The Journal of CPRI,
Vol. 12, No. 1, March 2016 pp. 51-58

Performance analysis of distribution static compensator for power quality perspective

Sanath Saralaya* and Manjunatha Sharma K**

In recent years the use of nonlinear loads in the distribution system has increased drastically. Due to these nonlinear loads, power quality problems occurs in the system. Distribution Static Compensator (DSTATCOM) is a voltage source converter based shunt connected custom power device, used in distribution system for performance improvement. DSTATCOM will maintain constant voltage at load terminals and limit the Total Harmonic Distortion (THD). This paper presents a case study on investigation of performance of DSTATCOM at different operating scenarios. IEEE 13 bus industrial system is used to study the performance of three leg DSTATCOM. Voltage control mode with PI controller is used to control RMS voltage at Point of Common Coupling (PCC). PSCAD/EMTDC™ tool is used to study the performance. From the study it is found that DSTATCOM is able to maintain voltage at 1 pu.

Keywords: *DSTATCOM, THD, PI controller, VCM, CCM.*

1.0 INTRODUCTION

In power system, the distribution system is the last link between the generation side and load side. The current scenario of distribution system is very complex because of different types of loads like linear and nonlinear loads. These loads will induce power quality issues such as harmonic distortions and voltage unbalance. In recent years, lot of work has been carried out in order to connect renewable energy sources to distribution system. Due to this, the issues related to power quality have increased.

Custom power devices are the best solution to overcome power quality problems [1]. These devices are connected in series or shunt with the network. Distributed Static Compensator (DSTATCOM) is one such shunt connected custom power device. DSTATCOM is consists of a voltage source converter (VSC). A capacitor is connected at the DC side of the converter to supply the required reactive power. The basic structure of DSTATCOM is shown in Figure 1. Many power quality issues like power factor correction, voltage unbalance, sag, swell, flicker and harmonics are mitigated by the DSTATCOM by supplying required reactive power. The performance of DSTATCOM mainly depends on the reference generation algorithm and the control technique which is used to generate switching pulses for semiconductor devices. Semiconductor devices such as Gate Turn Off Thyristors (GTO) or Insulated Gate Bipolar Transistors (IGBT) are used to enable the application of modern control algorithms.

In recent years, many researchers have concentrated on improving the performance of DSTATCOM under different operating conditions. Many reference generation techniques and control algorithms are proposed in the literature. These

*Research Scholar, Electrical And Electronics Engineering, National Institute of Technology Karnataka, Surathkal - 575025,
E-mail: sanathsaralaya@gmail.com, Mobile: +91-9743080918

control algorithms can be divided into Voltage Control Mode (VCM) and Current Control Mode (CCM) [2]. Both control modes have their own advantages and disadvantages. From the literature it is found that, VCM techniques performs better in mitigating voltage sag and swell, and able to maintain the voltage at Point of Common Coupling (PCC) to desired value but it fails in mitigating current related issues. Therefore, CCM techniques have become more popular. But CCM method cannot compensate voltage disturbances. Synchronous Reference Frame (SRF) theory, Instantaneous reactive power theory and Instantaneous symmetrical component theory are some of current reference generation techniques are listed in [3]. Other proposed reference generation techniques are based on neural network and fuzzy logic technique [4]-[7]. Research is in progress to achieve the advantages of both VCM and CCM in a single control algorithm [8], [9]. Different control techniques are proposed to control the DC link voltage at a constant value. Different topologies are proposed for three phase three wire and three phase four wire systems. The DSTATCOM is also used to supply active power and reactive power by connecting energy source to the DC link of VSC [10], [11]. Depending on the applications suitable topologies are selected.

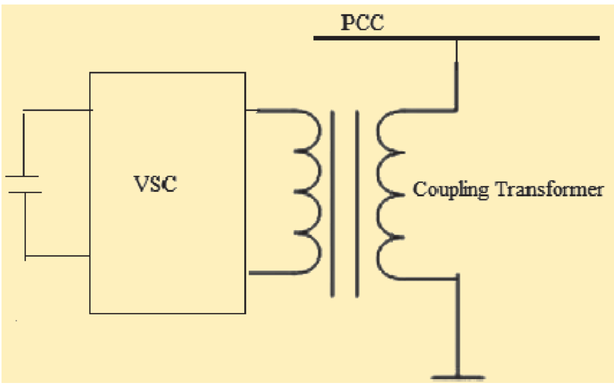

FIG. 1 STRUCTURE OF DSTATCOM

In this paper, a case study has been presented to study the performance of DSTATCOM in voltage controlled mode. To control voltage at the PCC a controller is used. To simulate and study the performance of DSTATCOM, PSCAD/ EMTDC™ software package is used. Section 2 presents the details of the system used and explains about the controller used for the simulation. The results obtained in different cases considered for the simulation are given in section 3. Finally, the conclusions are given in section 4.

2.0 SYSTEM DETAILS

2.1 IEEE 13 Bus System

The test system consists of 13 buses and represents the industrial loads [12] which represents a medium sized industrial plants. The test system has utility supply of 69 kV and local Distributed Generation (DG) source of 13.8 kV. Figure 2 shows the test system.

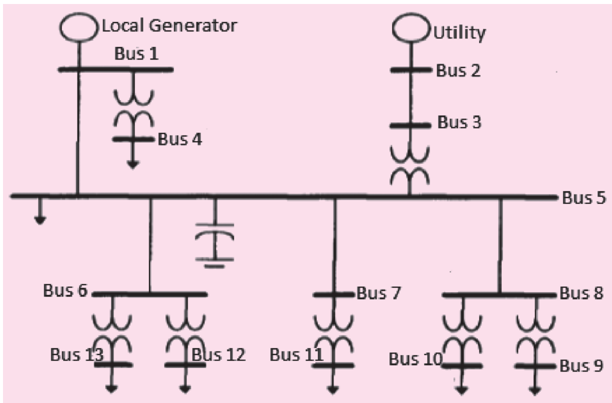

FIG. 2 IEEE 13 BUS INDUSTRIAL SYSTEM [12]

2.2 DSTATCOM

For this case study the DSTATCOM used is a three leg VSC topology with a capacitor connected in DC link. It has six semiconductor switching devices. The three leg DSTATCOM is interfaced through a coupling transformer. The arrangement of six pulse DSTATCOM is shown in Figure 3. In this study, a three winding three phase transformer is used to connect DSTATCOM to the system.

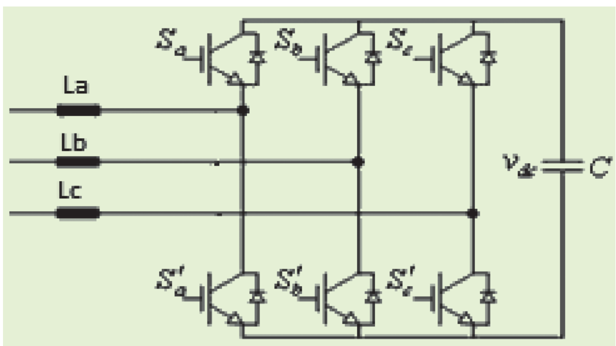

FIG. 3 SIX PULSE DSTATCOM

2.3 Control Method

Figure 4 shows the block diagram of control scheme used for controlling DSTATCOM [13]. V_{act} is a measured RMS value of voltage at the point of common coupling. This measured value of voltage is compared with V_{ref} (V_{ref}=1 pu). The error obtained by comparison of actual signal and reference signal is processed by Proportional Integral (PI) controller in order to obtain the phase angle delta. The obtained phase angle is used as phase angle of sinusoidal modulation signal. A triangular wave of frequency of 5 kHz is used as a carrier wave for PWM generator with a modulation index of 1.

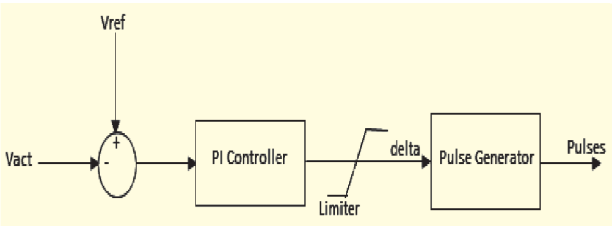

FIG. 4 CONTROL SCHEME FOR DSTATCOM

3.0 SIMULATION RESULTS

Total four cases are considered as listed in Table 1. In each case, voltage profile at bus 5 and source current are analysed. The system is simulated for 5 s. The line to ground (LG) fault is applied at 3 s and removed at 3.5 s. Figure 5 shows the implementation of IEEE 13 bus industrial system with DSTATCOM in PSCAD^{TM}. The DSTATCOM is connected to three phase three winding transformer along with a switch for compensation of PCC voltage at bus 5. The performance of DSTATCOM is studied and voltage profile at PCC is observed.

TABLE 1

DIFFERENT CASES CONSIDERED FOR SIMULATION

Case No.	With DSTATCOM	With LG fault at Bus 3
1	No	No
2	Yes	No
3	No	Yes
4	Yes	Yes

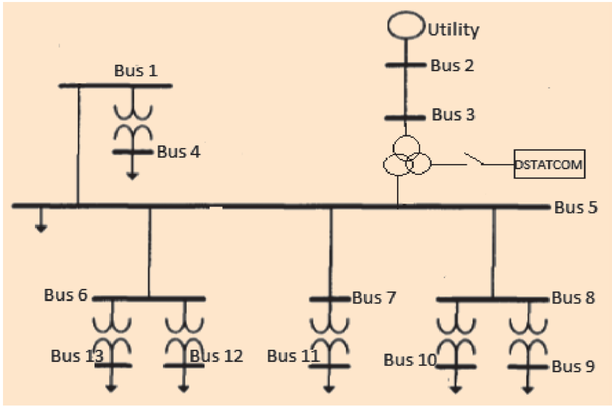

FIG. 5 IEEE 13 BUS INDUSTRIAL SYSTEM WITH DSTATCOM

3.1 Case 1- Without DG, without DSTATCOM and without fault

Figure 6 shows the RMS value of the voltage at PCC in per unit. It is found that the value of RMS voltage is 0.95 pu. Figures. 7 and 8 show the voltage and current waveform of phase A at PCC, respectively.

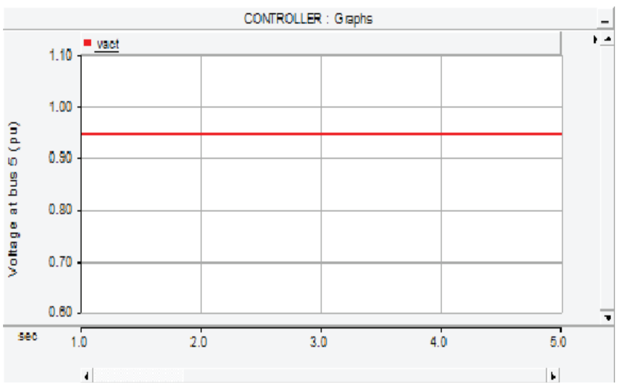

FIG. 6 RMS VALUE OF PCC VOLTAGE-WITHOUT DSTATCOM AND WITHOUT FAULT

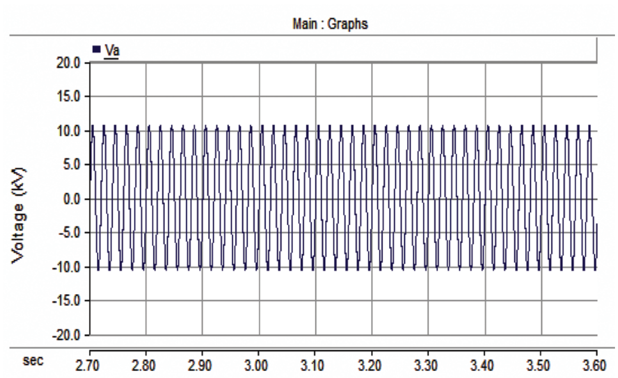

FIG. 7 VOLTAGE AT PHASE A AT PCC- WITHOUT DSTATCOM AND WITHOUT FAULT

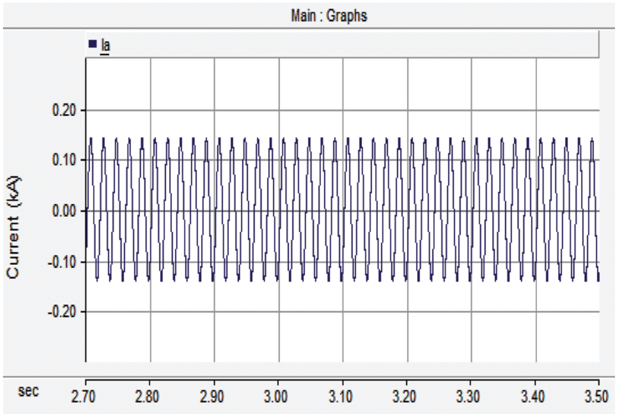

FIG. 8 SOURCE CURRENT AT PHASE A-WITHOUT DSTATCOM AND WITHOUT FAULT

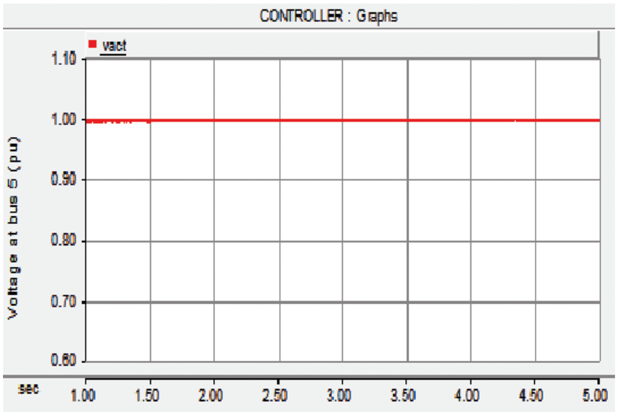

FIG. 9 RMS VALUE OF PCC VOLTAGE- WITH DSTATCOM AND WITHOUT FAULT

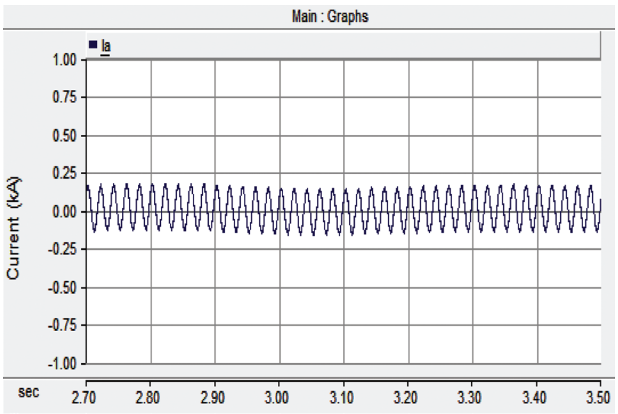

FIG. 10 SOURCE CURRENT AT PHASE A- WITH DSTATCOM AND WITHOUT FAULT

3.2 Case 2- Without DG, with DSTATCOM and without fault

Figures 9 and 10 show the RMS value of PCC voltage and source current in phase A, respectively. By connecting the DSTATCOM, the RMS voltage at PCC is maintained at 1 pu. The obtained value of voltage THD is 2.811% and current THD is 1.713%. Both values of THDs are within the limit as specified in IEEE standard.

3.3 Case 3- Without DG, without DSTATCOM and with fault

Figures 11 and 12 show the RMS voltage at PCC and source current in pre-fault condition, respectively. Figure 13 shows the current during fault condition. The voltage is reduced to 0.7 pu during the fault period.

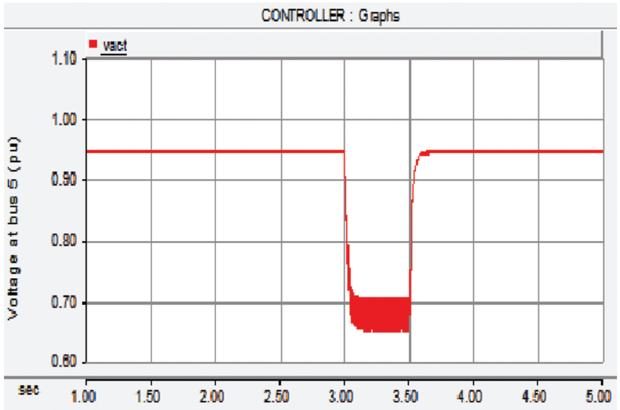

FIG. 11 RMS VALUE OF PCC VOLTAGE- WITHOUT DSTATCOM AND WITH FAULT

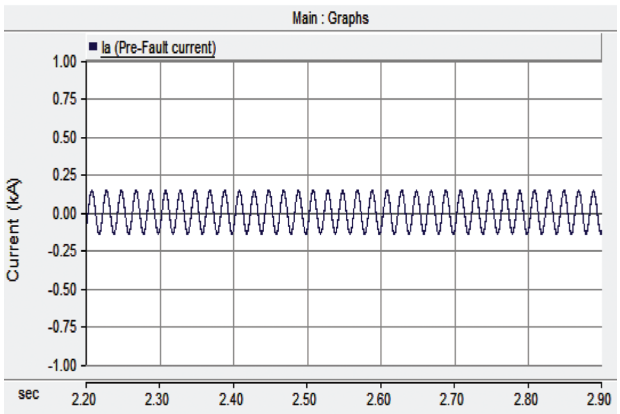

FIG. 12 PRE-FAULT SOURCE CURRENT AT PHASE A- WITHOUT DSTATCOM AND WITH FAULT

3.4 Case 4- Without DG, with DSTATCOM and with fault

Figures 14 and 15 shows the RMS voltage at PCC and source current in pre-fault condition, respectively. Figure 16 shows the current during fault condition. By connecting the DSTATCOM, the RMS voltage at PCC is maintained at 1 pu. The obtained value of voltage THD is 2.814% and current THD is 1.796% both values of THDs are within the limit of the IEEE standard.

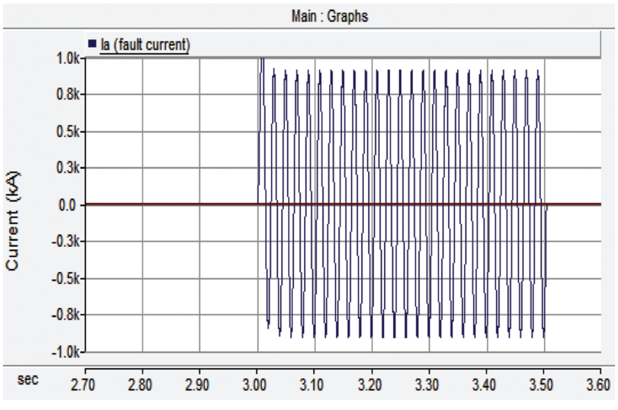

FIG. 13 SOURCE CURRENT AT PHASE A DURING FAULT- WITHOUT DSTATCOM AND WITH FAULT

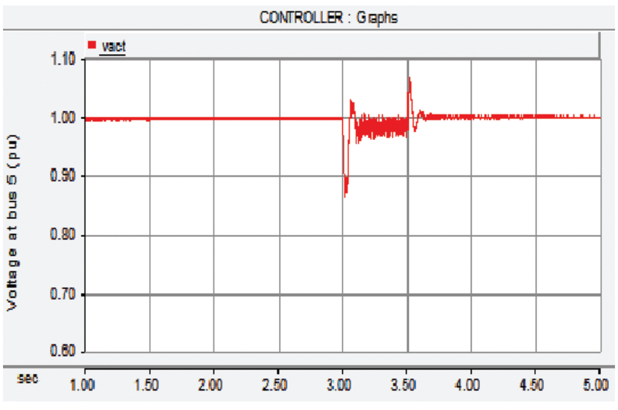

FIG. 14 RMS VALUE OF PCC VOLTAGE- WITH DSTATCOM AND WITH FAULT

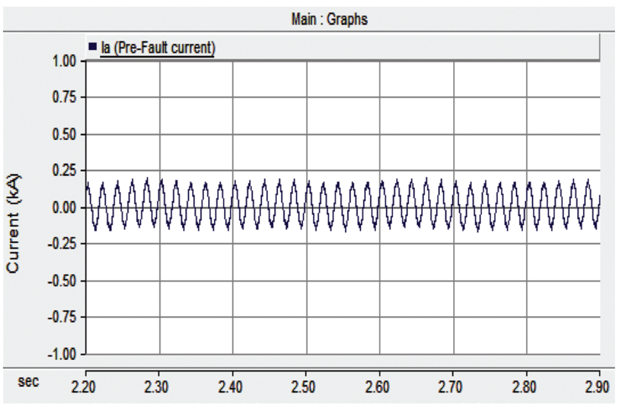

FIG. 15 PRE-FAULT SOURCE CURRENT AT PHASE A- WITH DSTATCOM AND WITH FAULT

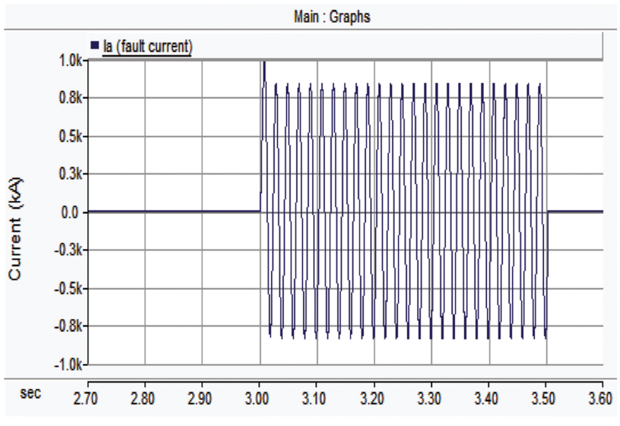

FIG. 16 SOURCE CURRENT AT PHASE A DURING FAULT- WITH DSTATCOM AND WITH FAULT

Table 2 shows the voltage and THDs for different cases, which gives the summary of case studies conducted. DSTATCOM is able to maintain the PCC RMS voltage at PCC at 1 pu

TABLE 2

VOLTAGE AND THD FOR DIFFERENT CASES

Case No.	Voltage at Bus 5 (pu)	Current THD (%)	Voltage THD (%)
1	0.950	0.0002	-
2	1	1.713	2.811
3	0.7 (during fault)	0.005	-
4	1	1.796	2.814

4.0 CONCLUSIONS

A simulation based case study is conducted using PSCAD/EMTDC™ simulation tool to analyse the performance of DSTATCOM in different operating condition. From the case studies conducted, it can be observed that the DSTATCOM gives satisfactory performance in all the situations by maintaining the voltage at the point of common coupling at 1pu. It is also observed that harmonics are increased when the DSTACOM is connected to the system but it remains within the limit of the IEEE 519 standard. Further, it can be concluded that the VCM based control algorithm is suitable for mitigating voltage related disturbances.

APENDIX

The line, transformer and load data of IEEE 13 bus system are given in Table 3, 4 and 5, respectively. Base values of 13.8 kV and 10 MVA.

TABLE 3

LINE DATA OF IEEE 13 BUS SYSTEM

From Bus	To Bus	R (pu)	X(pu)
2	3	0.00139	0.00296
1	5	0.00122	0.00243
5	6	0.00075	0.00063
5	7	0.00157	0.00131
5	8	0.00109	0.00091

TABLE 4

TRANSFORMER DATA OF IEEE 13 BUS SYSTEM

From Bus	To Bus	Voltage (kV)	Tap	kVA
3	5	69:13.8	69	15000
1	4	13.8.:0.48	13.45	1500
6	13	13.8:0.48	13.45	1250
6	12	13.8:4.16	13.11	1725
7	11	13.8:0.48	13.45	1500
8	10	13.8:0.48	13.8	1500
8	9	13.8:2.4	13.11	3750

TABLE 5

LOAD DATA OF IEEE 13 BUS SYSTEM

Bus No.	P (kW)	Q (kVAR)
4	600	530
5	2240	2000
9	2800	2500
10	370	330
11	810	800
12	1310	1130
13	1150	290

REFERENCES

[1] M M Osborne, R H Kitchin and H M Ryan, Custom power technology in distribution systems - An overview, IEEE Symp. Reliability Security of Distrib. Sys.

[2] C Kumar and M K Mishra, A Voltage Controlled DSTATCOM for Power Quality Improvement, IEEE Transactions on Power Delivery, Vol. 29, No. 3, pp. 1499-1507, June 2014.

[3] B Singh, P Jayaprakash, D P Kothari, A Chandra and K A Haddad, Comprehensive study of DSTATCOM configurations, IEEE Trans. Ind. Inf., Vol. 10, No. 2, pp. 854-870, May 2014.

[4] B Singh and P Jayapraksh, S Kumar, D P Kothari, Implementation of neural network controlled three leg VSC and a transformer as three phase four wire DSTATCOM, IEEE Trans. Ind. Appl., Vol. 47, No. 4, pp. 1892-1901, Aug. 2011.

[5] S R Arya, B Singh, Performance of DSTATCOM using leaky least mean square algorithm, IEEE Journal of Emerging and Selected Topics in Power Electronics, Vol. 1, No. 2, pp. 104-113, June 2013.

[6] S R Arya and B Singh, Implementation of DSTATCOM for power quality enhancement using learning vector quantisation, IET Gener., Transmiss. Distrib., Vol. 7, No. 11, pp. 1244-1252, 2013.

[7] B Singh and S R Arya, Neural network based conductance estimation control algorithm for shunt compensation, IEEE Trans. Ind. Inf., Vol. 10, No. 1, pp. 569-577, Feb. 2014.

[8] C Kumar and M K Mishra, A multifunctional DSTATCOM operating under stiff source, IEEE Trans. Ind. Electron., Vol. 61, No. 7, pp. 3131-3136, July 2014.

[9] C Kumar, M K Mishra, An Improved hybrid DSTATCOM topology to compensate reactive and nonlinear loads, IEEE Trans. Ind. Electron., Vol. 61, No. 12, pp. 6517-6527, Dec. 2014.

[10] V K Kannan and N Rengarajan, Photovoltaic based DSTATCOM for power quality improvement, Electrical Power and Energy Systems., Vol. 42, pp. 685-692, 2012.

[11] C K Sundarabalan and K Selvi, PEM fuel cell supported DSTATCOM for power quality enhancement in three phase four wire distribution system, International Journal of Hydrogen Energy, Vol. 39, pp. 19051-19066, 2014.

[12] IEEE Power Engineering Society, Test Systems for Harmonic modelling and Simulation, IEEE Trans. Power Del., Vol. 14, No. 2, April 1999.

[13] S H Hosseini, A Nuzarloo and E Babaei, Super Capacitor Based DSTATCOM applied in IEEE 13 bus industrial Distribution system, in Proc. 8th Electric. Engg. Electron. Comp. Telecommun. Inf. Techn. Conf., pp. 715-718, 2011.

[14] O A Lara and E Acha, Modelling and analysis of custom power systems by PSCAD/EMTDC, IEEE Trans. Power Del., Vol. 17, No. 1, pp. 266-272, Jan. 2002.

[15] K R Padiyar, FACTS controllers in power transmission and Distribution, New Age International Publishers, New Delhi, 2013.