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ACTIVE POWER FILTER BASED OPTIMUM DESIGN OF PI CONTROLLER USING PARTICLE SWARM OPTIMIZATION METHOD

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ABSTRACT

This paper proposes an optimal design method for Shunt Active power filter (SAPF). An active harmonic filter is used to eliminate current harmonics caused by nonlinear loads. The current control strategy utilizes Synchronous Reference Frame method to improve power quality through compensating harmonics and reactive power required by a nonlinear load. The power quality standard IEEE-519 states that the total harmonic distortion (THD) caused by electrical equipment gear should be within the agreeable range of 5%. This study is conducted to investigate the utilization of Particle Swarm Optimization (PSO) in optimizing PI controller for SAPF's DC link voltage. The simulation model of the overall system is developed in MATLAB/Simulink environment. From analysis, it has been found that PSO technique proves to be effective in reducing the THD of the source current.

Keywords:APF, THD, PWM, PI, PSO.

1. INTRODUCTION

With the growth of modern technology that relies on DC powered load, there has been a steady increase in the use of power electronic equipment but the application has resulted in the increase of harmonics in AC mains current (Boukadoum et al. 2013). The effectiveness of an active filter depends at most on the selected reference generation scheme. The control strategy for a shunt active power filter (SAPF) generates the reference current that must be provided by the power filter to compensate the reactive component and the harmonics component demanded by the load. The harmonics are extracted based on the different power component and current component theories (Zaveri and Chudasama, 2011).

Due to the widespread proliferation of nonlinear distorting loads, the problems caused by harmonics are of increasing importance. These waveform distortions can cause problems as it tends to have an overall negative effect on the quality of electric power(Srinivas and Ram, 2013). Traditionally, passive L-C filters were used to reduce harmonics. Among the advantages of passive filters are simplicity in circuits, cheap to fabricate and easy to maintain; however, its disadvantages include having fixed compensation characteristics, tuning problems, series and parallel resonance , harmonic amplification, possible overload and large size. Active filters have a better performance than passive filters(Yarahmadi et al. 2013); in the case of SAPF, a three-phase inverter, formed in two or more levels, are connected to the AC mains and a DC capacitor (or an inductor in some cases) (Tsengenes and Adamidis, 2010).The creation of current in the filter, which includes the basic harmonic (properly shifted by φ) and its upper harmonics, may remove unwanted harmonics as well as compensate the reactive power (Zouidi et al., 2006).This paper presents a strategy to improve the performance of the SAPF, in which the non-linear load is a three-phase full-bridge diode rectifier supplying a resistive load as shown in Figure 1.

Figure 2 shows the block diagram of an active filter. A new design strategy using optimal controller parameters, KP and KI controller of a DC-link PI-controller based on Particle Swarm Optimization (PSO) is proposed. This paper presents a PSO-PID controller for searching the optimal or near optimal controller parameters KP and KI using the PSO algorithm. As an overview, this paper presents the effectiveness of using PSO in the PI tuning process; the search for optimal coefficient to mitigate the reactive and harmonics power components of a nonlinear load.

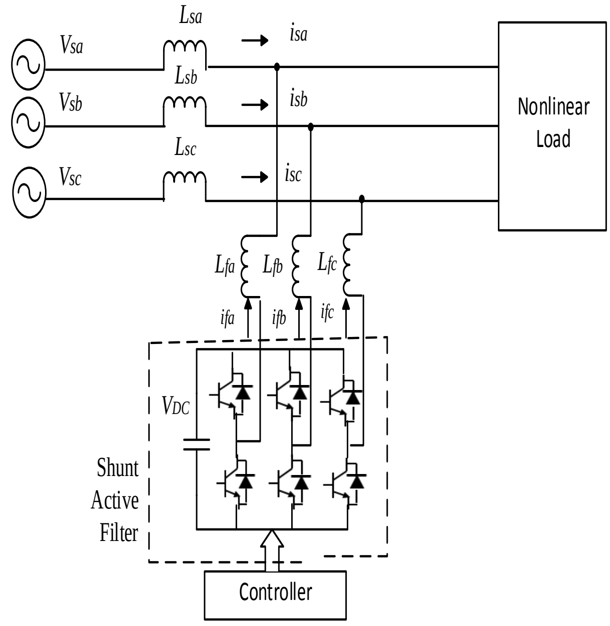

Figure 1 Basic System Configuration for shunt active filter

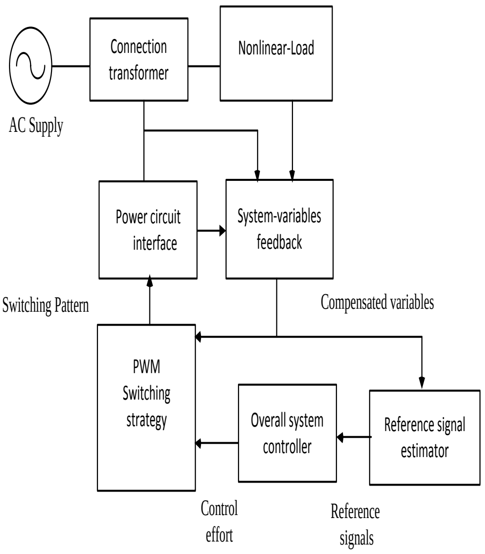

Figure 2 Block diagram of an active filter

2. SYNCHRONOUS REFERENCE FRAME THEORY CONTROL METHOD

Techniques that are used to extract and identify current and voltage harmonic distortion are categorized as, frequency analysis, time domain analysis and time-frequency approach (Boukadoum et al. 2013). A control system based on the synchronous reference frame (SRF) method for eliminating harmonics and reactive power compensation is presented in this paper. SRF theory in time domain based on reference current generation techniques have been developed(Karuppanan and Mahapatra, 2010). Figure 3 shows the block diagram of the synchronous reference frame controller. The traditional SRF algorithm is known as d-q, while in this study, an active filter compensation method based on a−b−c to d−q−0 transformation (Park transformation) (Rejil et al. 2013) is proposed. The proposed algorithm derive i_d-i_q rotating coordinate current from a three-phase stationary coordinate load current i_La, i_Lb, i_Lc using the following expressions:

$$i_d=2/3[i_{La}sin(wt)+i_{Lb}sin(wt-2\pi/3)+i_{Lc}sin(wt+2\pi/3)] \qquad (1)$$

$$i_q=2/3[i_{La}cos(wt)+i_{Lb}cos(wt-2\pi/3)+i_{Lc}cos(wt+2\pi/3)] \qquad (2)$$

The desired reference currents are then derived by the inverse transformation of the currents in d - q rotating frame to that of a – b – c stationery frame using the following equations:

$$i_{sa}{}^*=i_d sin(wt)+i_q cos(wt) \qquad (3)$$

$$i_{sb}{}^*=i_d sin(wt-2\pi/3)+i_q cos(wt-2\pi/3) \qquad (4)$$

$$i_{sc}{}^*=i_d sin(wt+2\pi/3)+i_q cos(wt+2\pi/3) \qquad (5)$$

To maintain constant DC-side capacitor voltage and to remove the steady-state error of the inverter DC-component, proportional integral (PI) controller is used. The steady-state error is eliminated by removing the harmonic components of the direct axis from the output of the PI controller. Similarly, the reference signals for the filter are obtained by separating and inversely transforming the fundamental frequency and its harmonics of the currents in d – q rotating frame to that in a – b – c stationery frame. Figure 4 shows the block diagram of the proportional integral control scheme for the active power filter. The value of the maximum reference is estimated by the PI controller and controls the DC side of the inverter capacitor voltage(Vijayasree.J& 2012), which is converted using the following function:

$$H(s) = K_P+K_I/S \qquad (6)$$

Figure 5 shows the block diagram of a PSO-based PI controller. The overall performance (efficiency, optimization accuracy and speed of convergence) of PSO algorithm proposed PI tuning depending on objective function (OF), which monitors the optimization search. The selection of OF is to minimize the preferred limits or to maximize the domain constrains. First, PSO algorithm assigns arbitrary values to KP and KI, after which the OF is calculated, and this procedure continues until the last iteration number is reached (Latha et al. 2013).

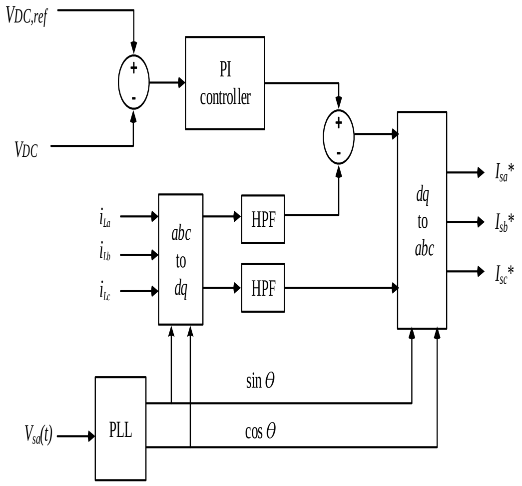

Figure 3 Synchronous Reference Frame Controller

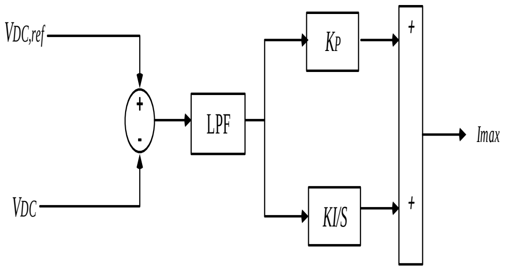

Figure 4 PI Controller

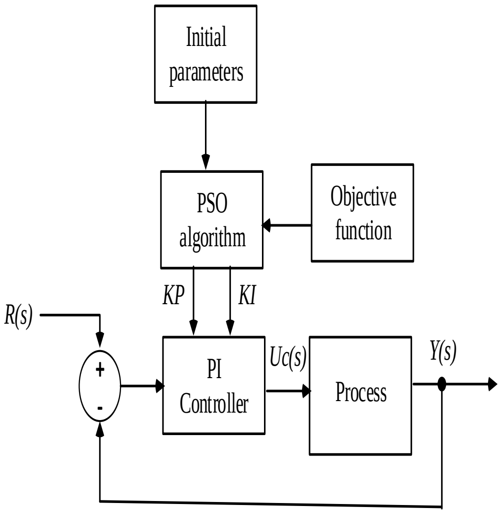

Figure 5 PSO-based PI controller design

3. HYSTERESIS BAND CURRENT CONTROL APPROACH

The hysteresis current controller (HBCC) is widely used among all current control techniques because of the fast response current loop and its simplicity of implementation. To keep the current provided within the hysteresis band, the HBCC derives the switching signals of the inverter based on the comparison of the reference current(Xia et al., 2011). The hysteresis band is used to determine switching signals for the inverter control gates and load currents. Hysteresis current control is one of the best methods for power control of the voltage source inverter due to its fast response, good stability, easy operation, high accuracy, load parameter variation independence and self-surge current limiting. In this approach, the difference between the inverter and the reference currents is controlled by the control band surrounding the hypothetical reference current (Zabihi&Zare, 2006). Figure 6 shows a conventional single phase fixed hysteresis band. When the load current exceeds the upper band output voltage is changed to reduce the load current between the bands, while the comparator output is activated when the load current is smaller than the lower limit. The switching frequency varies in relation to the distance between the upper and lower bands. Also the other parameters such as inverter-network inductance and DC link voltage has a significant influence on the switching frequency (Kale &Ozdemir, 2005). The highest switching frequency is determined as follows(Rukonuzzaman&Nakaoka, 2002):

$f_{sw(max)}=V_{dc}/9HBL$ (7)

where, L and HB are load inductance and hysteresis band, respectively.

4. PARTICLE SWARM OPTIMIZATION (PSO)

PSO is a stochastic optimization algorithm based on swarm behaviour inspired by the population of animals in nature. For solving optimization problems, PSO learns from a scenario and use what it has learnt. In PSO, each single solution in the search space is a bird and we call it particle. All particles have velocities which direct the flying of the particles and have fitness values which are evaluated by the fitness function **to** be optimized(Suresh et al. 2012).

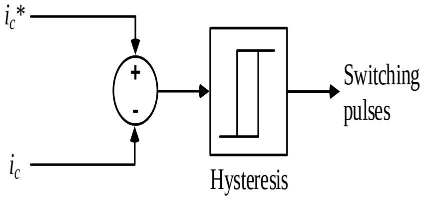

Figure 6 Conventional hysteresis band current controller

In d-variable optimization problem, a group of particles with randomly selected velocity and position are included in the d-dimensional search space and their best position are determined. The velocity of each particle, adjusted in accordance with his own flying experience and that of other particles fly(Gaing et al., 2004). All particles are represented as xi= (xi,1,xi,2…xi,d) in the d-dimensional space.

The best recorded previous position of the ith particle is represented as:

Pbesti=(Pbesti,1,Pbesti,2,…,Pbesti,d) (8)

$v_{i,m}^{(t+1)}=\omega.v_{,m}^{(t)}+c1*rand()*(Pbesti,m-,m(t))+c2*Rand*()$ (9)

$X_{i,m}^{(t+1)}=x_{i,m}^{(t)}+v_{i,m}^{(t+1)}$ (10)

where: i=1, 2... n, m=1, 2,..
d , n: dimension, particles number
t: iterations pointer
νi,m(t): particle velocity at iteration t
Vd(min)≤νi,d(t)≤Vd(max)
w: factor of inertia weight
c1, c2 : constant of acceleration
(): Random number between 0 and 1,
Xi,d(t) :current position of particle i at iterations,
Pbesti : Best previous position of the ith particle
gbest :Best particle among all the particles(Gaing, 2004).

The most common performance criteria in PI controller design methods, which are integrated absolute error (IAE), the integration of squared error (ISE) and integration of time weight square error (ITSE) , can be analytically evaluated in the frequency domain (Krohling & Rey, 2001; Mitsukura et al., 1999). These three integral performances criteria in the frequency domain have their own advantages and disadvantages. However, ITSE can be used to improve the performance of the step response of ISE (Krohling et al., 1997).

Despite the advantages of these performance criteria, there is no accurate control on overshoot, rise time and settling time. So, in this paper, a time domain performance criterion is developed and applied to evaluate the PI parameters. The innovated formula is as shown in Equation 11.

$$\text{Min}_{\text{kstabilizing}} W(K)=(1-e-\beta).(Mp+Ess)+e-\beta.(ts-tr) \quad (11)$$

Where K is [KP, KI] and β is the weighting factor, Mp is maximum peak, ts is settling time, tr is rise time. The performance criterion W(K) can satisfy the designer requirements using the weighting factor β value. β smaller than 0.7 is set in order to reduce the settling time and the rise time can be also greater than 0.7, to reduce steady-state error and the overshoot(Gaing, 2004). In this paper, as a test, β is set to 0.9 to optimize the speed control system step response. The fitness function, which is the reciprocal of performance criteria, is expressed as:

$$f=1/(W(K) \quad (12)$$

5. SIMULATION RESULTS

The simulation results obtained from harmonic distortion analysis of the source current with nonlinear loads without APF in a-phase, are shown in Figure 7. The Total Harmonic Distortion (THD) spectrum of the current source waveform in the system without filter is 22.95%, as shown in Figure 8. PI control scheme involves the regulation of DC link voltage to set the current amplitude reference for harmonic and reactive power compensation. In this study, a particle swarm optimization (PSO) is implemented to optimize the gains of a proportional-integral (PI) algorithm to control the APF and the optimized gains obtained are: KP = 0.6284 and KI = 29.7741. The parameters used for the PSO are as shown in Table 1.

According to the trials, the PSO parameters are used for verifying the performance of the PSO-PI controller in searching the PI controller parameters as shown in table 2. As can be seen, through about population size (number of birds 50), the PSO method can prompt convergence and obtain good evaluation value, since a good control parameters KP and KI can yield a good step response that will result in performance criteria minimization in the time domain.

Table 1 Parameters of PSO algorithm

No. of birds	50
birds steps	100
w	0.9
C1	1.2
C2	0.8
Dimension of the problem	2

By using PSO method, when APF is put into operation, the THD is 3.33%, which is greatly improved compared to that obtained when PSO is not used. The specification of the test system is given in Table 3. The current source and the THD spectrum waveform in a-phase of the grid with APF control strategy are shown in Figure 9 and Figure 10 The simulation results of the source voltage with nonlinear load in a-phase, are shown in Figure 11. Curve feedback voltage DC link system that used optimized parameters PI shows in the Figure 12, while Figure 13 depicts the convergence of particles with optimal solution. Distortion was clearly reduced and harmonic distortion was reduced compared to that of SAPF using the conventional method of controller. Figure14 shows the fundamental current harmonic spectrums; in state of without the APF; IEEE 519 Limit & APF with PSO

Table 2 The effect of changing No. of birds

No. Of bird	KP	KI	THD%
10	2.072	2.324	7.47
20	1.610	7.525	5.56
30	1.442	6.115	5.2
40	1.226	24.754	4.78
50	0.628	29.774	3.33
60	0.5001	36.9894	3.30

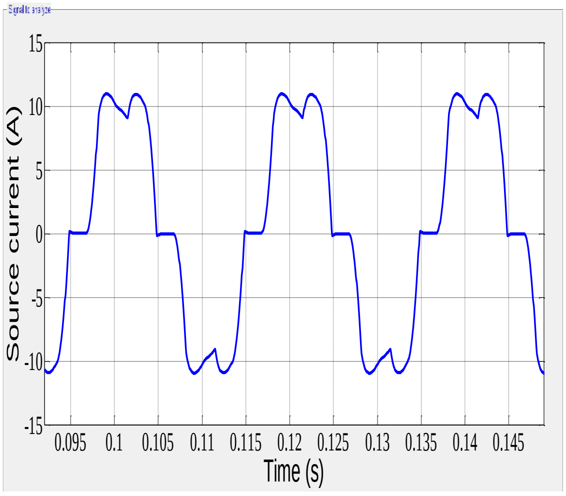

Figure 7 Source current, Isa without APF

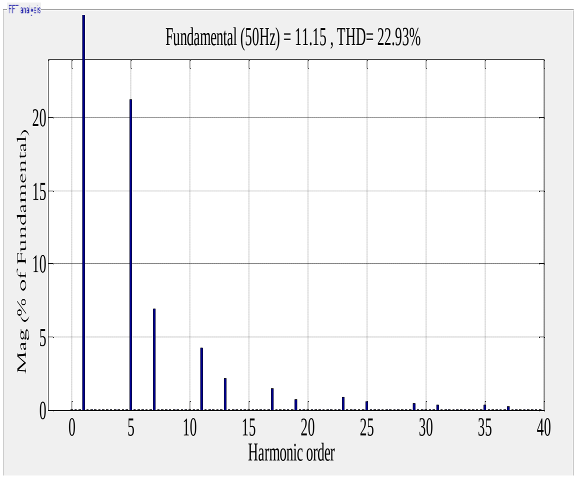

Figure 8 I_{sa}harmonic spectrum without APF

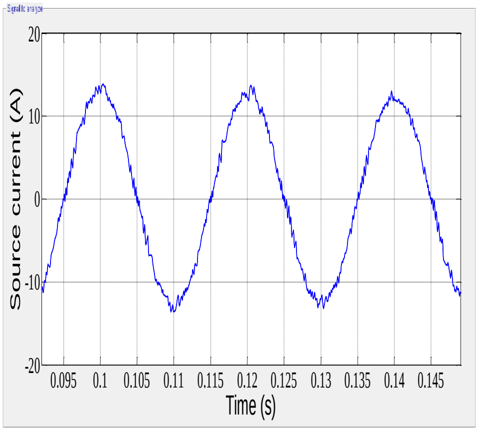

Figure 9 Source current, Isa with APF& PSO

Table 3 Parameters of the System

Supply phase voltage (Amplitude)	311 V
Supply frequency fs	50 Hz
Line inductor LL	10 mH
Filter inductor Lf	6 mH
DC link capacitor Cf	1000 µF
DC link capacitor Voltage	650 V
Load rectifier bridge	50 Ω
Sample time TS	50 µs

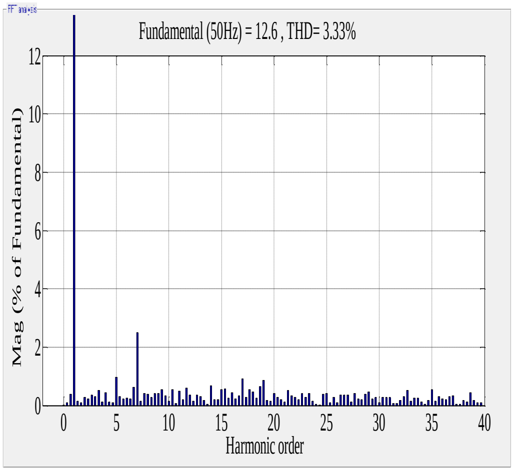

Figure 10I_{sa} harmonic spectrum with APF & PSO

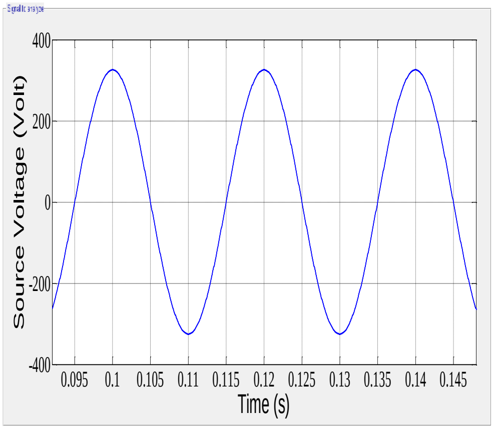

Figure 11 Supply voltage waveform

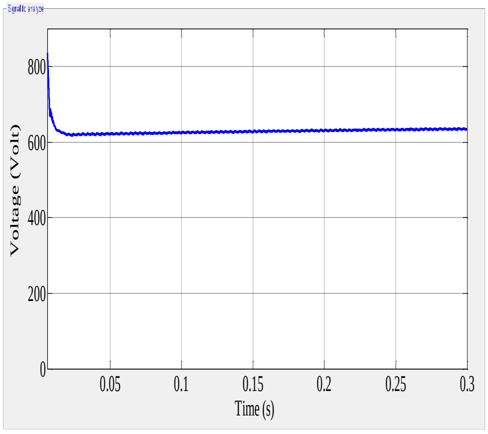

Figure 12 Capacitor voltage waveform (V_{DC})

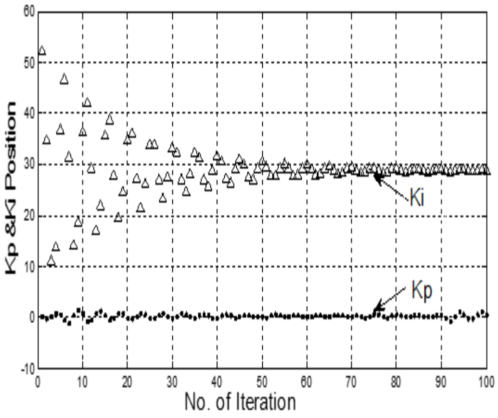

Figure 13 Convergence of particles with optimal solution

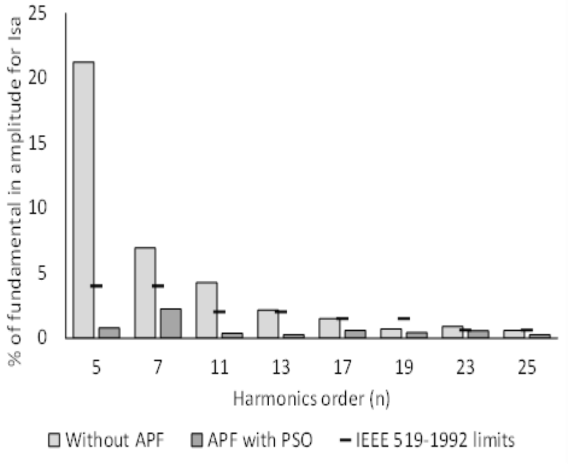

Figure14 The fundamental current harmonic spectrums; in state.

6. CONCLUSION

Active power filters are an optimal solution for harmonic mitigation and reactive power compensation. The proposed technique design optimal PI parameter gains and is found to satisfactorily reduce the THD and thus improves thesource current. The results of APF performance was compared with that obtained from model simulations. estimated using particle swarm optimization technique (PSO) to achieve fast speed dynamic THD of 22.95% was obtained from the simulation for asampled load without APF compared to 3.33% THD when using PSO algorithm. Therefore, PI gains are response and better compensation effect. The PI with PSO algorithm is the best controller as itachieves satisfactory performances, minimal rise time and less overshoot compared with classical PI. Moreover, results have proved that the control strategy

With PSO for DClink voltage is efficient for compensating the current harmonics.

REFERENCES

Boukadoum, A., Bahi, T., Bouguerne, A., Soufi, Y., & Oudina, S. 2013. Hysteresis Band Current And Fuzzy Logic Control For Active Power Filter, Paper presented at the Ecological Vehicles and Renewable Energies (EVER), 2013 8th International Conference and Exhibition on.

Gaing, Z.L. 2004. A Particle Swarm Optimization Approach For Optimum Design Of PID Controller In AVR System. Energy Conversion, IEEE Transactions on 19(2): 384-391.

Kale, M., & Ozdemir, E. 2005. An Adaptive Hysteresis Band Current Controller For Shunt Active Power Filter,Electric Power Systems Research 73(2): 113-119.

Karuppanan, P., & Mahapatra, K. 2010. A Novel SRF Based Cascaded Multilevel Active Filter For Power Line Conditioners, Paper presented at the India Conference (INDICON), 2010 Annual IEEE.

Krohling, R., Jaschek, H., & Rey, J. 1997. Designing PI/PID Controllers For A Motion Control System Based On Genetic Algorithms. Paper presented at the Intelligent Control, 1997. Proceedings of the 1997 IEEE International Symposium on.

Krohling, R.A., & Rey, J.P. 2001. Design Of Optimal Disturbance Rejection PID Controllers Using Genetic Algorithms,Evolutionary Computation, IEEE Transactions on 5(1): 78-82.

Latha, K., Rajinikanth, V., & Surekha, P. 2013. PSO-Based PID Controller Design For A Class Of Stable And Unstable Systems, ISRN Artificial Intelligence, 2013.

Mitsukura, Y., Yamamoto, T., & Kaneda, M. 1999. A Design Of Self-Tuning PID Controllers Using A Genetic Algorithm. Paper presented at the American Control Conference, 1999. Proceedings of the 1999.

Suresh, P., Kalaignan,T.P.M.V. 2012. Analysis Of Reference Current Generation For APF Using PSO And ACO,International Journal of Advanced Technology &Engineering Research 2(2): 16-22.

Rejil, C.A.M. 2013. Design And Simulation Of Three Phase Shunt Active Power Filter Using SRF Theory,Advance in Electronic and Electric Engineering 3 (6): 651-660.

Rukonuzzaman, M., & Nakaoka, M. 2002. Single-Phase Shunt Active Power Filter With Harmonic Detection. Electric Power Applications, IEE Proceedings 149 (5): 343-350.

Srinivas, K., and Ram, T.S. 2013. Enhancement Of THD In HVDC System Using Shunt Active Power Filters,International Journal of Computer Applications 77 (14): 19-25.

Tsengenes, G., and Adamidis, G. 2010. An Improved Current Control Technique For The Investigation Of A Power System With A Shunt Active Filter, Paper presented at the Power Electronics Electrical Drives Automation and Motion (SPEEDAM), 2010 International Symposium on.

Vijayasree, J.V.B., Babu, R.Y. 2012. Implementation Of Srf Based Multilevel Shunt Active Filter For Harmonic Control,International Journal of Engineering Research and Development 3 (8): 16-20.

Xia, L., Taihang, D., &Shengxue, T. 2011. A Fuzzy Logic Variable Hysteresis Band Current Control Technique For Three Phase Shunt Active Power Filter, Paper presented at the Control, Automation and Systems Engineering (CASE), 2011 International Conference on.

Yarahmadi, S., Markade, A.G., & Soltani, J. 2013. Current Harmonics Reduction Of Non-Linear Load By Using Active Power Filter Based On Improved Sliding Mode Control. Paper presented at the Power Electronics, Drive Systems and Technologies Conference (PEDSTC), 2013 4th.

Zabihi, S., & Zare, F. 2006. Active Power Filters With Unipolar Pulse Width Modulation To Reduce Switching Losses, Paper presented at the Power System Technology, 2006. PowerCon 2006. International Conference on.

Zaveri, N., and Chudasama, A. 2011. Evaluation Of Control Strategies For Parallel Active Filter Under Different Supply Voltage Conditions, Paper presented at the Innovative Smart Grid Technologies-India (ISGT India), 2011 IEEE PES.

Zouidi, A., Fnaiech, F., & Al-Haddad, K. 2006. Voltage Source Inverter Based Three-Phase Shunt Active Power Filter: Topology, Modeling And Control Strategies.Paper presented at the Industrial Electronics, 2006 IEEE International Symposium on.