International Journal of Engineering & Technology, 7 (3.3) (2018) 54-59

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper



VSI Based DSTATCOM for Compensating Nonlinear and Unbalanced Loads

S.R.REDDY[1]*, P.V.PRASAD[2], G.N.SRINIVAS[3]

[1]EEE Department GNITC, Hyderabad, India.
[2]EEE Department CBIT, Hyderabad, India.
[3]EEE Department JNTU, Hyderabad, India.
**Corresponding author E-mail sadurajender@gmail.com.*

Abstract

This paper presents study of distribution static compensator (D-STATCOM) for compensation of neutral current, source&PCC current harmonic distortion, PCC voltage regulation and compensation of unbalanced current waveform for the three phase four wire nonlinear and unbalanced load medium voltage distribution system. The proposed control algorithm is developed based on synchronous reference frame theory with PI controller. The obtained reference current signal from control algorithm is compared in hysteresis band current controller for better switching of D-STATCOM. The performance of system without & with D-STATCOM is also analysed and compared. The proposed control method is implemented on 11/0.4kv medium voltage distribution system and it is provided effective compensation for reactive power and harmonic distortion mitigation. The simulation results are obtained using MATLAB/SIMULINK.

Keywords: Distribution static compensator (D-STATCOM), Synchronous reference frame (SRF) theory, PI controller, voltage source inverter (VSI), hysteresis current controller, harmonic distortion.

1. Introduction

In last one decade, power electronic devices are widely used in industrial applications for transferring power in more efficient way [1-3]. The excessive use of power electronic equipments, which represent nonlinear loads, in a distribution network has caused many disturbances in the quality of power such as harmonic pollutions, unbalanced load currents, and reactive power problems. As a result poor power factor, weakening efficiency, overheating of motors and transformers, malfunction of sensitive devices etc occurs [4-5]. Another power quality problem is unbalancing the source voltage due to unbalanced load. The unbalanced source voltage may generate the lower order harmonic component in the power system and also cause a negative sequence current and torque reduction in case of electric machine drive system [6, 7]. These power quality problems are addressed using custom power devices such as distribution static compensators (DSTATCOM), dynamic voltage restorer (DVR) and unified power quality conditioner (UPQC). In which the distribution static compensators is more suitable for reactive power compensation and harmonic current mitigation in the distribution network compared to other custom power devices [8]. The DSTATCOM operate in two modes such as transformer based topology and inverter based topology. In transformer based topology DSTATCOM includes three-leg VSI combined with zig-zag transformer [9] or T-connected transformer [10] or star-delta transformer etc. In this scheme the zero sequence component of current is eliminated using transformer and the positive and negative component of current is compensated using three-leg VSIs. Inverter based topology DSTATCOM includes three single phases VSI [11], four legs VSI [12, 13], and three-leg VSI with split phase capacitor [14-18]. All these methods having its own advantages and disadvantages. In general, for neutral current compensation either spilt phase or four leg VSI inverter are used. In this paper combination of four leg VSI with split phase capacitor is used for better neutral and source current compensation as compared to their individual performances. The SRF control scheme need PI controller for regulating DC-link voltage. The tuning of the PI controller is done Ziegler-Nichols method. In practical applications the distribution system is stepped down to 400v using 11/400kv three phase transformer. By connecting DSTATCOM at the PCC harmonic and reactive is compensated due to linear/nonlinear and balanced/unbalanced loads. In this proposed method the effect of transformer (11/0.4kv) is not taken into consideration. In this paper 11/0.4kv distribution transformer is considered. The harmonic and reactive power compensation before (BUS-1) and after (BUS-2) transformer is considered and analyzed.

In this paper SRF controlled DSTATCOM with split phase capacitor four leg VSI is proposed and implemented on 11/0.4kv distribution system. The performance of the proposed DSTATCOM is analyzed under nonlinear and unbalanced loads conditions in terms of harmonic mitigation, neutral current compensation and voltage regulation at the PCC. The obtained results are validated using MATLAB/SIMULINK software. The paper is organised as follows; Section-II presents system configuration, Section-III represents control strategy, section IV gives the results & discussion, finally section-V gives Conclusions.

2. System Configuration

Fig-1.shows the system configuration of proposed Distribution static compensator (D-STATCOM) for the three phase four wire distribution system with nonlinear and unbalanced loads. Three phase source voltage of 11kv is stepped down to 400V by using

Copyright © 2018 Authors. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

11/0.4Kv three phase distribution transformers and connected to nonlinear and unbalanced loads. The connected unbalanced non-linear load introduces harmonic at the PCC. By Connecting DSTATCOM at the PCC, the unbalanced at the PCC and in load voltage wave form is eliminated and also current harmonics are mitigated. The DSTATCOM consist of four leg voltage source inverter with split phase capacitor with interface inductor (L_f), resistance (r_f) and split phase capacitor for dc-link voltage regulation. The four legs VSI consists eight IGBT switches. In six IGBTs switches are used for compensating harmonics and unbalanced in current wave and remaining two IGBTs switches are used for neutral current compensation. The nonlinear load consists of three phase bridge rectifier with R-L load. The combination of split phase and fourth leg provides effective neutral current compensation compared to their individual performance. The unbalanced load consists of three phase loads having three different magnitudes of resistance and inductance values. The rating of the transformer kept 5Mva for maintaining the voltage at the PCC is constant and compensation done for source and PCC cuurents.The main advantage of this model that requirements of filters are eliminated.

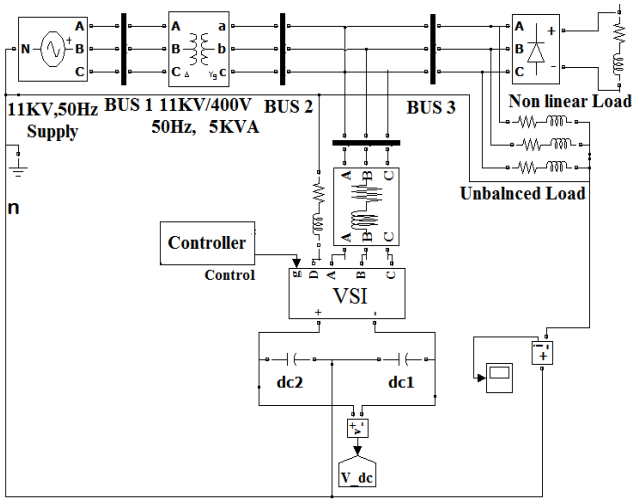


Fig. 1: System configuration

3. Control strategy

The block diagram of the proposed SRF control algorithm is shown in Fig-2. The control algorithm is used for extracting the fundamental reference control signals to switching of VSI based DSTATCOM for harmonic and reactive power compensation during unbalanced nonlinear load condition.

The non linear load currents consist of active, reactive and harmonic current in three phase system. In this, the reactive and harmonic components of currents are separated, for compensation. The separation includes converting the instantaneous three phase load currents into two phase stationary α-β-0 axis using Clark's transformation equation given in eq. (1).

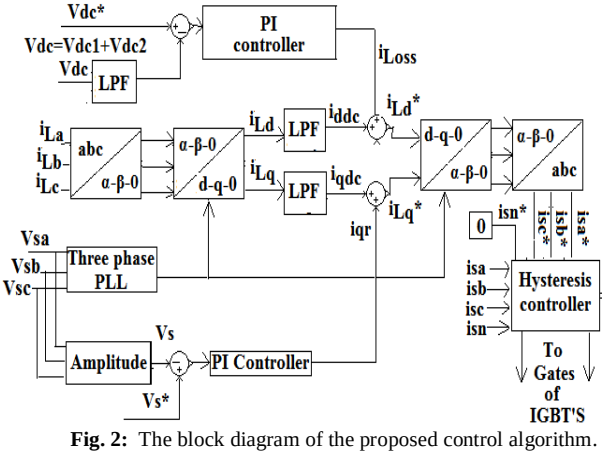


Fig. 2: The block diagram of the proposed control algorithm.

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

The stationery α-β-0 current axis components are transformed into d-q-0 (d-direct axis, q-quadrature axis components) rotating reference frame by using below park transformation equation.

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

Here the θ is the transformation angle. The cosθ and sinθ is obtained from the three phase PLL block (phase locked loop) of voltage source for synchronization of voltage and current. The obtained i_{Ld} and i_{Lq} current components are called instantaneous active and reactive load current components. Each current component has an average value (dc component) and oscillating value (ac component) as given in equation (3) & (4).

$$i_{Ld}=i_{ddc}+i_{dac} \quad (3)$$

$$i_{Lq}=i_{qdc}+i_{qac} \quad (4)$$

$i_{d\,dc}$ 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 component (harmonic) appears like ripples. After eliminating the oscillatory current component by using Low pass filter, the average active and reactive current components are given in Equation (5) & (6).

$$i_{Ld}=i_{ddc} \quad (5)$$

$$i_{Lq}=i_{qdc} \quad (6)$$

In order to maintain the constant DC link voltage and to supply the losses in DSTATCOM, the output current of the PI controller is considered as loss current component (i_{Loss}) is added to the average active reference current component of d-axis in d-q frame. Then the active reference current component is

$$i_{Ld}{}^{*}=i_{ddc}+i_{loss} \quad (7)$$

The loss reference component of current (i_{LOSS}) is extracted, by comparing the reference dc bus voltage $V_{dc*}$with the actual dc bus voltage $V_{dc}(V_{dc}=V_{dc1}+V_{dc2})$ of VSI at the n^{th} sampling instant

$$V_{de(n)} = V_{dc*(n)} - V_{dc(n)} \quad (8)$$

The compared error signal $V_{de(n)}$ is processed through a PI controller to compute the loss component (i_{Loss})at n^{th} sampling instant is expressed as

$$i_{\,Loss(n)} = i_{loss(n-1)} + k_{pd}\,(V_{de(n)} - V_{de(n-1)}) + k_{id}\,V_{de(n)} \quad (9)$$

Here the k_{pd} and k_{id} are the proportional and integral gains of PI controller. The output of the PI controller is the loss reference component (i_{Loss}) of the DSTSTCOM. The loss reference current component (i_{loss}) is added to the average active reference component (i_{Ld}) for regulating the active reference component of current (i_{Ld*}).

The direct axis reference current component (i_{Ld}*) is used for compensation of harmonic and power factor. Similarly for regulating the voltage at the PCC, the source must need to deliver the reactive current (i_{qr}) ,to be added to the average reactive reference component of current ($i_{q\,dc}$)of q-axis in d-q frame same as direct current axis component. Then the resultant reactive reference current component is

$$i_{Lq}^*=i_{qdc}+i_{qr} \quad (10)$$

The reactive current (i_{qr}) is obtained from the PI controller output, the input to the PI controller is obtained by subtracting the voltage amplitude Vs from the reference voltage Vs* and is fed to PI controller.
Here the amplitude of the PCC voltage is given as

$$Vs = \sqrt{2/3\,(V_{sa}^2 + V_{sb}^2 + V_{sc}^2)} \quad (11)$$

The PI controller output is given as

$$V_{qr(n)}=V_{qr(n-1)}+K_{pq}(V_{te(n)}-V_{te(n-1)})+K_{iq}V_{te(n)} \quad (12)$$

Where $V_{te(n)} = V^*_s - V_{s(n)}$ is the error between the reference (V^*_s) and actual(V_s) terminal voltage amplitude at the nth sampling instant. 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 component (i_{Ld}*, i_{Lq}*) are transformed in to α-β-0 frame obtained by using inverse park's Equation (13)

$$\begin{bmatrix} i_{s0}^* \\ i_{s\alpha}^* \\ i_{s\beta}^* \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta \\ 0 & \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} i_{L0}^* \\ i_{Ld}^* \\ i_{Lq}^* \end{bmatrix} \quad (13)$$

The reference currents from the Inverse Park's are transformed into three phase reference current (a-b-c) by using inverse Clark's Equation (14)

.

$$\begin{bmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 0 & 1 & 0 \\ 0 & -1/2 & \sqrt{3}/2 \\ 0 & -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{s0}^* \\ i_{s\alpha}^* \\ i_{s\beta}^* \end{bmatrix} \quad (14)$$

The obtained three phase reference currents (i_{sa}*, i_{sb}*, i_{sc}*) are compared with the actual compensating filter currents in hysteresis band controller for better switching of VSI of IGBT's. The main advantage of this hysteresis band controller is easy implementation, better stability, faster response as compared to the other controller like carrier based, bead beat and feed forward etc [19].

The neutral current compensation is obtained using fourth leg VSI.The gate switching of reaming two IGBTs of fourth leg VSI is obtained by comparing the reference neutral current (i_{sn}*) with actual compensating neutral current (i_{sn}) in hysteresis band controller.

$$I_{sn} = -(i_{sa} + i_{sb} + i_{sc}) \quad (15)$$

$$i_{sn}^* = 0 \quad (16)$$

4. Results and Discussion

The proposed split phase VSI based DSTATCOM model is implemented in MATLAB/SIMULINK software by using synchronous reference frame control algorithm with PI controller. The model is verified under nonlinear and unbalanced load condition. The proposed model is used for unbalanced compensation, harmonic mitigation, power factor correction at the PCC. The simulation period is taken from 0.2s to 0.3s for the better observation. The performance of DSTATCOM is observed for the following cases.

- Non linear & unbalanced load without DSTATCOM
- DSTATCOM with PI Controller
- Neutral current compensation
- THD analysis.

4.1. *Non linear & unbalanced load without DSTATCOM*

The When nonlinear & unbalanced load is connected to the proposed distribution system causes harmonics and unbalanced in source current (Bus-1) as shown if Fig- 3(b). The nonlinear & unbalanced load also introduces harmonics in the PCC current wave form (bus-2).is shown in Fig-3(c). The harmonics current effects the loads connected the PCC. Fig-3(e) &3(f) shows the load voltage and load current.

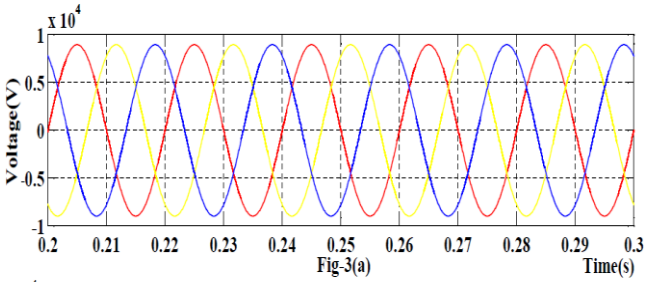


Fig-3(a)

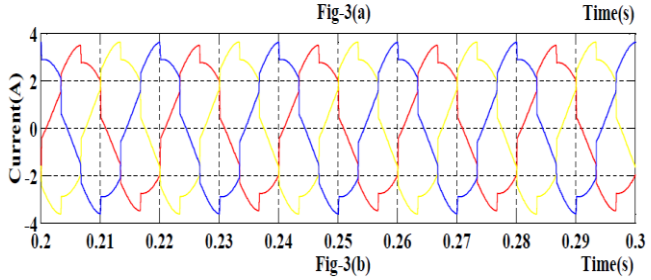


Fig-3(b)

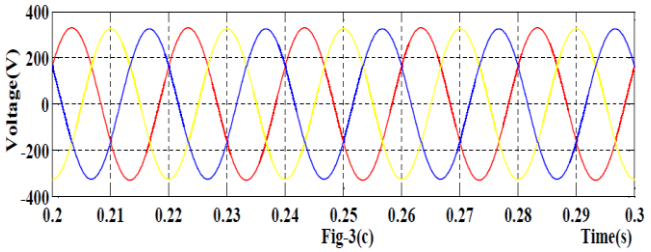


Fig-3(c)

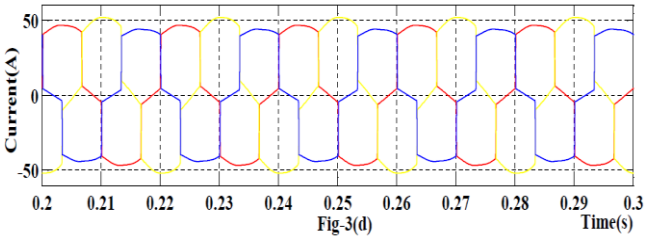


Fig-3(d)

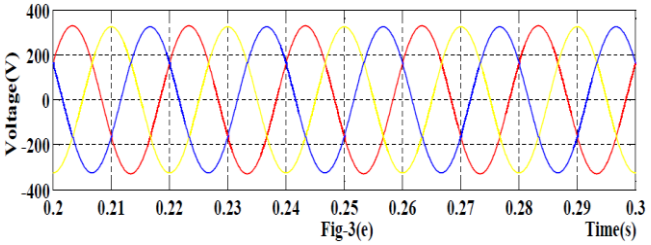


Fig-3(e)

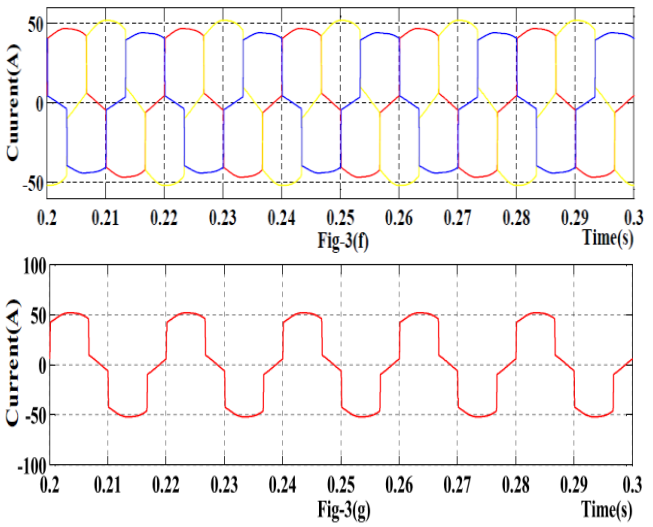
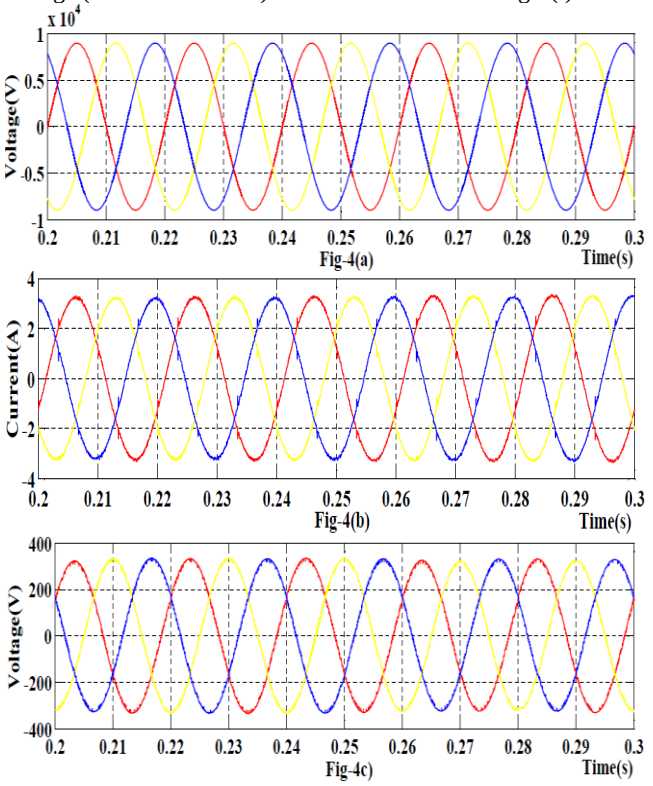


Fig. 3: (a)Source voltage wave form, (b). Source current wave form, (c).voltage waveform at the PCC (Bus-2), (d). Current waveform at the PCC (Bus-2), (e).Load voltage wave form, (f).Load current wave form, (g). Per phase representation of current wave form at the PCC, during unbalanced nonlinear load without D-STATCOM.

4.2. DSTATCOM 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 source and PCC current harmonics and unbalanced in the waveform also. The DC-link voltage is regulated by using PI controller. The compensated source and PCC current waveforms are shown in Fig-4(b) & 4(d). Fig-4(c) shows the PCC voltage waveform. Load voltage and current waveform is as shown in Fig-4(e) &4(f). Per phase representation of the load & PCC current wave form are shown in fig-4(g) & 4(h). The DC-link voltage (Vdc=Vdc1+Vdc2) wave form as shown in fig-4(i).



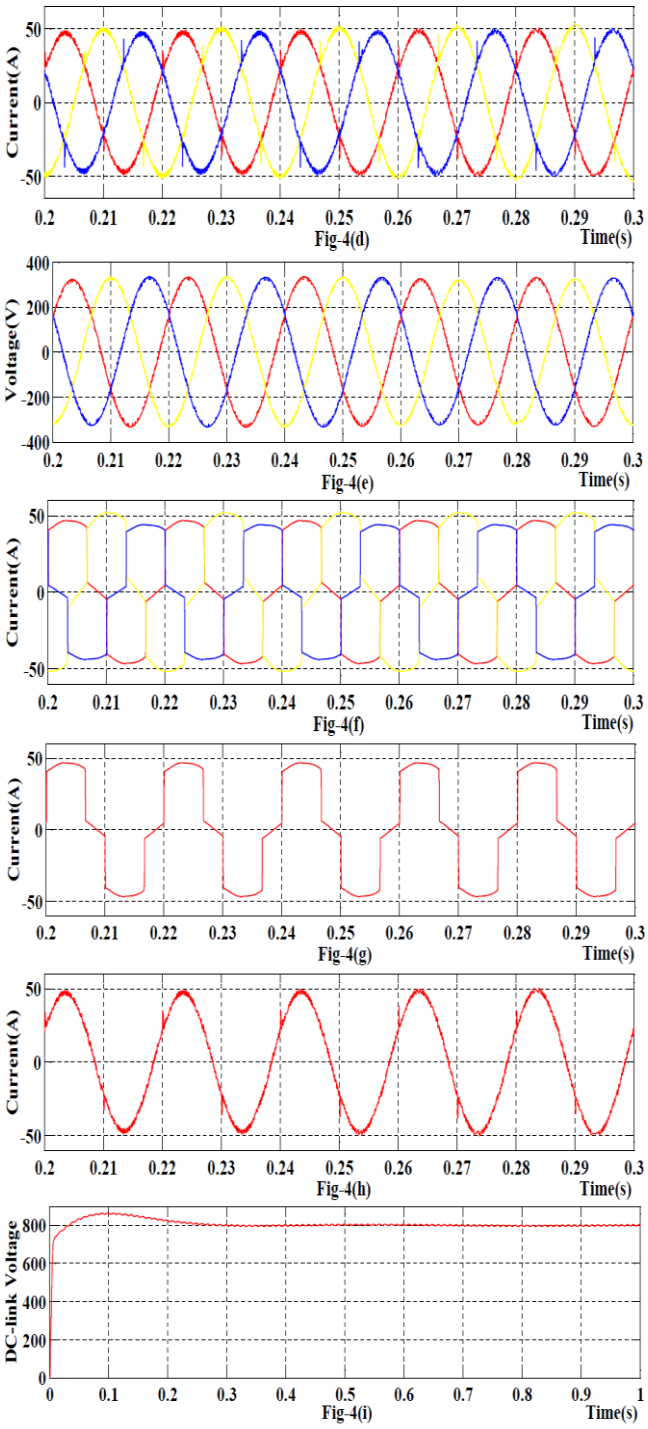


Fig. 4: (a) Source voltage wave form, (b). Source current wave form, (c).voltage waveform at the PCC (Bus-2), (d). Current waveform at the PCC (Bus-2), (e).Load voltage wave form, (f).Load current wave form, (g). Per phase representation of load current wave form, (h). Per phase representation of current wave form at the PCC (i).DC-link voltage form (Vdc), with PI controlled D-STATCOM.

4.3. Neutral Current Compensation

The unbalanced loads causes current flowing through the neutral wire. The current flowing through neutral wire during unbalanced load condition is observed as shown in fig-5(a).By providing appropriate control algorithm with split phase capacitor the current in supply neutral wire is compensated and is observed as shown in fig-5(b).with the combination of four leg VSI with split phase capacitor provided effective compensation for the both neutral current and line currents of the proposed system.

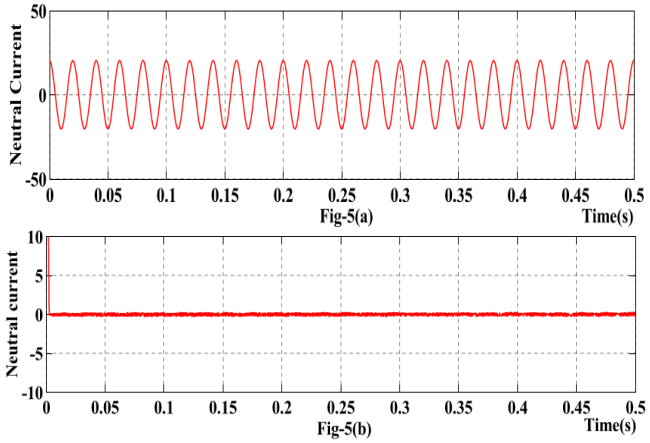


Fig-5. (a). Neutral current wave form without compensation, (b). Neutral current wave form after compensation.

4.4. Total Harmonic Distortion analysis

The total harmonic distortion of the PCC and source currents wave forms for the proposed system with and without DSTATCOM is discussed here.

4.4.1. Non Linear & Unbalanced Load without DSTATCOM

The total harmonic distortion of the system by connecting nonlinear & unbalanced load without DSTATCOM is shown in Fig-6. The Current harmonic distortion at the PCC (BUS-2) is observed that 21.48%. As shown in Fig-6(a). The source current harmonic distortion is 16.03% as shown in Fig-6(b).respectively.

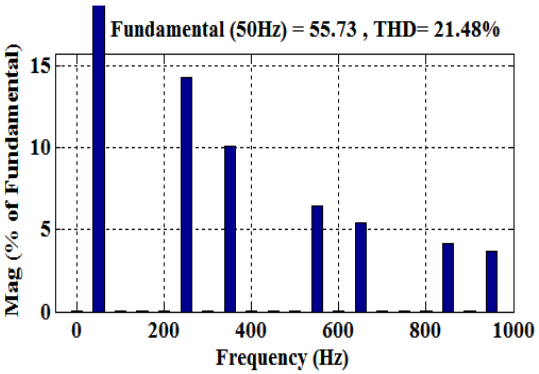


Fig. 6(a): Current THD at PCC (BUS-2)

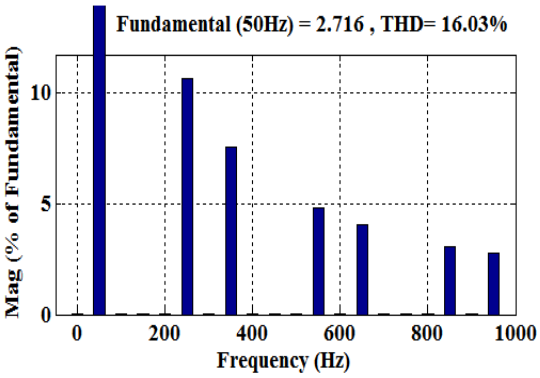


Fig.6 (b): Source current THD (BUS-1)

4.4.2. DSTATCOM with PI Controller

BY Connecting DSTATCOM to the proposed system, the current harmonics distortion at the PCC (BUS-2) is reduced to 2.43% as shown in Fig-7(a).The source current harmonic distortion is reduced to 2.02%, as shown in Fig. 7(b).

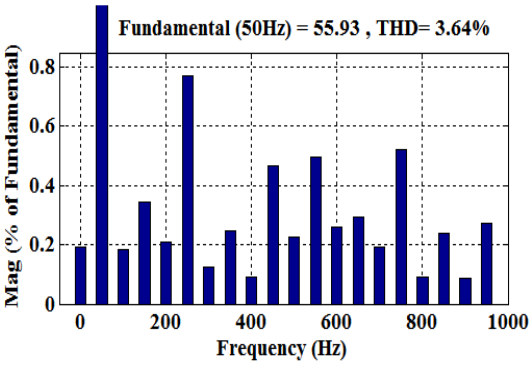


Fig.7(a): Current THD at PCC (BUS-2)

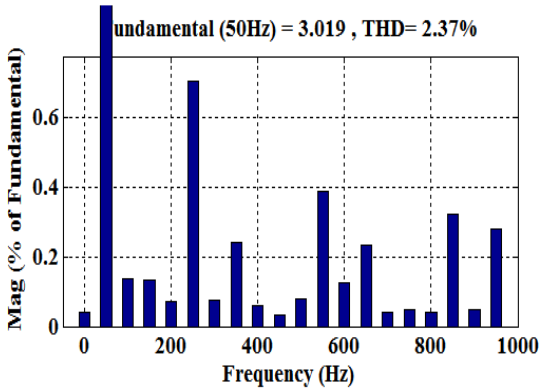


Fig.7(b): Source current THD (BUS-1).

5. Conclusion

In this paper, the performance of split phase capacitor supported four leg VSI based DSTATCOM has been analyzed and implemented using synchronous reference frame control algorithm. The combination of split capacitor and four leg inverter provided better neutral, PCC current compensation compared to their individual performance, and it also reduce the requirements of filters. The dc bus voltage is maintained constant under all disturbance conditions by using PI controller. The control logarithm is simple and provided better compensation for reactive power, harmonic, neutral current, unbalanced in currents and voltage regulation at the PCC in three phase three wire nonlinear & unbalanced load distribution system. The proposed control algorithm on the 11/0.4kv distribution system model is working satisfactory and provided better harmonic compensation at the PCC and source side. The simulation results are obtained using MATLAB/SIMULINK software.

References

[1] B. Bose, “Global energy scenario and impact of power electronics in 21st. century,” IEEE Trans. Ind. Electron., vol. 60, no. 7, pp. 2638-2651, July 2013.

[2] Hive S, Chatterjee K, Fernandes BG. VAr compensation and elimination harmonics in three-phase four-wire system based on unified constant frequency integration control. In: IEEE 11th international conference on harmonics and quality of, power; 2004. p. 647–51.

[3] George M, Basu KP. Modelling and control of three-phase shunt active power filter. Am J Appl Sci 2008; 5(5):1064–70.

[4] G.-Myoung Lee, Dong-Choon Lee, Jul-ki Seok, ‘’Control of series Active power filters Compensating for source voltage Unbalance and current harmonics’’, IEEE Transactions on Industrial Electronics, vol.51.no.1.pp.132-139, February 2004.

[5] Singh B, Chandra A, Al-Haddad K. Reactive power compensation and load balancing in electric power distribution systems. Int J Electr Power Energy Syst 1998; 20:375–81.Aug.

[6] Sabha Raj Arya, Bhim Singh, Ram Niwas, Ambrish Chandra, and Kamal Al-Haddad. "Power Quality Enhancement Using DSTATCOM in Distributed Power Generation System,” IEEE Tran. Ind. App. Nov 2016, VOL. 52(6):5203-52122.

[7] B. Singh, P. Jayaprakash, D. Kothari, A. Chandra, and K. Al Haddad,"Comprehensive study of DSTATCOM configurations," *IEEE Trans. On Ind. Informatics*, vol. 10, no. 2, pp. 854–870, May 2014.
[8] AredesM, Hafner J,Heuman K. Three phase four wire shunt active filter control strategies. IEEE Trans Power Electron Mar. 1997;12(2):311–8.
[9] B. Singh, P. Jayaprakash, T. R. Somayajulu, and D. Kothari, "Reduced rating VSC with a zig-zag transformer for current compensation in a three-phase four-wire distribution system," *IEEE Trans. on Power Del.*,vol. 24, no. 1, pp. 249–259, Jan. 2009.
[10] B. Singh, P. Jayaprakash, and D. Kothari, "A T-connected transformer and three-leg VSC based DSTATCOM for power quality improvement," *IEEE Trans. on Power Electron.*, vol. 23, no. 6, pp. 2710–2718, Nov.2008.
[11] B. Singh, S. Arya, C. Jain, and S. Goel, "Implementation of four-leg distribution static compensator," *IET Generation Transmission Distribution*,vol. 8, no. 6, pp. 1127–1139, Jun. 2014.
[12] Mahesh K. Mishra, A. Ghosh, A. Joshi, and H. Suryawanshi, "A novel method of load compensation under unbalanced and distorted voltages,"*IEEE Trans. on Power Del.*, vol. 22, no. 1, pp. 288–295, Jan. 2007.
[13] S. Karanki, N. Geddada, Mahesh K. Mishra, and B. Kumar, "A DSTATCOM topology with reduced dc-link voltage rating for load compensation with nonstiff source," *IEEE Trans. on Power Electron.*,vol. 27, no. 3, pp. 1201–1211, Mar. 2012.
[14] A. Bhattacharya, C. Chakraborty, and S. Bhattacharya, "Parallel connected shunt hybrid active power filters operating at different switching frequencies for improved performance," *IEEE Trans. on Ind. Electron.*, vol. 59, no. 11, pp. 4007–4019, Nov. 2012.
[15] A. Ghosh and A. Joshi, "A new approach to load balancing and power factor correction in power distribution system," *IEEE Trans. on Power Del.*, vol. 15, no. 1, pp. 417–422, Jan. 2000.
[16] D. M. Brod and D. Novotny, "Current control of VSI-PWM inverters," *IEEE Trans. on Ind. Appl.*, vol. IA-21, no. 3, pp. 562–570, May 1985.
[17] U. Rao, Mahesh K. Mishra, and A. Ghosh, "Control strategies for load compensation using instantaneous symmetrical component theory under different supply voltages," *IEEE Trans. on Power Del.*, vol. 23, no. 4, pp. 2310–2317, 2008.
[18] Mahesh K. Mishra., A. Ghosh, and A. Joshi, "A new STATCOM topology to compensate loads containing AC and DC components," in Power Engineering Society Winter Meeting, 2000. IEEE, vol. 4, 2000, pp. 2636–2641.
[19] A. Ghosh and G. Ledwich, Power Quality Enhancement Using Custom *Power Devices*, ser. Kluwer international series in engineering and computer science. Springer US, 2002.313.