International Journal of Engineering &Technology, 7 (4.24) (2018) 9-13

International Journal of Engineering & Technology

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

Research paper

Power Quality Improvement in Distribution System Using Parallel DSTATCOM

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Abstract

DSTATCOM is one among FACTS controllers to reduce harmonic effect in power system. Presence of non-linear loads induces harmonics to source components which in-turn affects other sensitive loads. Parallel custom devices share the compensating currents and as a result stress on individual custom device reduces. This paper presents power quality improvement using parallel DSTATCOM in power distribution system. The parallel DSTATCOM are controlled with a common single control scheme using synchronous reference frame theory. Proposed concept was implemented with MATLAB/SIMULINK software and results were discussed considering different loading conditions of the proposed system like balanced case non-linear load and unbalanced case non-linear load conditions.

Keywords: power *quality; DSTATCOM; control; harmonics; distribution system, non-linear*

1. Introduction

The ability of grid or electrical network to deliver clean and stable power is power quality. However, qualified clean power generates a power supply which is always available and consisting of very low noise. Clean supply refers to sinusoidal wave shape and is voltage and frequencies within acceptable tolerance. With energy demand ever increasing, loads connected to power network induce disturbances on grid side and make grid parameters deviate from ideal conditions [1-5]. Variation of source side parameters makes reduces equipment performance, energy loss and unwanted breakdowns. Reactive power issues, harmonic issues, network unbalance, transients, voltage variations, flickers, oscillations are some of the power quality problems. Poor power quality [6] makes system to experience stalled production, increased energy consumption, reduction in production pace, malfunctioning of equipment, reduced efficiency, reduction in life time of equipment.

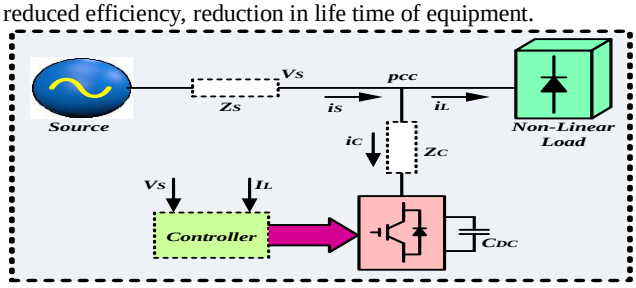

Fig. 1: Block diagram of DSTATCOM in distribution system

Presence of non-linear loads deteriorated system quality. Non-linear loads induce harmonic in to source parameters. Custom power devices [7-10] are viable solution for improving power quality in distribution system. STATCOM in distribution system (DSTATCOM) reduces the riskof harmonics in source components inducing negative harmonic currents to PCC. Block representation of DSTATCOM in distribution system is illustrated in figure 1.

The paper presents power quality improvement using parallel DSTATCOM in power distribution system. The parallel DSTATCOM are controlled with a common single control scheme using synchronous reference frame theory. Proposed concept was implemented with MATLAB/SIMULINK software and results were discussed considering different loading conditions of the proposed system like for balanced non-linear and unbalanced non-linear load conditions.

2. Parallel DSTATCOM Configuration

System with non-linear loads can deteriorate power system. The system consists of source with source inductance delivering power to non-linear industrial load represented with a connection of non-linear components. If single DSTATCOM (as conventional method) is connected to system, the total compensating currents are to be sent to point of common coupling for compensation of harmonics from the same one DSTATCOM which eventually raises the ratings of devices or components connected in VSI (voltage source inverter) of DSTATCOM. Two parallel DSTATCOM's connected together with common interfacing inductors for harmonics mitigation can eventually reduce the rating of the device which causes switching losses to be reduced.

The two parallel DSTATCOM's share the total DC-link voltage. This reduces the stress across switches of individual DSTATCOM. Less rating leads to less switching losses. Parallel DSTATCOM share the compensating currents.Proposed parallel DSTATCOM configuration is illustrated in figure 2.

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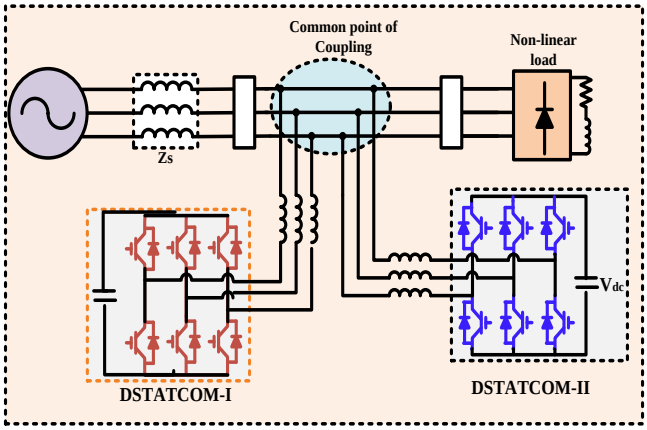

Fig 2: Proposed parallel DSTATCOM configuration

3. Control of Parallel DSTATCOM

Two parallel DTSTAOCOM's are controlled from a single control algorithm. In this paper, two parallel DSTATCOM's are controlled from synchronous reference frame theory.
The final reference current is compared to actual current for deriving the optimal switching states with the help of hysteresis current controller.

3.1 SRF theory for DSTATCOM

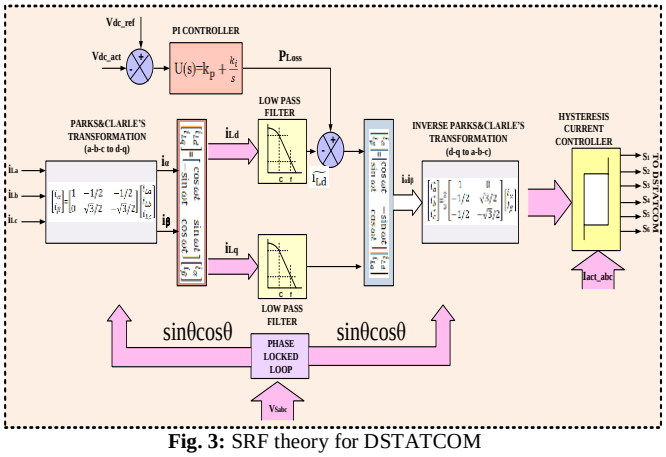

Fig. 3: SRF theory for DSTATCOM

The direct (d-axis) and quadrature (q-axis) components are positioned based on angle (θ) with respect to the utilizing the α-β axis in SRF theory. Current signals are transformed to direct (d-axis) and quadrature (q-axis) components using necessary equations and are passed through low pass filters. The LPF (Low-Pass Filter) is used to distinct the harmonic sequences, from the d-q on the half of the fundamental frequency. Acquired harmonic current components are re-transformed into actual three-phase (a-b-c) quantities by employing Inverse-Park's and Inverse Clarke's transformation process. The DC-link controller comprised of PI regulator, which regulates the DC voltage for maintain loss-less voltage at shunt-VSI. Actual Dc voltage is compared to reference DC voltage and error is fed to PI controller for suppression of error in P_{Lerr}. The suppressed signal is compared to direct component of current and sent to inverse transformation for reference current signals.
The hysteresis current controller is engaged to implement the supervision of shunt-VSI of DSTATCOM. Hysteresis loop or band (HL) is acts as the boundary limit of compensation current. Hysteresis current controller takes inputs actual and obtained reference signals to generate gate pulses to VSI of DSTATCOM. Figure 3 illustrates SRF control algorithm for the generation of reference currents and gate pulses to conventional DSTATCOM.

3.2. Parallel DSTATCOM with SRF Control in Power System

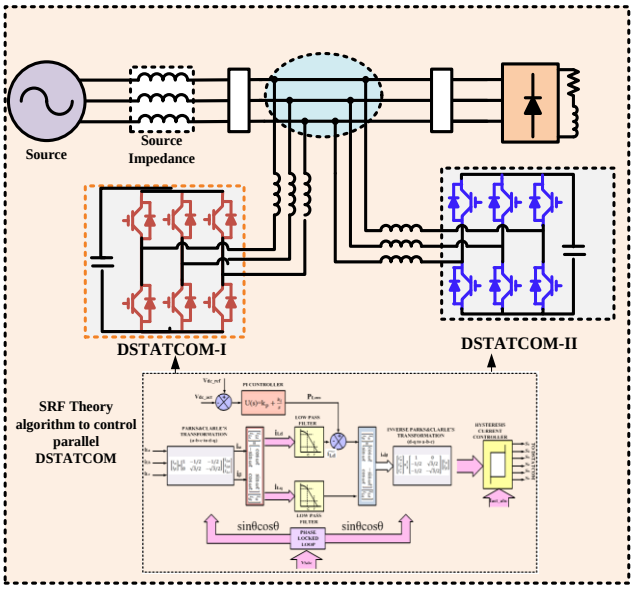

Fig. 4: Parallel DSTATCOM in power system controlled with SRF theory

Figure 4 illustrates Parallel DSTATCOM in power system controlled with SRF theory. SRF theory algorithm generates reference currents which in-turn when compared with actual currents through hysteresis current controller (HCC) generates gate pulses to parallel DSTATCOM.
The complete SRF theory for generation of gate pulses to DSTATCOM is explained in the previous section. Single control algorithm drives two VSI's of parallel DSTATCOM topology. The parallel DSTATCOM topology upon controlled with SRF algorithm generates controlled compensating signals to reduce harmonic effect in the power system. Parallel DSTATCOM topology shares the compensating currents and releases the stress across individual DSTATCOM's which in-turn reduces the switching losses and rating. Table 1 illustrates the system parameters used for the simulation study.

4. Simulation Analysis

Table 1: System Parameters

Parameter	Value
Source Voltage	415 V RMS
Source Impedance	R=0.1 Ohms, L=0.9mH
Filter Impedance	R=0.1 Ohms, L=5mH
Load Impedance	R=30 Ohms, L=30mH
DC-Link Capacitance	4000μF

4.1. Simulation results of balanced non-linear load power system with parallel DSTATCOM

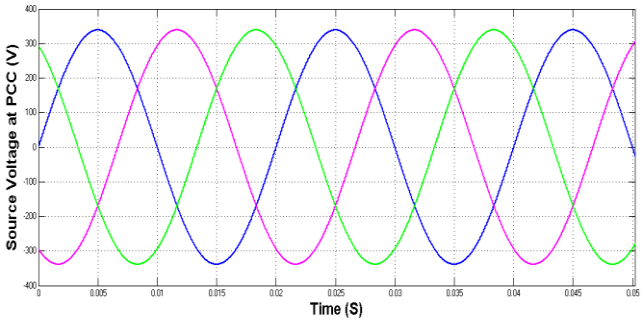

Fig.5: Terminal voltage at PCC

Figure 5 illustrates the three-phase terminal voltage at PCC of DSTATCOM connected to distribution system. Source voltage is undistorted and peak voltage is maintained constant.

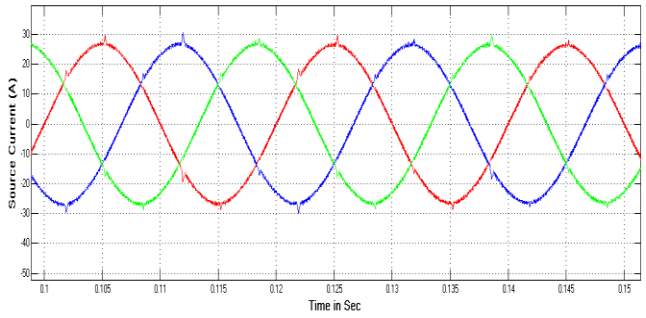

Fig.6: Source current at PCC

Figure 6 illustrates the three-phase source voltage of distribution system connected with parallel DSTATCOM. Currents in three phases are harmonic free (within nominal limit) with constant peak.

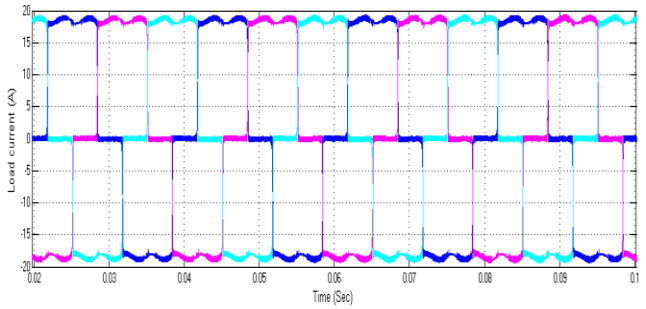

Fig.7: Load currents

Figure 7 depicts three-phase load currents to non-linear type of load connected to distribution system. Load is of non-linear nature and hence currents drawn by load section are non-linear in nature

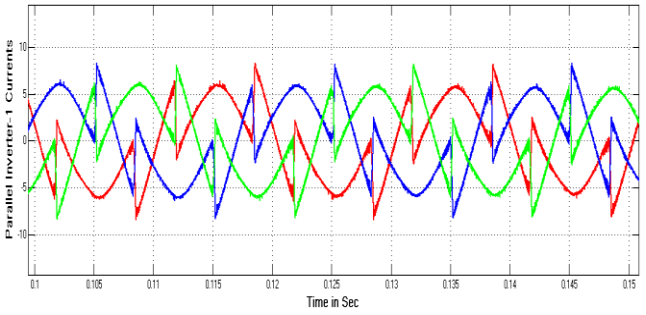

Fig.8: Compensating currents from DSTATCOM-I

Figure 8 shows the compensating filter currents fed to distribution system from DSTATCOM-I to compensate harmonics produced from non-linear load. Compensating currents compensate harmonics making source current distortion within nominal limits.

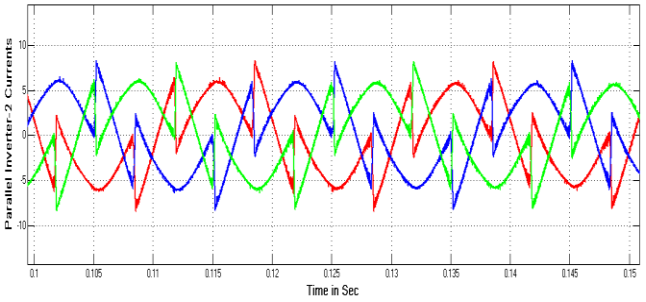

Fig.9: Compensating currents from DSTATCOM-II

Figure 9 shows the compensating filter from DSTATCOM-II to compensate harmonics produced from non-linear load.

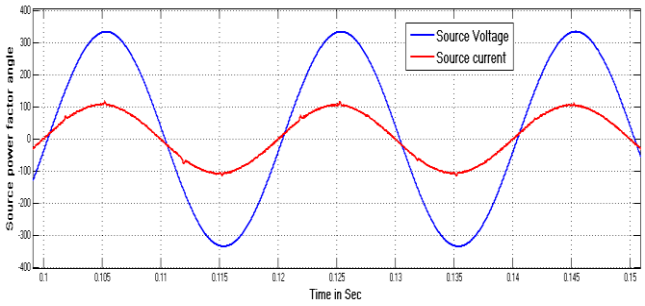

Fig.10: Power factor angle between current and voltage

The power factor cosine angle difference between current and voltage is shown in figure 10. Angle difference is almost very less and PF tends to unity.

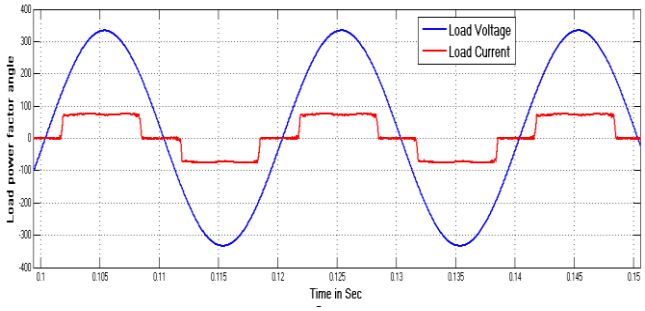

Fig. 11: Power factor angle of current and voltage

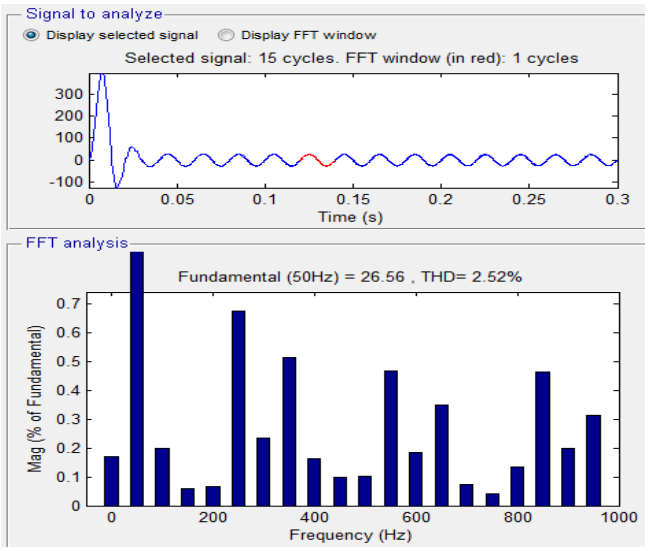

Fig. 12: Distortion FFT analysis of source current

Harmonic distortion FFT analysis for source current is shown in figure 12. Distortion of 2.52% is present in source current and maintained within specified limit. Parallel DSTATCOM (controlled with SRF theory) limits the source current distortion to be within limits.

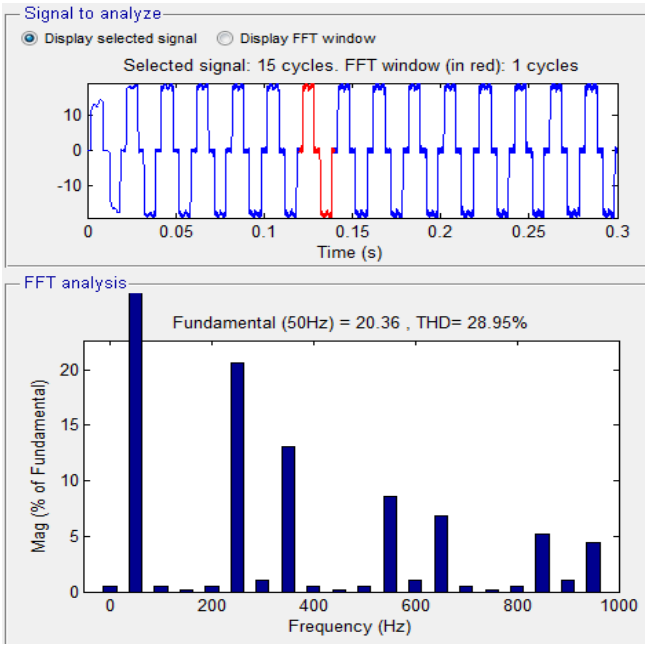

Figure 13: Distortion FFT analysis of load current

Harmonic distortion FFT analysis for load current is shown in figure 13. Distortion of 28.95% is present in load current.

4.2. Simulation results of unbalanced non-linear load power system with parallel DSTATCOM

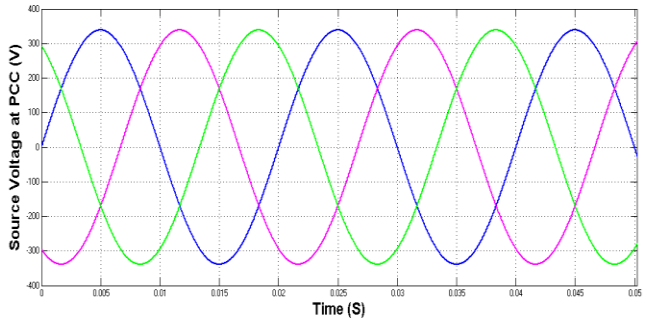

Fig. 14: Terminal voltage at PCC

Figure 14 illustrates the three-phase terminal voltage at PCC of DSTATCOM connected to distribution system. Source voltage is undistorted and peak voltage is maintained constant with unbalanced load.

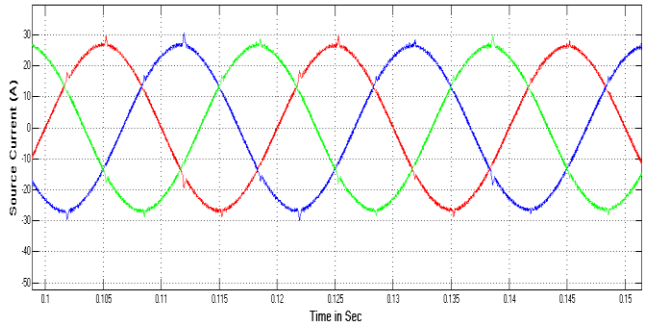

Fig. 15: Source current at PCC

Figure 15 illustrates the three-phase source voltage of distribution system connected with parallel DSTATCOM. Currents in three phases are harmonic free (within nominal limit) with constant peak.

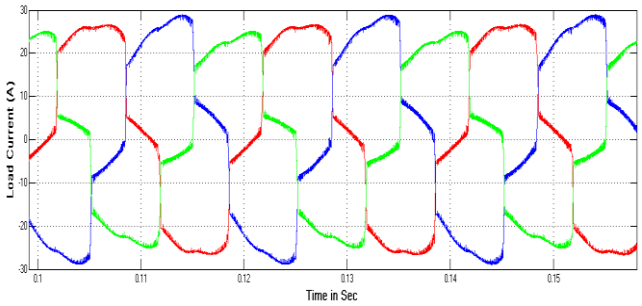

Fig. 16: Load currents

Figure 16 depicts three-phase load currents to unbalanced non-linear type of load connected to distribution system. Load is of unbalanced non-linear nature and hence currents drawn by load section are non-linear in nature and unbalanced.

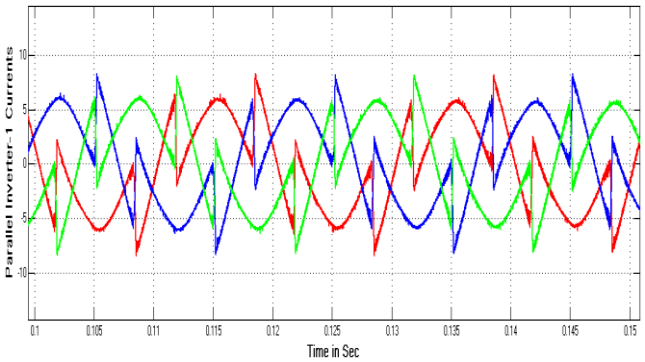

Fig. 17: Compensating currents from DSTATCOM-I

Figure 17 shows the compensating filter currents fed to distribution system from DSTATCOM-I to compensate harmonics produced from unbalanced non-linear load. Compensating currents compensate harmonics making source current distortion within nominal limits.

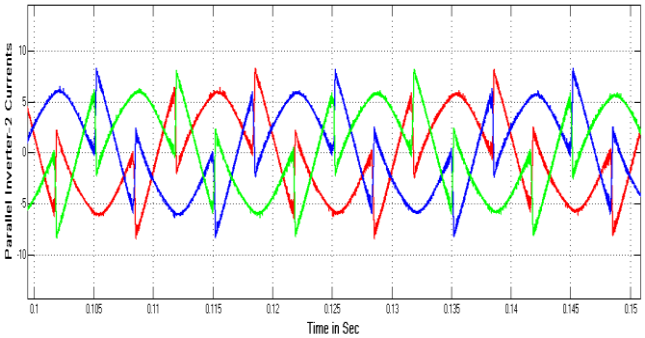

Fig. 18: Compensating currents from DSTATCOM-II

Figure 18 shows the compensating filter currents from DSTATCOM-II. Compensating signals compensate for harmonics in source currents.

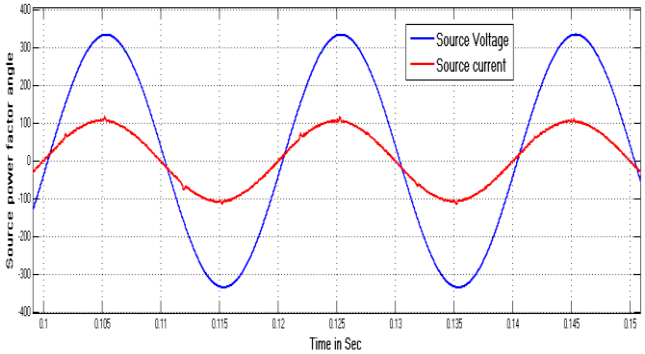

Fig. 19: Power factor of source current and voltage

Power factor in source is shown in figure 19 by illustration of angle difference of source current and voltage. Angle difference tends to almost zero and power factor tends to unity in source.

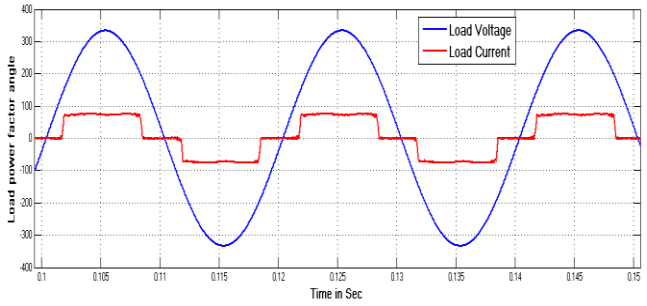

Fig. 20: Power factor of load current and voltage

Load power factor is shown in figure 20. Load current is far in phase with voltage and Angle difference tends to almost non-zero value and load power factor tends to non-unity.

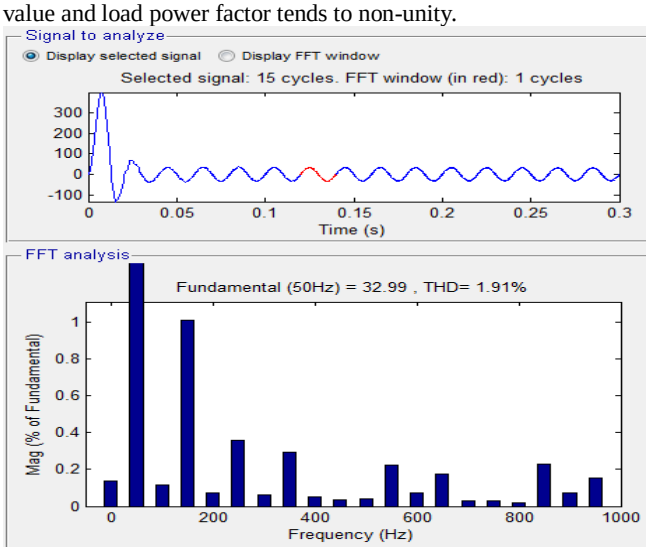

Fig. 21: Distortion FFT analysis of source current

Harmonic distortion FFT analysis for source current is shown in figure 21. Distortion of 1.91% is present in source current and maintained within specified limit. Parallel DSTATCOM (controlled with SRF theory) limits the source current distortion to be within limits with unbalanced non-linear load.

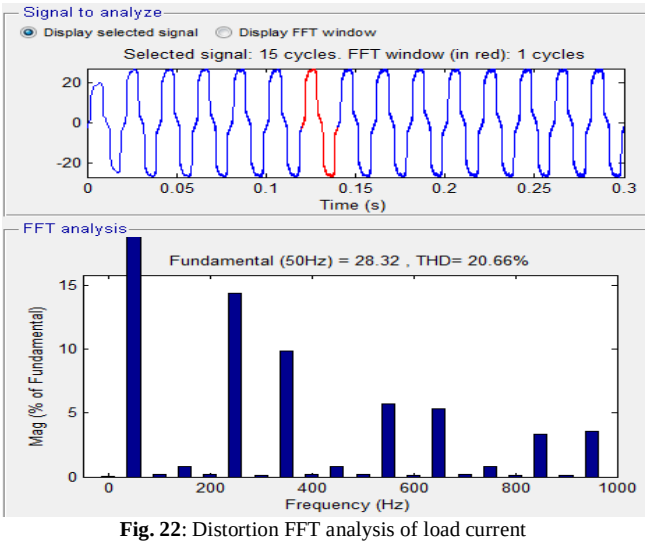

Fig. 22: Distortion FFT analysis of load current

Harmonic distortion FFT analysis for load current is shown in figure 22. Distortion of 20.66% is present in load current. As load is of unbalanced non-linear nature, load current distortion is high. Table II illustrates the harmonic distortion analysis with parallel DSTATCOM in power system with different load conditions.

Table 2: Harmonic distortion analysis

THD	Source Current	Load Current
Balanced Non-linear load	2.52%	28.95%
Unbalanced Non-linear load	1.91%	20.66%

Harmonic distortion analysis in table 2 illustrates the effectiveness of parallel DSTATCOM in mitigating harmonics in source currents with different load conditions in power system.

5. Conclusion

The paper presents the parallel DSTATCOM concept for harmonic elimination in industrial type of non-linear loads. DSTATCOM, a type of custom power devices can effectively address the harmonic problem in power system. Parallel DSTATCOM concept share the harmonic current injection for compensation eventually reducing the rating and as a result switching losses in DSTATCOM. The parallel DSTATCOM are controlled with a common single control scheme using SRF theory. Proposed concept was implemented using MATLAB/SIMULINK software and results were discussed considering different loading conditions of the proposed system. Harmonic distortion analysis in table II illustrates the effectiveness of parallel DSTATCOM in mitigating harmonics in source currents with different load conditions in power system.

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