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PSO based optimized PI controller design for hybrid active power filter

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ABSTRACT

This research study presents the design and simulation of a hybrid active power filter (HAPF) for reducing harmonics. The reference currents have been determined using the synchronous reference frame technique. To achieve its goals, the proposed HAPF employs AI algorithm known as particle swarm optimization (PSO) to fine-tune the proportional-integral PI controller's parameters. With the help of PI-PSO controller the DC link voltage is regulated in the HAPF-inverter. A non-linear current control strategy based on hysteresis employed here to construct the pulse gate by comparing the retrieved reference and real currents necessitated by the HAPF. Simulations were carried out in MATLAB and shown that the proposed method is extremely adaptable and efficient in reducing harmonic currents caused by non-linear loads.

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1. INTRODUCTION

Power static inverters are being used more frequently in electric machinery as a result of developments in power electronics, increasing energy requirements, and the adaptability of semiconductors. Typically, these gadgets stand in for nonlinear loads, which act like harmonics generators by taking in a current that isn't sinusoidal. They also have a tendency to use reactive energy. As a result, the source current wave becomes less sinusoidal and the power factor drops [1]–[3]. Two types of filters, active and passive, are provided to mitigate the impact of harmonic distortion. Reduced harmonic distortion in industrial power systems has traditionally been achieved through the use of passive filters [4]–[6]. However, they have drawbacks such as erratic performance, unintended harmonic current absorption from neighboring non-linear loads, and the possibility of harmonic resonance with the system's series impedance, which could lead to further harmonic propagation throughout the power system [7]–[9]. To increase the power factor and reduce the harmonics, capacitors, high pass filters, and shunt passive filters made out of inductors and capacitors have traditionally been used, but these methods are permanent, clumsy, and can cause new utility resonances [10], [11]. Insulated-gate bipolar transistor (IGBT) devices with a hysteresis current controller are utilised with analogue cards to generate pulses for usage in inverter applications [12], [13]. In compliance with the recommended IEEE 519-1992 harmonic standard limitations, the test results analysis under both steady-state and transient settings [14].

Direct power control with predictive phasor measurement for shunt active power filters. The fundamental concept is to adjust for basic reactive power from non-linear loads while simultaneously eliminating harmonic distortion [15]. By utilizing a static compensator (STATCOM) hybrid and a serial resistance resistor (SDBR), voltage fluctuations in the low-voltage ride-through capability (LVRT) can be mitigated and the LVRT's performance enhanced [16]. In an effort to address the shortcomings of traditional filters, power utilities have begun implementing a new technology known as shunt active power filters (SAPF) that are powered by voltage source inverters (VSI) based on power electronics [17]-[19].Modern automatic control systems frequently utilize cutting-edge soft computing techniques to optimise the system's parameters. Particle swarm optimization (PSO) methods are used to fine-tune the PI controllers' gain settings [20], [21]. Gain settings of the PI controller in SAPFs have been optimized using evolutionary algorithms including genetic algorithm (GA) [22], bacterial foraging (BF) [23], firefly [24], ant colony optimization (ACO) [25], and differential evolution (DE) [26], and to steer clear of sub-optimal pitfalls. More recently PSO has been outlined for solving optimization problems; it is a swarm intelligence based stochastic optimization technique.The primary objective is to devise a strategy for optimizing all SAPF design controller parameters and to reduce the THD. This method combines PSO (PSO-PI) and uses PSO to find the optimal gains for the controller employed in shunt active filter.

2. PROPOSED CONTROL STRATEGY

The configuration of hybrid shunt active filter (HAPF) consists of non-linear load, a hybrid active power filter, and three-phase supply voltages shown in Figure 1. The HAPF consists of active shunt power filter and a passive shunt filter. The rule established by the APF involves determining the presence of harmonic components, isolating the fundamental component, and then converting the other harmonic components into reference currents. These reference currents are injected into the utility source with opposite phase in real time by a control method using a power circuit, which consists of an inverter and an output filter. The non-linear load and the shunt passive filter are linked together. The fifth and seventh harmonics are tuned and filtered with the help of LC branches.

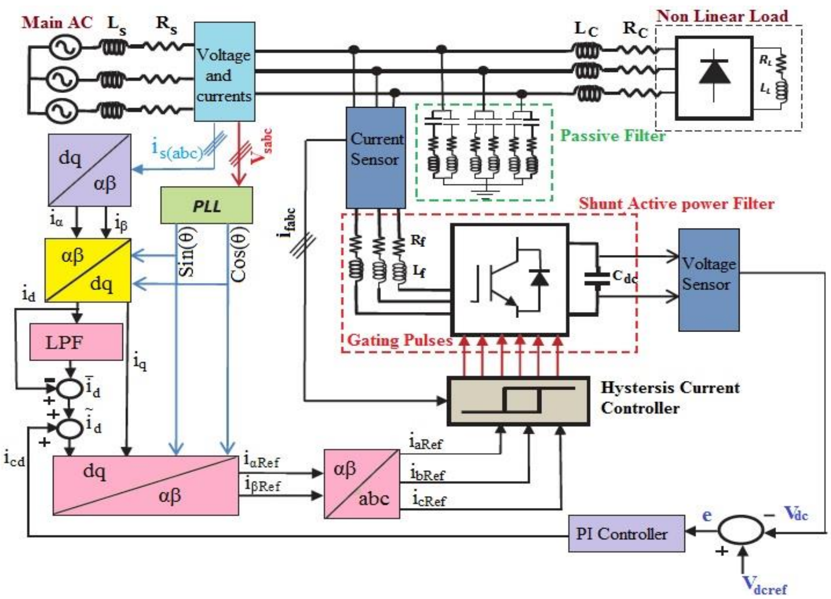

Figure 1. Proposed controller scheme for HAPF

The Value of inductance and capacitance parameters in passive filter for any branch can be tuned for "n" order harmonics must satisfy the give condition [26]:

$$\omega_n = 2\pi f_n = \frac{1}{\sqrt{L_n C_n}} \tag{1}$$

the proposed control strategy is divided in to the following areas: synchronous reference frame (SRF) current extraction method, DC link voltage and hysteresis current control method and particle swarm optimization (PSO).

2.1. SRF current extraction method

The three phase currents i_a, i_b, i_c are transformed in to two phase i_α and i_β which refers the stationary reference frame. The control strategy employed in this work is to compensate the harmonic currents by using synchronous reference frame (SRF) method.

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

From the phase locked loop, cosθ and sinθ is the generated for the phase voltage sources. The dq reference frame is expressed as (3).

$$\begin{bmatrix} I_d \\ I_q \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \cdot \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{3}$$

The dc values and other quantities are converted in to non-DC quantities by using low pass filter which is expressed in the (4).

$$\begin{bmatrix} I_d \\ I_q \end{bmatrix} = \begin{bmatrix} \bar{I}_d + \tilde{I}_d \\ \bar{I}_q + \tilde{I}_q \end{bmatrix} \tag{4}$$

The $i_{\alpha ref}$ and $i_{\beta ref}$ are the reference currents expressed as (5).

$$\begin{bmatrix} i_{\alpha ref} \\ i_{\beta ref} \end{bmatrix} = \begin{bmatrix} \sin\theta & \cos\theta \\ -\cos\theta & \sin\theta \end{bmatrix} \cdot \begin{bmatrix} I_d + I_q \\ I_d \end{bmatrix} \tag{5}$$

The reference currents in abc frame are given by (6).

$$\begin{bmatrix} i_{refa} \\ i_{refb} \\ i_{refc} \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \cdot \begin{bmatrix} i_{\alpha ref} \\ i_{\beta ref} \end{bmatrix} \tag{6}$$

The generated reference current values are compared with the filter currents to generate the compensating current through gate pulses.

2.2. DC-link voltage control

In this study, a proportional and integral controller PI is employed to mitigate inverter losses while maintaining a fixed DC-link voltage V_{dc}. This current i_{cd} is the result of the control loop comparing the observed voltage Vdc to the reference voltage V_{dcRef}. Figure 2 depicts a schematic representation of the system used to maintain a constant voltage across the DC link.

The purpose of this work is to determine the appropriate values for the PI controller's K_P and K_i, so that the system's transient response performance indexes are minimized. Gate currents for HAPF components are calculated by comparing reference and real three-phase source currents shown in Figure 3. The HAPF on/off sequence is determined by the controller. The following rules define the logic of the switches: If i_{filter}<($i_{Reference}$–Hysteresis band width)=lower switch is ON and upper switch is OFF and If i_{filter} >($i_{Reference}$ + Hysteresis band width)=lower switch is OFF and upper switch is ON.

2.3. Particle swarm optimisation

Eberhart and Kennedy created the population-based stochastic optimization method known as particle swarm optimization (PSO) in 1995, taking cues from the cooperative behavior of flocking birds and schooling fish. PSO learns from the scenario and uses it to solve the optimization difficulties. Finding the maximum or smallest value of a function under specified conditions is the essence of the optimization problem.

Each particle moves through the problem space at a speed that is chosen at random. Particles preserve their best positions is known as "P_{best}" and the fitness values associated with those positions. The Global fitness particle over a search space is known as the global best (G_{best}). Each particle is given a weighted random acceleration towards its P_{best} and G_{best} locations at every time step, this is the core idea behind the PSO approach. The algorithm and steps are explained through the flowchart given in the Figure 4.

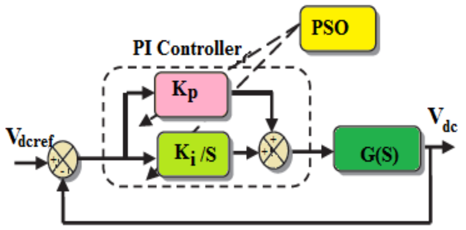

Figure 2. DC link control schematic diagram

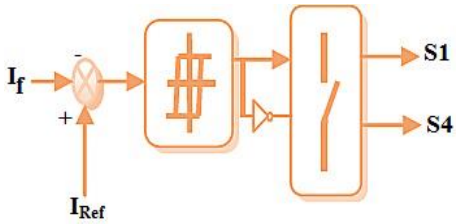

Figure 3. Hysteresis current control method

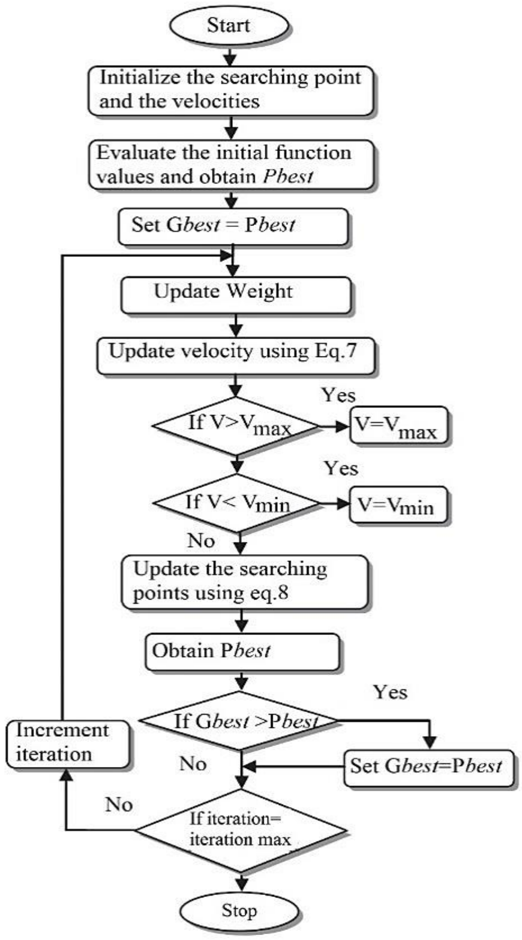

Figure 4. PSO Flowchart for proposed controller

The velocity is searched by (7).

$$vel_i^{k+1} = Xvel_i^n + a_1 rdm_1(pbest_i - w_i^n) + a_2 rdm_2(Gbest - w_i^n) \tag{7}$$

Where, $a_{1,2}$ – acceleration factors, Gbest – Gbest among the group, Pbest – Pbest of agent i, Rdm – random value between 0 and 1, w_i^k – current position i for iteration k, vel_i^k – velocity position i for iteration k, X – weight of the particle.

New position of the particle is according to:

$$w_i^{n+1} = w_i^n + vel_i^{n+1} \tag{8}$$

where w_i^{n+1} – current position at iteration k+1, vel_i^{n+1} - velocity position at iteration k+1.

3. SIMULATION RESULTS AND DISCUSSION

The goal of the simulation is to demonstrate the HAPF's capability of mitigating the harmonic pollution resulting from the use of the PSO algorithm on a non-linear load. The proposed algorithm's initial parameter values for designing a PI controller for DC link regulation are shown in Table 1. Table 2 lists the values used in the HAPF model.

Table 1. PSO Parameters

Parameters	Values
No of iterations	40
Size of population	30
X_{max}	0.9
X_{min}	0.3
a1=a2	1.5

Table 2. Parameters of HAPF

Parameters	Values
Supply voltage	230 V
Frequency	50 Hz
R_s	0.4 Ω
L_s	2 mH
Nonlinear load	Diode bridge rectifier with RL branch with an angle $\alpha = 30^0$, $R_L = 6.5\ \Omega$, $L_c = 0.4$ mH
Load resistor and capacitor values in line	$R_c = 0.35\ \Omega$, $L_c = 0.4$ mH
Filter values	$R_F = 1$ m Ω, $L_f = 1.4$ mH
Values of DC link capacitor	$C_{dc} = 3000\ \mu F$, $V_{dc} = 450$ V
Values of Passive filter	C = 306 μF, L = 2 mH, R = 0.02 Ω

The parameters of a standard PI controller have traditionally been set using a classical approach. The DC-link regulation and its effect on suppressing harmonic currents and lessening total harmonic distortion are seen using a standard PI controller. With a HAPF based on a typical PI controller, the total harmonic distortion (THD) may be decreased from 15.40% to 1.80%, as shown by the simulation results for the line currents and their spectra before compensation shown in Figure 5 and Figure 6, after compensation shown Figure 7 and Figure 8, and for the injected current shown in Figure 9 and DC-link voltage waveforms depicted in Figure 10.

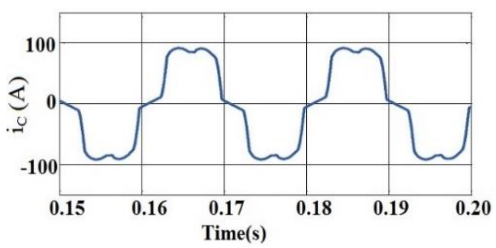

Figure 5. Load current waveform (phase A)

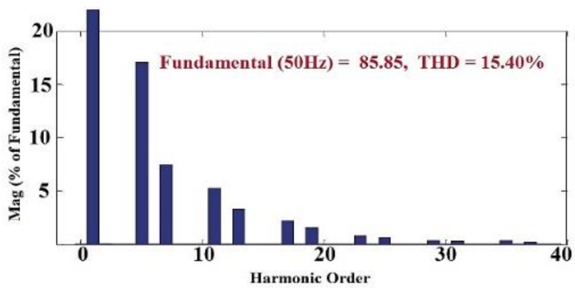

Figure 6. THD spectrum for supply current

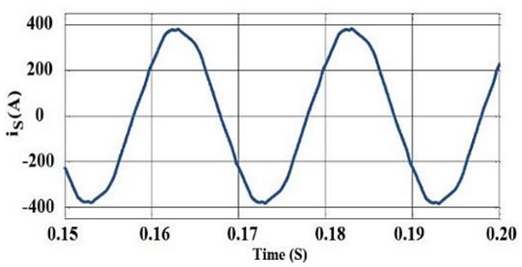

Figure 7. Supply current waveform using PI controller (phase A)

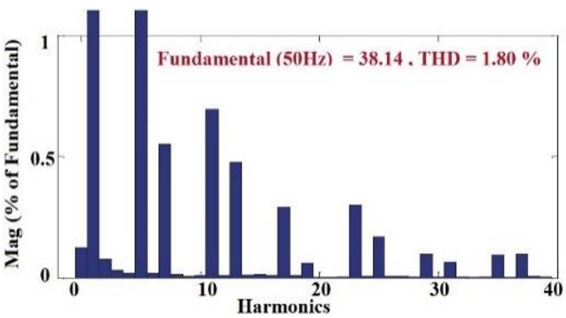

Figure 8. THD spectrum for supply current using PI controller

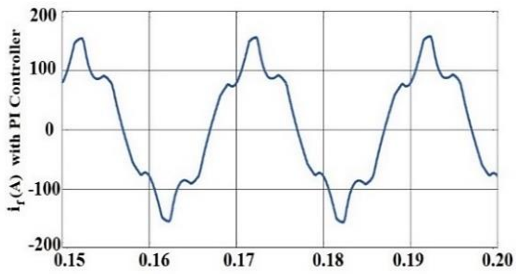

Figure 9. Injected waveform using PI

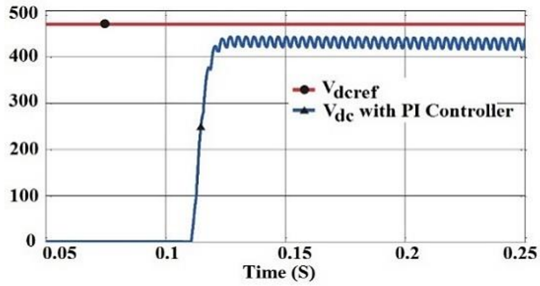

Figure 10. DC link voltage

The proposed solution employs a hybrid active power filter optimized by PSO to enhance power quality. The integral of the time-weighted absolute error and the maximum overshoot is the primary metric for measuring success in system control, with minimization of fitness functions specified in (9).

$$F = f_{os} + f_{ias} \tag{9}$$

For a more accurate assessment of fitness, we multiplied the term of the integral of the time-weighted absolute error by coefficient. Then, we can define the novel objective function as (10).

$$F = f_{os} + \alpha \times f_{ias} \tag{10}$$

To evaluate the effectiveness of the suggested strategy, simulation studies were conducted. Figure 11 and Figure 12 displays the THD spectrum and supply current. The optimal solution results in the waveforms of injected current and DC link voltage depicted in Figures 13 and 14. Table 3 compares the index values of different strategy and Figure 15 compares the HAPF's performance before and after optimization. In light of the data and calculations, it can be concluded that the suggested control algorithm reduces the THD of the source current with HAPF from 1.8% with the PI controller to 0.59%.

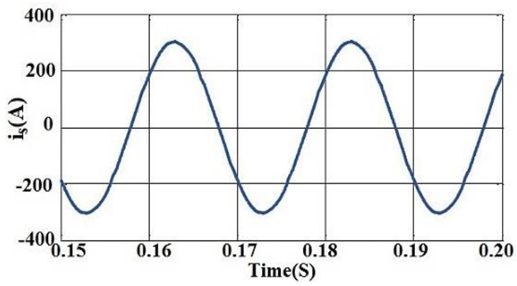

Figure 11. Supply current waveform with PSO optimized PI controller (phase A)

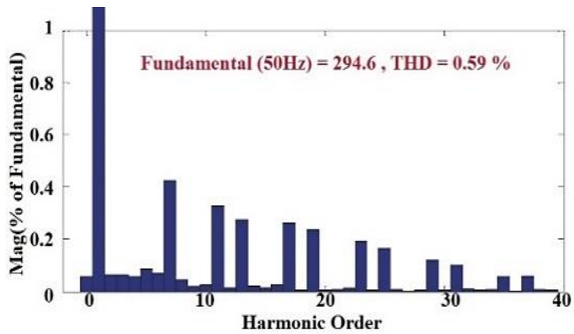

Figure 12. THD for supply current based PSO optimized PI controller (phase A)

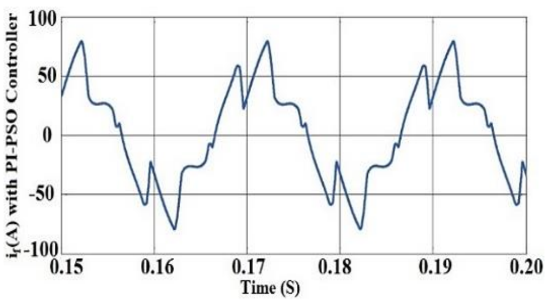

Figure 13. Injected current waveform with PSO optimized PI controller (phase A)

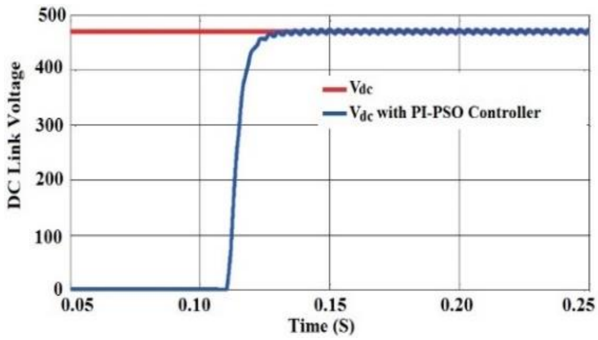

Figure 14. DC link voltage for PSO optimized PI controller

Table 3. Comparison between PI and PI- PSO employed HAPF

Parameters	PI controller	PSO Optimized PI Controller
K_P	0.1	0.01
K_I	4	1.4
Percentage Overshoot	96.24	99.50
Absolute error	4.4	2.7
Fitness function	1.097e^4	1.019e^4
THD	1.80%	0.59%

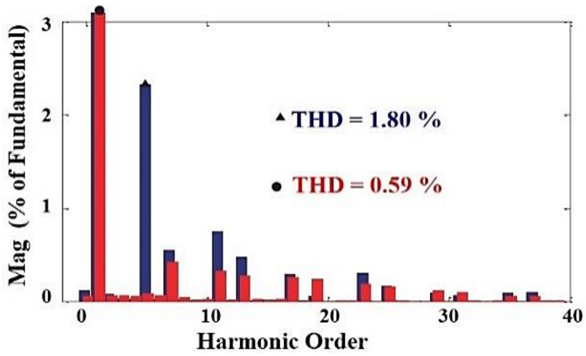

Figure 15. Comparison of THD

4. CONCLUSION

In this research, we propose a configuration of a hybrid active power filter that uses PSO for DC-link control under ideal voltage settings to enhance power quality by lessening the THD. MATLAB/Simulink were used to create the virtual environment to validate the proposed system. Overall, the results show that the PSO is successful in identifying the best fitness function and determining the best values for Kp and Ki in the DC-link voltage-HAPF controller. Total harmonic distortion (THD) was reduced from 1.80% to 0.59% after HAPF with PSO-PI controller was implemented. Results from the past indicate that the suggested controller improves upon the dynamic performance and resilience of the existing controller. The HAPF control approach has proven effective at suppressing harmonics.

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