A Novel Hysteresis Control Technique of VSI Based STATCOM

R.A.Kantaria[1], *Student Member, IEEE*, S.K.Joshi[2], K.R.Siddhapura[3]

Abstract:-**The Static Synchronous Compensator (STATCOM) is increasingly popular in power quality application. The Voltage Source Inverter (VSI) based STATCOM is used for eliminating current harmonics and compensating reactive power. This VSI draw or supply a compensating current from the utility such that it cancels current harmonics on the AC side. STATCOM generates a current wave such that it compensate by cancelling out the non-linear current waveform generateted by load. In this paper hysteresis controller based STATCOM is proposed. The STATCOM modeled using Simulink of MATLAB. Simulation result of 6 pulse VSI based STATCOM validate current control strategy to prevent harmonics current and compensate reactive power.**

Index Terms:- Power Quality, Harmonics, Voltage Source Inverter.

I. INTRODUCTION

Power electronic based power processing offers higher efficiency, compact size and better controllability. But on the flip side, due to switching actions, these systems behave as non-linear loads. This create power quality problems such as voltages Sag/Swell, flickers, harmonics, asymmetric of voltage have become increasingly serious [1]. At the same time, modern industrial equipments are more sensitive to these power quality problems than before and need higher quality of electrical power.

Until now, to filter these harmonics and to compensate reactive power at factory level, only capacitor and passive filters were used. More, new PWM based converters for motor control are able to provide almost unity power factor operations. This situation leads to two observations: on one hand, there is electronic equipment which generates harmonics and, on the other hand, there is unity power factor motor drive system which doesn't need power factor correction capacitor. Also, we cannot depend on this capacitor to filter out those harmonics. This is one of the reasons that the research is being done in the area of Active Power Filter (APF) and less pollutant drives. Loads, such as, diode bridge rectifier or a thyristor bridge feeding a highly inductive load, presenting themselves as current source at point of common coupling (PCC), can be effectively compensated by connecting an APF in shunt with the load [2-4].

[1& 2] Department of Electrical Engineering, M. S. University, Baroda, India
[3]Department of Electrical Engineering, Darshan Institute of Engineering & Technology, Rajkot, India

978-1-4244-7882-8/11/$26.00 ©2011 IEEE

The shunt APF acts as a current source and inject a compensating harmonic current in order to have sinusoidal, inphase input current. The developments in the digital electronics, communications and in process control system have increased the number of sensitive loads. In order to meet limits proposed by standards it is necessary to include some sort of compensation. In the last few years, solutions based on shunt Active filter have appeared [2]. Its main purpose is to compensate for load current imperfections, such as harmonics, reactive currents [2-3], and current unbalance. The control technique presented here is very simple.

The system configuration under consideration is discussed in section II. The proposed control technique based on unit vector template generation is explained in section III. A SIMPOWERSYSTEM (SPS) Matlab/Simulink model based on proposed control strategy is given in the section IV. The simulation results are discussed in section V and final section VI concludes the paper.

II. SYSTEM DESCRIPTION

Fig. 1 shows the basic compensation principle of shunt active power filter. A voltage source inverter (VSI) is used as the shunt active power filter [3]. This is controlled to generates a current wave such that it compensate by cancelling out the nonlinear current waveform generateted by load i.e. this active power filter (APF) generates the nonlinearities opposite to the load nonlinearities. Fig. 2 shows the different waveforms i.e. the load current, desired source current and the compensating current injected by the shunt active power filter which contains all the harmonics, to make the source current purely sinusoidal. This is the basic principle of shunt active power filter to eliminate the current harmonics and to compensate the reactive power.

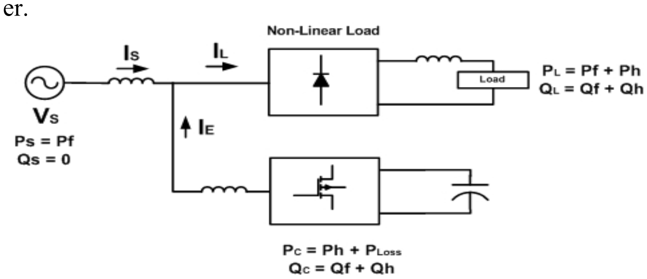

Fig. 1. Basic Compensation Technique

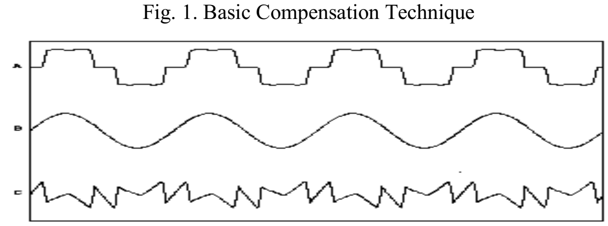

Fig. 2. Waveforms for the actual load current, desired source current and the compensating current

Total instantaneous power drawn by the nonlinear load can be represented as:- $P_L(t)=P_f(t)+P_r(t)+P_h(t)$.(01)

where *f, r, h* stands for fundamental, reactive, and harmonic contents.

Real power supplied by the source $P_s = P_f$ …..(02)
Reactive power supplied by the source $Q_s = 0$ …...(03)
Real power drawn by the load $P_L = P_f + P_h$ ....(04)
Reactive power drawn by the load $Q_L = Q_f + Q_h$ ......(05)
Real power supplied by the APF $P_c = P_h - P_{Loss}$ …...(06)
Reactive power supplied by APF $Q_c = Q_f + Q_h$ …..(07)
Where P_{Loss} is the loss component of the APF

From the single line diagram

$$i_s(t)=i_L(t)+i_c(t) \quad \text{…...(08)}$$

The utility voltage is given by

$$v_s(t)=V_m \sin \omega t \quad \text{…...(09)}$$

The load current will have a fundamental component and the harmonic components which can be represented as

$$i_L(t)=\sum_{n=1}^{\infty} I_n \sin(n\omega t+\phi_n) \quad \text{…...(10)}$$

$$=I_1 \sin(n\omega+\phi_1)+\sum_{n=2}^{\infty} I_n \sin(n\omega t+\phi_n) \quad \text{…...(11)}$$

Instantaneous load power $p_L(t)$ can be expressed as

$$p_L(t)=v_s(t) i_L(t) \quad \text{…...(12)}$$

$$= V_m \sin\omega t\, I_1 \sin(n\omega+\phi_1)+ V_m \sin \omega t \sum_{n=2}^{\infty} I_n \sin(n\omega t+\phi_n)$$

$$= V_m \sin \omega t \left(I_1 \sin \omega t \cos\phi_1 + I_1 \cos \omega t \sin\phi_1 \right) + V_m \sin \omega t \sum_{n=2}^{\infty} I_n \sin(n\omega t+\phi_n)$$

$$= V_m I_1 \sin^2 \omega t \cos\phi_1 + V_m I_1 \sin \omega t \cos \omega t \sin\phi_1 + V_m \sin \omega t \sum_{n=2}^{\infty} I_n \sin(n\omega t+\phi_n) \quad \text{……(13)}$$

$$= p_f(t)+p_r(t)+p_h(t) \quad \text{……(14)}$$

$$= p_f(t)+p_c(t) \quad \text{……(15)}$$

Where, the term $p_f(t)$ is the real power (fundamental), the term $p_r(t)$ represents the reactive power and the term $p_h(t)$ represents the harmonic power drawn by the load. For ideal compensation only the real power (fundamental) should by supplied by the source while all other power components (reactive and the harmonic) should by the active power filters i.e. $p_c(t)=p_r(t)+p_h(t)$ be supplied

$$P_r(t) = V_m I_1 \sin^2 \omega t \cos\phi_1 \quad \text{……(16)}$$

$$= v_s(t)\, i_s(t) \quad \text{……(17)}$$

$$= I_1 \cos\phi_1 \sin \omega t \quad \text{……(18)}$$

i.e. $i_s(t)=p_r(t)/v_s(t)$

$$= I_{sm} \sin \omega t$$

Where, $I_{sm} = I_1 \cos\phi_1$

Since, there are some switching losses in the inverter. Therefore, the utility must supply a small overhead for capacitor leaking and inverter switching losses in addition to the real power of load. Hence, total peak current supplied by the source

$$I_{\max}=I_{sm}+I_{sL} \quad \text{……(19)}$$

If active power filter provide the total reactive and harmonic power, then $i_s(t)$ will be in phase with the utility and pure sinusoidal. At this time, the active filter must provide the following compensation current:

$$i_s(t)=i_L(t)+i_c(t) \quad \text{……(20)}$$

Hence, the accurate value of the instantaneous current supplied by the source, $I_s(t) = I_{\max} \sin \omega t$

The peak value of the reference current $I_{\max}$ can be estimated by controlling the DC link voltage. The ideal compensation requires the mains current to be sinusoidal and in phase with the source voltage irrespective of load current nature. Hence, the desired source currents after compensation can be given as

$$I_{sa}^* = I_{\max} \sin \omega t \quad \text{……(21)}$$

$$I_{sa}^* = I_{\max} \sin(\omega t - 2\pi/3) \quad \text{……(22)}$$

$$I_{sa}^* = I_{\max} \sin(\omega t - 4\pi/3) \quad \text{……(23)}$$

Where, $I_{\max} (= I_1 + I_{sL})$ is the amplitude of the desired source currents. So, these currents are taken as the reference currents for the shunt APF.

III. Design Of STATCOM

STATCOM is operated in hysteresis control mode to regulate the load reactive power and eliminate harmonics from the supply currents. Mainly design include capacitor, Hysteresis controller based PI controller, unit vector template [4-6] .

A. Design of Capacitor

The reference value of the capacitor voltage $V_{dc\,ref}$ is selected mainly on the basis of reactive power compensation capability. For satisfactory operation the magnitude of $V_{dc\,ref}$ should be higher than the magnitude of the source voltage V_s. By suitable operation of switches a voltage V_c having fundamental component V_{c1} is generated at the ac side of the inverter. This results in flow of fundamental frequency component I_{s1}, as shown in Fig. 2. The phasor diagram for $V_{c1} > V_s$ representing the reactive power flow is also shown in this figure. In this I_{s1} represent fundamental component.

$$I_{c1} = \frac{V_{c1} - V_s}{\omega L_f} = \frac{V_{c1}}{\omega L_f}\left(1 - \frac{V_s}{V_{c1}}\right) \qquad \ldots\ldots(24)$$

$$Q_{c1} = Q_{L1} = 3V_s I_{c1} \qquad \ldots\ldots(25)$$

$$Q_{c1} = 3V_s \frac{V_{c1}}{\omega L_f}\left(1 - \frac{V_s}{V_{c1}}\right) \qquad \ldots\ldots(26)$$

$$V_{dc} = 2\sqrt{2}V_{c1} \qquad \ldots\ldots(27)$$

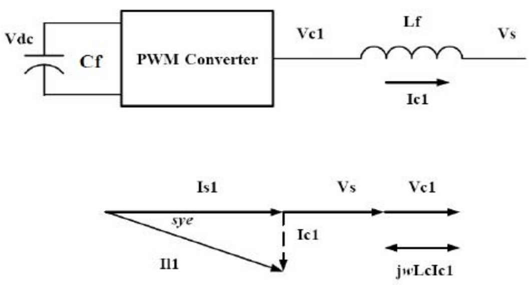

Fig. 3. Single line and vector diagrams for STATCOM

B. Design of PI controller

The controller used is the discrete PI controller that takes in the reference voltage and the actual voltage and gives the maximum value of the reference current depending on the error in the reference and the actual values [6]. The mathematical equations for the discrete PI controller are:

The voltage error $V(n)$ is given as:

$$V(n) = V^*(n) - V(n) \qquad \ldots..(28)$$

The output of the PI controller at the nth instant is given as:

$$I(n) = I(n-1) + K_p[V(n) - V(n-1)] + K_i V(n) \ldots..(29)$$

When the DC link voltage is sensed and compared with the reference capacitor voltage, to estimate the reference current, the compensated source current will also have sixth harmonic distortion for three-phase system and second harmonics distortion for single phase system.

A low pass filter is generally used to filter these ripples which introduce a finite delay and affect the transient response. To avoid the use of this low pass filter the capacitor voltage is sampled at the zero crossing of the source voltages.

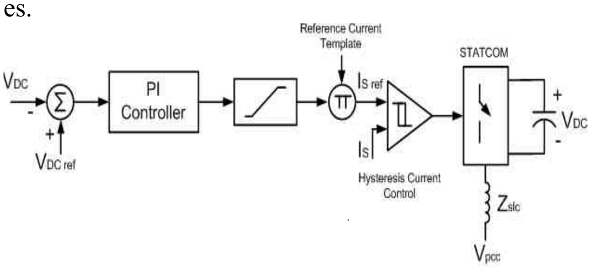

Fig. 4. Closed loop Schematic block diagram of STATCOM

C. Hysteresis Controller

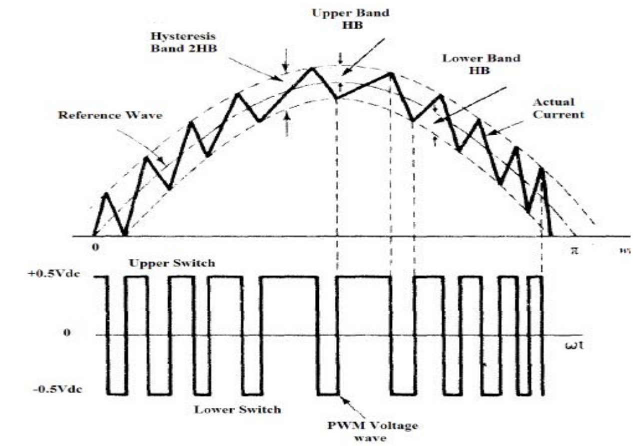

Fig. 5. Basic principal of hysteresis controller

With the hysteresis control, limit bands are set on either side of a signal representing the desired output waveform [6]. The inverter switches are operated as the generated signals within limits. The control circuit generates the sine reference signal wave of desired magnitude and frequency, and it is compared with the actual signal. As the signal exceeds a prescribed hysteresis band, the upper switch in the half-bridge is turned OFF and the lower switch is turned ON. As the signal crosses the lower limit, the lower switch is turned OFF and the upper switch is turned ON. The actual signal wave is thus forced to track the sine reference wave within the hysteresis band limits.

D. Pulse Generation Technique

Pulse generation is main and important part of this technique. Here we have used hysteresis technique for switching technique.

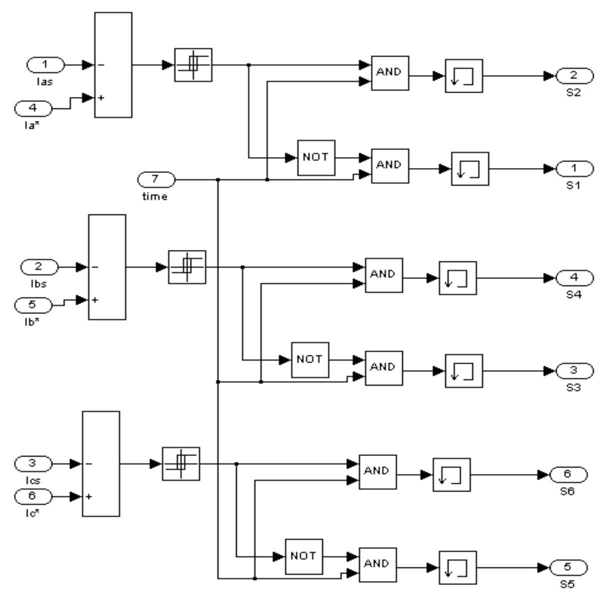

Fig. 6. Pulse generation diagram

E. Extraction of Unit Vector Template

The schematic diagram of unit vector template generation [7] is shown in Fig. 7

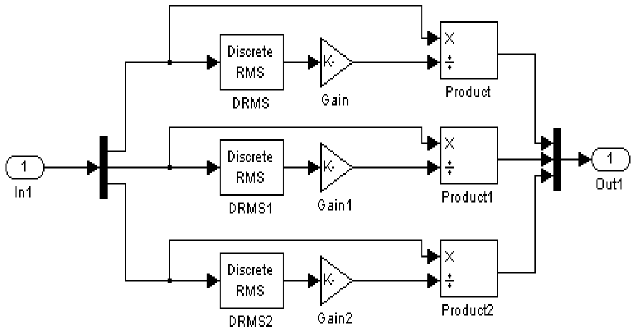

Fig. 7. Extraction of unit vector template

The input source voltage at PCC is sensed and *rms* value of the voltage is measured. This rms value is multiplied by square root of two. This peak voltage id divided by input supply voltage. Which will give us the unit vector template of the three phase.

IV. Operation of Simulation Model

The operation of the simulation model shown in Fig. 8. First the capacitor voltage is sensed which is compared with the reference voltage and the error signal is given to the PI controller for processing to obtain the maximum value (I_m) of the reference current [8-9]. This signal is now delayed by 120^0 for getting the reference current for phase b, which is further delayed by 120^0 to get the reference current for the phase c. these reference currents are now compared with the actual source currents and the error is processed in the hysteresis controller to generate the firing pulses for the switches of the inverter.

V. Simulation Results

Fig. 9 shows the supply voltage, supply current and injected current wave forms of the line current before the shunt current and after the shunt current injection. The overall simulation run time is 0.2 sec. the control strategy is started after 0.1 sec. After 0.1 sec the PI controller acted to settle the reference DC link voltage and current from the shunt converter injected to make the supply current sinusoidal. It is observed that after the control strategy started the wave shape of the line current at the input side is improved in term of the harmonic distortion. It is also observed that the supply voltage does not affected. Fig. 10 shows the Load voltage and current remain unaffected throughout the operation.

Fig. 11 shows the current on the main line side before injection and frequency contain in it. Fast Fourier Transformation (FFT) analysis of the same current is carried out and the Total Harmonic Distortion (THD) in this case is 25.59%. Fig. 12 shows the current on the main line side after injection and frequency contain in it. FFT analysis of the same current is carried out the THD in this case is 3.93%.

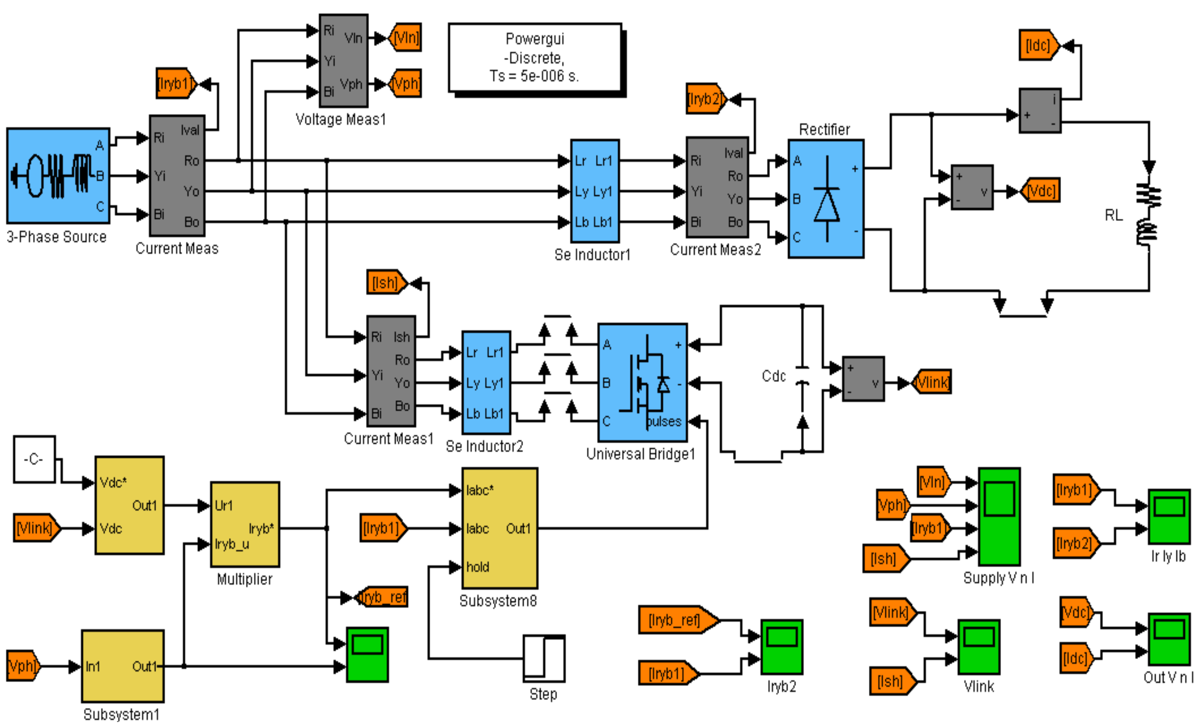

Fig. 8. Overall Control circuit of STATCOM based on MATLAB Simulink

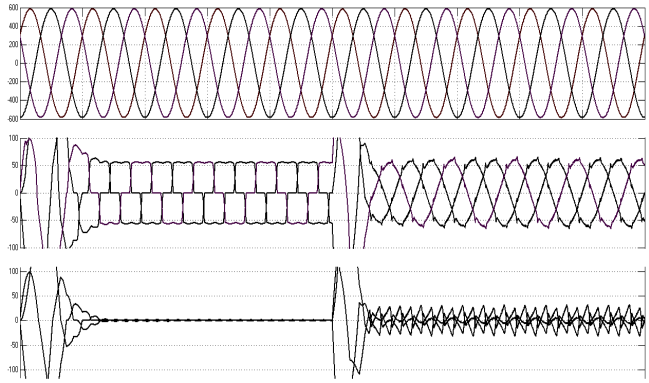

Fig. 9. Supply voltage, current and injected current

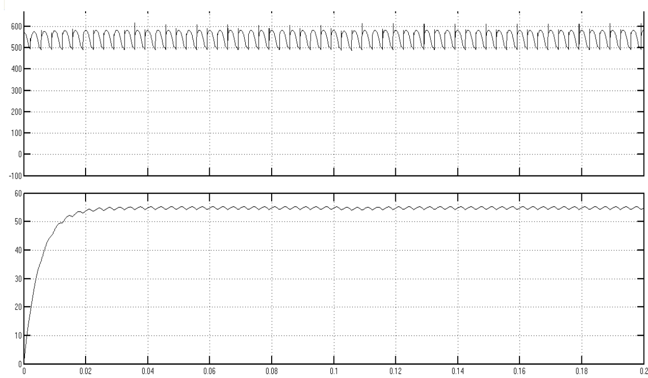

Fig. 10. Load voltage and current

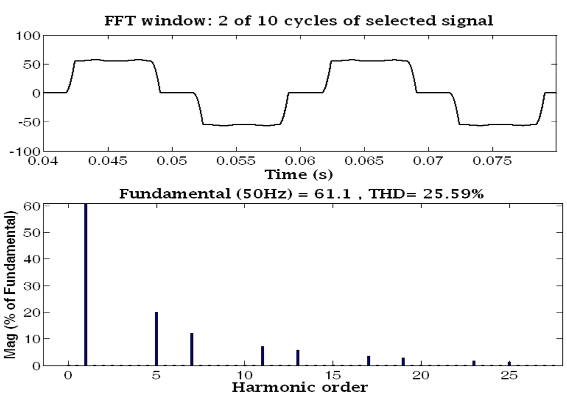

Fig. 11. FFT analysis of supply current before control

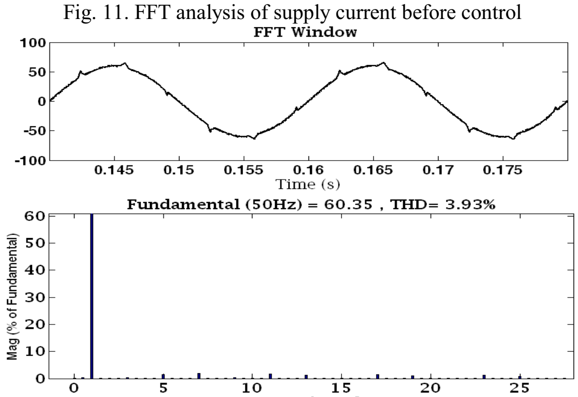

Fig. 12. FFT Analysis of supply current after using STATCOM

VI. CONCLUSION

A very simple hysteresis current controller based control technique with help of unit vector template is proposed for STATCOM. A MATLAB/Simulink based model has been simulated. Simulation result shows the input current harmonics produced by nonlinear load is reduced after using the control strategy. FFT analysis shows the reduction in THD is remarkable.

VII. REFERENCES

[1] Rakesh Kantaria and S.K.Joshi “A review on power quailty problems and solutions” Power electronics National Conference November 2008.

[2] Bhim Singh, Ambrish Chandra and Kamal Al-Haddad “A Review of Active Filters for Power Quality Improvement” IEEE Trans. Ind. Electronics, VOL. 46, NO. 5, pp 960-971 OCTOBER 1999

[3] Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems. Narain G. Hingorani, Laszlo Gyugyi. Wiley IEEE press.

[4] Amit Jain, Ned Mohan, Karan Joshi and Aman Behal "voltage Regulation with STATCOMS:Modeling ,Control and Results." IEEE Transactions on Power Delivery, Vol 21, NO. 2, April 2006 PP 726-734.

[5] Yaden Li and Bin Wu “A Novel DC Voltage Detection Technique in the CHB Inverter based STATCOM” IEEE Transactions on Power Delivery, Vol. 23, NO. 4, July 2008 PP 1613-1619

[6] Yashomani Y. Kolhatkar, and Shyama P. Das,; “Experimental Investigation of a Single-Phase UPQC With Minimum VA Loading” IEEE Transactions on Power Delivery, Vol. 22, NO. 1, January 2007 PP 373-380

[7] Vadirajacharya.K , Pramod Agarwal and H.O.Gupta,“A Simple Control Strategy ForUnified Power Quality Conditioner Using Current Source Inverter” The 8th International Power Engineering Conference – IPEC2007 3-6 December 2007, Singapore

[8] Y.Kolhatkar, P.A.Agraval, A.O.Barry and T.D.Nguyen,; “A simple New Control Technique for Unified Power Quality conditioner (UPQC), The 11th International Conference on Harmonics and Quality of Power 2004.

[9] Ronny Sternberger and Dragan Jovic “Analytical modelling of a square-wave controlled cascade Multilevel STATCOM” IEEE Transactions on Power Delivery, Vol. 24, NO. 4, October 2009 PP 2261-2269