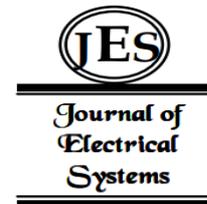


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**Power Quality Improvement
based on VSHDE Algorithm
Incorporating Shunt Active
Power Filter**



The usage of the word Power quality in recent times acquired intensified interest due to the complex industrial processes. The usage of intelligent tools to improve power quality is increasing day by day, as assumption of present day power system as a linear model is unsatisfactory. This paper deals with analysis of Differential Evolution (DE), Hybrid Differential Evolution (HDE) and Variable Scaling Hybrid Differential Evolution for harmonic reduction in the source current with optimal tuning of PI controller gain values. Shunt Active power Filter is one of the better solution to suppress the source current harmonics which are induced into power system because of nonlinear loads. Current controller called HBCC is considered for gating operation of switches in Voltage Source Inverter. The Intelligent tuned PQ theory is used for reference current generation. The then obtained compensating currents are injected at point of common coupling for current disturbance mitigation. Simulations of MATLAB/SIMULINK environment of the present work shows the efficacy.

Keywords: Shunt Active Power Filter (SAPF), Intelligent Instantaneous Active and Reactive Power (IPQ) Theory, Hysteresis band current controller (HBCC), Variable Scaling Hybrid Differential Evolution (VSHDE) and Total Harmonic Distortion (THD), Power Quality (PQ).

1. Introduction

The widespread use of switching equipment in domestic and industrial purpose is very much noticeable. This electronic equipment, driving energy transit equipment is the major source of voltage and current variations which might lead the power quality issues like harmonics and sags/swells in the power utility systems. The presence of these PQ issues may diminish and cause low power factor, flicker voltage distortion and electromagnetic interference etc. Such adverse effects are usually addressed by power engineers and researchers [1], [2]. If these PQ not addressed at right time then these may often make system to malfunction and finally tend to complete power system shutdown.

The power quality issues under current variations are first discussed by L. Gyugyi [1] in 1970's. The current variation issue can be addressed using power quality analyzers and synthesizers, i.e. shunt active power filters. H. Akagi [2] is other prominent researcher who stressed active filters dealing power quality variations and their measurement in processed control and power utility systems. With the advent of flexible AC transmission devices in the transmission line, which reduces the operational cost without increasing the installation cost the power engineers and researchers are also looking for such transit solutions to take care of the system in distributed side. These are usually called as custom power devices (CPDs). One such cost effective solution to reduce current variations is shunt active power

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filter. The researchers have looked into various factors of topological structures, sizing factors, optimal placement and control factors of SAPF. These have left few gaps like inappropriate compensation, switching related problems in this direction of work. Hence researchers focused on better filter architecture to sort of this problem.

The performance of the system is measured and standardized universally by different international bodies like IEEE, IEC which have set the limits for various power quality issues and events [3].

As conventional low power and medium power SAPF is not fit to resolve present day power quality problems regarding effective compensation [4] and appropriate switching. Hence, engineers looked into MLI based architecture [5] instead of concentrating on control and placement issues, which sorted out compensation related issues. The present paper focus on the further enhancement capabilities of such developed cascaded MLI based SAPF (MLISAPF). The reference current generation and respective switching mechanism is discussed by PQ theory and Hysteresis Band Current Controller (HBCC) [6]. The control strategy is optimized with Particle swarm Optimization [7]-[9] which is good in search space problems. The self-tuned PSO called APSO is proposed and applied for enhancement of the concerned issues further. The control variables are gains of the PI controller which makes the conventional PQ theory evolved as Intelligent Computing active and reactive power (ICPQ) theory. Using this technique, the current variations aspect of the system can be improved. In MATLAB/SIMULINK, dynamic simulations are conducted to compare the results with those from other cases (other artificial intelligence techniques). The MLISAPF working phenomenon is illustrated in Figure 1.

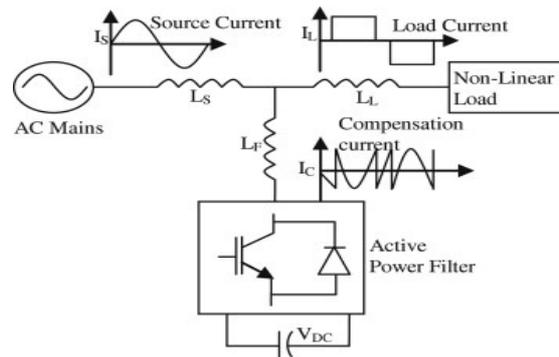


Fig.1: Working illustration of Shunt Active Power Filter.

The APF's developed by Akagi, are good enough to ease harmonics in the utility system with improvised mechanism [2],[5].

The PI controller in the control strategy addresses harmonic content mitigation. The PI controller needs the calculation of proportional and integral gain values. Usually for power systems with linear loads, methods like Ziegler–Nichols, Cohen-Coon help in finding the KP and KI values empirically. These methods of linear control do not work for system with nonlinear loads.

Presently, intelligent and optimal tuning algorithms such as Evolutionary Programming (EP) [10], Genetic Algorithm (GA) [10], Particle Swarm optimization (PSO), Simulated Annealing (SA), Differential Evolution (DE) [11]-[13], Expert Systems, Tabu

Search (TS) [14] Algorithm, were developed to solve the dynamic electric system problems with enhanced optimal tuning FACTS devices.

Later, Storn and Price [11] introduced another evolutionary computing based algorithm called DE to solve engineering electric system problems. M.Basu [15] applied DE to solve PQ issues incorporating FACTS devices. In later recent years, some hybrid algorithms with extended features have been developed to enhance and explore search efficiency. Thus developed HDE Algorithm [16], [17] sorted out large capacitor placement problem in utility system. The research in this direction is promising and encouraging as far as with obtained results.

This paper employs an improved Hybrid algorithm called Variable Scaling Hybrid differential Evolution (PSODE) algorithm [18], [19] to solve the power quality issues discussed. This algorithm is the hybridization and modification done to DE algorithm. The SAPF as a FACTS device which is incorporated to address the power issues. A SAPF connected to utility power system mitigates the concerned power quality disturbance. The harmonic disturbances, which are introduced into the system, are eased with the help of SAPF by injecting reverse harmonic currents into the power system. The PQ theory is used for reference currents and voltage generation. These reference currents and voltages are utilized for generation of gating pulses by the Hysteresis Band Current Controller. The PI controller in PQ theory with intelligent and optimal tuning take care of harmonic mitigation. The optimal tuning of PI controller gains is done with the proposed VSHDE optimization technique. Later is compared with conventional PI controller [20]. The active filter is further planned to be enhanced with photovoltaic's as discussed in [21]. The single objective optimization is planned to be enhanced as multi objective optimization as discussed in [22].

2. Shunt Active Power Filter (SAPF)

A sample case study with 3- ϕ , 415V, 50Hz supply is constructed to discuss the complicated process control system with nonlinear load. The SAPF intended to ease current disturbances needs the discussion of the following design parameters:

2.1. Specifications of SAPF

A 3- ϕ three leg six pulse shunt active filter with line to line voltage of 415V is considered. The DC bus Synchronizing voltage and its capacitor capacitance calculation is made as follows:

2.1.1. Synchronizing DC Bus Capacitance

The capacitance (C_{dc}) is calculated with:

$$\frac{1}{2} C_{dc} [(V_{dc})^2 - (V_{dc1})^2] = 3V(aI)t \quad (1)$$

Where, V_{dc} and V_{dc1} are the reference and minimum level of dc bus voltages respectively, 'a' loading factor set as 1.2, V and I are phase voltage and current respectively and t is recovery time of dc bus [5].

2.1.2. Synchronizing DC Bus Capacitor Voltage

Upon the measurement of three phase voltages (VLL) and with specified modulation index m the dc bus voltage can be obtained as follows [5]:

$$V_{dc} = \frac{2\sqrt{2}}{\sqrt{3}} \frac{V_{LL}}{m} \quad (2)$$

2.2. PQ Theory

The PQ theory is explained clearly with the help of the Fig. 2. PQ theory deals with conversion of three phase (a, b, c) voltages and currents to two-phase (α , β , 0) using the direct conversion and once again the inverse phenomenon backed with a filter [2-5]. The Butterworth filter extract the fundamental component that are required for reference current or voltage generation. The source voltages and load currents are sensed and from which the required reference currents are developed. The illustration, development and design is clearly shown with expressions in Fig. 2.

The active and reactive power components are illustrated as follows:

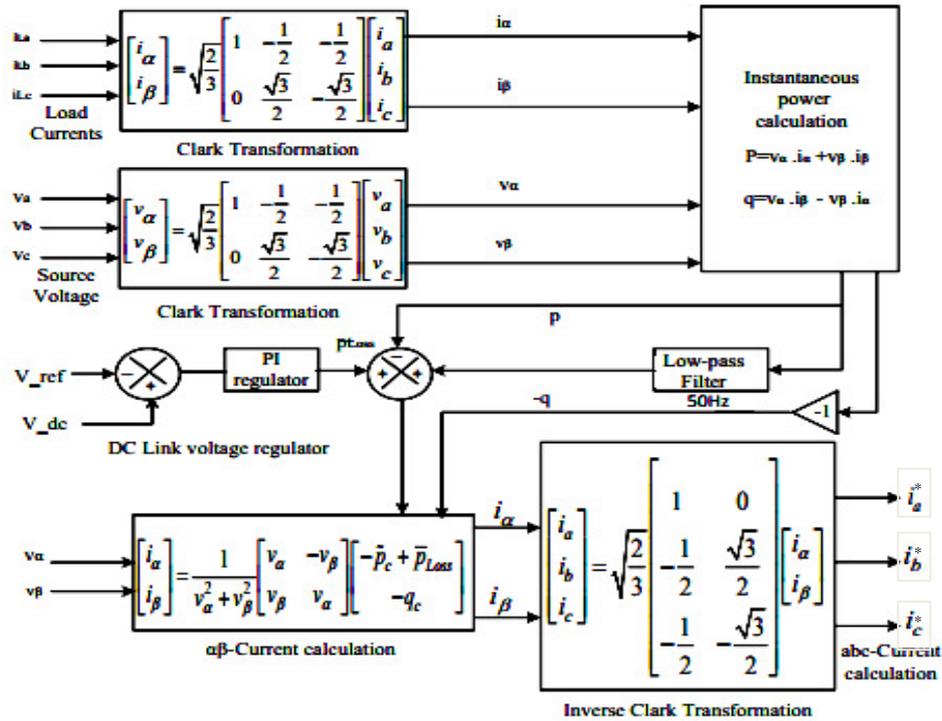


Fig.2. PQ Theory for Reference Current Generation.

Where \bar{p}, \bar{q} : Fundamental active and reactive power components.

\tilde{p}, \tilde{q} : AC equivalent values of active and reactive power components.

\tilde{i}_{α} & \tilde{i}_{β} : instantaneous and fundamental components of currents.

i_a^*, i_b^* and i_c^* : reference currents of three phases.

The PI controller gain values are obtained by the proposed VSHDE optimization technique and thus the PQ theory can be called as Intelligent PQ (IPQ) theory.

2.3. HBCC [2],[3],[5]

The reference currents (i_{abc}^*) and the actual injection harmonic currents (i_{abc}) are sensed first, the error between these are supplied to HBCC which intern generates the gate pulses required by the VSC. The HBCC of the proposed work is as follows:

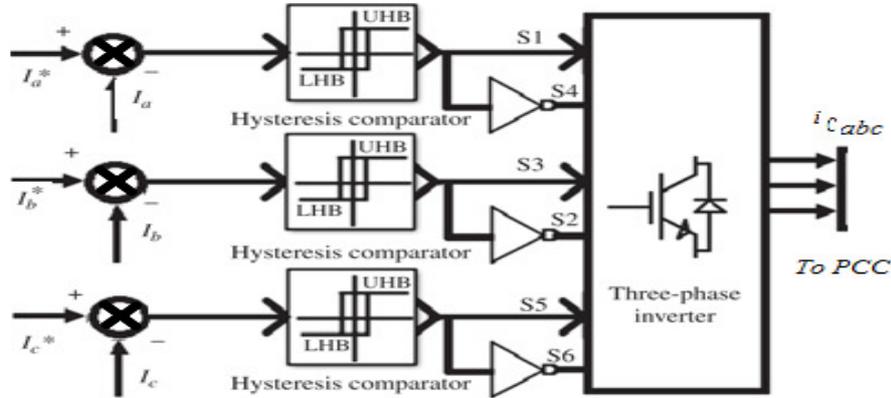


Fig.3. HBCC controlling switches of VSI.

The outputs of HBCC (S1-6) are the gating signals to the six switches of VSC, which is shown in Fig. 3.

3. Proposed Variable Scaling Hybrid Differential Evolution (VSHDE) For SAPF [18], [19]

DE has the limitation of premature convergence [16], [17]. The improved HDE with migration operation overcomes this limitation of HDE. But, HDE has problem of fixed scaling factor (F) [18], [19]. The proposed VSHDE algorithm is an improvement made for HDE algorithm.

The concept of the VSHDE is to use the 1/5 success rule for the variable scaling factor. The updating scaling factor following the above rule is as follows [18], [19] :

$$F^{t+1} = \begin{cases} c_d \times F^t, & \text{if } \rho_s^t < 1/5 \\ c_j \times F^t, & \text{if } \rho_s^t > 1/5 \\ F^t, & \text{if } \rho_s^t = 1/5 \end{cases} \quad (3)$$

where ρ_s^t is the regularity of winning mutations measured.

Whenever the scale factor is too small then it is reset to find the improved result in the elucidation process.

The flow chart representation of VSHDE algorithm is as shown in Fig. 4.

4. Problem definition

The minimization objective function is defined as follow:

$$F = \text{THD of Source Current} \quad (4)$$

subjected to gains of PI controller.

The PI controller mathematical model is given as :

$$G_c(s) = k_p + \frac{k_I}{s} \tag{5}$$

The gains K_p and K_I of PI controller are tuned by the VSHDE algorithm as shown in Fig. 5.

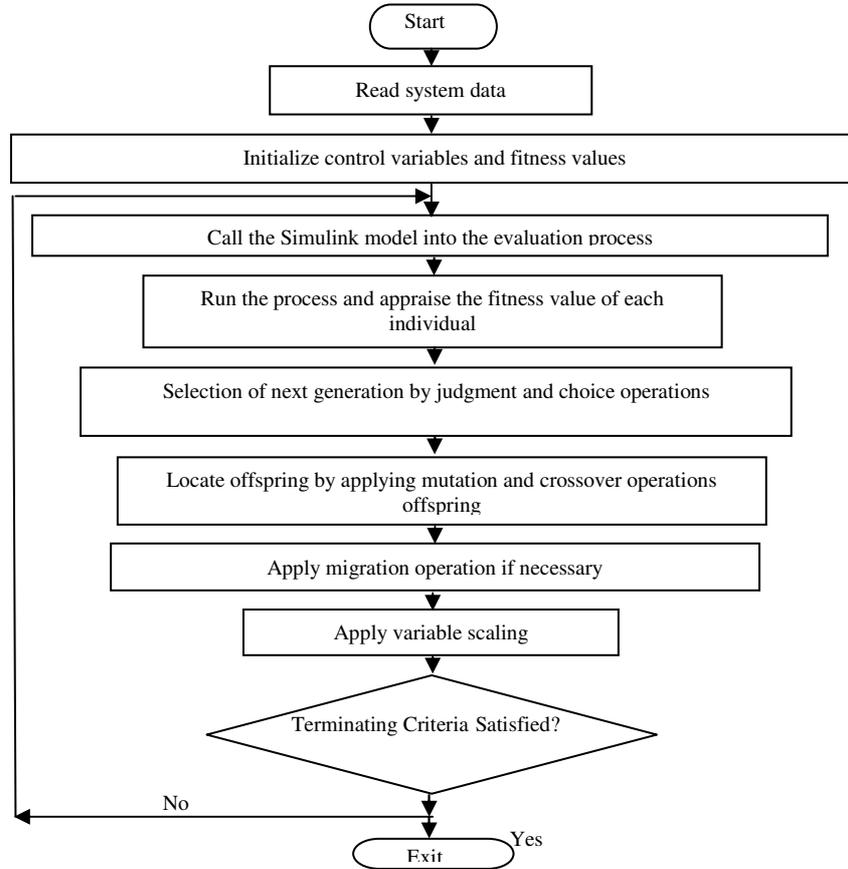


Fig.4. Flowchart of VSHDE algorithm.

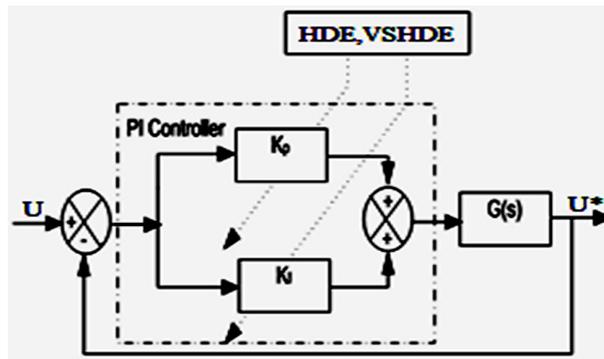


Fig. 5.PI -VSHDE Control System.

The PI controller output $u(t)$ is given by:

$$u(t) = k_p e(t) + k_i \int_0^t e(t) dt \tag{6}$$

5. Simulation Results

The power quality issue particularly concentrated in this paper are source current harmonics. The current harmonics are mainly caused due to nonlinear loads. The nonlinear load phenomenon is implemented with the help of power electronic converter (diode bridge rectifier) with RL load. The MATLAB/Simulink representation of SAPF for PQ enhancement is shown in Fig. 6.

Table 1 System parameters for simulation

Parameters	Values
Supply voltage /frequency	415V/50Hz
Smoothing inductor(Rs, Ls)	1Ω , 0.1mH
Diode rectifier	6-diode
Load resistor(RL), Load inductor(LL)	50Ω, 40mH
Interface inductor(RcLc)	1 Ω ,1mH
DC side capacitance(Cdc)	1800μF
Reference voltage(Vdc,ref)	880V
Voltage source inverter	6 IGBTs

The compensating current generated by the IPQ theory is shown in Fig. 7(b). The graphical illustration of reduction of harmonics in the system is shown in the Fig.7(c).

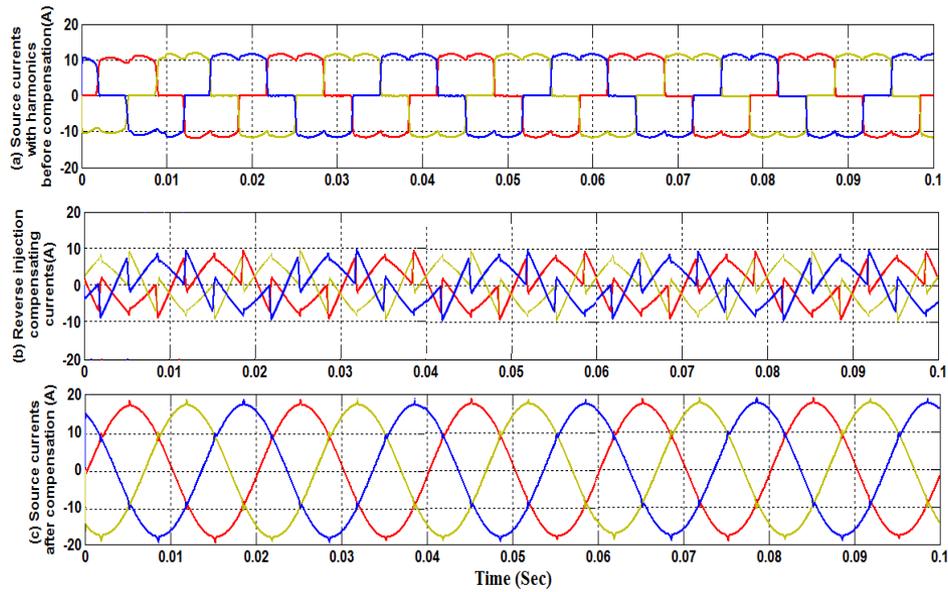


Fig. 7. The simulation results with VSHDE Algorithm showing a) source current with harmonics before compensation. b) SAPF reverse injection compensating currents. c) source current after compensation.

The SAPF helps to supply by injecting the required compensating currents into the line and make source current sinusoidal. The compensating currents and the resultant source currents are shown in Fig. 7.

This section compares the THD of source current with SAPF for different algorithms. The SAPF controlled and optimized by DE based PI controller, HDE based PI controller and VSHDE based PI controller are evaluated and later employed for comparison.

The DE, HDE, VSHDE Algorithms based PI controller was tested and implemented to ease the THD in source current. The fitness convergence is subjected with K_p and K_i values of PI controller. The population size is taken as 10. The optimized control parameters and corresponding fitness values are given in Table 3, Table 4 and Table 5 respectively. The fitness value of THD is reduced to 1.32% with DE, further to 1.31% with HDE and 1.30% with VSHDE (The value after 10 runs each) subjecting K_p and K_i ranging between 0 to 200 (By Expert system) varying CR and F in case of DE and HDE whereas varying CR and randomly choosing F in case of VSHDE. Where CR and F are crossover and mutation coefficients of proposed algorithms. The optimization is run for 100 iterations. The corresponding fitness convergence graphs with DE algorithm are shown in Fig. 8, HDE algorithm are shown in Fig. 9 and VSHDE algorithm are shown in Fig. 10 respectively. The suitable crossover rate (CR) for better optimization is 0.9 and Mutation constant (F) is varying between $0.5 < F < 1$ which is evaluated by experimentation validation.

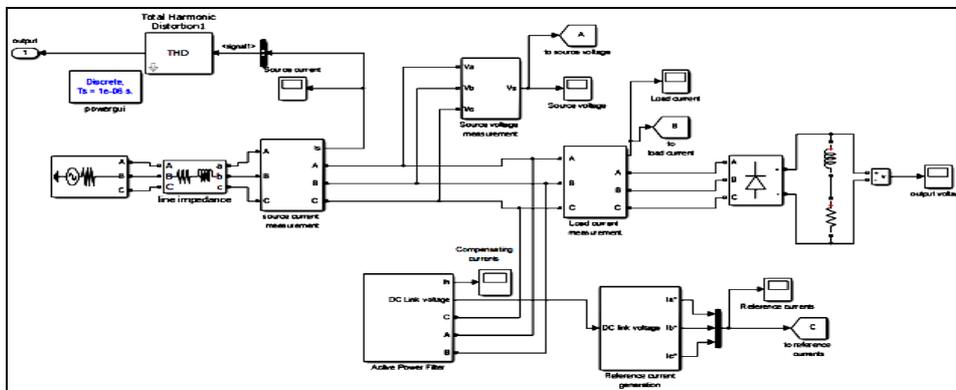


Fig. 6. MATLAB/Simulink representation For power quality enhancement.

Table.2 Control parameter convergence of source current THD in SAPF with DE Algorithm

S.No.	CR	F	KP	KI	%THD
1	0.9	0.5	62.255	102.45	1.77
2	0.9	0.6	49.942	98.808	1.79
3	0.9	0.7	62.219	200	1.70
4	0.9	0.8	5.2322	199.98	1.34
5	0.9	0.9	5.2627	200.00	1.32
6	0.9	1.0	12.698	200.00	1.56

Table.3 Control parameter convergence of source current THD in SAPF with HDE Algorithm

S.No.	CR	F	KP	KI	%THD
1	0.9	0.5	4.7006	200.00	1.34
2	0.9	0.6	2.3027	199.54	1.31
3	0.9	0.7	6.6474	195.99	1.32
4	0.9	0.8	3.4427	199.83	1.32
5	0.9	0.9	6.6372	196.11	1.32
6	0.9	1.0	12.6987	182.67	1.49

Table.4 Control parameter convergence of source current THD in SAPF with VSHDE Algorithm

S.No.	CR	KP	KI	%THD
1	0.4	4.1273	200.00	1.33
2	0.5	3.4345	200.00	1.33
3	0.6	4.9362	199.98	1.31
4	0.7	6.0917	200.00	1.33
5	0.8	5.4126	195.08	1.36
6	0.9	4.569	199.99	1.30
7	1.0	3.5518	200.00	1.30

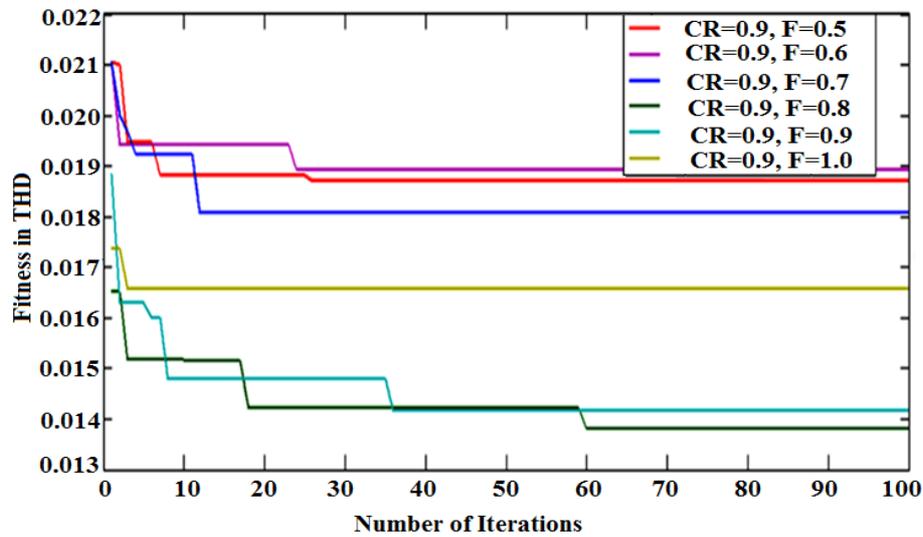


Fig. 8. Convergence of fitness (source current THD) with DE Algorithm making CR=0.9 constant and F variable.

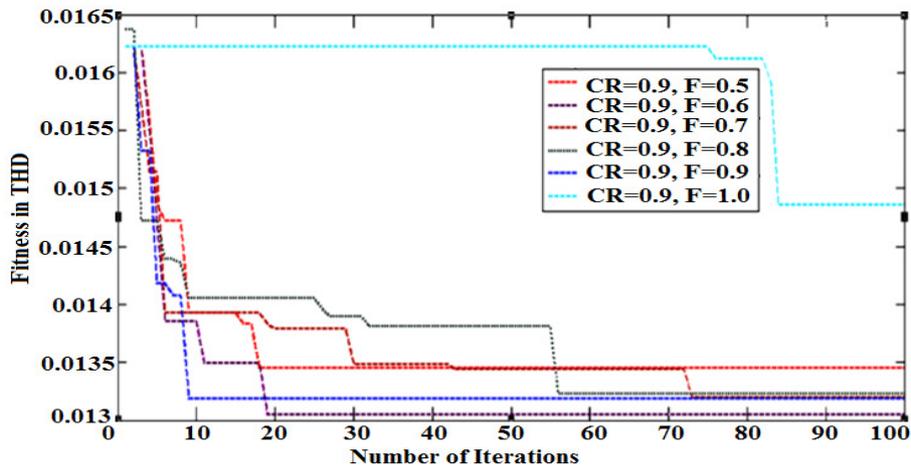


Fig.9. Convergence of fitness (source current THD) with HDE Algorithm making CR=0.9 constant and F variable.

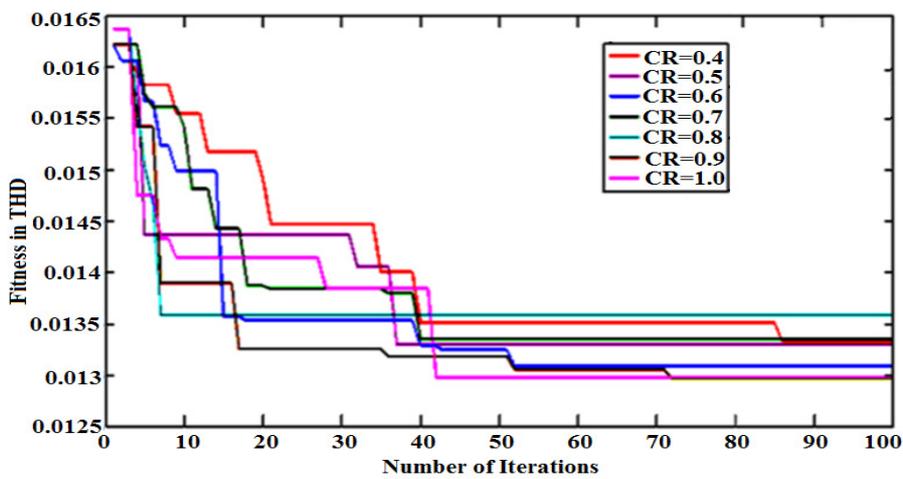


Fig.10. Convergence of fitness (source current THD) with VSHDE Algorithm making with CR Variable and F randomly chosen by the algorithm.

The main concentration is kept on how the hybridized algorithm of VSHDE effectively works overcoming the limitations of DE and HDE. Table. 6 illustrates the comparative convergence of DE, HDE and VSHDE algorithms. The comparative convergence of the DE, HDE and VSHDE algorithm for best result of the 10 test runs performed is shown in Fig.11.

Table 5 Control parameter convergence of source current THD with Different Algorithms

Algorithm	Best	Average	Variation
DE	1.32	1.52	0.20
HDE	1.31	1.42	0.11
VSHDE	1.30	1.33	0.03

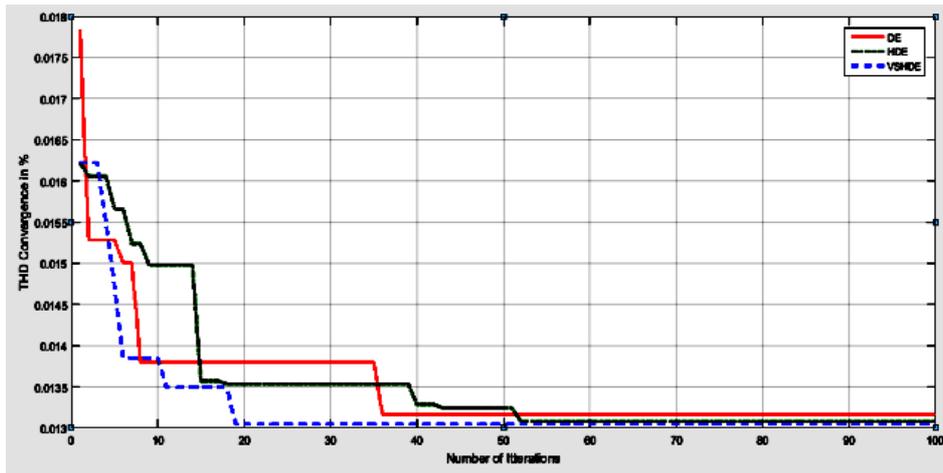


Fig. 11. Comparison of Convergence of fitness (source current THD) with DE, HDE, VSHDE Algorithms.

Table 6 proves the superiority of VSHDE algorithm over other methods in reducing the THD value. Though the methods in Table 6 also got THD values less than 5 % as prescribed by IEEE standards [3], it is always desirable to reduce THD as much as possible. This minimizes the heating of various equipment and mechanical stress on bearings and shafts of motors. This reduction in THD is achieved with optimizing the PI parameters and without any additional device or cost.

Table 6 The comparison of source current THD with other methods

Type of Controller/ Algorithm	THD(%)
PI Controller [20]	3.84
DE Based PI	1.32
HDE Based PI	1.31
VSHDE Based PI	1.30

6. Conclusion

The performance analysis of SAPF based on DE, HDE and VSHDE techniques is presented and compared in the present work. The Comparative analysis of DE, HDE and VSHDE techniques shows the superiority of VSHDE over others. The limitations of DE and HDE are overcome in VSHDE. The rate of convergence and searching process is better in VSHDE when compared with DE and HDE. The stability of dc bus voltage maintaining constant voltage equal to the reference voltage is phenomenal. The efficacy of the proposed algorithm is shown with MATLAB simulation results.

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