Comparative Analysis of Star/Delta and Zig/Zag Transformer Based DSTATCOM for Power Quality Improvement

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Abstract - Now a day's power quality improvement is an important issue in respect of increasing application for nonlinear loads. A group of devices, called Custom Power Devices (CPDs) are in use now days, for power quality improvement. One of the CPD the distributed static compensator (DSTATCOM) is proposed for compensating the power quality problems. The DSTATCOM is design for improvement, performance of distribution system under linear and nonlinear loads. Especially in nonlinear load DSTATCOM inject harmonics current components into the system to improve power quality of source current and source voltage. Further in the proposed systems the rating and size of DSTATCOM is reduced with the help of Star/Delta and Zig/Zag transformer. The proposed systems is employed for the reduce rating of dc current, compensation of harmonic current, reactive power, neutral current, load balancing and the voltage regulation. In this dissertation comparison of proposed topology of DSTATCOM consisting of a three leg VSC with the Star/Delta and Zig/Zag transformer is employed for power quality improvement. The performance of proposed DSTATCOM system is demonstrated under balanced, nonlinear loads in MATLAB/Simulink environment.

Keywords – DSTATCOM, VSC, power quality, nonlinear load, neutral current compensation, voltage regulation, reactive power, Star/Delta and Zig/Zag transformer.

1. INTRODUCTION

The continuity of supply and the quality of power always an important task in the distribution system. The quality of to the different type of non-linear loads and unplanned expansion in distribution system. The result is the power quality problems in the distribution system. The power quality problems such as high reactive power demand, harmonics current burden, and unbalance in the load and excessive neutral current in the present day are widely reported. Presently, the power quality has big issue in the distribution system. Three phase four wire distribution system are used in commercial building, office buildings, hospitals, etc. The majority of loads in the power distribution system are mostly non-linear and unbalanced loads. The typical loads may be computer loads office automation machines, adjustable speed drives (ASD) in small air conditioners, fans and pumps, variable frequency drives and other power converters with poor power factor used in industries as well as in home appliances. These loads generally behaves as non-linear loads, these loads may create problems of high input current harmonics and excessive neutral current both of fundamental and harmonic frequency, and neutral conductor gets overloaded. A group of the controllers are used in the distribution system is known as custom power devices (CPD). The CPD include the DSTATCOM (distributed static compensator), DVR (dynamic voltage restorer) and UPQC (unified power quality conditioner), are used for compensating the many power quality problems in the current, voltage and both current and voltage respectively. The Distributed Static Compensator (DSTATCOM) is a shunt connected device, which is used to mitigate the power quality problems. Many topologies of DSTATCOM are reported to compensate the power quality problems. The proposed topologies consisting Star/Delta and Zig/Zag transformer with DSTATCOM is very efficient to mitigate the power quality issues.

2. SYSTEM CONFIGURATION AND DESIGN

Fig. 1 shows the shunt connected DSTATCOM based distribution system with Star/Delta and Zig/Zag transformer. These are two different operation one is for Star/Delta transformer and another one is for Zig/Zag transformer. The DSTATCOM shown in fig. 2, consists of a voltage Source Converter (VSC), a dc energy storage device and a coupling transformer is linked 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 connected with the ac system through the reactance of the coupling transformer. Suitable arrangement of the phase and magnitude of the DSTATCOM output voltages allows effective control of active and reactive power changes between the DSTATCOM and the ac system. Such configuration allows the device to consume or generate controllable active and reactive power. Proposed system consisting DSTATCOM with Star/Delta and Zig/Zag transformer for power quality improvement.

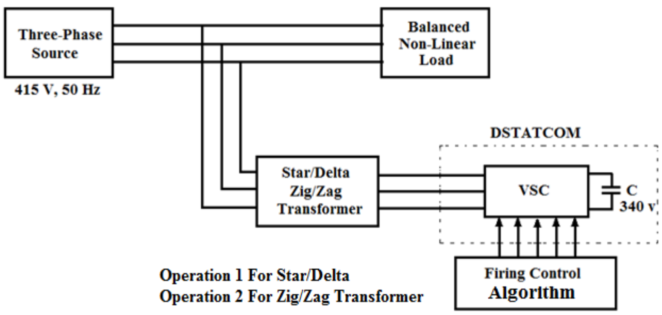

Fig.1. Single line diagram of proposed systems

a) Three leg VSC based DSTATCOM

The DSTATCOM in this configuration uses PWM controlled three-leg IGBT based VSC. The ripple filter are selected as per the design. The rating of the VSC switches is depend on the voltage and current rating of the compensation system.

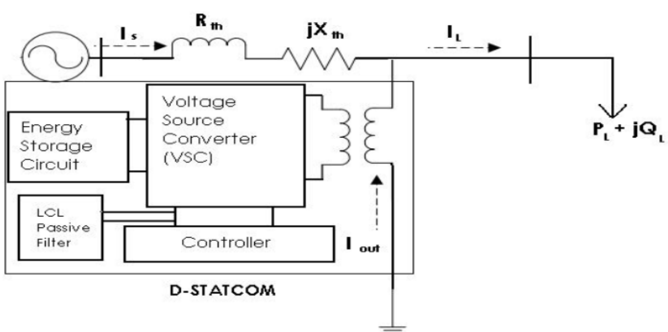

Fig. 2. Shunt connected DSTATCOM distribution system.

b) Star/Delta Transformer

The primary is connected in star fashion while the secondary is in delta fashion such connections are used principally where the voltage is to be stepped. The star delta has no problem with third harmonics components due to circulating current in delta. In this system, line voltage ratio is 1/√3 Times of transformer turn-ratio and secondary voltage lags behind primary voltage by 30°. The connection of the Star/Delta transformer is shown in fig.3 (a) and the phasor diagram in fig.3 (b) the current Io is the circulating current in the case of any zero sequence current in the load.

The current rating of this transformer windings is based on this circulating current and the compensation current to be provided by the voltage source converter (VSC). The primary winding voltage is,

$$V_a = V_{LL}/\sqrt{3} = 415/\sqrt{3} = 239.60V$$

Three numbers of single-phase transformers of each of rating 3.5 kVA is selected and the voltage ratio of the transformer is 240V/140V for the proposed system.

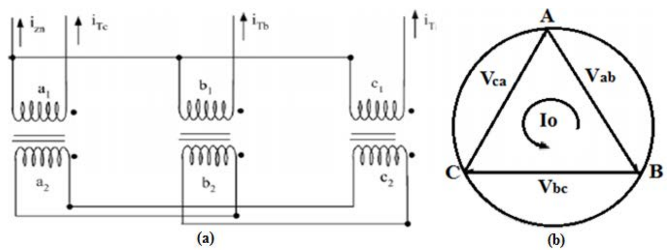

Fig. 3. (a) Star/Delta transformer winding (b) Phasor diagram

c) Zig/Zag Transformer

A Zig/Zag transformer is a special purpose transformer with a Zig/Zag arrangement. The Zig/Zag transformer provides a low impedance for the zero sequence fundamental and harmonic currents and hence offers a path for neutral current when connected in the shunt with the PCC [14]. The Zig/Zag transformer used for reduction of neutral current due to passive compensation, rugged, and less complex over the active compensation techniques. It has a special connection of three single-phase transformer windings or three-phase windings. The phasor diagram of the Zig/Zag transformer is shown in Fig. 4. Three number of single phase transformers of rating 3kVA and voltage ratio of the transformer is 140V/140V/140V is selected.

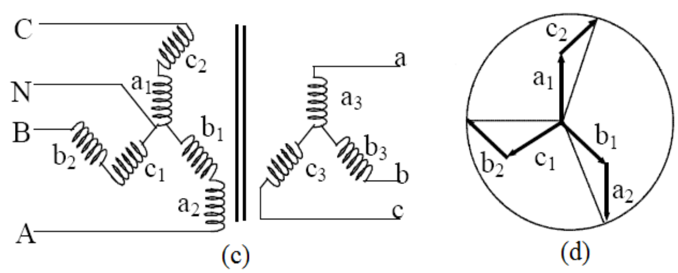

Fig. 4. (c) Zig/Zig transformer connection (d) Phasor diagram

d) Control technique

The control technique is the heart of the DSTATCOM system. There are many theories available for the generation of reference source currents, for the control of VSC (voltage source converter) of DSTATCOM in three phase four wire system are, instantaneous reactive power theory (p-q theory), and synchronous reference frame or SRF theory, power balance theory etc. Among the different control techniques used to three-phase three-wire compensator, the unit quadrature vector theory based technique is found to be suitable for different topologies of DSTATCOM.

The unit quadrature vector theory is simple and proven to be one of the best performances under various operating conditions.

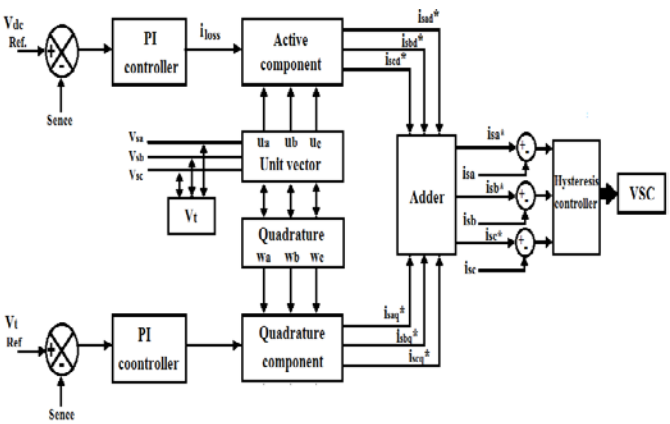

Fig.5 Control techniqure for DSTATCOM

Hence this theory is used for the control of proposed scheme. Figure shows the control scheme of the DSTATCOM to regulate the frequency and voltage of the system. Basic equations of this control scheme for voltage and frequency control are given as follows.

e) Active Component of Reference Source Currents

Three-phase voltages at the PCC are considered sinusoidal and hence their amplitude is computed as,

$$V_t = \{(2/3)\ (v_{Sa}^2 + v_{Sb}^2 + v_{Sc}^2)\}^{1/2} \quad (1)$$

The unit vector in phase with Vsa, Vsb and Vsc are derived as,

$$u_a = v_{Sa}/V_t;\ \ u_b = v_{Sb}/V_t;\ u_c = v_{Sc}/V_t \quad (2)$$

The error in dc bus voltage of VSC (Vdcer (n)) of a DSTATCOM at nth sampling instant is as,

$$Vdcer_{(n)} = Vdcref_{(n)} - V_{dc(n)} \quad (3)$$

The output of the PI controller for maintaining dc bus voltage of the VSC at the nth sampling instant is expressed as,

$$i_{loss(n)} = i_{loss(n-1)} + K_{pd}\ \{ Vdcer_{(n)} - Vdcer_{(n-1)}\} + KidVdcer_{(n)} \quad (4)$$

In-phase components of reference source currents are estimated as:

$$i_{sad}* = u_a\ i_{loss}\ ;\ i_{sbd}* = u_b\ i_{loss}\ ;\ i_{scd}* = u_c\ i_{loss} \quad (5)$$

f) Quadrature Component of Reference Source Currents

The unit vectors (wa, wb and wc) in quadrature with Vsa, Vsb and Vsc may be derived using a quadrature transformation of the in-phase unit vectors u_a, u_b and u_c as,

$$w_a = -u_b / \sqrt{3} + u_c / \sqrt{3} \quad (6)$$

$$w_b = \sqrt{3}\ u_a / 2 + (u_b - u_c) / 2\sqrt{3} \quad (7)$$

$$w_c = -\sqrt{3}\ u_a / 2 + (u_b - u_c) / 2\sqrt{3} \quad (8)$$

The error in PCC voltage of VSC (Vter (n)) of a DSTATCOM at nth sampling instant is as,

$$V_{ter(n)} = Vtref_{(n)} - V_{t(n)} \quad (9)$$

The output of the PI controller for maintaining amplitude of PCC voltage at the nth sampling instant is expressed as,

$$i_{qr(n)} = i_{qr(n-1)} + K_{pq}\ \{ V_{ter(n)} - V_{ter(n-1)}\} + KiqVter_{(n)} \quad (10)$$

The quadrature components of reference source currents are estimated as:

$$i_{saq}* = w_a i_{qr}\ ;\ i_{sbd}* = w_b i_{qr}\ ;\ i_{scd}* = w_c i_{qr} \quad (11)$$

g) Reference Source Currents

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Total reference source currents are sum of in-phase and quadrature components of the reference source currents as,

$$i_{sa}^{*} = i_{sad}^{*} + i_{saq}^{*} \quad (12)$$

$$i_{sb}^{*} = i_{sbd}^{*} + i_{sbq}^{*} \quad (13)$$

$$i_{sc}^{*} = i_{scd}^{*} + i_{scq}^{*} \quad (14)$$

These reference source currents (isa*, isb* and isc*) are compared with the sensed source currents (isa, isb and isc) in current controller. These current errors for all the phases are used to generate gating signals of IGBTs of VSC of DSTATCOM using PWM current controller

3. PROPOSED METHODOLOGY

Three leg VSC based DSTATCOM integrated with Star/Delta and Zig/Zag transformer connected to the three phase-system is modeled and simulated using MATLAB/Simulink. A DSTATCOM integrated with Star/Delta transformer modelled in MATLAB is shown in fig.6, another system DSTATCOM with Zig/Zag transformer modeled in MATLAB shown in fig.7. The ripple filter is also connected to the VSC of the DSTATCOM (distribution static compensator) for filtering the ripple in the PCC.

The control algorithm of DSTATCOM is also modelled in MATLAB/simulink. The reference source currents are derived from the sensed PCC voltages (va, vb, vc,) load currents (iLa, iLb, iLc,) and the DC bus voltage of DSTATCOM (Vdc). A pulse width modulated (PWM) current controller are used over the reference and source currents to generate the gating signals for the IGBTs of VSC of the DSTATCOM.

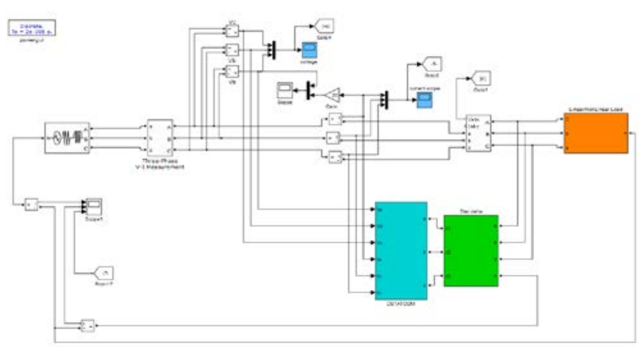


Fig.6 MATLAB model of Star/Delta transformer based DSTATCOM

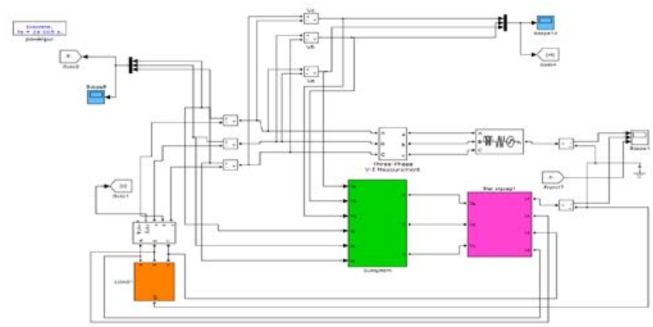


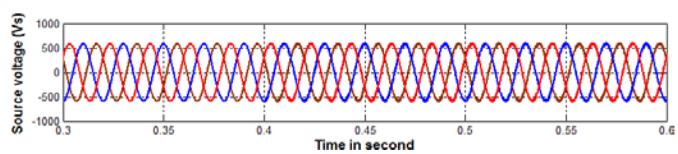
Fig.7 MATLAB model of Zig/Zag transformer based DSTATCOM

5. SIMULATION/EXPERIMENTAL RESULTS

The performance of the three leg VSC based DSTATCOM integrated with Star/Delta and Zig/Zag transformer is demonstrated for reduced rating of dc current, harmonic reduction, power factor correction and voltage regulation, and neutral current compensation. The source voltage (v_s), source current (i_s), load current (I_L), dc voltage (v_{dc}), terminal voltage (v_t) and load neutral current (I_{Ln}) are demonstrated under various nonlinear load conditions with Star/Delta and Zig/Zag transformer. It is observed the source current is balanced even load current is highly unbalanced in both condition. The dc bus voltage (v_{dc}) is regulated by controller and the terminal voltage (v_t) is regulated to the reference value. The results for the Star/Delta and Zig/Zag transformers are shown in fig. 8 and 9. The FFT analysis of these systems also obtained the frequency spectrum or source current and total harmonic distortion (THD) in source current is shown in fig.

A. *Performance of DSTATCOM With Star/Delta Transformer for Nonlinear Load*

The dynamic performance of DSTATCOM with Star/Delta transformer for Dc voltage reduction, harmonics elimination along with neutral current compensation under nonlinear load is shown in fig.8.



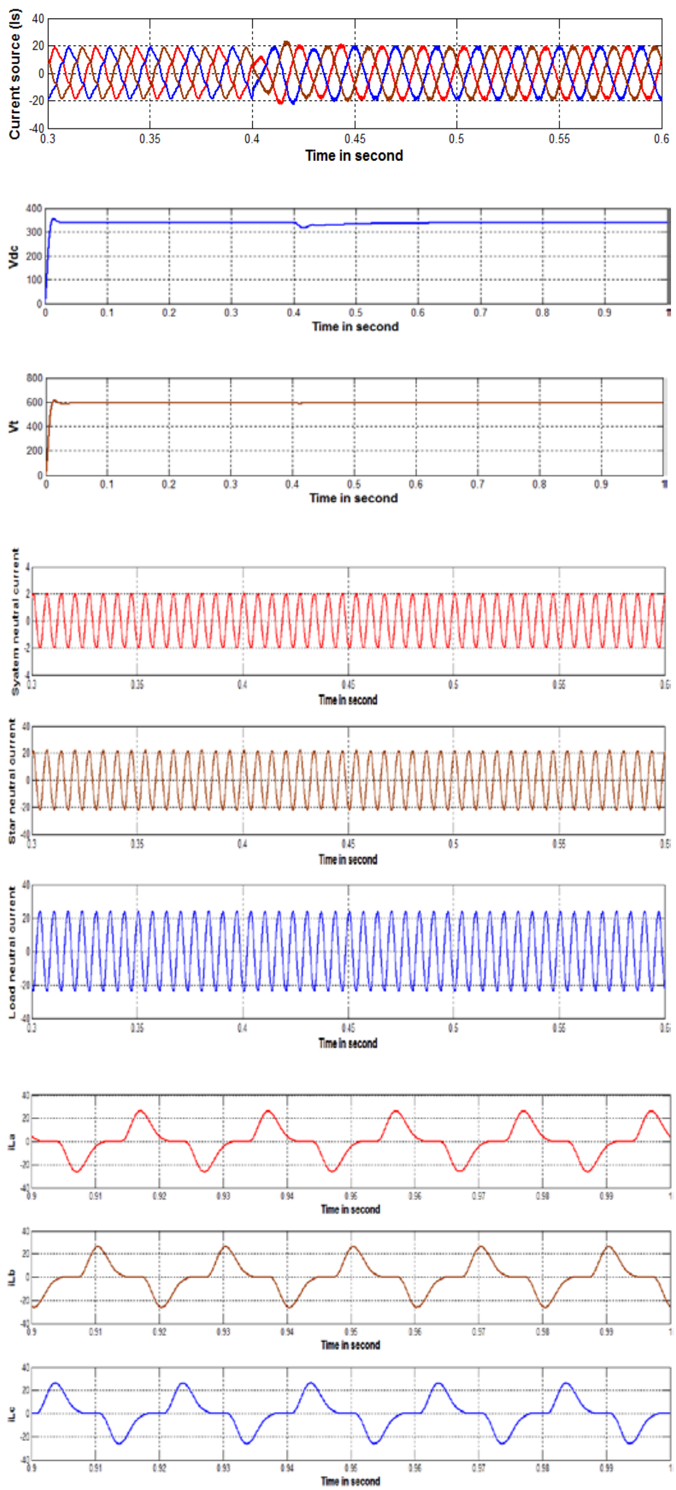


Fig.8 Performance of DSTATCOM with Star/Delta transformer

FFT analysis of DSTATCOM with Star/Delta transformer with nonlinear load is shown the total harmonic distortion is 4.6% supply current is near to the prescribe limit of the lower order harmonics.

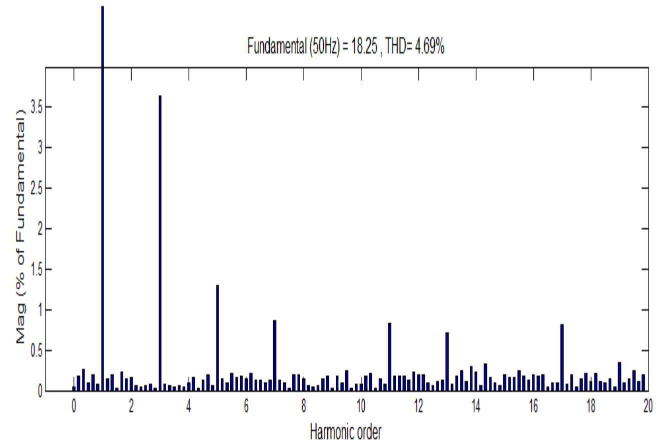
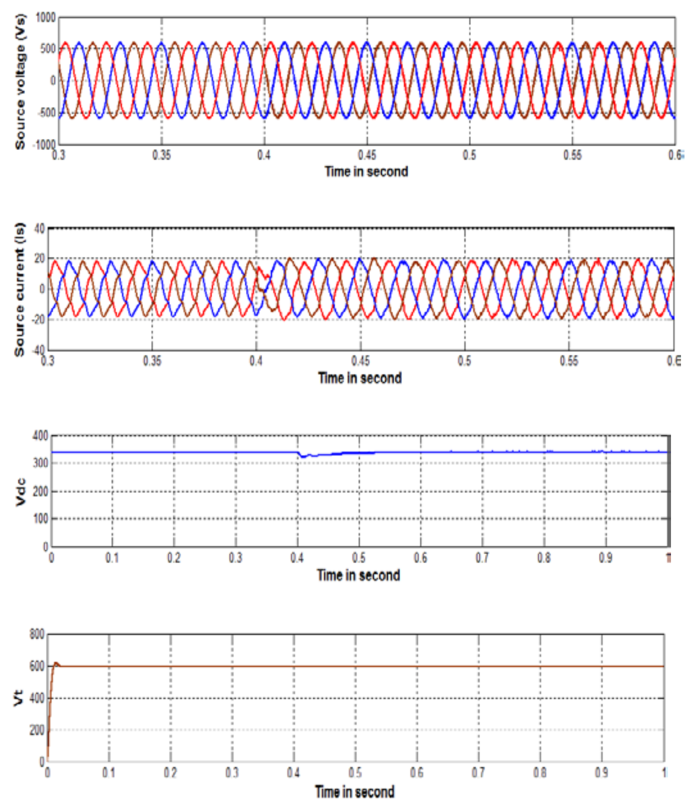


Fig 8(a). Frequency spectrum of source current

B. Performance of DSTATCOM With Zig/Zag Transformer for Nonlinear Load.

DSTATCOM with Zig/Zag transformer in the three phase four wire system for voltage regulation, neutral current compensation for nonlinear, balanced load are shown in figure 9.



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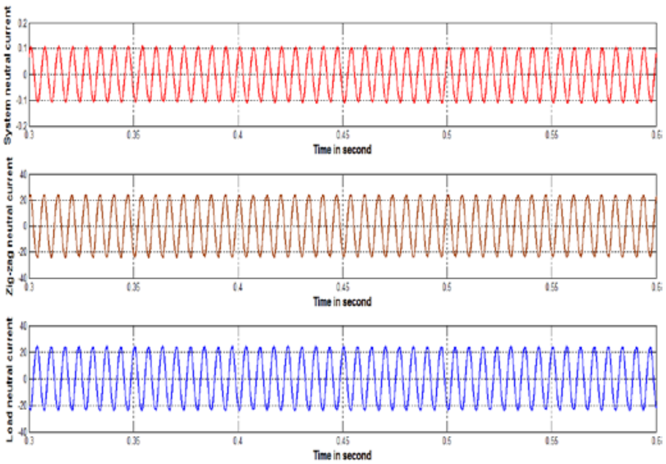

FFT analysis of DSTATCOM with Star/Delta transformer with nonlinear load is shown the total harmonic distortion is 4.3% supply current is near to the prescribe limit of the lower order harmonics.

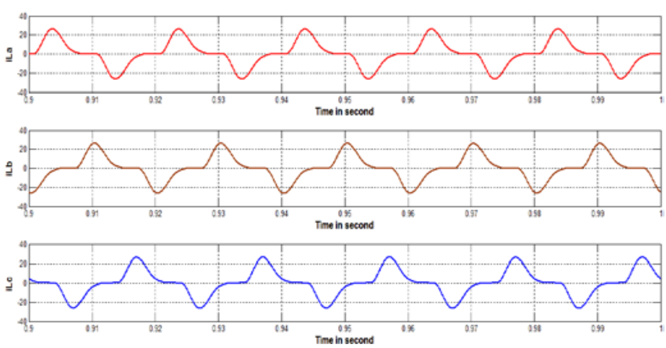

Fig.9 Performance of Zig/Zag transformer based DSTATCOM

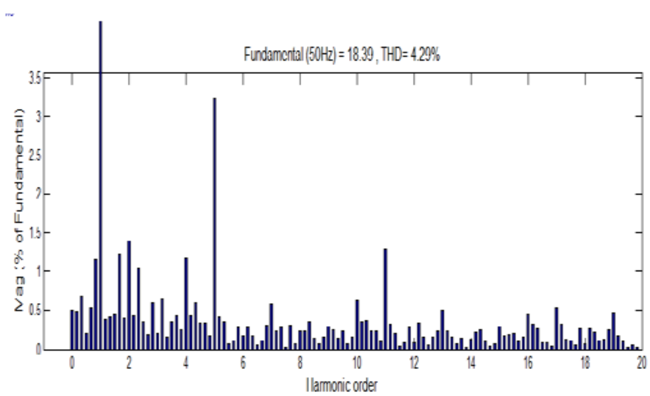

Fig.9(a) Frequency spectrum of source current

C. Comparison of Star/Delta and Zig/Zag transformer based DSTATCOM

S.No.	Parameter	DSTAT COM	Zig/Zag	Star/ Delta
1.	kVA	-	3	3.4
2	Input Voltage	415v, 50Hz	140 v	240 v
3.	DC Voltage	700	340	340
4.	DC Bus Capacitance	4200 μf	3200 μf	3200 μf
5.	Transformer Required	-	240v/140 v	140v/140 v/140v
6.	VSC	4 lag	3 lag	3 lag
7.	No. of switches	8	6	6

Table 10. Comparison of proposed systems

The modeling and simulation of DSTATCOM consisting three-leg VSC with Star/Delta and Zig/Zag transformer has been carried out and demonstrated for neutral current compensation, harmonic elimination, load balancing and power factor correction. The Star/Delta transformer has reduced the rating of dc current, compensated the neutral current and it has been found effective for compensating the zero sequence fundamental and harmonics currents. The kVA rating of Star/Delta transformer is higher compared to the Zig/Zag transformer.

6. CONCLUSION

In the performace It is observed that the control alogrithm is having fast response to perform various power quality problems in the distribuition syatem. The performance of system consisting DSTATCOM with Star/Delta and Zig/Zag transformer has been demonstrated for reactive power compensation along with harmonic elimination, neutral current compensation and load balancing. The voltage regulation and power factor correction of DSTATCOM has been achieved in satisfactory manner. The Star/Delta transformer has been reduced the rating of dc current and found effective for compensating to solve power quality issues.

7. FUTURE SCOPES

The DSTATCOM can be designed using a current source inverter. The DSTATCOM can be used as a custom power device for compensating large loads. An integrated DSTATCOM controller can be designed for voltage regulation, reactive power compensation, power factor improvement and unbalanced load compensation.

REFERENCES

[1] Bhim singh, P Jayaprakash, and D.P. Kothari, "Three-phase Four wire DSTATCOM with H-Bridge VSC and Star/Delta Transformer for Power Quality Improvement". *IEEE*2008.

[2] Bhattacharya Sourabh, "Applications of DSTATCOM Using MATLAB/Simulation in Power System" *ISSN 2277 - 2502 Vol. 1(ISC-2011), 430-433 (2012) Res.J.Recent.Sci*

[3] P Jayaprakash, Bhim singh, and D.P. Kothari, "Reduction In Rating of Voltage Source Converter of DSTATCOM using a Zig-zag Transformer". *IEEE*2012.

[4] Sai Kiran Kumar.Sivakoti, Y.Naveen Kumar, D.Archana "Power Quality Improvement in Distribution System Using D-Statcom in Transmission Lines" International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 Vol. 1, Issue 3, pp.748-752.

[5] Bindeshwar Singh, K.S. Verma, Pooja Mishra, Rashi Maheshwari, Utkarsha Srivastava, and Aanchal Baranwal "Introduction to FACTS Controllers: A Technological Literature Survey" International Journal of Automation and Power Engineering Volume 1 Issue 9, December 2012

[6] M.Bhanu Siva, M.R.P Reddy, Ch.Rambabu "Power Quality Improvement of Three-phase four-wire DSTATCOM with Fuzzy logic Controller" (IJCSIT) International Journal of Computer Science and Information Technologies, Vol. 2 (5) , 2011, 2273 – 2276.

[7] Bhim singh, P Jayprakash, T R Somayajulu, D P Kothari, Ambrish Chandra,and Kamal-Al-Haddad, "Intgrated Three-leg VSC with a Zig-zag Transformer based Three-phase Four-wire DSTATCOM for Power Quality Improvement". *IEEE*2008.

[8] Akwukwaegbu I. O, Okwe Gerald Ibe "Concepts of Reactive Power Control and Voltage Stability Methods in Power System Network" IOSR Journal of Computer Engineering (IOSR-JCE) e-ISSN: 2278-0661, p- ISSN: 2278-8727Volume 11, Issue 2 (May. - Jun. 2013), PP 15-25 www.iosrjournals.org

[9] Bhim Singh, P.Jayaprakash, T.R. Somayajulu, and D.P. Kothari, "Reduced Rating VSC With a Zig-Zag Transformer for current compensation in a three- phase Four-Wire Distribution system" *IEEE transactions on power delivert, vol.24.no. 1. January 2009.*

[10] Bhim Singh, V Rajagopal "Power Balance Theory Based Control of an Electronic Load Controller for an Isolated Asynchronous Generator Driven by Uncontrolled Pico hydro Turbine" *2009.*

[11] Ch. Siva Koti Reddy, Dr. P.Linga Reddy, "A DSTATCOM-Control Scheme for Power Quality Improvement of Grid Connected Wind Energy System for Balanced and Unbalanced Nonlinear Loads" International Journal of Modern Engineering Research (IJMER) www.ijmer.com Vol.2, Issue.3, May-June 2012 pp-661-666 ISSN: 2249-6645

[12] Sunil Kumar and Bhim Singh "Control of 3-Leg VSC Based 3-Phase 4-Wire DSTATCOM using Modified Instantaneous Symmetrical Component Theory" International Journal of Automation and Power Engineering (IJAPE) Volume 2 Issue 6, September 2013.

[13] Bhim singh, P Jayaprakash, and D.P. Kothari, "Implementation of An Isolated Three-leg VSC with Stat/Hexagon Transformer based Three-Phase Four-wire DSTATCOM". *Second international conference on emerging trends in engineering and technology, ICETET*-09.

[14] Bhim singh, P Jayaprakash, and D.P. Kothari, "isolated H-Bridge VSC based 3-phase 4-wire DSTATCOM for Power Quality improvement". *ICSET*2008.

[15] A. de Almeida, L. Moreira. J. Delgado "Power Quality Problems and New Solutions" ISR – Department of Electrical and Computer Engineering University of Coimbra, Pólo II 3030-290 Coimbra (Portugal).

[16] Bhim singh, P Jayaprakash, and D.P. Kothari, "a T-connected transformer and three-leg VSC based DSTATCOM for Power Quality improvement". *IEEE transactions on power electronics, vol.23,no. 6 november 2008.*

[17] C. Sankaran, "Power Quality" CRC Press new yark 2002.

[18] Bassy W. Kennedy, "Power Quality Primer" chaptor-2 pg no. 33 to 43. McGraw hill new yark.

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