International Journal of Modern Engineering Research (IJMER)
www.ijmer.com Vol. 3, Issue. 6, Nov - Dec. 2013 pp-3521-3528 ISSN: 2249-6645

DSTATCOM with LCL Filter to Improve Voltage Sags and Current Harmonics in Power Distribution System

Firas Marwan Flaih[1], Jyoti Shrivastava[2]
*(Department of Electrical Engineering (Power System), SHIATS, Allahabad)
** (Department of Electrical Engineering , SHIATS, Allahabad)

ABSTRACT: *An increasing demand for high quality, reliable electrical power and increasing number of distorting loads may leads to an increased awareness of power quality both by customers and utilities. The most common power quality problems today are voltage sags, harmonic distortion and low power factor. This paper presents the improvement of voltage sags, harmonic distortion and low power factor using Distribution Static Compensator (D-STATCOM) with LCL Passive Filter in power distribution network. The model is based on the Voltage Source Converter (VSC) principle. The D-STATCOM injects a current into the system to mitigate the voltage sags. a LCL(inductor-capacitor-inductor) Passive Filter with pulse width modulation (PWM) was then added to D-STATCOM to improve current harmonic distortion. The simulations were performed using MATLAB SIMULINK version R2009b.*

Keywords: *Distribution static compensator(D-STATCOM),(inductor-capacitor-inductor) LCL filter, Voltage Source Converter (VSC), Sine Pulse Width Modulation(SPWM), Voltage Sags, Total Harmonics Distortion (THD).*

I. INTRODUCTION

DSTATCOM is one of the custom power devices, used for supplying reactive, harmonic currents of load demand in distribution system. DSTATCOM is connected in parallel to load at the point of common coupling (PCC) through interface filter. [1]

In other words, the switching frequency voltage at the leg of current controlled VSI is properly shaped by low pass L filter to inject the desired filter currents at PCC. Thus, the injected filter currents consist of switching frequency current ripple. These ripples are transferred to source currents, and also to the PCC voltages in presence of feeder impedance. Amplitude of this current ripple has inverse relation with respect to value of L filter. Thus, large value of L is required to have sufficient ripple attenuation, which increases cost, deteriorate compensation slew rate and consequently dynamic performance of system [2].

Higher order LCL filter has better switching ripple attenuation capability compared to L filter, and this can be achieved by using small values of overall inductance and capacitance [3].

An increasing demand for high quality, reliable electrical power and increasing number of distorting loads may leads to an increased awareness of power quality both by customers and utilities. The most common power quality problems today are voltage sags, harmonic distortion and low power factor Voltage sags is a short time (10 ms to 1 minute) event during which a reduction in r.m.s voltage magnitude occurs [4].

Voltage sags are one of the most occurring power quality problems. For an industry voltage sags occur more often and cause severe problems and economical losses. Utilities often focus on disturbances from end-user equipment as the main power quality problems [5].

Harmonic currents in distribution system can cause harmonic distortion, low power factor and additional losses as well as heating in the electrical equipment. It also can cause vibration and noise in machines and malfunction of the sensitive equipment [6].

power quality problems in transmission and distribution systems. Among these, the D-STATCOM is one of the most effective devices. A new PWM-based control scheme has been implemented to control the electronic valves in the DSTATCOM. The D-STATCOM has additional capability to sustain reactive current at low voltage, and can be developed as a voltage and frequency support by replacing capacitors with batteries as energy storage. [7, 8]

D-STATCOM is connected in shunt or parallel to the 11 kV test distribution system. It also is design to improve power quality such as voltage sags, harmonic distortion and low power factor in power distribution network.

II. DISTRIBUTION STATIC COMPENSATOR

A DSTATCOM is a controlled reactive source, which includes a Voltage Source Converter (VSC) and a DC link capacitor connected in shunt, capable of generating and/or absorbing reactive power. The operating principles of a DSTATCOM are based on the exact equivalence of the conventional rotating synchronous compensator.[9]

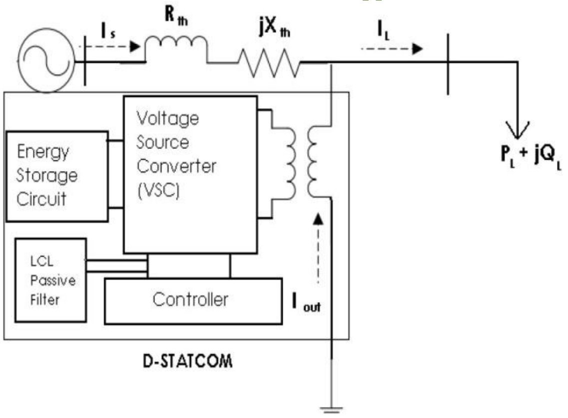


Figure2.1. Schematic diagram of a D-STATCOM

A D-STATCOM consists of a two-level VSC, a dc energy storage device, controller and a coupling transformer connected in shunt to the distribution network. Figure 2.1 shows the schematic diagram of D-STATCOM.

$$Iout = IL - IS = IL - \frac{Vth - VL}{Zth} \quad (2.1)$$

$$Iout < \gamma = IL < (-\theta) - \frac{Vth}{Zth} < (\gamma - \beta) + \frac{Vth}{Zth} < (-\beta) \quad (2.2)$$

Iout = output current
IS =source current
IL =load current
VL =load voltage
Vth =Thevenin voltage
Zth =impedance

Referring to the equation 2.2, output current, Iout will correct the voltage sags by adjusting the voltage drop across the system impedance, (Zth =R+jX). It may be mention that the effectiveness of D-STATCOM in correcting voltage sags depends on:
a) The value of Impedance, Zth = R+jX
b) The fault level of the load bus.

2.2 Voltage source converter (VSC)

Two level Voltage Source Converter is a standard application widely used in industry as a rectifier, inverter and compensator system. This application is chosen as basic by leading world electrical companies for its efficiency and simplicity. Although it is regarded as a well known and established system, there are still some aspects worth analysing. Concurrently to multilevel converter systems development the high precision control and modulation systems of two level VSC are still considered[10]

A voltage-source converter is a power electronic device that connected in shunt or parallel to the system. It can generate a sinusoidal voltage with any required magnitude, frequency and phase angle. The VSC used to either completely replace the voltage or to inject the 'missing
voltage'. The 'missing voltage' is the difference between the nominal voltage and the actual. It also converts the DC voltage across storage devices into a set of three phase AC output voltages [11].

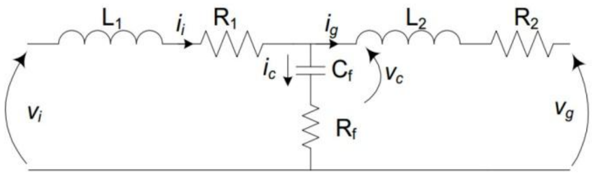
Suitable adjustment of the phase and magnitude of the DSTATCOM output voltages allows effectives control of active and reactive power exchanges between D-STATCOM and AC system. In addition, the converter is normally based on some kind of energy storage, which will supply the converter with a DC voltage [12].

2.3 LCL Passive Filter

Commonly a high-order LCL filter has been used in place of the conventional L-filter for smoothing the output currents from a VSI [13].

The LCL filter achieves a higher attenuation along with cost savings, given the overall weight
and size reduction of the components. LCL filters have been used in grid-connected inverters and pulse-width modulated active rectifiers [14].
because they minimize the amount of current distortion injected into the utility grid, Good
performance can be obtained in the range of power levels up to hundreds of kW, with the use of small values of inductors and capacitors [15].
The following per-phase equivalent model has been fully described in an earlier paper written by the authors [16]. The LCL filter model is shown in Fig.2.2

www.ijmer.com Vol. 3, Issue. 6, Nov - Dec. 2013 pp-3521-3528 ISSN: 2249-6645



where L1 is the inverter side inductor, L2 is the grid-side inductor, Cf is a capacitor with a series Rf damping resistor, R1 and R2 are inductors resistances, voltages Vi and Vg are the input and output (inverter voltage and output system voltage). A functional block diagram for the grid connected inverter using this LCL filter is shown in Fig 2.3

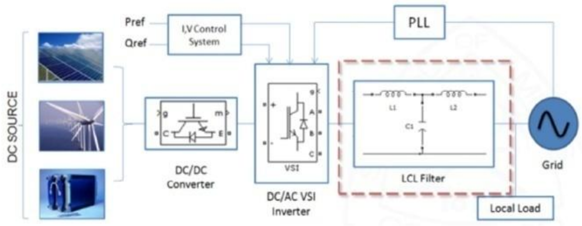


Fig. 2.3 General schematic for grid interconnected DC power source

To design it, equation (2.3), (2.4) and (2.5) are used [17].

$$L_g = \frac{E_n}{2\sqrt{6}\, i_{ripm} . f_{sw}} \qquad (2.3)$$

$$L_c = \frac{L_g}{2} \qquad (2.4)$$

$$C_f = \frac{L + L_g}{L L_g \, (2\pi f_{res})^2} \qquad (2.5)$$

Where *Lg =L1* , *Lc= L2*

To design an efficient LCL Passive filters make sure that,

$$10 f_n \leq f_{res} \leq 0.5 f_{sw}$$

2.4 Controller

Proportional-integral controller (PI Controller) is a feedback controller which drives the system to be controlled with a weighted sum of the error signal (difference between the output and desired set point) and the integral of that value.
Figure 2.4 shows the block diagram of Controller system. The controller system is partially part of distribution system.

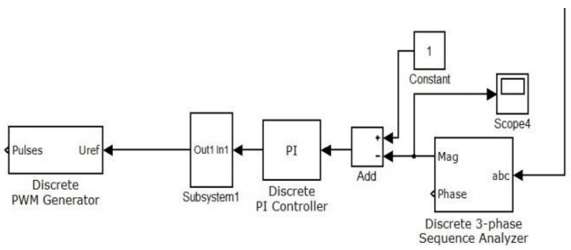


Figure 2.4.Block Diagram of Controller System

PWM generator is the device that generates the Sinusoidal PWM waveform or signal. To operate PWM generator, the angle is summed with the phase angle of the balance supply voltages equally at 120 degrees. Therefore, it can produce the desired synchronizing signal that required. PWM generator also received the error signal angle from PI controller. The modulated signal is compared against a triangle signal in order to generate the switching signals for VSC valves[18].

2.5 Energy Storage Circuit

DC source is connected in parallel with the DC capacitor. It carries the input ripple current of the converter and it is the main reactive energy storage element. This DC capacitor could be charged by a battery source or could be recharged by the converter itself as shown in figure 2.1 in energy storage circuit[18].

Symbol	**Name**	**Quantity Value**
En	RMS value of grid voltage	19kV (rms)
i ripm	15% of peak value fundamental Harmonic current	793.1mA (rms)
Lg	Grid-side filter inductance	1630 mH
Lc	Converter-side filter inductance	815 mH
Cf	Filter capacitance	0.0017 uF
Rf	Resistance of converter-side filter	15 Ω
fsw	Switching frequency	20kHz
fres	Resonance frequency	5.25 kHz

TABLE 2.1. LIST AND VALUE OF PARAMETERS USE IN SIMULATION

Figure 2.5 shows the input current harmonic spectrum with respect to the IEEE STD 519-1992 harmonic limits.

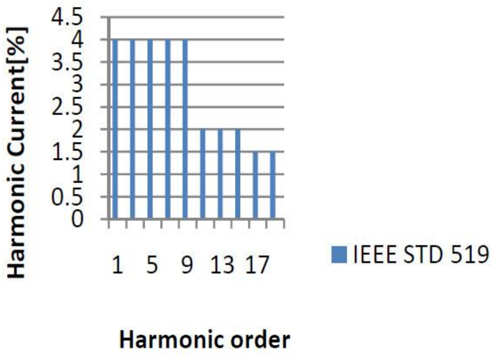


Figure 2.5.IEEE STD 519-1992 of current Harmonic spectrum

III. METHODOLOGY

To enhance the performance of distribution system, DSTATCOM was connected to the distribution system. DSTATCOM was designed using MATLAB simulink version R2009b.

3.2 Test System

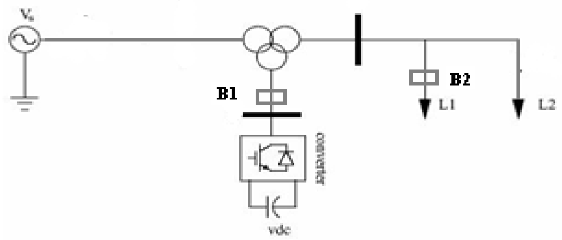


Figure3.1.Single line diagram of the test system

The test system shown in figure 3.1 comprises a 19kV, 50Hz transmission system, represented by a Thevenin equivalent, feeding into the primary side of a 3-winding transformer connected in Y/Y/Y, 19/11/11 kV. A varying load is connected to the 11 kV, secondary side of the transformer. A two-level D-STATCOM is connected to the 11 kV tertiary winding to provide instantaneous voltage support at the load point. A 750 μF capacitor on the dc side provides the D-STATCOM energy storage capabilities. Breaker 1 is used to control the period of operation of the D-STATCOM and breaker 2 is used to control the connection of load 1 to the system.

3.3 Simulink Model for the test system

The test system was design using MATLAB simulink is shown in figure 3.2 below.

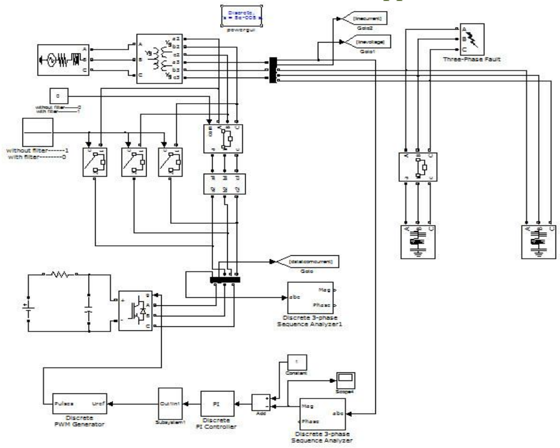


Figure3.2.Diagram of the test system

IV. RESULTS AND DISCUSSION

To create distortion in the distribution system, different types of fault such as Three Line to Ground (TLG), Double Line to Ground (DLG), Line to Line (LL), and Single Line to Ground (SLG) are injected.

4.2 Without insertion of D-STATCOM

TABLE4.1. RESULTS OF VOLTAGE SAGS FOR DIFFERENT TYPES OF FAULT.

Fault resistance ***Rf*,Ω**	Voltage sags for **TLG** fault (p.u)	Voltage sags for **DLG** fault (p.u)	Voltage sags for **LL** fault (p.u)	Voltage sags for **SLG** fault (p.u)
0.6	0.6296	0.6820	0.7388	0.8123
0.7	0.6803	0.7237	0.7719	0.8530
0.8	0.7270	0.7625	0.8035	0.8563
0.9	0.7678	0.7971	0.8327	0.8756

Table 4.1 shows the overall results of voltage sags in p.u for different types of fault. From the table, it can be observed that when the value of fault resistance is increase, the voltage will also increased for different types of fault.

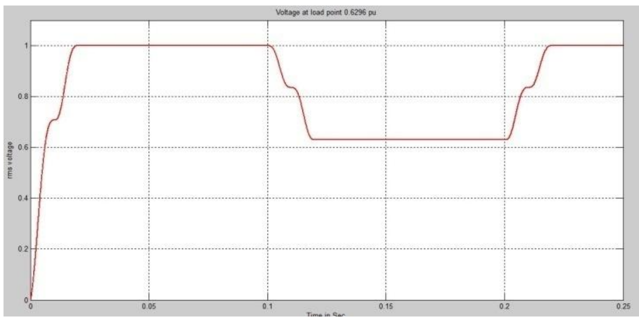


Figure4.1(a).voltage at load point is 0.6296 p.u **TLG**

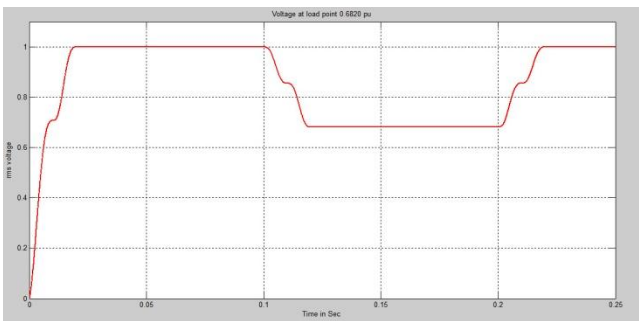


Figure4.1(b).voltage at load point is 0.6820 p.u **DLG**

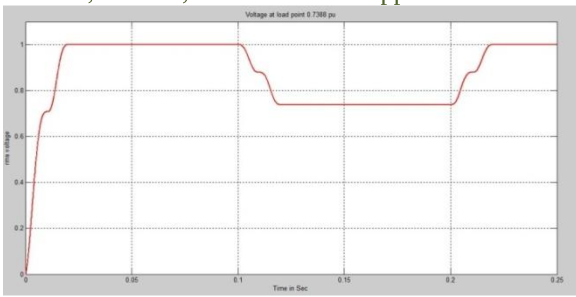


Figure4.1(c).voltage at load point is 0.7388 p.u **LL**

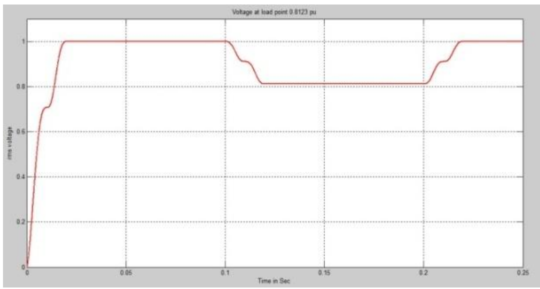


Figure4.1(d).voltage at load point is 0.8123 p.u **SLG**

Figure 4.1(a) to 4.1(d) show the simulation results of the test system for different types of fault. The fault occur during (100-200ms) when the fault resistance, Rf =0.6 Ω.

4.3 With insertion of D-STATCOM

Fault resistance ***Rf*,Ω**	Voltage sags for **TPG** fault (p.u)	Voltage sags for **DLG** fault (p.u)	Voltage sags for **LL** fault (p.u)	Voltage sags for **SLG** fault (p.u)
0.6	0.9317	0.9796	1.0184	0.9849
0.7	0.9400	0.9802	1.0158	0.9829
0.8	0.9487	0.9827	1.0146	0.9835
0.9	0.9580	0.9879	1.0156	0.9881

TABLE4.2. RESULTS OF VOLTAGE SAGS FOR DIFFERENT TYPES OF FAULT

Table 4.2 shows the overall results of voltage sags in p.u with different types of fault. From the table, it can be observed that voltage sags improved with insertion of D-STATCOM. The value of voltage sags is between (0.9317 to 1.0184 p.u.).

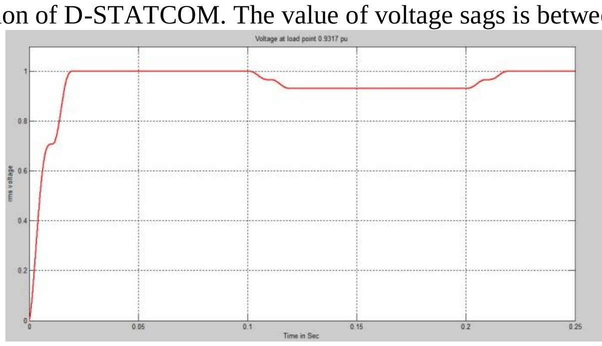


Figure4.2(a).voltage at load point is 0.9317 p.u **TLG**

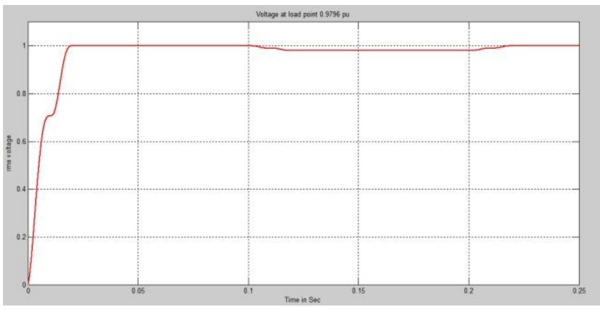


Figure4.2(b).voltage at load point is 0.9796 p.u **DLG**

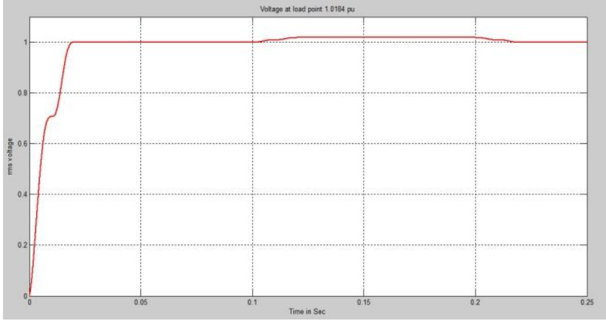


Figure4.2(c).voltage at load point is 1.0184 p.u **LL**

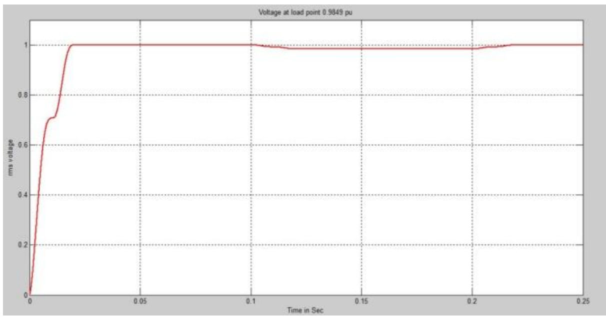


Figure4.2(d).voltage at load point is 0.9849 p.u **SLG**

Figure 4.2(a) to 4.2(d) show the simulation results of the test system for different types of fault. The fault occurs during (100-200ms) when the fault resistance is 0.6 Ω.

4.4 D-STATCOM without LCL Filter

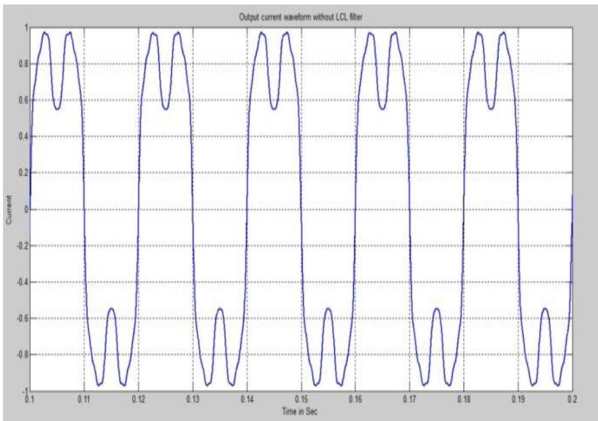


Figure4.3.waveform of distortion output current without LCL Filter

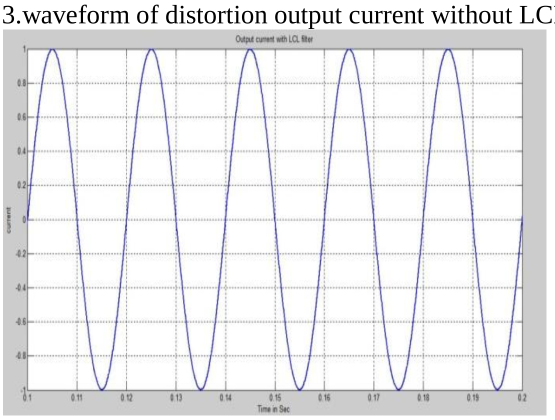


Figure4.4.waveform of output current with LCL Filter

Figure 4.3, shows the waveform of distortion output current without LCL Filter and Figure4.4.shows waveform of sinusoidal output current with LCL Filter.

V. CONCLUSION

The simulation results show that the voltage sags can be mitigate by inserting D-STATCOM to the distribution system. By adding LCL filter to D-STATCOM, The power factor also increase close to unity. Thus, it can be concluded that by adding D-STATCOM with LCL filter the voltage and current are improved.

REFERENCES

Journal Papers:

[1] B. C. Parikshith, "'Integrated approach to filter design for grid connected power converters', Master of Science Thesis, Indian Institute of Sciences, Bangalore, India, ," 2009 .

[2] W. Zhao and G. Chen, "Comparison of active and passive damping methods for application in high power active power filter with LCL filter," in International Conference on Sustainable Power Generation and Supply, pp 1-6, Apr. 2009.

[3] M. Liserre, F. Blaabjerg, and S. Hansen, "Design and control of an LCL filter-based three-phase active rectifier," IEEE Trans. Ind. Appl., vol. 41, no. 5, pp. 1281–1291, Sept.-Oct.2008.

[4] Anaya-Lara O, Acha E., " Modelling and Analysis Of Custom Power Systems by PSCAD/EMTDC", IEEE Transactions on Power Delivery, Volume 17, Issue: 2008, Pages: 266-272.

[5] Bollen, M.H.J.," Voltage sags in Three Phase Systems", Power Engineering Review , IEEE, Volume 21, Issue :9, September 2011, PP: 11-15.

[6] Noramin Ismail, Wan Norainin Wan Abdullah " Enhancement of Power Quality in Distribution System Using D-STATCOM" The 4th International Power Engineering and Optimization Conference (PEOCO2010), Shah Alam, Selangor, MALAYSIA. 23-24 June 2010,pp:418-224

[7] M.Madrigal, E.Acha., "Modelling OF Custom Power Equipment Using Harmonics Domain Twchniques",IEEE 2009

[8] R.Meinski, R.Pawelek and I.Wasiak, "Shunt Compensation For Power Quality Improvement Using a STATCOM controller Modelling and Simulation", IEEE Proce, Volume 151, No. 2, March 2008.

[9] Kolli Nageswar Rao, C. Hari Krishna, Kiran Kumar Kuthadi " Implementation of D-STACTOM for Improvement of Power Quality in Radial Distribution System", International Journal of Modern Engineering Research (IJMER), Vol. 2, Issue. 5, Sep.-Oct. 2012 pp-3548-3552.

[10] G. Radomski, "Modelling and modulation of voltage source converter",13th Int. Power Electronics and Motion Control Conf. 1, 504–511 (2008).

[11] J.Nastran , R. Cajhen, M. Seliger, and P.Jereb,"Active Power Filters for Nonlinear AC loads, IEEE Trans.on Power Electronics Volume 9, No.1, PP: 92-96, Jan 2009.

[12] L.T. Moran ,P.D Ziogas, and G.Joos , Analysis and Design Of Three Phase Current source solid State Var Compensator, IEEE Trans, on Indutry Applications. Volume 25, No.2, 2009, PP:356-365.

[13] F. Bouchafaa, D. Beriber, and M. S. Boucherit, "Modeling and control of a gird connected PV generation system," in Control & Automation (MED), 18th Mediterranean Conference, 2010, pp. 315 – 320.

[14] V. Blasko and V. Kaura, "A Novel Control to Actively Damp Resonance in Input LC Filter of a Three-Phase Voltage Source Converter," IEEE Transactions on Industry Applications, vol. 33, no. 2, pp. 542–550, 2007.

[15] Y. Tang, S. Member, P. C. Loh, P. Wang, and F. H. Choo, "Generalized Design of High Performance Shunt Active Power Filter With Output LCL Filter," IEEE Transactions on Industrial Electronics, vol. 59, no. 3, pp. 1443–1452, 2012.

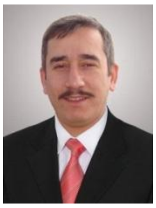
[16] A. Reznik, M. G. Simões, A. Al-durra, and S. M. Muyeen, "LCL Filter Design and Performance Analysis for Small Wind Turbine Systems," in Power Electronics and Machines in Wind Applications (PEMWA), IEEE, 2012, pp. 1–7.

[17] A. Reznik, M.Godoy Simões, Ahmed Al-Durra, S. M. Muyeen "LCL Filter Design and Performance Analysis for Grid Interconnected Systems", in The 7th International Conference on Power Electronics, 2012, pp. 1133–1138.

Books:

[18] Narain G. Hingorani , Laszlo Gyugyi "Understanding FACTS" 2013 pp.171-177.

BIOGRAPHIES



Firas Marwan Fakhraldin *has done his B.Tech degree in Electrical Engineering from University of Mosul , Mosul, Iraq, and his M.Tech degree in Electrical Power Systems from SHIATS, Allahabad, UP, India. He is working as Engineer in North Distribution Electricity , Ministry of Electricity, Iraq .*

Dr. Jyoti Shrivastava *has done her graduation in Electrical Engineering and her post graduation in Design of Heavy Electrical Equipments. At present she is serving as an Senior Assistant Professor in Electrical Engineering department at college of Engineering and Technology, SHIATS, Allahabad, India. She has several international and National papers to her credit. Her field of interest and research are Power system control and operation, power quality improvement and condition monitoring of heavy electrical equipments. Her research aims to increase Transmission & Distribution system capacity and enhancing system reliability.*