POWER QUALITY IMPROVEMENT BASED ON PSO ALGORITHM INCORPORATING UPQC

B. M. Babu[1*], L. R. Srinivas[2] and S. S. T. Ram[3]

[1] Department of Electrical and Electronics Engineering, Gudlavalleru Engineering College, Andhra Pradesh, India.

[2] Department of Electrical and Electronics Engineering, Gudlavalleru Engineering College, Andhra Pradesh, India.

[3] Department of Electrical and Electronics Engineering, Jawaharlal Nehru Technological University, Hyderabad, Telangana, India.

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ABSTRACT

The usage of the term power quality is increasing day by day with extensive usage of large capacity loads and nonlinear loads. The major power quality issues are voltage disturbances and current disturbances in the present-day power systems. Today, with the advent of power semiconductor devices these power quality issues are solved to a great extent. The unified power quality conditioner is one such power semiconductor device which utilizes active filtering methodology to deal with the concerned power quality issues. Here an attempt is made to control and generate the reference currents and voltages for a unified power quality conditioner with the optimal tuned synchronous reference frame theory. The particle swarm optimization is employed to evolve gains of the proportional-integral controller. The unified power quality conditioner is a combination of shunt and series voltage source converters. The hysteresis band current controller for series and the pulse width modulation current controller for the shunt active filter are used for generation of gating pulses required by the switches of the voltage source converters in the unified power quality conditioner. The performance evaluation of multi-objective convergence fitness function (dealing: the voltage sag, the source current variations, and the load voltage variations) with unified power quality conditioner based on particle swarm optimization algorithm is performed. The efficacy of the proposed work is validated by conducting simulations in MATLAB/SIMULINK software environment.

KEYWORDS*: Power Quality (PQ); Unified Power Quality Conditioner (UPQC); Optimal Tuned Synchronous Reference Frame (OTSRF) Theory; Particle Swarm Optimization (PSO)*

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* Corresponding Email: basam0219@gmail.com

1.0 INTRODUCTION

The term power quality is particularly related to performance and economic aspects of the electric power system. The electric power phenomenon such as voltage, current and frequency are usually affected due to the usage of large electric loads and nonlinear loads.

The variation regarding these issues are termed as power quality disturbances (Bollen, 2000). Such disturbances in concern are source current variations and load voltage variations. Harmonics are the major current disturbances that occur due to the usage of nonlinear loads whereas the sags/swells are the major voltage variations that are mainly caused due to starting/stopping of heavy loads and faults in transmission line.

The power semiconductor technology based active power filter is evolved as one of the most versatile tools for mitigation of the mentioned power quality disturbances. During 1970's, Gyugyi and Strycula (1976) developed and used these active filters to solve these power quality problems. Even though the order of the day is changing, still investigations are progressing in various directions on different issues of active power filters connected to arrangement, quantification, setting up and organization. Later, Akagi (1996) explained the control methodologies for active power filter as three modes, supply, load current detection and voltage detection for different applications.

Since 1970, with rapid growth in semi-conductor technology the power electronic devices evolved as one of the best options in terms of performance, control and economic point of electric power system. Such developed active power filter (APF) with the power electronic devices is one of the best solutions in easing out current and voltage variations to improve power quality, which in turn ensures a healthy power distribution system.

Later, few electrical companies of international repute imposed several recommendations and necessities for current and voltage variations to meet the regulated standards (IEEE Standard, 2014). According to literature survey, there are two types of APFs to discuss the power quality problems in the electric power system. The series APF's for compensating voltage variations such as sags/swells. The shunt APF's for mitigation of current variations like current harmonics (Habrouk, Darwish & Mehta, 2000; Peng, Akagi & Nabae, 1993; Demirdelen, Kayaalp & Tumay, 2016). In later years, the series and shunt combined APF (Mishra & Kumar, 2001) called UPQC (Tekel & Tumayl, 2001; Ivanov, Ciontu, Sacerdotianu & Radu, 2017) is developed to have aided advantage of both shunt connected and series connected APF's. The APF's, created by Akagi (1996), initially provide, the better illustration of harmonic removal and voltage sag compensation (Gyugyi & Strycula, 1976; Peng et al., 1993).

The main basis for active filtering control is generation of reference signals by the reference current and voltage theories. Such generated reference currents and voltages are involved to evcolve gating pulses required by the voltage source converters (VSC's). The precise switching control of VSC's mitigates the harmonic currents and compensates the voltage sags. Usually the proportional-integral (PI) controller, takes care of harmonic mitigation and the sags compensation, will even take care of the active and reactive power control. The PI controller of that kind needs the precise tuning of proportional (KP) and integral gain (KI) values. The ziegler–nichols and cohen-coon methods are used to tune the KP and KI values of PI for controler incorporated in linear electric power systems, but these conventional methodologies will not hold good for todays practcal nonlinear power electic systems. In such cases, non linear systems with empirical optimal tuning methodologies help in finding the KP and KI values.

Hence in recent years, heuristic algorithms like evolutionary programming (EP) (Back & Schwefel, 1993), genetic algorithms (GA) (Michalewicz, 1999) is applied to economic load dispatch problems (Al-Shetwi & Alomoush, 2016), simulated annealing (SA) and tabu search (TS) (Chang, 1998) were become more prominanat to solve these kind of nonlinear nonsinusoidal function based power system problems. Later, Storn and Price (1997) findings discuss about another potent evolutionary algorithm called differential evolution (DE) to answer electrical engineering problems (Back & Schwefel, 1993; Michalewicz, 1999; Al-Shetwi & Alomoush, 2016; Chang, 1998; Storn & Price, 1997; Basu, 2008). Then, Chang (1998) and Basu (2008) applied DE to shunt harmonic filters enhancing research in optimal control of flexible alternating current transmission system (FACTS) devices.

Inspiring from the findings of Akagi (1996) and Basu (2008) an attempt is made to apply one such optimal methodology called particle swarm optimization (PSO) (Angeline, 1998; Hashim, Imran & Khalid, 2013; Amin, Hudha, Amer, Abd Kadir & Faiz, 2015; Berbaoui, Benachaiba & Dehini, 2010; Nunes et al, 2016; Rodriguez-Guerrero et al., 2018) to solve the mentioned power quality problems. The UPQC, which is a back to back connection of series and shunt APF's and a FACTS device, is integrated to deal with the mentioned power quality problems. The present work focus on mitigation and compensation of power quality issues like current harmonics, voltage swell and sag in the power system. The mitigation of current harmonics in the power system is taken care by shunt active filter by the injection of required harmonic compensating currents into the utility line to make it harmonic free. Whereas, series active filter takes care of voltage sag/swells injecting the required compensating voltages to make load voltage sag/swell free. The required reference currents and voltages are generated by the proposed Optimal Tuned Synchronous Reference Frame (OTSRF) theory. These reference currents and the voltages inturn are utilized to generate gating pulses with the help of Hysteresis Band Current Controller (HBCC) for series APF and Pulse Width Modulation (PWM) current controller for shunt APF. Thus generated gating pulses are utilized for active switching of VSC's, to sort out the power quality issues. Further, the proposed PSO algorithm is applied to the applied methodology. Thus particle swarm optimal control based PI controller, tunes the proportional (Kp) and integral gain (KI) values which enhances the performance of the considered electric power system. this in turn improves the power quality of the considered electric power systems. The performance evaluation of multi objective convergence fitness function (dealing: the voltage sag, source current variations and load voltage variations) with unified power quality conditioner using particle swarm optimization algorithm is performed. Efficacy of the proposed work is validated by conducting simulations in MATLAB/SIMULINK software.

2.0 POWER QUALITY PROBLEM AND PROPOSED SOLUTION

The objective of a power quality problem is to minimize the power quality issues like current harmonics (THD), voltage sag/swell (V_{sag}/V_{swell}) under different weighted conditions. The fitness function to be minimized is defined in Equation (1):

$$f = (w1)*(\text{THD of source current}) + (w_2)* (\text{THD of Load voltage}) + (w_3)*(V_{sag}/V_{swell}) \quad (1)$$

where Equation (1) represents the fitness function under case study: hybrid filtering with unified power quality conditioning. Parameters w_1, w_2, w_3 are the weights imposed for dynamic evaluation of multi objective fitness function.

The unified power quality conditioner with proposed OTSRF theory discuss the above defined problem in a better way. The OTSRF controlled Unified Power Quality Conditioner (UPQC) consists of PI controller which leads the above discussion being at front end.

The optimization parameters are proportional gain (K_p) and integral gain (K_I) of the PI controller, the transfer function of PI controller is defined by Equation (2):

$$G_c\,(s) = K_P + \frac{K_I}{S} \qquad (2)$$

The gains K_P and K_I of PI controller are tuned by the proposed particle swarm optimization algorithm as shown in Figure 1.

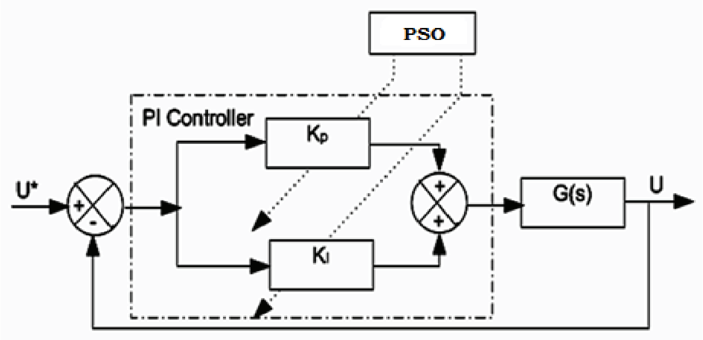

Figure 1. PI -PSO controller illustration

The gain G(s) is the considered plant. The PI controller parameters KP and KI are adjusted for getting the desired performance in the considered system.

The output of the PI controller u(t) is given by Equation (3):

$$u(t) = K_P.e(t) + K_I \int_0^t e(t)\,dt \qquad (3)$$

The detailed discussion of each and every considered criterion is explained, illustrated and can be explained in the subsequent sections.

3. 0 UNIFIED POWER QUALITY CONDITIONER

Among the available active power conditioners, UPQC is a specific one which solves most of the power quality problems like compensation and mitigates power quality issues like voltage and current variations. The nonlinear power system outline of a three phase UPQC is shown in Figure 2. The UPQC is a combination of one shunt APF and one series APF cascaded by a common direct current (DC) bus as shown in Figure 2. The shunt APF does harmonic mitigation during the action of nonlinear loads. The series APF provides the required compensating voltage whenever the supply voltage undergoes voltage sag/swell. Thus, UPQC improves the power quality by addressing the current variations in the supply side and voltage variations in the load side.

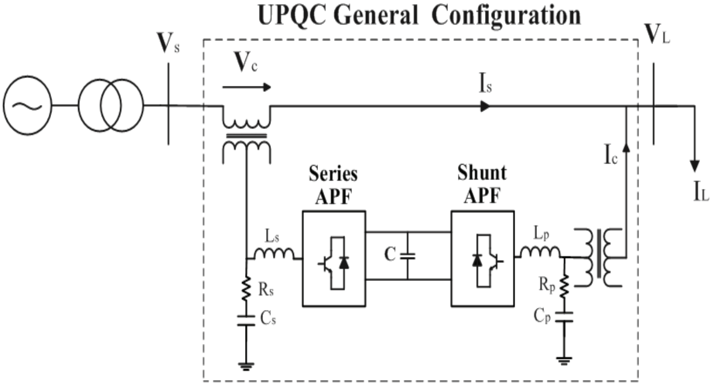

Figure 2. Single line diagram of UPQC

Figure 3 shows the single phase analogous representation of Figure 2, from which the required voltage compensation and reverse current harmonic content injection can be estimated and controlled by chosen parameters of shunt and series APF's. The voltage compensation (Vcomp) dealt by series VSI estimation and Current injection (Icomp) dealt by shunt APF's. The power conditioner UPQC with non-linear sensitive load is combined with active source that produce an equivalent circuit.

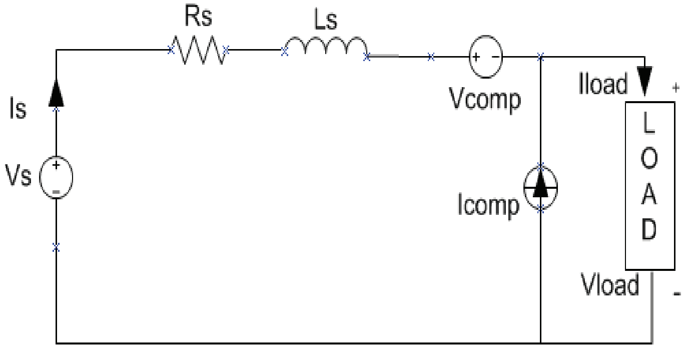

Figure 3. The equivalent circuit illustrating the UPQC phenomenon

4.0 OPTIMAL TUNNED SYNCHRONOUS REFERENCE FRAME (OTSRF) THEORY

The conventional Synchronous Reference Frame (SRF) theory is modified for optimal control as OTSRF theory is proposed to generate the reference currents (for shunt APF) and voltages (for series APF). The conventional SRF theory is based on Park's transformation. Usually in Park's transformation, the three-phase synchronous (a-b-c) reference frame currents and the voltages are transformed into stationary (d-q-o) reference frame currents and voltages. For a precise control with the help of SRF theory, the active and reactive powers are made independent of each other. The synchronizing action is done by phase-locked loop (PLL). The reference DC bus voltage of the cascaded DC link is compared with the actual happening voltage to calculate the error. Such calculated error ($e = _{vdcref} -_{vdc}$) is sent to the PI controller and then evaluated with the low pass filter in SRF theory. The used low pass filter of SRF theory suppresses the variations and allows fundamental components of voltage and current. This stationary (d-q-o) reference frame currents and voltages are once again converted back into synchronously (a-b-c) reference frame to get necessary reference currents ($I_{a\ ref}$, $I_{b\ ref}$, $I_{c\ ref}$) and voltages ($V_{a\ ref}$, $V_{b\ ref}$, $V_{c\ ref}$) as shown in Figure 4.

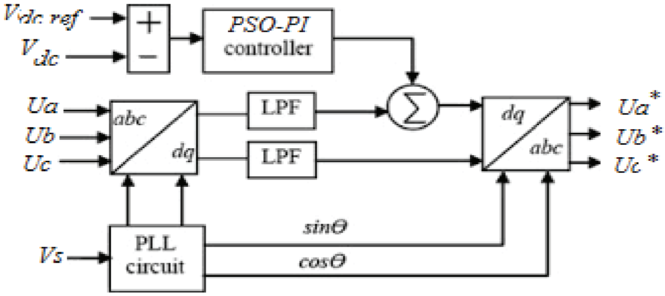

Figure 4. Control block for UPQC

These are then given to the HBCC and PWM pulse generation controllers of series and shunt APF's respectively. Now this PI controller is optimally tuned with the proposed PSO Algorithm to enhance the performance of UPQC as shown in Figure 1. The Figure 1 is integrated into Figure 4 to make SRF theory as OTSRF theory.

The reference three phase voltages for the series filtering are given by Equations (4) to (9) as follows:

$$\begin{bmatrix} V_{qs} \\ V_{ds} \\ V_o \end{bmatrix} = \left(\sqrt{\frac{2}{3}}\right) * \begin{bmatrix} \mathrm{Cos}(\theta) & \mathrm{Cos}(\theta - \frac{2\pi}{3}) & \mathrm{Cos}(\theta + \frac{2\pi}{3}) \\ \mathrm{Sin}(\theta) & \mathrm{Sin}(\theta - \frac{2\pi}{3}) & \mathrm{Sin}(\theta + \frac{2\pi}{3}) \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \tag{4}$$

$$(V_{qdos}) = KV_{abs} \tag{5}$$

$$(V_{abs}) = K^{-1}(F_{qdos})^{T} \tag{6}$$

where

$$K^{-1} = \begin{bmatrix} \mathrm{Cos}\ (\theta) & \mathrm{Sin}\ (\theta) & 1 \\ \mathrm{Cos}(\ \theta - \frac{2\pi}{3}) & \mathrm{Sin}\left(\ \theta - \frac{2\pi}{3}\right) & 1 \\ \mathrm{Cos}\ \left(\theta + \frac{2\pi}{3}\right) & \mathrm{Sin}\left(\theta + \frac{2\pi}{3}\right) & 1 \end{bmatrix} \tag{7}$$

Similarly, the three phase reference currents for shunt filtering are as follows:

$$\begin{bmatrix} I_{qs} \\ I_{ds} \\ I_o \end{bmatrix} = \left(\sqrt{\frac{2}{3}}\right) * \begin{bmatrix} \mathrm{Cos}(\theta) & \mathrm{Cos}(\theta - \frac{2\pi}{3}) & \mathrm{Cos}(\theta + \frac{2\pi}{3}) \\ \mathrm{Sin}(\theta) & \mathrm{Sin}(\theta - \frac{2\pi}{3}) & \mathrm{Sin}(\theta + \frac{2\pi}{3}) \\ 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \tag{8}$$

$$\begin{bmatrix} I_{a\_ref} \\ I_{b\_ref} \\ I_{c\_ref} \end{bmatrix} = \left(\sqrt{\frac{2}{3}}\right) * \begin{bmatrix} \mathrm{Sin}(\theta) & \mathrm{Cos}(\theta) & 1 \\ \mathrm{Sin}(\theta - \frac{2\pi}{3}) & \mathrm{Cos}(\theta - \frac{2\pi}{3}) & 1 \\ \mathrm{Sin}(\theta + \frac{2\pi}{3})\ 1 & \mathrm{Cos}(\theta + \frac{2\pi}{3}) & 1 \end{bmatrix} \begin{bmatrix} I_{ds} \\ I_{qs} \\ I_o \end{bmatrix} \tag{9}$$

5.0 THE DESIGN SPECIFICATIONS OF UPQC

The corresponding design parameters of UPQC like DC link capacitor voltage, the DC link capacitance, the excitation voltage rating of series APF, the kilovolt-amp (KVA) rating of the series injection transformer and the ripple filter frequency of low pass filter are explained in this section.

The DC link capacitor voltage upon the supply voltage is calculated as shown in Equation (10).

$$V_{dc} = (2\sqrt{2} * V_{LL}) / \sqrt{(3 * m)}) \tag{10}$$

where m is modulation index.

The DC link capacitance upon the dynamic variations in the load is calculated as given in Equation (11):

$$E = P * \Delta t = 1/2 * C_{dc} (V_{dc1}^2 - V_{dc}^2) \tag{11}$$

where Vdc = DC bus voltage,

V_{dc1} ($V_{dc1} = (2 * V_s)$) = the minimum DC bus voltage level with C_{dc} DC link capacitance

P = power ($P = 3 * V_s * I_s$) happening in Δt time interval to have E energy.

Parameter V_s is a source voltage and I_s is a source current. The excitation voltage rating of series APF is the maximum voltage to be injected during sag/swell occurrences. The series APF injected voltage is calculated as expressed in Equation (12).

$$V_{\text{series APF}} = \sqrt{(V_s^2 - V_L^2)} \tag{12}$$

where $V_{\text{series APF}}$ is series APF's injecting voltage and V_L is load voltage.

The kVA rating of the series injection transformer is calculated as given in Equation (13).

$$S= (3V_s*I_s)/1000 \tag{13}$$

where S is power in kVA.

The ripple filter is a cascaded connection of R_r and C_r. The ripple filter is essentially provided to eliminate the switching ripples connected across the series injection transformer. The ripple filter frequency is calculated as given in Equation (14).

$$f_r= 1/(2\pi*R_r*C_r) \tag{14}$$

where f_r is switching frequency. Usually the range is in between 5kHz – 20kHz, R_r and C_r are the resistance and capacitance values of ripple filter.

6.0 PROPOSED PSO ALGORITHM FOR POWER QUALITY ENHANCEMENT

The Particle swarm optimization (PSO) algorithm is a bio inspired arbitrary evolving optimization algorithm. It is based on the collective nature of fish and bird flocking. PSO learns from the circumstances with that knowledge tries to solve the corresponding optimization problems (Basu, 2008; Amin et al., 2015). The position changeover of the birds is replicated as moments of particles. All such particles have a specific objective values which are intended by the objective function that is to be optimized. The velocities of the particles guide the progress of the particles.

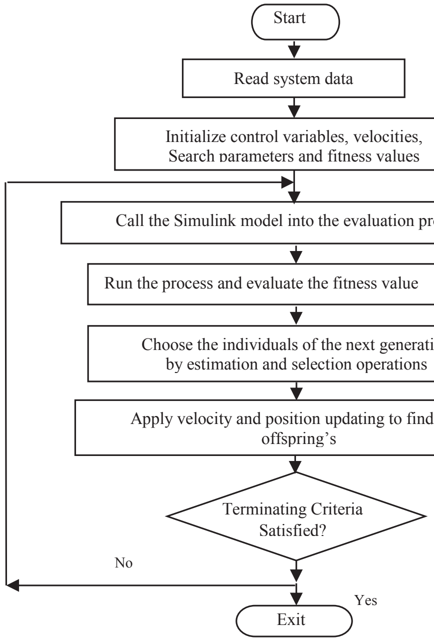

Figure 5. The proposed PSO algorithm flow chart

The flow chart of the proposed Algorithm is shown in Figure 5. The mathematical representation of position moment of particle is as expressed in Equations (15) to (17).

$$X_s\,(t+1) = X_s\,(t) + V_s\,(t+1) \tag{15}$$

$$V_s\,(t+1) = wV_s\,(t) + C_1\,r_1\,(P_{best} - X_s\,(t)) + C_2\,r_2\,(G_{best} - X_s\,(t)) \tag{16}$$

$$X_s\,(t+1) = X_s\,(t) + V_s\,(t+1) \tag{17}$$

where $V_s^{(t)}$ demonstrate the progress vector of particles in *t* time; $X_s^{(t)}$ demonstrate the position vector of particles in *t* time; P_{best} is the own best location of the particles, G_{best} is the finest location of the particles found nearby; *w* represents inertia weight; C_1 is cognitive and C_2 is social acceleration constants. ($C_1+C_2 = 4$); and r_1 and r_2 are two random generation values in the range [0, 1] for better optimization.

7.0 SIMULATION RESULTS

The power quality enhancement in this context mainly aims to optimize the subjected power quality issues with several limiting constants of the concerned controller. The power system problem of this kind is mathematically represented as in Equation (1), however, the objective fitness function is the minimization of Equation (1) and written as in Equation (18).

$$f = (w_1)^*(\text{THD of source current}) + (w_2)^*\ (\text{THD of Load voltage}) + (w_3)^*(\text{Vsag}) \qquad (18)$$

where w_1, w_2, w_3 are the weights decided once again heuristically by algorithm.

The experimental simulations run on the MATLAB/SIMULINK environment. This paper aims to solve power quality issues like voltage and current harmonics and voltage sag for a 33kV, 50Hz, three phase feeder line. The current variations are usually caused due to nonlinear loads and voltage variations arises due to short circuits or starting/stopping of large loads. The practical non-linear load phenomenon is realized with the help of power electronic converter (diode bridge rectifier with RL load) and voltage sag is created with the help of a programmable source during 0.05-0.1s. The UPQC is applied to the considered power transmission line which is shown in the Figure 6.

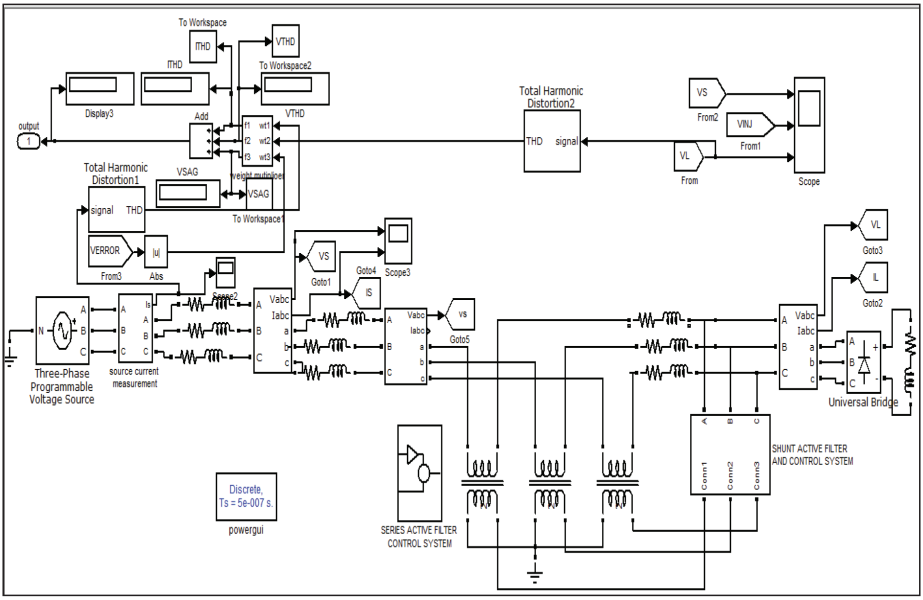

Figure 6. MATLAB/Simulink illustration of the UPQC and transmission line

Due to the considered power electronic nonlinear load, entire current waveform gets distorted and due to programmable source as a fault generator, a votage sag is observed during the interval 0.05-0.1s as shown in Figure 7.

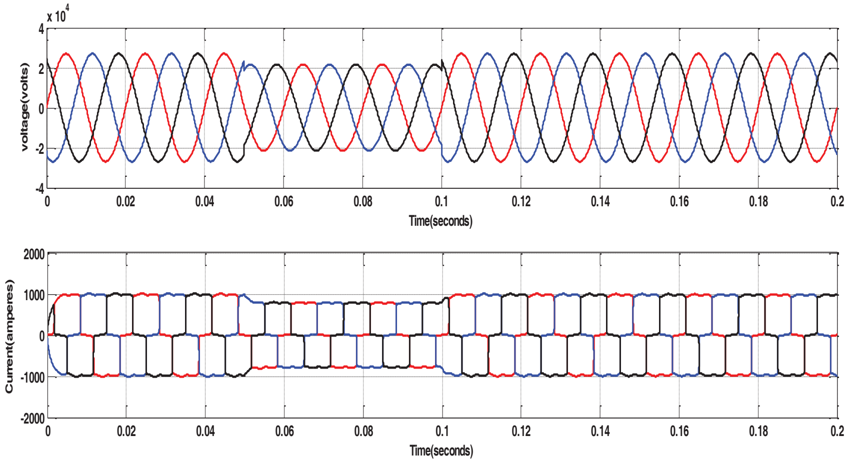

Figure 7. Illustration of voltage sag and current harmonic waveforms without compensation

The UPQC designed and developed to sort out these power quality issues injects the required compensating currents into the line at point of coupling and make source current harmonic free. The such harmonic compensating phase currents ia, ib and ic and resultant source currents after compensation are shown in Figure 8.

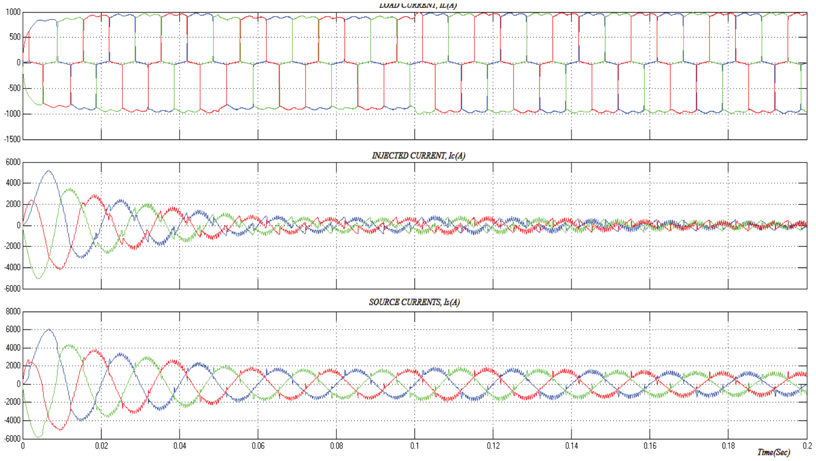

Figure 8. Compensating currents using UPQC and the resultant source current with PSO algorithm

The UPQC provides the required compensating voltages into the line during sag conditions. The complementing per phase voltages (Vc abc) and the load voltage after mitigation of sag are shown in Figure 9.

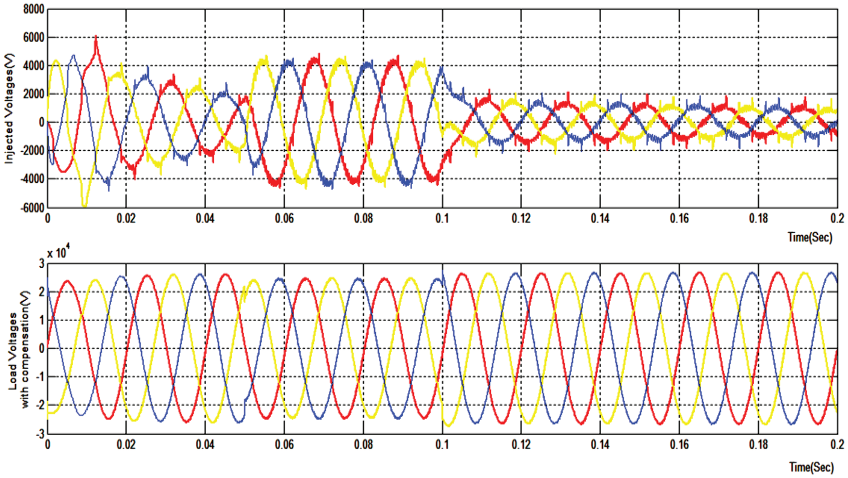

Figure 9. Injected complementing voltages and load voltages after sag compensation with PSO algorithm.

The cascaded DC link capacitor comes into operation during abnormal conditions in power utility transmission line. Here, the abnormality is created with programmable voltage source during 0.05 – 0.1s, and with the effect of capacitor action the voltage is normalized during this interval. Thus the variation in voltage requirement is taken care by the DC link capacitor. By considering $K_{P1} = 0.05$, $K_{I1} = 0.2$, $K_{P2} = 10$, $K_{I2} = 0.1$, the THD of source current is 8.37%, THD of source voltage is 2.01% and load voltage has a dip variation of 10%.

Usually the K_P and K_I parameters of PI controller are obtained from initial expert knowledge and is not a good practice, besides they will not work out practically for nonlinear systems. This limitation is overcome by optimal tuning of K_P and K_I values of PI controller. PSO is one such evolutionary population based optimization technique. The idea behind this technique is learning behavior of particles and their moment illustrations to evolve fitness function. The optimization control variables are K_P and K_I of PI controller, where K_P and K_I represent proportional and integral gains respectively.

The output and input relation of PI controller is represented by the following transfer function as given in Equation (19).

$$K_c(s) = K_P + \frac{K_I}{s} \tag{19}$$

PSO algorithm based PI controller is tested to limit the THD in the source current and voltage and to discuss the corresponding sag voltage. The fitness convergence is evolved by the optimal tuning of K_P and K_I values of the PI controller. The fitness value is reduced to 2.44% (average value after 10 runs each making the K_P and K_I ranging from (0, 10) varying C_1 and C_2 (following the empirical relation $C_1+C_2=4$ by literature survey) where C_1 and C_2 are acceleration coefficients of PSO algorithm. The optimization is run for 50 iterations. The corresponding fitness convergence graphs for various possible C_1 and C_2 values of PSO algorithm are shown in Figure 10.

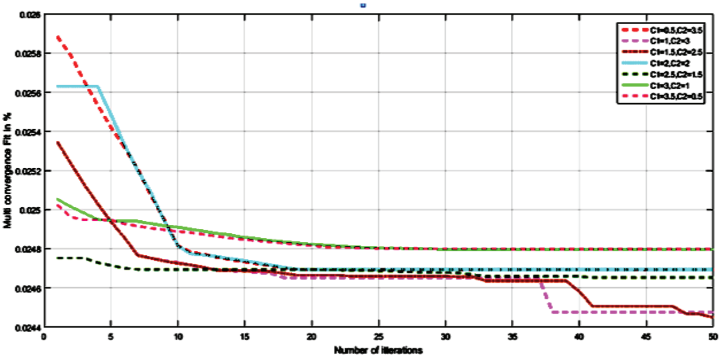

Figure 10. Multi objective convergence of fitness (the voltage sag, source current THD and load voltage THD) with UPQC using PSO algorithm

Table 1. Convergence of fitness with PSO Algorithm

Proposed PSO Multi Objective convergence in %				
C1	**C2**	**Is_{THD}**	**Vs_{THD}**	**Vs_{ERROR}**
0.5	3.5	1.482	0.247	0.741
1	3	1.4676	0.2446	0.7338
1.5	2.5	1.4652	0.2442	0.7326
2	2	1.4832	0.2472	0.7416
2.5	1.5	1.4784	0.2464	0.7392
3	1	1.488	0.248	0.744
3.5	1	1.4892	0.2482	0.7446

Table 1 illustrates the convergence of fitness with PSO algorithm varying C_1 and C_2 parameters. The performance evaluation with the PI controller tuned with PSO Algorithm for the best run with the considered fitness function (after 10 runs with each C_1 and C_2) is studied. This reduction in THD is achieved by optimizing the PI parameters without any additional device or cost with the same existing hardware. Further Table 1 illustrates the individual objectives of Is_{THD}, Vs_{THD} and Vs_{ERROR} from the obtained converged fitness value.

Table 2. Comparison of the UPQC performance with the PI (Trial and Error based) and proposed PSO algorithm.

Parameter Variable	**Is_{THD} (%)**	**Vs_{THD} (%)**	**Vs_{ERROR} (%)**
PI	8.37	2.01	10
PSO	1.4652	0.2442	0.7326

Table 2 gives the performance evaluation with the conventional PI controller and proposed PSO algorithms for the best run with the considered fitness function. This reduction in THD is achieved by optimizing the PI parameters without any additional hardware and economy.

Table 3. Comparison of control parameters of UPQC with PI (Expert knowledge) and proposed PSO algorithm.

Parameter Variable	**K_{p1}**	**K_{I1}**	**K_{p2}**	**K_{I2}**
PI	0.05	0.2	10	0.1
PSO	2.583	0.56	3.76	0.88

Table 3 gives the control parameter comparison with the conventional PI controller and PSO Algorithms for the best run with the considered fitness function. The thus evolved PI parameters are submitted and verified with dynamic simulation of UPQC.

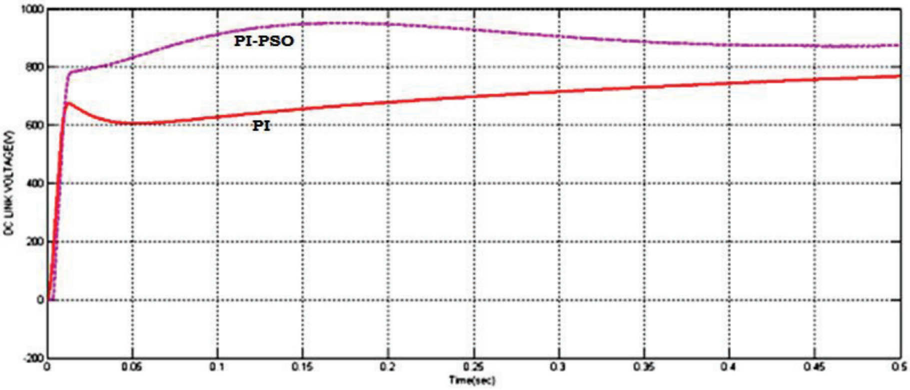

Figure 11. DC Link voltage representation with Shunt Active filter controlled by PI and proposed PSO algorithm

The DC link capacitor will act as a supporting medium between series and shunt VSC's. The DC link voltages for the conventional PI and proposed PSO algorithm is shown in Figure 11. The Figure 11 illustrates the realization for the best tuned value of the proposed PSO Algorithm Vs conventional PI controller. This explains that for every variation in voltage and current, the DC link responds to each such variations accordingly.

8.0 CONCLUSION

In this paper, performance of PSO algorithm is illustrated to decrease the harmonic effect which in turn reduces the heating effect caused by harmonic loads and compensating the voltage dips due to starting of large machines. The performance evaluation of the proposed approach is compared with the traditional PI controlled UPQC. The comparative analysis of the conventional PI controller and proposed PSO algorithm has shown that PSO algorithm has been proved to be better in terms of harmonic reduction and voltage sag compensation. The simulation outcomes are handy to demonstrate the ability of the proposed algorithm.

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REFERENCES

Akagi, H. (1996). New trends in active filter for power conditioning. *IEEE Transaction on Industry Application*, 32: 1312-1322.

Al-Shetwi, A. Q. & Alomoush, M. I. (2016). A new approach to the solution of Economic Dispatch using Genetic Algorithm. *Journal of Engineering and Technology*, 7(1): 2180-3811.

Amin, M. H. I. M., Hudha, K., Amer, N.H., Abd Kadir, Z. & Faiz, A (2015). Modelling and Control of Seven Dof Ride Model using Hybrid Controller Optimized by Particle Swarm Optimization. *Journal of Engineering and Technology,* 6(2): 2180-3811.

Angeline, P. J. (1998). Evolutionary Optimization versus Particle Swarm Optimization: Philosophy and Performance Differences. Evolutionary Programming VII, *Lecture Notes in Computer Science, Springer*, 1447: 601-610.

Back, T. & Schwefel, H. P. (1993). An overview of evolutionary algorithms for parameter optimization. *Evolutionary Computation*, 1(1): 11-23.

Basu, M. (2008). Optimal power flow with FACTS devices using differential evolution. *International Journal of Electric Power Energy and Systems*, 30:150-156.

Berbaoui, B., Benachaiba, C. & Dehini, R. (2010). Design of optimal PI controller for Shunt Active Power Filter using Particle Swarm Optimization. *Quatrième Conférence Internationale surle Génie Electrique CIGE'10, Université de-Bechar, Algérie.*

Bollen, M. (2000). *Understanding power quality problems*. IEEE Piscataway, NJ, USA, ch. 1:1-35.

Chang, T. (1998). Application of differential evolution to passive shunt harmonic filters planning. *8th International Conference On harmonics and Quality of Power*.

Demirdelen,T. C., Kayaalp, I. & Tumay, M. (2016). PSO - PI Based DC Link Voltage Control Technique for Shunt Hybrid Active Power Filter. *Second International Conference on Systems Informatics, Modelling and Simulation, IEEE*, 978-1-5090-2693-7/16.

EI-Habrouk, M., Darwish, M. K. & Mehta, P. (2000). Active power filters: A review. Proceedings in *IEE on Electric Power Applications*, 147: 403-412.

Gyugyi, L. & Strycula, E. C. (1976). Active AC power filter. *Proceedings in IEEE IAS Annual Meeting*, 529–529.

Hashim, R., Imran, M. & Abd Khalid N. E. (2013). Particle Swarm Optimization (PSO) Variants with Triangular Mutation. *Journal of Engineering and Technology*, 4(1): 2180-3811.

IEEE Standard 519-1992 (2014 revised). *IEEE recommended practices and requirements for harmonic control in electrical power systems*.

Ivanov, S., Ciontu, M., Sacerdotianu, D. & Radu, A. (2017). Simple Control Strategies of the Active Filters within a Unified Power Quality Conditioner (UPQC. *The 7th International Conference on Modern Power Systems* (MPS 2017), IEEE 978-1-5090-6565-3/17.

Michalewicz, Z. (1999). *Genetic Algorithms+Data Structures = Evolution Programs.* 3rd edition, Springer, New York.

Mishra, M. K. & Kumar, C. (2014). A voltage controlled DSTATCOM for Power Quality Improvement. *IEEE Transations on power delivery*, 29(3): 1499-1507.

Nunes, V., Maira, C., Monteiro, R. Zambroni de Souza, A.C. (2016). Particle swarm optimization applied to reactive power compensation. *17th International Conference on Harmonics and Quality of Power*.

Peng, F. Z., Akagi, H. & Nabae, A. (1993). Compensation characteristics of the combined system of shunt passive and series active filters. *IEEE Transaction on Industry Applications*, 29: 144-152.

Rodriguez-Guerrero, M. A., Cuellar, A. Y. J., Carranza-Lopez-Padilla, R. D., Osornio-Rios, R. A., Ruiz, G. H. & Romero-Troncoso, R. J. (2018). Hybrid Approach Based on GA and PSO for Parameter Estimation of a Full Power Quality Disturbance Parameterized Model. *IEEE Transactions on Industrial Informatics,* 14(3): 1016-1028.

Storn, R. & Price, K. (1997), Differential Evolution - a simple and special heuristic for global optimization over continuous spaces. *Journal of Global Optimization*, 11:341-359.

Tekel, A. & Tumayl, M. (2001). Unified Power Quality Conditioner: A Literature Survey. *Journal of Electrical Systems*, 7-1, 122-130.