POWER QUALITY IMPROVEMENT USING SERIES ACTIVE POWER FILTER BASED ON GRAVITATIONAL SEARCH ALGORITHM

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ABSTRACT

This paper proposes a heuristic control of the series active power filter for power quality enhancement. In this context, the series active filter is better utilized as a voltage source controller contrary to its conventional usage as variable impedance. The present-day utility system as a linear model is unsatisfactory and the steps are laid down to discuss utility system as a nonlinear model. This paper deals power quality disturbances like voltage sag/swell, voltage error and THD with robust heuristic algorithms like the gravitational search algorithms (GSA) and it is further compared with Firefly (FF) algorithm. The harmonic reduction in the source current and mitigation of sags/swells in the load voltage is carried out with optimal tuning of the PI controller. The series active power filter as a harmonic suppressor with a specific reference controlled strategy is discussed in this paper. The synchronous reference frame (SRF) theory is used to generate the reference voltage signals required for compensation. The hysteresis band current controller (HBCC) is used to perform the switching operation of Voltage Source Inverter. Simulations are carried out in the MATLAB/SIMULINK environment.

KEYWORDS*: Series Active Power Filter (SeAPF); Synchronous Reference Frame theory (SRF); FireFly Algorithm (FF); Gravitational Search Algorithm (GSA)*

1.0 INTRODUCTION

The growing need and widespread usage of power semiconductor devices and its equipment at various levels in day to day life is appreciable. This power electronic equipment, driving huge machines, is a source of power quality problems in the

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utility systems. This sag/swell and nonlinearities may lead to undesirable effects such as electromagnetic interference, flicker voltage distortion, low power factor, etc. These power quality events need to be addressed by the power electronic researchers to mitigate them (Akagi et al., 1990; Gyugyi & Strycula, 1976). These disturbances might harm industries/domestic customers ranging from not working of the system to total shutting down of the plants.

These days research is making headway on several other issues of active power filters related to design, calculation, run, and initiation. The series active power conditioner, refined based on power electronics technology, is presently taken as the most adaptable equipment for curbing and compensation of power quality disturbances like sags/swells and harmonics.

In the 1970's the concept of active power filter is for the most part developed by Gyugyi and Strycula (1976). Three best ways of control methodologies are proposed by Akagi et al. (1990). They are voltage detection, load current detection and supply current detection for active power filter applied in specific applications. International power quality standards for power quality problems and harmonic control in power utility systems impose some restrictions on harmonics as given in (IEEE Std 519).

The power semiconductor based Active Power Filter (APF) is the majority opted good-looking solution to solve the power quality problems, which in turn ensures a better power distribution system, from 1970s onwards. Usually, there are two types of active power conditioners one connected in series and other in shunt as series and shunt active filters (Peng et al., 1993; Akagi, 1996; EI-Habrouk et al., 2000). In terms of Research and Development, the shunt connected active power conditioner is well-suited in the direction of reduction of harmonics in the supply current, while the series active power conditioners best chosen to compensate voltage disturbances in load required voltage (Akagi et al., 1990: Gyugyi & Strycula, 1976). SeAPF is more efficient, cost-effective, simple in control device and has fast response. This is the main reason for extensive use of the SeAPF out of all other custom power devices for the voltage restoration (Ghosh & Ledwich, 2002; Chang et al., 2000). In addition, SeAPF also has features like harmonic mitigation, reactive power compensation, and power factor correction. So it is clear that compared to other custom power devices SeAPF is a better option to mitigate power quality problems.

The required voltage or the current reference generation is done based on the reference currents and voltage theories (Akagi et al., 1990; Gyugyi & Strycula, 1976). The gating pulses required by VSI's are generated utilizing these reference currents and voltages. By controlling the switching of VSIs, the harmonic currents are mitigated and the sags are compensated. The PI controller, which controls the active and reactive power of VSIs, takes care of harmonic mitigation and the sags compensation. The PI controller needs the tuning of Proportional Gain (K_p) and Integral Gain (K_I) values. For linear systems with linear loads, methods like Ziegler–Nichols and Cohen-Coon tuning methods help in finding the K_P and K_I values empirically (Ziegler & Nichols, 1942). These methods are not easily applicable to a nonlinear system with nonlinear loads.

Hence, in recent years, heuristic algorithms (Yang, 2008) such as Genetic Algorithm (GA) (Al-Shetwi & Alomoush, 2016). Particle Swarm Optimization (PSO) (Amin et al., 2015), Differential Evolution (DE), Simulated Annealing (SA), Evolutionary Programming (EP) and Tabu Search (TS) were implemented with Flexible Alternating Current Transmission Systems (FACTS) devices to resolve the problems related to power systems. In later recent years, many more hybrid algorithms have been introduced to enhance search efficiency. The results, obtained using the above algorithms, were promising and encourage further research using enhanced versions of these algorithms.

This paper proposes a method using Gravitational Search Algorithm (GSA) (Gu et al., 2010) and FireFly Algorithm (FF) (Saibal et al., 2012) to solve the power quality problems with nonideal voltage and current functional signal. SRF theory and its modified versions are used to generate reference currents and voltages. These reference currents and voltages are utilized to generate controlled gating pulses with the help of the Hysteresis Band Current Controller. By controlling switching of the VSI, harmonic currents and sags are mitigated. The PI controller in SRF theory needs the tuning of proportional and integral gain values. The K_P and K_I values of the PI controller are optimized with the help of Gravitational Search Algorithm (GSA) and FireFly Algorithm (FF). Further, these two contemporary search algorithms which are robust are compared as they operate in search space in a similar manner.

2.0 THE OPERATION OF SeAPF

The SeAPF is a solid-state device connected in series as shown in Figure 1. It injects the required compensating voltage into the utility system such that the unbalanced or distorted load-side voltage is regulated to the desired level (Farahani et al., 2001; Gu et al., 2010; Yang, 2008). This phenomenon further takes care of injection of active/reactive power from the SeAPF to the utility (Gu et al., 2010).

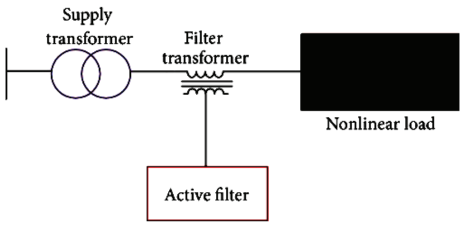


Figure 1 Single line diagram representing SeAPF

The broad construction of the SeAPF consists of the power circuit and control circuit. The corresponding circuit diagram is as shown in Figure 2. The analogous circuit diagram is simply represented by an expression in Equation (1) as follows: -

$$V_{SeAPF} = V_L + Z_{TH} I_L + V_{TH} \qquad (1)$$

Where V_L is the desired load voltage magnitude, Z_{TH} is the load impedance, I_L is the load current and V_{TH} is the system voltage (during the faulty condition).

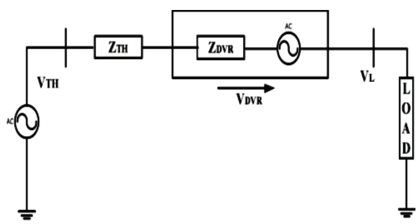


Figure 2 The equivalent circuit diagram for the single line diagram of Figure 1

The load side current (I_L) is given by an expression in Equation (2) as follows: -

$$I_L = \frac{P_L + jQ_L}{V_L} \qquad (2)$$

When V_L is well thought-out as a reference quantity, the equation can be written as in expression in Equation (3) as follows: -

$$V_{SeAPF}\angle\alpha = V_L\angle 0 + Z_{TH}I_L\angle(\beta - \theta) + V\angle\delta \quad (3)$$

Where α is the angle of SeAPF, β is the angle of Z_{TH}, δ is the angle of V_{TH} and θ is the load power angle, which is given by Equation (4) as follows: -

$$\theta = \tan^{-1}\left(\frac{Q_L}{P_L}\right) \quad (4)$$

The complex power injection done by the SeAPF can be written as in the expression in Equation (5) as follows: -

$$S_{SeAPF} = V_{SeAPF}^{*} I_L \quad (5)$$

3.0 CONTROL OF SeAPF

The flow chart in Figure 3 depicts how the SeAPF will be operated under sudden load/fault conditions. At first, the line voltage (V_s) and the load voltage (V_{L1}) at the sensitive load end are measured. Under this case, the measured values of both V_s and V_{L1} are maintained equally. When a sudden disturbance occurs (fault or application/ removal of load), then the magnitude of load side voltage (V_{L2}) is changed suddenly and is termed to be sag/swell. Then V_{L2} is compared with the V_{L1}. If both are equal, then SeAPF is said to be in no operation, i.e., no voltage is injected into the line which is treated as SeAPF operating in standby mode. But when V_{L2} is less/more than V_{L1}, then SeAPF will be operating in boosting/bucking mode, i.e., the SeAPF will inject a sag or swell voltage (V_{sag}/ V_{swell}). The injection of voltage will be $V_{L1} = V_{L2} + V_{sag}$ in case of sag or $V_{L1} = V_{L2} - V_{swell}$ in case of the swell. The SeAPF will inject/suck out the voltage till the normal voltage is reached.

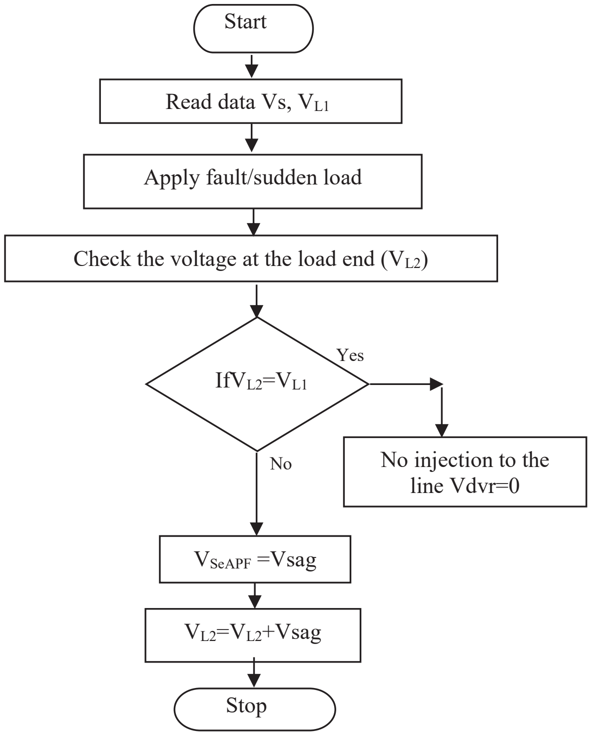


Figure 3 Flow chart of the control scheme of SeAPF

The necessary purpose of a controller in a SeAPF is to detect the voltage sag/ swell power quality events in the utility system. In this paper, the Synchronous Reference Frame (SRF) theory is used to control the SeAPF. The voltage sag can be detected when the supply voltage drops below 90% of the reference value, similarly, voltage swell is above 10% of the reference value as per IEEE standard. The controller of this kind can also be used to shift the voltage in voltage source converter of the series active power conditioner into a rectifier mode and to charge the capacitor in the DC link in the absence of voltage sag/ swells. The basic block representation of SRFT is illustrated as in Figure 4.

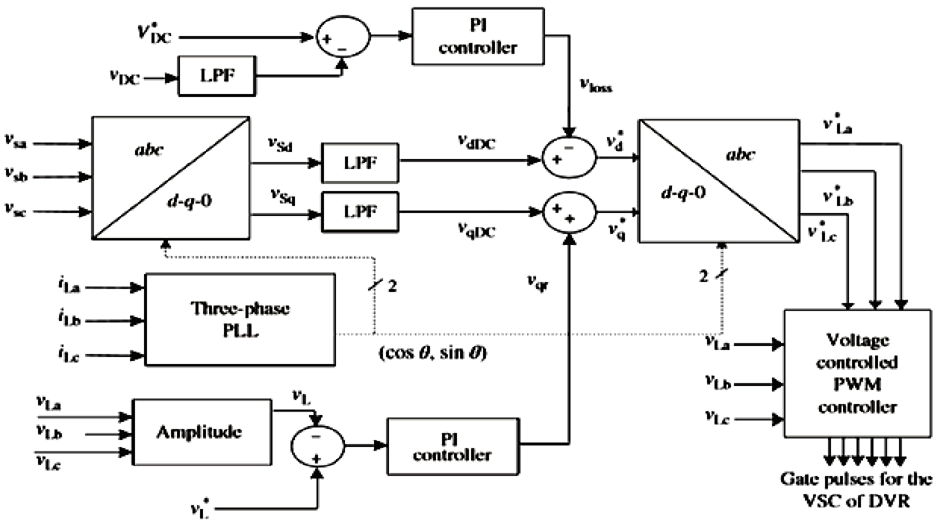


Figure 4 SRFT Control block of SeAPF

Park's transformation or dq0 transformation is used to maintain the power invariance, which is represented in Equations (6) and (7) as follow: -

$$\begin{bmatrix} fqs \\ fds \\ f0s \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos\theta & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ \sin\theta & \sin(\theta - \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} fas \\ fbs \\ fcs \end{bmatrix}$$

$$(f_{qd0s}) = \mathrm{K} f_{abcs} \tag{6}$$

$$(f_{abcs}) = \mathrm{K}^{-1}(f_{qd0s})^{T} \tag{7}$$

where '*f*' represents a voltage and

$$\mathrm{K}^{-1} = \begin{bmatrix} \cos\theta & \sin\theta & 1 \\ \cos(\theta - \frac{2\pi}{3}) & \sin(\theta - \frac{2\pi}{3}) & 1 \\ \cos(\theta + \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) & 1 \end{bmatrix}$$

Instead of deriving the transformation for each and every particular reference, it is advantageous to derive the general transformation for any arbitrary rotating reference frame. The voltage equation (V_{sa}, V_{sb}, V_{sc}) in the three-phase abc reference frame can be transformed into the stationary dq reference frame (Vd, Vq) (where d-represented as an active power component, q is represented as the reactive power component). The components of voltages in the d- and q-axes are given by Equations (8) and (9) as follow: -

$$vd=vddc+vdac \quad (8)$$

$$vq=vqdc+vqac \quad (9)$$

The error from the DC link capacitor voltage is utilized to find the amount of real voltage in phase with the line current to be injected into the utility system. The PI controller reduces the steady state as well as a transient error and also increases the speed of response. After that, the result is converted back to the original signal using inverse Park's transformation. These signals are combined referred to as Reference signal (V_{sa}*, V_{sb}*, V_{sc}*, V_{SI}* = V_{sabc}*). Then the reference voltage signal is compared with the actual load voltage (V_{Labc}) which gives an error signal. This error signal is used as a modulation signal to generate a commutation pattern for the IGBT switches in the VSI. The pulses required for VSI are generated by means of pulse width modulation (PWM) technique.

4.0 SYSTEM CONFIGURATIONS

A 3-Φ, 415 V, 50 HZ power supply, transmission utility with nonlinear load and SeAPF system is developed in the MATLAB/SIMULINK using the simpower system toolbox. A specification of different parameters of SeAPF is given in Table 1.

Design parameters of SeAPF consists of voltage rating, current rating and KVA rating of the VSI, transformer rating, DC bus voltage, and filter parameters, is illustrated in Section 4.1 - 4.5.

4.1 Voltage Rating of the VSI of SeAPF

The voltage rating of VSI depends on the utmost voltage to be injected in case of any voltage variations of the load. In case of a self-supported SeAPF, the injected voltage is in quadrature with the load current. So, the voltage rating of the VSI is calculated based on the load requirement. The injected voltage is estimated using an expression in Equation (10) as follow:-

$$VC = \sqrt{(V_s^2 - V_L^2)} \quad (10)$$

4.2 KVA Rating of the Transformer

The *KVA* rating of the injection transformer is the same as that of the VSI rating of SeAPF. *KVA* rating of the transformer is calculated using Equation (11) as follow:-

$$S = (3V_{S*}I_S)/1000 \tag{11}$$

4.3 DC Capacitor Voltage

The DC capacitor voltage is calculated based on the following relation as given in Equation (12) as follows: -

$$V_{dc} > 2\sqrt{2}*V_{DVR} \tag{12}$$

4.4 DC Bus Capacitance of the VSI

The DC bus capacitance is calculated based on how much energy is required during the change in load, it is calculated using Equation (13) as follow: -

$$E = 1/2*C_{dc}\,(V_{dc}^2 - V_{dc1}^2) \tag{13}$$

Where V_{dc} is DC bus voltage and V_{dc1} is changing in bus voltage during the disturbance.

In addition, Equation (14) is also considered as shown below:-

$$P*\Delta t = 1/2*C_{dc}\,(V_{dc}^2 - V_{dc1}^2) \tag{14}$$

Where $P = 3*V_C*I_S$

4.5 Ripple Filter

The ripple filter is intended to eliminate the switching frequency ripples from injected voltage. The DC side disturbance mitigating filter consists of a series connected R_r and C_r, in which the following expression as given in Equation (15) is sought as follows:-

$$f_r = 1/(2\pi*R_{r*}C_r) \tag{15}$$

Where f_r is chosen as half of the switching frequency. The maximum and minimum limits of switching frequency are taken as 5 KHz and 20 KHz.

Table 1 Specifications of SeAPF System

Parameters	Ratings
AC line voltage	415V, 50Hz
Line impedance	L_s = 3mH, R_s = 0.01Ω
Ripple filter	C_f = 10μF, R_f = 4.8Ω
DC voltage of SeAPF(V_{DC})	300V
PWM switching frequency	10KHz
Series Transformer	10KVA, 200V/300V

5.0 OPTIMAL TUNING METHODS

The present work in the paper exploits the fitness function as the minimization of THD in source current, the voltage sag, and the DC link voltage. The objective function is mathematically represented in Equation (16) as follows:

$$F = f(I_{THD}) + f(Vsag) + f(Vdc) \tag{16}$$

The optimal tuning parameters are the proportional gain (Kp) and the integral gain (Ki). The output function of the PI controller is mathematically represented by an expression in Equation (17) as follows: -

$$G_c(s) = k_p + \frac{k_i}{s} \tag{17}$$

The gains of the PI controller (K_p and K_I) are generated and updated by the FF and GSA algorithms for a given plant, as shown in Figure 5.

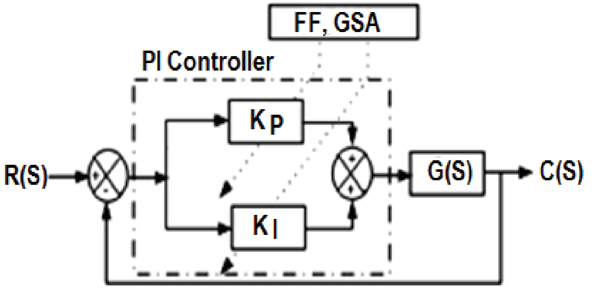


Figure 5 PI controller mechanism illustration

The output of the PI controller u(t) is given by Equation (18) as follows: -

$$u(t) = k_p e(t) + k_i \int_0^t e(t)dt \tag{18}$$

For the taken plant, the problem of designing a PI controller is to adjust the parameters k_p and k_i for getting a desired performance of the considered system. In this paper, two tuning methods are used; the description of each method is described below:

5.1 Firefly Algorithm

Firefly Algorithm (FA or FFA) was developed by Xin-She Yang at Cambridge University in 2007. Sporadic uniqueness of fireflies is used to develop the Firefly-inspired algorithm. In the firefly algorithm, there are significant keynotes: the variation in the light intensity and formulation of the attractiveness.

The direction of the firefly i is engrossed to a new more striking (brighter) firefly j is resolute by an expression given in Equation (19) as follows: -

$$x_i = x_i + \beta_0 e^{-\gamma r_{i,j}^2}(x_j - x_i) + \alpha \epsilon_i \tag{19}$$

Here the second term is due to the attraction and the third term is randomization with α being the randomization parameter (0 to 1), and ϵ_i is a vector of random numbers being drawn from a Gaussian distribution or uniform distribution.

The distance between any two fireflies i and j at xi and x_j, respectively is the Cartesian distance, which is given by Equation (20) as follows:-

$$r_{i,j} = \|x_i - x_j\| = \sqrt{\sum_{k=1}^{d}(x_{i,k} - x_{j,k})^2} \tag{20}$$

Where $x_{i,k}$ is the k_{th} component of the spatial coordinate x_i of i^{th} firefly.

In 2-D case, we have

$$r_{i,j} = \sqrt{(x_i - x_j)^2 - (y_i - y_j)^2} \tag{21}$$

Since a firefly's attractiveness is proportional to the light intensity seen by adjacent fireflies, we can now define the attractiveness β of a firefly as shown in Equation (22) as follows: -

$$I(r) = \frac{I_S}{r^2} \tag{22}$$

where I(r) is light intensity and I_s is intensity of source and r is distance with inverse square law to intensity.

In addition, Equation (23) is also considered, with an expression as follows:-

$$\beta=\beta_0 e^{-\gamma r^2} \quad (23)$$

Where β is attractiveness and β0 is the attractiveness at r = 0 and γ is fixed light absorption coefficient (0 to 10).

5.2 Gravitational Search Algorithm (GSA)

Gravitational Search Algorithm is based on the Newtonian gravity: ''Every particle in the universe attracts every other particle with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them''.

In a system with *N* agents, the position of the i_{th} agent is defined as in Equation (24) as follows:-

$$X_i= (x_{i1},\ldots, x_{id},\ldots,x_{in})\ for\, i = 1,2,\ldots,N \quad (24)$$

Where x_{id} represent the position of the i_{th} agent in the dth dimension, and n is the dimension of the search space. At the time t a force acts on mass *i* from mass *j*. This force is defined as given in an expression in Equation (25) as follows: -

$$F_{ij}{}^d = G(t)\frac{\mathrm{Mpi\ (t)\times Maj(t)}}{\mathrm{Rij+\varepsilon}}(x(t) - x_i{}^d(t)) \quad (25)$$

Where M_{aj} is the active gravitational mass of agent *j*, M_{pi} is the passive gravitational mass of agent *i*, $G(t)$ is gravitational constant at time *t*, ε is a small constant, and $R_{ij}(t)$ is the Euclidian distance between two agents *i* and *j*.

In addition, the following expression in Equation (26) is also considered, as below: -

$$R_g(t) = \|X_i(t).\ Xj(t)\|_2 \quad (26)$$

The total force acting on mass *i* in the d^{th} dimension in time *t* is given in Equation (27) as follows:-

$$F_i^d\ (t) = \sum_{j\epsilon Kbest, j\neq i}^{N} rand_j\ F_{ij}^d(t) \quad (27)$$

Where rand $_j$ is a random number in the interval [0, 1], K best is the set of first K agents with the best fitness value. The acceleration related to mass i in time t in the d_{th} dimension is given as follows:

$$a_i^d = \frac{\mathrm{Fid(t)}}{\mathrm{Mii(t)}} \tag{28}$$

Where M_{ii} is the inertial mass of i^{th} agent. The next velocity of an agent could be calculated as a fraction of its current velocity added to its acceleration.

Position and velocity of agent is calculated using the expressions in Equations (29) and (30) as follows:-

$$(t+1) = ra(t) + a_i^d t) \tag{29}$$

$$(t+1) = (t) + v_i^d\ (t+1) \tag{30}$$

Where rand $_i$ is a uniform random variable in the interval [0, 1].

Gravitational constant, G, is initialized at the beginning of the search and will be reduced with time to control the search accuracy as in Equation (31) as follows:-

$$\mathrm{G}(t) = G_0 e^{-\alpha\frac{\mathrm{t}}{\mathrm{T}}} \tag{31}$$

where T is the number of iteration, G0 and α are given constant. The gravitational mass and the inertial mass are updated by Equations (32) to (34) as follow: -

$$M_{ai} = M_{pi} = M_{ii} = \ldots = 1,2,\ldots,N \tag{32}$$

$$\mathrm{m_i}(t) = \frac{\mathrm{fit_i(t) - worst(t)}}{\mathrm{best(t) - worst(t)}} \tag{33}$$

$$\mathrm{M_i}(t) = \frac{\mathrm{m_i(t)}}{\sum_{\mathrm{j=1}}^{\mathrm{N}} \mathrm{m_j(t)}} \tag{34}$$

where $\mathrm{fit_i(t)}$ represent the fitness value of the agent 'i' at time 't', and, worst(t) and best(t) are given in Equations (35) and (36) for a minimization problem, as follow:-

$$\mathrm{best}(t) = \min_{\mathrm{j}\in\{1,..,\mathrm{N}\}} \mathrm{fit_j(t)} \tag{35}$$

$$\mathrm{worst}(t) = \max_{\mathrm{j}\in\{1,..,\mathrm{N}\}} \mathrm{fit_j(t)} \tag{36}$$

6.0 SIMULATION RESULTS

The simulations have been run on the MATLAB environment. The power quality disturbances focused in this paper are voltage sag/swell and current harmonics. The current harmonics are mainly caused due to nonlinear loads and voltage sag arises due to short circuits or starting/removal of large loads. The nonlinear load phenomenon is implemented with the help of power electronic converter (diode bridge rectifier). The SeAPF is applied to the power transmission line which is shown in Figure 7.

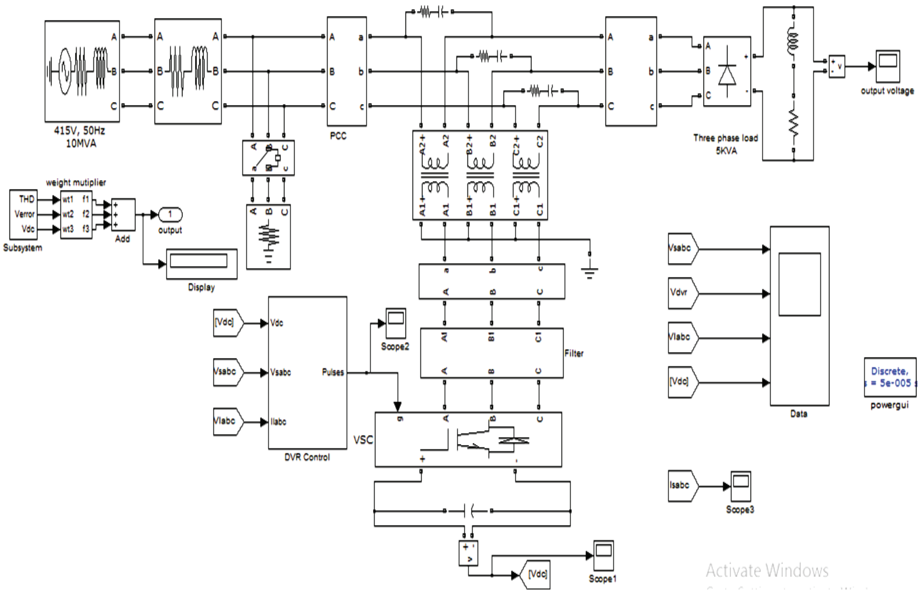


Figure 7 The MATLAB/Simulink illustration of SeAPF in the Utility System

The utility power supply is considered as 415V and 50Hz. Here voltage swell and then the sag is created by removing and adding a sudden load (VL2) to the line through the circuit breaker phenomenon in the duration of 0.2 to 0.4 and 0.5 to 0.7 respectively, current harmonics into the system due to the nonlinear load as shown in Figure 7. The load on the system is increased/reduced by 10% as per IEEE norms to create a sag/swell which is shown as Figure 8. In the duration of 0.2-0.4, the SeAPF will buck and in the duration of 0.5 to 0.7 the SeAPF will boost the required voltage into the system in order to maintain the presage/swell condition.

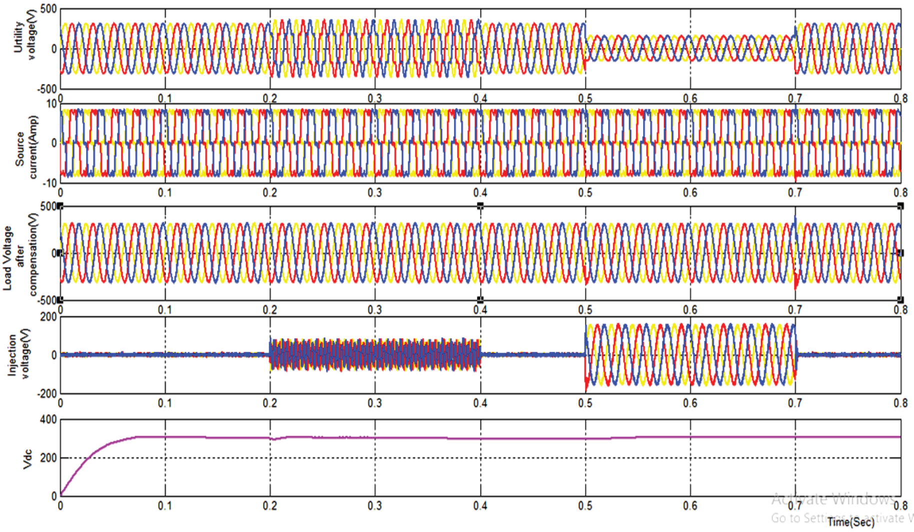


Figure 8 Performance evaluation of SeAPF in utility system

The minimization of error voltage, DC link error, and current harmonics is ensured using proposed FF and GSA algorithms. The main problem that one faces in voltage control are to determine the duty cycle. The primary goal is accomplishing the compensation of the required voltage all through sag/swell and the harmonic component in the source current. Figure 8 describes the total harmonic distortion, compensation of sag and swell and maintenance of dc-link error. SeAPF with the PI controller (trial and error) has THD of 22.29% which is shown in Figure 9.

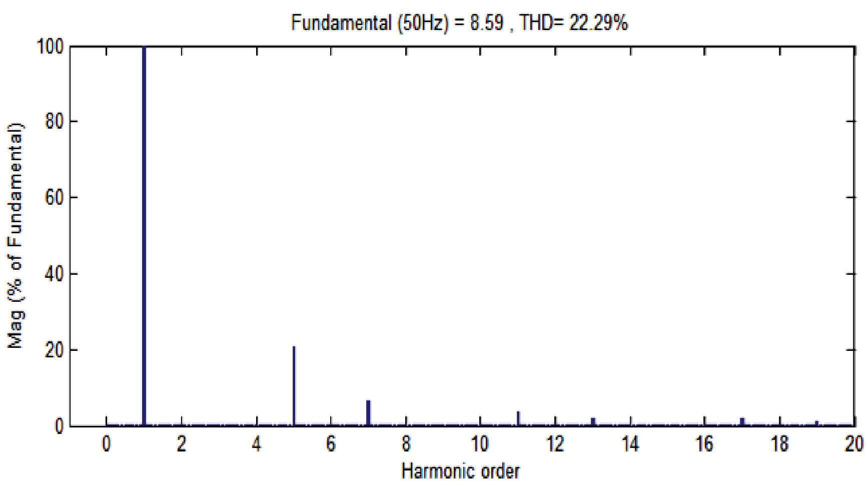
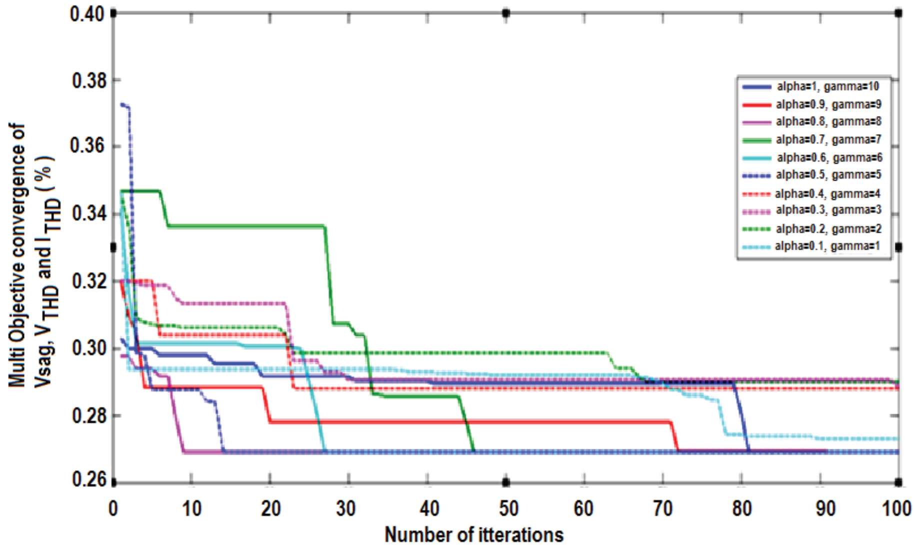
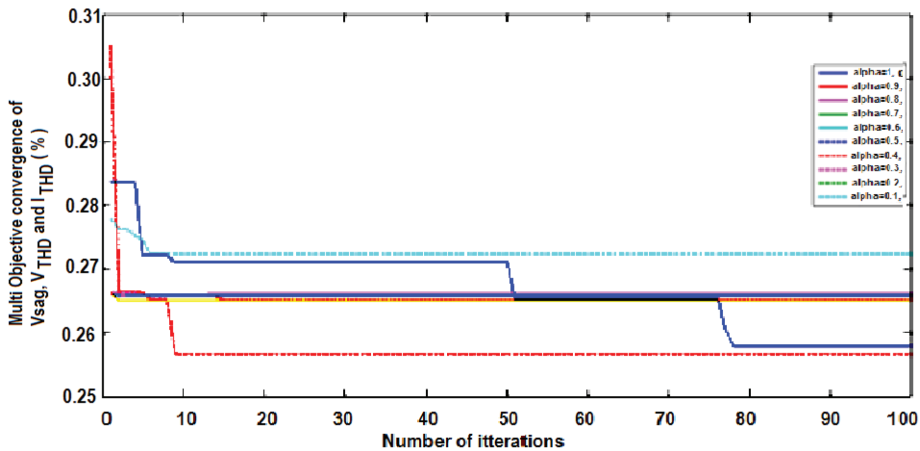


Figure 9 FFT analysis of the source current without compensation

The convergence of multi-objective fitness function with FF and GSA algorithms is illustrated as shown in Figure 10. The simulations are run for 100 iterations. The firefly algorithm is simulated taking the variation of α the randomization parameter (0 to 1) γ the fixed light absorption coefficient (1 to 10).



(a)



(b)

Figure 10 The multi-objective convergence of fitness (voltage sag/swell error, the source current THD) with (a) FF Algorithm and (b) GSA

The Gravitational Search Algorithm is simulated taking the variation of α the varying accuracy parameter (1 to 10). Table 2 gives the control parameter comparison with the PI controller tuned by trial and error, FF and GSA methods for the best run with the considered fitness function. Figure 11 shows the action of the DC link capacitor upon the sag/swell injection in the power utility system with the PI controller, FF, and GSA. Table 3 gives the performance evaluation with the PI controller, FF and GSA algorithms for the best run with the considered fitness function.

Table 2 Control parameters of SeAPF with PI (Trial and Error based), FF and GSA algorithms

Parameter Variable	PI	FF	GSA
K_{p1}	1	0.8986	0.5077
K_{I1}	1	0.4347	0.3458
K_{p2}	1	0.8986	0.5077
K_{I2}	1	0.4347	0.3458

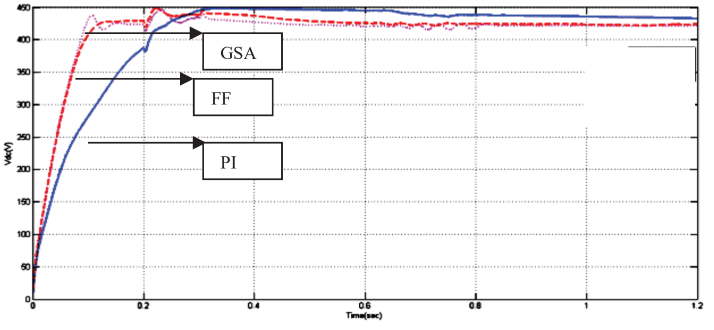


Figure 11 Comparison of DC Link voltage in SeAPF with PI, FF and GSA algorithms

FF and GSA algorithms based PI controller was tested to enhance the compensation of sag/swell with load variations and minimization of source current THD. The control variables considered for fitness convergence are K_p and K_i values of the PI controller. The population size is taken as 10. The comparison of SeAPF performance with the PI, FF and GSA algorithms (best value after 10 runs) is shown in Table 3. The minimum and maximum values of proportional gain (K_p) and integral gain (K_I) are 0 and 100 respectively (decided heuristically). The corresponding fitness convergence graphs with FF and GSA Algorithm are shown in Figure 10. Variation of average fitness from the best fitness is illustrated in Table 4.

Table 3 Comparison of SeAPF performance with the PI controller (Trial and Error based), FF and GSA algorithms

Parameter Variable	Is_{THD}(%)	Vs_{ERROR}(V)	Reduction in V_{DC}(V)
PI	22.29	41.20	100.00
FF	0.80	11.04	160.80
GSA	0.76	10.89	158.80

Figure 11 and Table 3 illustrate the reduction in source current harmonics, sag/swell error, and reduction in DC link voltage from the reference value.

Table 4 Comparison of variation of fitness (Verror, Vdc & THD) of Series APF with FF and GSA algorithms

No.of Iterations	population	Variation of average fitness from the best fitness	
		FF	GSA
100	10	0.18	0.16

7.0 CONCLUSION

In this paper, the implementation of FF and GSA are applied to the SeAPF system to solve the power quality problems with nonideal voltage and current functional signals of the utility system. The performance of the projected approach is compared with the traditional controlled DVR System. The comparative analysis of the PI controller, FF, and GSA shows that GSA has been proved to be better in terms of voltage sag/swell compensation and harmonic reduction (shown in Figure 10 and Table 3). The DC bus voltage has been maintained constant equal to the reference voltage. The simulation results show the effectiveness of the proposed method.

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