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Performance Comparison of DSTATCOM with PI and PSO-PI Controller under Nonlinear Load Condition

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Abstract

The paper presents the compensation of harmonic, reactive power, dc voltage regulation and power factor improvement under nonlinear load condition is achieved by using Distribution Static Compensator (D-STATCOM). The synchronous reference frame control algorithm is developed for generating switching reference control signals. The dc link voltage is regulating with PI and PSO-PI controller. The attain control algorithm reference switching signals compared in hysteresis signal for better switching of D-STATCOM. The behaviour of DSTATCOM with PI and PSO-PI controller is also study and measure in terms of for DC link voltage, harmonic distortion, power factor correction and reactive power mitigation by using MATLAB/SIMULINK software.

Keywords: DSTATCOM, Harmonic Compensation, Non linear Load, PI Controller, PSO-PI Controller, Power Factor Synchronous Reference Frame Theory, Reactive Power

1. Introduction

In last one decade, power electronic devices are widely used in industrial applications for transferring power in more efficient way. The number use of power electronic equipments, such as nonlinear loads, in a distribution system has generated more problems in the quality of power such as harmonic pollutions and reactive power problems. Due to this low power factor, poor efficiency, overheating of motors and transformers, malfunction of sensitive devices etc[1–3]. These power quality issues are remunerated utilizing custom power devices, such as, distribution static compensators (DSTATCOM), Dynamic Voltage Restorer (DVR) and unified power quality conditioner (UPQC)[4,5]. In which the distribution static compensator is progressively reasonable for mitigation of reactive power, harmonic compensation, load unbalancing voltage and current sounds in the distribution arrange contrasted with other custom force devices[6–10]. The SRF control need PI controller for managing DC-interface voltage. The DC interface voltage of VSI is regularly constrained by using ordinary PI control procedure. In customary strategy got PI esteems are not pleasant. For this situation, by using PSO control program the got PI esteems are careful and keep up the consistent dc bus voltage when compare to the conventional PI controller. Here the Proportional and Integral estimations of the of PI controller for the DC interface voltage is constrained by using PSO program as compared to conventional PI control for better harmonic decrease and power factor upgrade[11–15].

The SRF controlled DSTATCOM is proposed and executed on 11/0.4kv distribution framework. The exhibition of the proposed DSTATCOM is examined under various load conditions as far as harmonic, reactive power mitigation and DC interface voltage regulations. The goals of this work are:

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- Extracting the reference current control signal, utilizing synchronous reference theory to mitigate current harmonics at the PCC delivered by various disturbance influence different distribution load conditions.
- Also Compensate reactive power, power factor and controlling dc-interface voltage.
- Regulating the dc link voltage of voltage source inverter utilizing with PI and PSO-PI controller and contrasting the performance of DSTATCOM and independently utilizing PI and PSO-PI controller under nonlinear conditions.

All the above goals are done and compared independently with and PI and PSO-PI controller.

2. Proposed System Model

Figure 1 shows the framework setup of proposed Distribution static compensator (D-STATCOM) for the three phase three wire distribution framework under nonlinear conditions. Three phase source voltage of 11kv is stepdown down to 400V by utilizing 11/0.4Kv three phase transformers and associated with conveyed load. The associated load introduces harmonics at the PCC. By Connecting DSTATCOM at the PCC, harmonic and Reactive power mitigation and power factor correction at the bus are compensated. The DSTATCOM comprise of three leg voltage source inverter utilizing six IGBTs switches with interface inductor (Lf), dc link capacitor. The switching transients during DSTATCOM switching can be controlled by connecting a capacitor ripple filter (Cf). The balanced control switching signals to the VSI DSTATCOM is gotten from the Simultaneous Reference Control (SRF) system with hysteresis band control. The four-leg VSI comprises six IGBT switches. The nonlinear burden comprises of three phase bridge rectifier with R-L load.

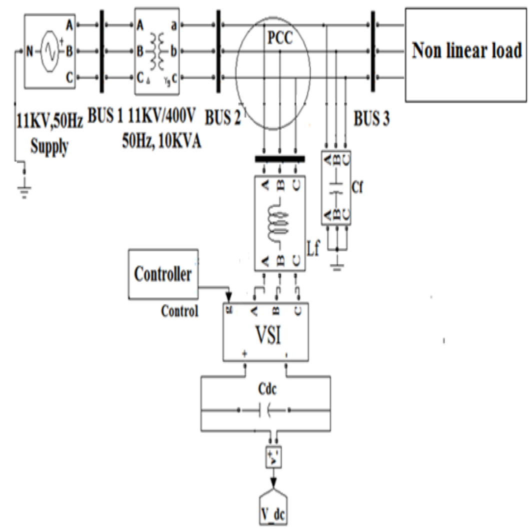

Figure 1. Proposed system configuration under nonlinear load condition.

3. Control Algorithm

The non linear burden flows comprise of active, reactive and harmonics flows in three phase framework. In this, the reactive and harmonics of flows are isolated, for mitigation.

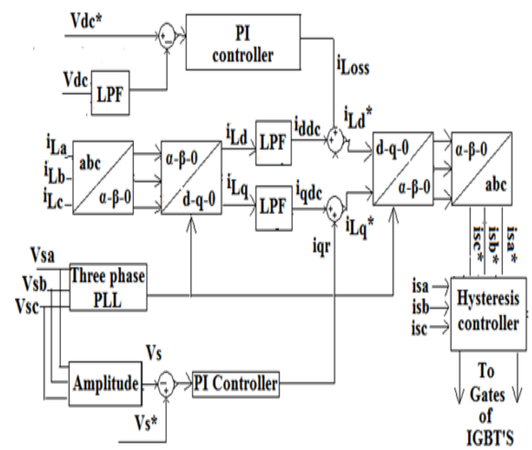

Figure 2. The block diagram of the proposed control algorithm.

The detachment incorporates changing over the immediate three phase load flows into two phase fixed α-β-0 axis utilizing Clark's change Equation (1).

$$\begin{bmatrix} i_{L0} \\ i_{L\alpha} \\ i_{L\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \quad (1)$$

The fixed α-β-0 current axis parts are changed into d-q-0 (d-direct axis, q-quadrature axis segments) turning reference outline by utilizing park change Equation (2).

$$\begin{bmatrix} i_{L0} \\ i_{Ld} \\ i_{Lq} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & \sin\theta \\ 0 & -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} i_{L0} \\ i_{L\alpha} \\ i_{L\beta} \end{bmatrix} \quad (2)$$

Here the θ is the transformation angle. The cosθ and sinθ is acquired from the three stage PLL block (phase locked loop) of voltage source for synchronization of voltage and current.

The iLd and iLq current parts are called instantaneous active and reactive burden current segments. Every current part has average value (dc segment) and oscillating (ac segment) as given Equation (3) and (4).

$$i_{Ld} = i_{d\,dc} + i_{d\,ac} \quad (3)$$

$$i_{Lq} = i_{q\,dc} + i_{q\,ac} \quad (4)$$

$i_{d\,dc}$ i_{Ldfh} and $i_{q\,dc}$ are the average or dc component of i_{Ld} and

$i_{d\,ac}$ and $i_{q\,ac}$ are the oscillating or ac component of i_{Lq} and

The oscillatory segment (harmonics) seems like waves. In this wiping out the oscillatory current part by utilizing Low pass filter, the active and reactive current segments are given in Equation (5) and (6).

$$i_{Ld} = i_{d\,dc} \quad (5)$$

$$i_{Lq} = i_{q\,dc} \quad (6)$$

The output current of the PI or PSO-PI controller is considered as loss current segment (iLoss) is added to the average current reference current part of d-axis in d-q outline, In request to keep up the consistent DC link voltage and to supply losses in the DSTATCOM. At that point the active reference current part is:

$$i_{Ld}^{*} = i_{d\,dc} + i_{loss} \quad (7)$$

The direct axis reference current segment (iLd*) is utilized for mitigation of harmonic and power factor.

Additionally for controlling the voltage at the PCC, the source must need to convey the reactive current (iqr) ,to be added to the average reactive reference part of current of ($i_{q\,dc}$)q-axis in d-q outline same as direct current axis segment. At that point the resultant reactive reference current part is given by:

$$i_{Lq}^{*} = i_{q\,dc} + i_{qr} \quad (8)$$

The reactive current (iqr) is acquired from the PI controller output, the input current to the PI controller is gotten by deducting the voltage amplitude Vs from the reference voltage Vs* and is taken care of to PI controller. Here the amplitude of the PCC voltage Vs is given as:

$$Vs = \sqrt{2/3\left(V_{sa}^2 + V_{sb}^2 + V_{sc}^2\right)} \quad (9)$$

The PI controller output is given as

$$V_{qr(n)} = V_{qr(n-1)} + K_{pq}(V_{te(n)-}V_{te(n-1)}) + K_{iq}V_{te(n)} \quad (10)$$

Where Vte(n) =V*s-Vs(n) is the error between the reference (V*s) and actual(Vs) terminal voltage amplitude at the nth sampling moment. Here K_{pq} and K_{iq} are the proportional and the integral gains of the PI controller.

The reactive reference current component (i_{Lq}^{*}) is used for ac voltage regulation and compensation of load reactive power.

The Active and reactive reference current segment (iLd*, iLq*) are changed in to α-β-0 frame got by utilizing reverse park's Equation (11).

$$\begin{bmatrix} i_{s0}^{*} \\ i_{s\alpha}^{*} \\ i_{s\beta}^{*} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta \\ 0 & \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} i_{L0}^{*} \\ i_{Ld}^{*} \\ i_{Lq}^{*} \end{bmatrix} \quad (11)$$

The reference current from the Inverse Park's are changed into three phase reference current (a-b-c) by utilizing inverse Clark's Equation (12).

$$\begin{bmatrix} i_{sa}^{*} \\ i_{sb}^{*} \\ i_{sc}^{*} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 0 & 1 & 0 \\ 0 & -1/2 & \sqrt{3}/2 \\ 0 & -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{s0}^{*} \\ i_{s\alpha}^{*} \\ i_{s\beta}^{*} \end{bmatrix} \quad (12)$$

The obtained three phase reference currents (i sa*, i sb*, i sc*) are compared with the actual compensating filter current flows in hysteresis band controller for better exchanging of VSI of IGBT's.

4. DC Link Voltage Regulation

The quality and execution of DSTATCOM relies on the age of the generation of reference current, in which dc link voltage regulation is the key factor. As per prerequisite of compensating current, the dc-link voltage (Vdc) is either increments or diminishes. For appropriate activity of VSI the dc side of the inverter should kept consistent at specific reference value. The filter and switching power lossless of VSI defeat by keeping up steady dc-link voltage. So as to managing or keeping up dc-link voltage consistent a controller is include to the average current part (id dc) of d-axis in rotating reference frame. Here the following two controllers have been included and analyzed.

- PI controller.
- PSO-PI Controller.

4.1 PI Controller

The Figure 3 shows the PI controller block diagram. It is the interior structure of the control circuit. The source must need to convey the loss reference part of current (iLOSS) along with active reference current segment (iLd), for the providing of losses in the DSTATCOM and filter. The loss reference part of current (iLOSS) is extracted, by contrasting the reference dc bus voltage Vdc*with the real dc bus voltage Vdc of VSI at the nth sampling moment.

$$V_{de(n)}=V_{dc^*(n)}-V_{dc(n} \tag{13}$$

The compared error signal Vde(n) is processed through a PI controller to figure the loss part (iLoss)at nth sampling moment is communicated as equation.

$$i_{Loss(n)} = i_{loss(n-1)} + k_{pd}(V_{de(n)} - V_{de(n-1)})+k_{id}V_{de(n)} \tag{14}$$

Here the kpd and kid are the proportional and integral ganis of PI controller. The yield of the PI controller is the loss reference segment (iLoss) of the DSTATCOM. The loss reference current part (iLoss) is added to the average active reference segment (iLd) for directing the active reference segment of current (iLd*).The evaluated reference current segment is contrasted and the real compensating filter currents in hysteresis band controller for better exchanging of VSI of IGBT's.

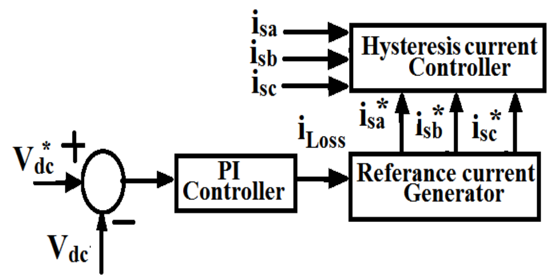

Figure 3. Block diagram of PI controller.

4.2 PSO-PI Controller

The Figure 4 shows the proposed PSO-PI controller. The actual dc link capacitor voltage is compared with the reference dc voltage. The obtained error signals are processed through the PSO-PI controller. For keep up the dc-link voltage steady, the PSO-PI controller output is added to the fundamental active current part and the resultant compensating current are contrasted and the genuine detected compensating filter current in hysteresis band, which gives error signal. The error signal chooses the action of the VSI.

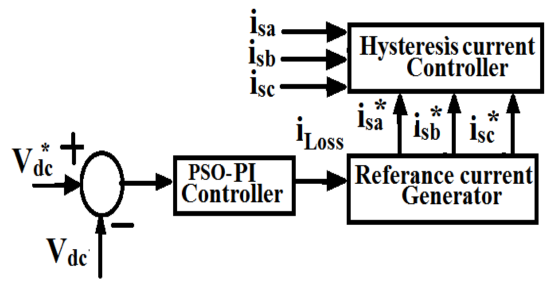

Figure 4. Block diagram of PSO-PI controller.

4.3 Particle Swam Optimization (PSO) Method

The Particle swam optimization is an iterative based enhancement procedure. It is actualized dependent on the conduct of winged animals rush and fish school.

In pso a particle with certain speed and position in a space is taken from the social conduct of creatures. Here population is called swarm. Swarm comprise of number of particles.

Every particle in swarm looking through the best situation on his own encounters and speaks with their neighboring best situation in swarm knowledge and gets the position and updates their position and speed. The molecule is search in the manner to show signs of improvement and better looking through position[10–13].

The change of speed of every molecule is their own encounters just as involvement in their neighbors.

PSO method is progressively proficient fathoming nonlinear, non differential and high dimensional issues. The pso procedure is increasingly basic, better seeing, and minimal effort computational calculation and gets precise local and global best qualities[14,15].

4.3.1 Iterative Algorithm

Step 1: Set the population size, number of iterations, constants of w, c1, c2 and random numbers r1, r2. Check the current situation of every particle in populace.

Step 2: Initialize the every particle in population with position (x), and speed (v). Set iteration count=0

Step 3: assess the wellness capacity of every particle and select the nearby best position (PLbest) of every particle is in its own present position.

Step 4: select the Global best position (Gbest), and its position is determined from Global best fitness = min (Local best fitness).

Step 5: Update the velocity and position of every particle in swarm. The refreshed velocity and position for the next iteration is communicated as:

$$v_i^{n+1} = w \cdot v_i^n + c_1 \cdot r_1 \cdot \left(xpbest_i - x_i^n\right) + c_1 \cdot r_1 \cdot \left(xgbest_i - x_i^n\right) \tag{15}$$

$$x_i^{n+1} = x_i^n + v_i^{n+1} \tag{16}$$

Step 6: Set the iteration count by i+1. Ascertain the current fitness capacity of every molecule. Check the Current fitness function < Local best fitness if yes than set local best fitness function = Current fitness function.

Step 7: Check the Current Global fitness function < Global best fitness function if yes than set Current Global fitness function = Global fitness function.

Step 8: Repeat the methodology of Step 4, 5 and 6. Up to most extreme number of iterations is reached as motioned in Step 1 or check the global best situation through calculation. In the event that there is no improvement in calculation than stop the calculation where there is no improvement.

PSO procedure is more productive solving nonlinear, non differential and high dimensional issues. The pso strategies are increasingly basic, better seeing and minimal effort computational calculation and get precise local and global best qualities.

From the both the controllers the PSO-PI controller provided the better response and improve the behaviour of shunt active power filter .

5. Results and Discussions

5.1 DSTATCOM under Non Linear Load Condition with PI and PSO-PI Controller

The proposed DSTATCOM model is executed in MATLAB/SIMULINK software utilizing synchronous reference frame control theory with PI and PSO-PI controller. The model is confirmed under nonlinear load condition. The proposed model is utilized for harmonic mitigation, power factor correction and reactive power compensation at the PCC. The simulation results with PI and PSO-PI controller is also compared. The simulation time frame is taken from 0.2 s to 0.3s for the better visualisation. Here the three phase wave form followed by R, Y and B Phase sequence. The performance of DSTATCOM is observed for the accompanying cases.

- Non Linear load without DSTATCOM.
- DSTATCOM with PI Controller.
- DSTATCOM with PSO-PI controller.
- THD analysis.
- Comparison of DC-link voltage (PI and PSO-PI controller).
- Power Factor Analysis.
- Active and Reactive Power Measurement.
- Comparison of DC-link voltage.

5.1.1 Non Linear Load without DSTATCOM

The When nonlinear load is connected to the proposed distribution system causes, harmonic in source current (Bus-1) as shown in Figure 5 (b). The nonlinear load also introduces harmonics at PCC current wave form (bus-2) is shown in Figure 5 (c). The harmonics effects the loads connected the PCC. Figure 5 (d) shows the load current wave form. The per phase representation of the current at the PCC is shown in Figure 5 (e).

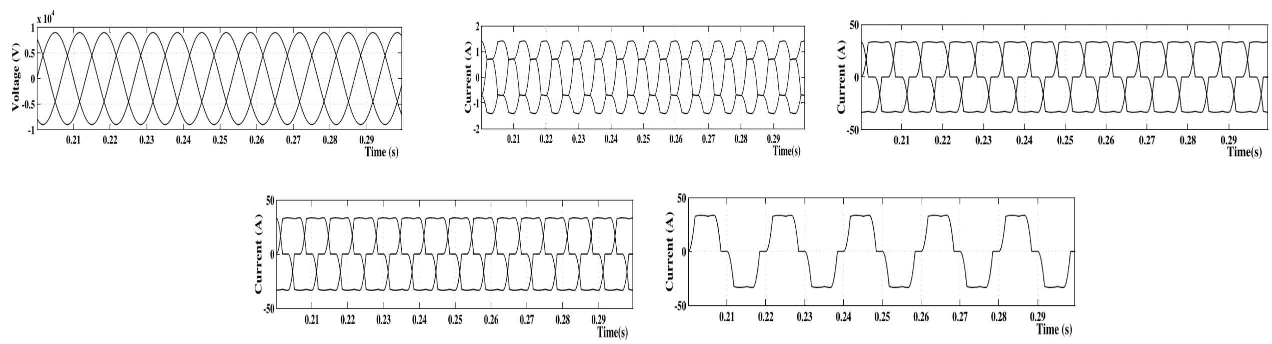

Figure 5. **(a)** Source voltage wave form, **(b)** Source current wave form, **(c)** Current waveform at the PCC (Bus-2), **(d)** Load current wave form, **(e)** Per phase representation of PCC current wave form, under nonlinear load without D-STATCOM.

5.1.2 D-STATCOM with PI Controller

When SRF controlled D-STATCOM is connected at the PCC, the D-STATCOM is injecting the required amount of reactive power for compensation of current and voltage harmonics at the PCC and it also compensating the source current harmonics. The DC-link voltage is regulating with PI controller. The compensated source and PCC current waveforms as shown in Figure 6 (b) and (c). Using R-C filter load and PCC Voltage also compensated. Figure 6 (d) shows the load current waveform. The DC-link voltage, per phase representation of the current wave form wave form as shown in Figure 6 (e) and (f). The improved power factor as shown in Figure 6 (g).

5.1.3 D-STATCOM with PSO-PI Controller

The PSO-PI with SRF controlled D-STATCOM is connected at the PCC, the D-STATCOM is injecting the required amount of reactive power for compensation of current and voltage harmonics at the PCC and it also compensating the source current harmonics. The DC-link **voltage is regulating with PSO-PI controller**. By comparing with PI controller the PSO-PI controller provided better harmonic and reactive power compensation and its corresponding waveforms as shown from Figure 7. The compensated source and PCC current

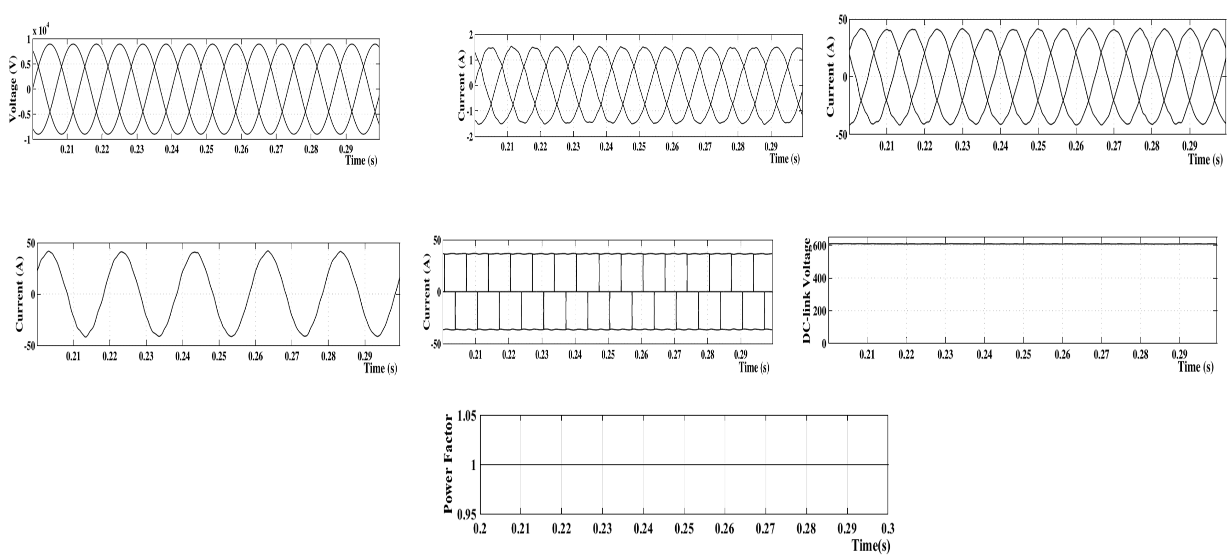

Figure 6. **(a)** Source voltage wave form. **(b)** Source current wave form. **(c)** Current waveform at the PCC (Bus-2). **(d)** Load current wave form. **(e)** DC-link voltage form. **(f)** Per phase representation of current wave form at the PCC. **(g)** Shows the power factor observation, under nonlinear load with PI controlled D-STATCOM.

waveforms as shown in Figure 7(b) and (c). Using R-C filter load and PCC Voltage is compensated. Figure 7 (d) shows the load current waveform. The DC-link voltage, per phase representation of the current wave form wave form as shown in Figure 7 (e) and (f).

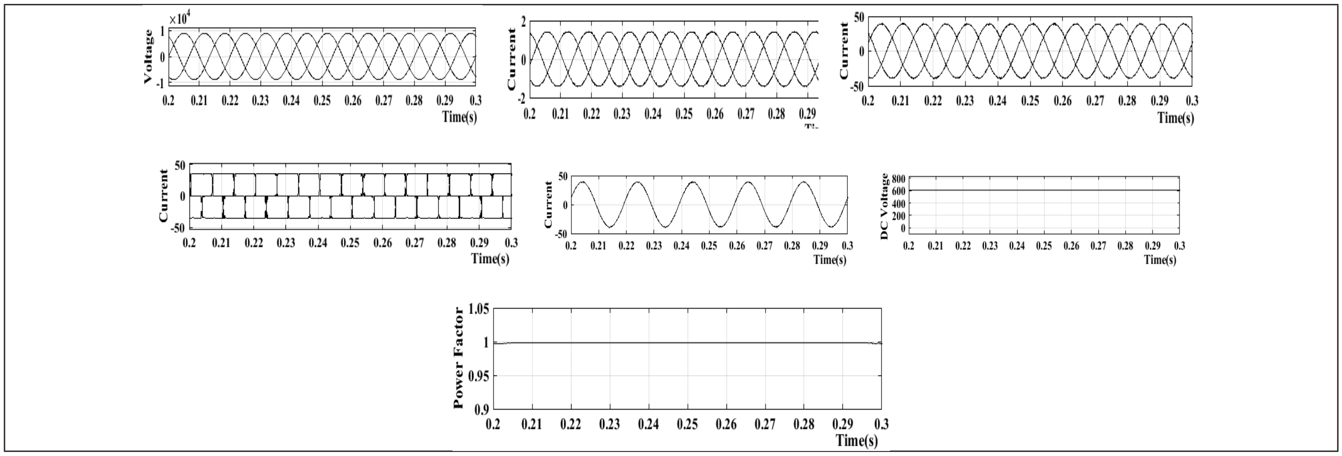

Figure 7 **(a).** Source voltage wave form. **(b)** Source current wave form. **(c)** Current waveform at the PCC (Bus-2), **(d)** Load current wave form. **(e)** Single phase representation of current wave form at the PCC. **(f)** DC-link voltage form. **(g)** Power factor observation wave form, with PSO-PI controlled D-STATCOM.

5.1.4 Total Harmonic Distortion Analysis

The total harmonic distortion at the source and PCC for the proposed system with and without DSTATCOM is discussed here. And also the analysis is done with PI and PSO-PI controller.

5.1.4.1 Non Linear Load without DSTATCOM

The total harmonic distortion of the system by connecting nonlinear load without DSTATCOM as shown in Figure 8. The PCC and source current harmonic distortion is observed that 19.20% and 19.11% as shown in Figure 8 (a) and (b).

5.1.4.2 DSTATCOM with PI Controller

With PI controlled DSTATCOM is connected to the proposed system, the PCC and source current harmonics distortion reduced to 2.41% and 2.13% as shown in Figure 9 (a) and (b).

5.1.4.3 DSTATCOM with PSO-PI Controller

With PSO-PI controlled DSTATCOM the PCC and source current harmonic distortion is reduced to 1.08% and 1.10% as shown in Figure 10 (a) and (b).

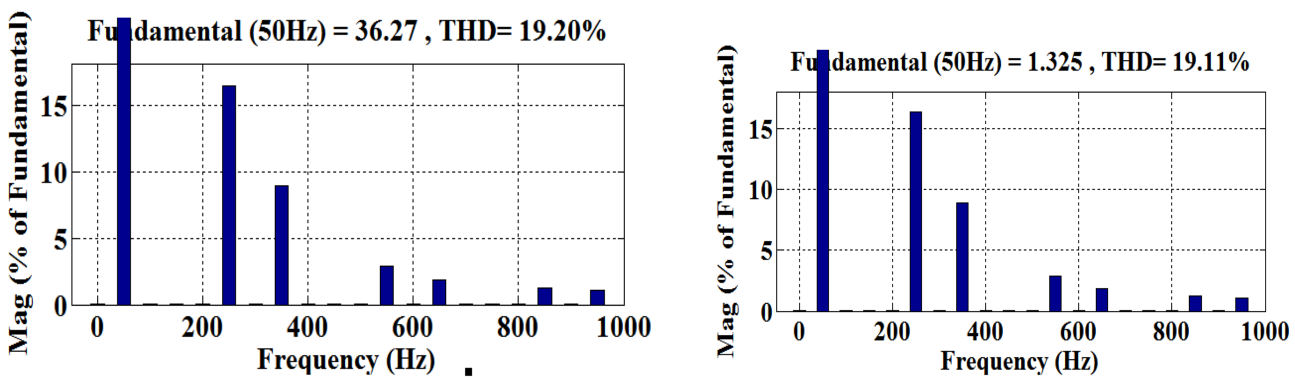

Figure 8 **(a)** Current THD at PCC. **(b)** Source current THD (BUS-1).

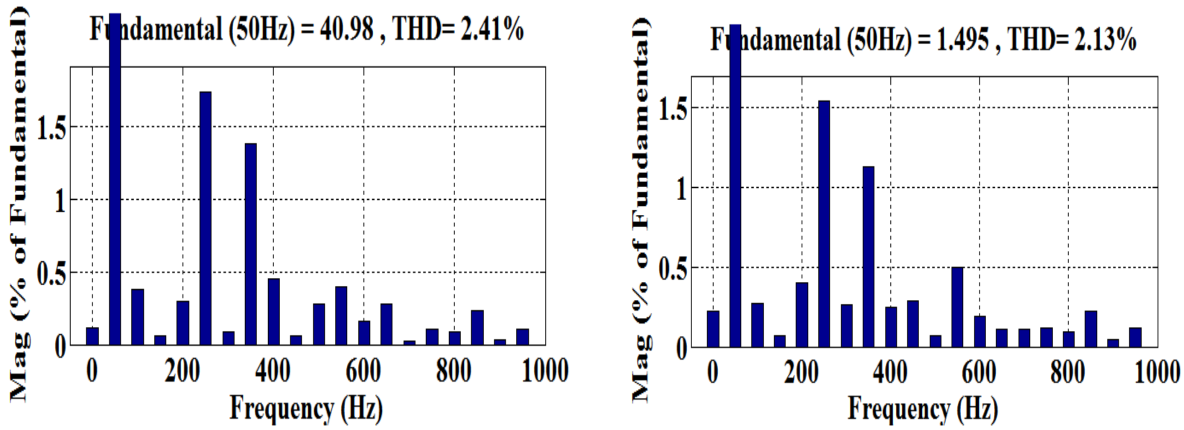

Figure 9 **(a)** Current THD at PCC. **(b)** Source current THD (BUS-1).

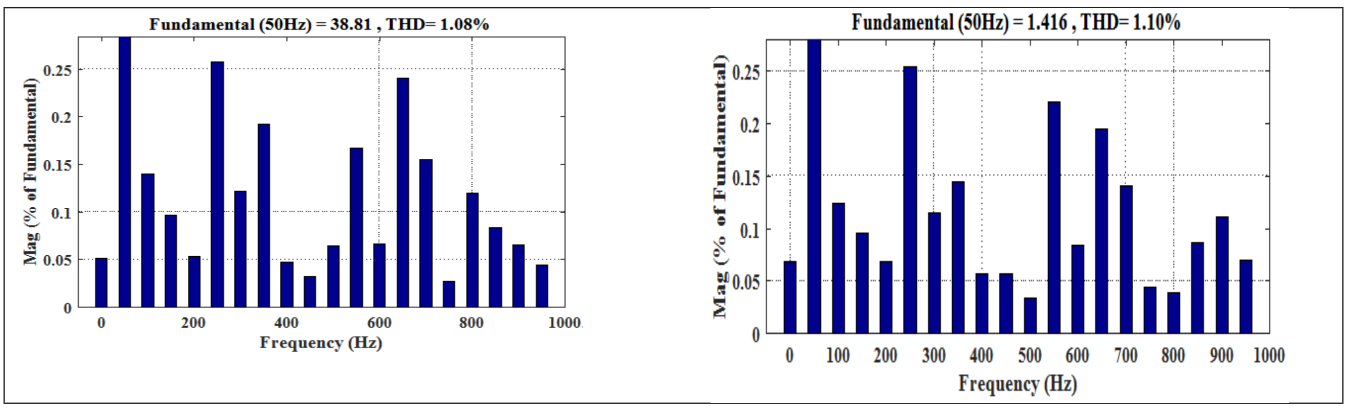

Figure 10 **(a)** Current THD at PCC. **(b)** Voltage THD at PCC. **(c)** Source current THD (BUS-1).

By observing from the above total harmonic distraction analysis the PSO-PI controlled DSTATCOM is providing better harmonic distortion as compare to the PI controller DSTATCOM.

The detailed analysis of total harmonic distortion without, with PI controlled and PSO-PI Controlled DSTATCOM for the each phase (R-Y-B) and also at source (BUS-1) and PCC (BUS-2) point as shown in Table 1.

Table 1. Comparative analysis of total harmonic distortion

Sl. no	Quantity	BUS-1 (THD)			BUS-2 (THD)		
		R-Phase	Y-Phase	B-Phase	R-Phase	Y-Phase	B-Phase
1.	Without DSTATCOM	19.11	19.11	19.11	19.21	19.21	19.21
2.	PI Controlled DSTATCOM	2.41	2.53	2.65	2.60	2.84	2.71
3.	PSO-PI Controlled DSTATCOM	1.10	1.14	1.24	1.08	1.23	1.19

5.1.5 Power Factor Analysis

The power factor of the system without, with PI and with PSO-PI controlled DSTATCOM as shown in from the Table 2.The variation of power factor at the source, PCC and load points are observed.

In three phase three wire nonlinear load condition the power factor is not much affected. The Table 2 shows that by connecting DSTATCOM the power factor has been increased.

Table 2. Power factor comparison without and with DSTATCOM

Corresponding BUS	Without DSTATCOM	With PI DSTATCOM	With PSO-PI DSTATCOM
BUS-1(SOURCE)	0.7741	0.9783	0.9784
BUS-2 (PCC)	0.9735	0.9842	0.9986
BUS-3 (Load)	0.9735	0.9996	0.9999

5.1.6 Active and Reactive Power Measurement

The amount of active and reactive power transfer from the source to load without with PI controlled, PSO-PI controlled.

DSTATCOM device as observed from the Table 3.When the DSTATCOM is connected to the proposed system at the PCC. The required amount of reactive power to the load is supplied from the DSTATCOM and the source is not supplying any reactive power to load observed from the table. The active and reactive power supplied by source, the load active & reactive power is and the injected active and reactive power of DSTATCOM at the PCC is shown from the Table 3. Across the DSTACOM also Small amount of real power consumption as observed from the table due to switching losses.

5.1.7 Comparison of DC-link Voltage

The comparison of Dc-link voltage with PI and PSO-PI controlled DSTATCOM as shown from the Figure 11. It is observed that the PSO-PI controlled DSTATCOM providing better rise and peak over shoot and also better settling time as compared to PI controlled DSTATCOM. The total harmonic distortion also improved by improving DC-link voltage.

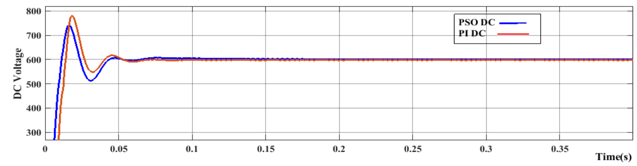

Figure 11. Comparison of DC-link voltage variation with PI and PSO-PI controller.

Table 3. Active and reactive power comparison

	Active Power			Reactive Power		
Corresponding BUS	**Supply (BUS-1)**	**Load (BUS-3)**	**DSTATCOM (BUS-2)**	**Supply (BUS-1)**	**Load (BUS-3)**	**DSTATCOM (BUS-3)**
Without DSTATCOM	16.5	16.5	0	3.89	3.89	0
PI Controlled DSTATCOM	20.4	15.4	0.5	1	3.69	6.7
PSO-PI Controlled DSTATCOM	18.5	18.5	0.05	1	1	0.5

6. Conclusions

The execution of DSTATCOM has been dissected by using the synchronous reference frame control theory for the compensation of reactive power, mitigation of harmonics and power factor upgrade for under nonlinear load condition. The simulation result for the proposed system is investigated and compared independently using PI and PSO-PI controller. The dc interface voltage is keeping up consistent for under all unsettling influence conditions with the two controllers. The two controllers providing good compensation, however PSO-PI controller giving predominant execution under all load conditions. The simulation results are procured in MATLAB/SIMULINK programming. It shows that the got PI esteems utilizing PSO count gives better framework dynamic response and consequently it upgrades transient state and power quality as contrast and the normal PI controlled DSTATCOM.

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