Analysis of Power Quality Improvement Using D-STATCOM

Srikrishna Agnihotri[1], Shobhna Jain[2]
[1]Research Scholar, Department of Electrical & Electronics Engineering, UIT, RGPV, Bhopal
[2]Asst. Prof, Department of Electrical & Electronics Engineering, UIT, RGPV, Bhopal

Abstract: This work deals with the control, performance and applications of STATCOMs equipped with energy storage for power quality improvements. The additional power quality applications, made possible by the energy storage, include a more complete mitigation of voltage dips. Furthermore, the energy storage also enables a STATCOM to support an entry into islanding operation, by rapid balancing of loads, after tripping of a single feeder. A complete design procedure of the conditioner control algorithm is presented. Proposed control scheme focuses on current harmonic compensation, balancing the unbalance load, fulfilling the reactive power demand of the load and improving the supply side power factor. It is shown that STATCOMs equipped with energy storages, due to the ability of controlling both active and reactive power, can keep the system performance practically unaffected during the same conditions. The designed control algorithm is tested in simulation and experimental conditions. It is proved, that the conditioner with energy storage and the proposed control structure is an effective tool for power quality improvement.

Keywords: Power Electronics, Voltage Source Converter (VSC), Distribution Static Synchronous Compensator (DSTATCOM), Energy Storage, Power Quality, Dynamic Loads

1. INTRODUCTION

Electrical energy is the smooth and regulated form of energy, which can changed undoubtedly in different structures. It has quality and consistency with great economy to keep it up. Today the term power quality for industries and customers has great concerned. Power quality issues raised because of electronic gadgets and non-linear loads. Electrical power affected from the numerous issues like voltage sag, voltage swelling, unbalance in voltage and current, power factor reduction, voltage interruption and harmonic distortion. This degrades proficiency limits and the consumer equipment lifetime reduces. This may create loss of the data and useful information.

Power electronics equipment creates serious effect on power supply quality and continuity. Due to Power electronics devices there are uninterrupted power supply, flicker, harmonics, voltage fluctuations, etc. System issues, switching transients, capacitor banks switching due to which there is voltage rise / dip such are additional power quality issues. Non-linear loads like computers, Laser, Printer, rectifiers use excessive electricity within the distribution system and create reactive power disturbances and harmonics injection. It is very much important to sort this type of problem because of it has adverse effect in the future and can create many problems.

Semiconductor devices nowadays with equipment as sensitive appears and always in the form of pollution [1]. Non-linear equipment, such as power electronics converters, increase the overall load demand by demanding more reactive power, and harmonic currents injected in the Distribution grid. It is well known that the reactive power demand declines Feeder voltage and increase the losses. Harmonic currents may cause additional losses and also the reason of voltage waveform distortion, and hence poor power quality problems. In addition, the number of sensitive devices which required balanced sinusoidal supply voltage is increased. Power sensitive electronic equipment increases the use of variety power conditioning technologies. So, to keep Standards proposed by the limitations within the power quality, some type is necessary to compensate the damage caused by the power quality problems.

For the moderation of power quality issues Distributed Static Compensator (DSTATCOM) is a standout amongst the most capable gadget in used to alleviate power quality issues. This part gives a brief and arranged writing audit about the exploration work done in the field of Power Quality Conditioners (PQC). This audit additionally incorporates different kinds of power quality issues emerge in the power framework and the dynamic power channels used to alleviate these issues.

In the present scenario, power quality has become one of the major factors both for electric suppliers and consumers. Deterioration of power quality results in heavy loss in power distribution system and also leads to the failure of electrical systems. Therefore to mitigate power quality problems power quality conditioners came into picture.

N.G. Hingorani [2] explains the concept of custom power device and power quality due to advancement of power electronics application in the industry. A. Ghosh and G. Ledwich [4] explain the enhancement of power quality using custom power devices.

These devices considers the structure, control and performance of series compensating DVR, the shunt DSTATCOM and the shunt with series UPQC for power quality improvement in electricity distribution system. A. Moreno-Munoz [5] writes a book about the improvement in power quality by the mitigation technologies in the distributed environment.

The reliability of the system is highly affected by the quality of power discussed by Duganet al. [6] and Schlabbachet al. [7]. These power quality problems with their causes and effects are discussed below:

Conventionally, passive filters are employed. But there are limitations with passive filters that it can be used to compensate the reactive power demand of load and designed to eliminate a particular harmonic. Apart from it is bulky, create resonance problems and affect the performance of the system. S. Khalidet al. [8] presents the harmonic distortion and low power factor using Shunt Active Power Filter (SAPF). The model is based on the Voltage Source Converter (VSC) principle. The SAPF injects a current into the system to mitigate the harmonic distortion and improve power factor.

2. CONTROL ALGORITHM FOR DSTATCOM

For harmonic elimination, balancing the unbalanced load current, reactive power compensation of the load and maintaining the unity power factor at the input side a control algorithm employed for controlling the DSTATCOM. The control algorithm for DSTATCOM is based on power balance theory (PBT). The main advantage of PBT is the fast detection of distortion with high accuracy and quick response extraction of reference source currents [27]. Fig 4.1 shows the MATLAB model of DSTATCOM.

The DSTATCOM have the advantage that it does not consume any amount of active power for harmonic cancellation. Harmonics can be cancelled out by consuming only reactive power. The control approach proposed for DSTATCOM should ensure three things which are given below

i. The reference current generated for DSTATCOM should be accurate.

ii. The DC link voltage should be maintained constant.

iii. Proper gate signals should be generated for DSTATCOM.

To estimate the reference signals for DSTATCOM different control schemes have already discussed. For generating gate signals different techniques have been developed.

Mostly PWM technique is used for generating the gate signals. Apart from this hysteresis band controller, space vector modulation, periodic sampling control and triangular carrier control are some techniques used for generating gate pulse.

The complete control algorithm of proposed DSTATCOM is discussed below

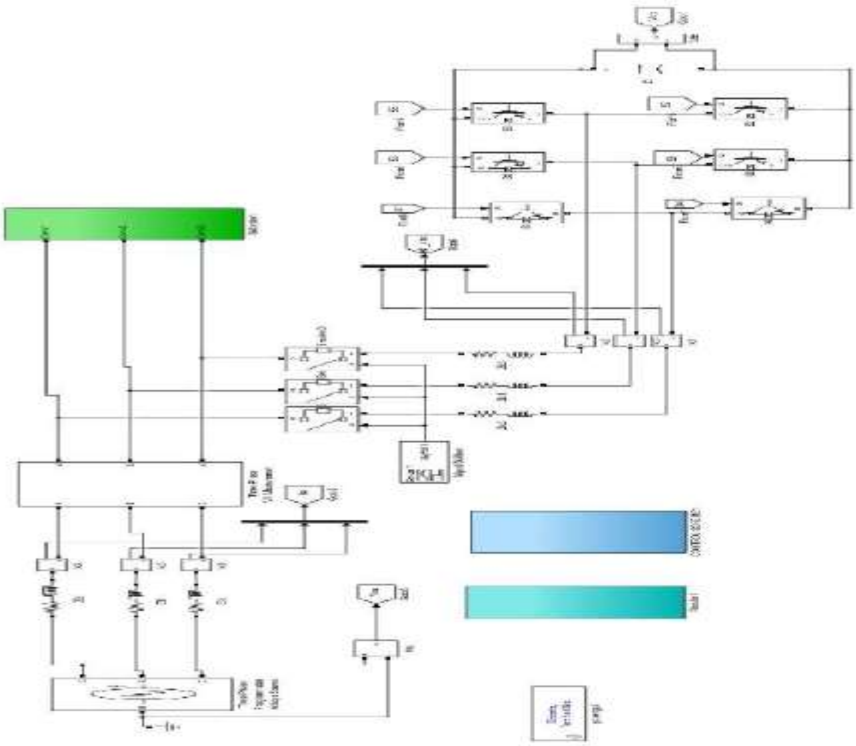

Fig 1: MATLAB Model of DSTATCOM

For computing reference source currents load voltages, source currents, load currents and dc link voltage are used. The control scheme is discussed in subsection. Fig. 2 shows the control scheme of DSTATCOM.
To generate the in phase unit template of load voltage, the amplitude of the PCC voltage and unit templates are estimated as

$$V_t = \sqrt{2(V_{La}^2 + V_{Lb}^2 + V_{Lc}^2)/3}$$

$$\left.\begin{aligned} U_a &= \frac{V_{La}}{V_t} \\ U_b &= \frac{V_{Lb}}{V_t} \\ U_c &= \frac{V_{Lc}}{V_t} \end{aligned}\right\}$$

To estimate the amplitude of load current, the load active powers (P_L) has to be computed. Computation of instantaneous load active power are estimated as

$$P_L = V_{La}\, i_{La} + V_{Lb}\, i_{Lb} + V_{Lc}\, i_{Lc}$$

Load Active Power has two component DC component and AC component

$$P_L = \overline{P_L} + \widetilde{P_L}$$

To compensate the load reactive power i.e. under PFC mode, the DC component of load active power is provided by the source. Therefore the DC component is filtered out by

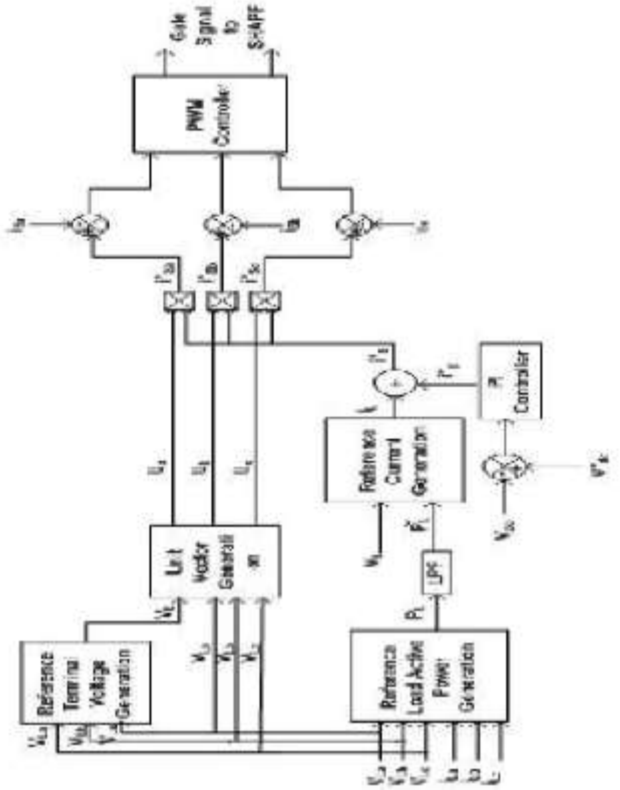

Fig. 2: Block diagram of control scheme for DSTATCOM

using a Lowpass Filter (cut off frequency 25Hz). Amplitude of active component of load current (I_L) is obtained as

$$I_L = \left(\frac{2}{3}\right)\frac{\widetilde{P_L}}{V_t}$$

3. RESULTS AND DISCUSSION

The simulation is performed using MATLAB-SIMULINK and SimPowerSystem Toolbox. The performance of DSTATCOM is observed under Harmonic Compensation and Unbalancing conditions. These parameters used in simulation model are given in Appendix. The model is used to supply non-linear as well as unbalances loads. These nonlinear loads are modelled using a three phase diode bridge rectifier feeding RL load on dc side with values given in Appendix. And Unbalance load is made by using a Star Connected 3 phase load having different load parameters in each phase. The system line voltage is taken as 400 V. An additional distortion in source voltage is created which can be compensated by using an RC ripple filter. Firstly, System results are shown without DSTATCOM and then with DSTATCOM showing the compensation capability of the compensator. The simulation results for DSTATCOM as a harmonic compensator and balancing the unbalance load current with additional distortion in supply voltages is shown in the below section. The input voltage (V_{input}), input currents (I_{input}), load voltage (V_{load}), current (I_{load}), shunt compensator currents (I_{sha} , I_{shb} , I_{shc}), DC bus voltage (V_{dc}), are used to obtained results.

Simulation results of DSTATCOM using power balance theory are shown. Comparative analysis of results for both load current and source current with the help of Total Harmonic Distortion (THD) in load currents and source currents under different conditions are given in Table 1.

3.1 Performance of DSTATCOM as Harmonic Compensator

The performance analysis of DSTATCOM with Power Balance Theory proposed for DSTATCOM is discussed in this section. During 0.5-0.7secs DSTATCOM is disconnected from the system.

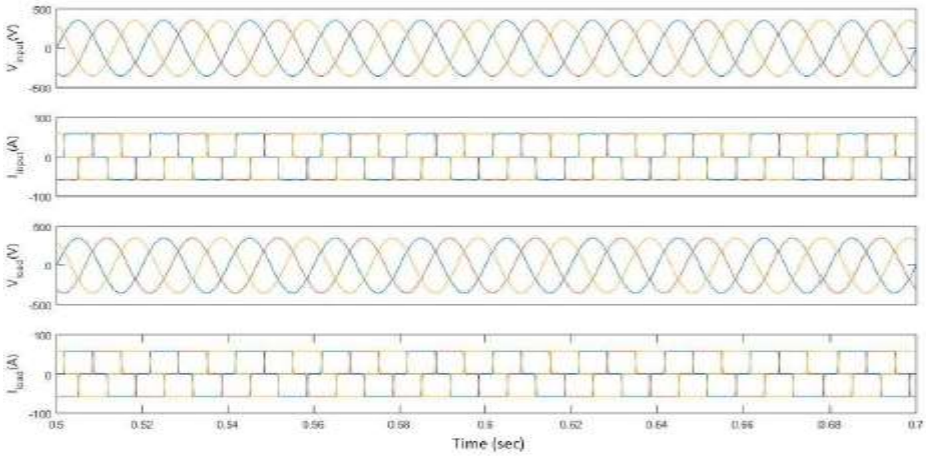

Fig. 3: Performance of System Parameter without DSTATCOM

The result obtained shows input voltage (V_{input}), input currents (I_{input}), load voltage (V_{load}), current (I_{load}). From the results obtained it is clearly shown that without DSTATCOM source current obtained are non-linear.

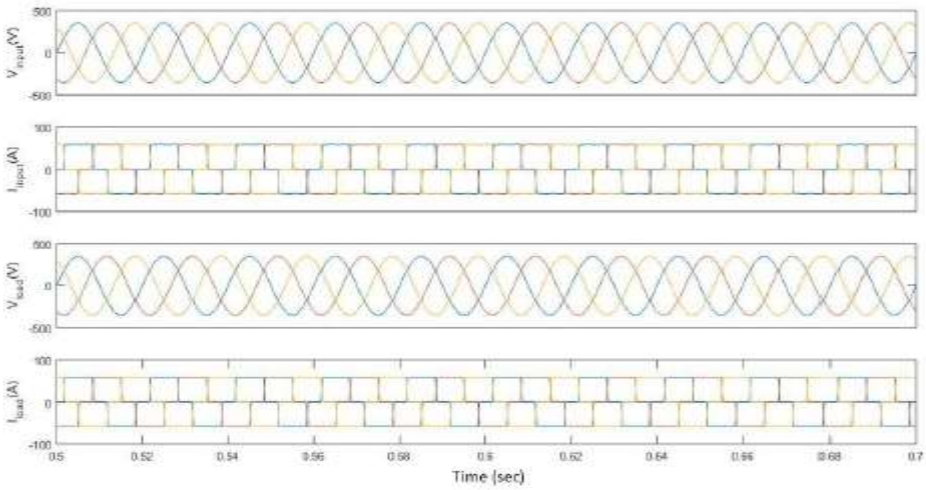

Fig. 4: Performance of System Voltages with DSTATCOM

Under this mode from 0.8-1.0 sec DSTATCOM performs the function of power factor correction and harmonic compensation in source currents by compensating the nonlinear load currents. The current injected by DSTATCOM make source currents sinusoidal and also maintain the input at unity power factor by compensating the reactive power requirement of the load. The dc link voltage is maintained almost constant during variations in source voltage. The improved source current profile is shown in the fig 5. The ripple filter compensates harmonics presents in source voltage and maintains load voltage distortion free.

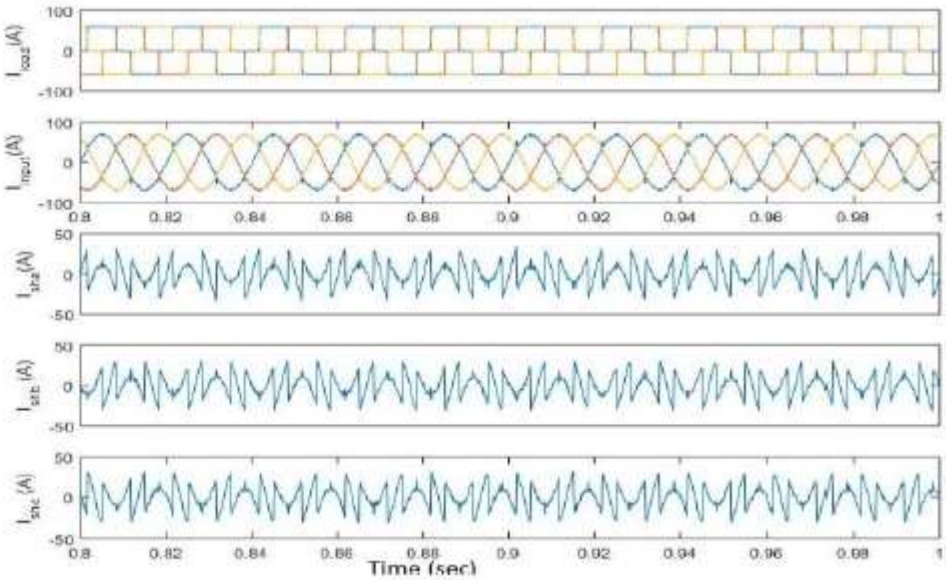

Fig. 5: Performance of DSTATCOM as a Harmonic Compensator

To study the harmonic compensating capability of DSTATCOM, source voltages are distorted by injecting 5th (5%) and 7th (3%) order voltage harmonics as shown in Fig. 6-7. The ripple filter compensates the source voltages to make load voltages sinusoidal and harmonic free.

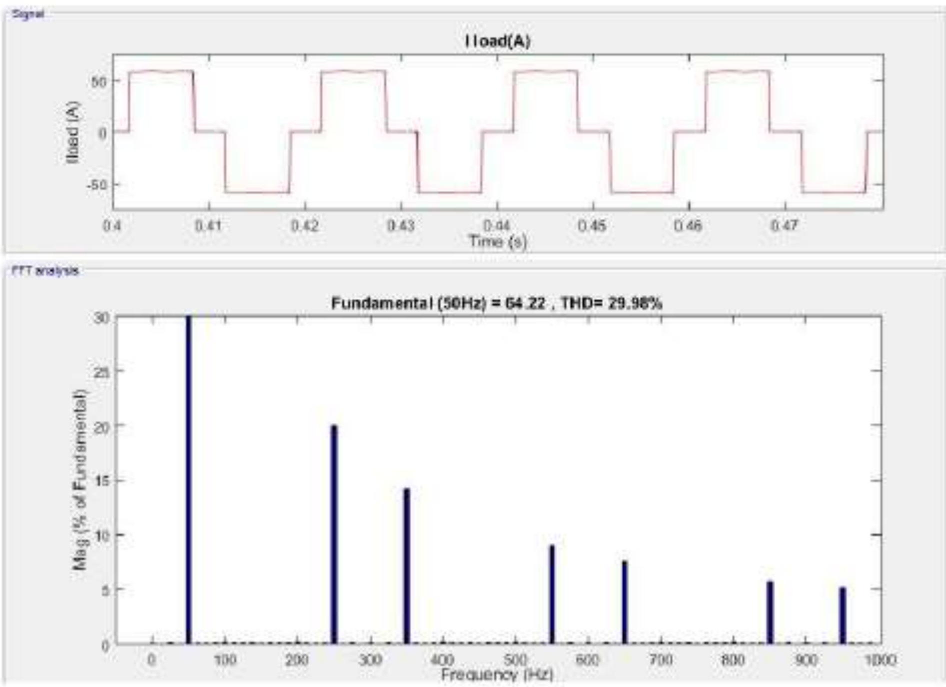

Fig. 6: Harmonic Spectrum of Load Current

It has been clearly seen in the above harmonic spectrum that the load current is non linear in nature and harmonic content of Load current is about 29.28% out of which 5^{th} harmonic is maximum.

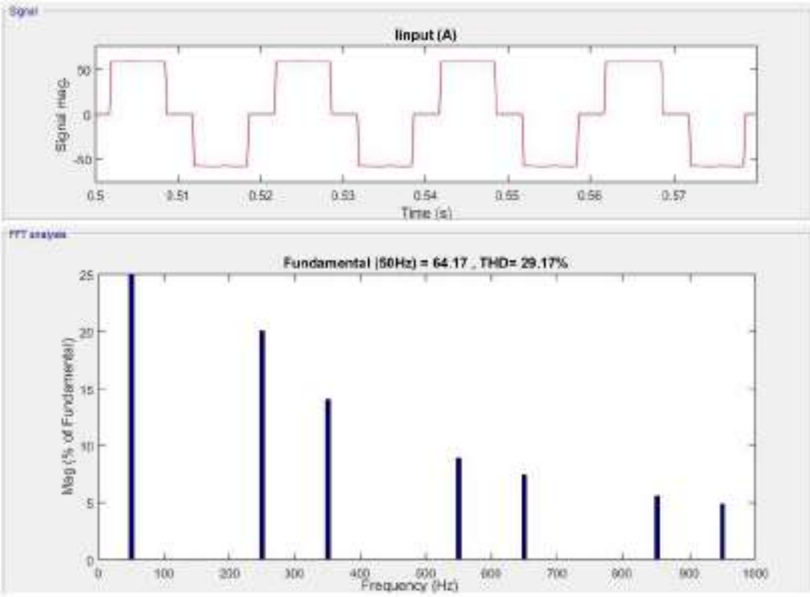

Fig. 7: Harmonic Spectrum of Uncompensated Input Current

The above figure shows the harmonic spectrum of uncompensated source current. It is clearly seen that the obtained input current is non-linear in nature and contains the harmonic of 29.17%. The 3rd harmonic is nearly zero but 5th order harmonic content is around 21%. As the order of harmonic increases their severity decreases. To compensate the harmonic and maintain the input current balanced and sinusoidal we have to add the DSTATCOM in shunt so that it could perform suitable compensation operation.

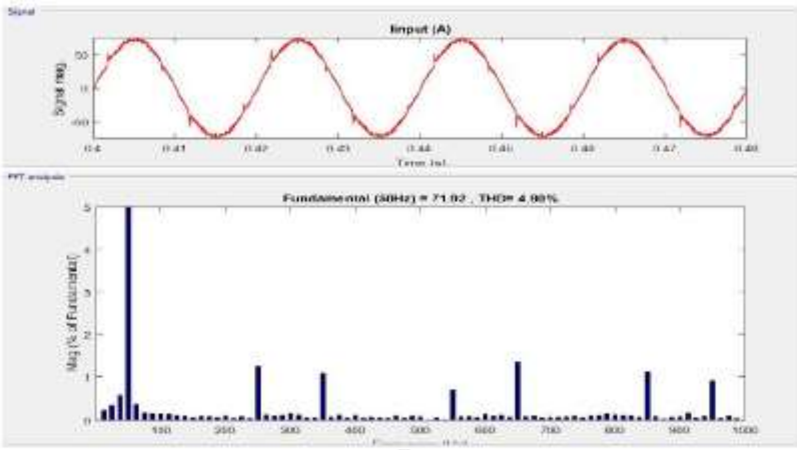

Fig. 8: Harmonic Spectrum of Compensated Input Current

Due to the compensation of DSTATCOM the input current is obtained with reduce harmonic content. A harmonic content of 4.90% is obtained ion input current which is under the permissible limit of IEEE. So we can say that DSTACOM is capable of compensating the harmonics as well as making the input current balanced and sinusoidal.

3.2 Performance of DSTATCOM compensating the Unbalance Linear Load

During normal condition the system supplied a linear balanced load. As the unbalance occurs the role of DSTATCOM came into picture.

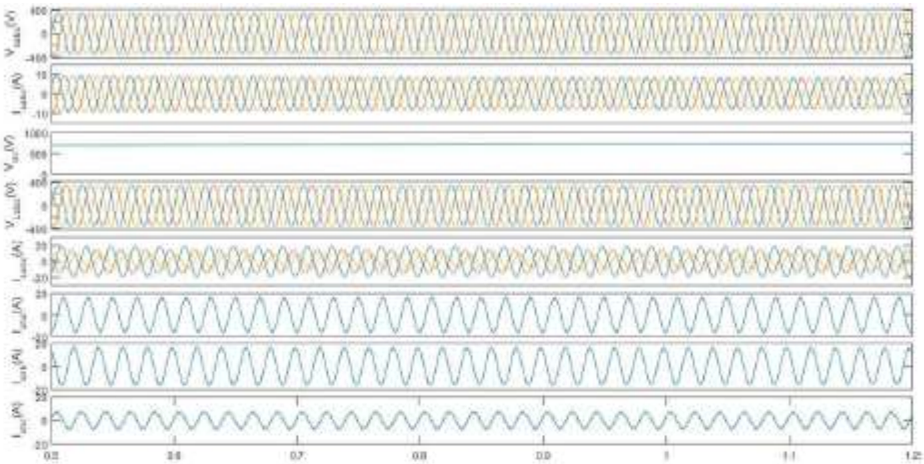

Fig. 9: Balancing of source current for linear load during the unbalanced load current

It is clearly seen that there is an amplitude difference in the load current waveform of each phases. DSTATCOM compensates the unbalance occur in the load currents efficiently as well as maintains the unity power factor at the input side. Fig 10 shows the clear view of load current, input current and DSTATCOM (shunt) current.

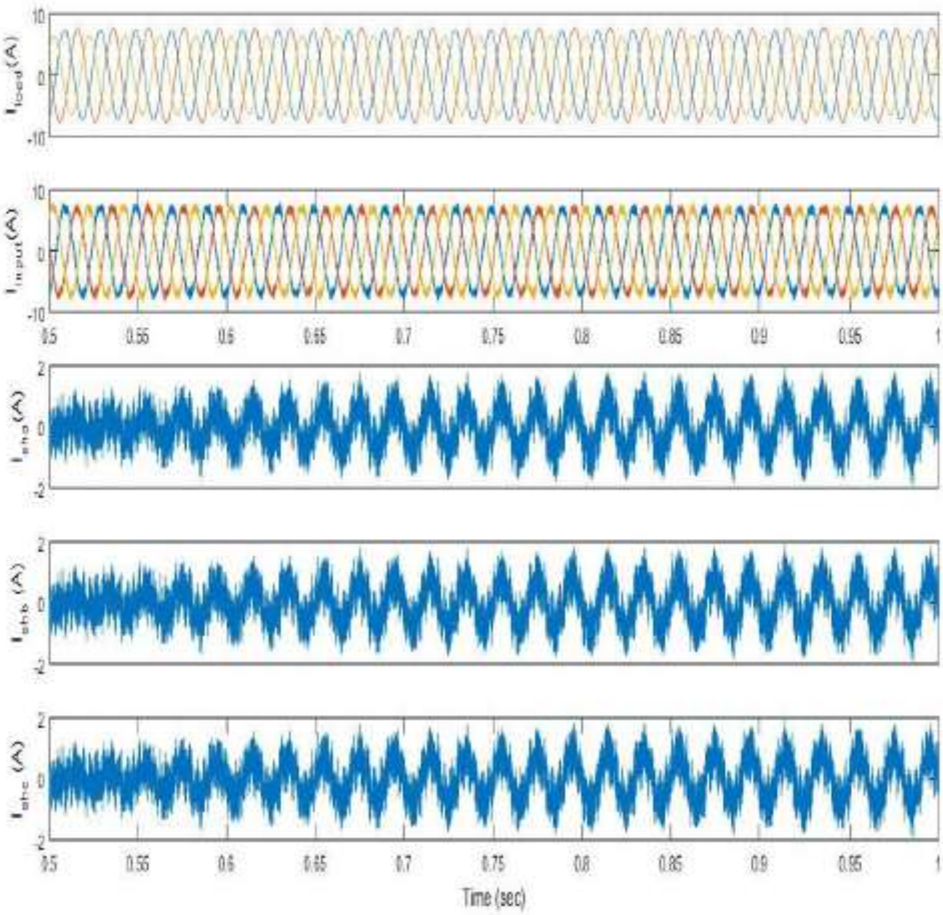

Fig. 11: DSTATCOM under Unbalance condition

A comparative analysis of the harmonic content of both load current & source current is done to find out the compensation capability of DSTATCOM under different operating conditions. Table 1, showing the THD of load and source currents under non-linear load and unbalance load condition.

Table 1: THD of I_L and I_S under different conditions for PBT

	Load current	Source current
Without Compensation	29.28 %	29.17 %
With Compensation	29.28 %	4.90 %
During Unbalance	15.06 %	5.01 %

4. CONCLUSION

It is clearly seen in the distortion tables that by using DSTATCOM there is a tremendous reduction in THD at input side currents in all conditions. DSTATCOM prevents source current from load current harmonics. DSTATCOM is also capable of fulfilling the reactive power demand of the system and improve the input side power factor. These results show the effectiveness of DSTATCOM in compensating harmonics, balancing the unbalanced load currents and maintain unity power factor at the supply side.

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