Science Front Publishers
Journal for Foundations and Applications of Physics, vol. 1, No. 1 (2014)
(sciencefront.org)
ISSN 2394-3688

Improvement of power factor of a grid connected load system using a static compensator

Manoj Kumar Kar, Bidyadhar Rout* and J K Moharana[a]

Department of Electrical Engineering,
Veer Surendra Sai University of Technology, Burla, Odisha, India

[a]Department of Electrical & Electronics Engineering,
GITA, Bhubaneswar, Odisha, India

**Corresponding author Email:* rout.bdr@gmail.com

(Received 10 June 2014, Published 28 July 2014)

Abstract

The power factor deteriorates due to non-linear loads, interconnected grid system, amplitude disturbances and wave shape disturbances. A low power factor system draws high internal current causing excessive heat. It requires heavier equipments to absorb internal energy requirements. Also large penalty is imposed on low power factor consumers. So power factor should be improved in order to get rid of the above problems. In this paper, a shunt connected Flexible AC Transmission Systems (FACTS) device such as Static Compensator (STATCOM) is used to improve the power factor by compensating the reactive power required by the load.

Keywords: *FACTS, Static Compensator (STATCOM), VSC, System Modeling*

1. Introduction

Power factor is the product of distortion factor and displacement factor. So in order to improve power factor we need to improve both. Distortion factor can be improved by filtering out the harmonics where as displacement factor can be improved by using compensating devices. Previously the classical methods like synchronous condenser, capacitor banks were used for compensating reactive power but having a number of disadvantages [1]. The reactive power (VAR) compensation and control have been recognized [2-6] as an efficient and economic means of increasing power system transmission capability and stability. The FACTS (Flexible AC Transmission Systems) devices such as STATCOM (Static Compensator) have been introduced [6-8] more recently which employs a VSC (voltage source converter) with a fixed DC link capacitor that provides the required VAR control [9-11], with a rapid control of bus voltage and improvement of utility power factor[12-16].

2. Modeling and Analysis

Operating Principles

The STATCOM is a shunt-connected device in which output current is controlled independent of variation of ac system voltage. The STATCOM is a voltage-source converter (VSC)-based device which maintains the bus voltage by injecting a variable ac current through a transformer and generates real (when power storage device is available) and reactive power at its ac terminals. This enables more robust voltage support. This device needs to be installed as close to the sensitive load as possible to maximize the compensating capability.

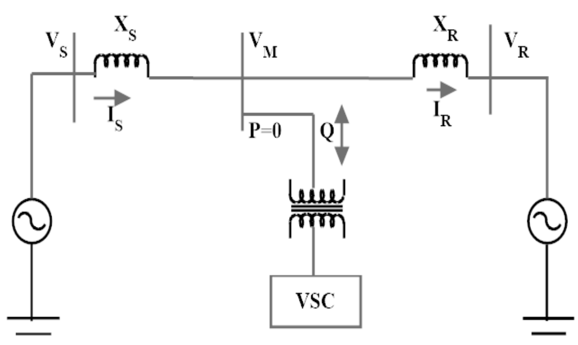


Figure-1 STATCOM model

In most cases, the DC voltage support for the VSC will be provided by the DC capacitor of relatively small energy storage purpose. Therefore, in steady state condition, the active power exchanged with the line has to be maintained at zero as shown in figure 1. The angle between the 3-phase system voltage V_s and STATCOM output voltage V_o is α. When the STATCOM operates with α=0, the active power sent to the system device becomes zero while the reactive power will mainly depend on the voltage module. If $V_o > V_s$, the reactive power will be sent to the 3-phase system from STATCOM (capacitive operation), causing a current flow in this direction. In the reverse case, the reactive power will be absorbed from the system through the STATCOM (inductive operation) and the current will flow in the opposite direction. Finally if the modules of V_s and V_o are equal, there won't be either current or reactive flow in the system.

System Model

The modeling of the STATCOM is carried out under the following assumptions:

- All switches are ideal
- The source voltages are balanced
- The harmonic contents produced by switching action are negligible

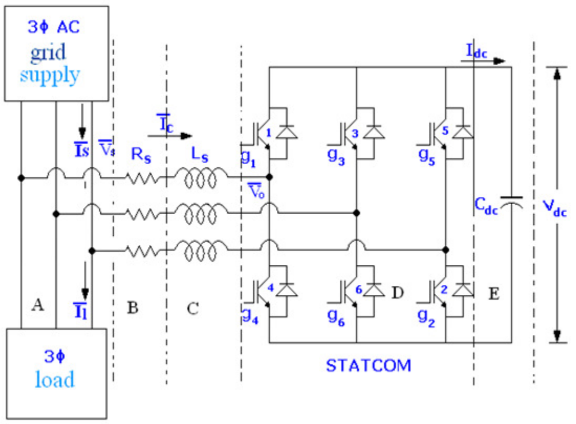


Figure 2: Main circuit diagram of statcom

The 3-phase system voltage $V_{s_{abc}}$ lagging with the phase angle α to the STATCOM output voltage $V_{o_{abc}}$ and differential form of the STATCOM currents are defined in (1) and (2).

$$V_{s_{abc}} = \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} = \sqrt{\frac{2}{3}} V_s \begin{bmatrix} \sin(\omega t - \alpha) \\ \sin(\omega t - \alpha - \frac{2\pi}{3}) \\ \sin(\omega t - \alpha + \frac{2\pi}{3}) \end{bmatrix} \quad (1)$$

The STATCOM current is governed by the following equations.

$$L_s \frac{d}{dt} \begin{bmatrix} i_{ca} \\ i_{cb} \\ i_{cc} \end{bmatrix} = -R_s \begin{bmatrix} i_{ca} \\ i_{cb} \\ i_{cc} \end{bmatrix} + \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} - \begin{bmatrix} V_{oa} \\ V_{ob} \\ V_{oc} \end{bmatrix} \quad (2)$$

The switching function S of the STATCOM is defined as

$$S = \begin{bmatrix} S_a \\ S_b \\ S_c \end{bmatrix} = \sqrt{\frac{2}{3}} m_c \begin{bmatrix} \sin(\omega t) \\ \sin(\omega t - \frac{2\pi}{3}) \\ \sin(\omega t + \frac{2\pi}{3}) \end{bmatrix} \quad (3)$$

Where m_c is the modulation index.

The mathematical model of the STATCOM in d-q frame is obtained as given below.

$$\frac{d}{dt} \begin{bmatrix} i_{cd}(t) \\ i_{cq}(t) \\ V_{dc}(t) \end{bmatrix} = \begin{bmatrix} -\frac{R_s}{L_s} & \omega & -\frac{m_c}{L_s} \\ -\omega & -\frac{R_s}{L_s} & 0 \\ \frac{m_c}{C_{dc}} & 0 & 0 \end{bmatrix} \begin{bmatrix} i_{cd}(t) \\ i_{cq}(t) \\ V_{dc}(t) \end{bmatrix} + \frac{V_s}{L_s} \begin{bmatrix} \cos\alpha \\ -\sin\alpha \\ 0 \end{bmatrix} \quad (4)$$

Steady State Analysis

In the steady state operation, all the d-q variables are denoted as steady state variables. The steady state responses of active I_{cd} and reactive I_{cq}, current components of the STATCOM and DC-link voltage V_{dc} are obtained on variation of 'α' in the interval of -5° to +5°. The detailed steady state responses with the Table.1 are given below and responses suggest the static and dynamic conditions of the STATCOM.

TABLE.1

Sl No.	STATCOM PARAMETERS	
	Parameters	*Values*
1	Frequency	50 Hz
2	Angular Frequency	314 rad/sec
3	RMS Line to Line voltage	415 V
4	Coupling Resistance	1.0 ohm
5	Coupling Inductance	5.0 mH
6	DC-Link Capacitor	500 uf
7	Modulation Index	0.979
8	Phase Angle	$\mp 5^0$
9	Load Resistance	52 ohm
10	Load Inductance	126 mH
11	Load Power Factor	0.79

3. Design of Controllers

The voltages and currents given in the equation (1) and (2) are transformed in to d-q frame as follows

$$L_s \frac{d}{dt}(i_{cq}) = -R_s i_{cq} - \omega L_s i_{cd} + v_{sq} - v_{oq} \quad (5a)$$

$$L_s \frac{d}{dt}(i_{cd}) = \omega L_s i_{cq} - R_s i_{cd} + v_{sd} - v_{od} \quad (5b)$$

The equation (5) can be modified as given in equation (6)

$$\frac{d}{dt} \begin{bmatrix} i_{cq} \\ i_{cd} \end{bmatrix} = \begin{bmatrix} -\frac{R_s}{L_s} & -\omega \\ \omega & -\frac{R_s}{L_s} \end{bmatrix} \begin{bmatrix} i_{cq} \\ i_{cd} \end{bmatrix} + \frac{1}{L_s} \left[\begin{bmatrix} v_{sq} \\ v_{sd} \end{bmatrix} - \begin{bmatrix} v_{oq} \\ v_{od} \end{bmatrix} \right] \quad (6)$$

So the equation (6) is a Multiple Input and Multiple Output (MIMO) system and its input and output are given in equation (7)

$$[u]=\begin{bmatrix} v_{oq} \\ v_{od} \end{bmatrix},[y]=\begin{bmatrix} i_{cq} \\ i_{cd} \end{bmatrix} \quad (7)$$

The active and reactive currents are coupled with each other through the reactance of the coupled inductor. So it is very essential to decouple the active and reactive current from each other and design the controller for getting the required value.

Design of current controller

This strategy attempts to decouple the d and q axes equations, so that the MIMO system reduces to two independent Single Input Single Output (SISO) systems. Hence, the control inputs v_{od} and v_{oq} are configured as,

$$v_{oq} = -v^*_{oq} - \omega L_s i_{cd} + v_{sq}$$
$$v_{od} = -v^*_{od} + \omega L_s i_{cq} + v_{sd} \quad (8)$$

The equation (9) given below can be obtained by replacing (6) by (8) which is independent of each other and thus defines an independent SISO system.

$$\begin{bmatrix} i_{cq} \\ i_{cd} \end{bmatrix} = \begin{bmatrix} -\frac{R_s}{L_s} & 0 \\ 0 & -\frac{R_s}{L_s} \end{bmatrix} \begin{bmatrix} i_{cq} \\ i_{cd} \end{bmatrix} + \frac{1}{L_s} \begin{bmatrix} v^*_{oq} \\ v^*_{od} \end{bmatrix} \quad (9)$$

$$G_i(s) = \frac{I_{cq}(s)}{V^*_{oq}(s)} = \frac{I_{cd}(s)}{V^*_{od}(s)} = \frac{1}{R_s + sL_s} \quad (10)$$

The transfer function of a PI controller is,

$$G_{pi}(s) = K(1+\frac{1}{s\tau}) = K_p + \frac{K_i}{s} \quad (11)$$

$$K_p = K, K_i = \frac{K}{\tau}$$

$$\tau = \frac{L_s}{R_s} = 0.3m\sec onds$$

$$K_p = 5.44\Omega, K_i = 10^3 \Omega.rad/s$$

Design of voltage controller

Relation between dc voltages v_{dc} and dc current i_{dc} is,

$$v_{dc} = \frac{1}{C}\int i_{dc} dt \quad (12)$$

The transfer function can be written as

$$G_v(s) = \frac{V_{dc}}{I_{dc}} = \frac{1}{sC} \quad (13)$$

Neglecting the power loss in the source resistance and power losses in the switches, balancing the power on both sides,

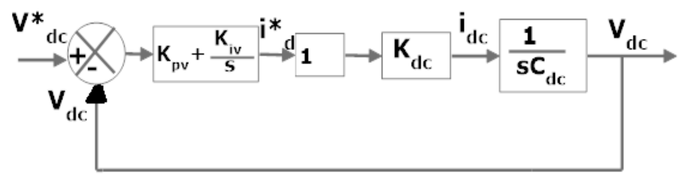
$$v_{sd} i_{cd} = v_{dc} i_{dc} \quad (14)$$

From the above equation we have,

$$\frac{i_{dc}}{i_{cd}} = \frac{v_{sd}}{v_{dc}} = \frac{415}{800} = 0.52 \quad (15)$$

The value of K can be determined from root locus as follows

$K_{pv} = 0.15, K_{iv} = 0.15 \times 10^2$



4. Simulations Results

The control scheme for DC link voltage, capacitor current, converter voltage, STATCOM current and steady state responses are obtained with MATLAB/SIMULINK with the parameters given in Table 1.

A. DC Link Voltage

The source current is regulated by the DC link voltage in the grid system. So the DC link voltage is kept constant across the capacitor. On increasing the magnitude of DC link voltage, the overshoot of all signals decreases.

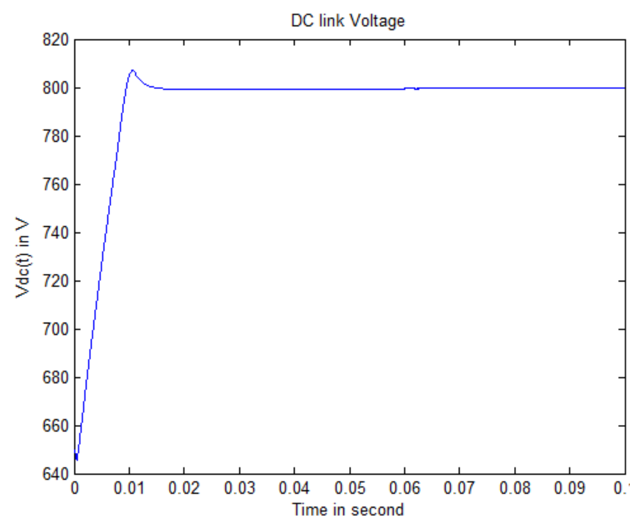


Figure-3 DC Link Voltage

B. Capacitor Current

The current through the DC link capacitor indicates the charging and discharging operation. The DC link capacitor contains the input ripple current of the converter and acts as the main reactive energy storage element.

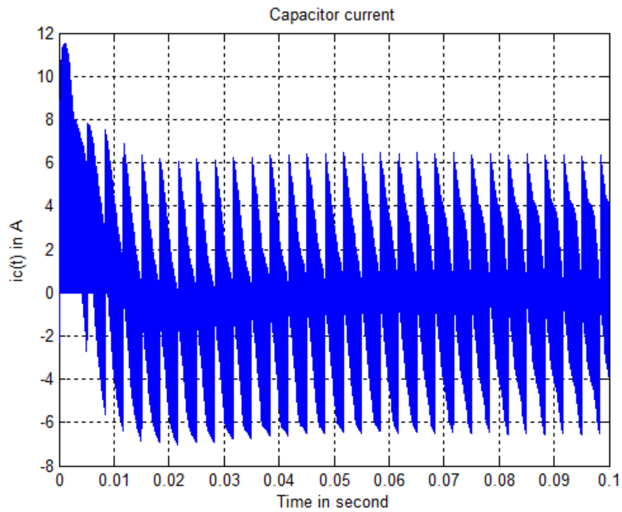


Figure-4 Capacitor current

C. STATCOM Current

When STATCOM controller is made ON, without changing any other load parameters, it starts to diminish for reactive demand as well as harmonic current. If the STATCOM devices are able to switch fast enough, it can also be used to inject harmonic currents in to the mains and operated as an active harmonic filter.

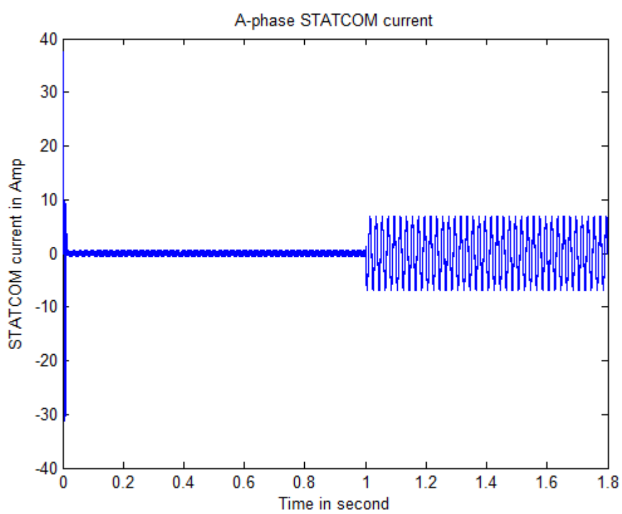


Figure-5 STATCOM current

Converter Voltage

By increasing the amplitude of the STATCOM terminal voltage, V_{oa}, above the amplitude of the utility voltage V_{sa} causes leading (capacitive) current I_{ca} to be injected to the system.

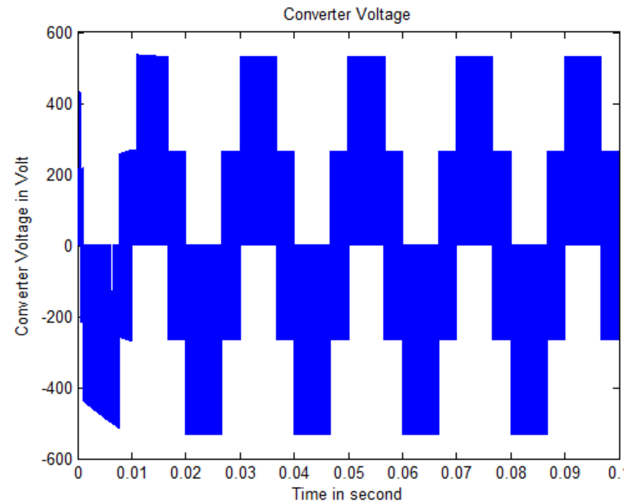


Figure-6 Converter voltage

Steady state Analysis

On variation of ' α' in the interval of -5° to + 5°, the following steady state responses are obtained and given in Figure-7(a),7(b) and 7(c). I_{cq} Varies linearly according to '∝'. The steady state value of the V_{dc} decreases as the value of modulation index increases. The reactive power has a linear variation according to 'α'. The active power always exists to cover the losses in the system and to maintain the DC-link voltage at the operating level.

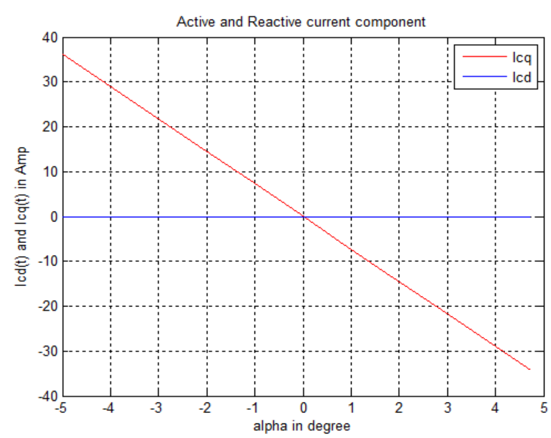


Figure 7(a) Active and reactive component of current

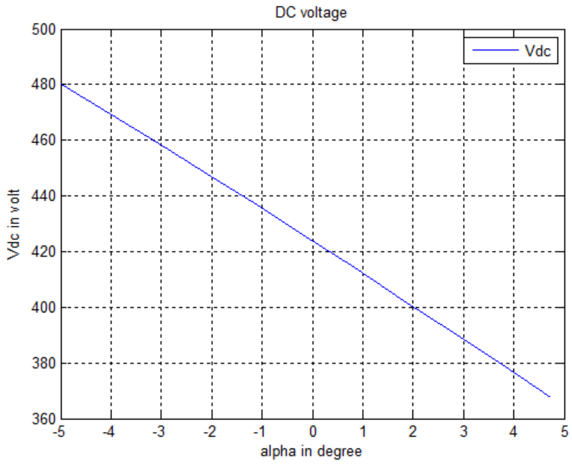


Figure 7(b) DC link voltage

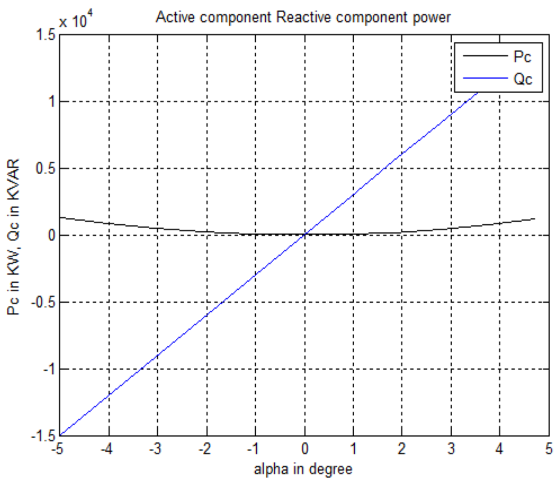
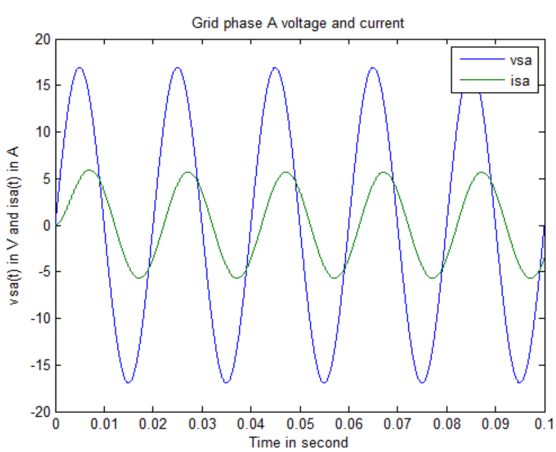


Figure 7(c) Active and reactive component of power

Grid Phase A Voltage and load Phase A current

Fig. 8 shows phase A load current lags behind the grid phase A voltage due to nonlinearity nature of load. The power factor in this case is 0.79.



.

Figure 8 Grid phase A voltage and load phase A current

Grid Phase A Voltage and STATCOM Phase A current:-

Figure 9 shows the grid phase A voltage and STATCOM phase A current. By injecting the STATCOM current to the load improves the power factor.

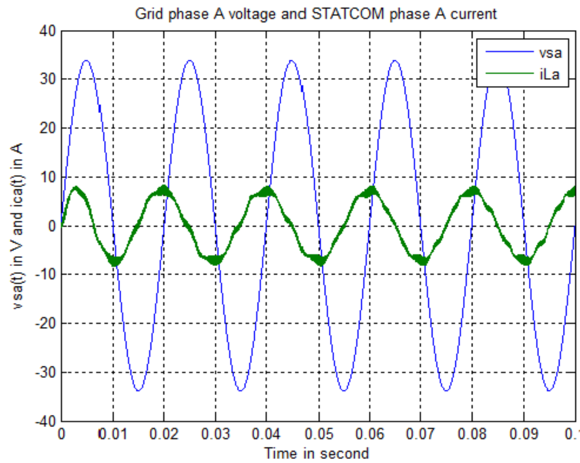


Figure 9 Grid phase A voltage and STATCOM phase A current

Grid Phase A Voltage and Phase A current:-

Figure 10 shows the grid phase A voltage and phase A current with unity power factor.

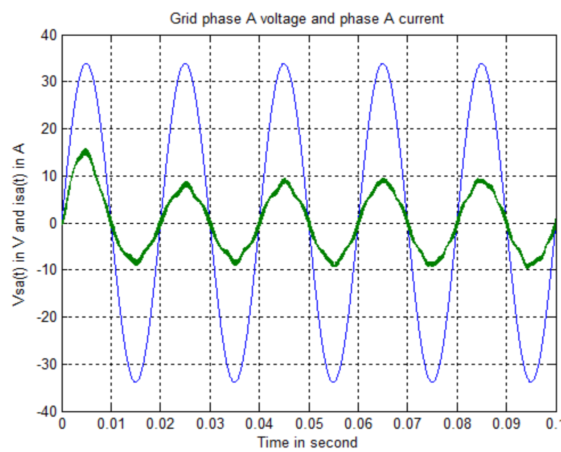


Figure 10 Grid phase A voltage and phase A current

5. Conclusion

This paper presents the design, modeling and analysis of STATCOM based control method for improving power factor. It uses PWM technique for switching strategy. Root locus method is used to find the controller parameters in DC voltage controller. The operation of the control system for the STATCOM is performed in MATLAB/SIMULINK. STATCOM cancels out the harmonic parts of the load current. It is seen that the STATCOM acts as a controlled reactive current source while compensating for internal losses and maintaining the dc bus voltage to a reference value. Thus it can improve power system performance.

REFERENCES

[1] C.W.Taylor and A.L.V.Leuven "Improving Power system stability Using the Time-Over voltage Capability of Large shunt Capacitor Banks", *IEEE Transactions on Power Delivery*, **11(2)**, 783 (1996)

[2] N.G.Hingorani and L. Gyugyi, "Understanding FACTS" *standard publishers Distributors* New Delhi, (1999)

[3] R.M.Mathur and R.K.Varma, "Thyristor based FACTS controllers for Electrical Transmission systems", *IEEE power Engineering society, Wiley-Interscience Publication*, (2002).

[4] Y.H.Song and A.T. John "Flexible AC Transmission Systems(FACTS)" *IEE power and Energy series Inc*.(1999)

[5] A.T.Johns, A.Ter-Gazarian and D.F.Wame, "Flexible ac transmission systems (FACTS)", *IEE power and Energy Series*, London

[6] A.M.Kulkarni and K.R.Padiyar, "Design of Reactive current and voltage controller of static condenser" *Electrical power and energy system*,**19**(6), 397 (1997)

[7] P.sensarma, K.R.padiyar and V.Ramnarayanam "Analysis and performance Evaluation of a DSTATCOM for compensating voltage fluctuations" *IEEE Transaction on power delivery*, **16(2)**, 259 (2001)

[8] Jovica V. Milanovic and Yan Zhang " Modeling of FACTs Devices for voltage sag mitigation studies in large power systems*" IEEE Transaction on power delivery*, **25(4)**, 3044 (2010)

[9] C.Hochgraf and R.H.Lasseter, "STATCOM controls for operation with unbalanced voltages" *IEEE Transaction on power delivery*,**13**(2), 538, (1998)

[10] Sharad W.Mohod, Mohan V.Aware "A STATCOM control scheme for Grid connected wind Energy system for power Quality Improvement", *IEEE systems Journal*,**4(3),** 346 (2010)

[11] D.Masand, S.Jain and G.Agnihotri "Control strategies for Distribution static compensator for power quality improvement" *IETE Journal of Research*, **54(6)**, 421, (2008)

[12] Amit Jain, Karan Joshi, Aman Behal and Ned Mohan "Voltage regulation with STATCOMs: Modeling, control and results" *IEEE Transaction on power delivery*, **21(2),** 726 (2006)

[13] P.W.Lehn and M.R.Iravant "Experimental Evaluation of STATCOM closed loop Dynamics" *IEEE Transactions on power delivery*, **13(4)**, 1378 (1998)

[14] B.Lin and Y.C.Lee, "Three-phase power Quality compensator under the unbalance source and nonlinear loads" , *IEEE Transactions on Industrial Electronics,***51(5),** 1009 (2004)

[15] B.S.Chen and Y.Y.Hsu "A minimal harmonic controller for a STACOM" *IEEE Transaction on Industrial Electronics*,**55(2)**, 655 (2008)

[16] H.Karshenas, H.Korjic and S.Dewan "Generalised techniques of selective harmonic elimination and current control in current source inverters/converters"*IEEE Transaction on power Electronics*,**10(5)**, 566 (1995)