IJSRD - International Journal for Scientific Research & Development| Vol. 3, Issue 05, 2015 | ISSN (online): 2321-0613

Harmonic Reduction and Load Balancing of Three Phase Four Wire DSTATCOM using Three Leg VSC and a Zig Zag Transformer

Ramya A R[1] T.M.Vasantha Kumara[2] K.R.Mohan[3] R D Satyanarayanarao[4]
[1,2,3,4]Department of Electrical and Electronics Engineering
[1,2,3,4]Adichunchanagiri Institute of Technology Chikkamagaluru-577102

Abstract— Power quality problems is severe in three phase four wire distribution system such as poor voltage regulation, high reactive power burden and harmonics current, excessive neutral current, load unbalancing, etc. In this paper, the three leg voltage source converter (VSC) along with zig zag transformer was functioned as a DSTATCOM (Distribution Static Synchronous compensator).The DSTATCOM is a compensating device which is used to control the flow of reactive power in the distribution systems. In three phase four wire distribution system DSTATCOM is used for compensation of reactive power and unbalance caused by various loads in distribution system. The transformer connected in zig-zag is used for providing a path to the zero-sequence current. The IGBT (insulated gate bipolar transistor) based VSC is supported by the capacitor and is mainly controlled for the required compensation of the load current. By varying the load conditions the dc bus voltage of the VSC is regulated. The simulation results are verified using MATLAB software with its Simulink and power system block set toolboxes.

Key words: Distribution static compensator (DSTATCOM), neutral current compensation, power quality (PQ), zig-zag transformer

I. INTRODUCTION

Maintaining power quality in a power system is very essential in today's scenario because of the increase in wide variety of loads that pollute the power system. Sensitive power electronic equipment and non-linear loads are widely used in industrial, commercial and domestic applications leading to distortion in voltage and current waveforms. The widespread use of electronic equipment, such as information technology equipment, power electronics based drives such as adjustable speed drives (ASD), programmable logic controllers (PLC), energy-efficient lighting, led to complete change in electric loads nature. These loads are the major causes for Power Quality (PQ) problems.

Three phase four wire distribution systems are facing severe power quality problems such as poor voltage regulation, high reactive power and harmonics current burden, load unbalancing, excessive neutral current etc. A three phase four wire distribution systems are used in commercial buildings, office buildings, hospitals etc. Most of the loads in these locations are nonlinear loads and are mostly unbalanced load in the distribution system. The use of non-linear loads in heavy industries leads to harmonics and wide variations in reactive power in power system. Normally the current drawn by this type of nonlinear loads are non-sinusoidal and therefore contains harmonics. These loads, draw non sinusoidal currents from the supply and lead to voltage distortion at the point of common coupling (PCC) and this affects the other neighbouring loads those are connected to the same system and cause of poor Power Quality. These nonlinear loads may also create problems of high input current harmonics and excessive neutral current. The neutral current consists of mainly triplen harmonics currents. The zero-sequence neutral current obtains a path through the neutral conductor. Moreover, the unbalanced single-phase loads also result in serious zero-sequence fundamental current. The total neutral current is the sum of the zero-sequence harmonic component and the zero-sequence fundamental component of the unbalanced load current, and this may overload the neutral conductor of the three-phase four-wire distribution system.

The major causes of neutral current in three-phase distribution systems are the phase current unbalance, third harmonic currents produced by single-phase rectifier loads, and the third harmonics due to source voltage third harmonics. Even balanced three-phase currents produce excessive neutral current with computer loads in the systems. The source voltage distortions in systems with computer loads can cause excessive neutral current

To mitigate power quality problems a variety of custom power devices are developed and successfully implemented to compensate various power quality problems in a distribution system. The distribution static synchronous compensator (DSTATCOM) is a shunt connected device for compensating power quality problems in the current and dynamic voltage regulator (DVR) is series connected device used for mitigating the power quality problems in the voltage while the unified power quality conditioner (UPQC) is used for solving current and voltage power quality problems.

The shunt-connected custom power device, called the STATCOM is often used in transmission system. When it is used in Distribution system, it is called DSTATCOM. The DSTATCOM is a key FACTS controller and utilizes power electronics to solve many PQ problems commonly faced in distribution system, injects current at the point of common coupling (PCC) so that harmonic filtering, power factor correction, voltage regulation and load balancing can be achieved. Comparing with the SVC, the D-STATCOM has quicker response time and compact structure. It is expected that the D-STATCOM will replace the roles of SVC in nearly future D-STATCOM and STATCOM are different in both structure and function, while the choice of control strategy is related to the main-circuit structure and main function of compensators.

Some of the topologies of DSTATCOM for three-phase four-wire system for the mitigation of neutral current along with power quality compensation in the source current are four-leg voltage source converter (VSC), three single-phase VSCs, three-leg VSC with split capacitors, three-leg VSC with zigzag transformer, and three-leg VSC with neutral terminal at the positive or negative of dc bus. The voltage regulation in the distribution system is improved by installing a shunt compensator. There are many control schemes reported for control of shunt active compensators such as instantaneous reactive power theory, power balance theory, synchronous reference frame theory, symmetrical components based, etc. The synchronous reference frame theory is used for the control of the proposed DSTATCOM.

II. SYSTEM CONFIGURATION AND DESIGN

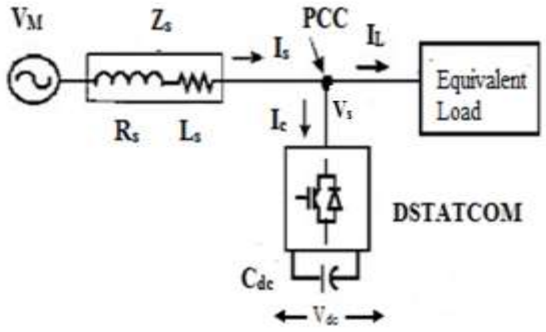

Fig. 1: Single-line diagram of DSTATCOM system.

Fig. 1 shows the single-line diagram of the shunt-connected DSTATCOM based distribution system. A D-STATCOM (Distribution Static Compensator), which is schematically depicted in Figure-1, consists of a two-level Voltage Source Converter (VSC), a dc energy storage device, a coupling transformer connected in shunt to the distribution network through a coupling transformer. The VSC converts the dc voltage across the storage device into a set of three-phase ac output voltages. These voltages are in phase and coupled with the ac system through the reactance of the coupling transformer.

The VSC connected in shunt with the ac system provides a multifunctional topology which can be used for up to three quite distinct purposes:

1) Voltage regulation and compensation of reactive power
2) Correction of power factor
3) Elimination of current harmonics.

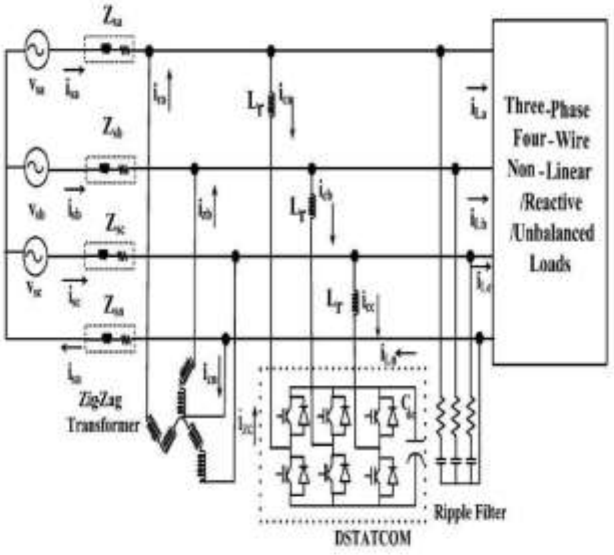

Fig. 2: Proposed three phase three leg DSTATCOM with ZIG-ZAG transformer for neutral current compensation.

The proposed compensator is a hybrid of a three-phase, three-wire VSC and a zig-zag transformer as a DSTATCOM. The DSTATCOM rating is reduced due to the elimination of a fourth leg compared to a three-phase four-leg VSC-based DSTATCOM. It compensates for neutral current along with the load voltage regulation, harmonics currents elimination, reactive power compensation, and load balancing. The considered configuration of the proposed system is shown in Fig 2. The zig-zag transformer connected at the load terminal provides a circulating path for zero-sequence harmonic and fundamental currents.

A. *Design of the DSTATCOM VSC*

A voltage-source converter is a power electronic device in Fig.1 which can generate a sinusoidal voltage with any required magnitude, frequency and phase angle. Voltage source converters are widely used in adjustable-speed drives, but can also be used to mitigate voltage dips. The VSC used as a DSTATCOM in this configuration is a three-leg pulse-width modulated (PWM) insulated-gate bipolar transistor (IGBT)-based VSC. The PWM signals are generated by the control scheme for which the reference source currents and the sensed source currents are the input signals. The rating of the switches is based on the voltage and current rating of the compensation system. For the considered load mentioned in the Appendix, the rating of the VSC is 12 kVA. The selection of the dc bus voltage, dc bus capacitor, ac inductor, and the ripple filter will be given.

1) *DC Bus Voltage*

The value of the dc bus voltage Vdc depends on the instantaneous energy available to the DSTATCOM.

For a VSC, the dc bus voltage is defined as

$$V_{dc} = 2\sqrt{2}\,V_{LL} / \sqrt{3}m \qquad (2.1)$$

Where m is the modulation index and is considered as 1. Thus, one may obtain the value of V_{dc} as 677 V for V_{L-L} of 415 V. Thus, V_{dc} of the value of 680 V is selected.

2) *DC Bus Capacitor*

The design of the dc capacitor is governed by the reduction in the dc bus voltage upon the application of load and rise in the dc bus voltage on removal of the load. Using the principle of energy conservation, the equation governing C_{dc} as

$$\tfrac{1}{2} C_{dc}\,[(V_{dc}^{2}) - (V_{dc1}^{2})] = 3V(\alpha I)t \qquad (2.2)$$

Where V_{dc} is the reference and V_{dc1} is the minimum voltage level of the dc bus voltage, α is the over loading factor, V is the phase voltage, I is the phase current of the VSC, and T is the response time of the DSTATCOM and is considered as 350 µs. considering V_{dc}=680V, V_{dc1}= 670v, V=415/√3 V, α=1.2, the calculated value of C_{dc} is as 2600µf. So C_{dc} is chosen to be 3000µF.

3) *AC Inductor*

The selection of the ac inductance depends on the current ripple $i_{cr(p-p)}$. The ac inductance is given as

$$L_f = \sqrt{3}m\,V_{dc} / 12\alpha\, f_s\, i_{cr(p-p)} \qquad (2.3)$$

Considering 5% current ripple, the switching frequency f=10 kHz, modulation index m=1, dc bus voltage of V_{dc}=680V and overload factor a=1.2, the value L_f is calculated to be 5.45 mH. And this L_f is been selected as 5.5 mH

4) *Ripple Filter*

A high pass first-order filter tuned at half the switching frequency is used to filter out the noise from the voltage at the PCC. The time constant of the filter should be very small compared to the fundamental time period (T)

$$R_f C_f << T/10 \qquad (2.4)$$

When T=20 ms, considering C_f=5 *u*F, R_f is chosen as 5Ω. This combination offers a low impedance of 8.1Ω for the harmonic voltage at a frequency of 5 kHz and 637Ω for fundamental voltage.

B. Design of the Zig-Zag Transformer

A zig-zag transformer is a special connection of three single-phase transformer windings or a three-phase transformer's windings. The zig-zag transformer in the past has been used to create neutral and to convert a three-phase three-wire system into a three-phase four-wire system. The new application of a zig-zag transformer is to connect in parallel to the load for filtering the zero-sequence components of the load currents.

The application of a zig-zag transformer for the reduction of neutral current is advantageous due to passive compensation, rugged, and less complex over the active compensation techniques [8]. Fig. 2 shows the connection of a zig-zag transformer in the system and the zig-zag transformer is shown in Fig. 3.

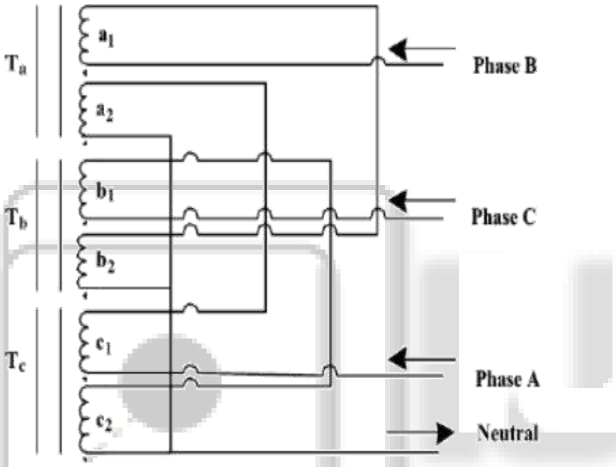

Fig. 3: Zig-zag transformer for neutral current compensation.

The phasor diagram of the zig-zag transformer is shown in Fig. 4. The currents flowing through the utility side of these three transformers are equal. Hence, the zig-zag transformer can be regarded as open-circuit for the positive-sequence and the negative-sequence.

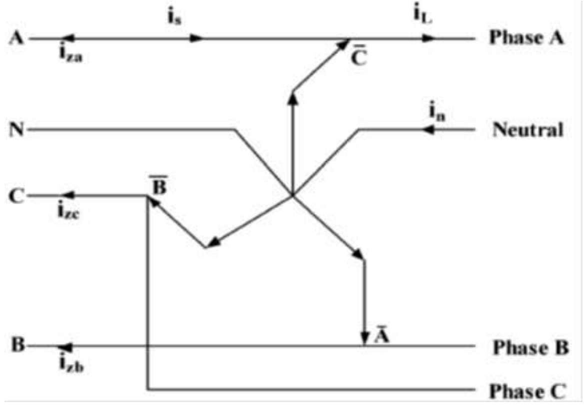

Fig. 4: Diagram showing the flow of currents of zig-zag transformer for neutral current compensation

Then the current flowing through the zigzag transformer is only the zero-sequence component. An application of a zig-zag transformer alone in a three-phase, four-wire system has the advantages of reduction in load unbalance and reducing the neutral current on the source side. But there are inherent disadvantages such as the performance being dependent on the location of the zig-zag transformer close to the load. Moreover, when the source voltage is distorted or unbalanced, the performance of reducing the neutral current on the source side is affected to an extent.

The zig-zag transformer provides a low impedance path for the zero-sequence currents and, hence, offers a path for the neutral current when connected in shunt and, hence, attenuates the neutral current on the source side. When a zig-zag transformer is used alone as a neutral current compensator, the rating of the zig-zag transformer depends on the amount of imbalance and harmonic content. Under the single-phase load, nearly half of the load current flows through the zig-zag windings. All six windings (two windings each of three phases) are rated as 150V, 10 A, and hence, three single-phase transformers of 5-kVA capacity each are selected in this investigation.

C. Control of DSTATCOM

There are many theories available for the generation of reference source currents in the literature viz. instantaneous reactive power theory (p–q theory), synchronous reference frame theory, power balance theory, etc. The synchronous reference frame theory-based method is used for the control of DSTATCOM.

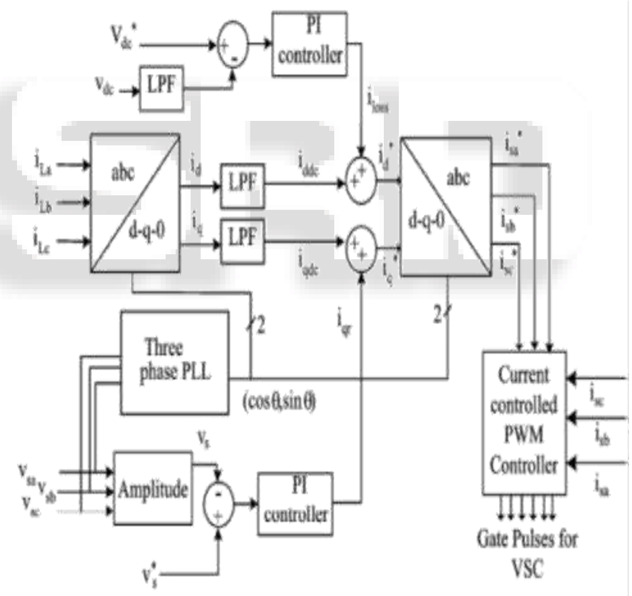

Fig. 5: SRF theory based control of DSTATCOM

A block diagram of the control scheme is shown in Fig. 5. The load currents(I_L) , the source voltages,(V_s) and dc bus voltage (V_{dc}) of DSTATCOM are sensed as feedback signals. The loads currents in the three phases are converted into the d-q -0 frame using the Park's transformation as in (2.5)

$$\begin{bmatrix} i_{Lq} \\ i_{Ld} \\ i_{Lo} \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos\theta & \cos\left(\theta-\frac{2\pi}{3}\right) & \cos\left(\theta+\frac{2\pi}{3}\right) \\ \sin\theta & \sin\left(\theta-\frac{2\pi}{3}\right) & \sin\left(\theta+\frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \qquad (2.5)$$

A three-phase phase-locked loop (PLL) is used to synchronize these signals with the source voltage. The components are then passed through low pass filters to extract the dc components of Id and Iq. The error between the reference dc capacitor voltage and the sensed dc bus voltage of DSTATCOM is given to a proportional-integral (PI) controller whose output is considered the loss Component of the current and is added to the dc component of Id. Similarly, a second PI controller is used to regulate the load terminal voltage. The amplitude of the load terminal voltage and its reference value are fed to a PI controller and the output of the PI controller is added with the dc component of iq..

The control strategy is to regulate the terminal voltage and the elimination of harmonics in the load current and load unbalance. The resulting currents are again converted into the reference source currents using the reverse Park's transformation. The reference source currents and the sensed source currents are used in the PWM current controller to generate gating pulses for the switches. For the power factor correction, only the dc bus voltage PI controller is used in the control algorithm.

III. MATLAB BASED MODELING OF DSTATCOM

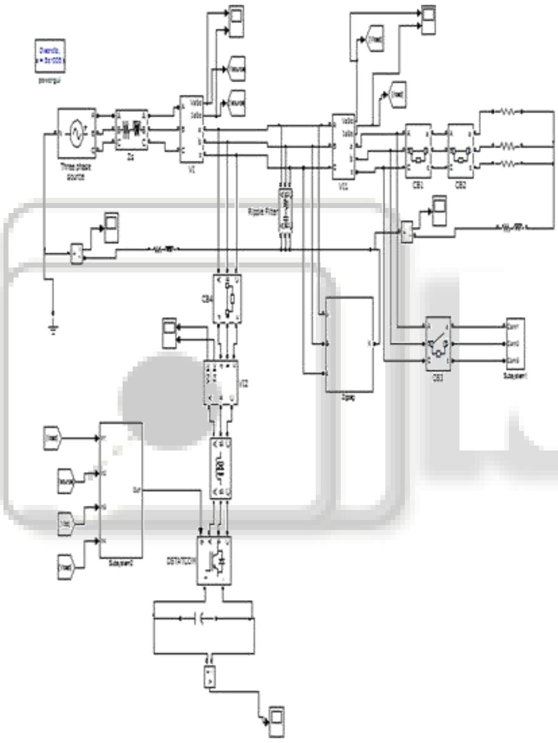

Fig. 6: MATLAB model of three phase three leg DSTATCOM and ZIG ZAG transformer

A three VSC and a zig-zag transformer is modelled and simulated using the MATLAB and its Simulink and Power System Blockset toolboxes. Fig.6. shows the MATLAB model of the DSTATCOM and zig-zag transformer-connected system for neutral current compensation. The considered load is a lagging power factor load. The ripple filter is connected to the VSC of the DSTATCOM for filtering the ripple in the terminal voltage. The system data are given in the Appendix. The control scheme for the DSTATCOM is also modelled in MATLAB. The reference source currents are derived from the sensed voltages (Vs), load currents (iL), and the dc bus voltage (Vdc) of DSTATCOM. A PWM current controller is used over the reference and sensed source currents to generate the gating signals for the IGBTs of the DSTATCOM VSC.

IV. SIMULATION RESULTS AND DISCUSSION

The performance of the DSTATCOM is demonstrated for voltage regulation along with harmonic reduction, load balancing and neutral current compensation.

A. System without DSATACOM

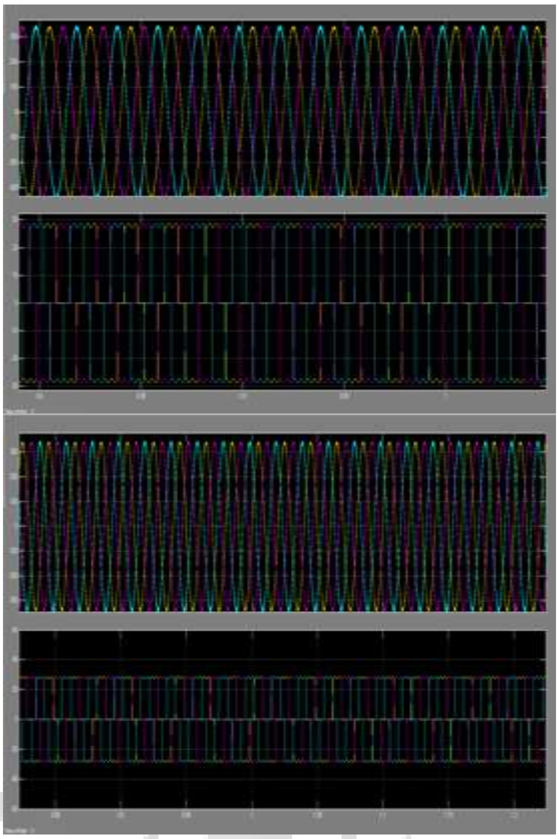

Fig. 7: System with non-linear load

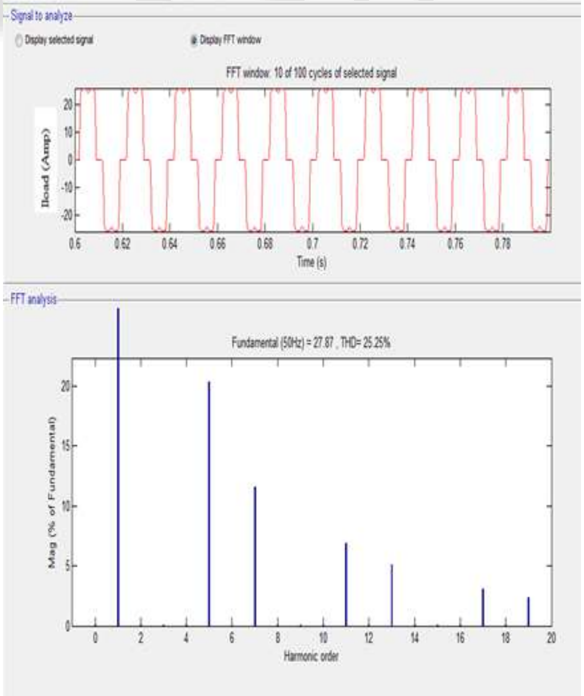

Fig. 8: FFT analysis of load current without DSTATCOM

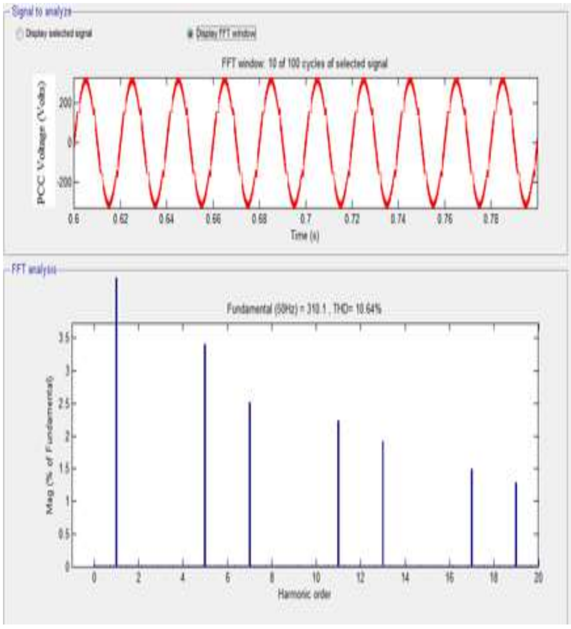

Fig. 9: FFT analysis of PCC voltage without DSTATCOM

B. SRF Control Strategy

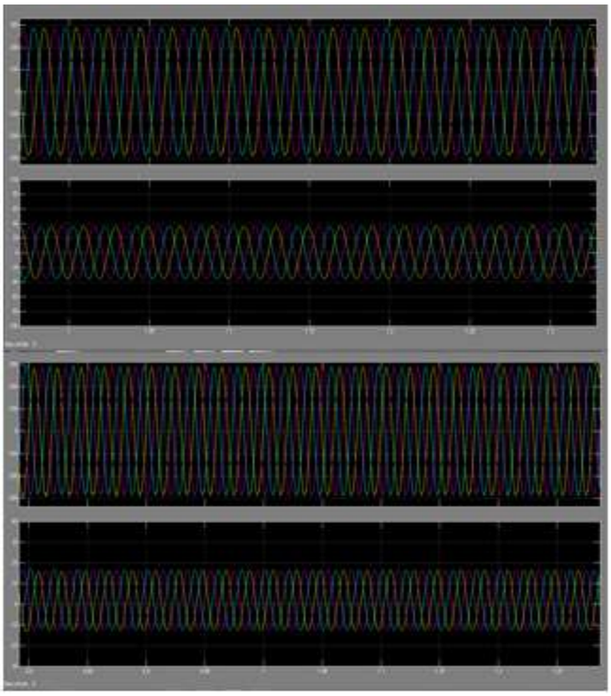

Fig. 10: System with non-linear load

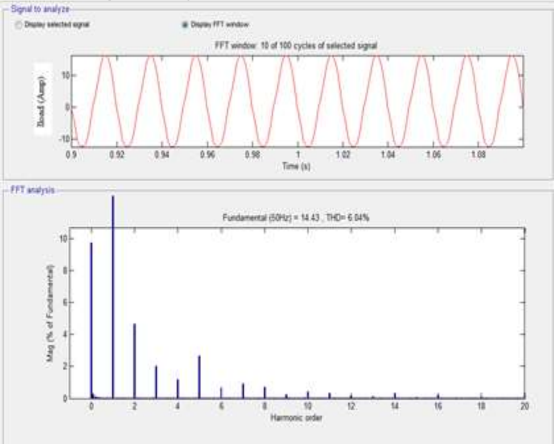

Fig. 11: FFT analysis of load current with DSTATCOM

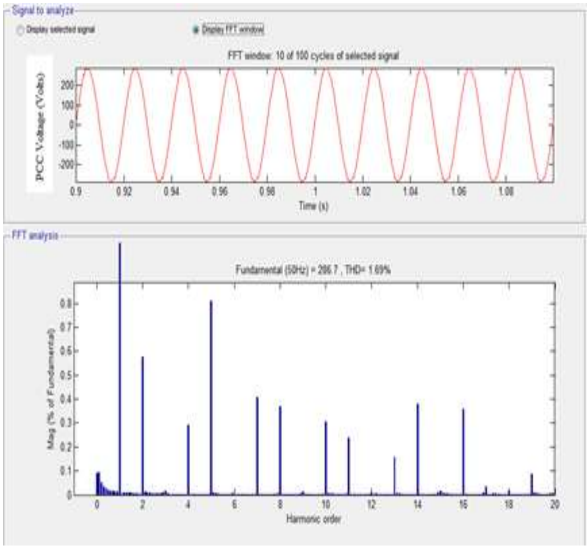

Fig. 12: FFT analysis of PCC voltage with DSTATCOM

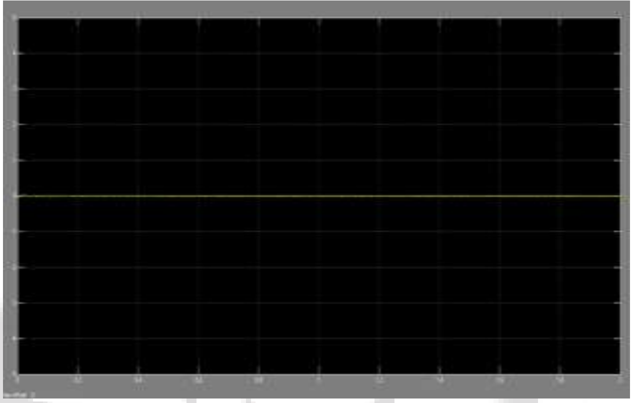

Fig. 13: Source neutral current

Some of the important mitigation techniques are analyzed and modeled using MATLAB. The voltages (V_s), balanced source currents (i_s), Load currents (i_L), compensator currents (i_c), source neutral current (i_{sn}), load neutral current (i_{Ln}), compensator neutral current (i_{Zn}), amplitude of the load terminal voltage (V_L), and dc bus voltage (V_{dc}) are demonstrated under unbalanced loads conditions. It is observed that the voltage amplitude is regulated to the reference value under all load disturbances.

The source current is balanced, even though the load current is highly unbalanced and this is achieved by using the unbalanced fundamental current injection by the DSTATCOM. The zero-sequence fundamental current of the load neutral current resulting from the unbalanced load current is circulated in the zig-zag transformer, and hence, the source neutral current is maintained at nearly zero. The dc bus voltage of the VSC of DSTATCOM is regulated by the controller and the voltage is maintained near the reference voltage.

The performance of the DSTATCOM with a zig-zag transformer for voltage regulation and load balancing along with neutral current compensation is shown in Fig.8. The voltages (V_s), balanced source currents (i_s), load Currents (i_L), compensator currents (i_c), source neutral current (i_{sn}), load neutral current (i_{Ln}), compensator neutral current (i_{Zn}), amplitude of the load terminal voltage (V_L), and dc bus voltage (V_{dc}) are demonstrated under various changing nonlinear loads. The dc bus voltage of the VSC of DSTATCOM is regulated by the controller.

V. CONCLUSION

The performance of a new topology of three-phase four-wire DSTATCOM consisting of three-leg VSC with a Zig-Zag transformer has been demonstrated for neutral current compensation along with reactive power compensation, harmonic compensation and voltage regulation for linear and nonlinear load under unbalanced condition. The modelling and simulation of the zig-zag transformer has been demonstrated for neutral current compensation. The performance of the proposed compensator is verified through simulation.

VI. APPENDIX

Line impedance Rs=0.01Ω, Ls=1mH ,

1) linear load: 20 kVA, 0.80-pf lag;
2) Nonlinear load: a three single-phase bridge rectifier with an R-C load with R=25Ωand c=470µF.

Ripple filter: R_f =5Ω, C=5µ F. DC bus capacitance: 3000µF.
DC bus voltage: 680 V. AC line voltage: 415 V, 50 Hz.
Zig-zag transformer: three numbers of single-phase transformers of 5 kVA, 150/150 V.

REFERENCES

[1] IEEE Recommended Practices and Requirements for Harmonics Control in Electric Power Systems, IEEE Std. 519, 1992.
[2] A.Ghosh and G. Ledwich, Power Quality Enhancement using Custom Power Devices, Kluwer Academic Publishers, London, 2002.
[3] R. C. Dugan, M. F. McGranaghan and H. W. Beaty, Electric Power Systems Quality. 2ed Edition, McGraw Hill, New York, 2006.
[4] Akagi, E H Watanabe and M Aredes, Instantaneous power theory and applications to power conditioning, John Wiley & Sons, New Jersey, USA, 2007.
[5] Antonio Moreno-Munoz, Power Quality: Mitigation Technologies in a Distributed Environment, Springer-Verlag London limited, London, 2007.
[6] Ewald F. Fuchs and Mohammad A. S. Mausoum, Power Quality in Power Systems and Electrical Machines, Elsevier Academic Press, London, UK, 2008.
[7] K. L. Parker, ―Active neutral current compensator,‖ U.S. Patent 5 574 356, Nov. 12, 1996.
[8] J. Pitel and P. Enjeti, ―Active harmonic power filter apparatus and method,‖ U.S. Patent 5 568 371, Oct. 22, 1996.
[9] E. Larsen, ―Filter for removing harmonic current from a neutral conductor,‖ U.S. Patent, 5 914 540, Jun. 22, 1999.
[10] T. M. Gruzs, ―a survey of neutral currents in three-phase computer systems,‖ IEEE Trans. Ind. Appl., vol. 26, no. 4, pp. 719–725, Jul./Aug 1990.
[11] H.-L. Jou, J.-C. Wu, K.-D. Wu, W.-J. Chiang, and Y.-H. Chen,―Analysis of zig-zag Transformer applying in the three-phase four-wire distribution power system,‖ IEEE Trans. Power Del., vol. 20, no. 2, pt. 1, pp. 1168–1173, Apr. 2005.
[12] M. C. Benhabib and S. Saadate, ―New control approach for four-wire active power filter based on the use of synchronous reference frame,‖ Elect. Power Syst. Res., vol. 73, no. 3, pp. 353–362, Mar. 2005.
[13] M. I. Milanés, E. R. Cadaval, and F. B. González, Comparison of control strategies for shunt active power filters in three-phase four-wire systems,‖ IEEE Trans. Power Electron., vol. 22, no. 1, pp. 229–236, Jan. 2007.
[14] M. Ucar and E. Ozdemir, ―Control of a 3-phase 4-leg active power filter under non-ideal mains voltage condition,‖ Elect. Power Syst. Res., vol. 78, no. 1, pp. 58–73, Jan. 2008.