IJCTA, 10(5) 2017, pp. 177-188

A Novel Fundamental Current Reference $I_d - I_q$ Theory Based DSTATCOM for Compensation of Reactive Power and Harmonics

Ch. Sri Prakash* **and Kesava Rao****

Abstract: This paper depicts DSTATCOM for reactive power and harmonic compensation in distribution system. A distribution static compensator (DSTATCOM) proves to be a viable solution for the mitigation of power quality problems. As the power demand raises every day and implication of non-linear loads increases power quality issues like reduction in reactive power and induction of harmonics. This problem in distribution system is addressed by employing DSTATCOM. By controlling DSTATCOM power quality issues can be addressed. $I_d - I_q$ control theory is simple and can control DSTACOM for reactive power issues and to reduce harmonics. Conventional $I_d - I_q$ theory suffers from high switching losses due to high frequency harmonic current as reference. This paper depicts a novel current reference $I_d - I_q$ theory for compensation of harmonics and reactive power reducing losses and thus system efficiency is increased. Reference signal is taken from the source current instead of conventional method of harmonic reference currents thus enabling the user to have complete control over the source parameters.

Keywords: Distribution Static compensator (DSTATCOM), harmonics, power quality, Reactive power, current reference.

1. INTRODUCTION

Due to increased power usage these days, supply uninterrupted power supply with good power quality is a major issue for power engineers these days. But the usage of non-linear loads degrades the quality of power and affects the remaining loads connected to distribution system. Large usage of power flags reactive power issues. The main aspect of power system is to deliver uninterrupted power supply to the connected loads with improved power quality. Maintaining voltage, current, frequency and power factor under nominal values is called power quality. Deviation in any of the parameters reports power quality issues.

The presence of non-linearity in load makes power network to disturb. Use of more power electronic converters in this modern era induces harmonics in to the system to which they are connected as they constitute non-linear loads. Also loads consume reactive power due to the presence of reactance. Many researchers have studied to improve the power quality by using many techniques. Use of custom power devices can help effectively to deliver power with good quality. FACTS devices are a type of custom power devices which can regulate the voltage, line impedance, phase angle between sending end and receiving end voltage. Some of the FACTS devices are STATCOM (static compensator), UPQC (unified power quality conditioner), and DVR (dynamic voltage restorer). STATCOM used in distribution system can be termed as DSTATCOM (distribution static compensator). DSTATCOM [1-4] can effectively control reactive power flow in the system and also can contribute to nullification of harmonics.

* Superintending Engineer at Trainning Institute,APGENCO, VTPS, Ibrahimpatnam, & Research Scholar, KL University, Guntur (Dst), AP, India. *Email: sriprakash670@gmail.com*

** Professor, Department of EEE, KL University, Guntur (Dst), AP, India

DSTATCOM could be a voltage-source electrical converter (VSI) primarily based shunt device typically accustomed to compensate reactive-power and disturbances caused by non linear loads connected in distribution system. Performance of DSTATCOM depends on the control strategy employed. For this there are many control techniques for DSTATCOM. Out of available control strategies and internal controls of a DSTATCOM play a very important role in the effectiveness of the DSTATCOM in maintaining the power quality at PCC (point of common coupling). For extraction of current reference parts varied management algorithms [5-9] are projected for the management of DSTATCOM like phase shift management, Decoupled current management ($p - q$ theory), hysteresis control and current reference $I_d - I_q$ theory. In this paper a modified $I_d - I_q$ theory is used to control DSTATCOM [10-12] reducing losses. Reference currents are drawn from the fundamental component rather to reference harmonic current in conventional theory. With this, complete hold over source can be achieved and can be easily extended for integration of DG in distribution system through DSTATCOM.

This paper deals with the planning of the management strategy for DSTATCOM. The distribution static synchronous compensator (DSTATCOM) with proposed control strategy is fundamental current reference $I_d - I_q$ theory is implemented for reactive power and harmonics compensation. The simulation model of a DSTATCOM has been build up with the help of MATLAB/SIMULINK; simulated results are compared with and without DSTSTCOM.

2. DSTATCOM CONNECTED IN DISTRIBUTION SYSTEM

A D-STATCOM (distribution static compensator) that is schematically represented in Figure 1 includes a voltage deliver tool (VSC), a dc hyperlink condenser, a coupling inductances connected in shunt to the distribution network at a point called common coupling (PCC). The VSC converts the dc voltage throughout the tool into a group of 3-phase ac output voltages. These voltages are coupled with the ac device via the electric phenomenon of the interfacing inductances. Appropriate adjustment of the component and

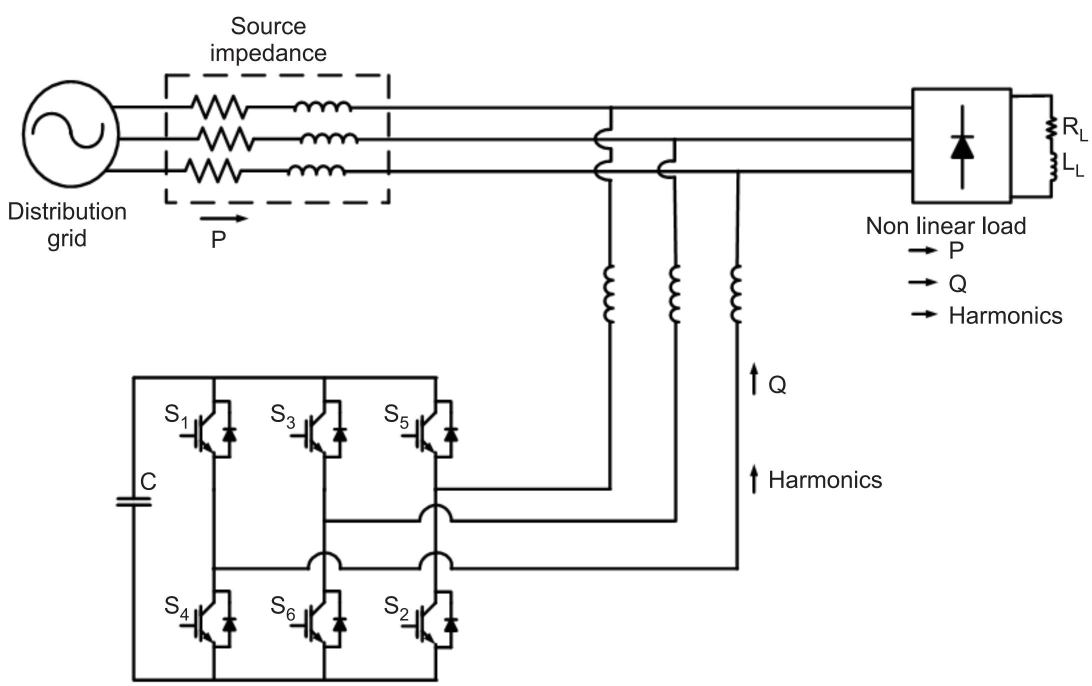

Figure 1: D-STATCOM connected in distribution system

importance of the DSTATCOM output voltages lets in powerful control of energetic and reactive power exchanges among the DSTATCOM and additionally the ac elements.

3. CONTROL STRATEGY OF DSTATCOM

(a) Proposed Fundamental Current Reference $I_d - I_q$ theory

The proposed fundamental current reference $I_d - I_q$ theory is showed in Figure 2. In this immediately energetic and reactive cutting-edge factor ($I_d - I_q$) method the lively currents I_{abc} may be received from the immediately lively and reactive cutting-edge additives I_d and I_q of the nonlinear load [4]. This technique is via using park transformation on segment $\alpha - \beta$ (by Clarke transformation) we are able to get $(d - q)$ additives. In park transformation phase $\alpha - \beta$ are fed to vector rotation block wherein it is going to be turned around over an angle θ to follow the body $d - q$. The definitions apply in either the $\alpha\beta 0$- or $dq0$-domains and for balanced sinusoidal three-phase systems would yield constant. The PLL is generates sin ωt and cos ωt components is given to conversion blocks ($abc - dq0$). PI controller have an input from the difference between actual and reference DC voltages. Finally Idc actual is generated is given to PWM generator which develops gate pluses for converter.

$$\begin{bmatrix} x_d \\ x_q \\ x_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos(\theta) & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta - \frac{4\pi}{3}\right) \\ -\sin(\theta) & \sin\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta - \frac{4\pi}{3}\right) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \tag{3.1}$$

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix} \tag{3.2}$$

Likewise current i_{sa}, i_{sb}, i_{sc} transformed as;

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{bmatrix} \tag{3.3}$$

Inverse Clarke transformation:

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} \tag{3.4}$$

v_0, v_α, v_β are zero sequence voltage, α axis, and β axis voltages respectively

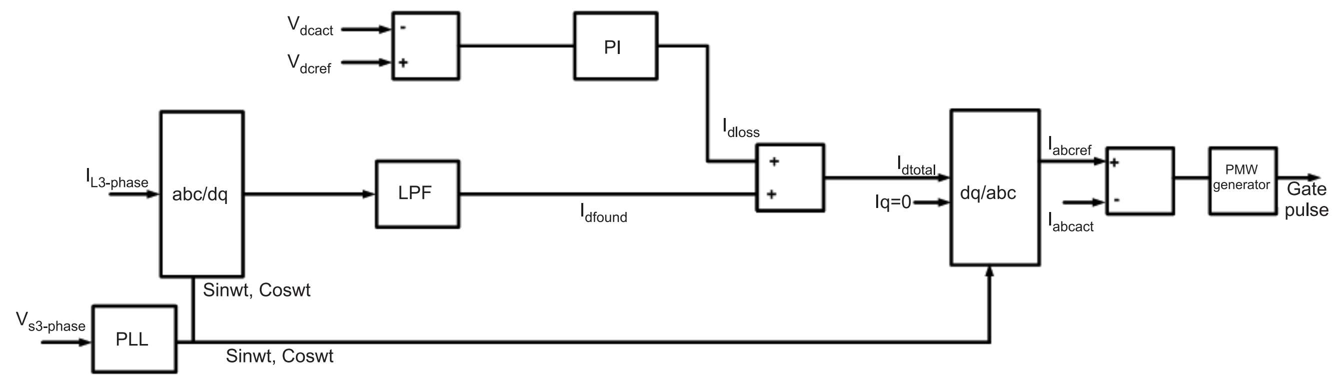

Figure 2: Proposed control algorithm

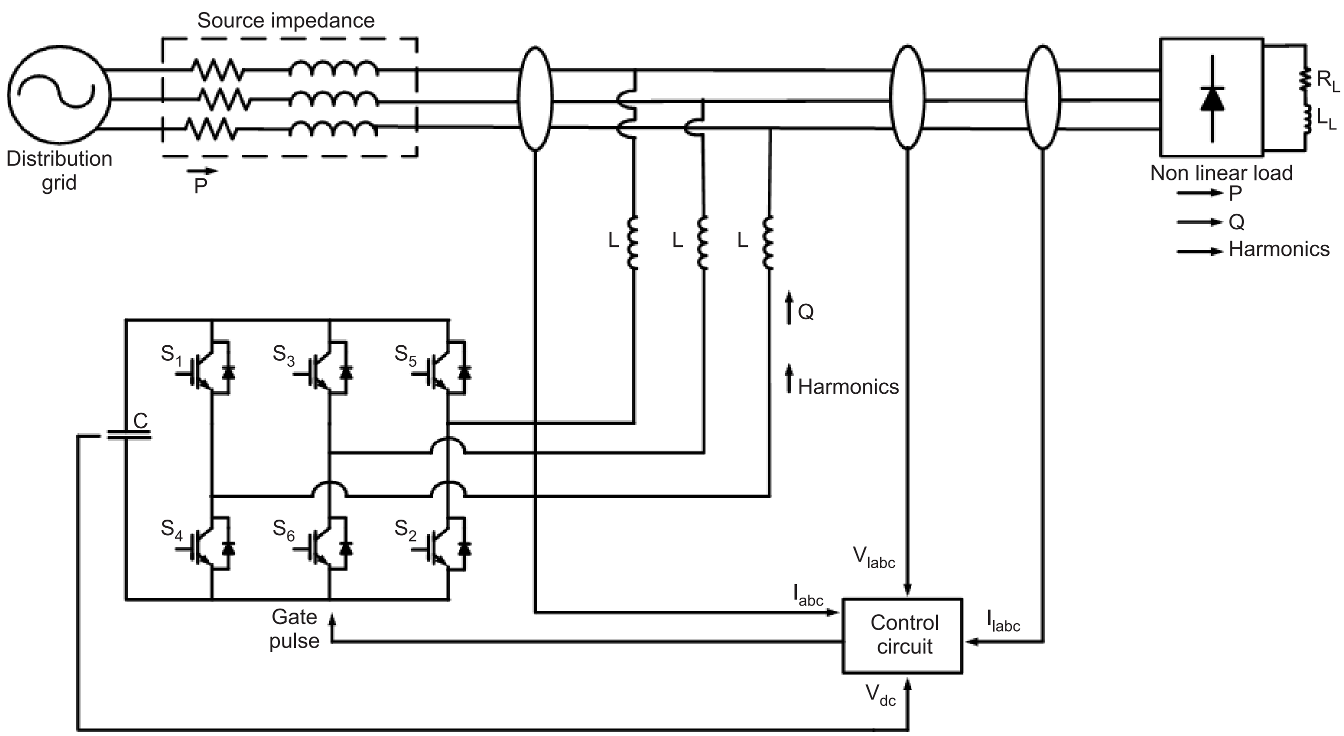

Figure 3: Block diagram of DSTATCOM with simplified control algorithm

(B) Block Diagram of DSTATCOM with Simplified Control Algorithm

The DSTATCOM is shunted with distribution system used to compensate harmonics and reactive power when non linear loads are connected with system. From Figure 3 it will shows clearly the DSTATCOM is integrated with system, for proper current reference signal a new control strategy is proposed is fundamental current reference $I_d - I_q$ theory. This control circuit taking an current signal before PCC, after PCC in distribution and V_{dc} reference from converter. Here the active and reactive current component ($I_d - I_q$) method is compare the currents form before and after PCC, this signal controls the conduction of IGBT connected in converter based on this compensation current is generated from converter [5-6].

4. COMPLETE BLOCK DIAGRAM FOR DSTATCOM WITH PROPOSED CONTROL STRATEGY

Figure 4 shows that complete block diagram of DSTATCOM with proposed control strategy connected with non linear load. DSTATCOM is to suppress voltage variation and control reactive power in phase with system voltage. DSTATCOM is connected to the power networks at a point of common coupling

(PCC) and measurement of all required voltages and currents are fed into the controller to be compared. The feedback of the outputs were conditioned, if required, by the controller and turn ON the switches in converter.

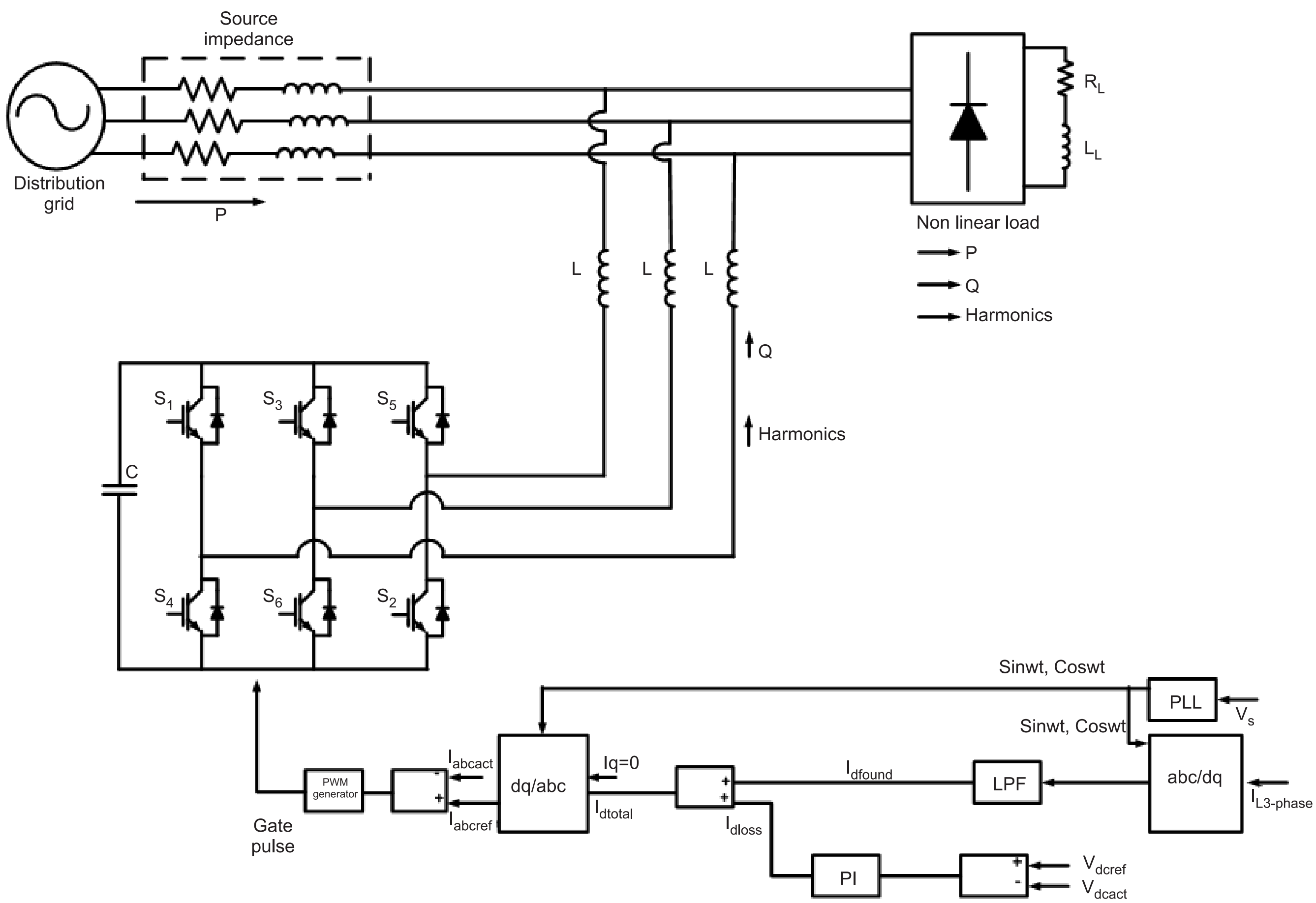

Figure 4: Complete block diagram of D-STATCOM with proposed control strategy

5. MATLAB/SIMULINK RESULTS AND DISCUSSIONS

Simulation models were built for the system without DSTATCOM and with DSTATCOM. Results for the source voltage, load current containing non-linearity, source currents with disturbances, power factor and DC link voltage of VSI converter are shown for all cases. Table 1 shows the system parameters used to develop the models. As case 1, system without DSTATCOM was shown and as case 2, system with DSTATCOM having fixed non linear load was shown. Models were developed using Matlab/Simulink.

Table 1
Simulation Parameters

Parameter	*Value*
Source Voltage (Ph-Ph RMS)	11 KV
Source Impedance	$0.1 + j0.282\ \Omega$
Load Impedance	$200 + j37.6\ \Omega$
DC Link Capacitance	1500 μF
Proportional Gain	0.8
Integral Gain	0.5

Case 1: Results for without DSTATCOM in Distribution system

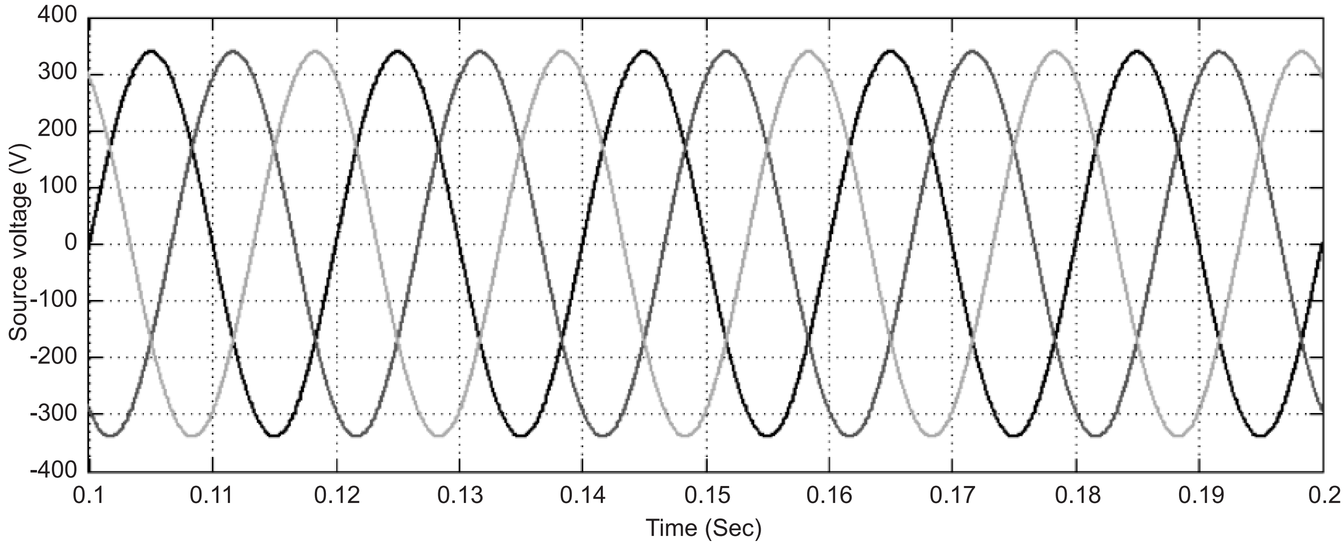

Figure 5: Source voltage without DSTATCOM

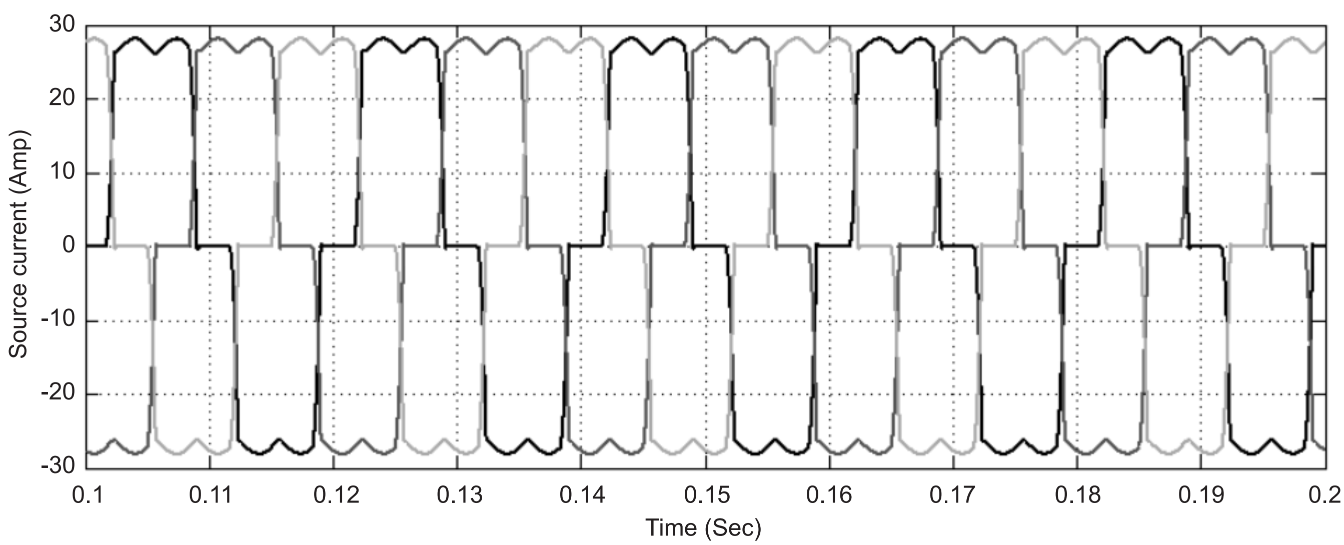

Figure 6: Source current without DSTATCOM

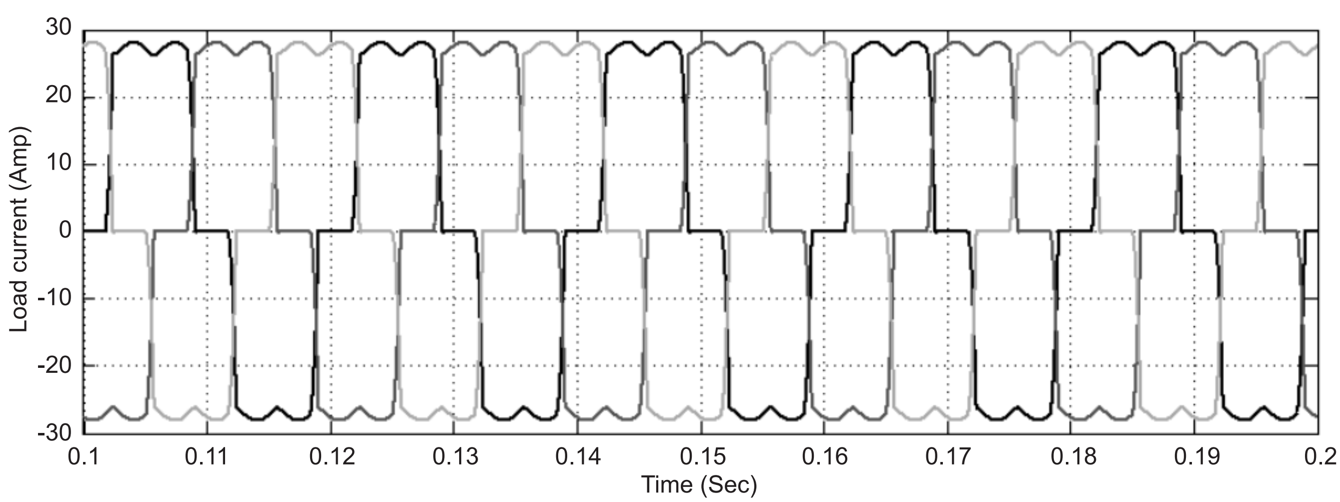

Figure 7: Load current without DSTATCOM

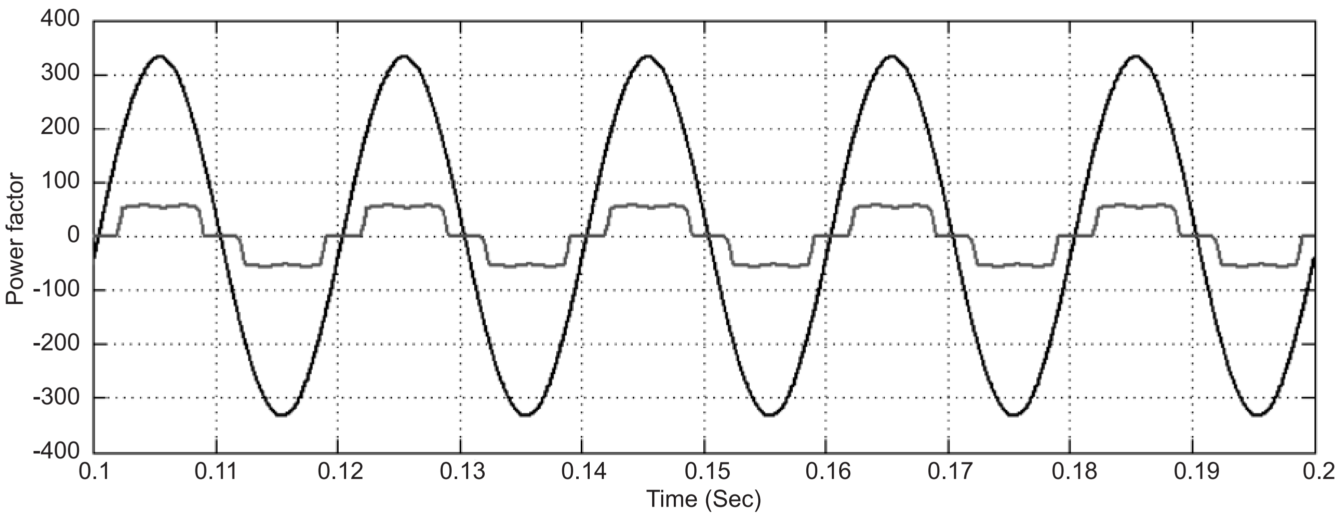

Figure 8: Power factor without DSTATCOM

Figure 5 shows the simulation result of three phase source voltage wave form at non linear load connected in Distribution system without DSTATCOM. The peak amplitude of source voltage is 320V. Figure 6 shows the source current waveforms at non linear load connected in Distribution system without DSTATCOM. Due to non linear load nature the current contains harmonics as showed and has peak current of 28A. as shown, both source current and load current contains harmonics as no compensation was placed. Figure 7 shows the simulation results of three phase load current wave form at non linear load connected in distribution system with magnitude of 28amps. Figure 8 shows the simulation results of power factor without using D-STATCOM.

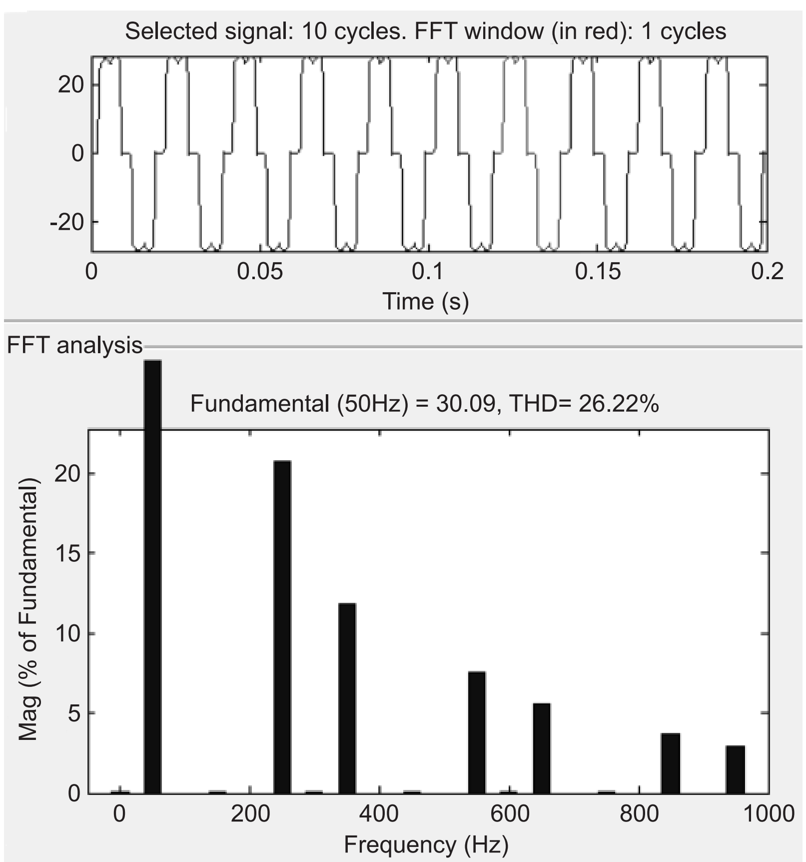

Figure 9: THD analysis of current through load

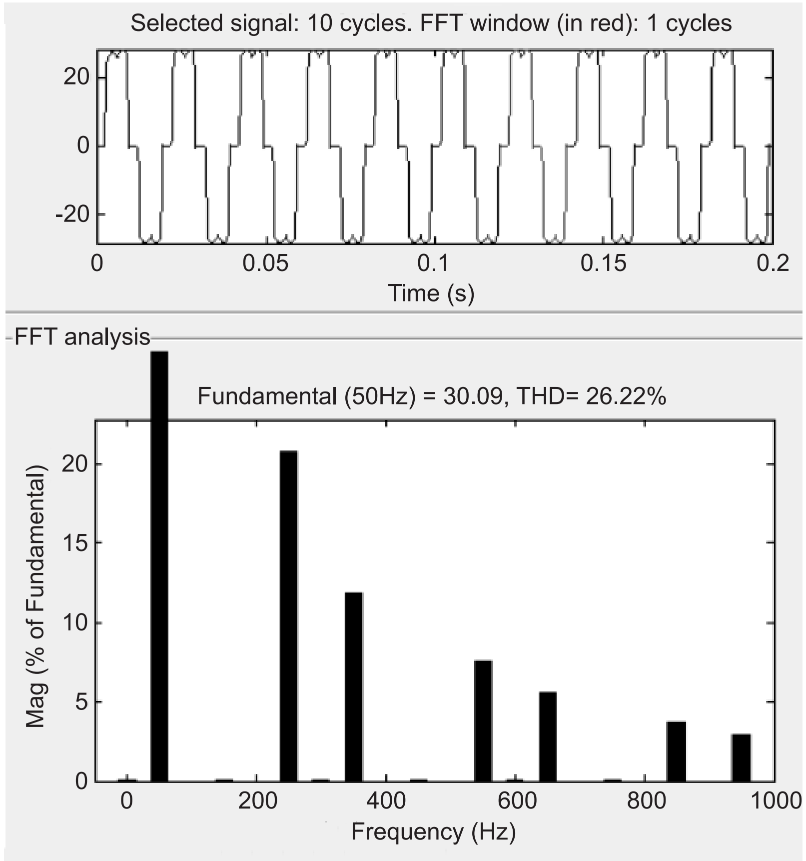

Figure 10: THD analysis of Source current

Figure 9 depicts the THD in load current. The THD in source current without DSTATCOM is 26.22% and Figure 10 shows the THD plot for source current. The % THD value of source current without DSTATCOM is 26.22%. This thd value indicates presence of harmonics in source current and load current.

Case 2: System with DSTATCOM

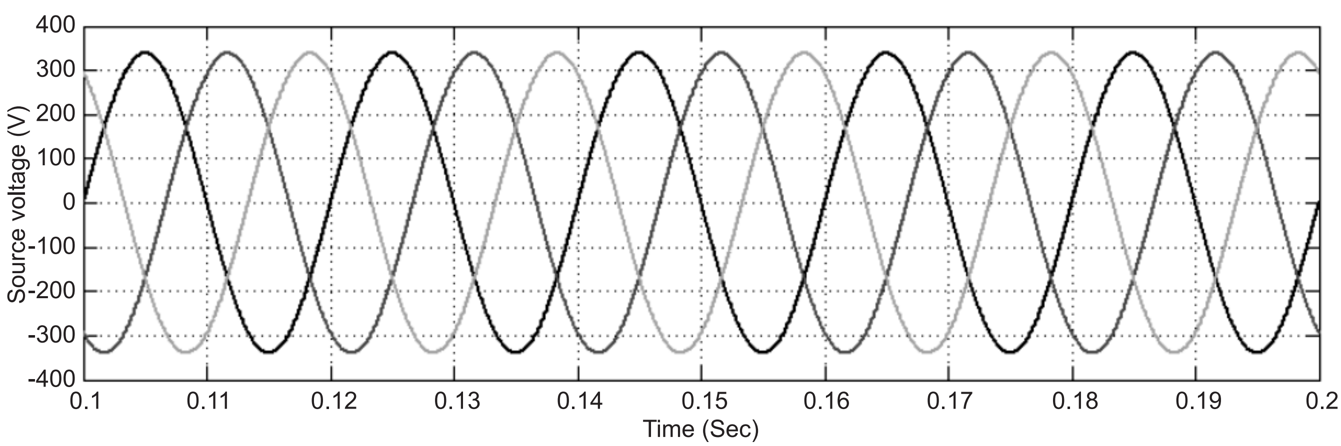

Figure 11: Source voltage with DSTATCOM

Figure 11 shows the simulation result of three phase source voltage wave form with non linear load connected in distribution system with DSTATCOM. The peak amplitude of source voltage is 320 V. Figure 12 shows the source current waveforms with non linear load connected in distribution system with

DSTATCOM. Due to non linear load nature the source current contains distortions without DSTACOM but here the source current is sinusoidal because the DSTACOM compensates the harmonoics and reactive component. It has peak current of 30A

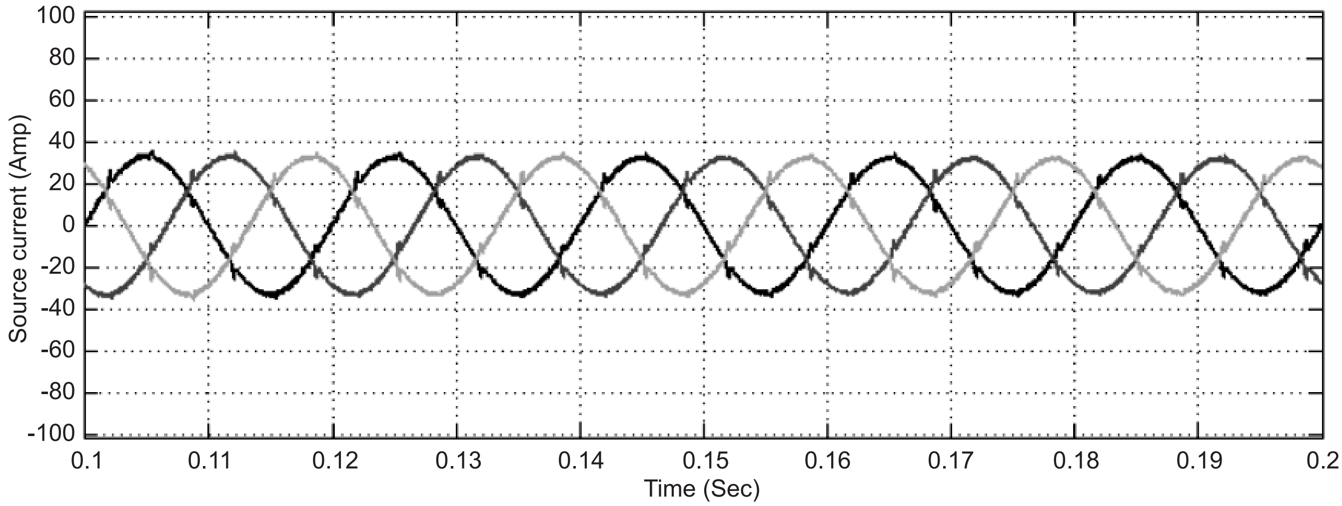

Figure 12: Source current with DSTATCOM

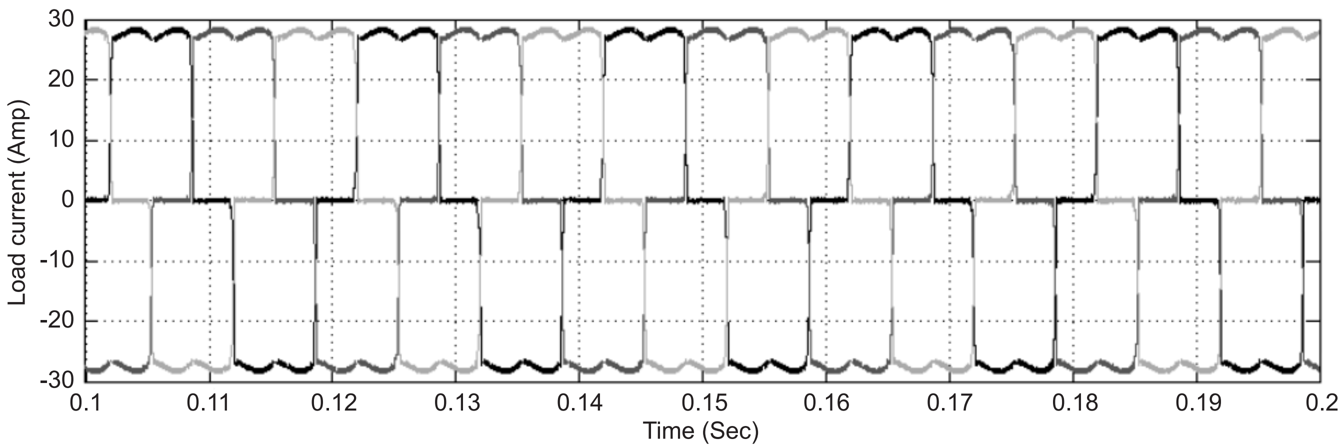

Figure 13: Load current with DSTATCOM

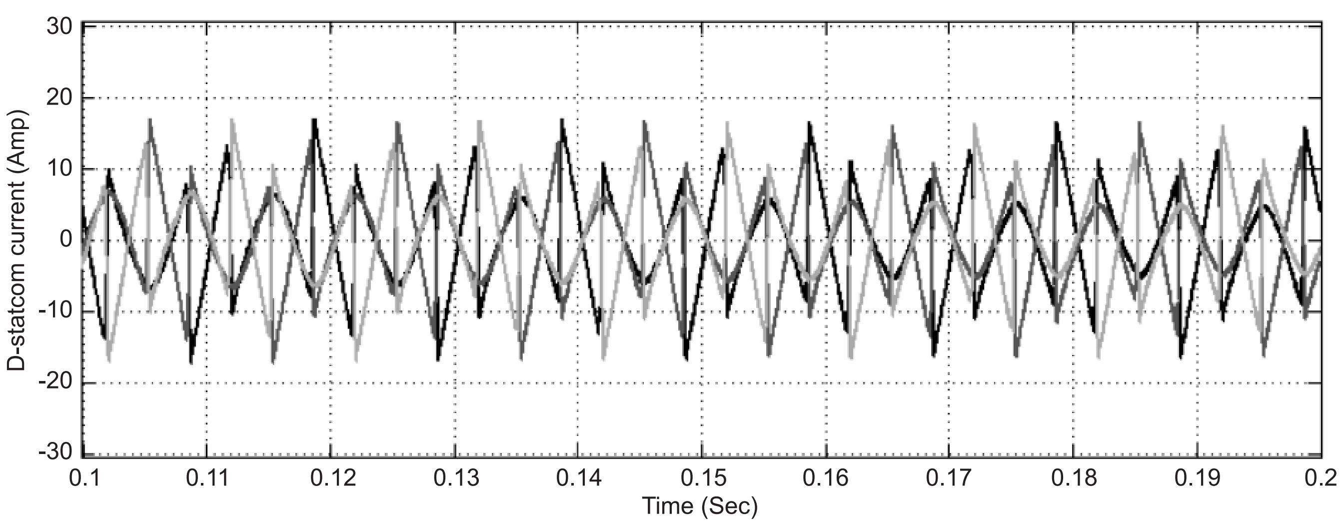

Figure 14: Compensating current

Figure 13 shows the simulation results of three phase load current wave form with magnitude of 28amps. Figure 14 shows the compensating DSTATCOM current waveforms injected in to distribution system for harmonic nullification. But load current draws non-linear components as observed from the result.

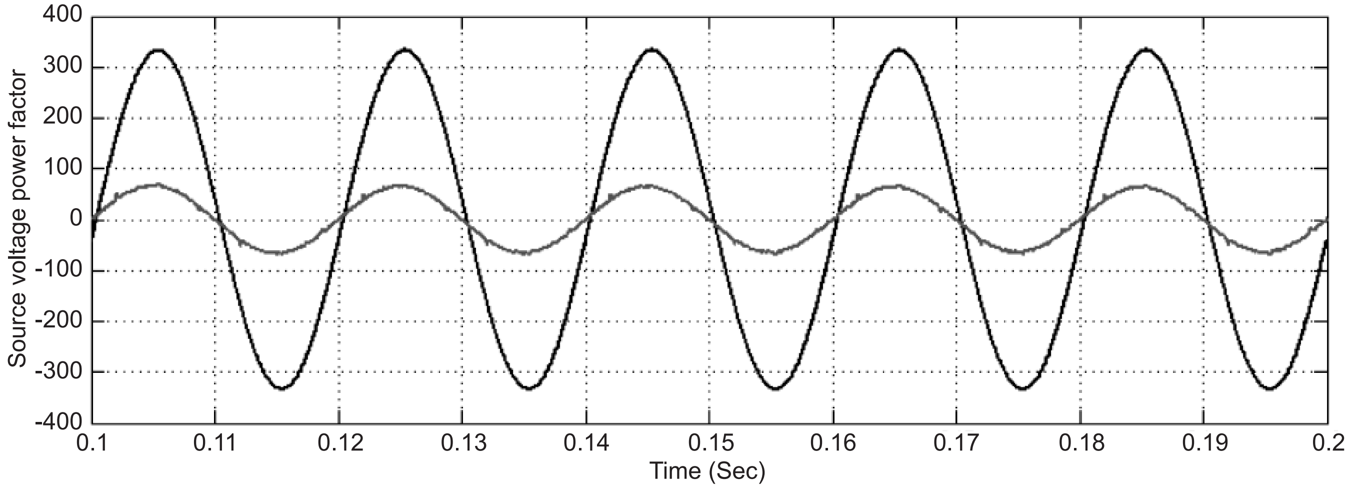

Figure 15: Power factor with DSTATCOM

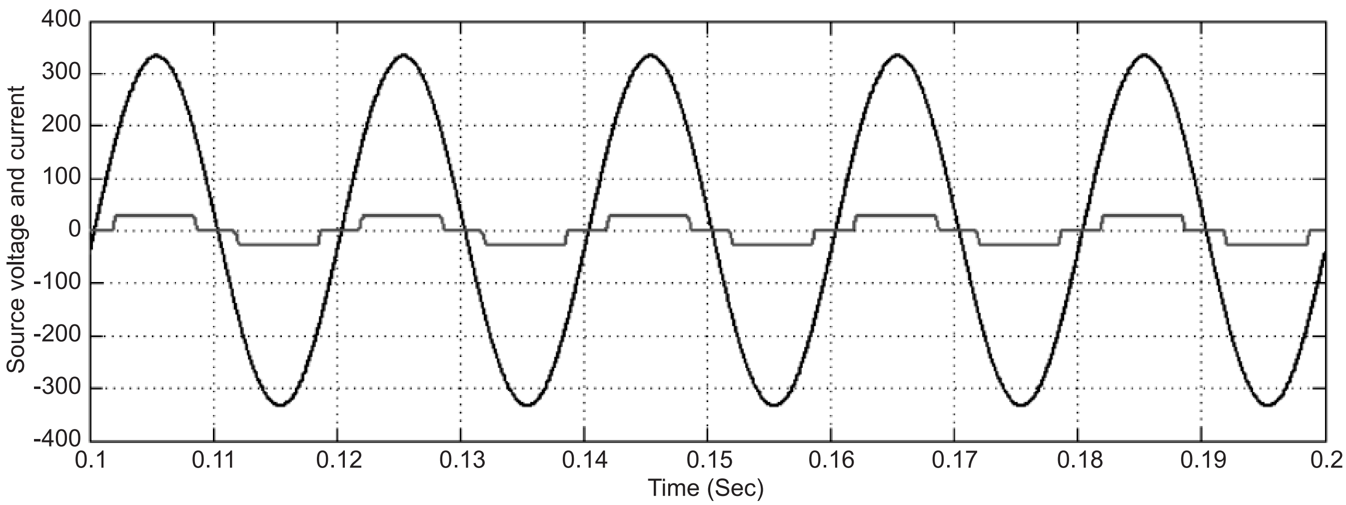

Figure 16: Load voltage and current

Figure 15 shows the simulation results of power factor with DSTATCOM, the power factor was maintained around unity. Figure 16 shows the simulation results of load voltage and current waveform. The magnitude of voltage value is 320 volts, and the magnitude of current value is 20 amps.

Figure 17 shows THD plot for the load current. The %THD value of load current with DSTATCOM is 28.54%. Figure 18 shows harmonic distortion FFT analysis in current through source and is 3.63%. Reduction in THD value can be clearly observed in source current since DSTATCOM is connected to compensate harmonics. THD comparison was listed in table 2.

Table 2
Thd Comparision

PARAMETERS	*THD of Source current without DSTATCOM*	*THD of Source current with DSTATCOM*
Nonlinear load	26.22%	3.63%

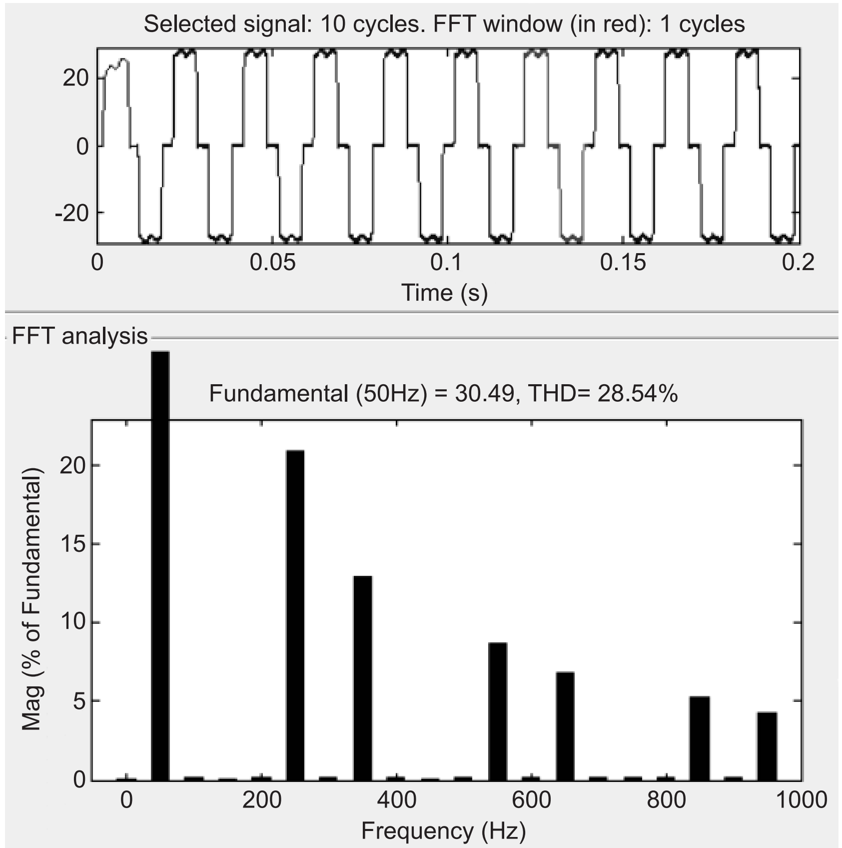

Figure 17: THD in current through load

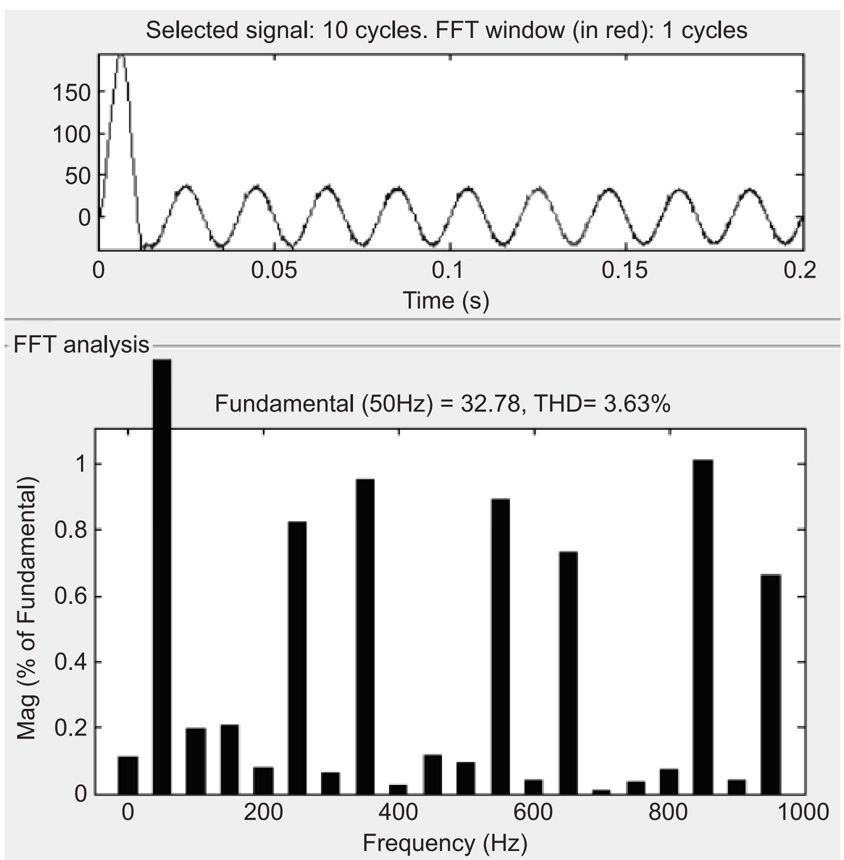

Figure 18: Harmonic Distortion of current in source

6. CONCLUSION

This paper depicts a novel control strategy over conventional method of $I_d - I_q$ theory based compensation of harmonics and reactive power compensation in power system. In conventional method of $I_d - I_q$ theory of controlling inverters, reference currents were obtained from harmonic current which increases losses as harmonic current will have high frequency. But here fundamental current was sent as reference signal reducing losses. Proposed $I_d - I_q$ theory for DSTATCOM proves satisfactory when performed on power system as shown in results. DSTATCOM effectively reduces harmonic contents in source current which can be observed with only 3.63% of THD when compared to 26.22% THD in source current without DSTATCOM. Since the switching of inverter power components are carried out with fundamental frequency, switching losses are reduced thus improving the system efficiency.

References

1. G. Hingoranai Narain and GYugyi Laszlo "Understanding Facts A JOHN WILEY & SONS" in 2000 Inc. publication.
2. R. C. Dugan M. F. McGranaghan and H.W. Beaty "Electrical power system quality" in Vol. 1, 1996 McGraw-Hill c1996.
3. K. Padiyar FACTS Controllers in Power Transmission and Distribution 2007 New Age International
4. Kundur Prabha "Power system Stability and Control" in 1994 McGraw-Hill.
5. S. P. Gopal and D. R. Patil, "Hysteresis Band Current Controller for voltage regulation and harmonic mitigation using DSTATCOM," *2016 International Conference on Computation of Power, Energy Information and Commuincation (ICCPEIC)*, Chennai, 2016, pp. 707-712
6. S. Arya; B. Singh; R. Niwas; A. Chandra; K. Al Haddad, "Power Quality Enhancement Using DSTATCOM in Distributed Power Generation System," in *IEEE Transactions on Industry Applications*, Vol. PP, No. 99, pp.1-1.
7. S. S. Pawar, A. P. Deshpande and M. Murali, "Modelling and simulation of DSTATCOM for power quality improvement in distribution system using MATLAB SIMULINK tool," *2015 International Conference on Energy Systems and Applications*, Pune, 2015, pp. 224-227.
8. F. Shahnia, "Application and control of a DSTATCOM to couple neighboring low voltage feeders," *2016 IEEE International Conference on Industrial Technology (ICIT)*, Taipei, 2016, pp. 476-481.
9. K. Kant, S. R. Arya and B. Singh, "Current sensorless control algorithm of DSTATCOM for power quality improvement," *2015 Annual IEEE India Conference (INDICON)*, New Delhi, 2015, pp. 1-5.
10. M. Angulo D. A. Ruiz-Caballero J. Lago M. L. Heldwein and S. A. Mussa "Active power filter control strategy with implicit closed-loop current control and resonant controller" IEEE Transactions on Industrial Electronics, Vol. 60, No. 7, pp. 2721-2730 July 2013.
11. P. Lohia M. K. Mishra K. Karthikeyan and K. Vasudevan "A minimally switched control algorithm for three-phase four-leg VSI topology to compensate unbalanced and nonlinear load", *IEEE Trans. on Power Electronics*, Vol. 23, No. 4, pp. 1935-1944 July 2008.
12. A. Ghosh and G. Ledwich "Load compensating DSTATCOM in weak AC systems" *IEEE Transactions on Power Delivery*, Vol. 18, No. 4, pp. 1302-1309 Oct. 2003.