.5%
49	Maciej Klimas 2021	PQ	Brute force algorithm	hysteresis current control	3.3%
50	Ashokkumar Lakum 2021	PQ	Grey Wolf optimizer	hysteresis current control	2.84%
51	Abhishek Srivastava 2018	DQ	WhaleOptimization Algorithm	hysteresis current control	3.07 %

6. Conclusion

This paper reviewed and analyzed the most prominent different control strategies applied to the shunt active power filter in a three-phase system. Out of this paper, One can conclude that many researchers use a control technique to reduce a total harmonic generated by a non-linear load, resulting in overheating, voltage distortion, flickering and Interference, decreased power factor, and poor electrical quality. Control techniques are used to estimate and produce a compensated current injected into the network to correct the waveform and perform this process well and in an integrated manner. Furthermore, the control technique reduces THD from 13% to 0.2% at many control techniques applied with control of PWM. Obviously, all techniques applied for control of SAPF successfully reduce a total harmonic. That is to say, all techniques of control using optimization algorithms tuning PI give good results. Consequently, this can be applied in other domains and arias like engineering and industry to improve system performance.

Author contribution

All authors contributed equally to this work.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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