Power Quality Improvement by using DSTATCOM with PSO Tuned PI Controller

S. Karuna[1*], P.V. Prasad[2]

[1*]*EEE Department, CBIT, Gandipet, Hyderabad, India*
[2]*EEE Department, CBIT, Gandipet, Hyderabad, India*

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Abstract - *The Distribution static synchronous compensator (DSTATCOM) is used for reactive power compensation, Power factor correction, reduction in total harmonic distortion and to stabilize the source and PCC currents. DSTATCOM is a parallel connected device connected at a point of common coupling (PCC). The Controlling algorithm for DSTATCOM is developed by using synchronous reference frame theory (SRF) and which is utilized for generating the reference currents. The DSTATCOM comprises of VSI, dc link capacitor and control circuit. The dc link capacitor voltage is regulated by using the PI controller. The K_p, K_I values obtained with conventional method may not give accurate results. Hence, In this paper a PSO based technique is proposed to obtain optimal results. The simulation representation is progressed using MATLAB simulation software.*

Keywords: DSTATCOM; voltage source inverter (VSI); SRF Theory; PI controller; PSO.

1. INTRODUCTION

In current years because of new advancement in technology most of the industries and commercial customers prefer the usage of Power electronics devices. Because of these non-linear loads distribution system is facing power quality (PQ) problems such as poor power factor, harmonics injection, voltage sag, voltage swell, high neutral current, unbalance in three phase loading, distortions in source currents. These distortions may pass through the entire network. These PQ problems may responsible for increase of power losses, violates the power flow limits, and reduce the system response time [1]. Various custom power devices such as DSTATCOM (Distribution Static Synchronous Compensator), Unified Power Quality Conditioner (UPQC), and Dynamic Voltage Regulator (DVR) are operating for power quality (PQ) improvement [2-3]. Among these devices DSTATCOM is preferred because of its features such as low power losses, generating few harmonics, ability of high regulatory, less cost, and compact size. For controlling of DSTATCOM various methods are used such as Synchronous Reference Frame (SRF) Theory, Instantaneous Reactive Power (IRP) Theory [4], and Instantaneous Symmetrical Component (ISC) Theory [5]. The performance of DSTATCOM depends on the reference currents generation. DSTATCOM is a VSI based custom device. For switching of VSI Hysteresis current controller [6-8] is used. Among the other PWM current controllers, Hysteresis controller gives the fast response, reduce peak current and shows better performance. PI controller is operated for regulating the DC link voltage [9-11]. For tuning of PI controller trial and error method is the simplest but it consume more time and the performance is also not good. Instead of Trial and error if soft computing techniques are used such as Ant colony Optimization, Genetic Algorithm (GA), Ziegler-Nichols technique and Particle Swarm Optimization (PSO) [12-15] technique, better results can be obtained. In this paper PSO which gives the best global gains for PI controller is applied for obtaining gains and DSTATCOM is simulated using MATLAB/SIMULINK software.

2. CONFIGURATION OF DSTATCOM

DSTATCOM is a practice power device connected at PCC through interfacing inductor. DSTATCOM is used for injecting or absorbing the reactive power into system to stabilize the voltages in the system due to variation of the load. It is also used to inject the compensating currents into the system. I_{sa}, I_{sb}, and I_{sc} are the source currents and V_{sa}, V_{sb} and V_{sc} are the source voltages of phase a, b, c, I_{la}, I_{lb} and I_{lc} are the load currents and compensating currents are symbolized as I_{fa}, I_{fb} and I_{fc}. Non linear load is supplied with the system source voltage of 11kV, 50Hz. Transformer is used for step down the voltage from source to load in distribution system, and this non linear load develop harmonics in the system. In order to compensate these harmonics DSTATCOM is connected at the Point of Common Coupling (PCC) to inject the compensating currents into the system to make the system balance. DSTATCOM configuration consists of VSI, dc capacitor, and control circuit. PI controller is operated to maintain the dc capacitor voltage constant. SRF theory is used for controlling the DSTATCOM by generating the reference currents and then actual currents and reference currents are compared, the initiated error signal is given to the VSI for switching of IGBT's [2]. DSTATCOM representation is shown in Fig .1.

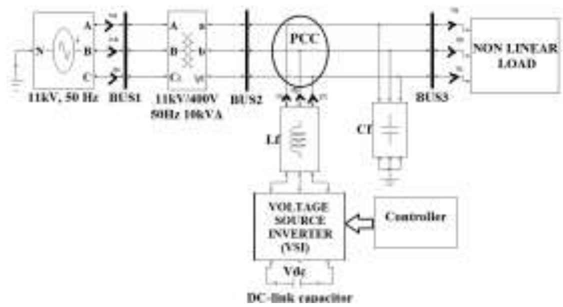

Fig – 1: Schematic diagram of DSTATCOM

3. CONTROL ALGORITHM FOR DSTATCOM

The control circuit for DSTATCOM is shown in
Fig – 2:

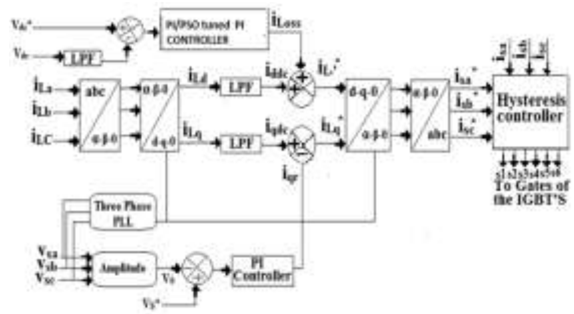

Fig – 2: Control circuit for DSTATCOM

The control scheme, for DSTATCOM is divided into two parts.

1. From the feedback signals reference signal will be produced.
2. By comparison of reference signal and actual sinusoidal signal, gate signal will be produced by using Hysteresis current controller.

From the control scheme, reference current signals will be generated by using proportional and integral controllers with SRF Theory, the three phase currents at the load are converted into α-β-0 axis by using Clark transformation. It is given by

$$\begin{bmatrix} I_0 \\ I_\alpha \\ I_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{pmatrix} \begin{bmatrix} I_{La} \\ I_{Lb} \\ I_{Lc} \end{bmatrix} \quad (1)$$

The transformed currents in α-β-0 axis again transformed into d-q-0 axis by using parks transformation and Θ angle is obtained from the three phase PLL (Phased Lock Loop) controller. The transformation for α-β-0 to d-q-0 is obtained from the equation (2).

$$\begin{bmatrix} I_0 \\ I_{Ld} \\ I_{Lq} \end{bmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & \sin\theta \\ 0 & -\sin\theta & \cos\theta \end{pmatrix} \begin{bmatrix} I_0 \\ I_\alpha \\ I_\beta \end{bmatrix} \quad (2)$$

The PLL consists of phase comparator and low pass filter within the loop. The input and output difference is measured in the phase comparator and outcome value is passed through the low pass filter which filter out and produces an error signal which gives the generated output current. The variables I_{Ld} and I_{Lq} are obtained from the synchronous reference frame, which are passed through Low pass filter to generate the exact reference signals. The each current component having a mean and oscillating values are given by (2).

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

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

The fundamental current is transferred into the mean value or dc component and remaining all other higher order harmonic components are transferred into the non dc components including the negative sequence currents components, but these are having the repetitive variation nature, it looks like ripples, these ripples are eliminated by using the filter. So now the reference current components are given by the equation (5) & (6).

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

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

Source must deliver the direct axis load current (I_{Ld}) along with the injected current component to keep the DC bus voltage and to supply the losses (I_{loss}) in DSTATCOM. The output of the PI controller is examined as the current loss (I_{loss}).

$$I_{loss(n)}=I_{loss(n-1)}+K_{pd}(I_{de(n)}-I_{de(n-1)})+K_{id}I_{de(n)} \quad (7)$$

Where $I_{de(n)}=I^*_{dc}-I_{dc(n)}$ which is the error generated between the reference current (I^*_{dc}) and injected dc current (I_{dc}) at the instant of n^{th} sampling. K_{pd}, K_{id} are the proportional and integral gains of the dc bus voltage PI controller respectively. The reference current is given by

$$I_{dc\,ref}=I_{d\,dc}+I_{loss} \quad (8)$$

To regulate the voltage at the load end, the sum of the Quadrature axis current ($I_{q\,dc}$) and the output of the PI controller current (I_{qr}) are used.

The ac source voltage amplitude is obtained from the equation given below.

$$v_{source} = \frac{2}{3}(\sqrt{(v_a)^2 + (v_b)^2 + (v_{ac})^2}) \quad (9)$$

By using PI controller, the load current (I_s) is controlled to its reference current (I^*_s) .Output of this PI controller is examined as the reactive current component (I_{qr}), which is given by the equation.

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

Where $I_{te(n)}=I^*_s-I_{e(n)}$ which is the error between reference current (I^*_s) and actual measured current at load end at the instant of n^{th} sampling. Where K_{pq} ,K_{iq} are the proportional gain and integral gain of the PI controller.

The quadrature axis reference current is given by

$$I_{q\,ref}=I_{q\,dc}-I_{qr} \quad (11)$$

The reference current signals $I_{d\,ref}$, $I_{q\,ref}$ are transformed into α-β-0 axis frame which is obtained by using the equation given below

$$\begin{bmatrix} I_{s0}^* \\ I_{s\alpha}^* \\ I_{s\beta}^* \end{bmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta \\ 0 & \sin\theta & \cos\theta \end{pmatrix} \begin{bmatrix} 0 \\ I_{dref} \\ I_{qref} \end{bmatrix} \quad (12)$$

The reference currents in a-b-c reference frame are obtained by the following equation.

$$\begin{bmatrix} I_{sa}^* \\ I_{sb}^* \\ I_{sc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} 0 & 1 & 0 \\ 0 & \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ 0 & \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{pmatrix} \begin{bmatrix} I_{s0}^* \\ I_{s\alpha}^* \\ I_{s\beta}^* \end{bmatrix} \quad (13)$$

The obtained reference currents from the control block are transferred to hysteresis current controller to supply switching signals to the VSI to compensate the harmonics injected by the non linear loads.

4. DESIGN OF PI CONTROLLER

To make the steady state error zero and to increase the response of the system PI controller is used. PI controller is the mostly used controller in industries because of its simple structure, which can be easily understood and implemented. The location of the PI controller is shown in Fig - 3. Tuning of PI controller is the main task [9,10]. If system is linear PI controller can be tuned by trial and error method but for complicated plants with higher order must be followed some tuning methods. Here the PSO technique is used to tune the PI controller in getting best results [11].

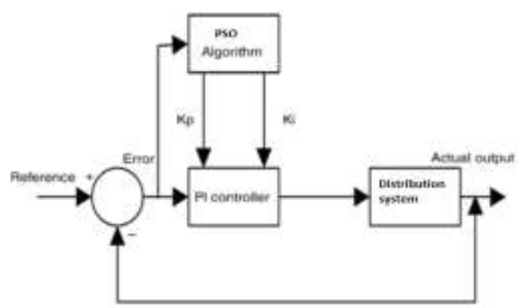

Fig – 3: Location of PI controller.

5. PARTICLE SWARM OPTIMIZATION (PSO) TECHNIQUE

There are various methods available for tuning the PI controller one of them is the particle swarm optimization. Particle swarm optimization is a robust stochastic optimization technique. PSO is first proposed by Russell Eberhart and James Kennedy in 1995. In PSO particle is an agent which constitutes a swarm which are searching for a best solution in search space [12-14]. The observant process is based on consideration of five fundamental principles are stability, quality, proximity, adaptability and response. In particle swarm optimization technique each particle is finding for best solution by comparing its position and velocity with their previous position and velocity and with the neighboring particle position and velocity [15]. Each particle is related with a set of parameters in multidimensional search space. The particle velocity is affected by the three components inertia, cognitive, and social. In every step each particle updates its position and velocity. The updated position and velocity is given by

$$V_{k+1} = w * v_t + c_1\, rand(0,1)(p_{best} - x_t) + c_2 rand(0,1)(g_{best} - x_t) \quad (14)$$

$$x_{t+1} = x_t + v_{t+1} \quad (15)$$

A large inertia weight (w) facilitates a global search while a small inertia weight facilitates a local search. Where C_1 and C_2 are acceleration coefficients, r1 and r_2 are the random numbers taken between [0, 1]. Second term represents cognitive component where the particle changes its velocity and position based on their own thinking and memory, the third term represents the social component where the particle changes its velocity and position based on their neighboring particles.

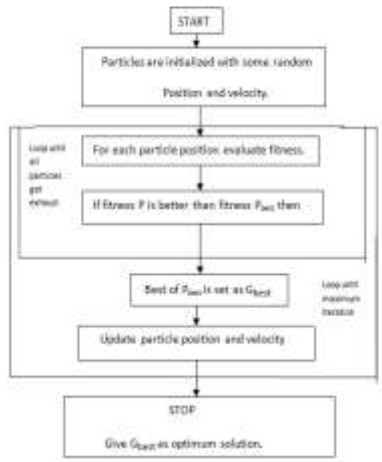

Fig – 4: PSO loop iteration Flow chart

6. RESULTS AND DISCUSSION

Execution of proposed DSTATCOM model is done in MATLAB/SIMULINK software by using SRF theory with PSO tuned PI controller. This model is tested under non linear load conditions. 0.2 to 0.5 is the simulation time for better results. The parameters of DSTATCOM and PI Controller with PSO are given in Appendix. DSTATCOM is used for Power factor improvement, reactive power compensation, compensates the harmonics to reduce THD values and to maintain the Voltage at PCC within limits. This model shows the comparison of PI controller tuned with conventional method and with PSO technique. The performance of DSTATCOM is given with the following cases:

- Non Linear Load without DSTATCOM
- Non Linear Load with PI controller
- Non Linear Load with PSO tuned PI controller.

6.1. System Response for Non Linear Load without DSATCOM

When DSTATCOM is not connected to the system, the connected Non Linear Load which draws non sinusoidal current from the source. This Non linear load is responsible for the injection of harmonics into the system. These harmonics distort the source currents Fig: 5(b) which is not a sinusoidal waveform. Fig – 5(a) shows the source voltage (V). These harmonics affect the PCC voltage as shown in Fig – 5(c) and PCC current as shown in Fig – 5(d). The load is non linear load, it develops the harmonics from load side, harmonics are absorbed in load voltage as shown in Fig – 5(e) and in load current as shown in Fig – 5(f).Source THD observed in this case when DSTATCOM is not connected 19.21% Fig: 8(a).

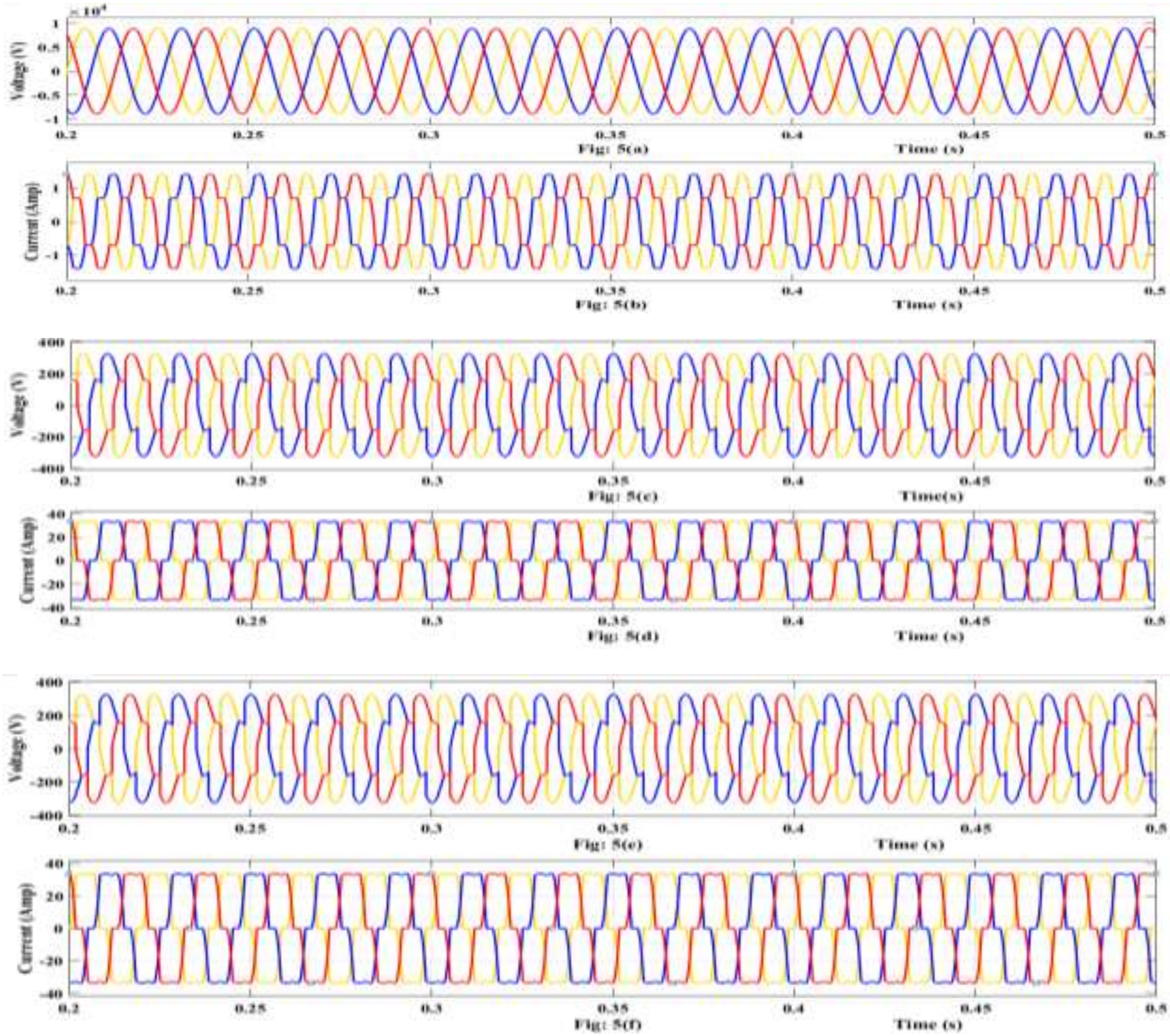

Fig – 5: (a) Source Voltage, (b) Source Current, (c) PCC Voltage, (d)PCC Current, (e) Load Voltage and (f) Load Current respectively.

6.2. System Response for Non Linear Load with PI controller

When DSTATCOM is connected to the system, the connected Non linear load injects the harmonics in to the system but source currents get balanced as shown in Fig-6(b) and source voltage is absorbed sinusoidal as shown in Fig – 6(a), because of compensating currents injected by the DSTATCOM into the system. For controlling of DSTATCOM Synchronous Reference Frame (SRF) theory is used. In this case PI controller gains are obtained from conventional method. Constant voltage is obtained at PCC as shown in Fig – 6(c) and PCC current get balanced as shown in Fig -6(d). The balanced Load voltage is absorbed from Fig – 6(e) and load current (A) from Fig – 6(f). PI controller maintains the DC link voltage as 600V as shown in Fig: 6(g). THD is reduced in this case is 4.11% as shown in Fig: 8(b).

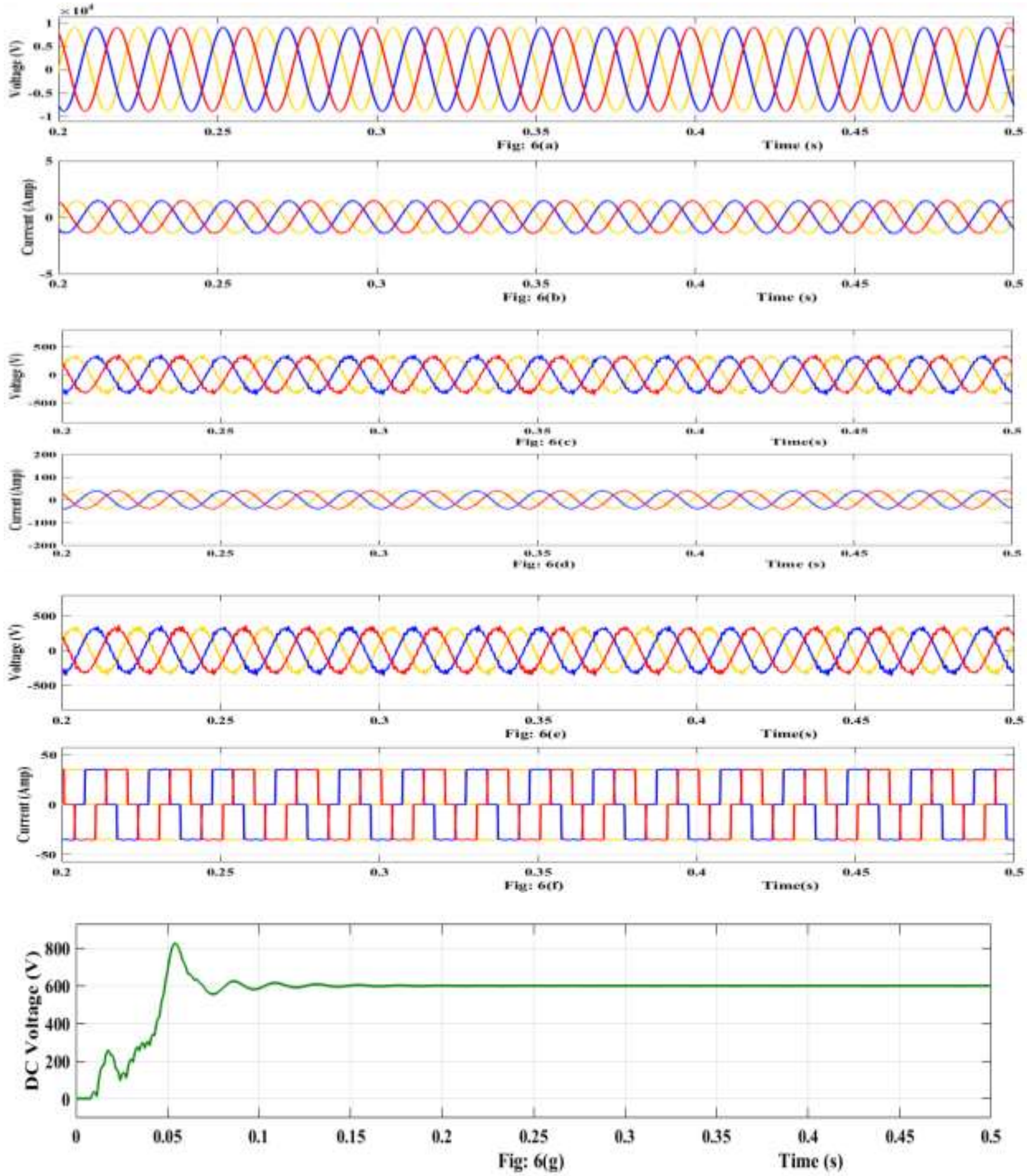

Fig – 6: (a) Source Voltage, (b) Source Current, (c) PCC Voltage, (d) PCC Current, (e) Load Voltage, (f) Load Current, (g) DC Link Voltage respectively.

6.3. System Response with PSO tuned PI Controller.

When DSTATCOM is connected to the system, the connected Non linear load injects the harmonics in to the system but source currents get balanced as shown in Fig - 7(b) and source voltage is sinusoidal as shown in Fig – 7(a), because of compensating currents injected by the DSTATCOM into the system. For controlling of DSTATCOM Synchronous Reference Frame (SRF) theory is used. In this case PI controller gains are obtained from Particle Swarm Optimization (PSO) Technique. Constant voltage (V) is obtained at PCC as shown in Fig – 7(c) and balanced PCC current as shown in Fig – 7(d). The balanced voltage is absorbed from Fig – 7(e) and load current from Fig – 7(f). The PI controller maintains DC link voltage as constant. The combined conventional tuned PI controller and with PSO technique tuned PI Controller are absorbed from Fig - 7(g). The injected compensating current into the system is shown in the Fig - 7(h). THD is reduced in this case is 2.78% as shown in Fig – 8(c). The PSO tuned PI controller gives the best global gains compared to conventional tuned PI controller.

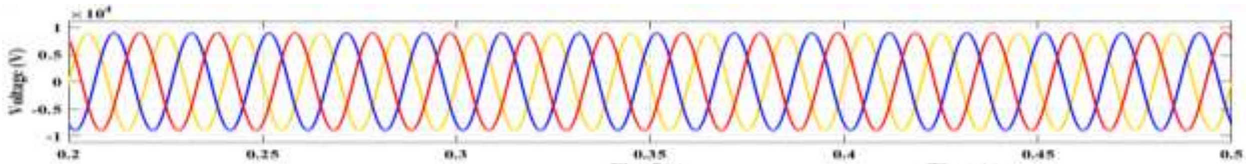

Fig: 7(a)

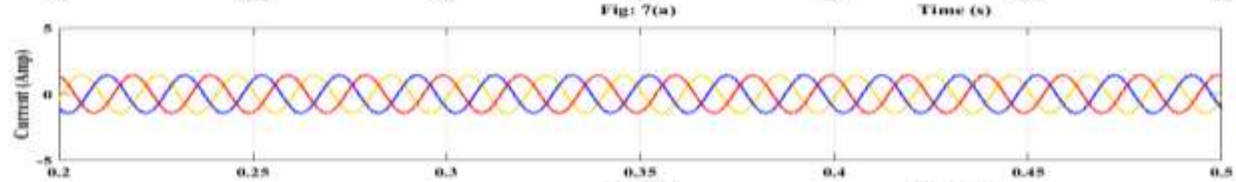

Fig: 7(b)

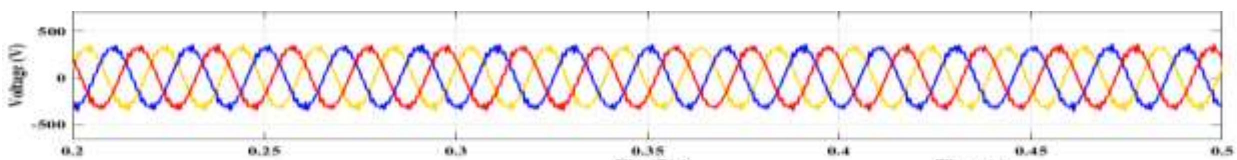

Fig: 7(c)

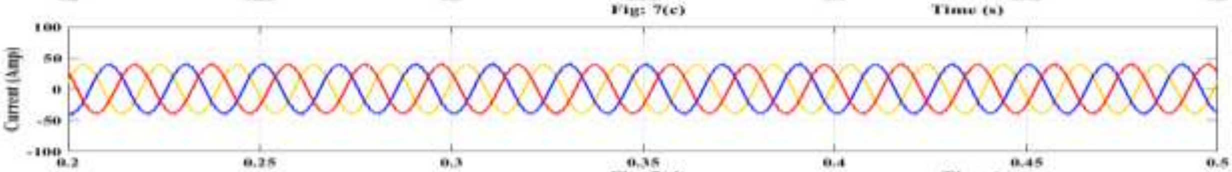

Fig: 7(d)

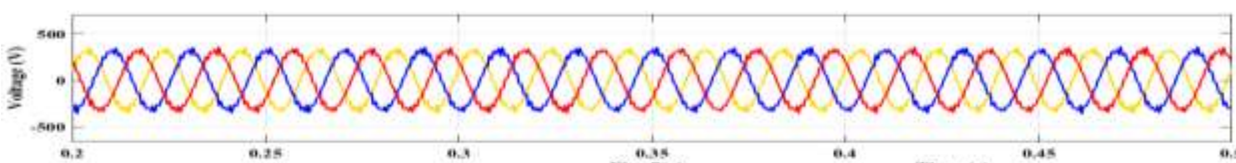

Fig: 7(e)

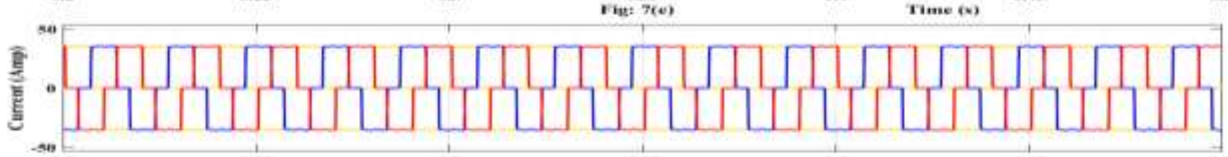

Fig: 7(f)

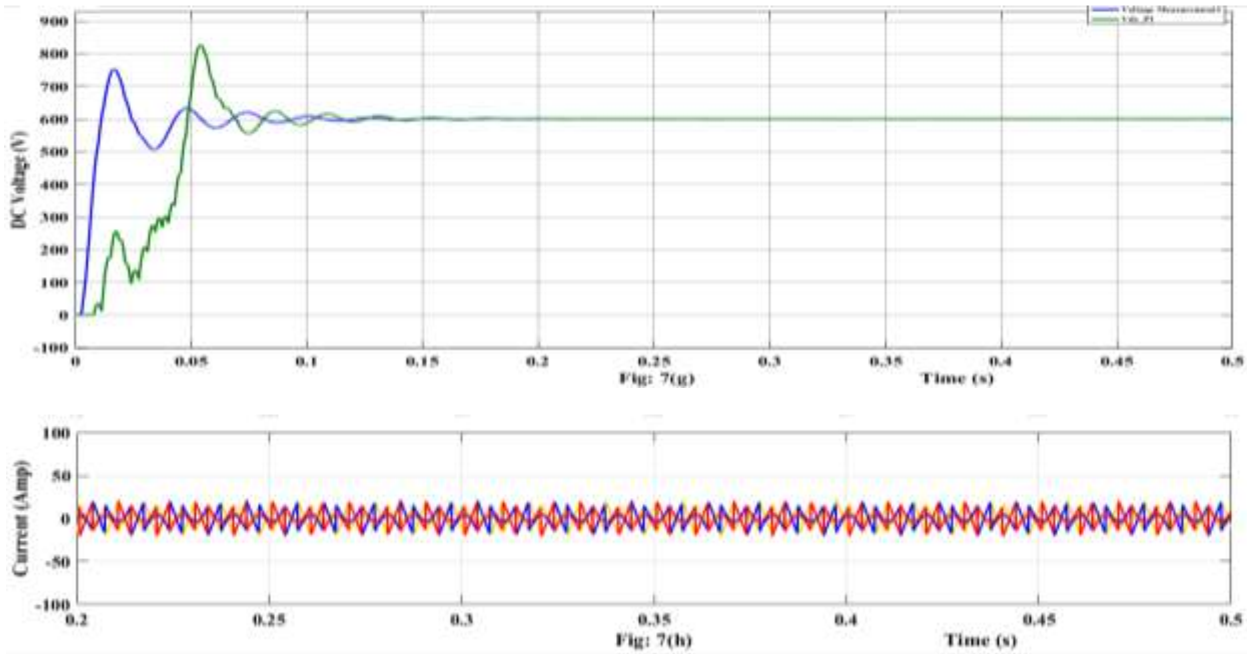

Fig – 7: (a) Source Voltage, (b) Source Current, (c) PCC Voltage, (d) PCC Current, (e) Load Voltage, (f) Load Current, (g) DC Link Voltage, (h) Compensator current.

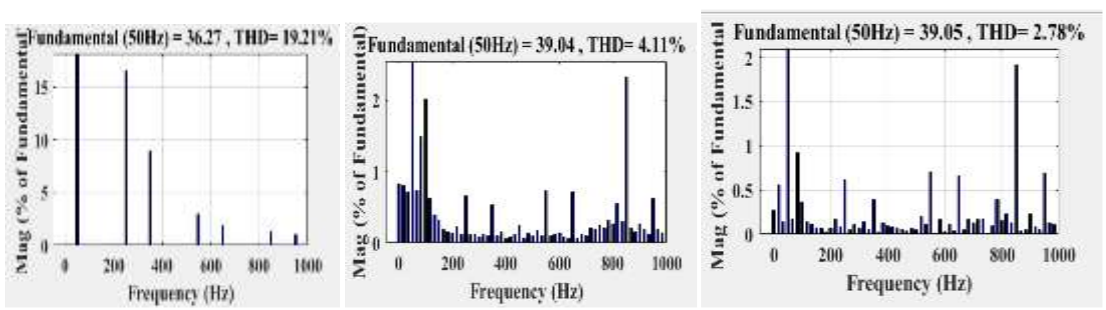

Fig – 8(a): Source THD without DSTATCOM 8(b): Source THD with PI controller 8(c): Source THD with PSO-PI

7. CONCLUSION

In this paper, The VSI based DSTATCOM is executed through MATLAB/SIMULINK software. DSTATCOM which injects the compensating currents into the system which produce the source currents as balanced with reduced THD and maintains the Voltage at PCC as constant .The simple and easy SRF Theory is used for controlling of DSTATCOM. DC voltage is maintained as constant with PI controller. Tuning of PI controller is done by conventional method and by using PSO technique and their comparison is analyzed. PSO technique which gives the best global gains for PI controller is observed.

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APPENDIX

Source Voltage	11KV, 50Hz
C_{dc}	3000µF
V_{dc}	600V
Hysteresis band	±0.2
K_p, K_i gains using PSO	K_p=0.8503, K_i=41.35.