VOLTAGE REGULATION VIA STATCOM BY COMBINED FUZZY AND PI CONTROLLER

Thenepalli Murali Mohan #1, Zeyauddin Sk Md*2

Department of Electrical and Electronics Engineering, Unversity college of engineering, JNTU kakinda
Address Including Country Name
tmmoham2009@gmail.com
ziya07.md@gmail.com

Abstract— **Transmission networks of modern power systems are becoming increasingly stressed because of growing demand and restrictions on building new lines. One of the consequences of such a stressed system is the threat of losing stability following a disturbance. Flexible ac transmission system (FACTS) devices are found to be very effective in a transmission network for better utilization of its existing facilities without sacrificing the desired stability margin. Flexible AC Transmission System (FACTS) such as Static Synchronous Compensator (STATCOM), employ the latest technology of power electronic switching device in electric power transmission systems to control voltage and power flow. A static synchronous compensator (STATCOM) is a shunt device of the flexible AC transmission systems (FACTS) family. The STATCOM regulates voltage at its terminal by controlling the amount of reactive power injected into or absorbed from power system. When system voltage is low, STATCOM generates reactive power and when system voltage is high it absorbs reactive power.**

This paper presents a new fuzzy and pi based controller for enhancement of voltage stability of a four machine 500kv, 13-bus grid connected power system using a 48-pulse, ±100Mvar GTO-based STATCOM. The controller is carried on a decoupled current control strategy using direct and quadrature components of STATCOM current. The combined Fuzzy and PI controller is used in voltage regulator block of a decoupled current STATCOM controller. To study the effectiveness of the STATCOM in enhancement of voltage stability, the different load changes are applied at different time intervals during the simulation and variations in voltage at the load end before and after the use of STATCOM controller is observed. Operation of STATCOM is validated on both capacitive and inductive modes. The complete power system its PSB model and results of investigations, showing the effectiveness of proposed Fuzzy and PI controller in voltage stabilization, have been presented. For the sake of comparison, time-domain simulation of same system has been carried out without controller. Analysis of the results and conclusion are presented.

I. INTRODUCTION

Voltage stability is increasingly becoming the limiting factor in planning and operation of power system, mainly in longitudinal lines. A suitable reactive power control scheme can provide a number of important benefits in power system operation such as reduction of voltage gradients, efficient utilization of transmission capacities, increase in voltage stability margin etc. Different control techniques have so far been applied to avoid the voltage collapse and also to maintain the load voltage within specified limits. Commercial availability of gate turn of thyristor (GTO’s) devices with high power handling capacities, and the advancement of other type of power-semi conductor devices such as IGBT’s, have led to the development of controllable reactive power sources utilizing electronic switching converter technology[1]. These technologies additionally offer considerable advantages over the existing ones in terms of space reductions and performance. The GTO thyristor enabled the design of solid state shunt reactive compensation equipment based on the converter switching technology. This concept was used to create flexible shunt reactive compensation device named static synchronous compensator (STATCOM) due to similarity in operating characteristics but without mechanical inertia. In this paper, a 48-pulse VSI converter based STATCOM build using a four 12-pulse VSI converters and is used as a ±100 MVAR STATCOM[3],[4]. For high power applications it is most suitable as harmonics of the order 48r±1, r=0,1,2,...only would be generated, Although by using 24-pulse converter with filter, tuned to the 23-25th adequate amount of harmonics could be eliminated. But, the 48-pulse converter scheme can ensure minimum power quality problems and reduced harmonics resonance conditions on interconnected grid network.

A PI controller has better performance under steady state condition and Fuzzy logic has a better performance under dynamic conditions. A hybrid Fuzzy-PI controller is used in the control of STATCOM to utilize the advantages of Fuzzy-PI controller. The proposed STATCOM is modelled in MATLAB/SIMULINK Sim power system tool boxes and developed model is used to simulate its performance under various operating conditions.

II. STATIC SYNCHRONOUS COMPENSATOR

The Static Synchronous Compensator (STATCOM) is shunt connected reactive compensation equipment which is capable of delivering or absorbing variable reactive power to control the required parameters of the electric power system. The STATCOM provides operating characteristics similar to those of a rotating synchronous compensator. Due to the use of solid state power switching devices it does not suffer from mechanical inertia and hence can provide rapid response. STATCOM is basically a three phase GTO or IGBT-based voltage source inverter (VSI) with a DC capacitor at one of its ends and a step-up transformer (called coupling transformer having leakage reactance) at the other-end; the secondary of the transformer remains connected in shunt with the line[12],[13]. The basic voltage-source inverter representation of STATCOM for reactive power generation is shown schematically in Fig. 1.

STATCOM is used to absorb reactive power from the line or to deliver the same to the line with the aim of regulating the bus voltage, dynamically. The basic principle of STATCOM operation can be illustrated by the phaser diagrams, shown in Fig. 2. By proper switching operation, the magnitude and phase of the STATCOM output (ac) voltage, Vs is controlled with respect to the bus (or line) voltage, V_B. The difference, $\Delta V_L=|V_B|-|V_S|$ between the line voltage and STATCOM voltage appears across the leakage reactance. Let, V_{SD} and V_{SQ} are the in-phase and out of phase components of STATCOM output voltage, VS with respect to the line voltage, V_S, such that $V_B = |V_B|∟00$& $V_S = V_{SD} + jV_{SQ}$. The potential difference between the line voltage and the in-phase component of STATCOM voltage, $\Delta V_D =|V_B|-|V_{SD}|$ appears across the leakage inductance between line and STATCOM and causes flow of reactive current, $I_Q=-j\Delta V_{LD}/XL$ from the line to the STATCOM and hence flow of reactive power, $Q_{BS}=V_BI_Q{*}= jV_B(\Delta V_{LD}/X_L)= j|V_B|[|V|-|V_{SD}|]/X_L$ from the line to the STATCOM.

When $|V_{SD}|<|V_B|$, Q_{BS} is positive and the STATCOM absorbs inductive power, Q_{BS} from the bus and acts like an inductor. On the other hand, when $|V_{SD}|>|V_B|$, Q_{BS} is negative and the STATCOM delivers inductive power, QBS to the bus and acts like a capacitor. When $|V_{SD}|=|V_B|$ reactive power exchange is zero. Thus, by controlling the magnitude of the in-phase component, V_{SD} of STATCOM with respect to the line voltage, V_B, the STATCOM can be made to absorb reactive power from the line or deliver the same to the line. The potential difference between line voltage and out of phase component of STATCOM voltage, $\Delta V_{LQ} = 0-j|V_{SQ}|$. It appears across the leakage inductance between line and STATCOM and causes flow of active current, $I_P =\Delta V_{LQ}/X_L=-V_{SQ}/X_L$ and hence flow of active power, $P_{BS}=V_BI_P{*}=-V_BV_{SQ}/X_L$ from the STATCOM to the line. Direction of active power flow can be reversed by reversing the sign of V_{SQ}, i.e., by making it to lag V_B. For delivering real power to the power system, energy storage device should be connected to the DC side of the STATCOM. When a capacitor is connected at the DC-side of STATCOM, under steady state operation V_{SQ} is kept lagging V_B by a very small angle to compensate the small active power losses in the inverter.

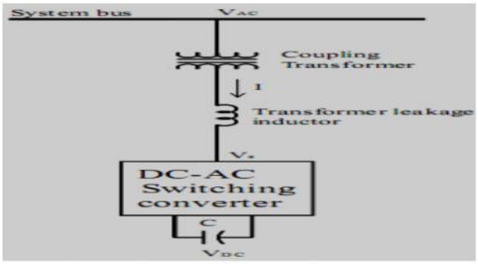
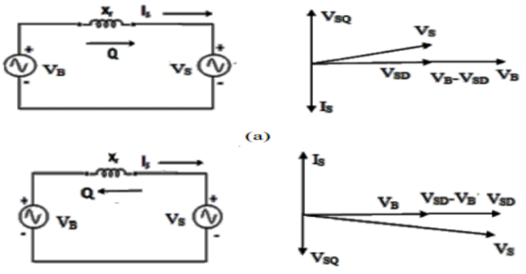


Fig1: Schematic diagram of STATCOM.



(b)

Fig2: STATCOM Operation (a) Inductive Operation (b) Capacitive Operation.

III. 48-PULSE VOLTAGE SOURCE GTO CONVERTER

It consists of four three-phase, three-level inverters and four phase-shifting transformers. In the 48-pulse voltage source converter, the dc bus V_{dc} is connected to the four three-phase inverters. The four voltages generated by the inverters are applied to secondary windings of four zig-zag phase-shifting transformers connected in Y or Ä. The four transformer primary windings are connected in series, and the converter pulse patterns are phase shifted so that the four voltage fundamental components sum in phase on the primary side.

Using a symmetrical shift criterion, the 7.5º are provided in the following way: phase-shift winding with -3.75º on the two coupling transformers of one 24-pulse converter and +3.75º on the other two transformers of the second 24-pulse converter. The firing pulses need a phase-shift of +3.75º, respectively.

The 48-pulse converter model comprises four identical 12-pulse GTO converters interlinked by four 12-pulse transformers with phase-shifted windings [9]. Fig. 3 depicts the schematic diagram of the 48-pulse VS-GTO converter model. The transformer connections and the necessary firing-pulse logics to get this final 48-pulse operation are modeled. The 48-pulse converter can be used in high-voltage high-power applications without the need for any ac filters due to its very low harmonic distortion content on the ac side. The output voltage have normal harmonics $n=48r\pm1$, where r=0,1,2,… , i.e., 47th, 49th, 95th,… , with typical magnitudes (1/47th,1/49th,1/95th…), respectively, with respect to the fundamental; on the dc side, the lower circulating dc current harmonic content is the 48^{th}.

1^{st} 12-pulse converter: The resultant output voltage generated by the first 12-pulse converter is

$\upsilon_{ab}12(t)\ 1 = 2[V_{ab1} \sin (\omega t+30^{o}) + V_{ab11} \sin (11 \omega t+195^{o}) + V_{ab13}\sin (13 \omega t+225^{o}) + V_{ab23} \sin (23\omega t+60^{o}) + V_{ab25} \sin(25\omega t+120^{o})+\ldots\ldots\ldots]$. ------------------- (1)

2^{nd} 12-pulse converter:

The resultant output voltage generated by the second 12-pulse converter is

$\upsilon_{ab}12(t)2 = 2[V_{ab1} \sin(\omega t+30°) +V_{ab11} \sin(11\omega t+15°) + V_{ab13} \sin(13\omega t+75°) + V_{ab23} \sin(23\omega t+60°) + V_{ab25} \sin(25\omega t+120°)+\ldots\ldots\ldots]$. ------------------- (2)

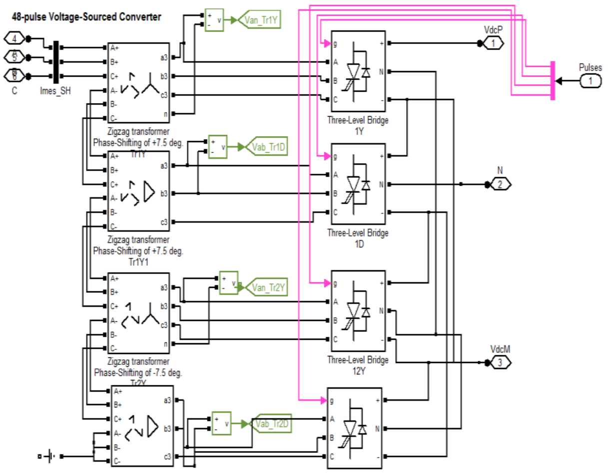


Fig.3 48-pulse GTO based converter

3rd Pulse Converter:

The resultant output voltage generated by the third 12-pulse converter is

$\upsilon_{ab12}(t)3=2[V_{ab1}\sin(\omega t+30°)+V_{ab11}\sin(11\omega t+285°)+V_{ab13}\sin(13\omega t+345°)+V_{ab23}\sin(23\omega t+240°)+V_{ab25}\sin(25\omega t+300°)+\ldots\ldots].$ ------------------- (3)

4th Pulse Converter:

The resultant output voltage generated by the fourth 12-pulse converter is

$\upsilon_{ab12}(t)3 = 2[V_{ab1}\sin(\omega t+30°) + V_{ab11}\sin(11\omega t+105°) + V_{ab13}\sin(13\omega t+165°) + V_{ab23}\sin(23\omega t+240°) + V_{ab25}\sin(25\omega t+300°)+\ldots\ldots].$ ------------------- (4)

These four identical 12-pulse converter provide shifted ac output voltages, described by (1)–(4), are added in series on the secondary windings of the transformers. The net 48-pulse ac total output voltage is given by

$\upsilon_{ab48}(t)=\upsilon_{ab12}(t)1+\upsilon_{ab12}(t)2+\upsilon_{ab12}(t)3+\upsilon_{ab12}(t)$___________(5)

$\upsilon_{ab48}(t)= 8[V_{ab1}\sin(\omega t+30°) + V_{ab47}\sin(47\omega t+150°) + V_{ab49}\sin(49\omega t+210°) + V_{ab95}\sin(95\omega t+330°) + V_{ab97}\sin(97\omega t+30°)+\ldots\ldots]$ _____________(6)

IV. POWER SYSTEM DISCRIPTION

A 13-bus four machines (G_1, G2, G3, G4 at 500kv), two area system with loads at bus 9 and bus bus9 as shown in fig.4 has been considered[2].

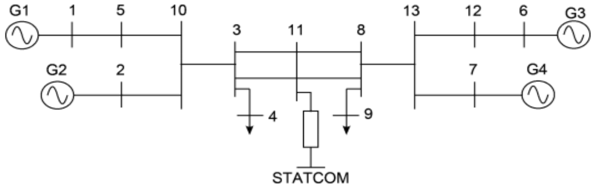


FIG.4: TWO-AREA SYSTEM

Two of generators are supplying from a programmable voltage source (voltage is varying between ±5% with time) and other two are supplied from three phase voltage source.

The 48-pulse, ±100 Mvar STATCOM has been connected at the mid-point bus 11 for controlling and maintaining the voltages near 1.0 p.u at bus-4, bus-9. The details of the system parameters are given below in table-1.

V.CONTROL ALGORITHM OF STATCOM

The various steps of control algorithm of STATCOM shown in below[14],

Decoupled current control strategy:

The new decoupled control system is based on a full - decoupled current control strategy using both direct and quadrature current components of the STATCOM ac current. The decoupled control system is implemented as shown in Fig. 7. A phase locked loop (PLL) synchronizes on the positive sequence component of the three-phase terminal voltage at interface Bus 2. The output of the PLL is the angle (è) that used to measure the direct axis and quadrature axis component of the ac three-phase voltage and current. The outer regulation loop comprising the ac voltage regulator provides the reference current (Iqref) for the current regulator that is always in quadrature with the terminal voltage to control the reactive power. The voltage regulator is a proportional plus integral PI controller with K_P=5 and K_i=0.09. The current regulator is also PI controller with K_p==12 and K_i=0.09. The PLL system generates the basic synchronizing-signal that is the phase angle of the transmission system voltage Vs, è and the selected regulation-slope k determines the compensation behavior of the STATCOM device. To enhance the dynamic performance of the full 48-pulse STATCOM device model, a supplementary regulator loop is added using the dc capacitor voltage. The dc side capacitor voltage charge is chosen as the rate of the variation of this dc voltage. Thus, for a fixed selected short time interval at, the variation in the Vdc magnitude is measured, and any rapid change in this dc voltage is measured and if this IVdcI change is greater than a specified threshold K, the supplementary loop is activated. The main concept is to detect any rapid variation in the dc capacitor voltage.

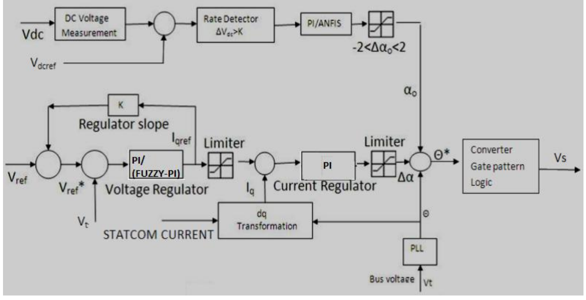


Fig.5Decoupled current controller for STATCOM

The strategy of a supplementary damping regulator is to correct the phase angle of the STATCOM device voltageθ^*, with respect to the positive or negative sign of this variation. If V_{dc}>, means the dc capacitor is charging very fast. This happens when the STATCOM converter voltage lag behind the ac system voltage; in this way, the converter absorbs a small amount of real power from the ac system to compensate for any internal losses and keep the capacitor voltage at the desired level. The same technique can be used to increase or decrease the capacitor voltage and, thus, the amplitude of the converter output voltage to control the Var generation or absorption. This supplementary loop reduces ripple content in charging or discharging the capacitor and improves fast controllability of the STATCOM.

Fuzzy Logic Based DC Voltage Controller:

Broadly the FLC (fuzzy logic controller) consists of three stages: fuzzification, rule execution and defuzzification. In first stage, fuzzification converts the crisp variables into the fuzzy variables. Membership functions are considered to be triangular. The shapes of the membership functions which are considered for the input variables error *'e'* (v^*_{dc}-v_{dcs}), change in error *'ce'* (*de/dt*) and change in output *'du'* as shown in Figs.3 (a), (b) and (c). Seven membership functions namely NB (negative big), NM (negative medium), NS (negative small), ZE (zero), PS (positive small), PM (positive medium) and PB (positive big) are chosen. In the second stage, the fuzzy variables are processed by an interface which executes 49 control rules as shown in Table I. In third stage as defuzzification, the fuzzy variables are converted back to crisp variables. The FLC gives the reference d-axis current '$i_d^*{}_{(FLC)}$'.

PI Controller Based DC Voltage Controller:

The expression for DC voltage controller from the PI controller can be written as,

$$i_d^*{}_{(PI)}(n) = i_d^*{}_{(PI)}(n-1) + K_p(v_{er}(n) - v_{er}(n-1)) + K_I v_{er}(n) \quad (1)$$

Where $v_{er}(n) = v^*_{dc}(n) - v_{dc}(n)$

And 'K_p' and 'K_I' are the proportional and integral gain constants of the DC link voltage controller respectively. 'v^*_{dc}' and 'v_{dc}' are the reference and sensed DC link voltages. The reference d-axis current from the PI controller is '$i_d^*{}_{(PI)}$'.

Combined Fuzzy and PI controller:

The output of the fuzzy-pi controller is decided by the error in DC bus voltage that decides the membership function shown in Fig.5 (d) for the PI controller and FLC controller. Three membership functions N (negative), Z (zero) and P (positive) are chosen.

The output of the fuzzy-pi controller is 'μ_{PI}' and '$\mu_{FLC} = 1 - \mu_{PI}$'.

The net reference d-axis current is as,

$$i_d^* = \mu_{PI}\, i_{d(PI)} + \mu_{FLC}\, i_d^*{}_{(FLC)}$$

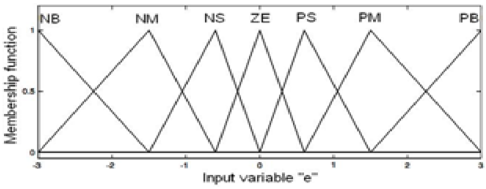


Fig. 3(a) Membership functions for error "e"

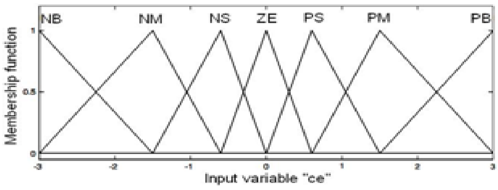


Fig. 3(b) Membership functions for change in error "ce"

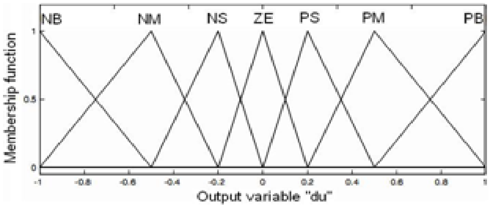


Fig. 3(c) Membership functions for change in output "du"

TABLE-I CONTROL RULE TABLE

e\ce	**NB**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NM	NM	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PM	PB
PM	NS	ZE	PS	PM	PM	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

Where

$I_{q*} = Q^*/v$

The reference voltage commands 'v^*_{cd}' and 'v^*_{cq}' can be expressed as,

$V^*_{cd} = V^*_{td} - k_{pd}(i^*_d - i^*_q)$

$V^*_{cq} = V^*_{tq} - k_{pd}(i^*_q - i^*_d)$

Where 'V_{td}' and 'V_{tq}' are decomposed AC terminal voltages and 'k_{pd}' and 'k_{pq}' are proportional gains.

The reference phase angle for maintaining the DC link voltage is given as,

$\delta^* = \tan^{-1}(V^*cq/V_1)$

Where v_1 fundamental AC converter output voltage.

VI.RESULTS AND DISCUSSIONS:

SYSTEM WITOUHT STATCOM:

The sample radial power system is subjected to load switching load1, load2 and load3 at t=0.01 to 0.04 seconds, t=0.14 to 0.18 seconds, t=0.3 to 0.34 seconds with P= 1p.u Q=0.8p.u, P=0.7p.u Q=0.5p.u, P=0.6p.u Q=0.4p.u respectively connected at load bus B4 and bus B9.Due to inductive load the voltage at load bus B9 is Vs=0.95p.u.At 0.5sec capacitive load is switched voltage is increased to Vs=0.98p.u.The digital simulation results are given as shown in Fig.6 (a) –Fig.6 (d)

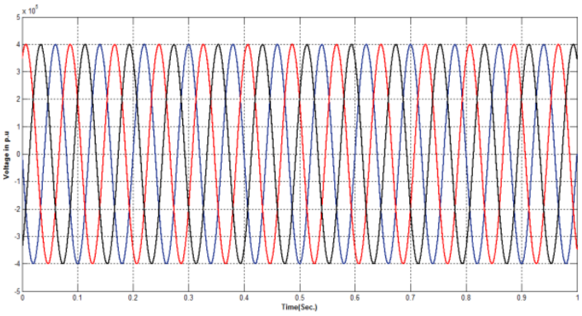


Fig.6 (a) Voltage in P.U at voltage source bus B1

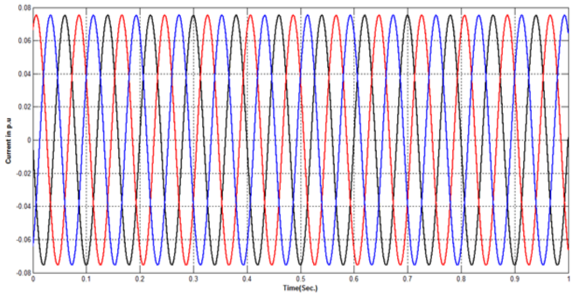


Fig.6(b) Current in P.U at bus B1.

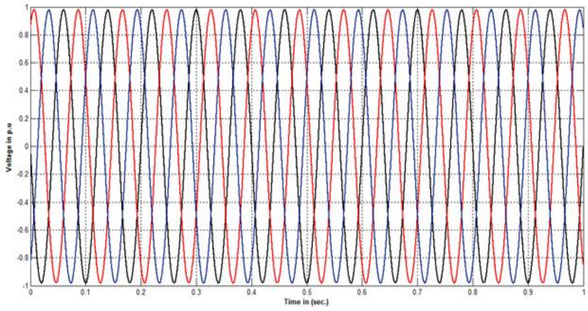


Fig6 (C) Voltage in P.U at load bus B9

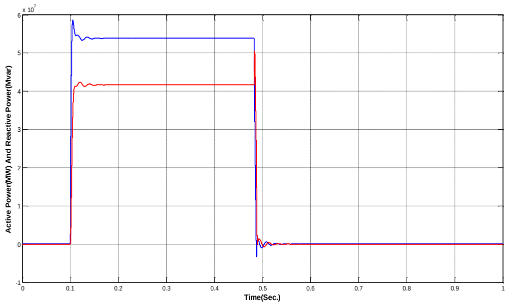


Fig6(d) Active and Reactive power at bus B1

SYSTEM INSTALLED WITH FUZZY-PI BASED STATCOM CONTROLLER:

Now system installed with Fuzzy-pi based STATCOM controller.

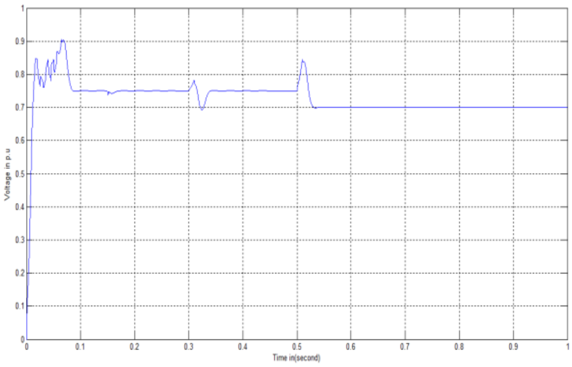


Fig.7(a) Capacitor DC voltage in p.u

Voltage and current of STATCOM Vs t

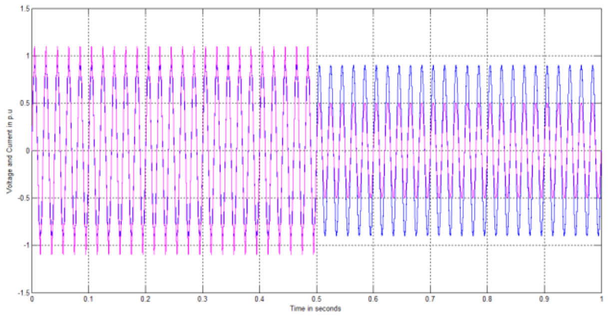


Fig.7(b) Voltage and current of STATCOM Vs t

Active and Reactive power of STATCOM Vs t

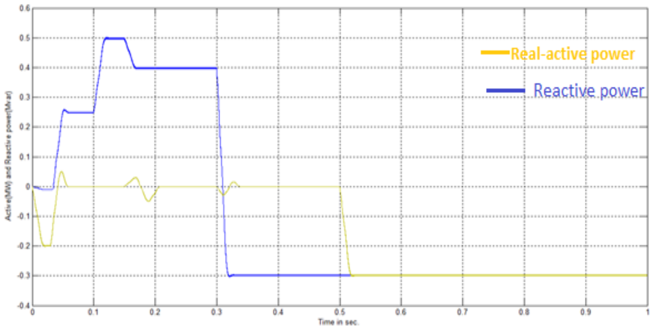


Fig.7(c) Active and Reactive power STATCOM Vs t

Active and Reactive power of load bus B9 Vs t

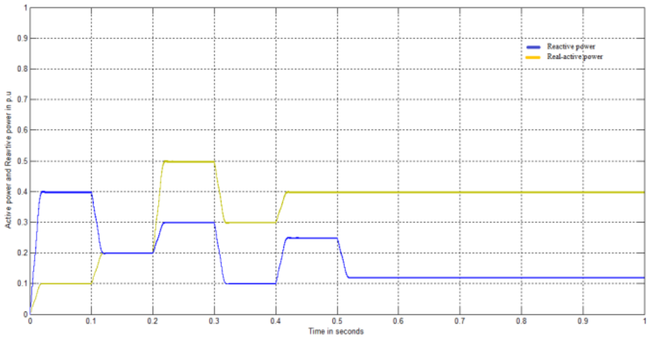


Fig.7(e) Active and Reactive power of load bus B9 Vs t

Voltage of a Uncompensated System Vs t

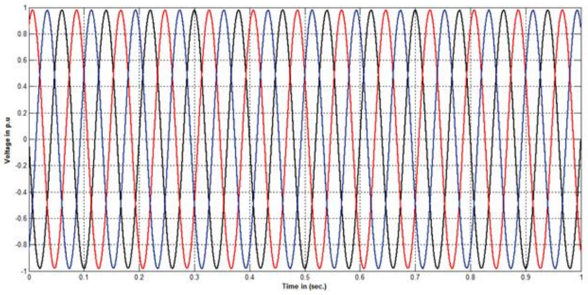


Fig.7(f) Voltage of a Uncompensated System Vs t

Regulated bus voltage Vg at bus Vs t

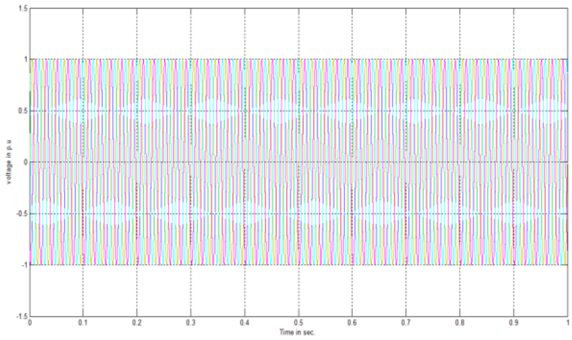


Fig.7(g) Regulated bus voltage at bus Vs t

Voltage at bus B4 Vs t

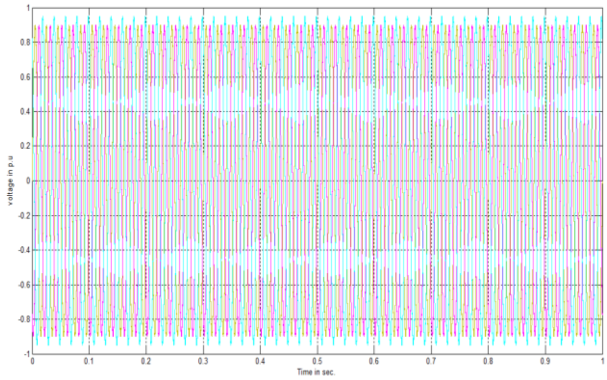


Fig.7(h) Voltage at bus B4 Vs t

Phase A Voltage at bus B9 Vs t

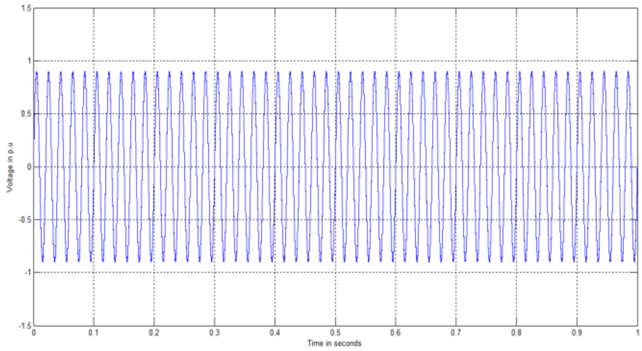


Fig.7(i) Phase A Voltage at bus B9 Vs t

When starting source voltage is such that STATCOM is inactive. It neither absorbs nor sends the reactive power to network. The network voltage Vg is 1.02p.u and only inductive load bus B9, and the STATCOM connected bus voltage at bus B11 is 1.03p.u.

Step-1)t=0.01s at this time the static synchronous compensator STATCOM is switched. The STATCOM is now operating capacitive mode and injects about 0.25p.u of reactive into the ac power system, as shown fig.7(C) .The bus voltage is increased to 1.05p.u as shown in fig.7(g). The STATCOM will draw 0.05p.u real-active power of from the network for the GTO switching losses and transformer resistive and core losses. The voltage regulation leads to increase in the transmitted real power to load bus B9 with PL=0.13 p.u, due to the reactive power compensation, the transmitted reactive power also decreases as shown in fig.7(e).

Step-2) t=0.15s at this time, the second inductive load P=0.7p.u and Q=0.5p.u is added to the ac power system bus at bus B9, therefore more dynamic reactive power compensation is required. As the STATCOM voltage phase displacement angle is increases, and therefore, the d.c capacitor voltage is increased as shown in fig.7(a). The STATCOM injects about 0.5 p.u of reactive power into the ac network at bus B11 and draws about 0.03p.u of real power to compensate GTO losses and transformer resistive and core losses. The regulated bus voltage is about 1.03p.u.

Step-3) t=0.3s the capacitive load with P=0.6p.u and Q=0.4p.u is now added to the power system at bus B9.The capacitive load have compensative effect so the STATCOM inject less reactive power into the ac power system at busB11. The injected reactive power is decreased by reducing dc capacitor voltage. While the STATCOM injects 0.415p.u of reactive power into the power system network at bus B11 and draws only 0.01p.u of real-active power for compensating the added losses.

Step-4) t=0.325s at this time load1 and load2 are rejected from bus B11, which is a severe load reduction, and only capacitive load remains connected to bus at B9.Due to thi capacitive load, the STATCOM operates in inductive mode to regulate the resultant over voltages. The STATCOM voltage leads the bus voltage.

As a result capacitor voltage drops as shown in figure7(a) The regulated bus voltage is 1.05p.u.,The dynamic performance of the 48-pulse converter voltage and current and transition sequence from the capacitive mode of operation to inductive mode of operation are shown in fig.7(b) with no transient over voltages appeared. This smooth transition is due to the novel controller , which is based on the decoupled control strategy and Fuzzy-PI controller employed in the voltage controller of decoupled current STATCOM controller strategy.

CONCLUSION

In this Thesis, dynamic behavior of four machine system 13-bus system grid connected system installed with STATCOM is investigated under different load changes. This project presents 48-pulse GTO voltage source converter of ±100 Mvar STATCOM model of FACTS devices. The full descriptive digital model connected to 500kv electric grid network is validated for digital stabilization, reactive power compensation using decoupled current control strategy. The control strategies implemented decoupled current control technique to ensure fast controllability, minimum oscillatory behavior, and minimum inherent phase locked loop time delay as well as system instability reduced impact due to a weak interconnected ac system.

Fuzzy-PI based STATCOM controller in the voltage regulator of STATCOM controller designed to improve the voltage profile of the given system. Controllers inputs are chosen carefully to provide better damping to the system and its range are determined by the simulation results of fuzzification process. For Fuzzy-PI based STATCOM controller, error i.e. difference of V_{meas} and V_{ref} and its derivative are taken as input parameters for voltage and its derivative are taken as input while K_p and K_i are taken as output parameters. Proposed controllers are implemented using MATLAB/SIMULINK. Fuzzy-PI based STATCOM controller compared with conventional uncompensated power system. Simulation results indicate that the Fuzzy-PI based STATCOM controller installed with four machine system provides better damping characteristics as compared to conventional PI based STATCOM controller and provides improved voltage profile as compared to conventional Fuzzy-PI based STATCOM controller.

TABLE I: SELECTED POWER SYSTEM PARAMETERS

Three Phase AC Voltage Source

(ii) Three Phase Constant Voltage Source 1	
Rated Voltage	500 (KV)
Frequency	50 (HZ)
S.C. Level	10000 (MVA)
Base Voltage	500 (KV)
X/R	8
(ii) Three Phase Constant Voltage Source 2	
Rated Voltage	500 (KV)
Frequency	50 (HZ)
S.C. Level	10000 (MVA)
Base Voltage	500 (KV)
X/R	8
(iii) Three Phase Constant Voltage Source 3	
Rated Voltage	500 (KV)
S.C. Level	9000 (MVA)
X/R	10
(IV) Three Phase Constant Voltage Source4	
Rated Voltage	500 (KV)
S.C. Level	9000 (MVA)
X/R	10
Transmission line	
Resistance	0.05 (Ohm)
Reactance	0.2 (Ohm)
Line Lenght	200 (Km)

Three Phase Load	**P(p.u)**	Q(p.u)
Load-1	1	0.8
Load-2	0.7	0.5
Load-3	0.6	0.4

STATCOM	
Primary Voltage	500 (KV)
Secondary Voltage	15 (KV)
Nominal Power	100 (MVAR)
Frequency	50Hz
Capacitance	3000μF
GTO Switches	
Snubber Resistance	1e-5 (ohm)
Snubber Capacitance	inf
Internal Resistance	1e-4 (ohm)
No. of Bridge arm	3

REFRENCES

[1] N. G. Hingorani and L. Gyugyi, Understanding FACTS, Concepts and Technology of Flexible AC Transmission Systems. Piscataway, NJ: IEEE Press, 2000.

[2] Power System Voltage Regulation via STATCOM Internal Nonlinear Control Keyou Wang, Member, IEEE, and Mariesa L. Crow, Fellow, IEE, IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 26, NO. 3, AUGUST 2011.

[3] A Novel Controller Based 48-Pulse STATCOM for Reactive Power Compensation and Voltage Stabilization in High Voltage Applications S.M. Padmaja[1], Dr. G. Tulasiram Das[2] [1]Shri Vishnu Engineering College for Women, Bhimavaram, India padmaja_vvr@yahoo.com [2]Jawaharlal Nehru Technological University, Hyderabad, India das_tulasiram@yahoo.co.in, ACEEE Int. J. on Electrical and Power Engineering, Vol. 02, No. 01, Feb 2011.

[4] Dynamic Performance of 48-pulse STATCOM, SSSC and UPFC controller RAVI BALAM1, KOTYADA.KALYANI2, B.SHANKARPRASAD3, International Journal of Engineering Research and Applications(IJERA).

[5] ANFIS based 48-Pulse STATCOM Controller for Enhancement of Power System Stability Subir Datta and Anjan Kumar Roy International Journal of Modeling and Optimization, Vol. 2, No. 4, August 2012.

[6] Novel Controllers for the 48-Pulse VSC STATCOM and SSSC for Voltage Regulation
and Reactive Power Compensation M. S. El-Moursi and A. M. Sharaf, Senior Member, IEEE, IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 20, NO. 4, NOVEMBER 2005.

[7] NON LINEAR CONTROL OF STATCOM 1M.Arun Bhaskar, 2Dr.S.S.Dash, 3C.Subramani, M.JagdeeshKumar,DeepikaHarish,R.Shalini 2010 International Conference on Recent Trends in Information,TelecommunicationandComputing.

[8] R. Mohan and R. K. Varma, Thyristor-Based FACTS Controllers for Electrical Transmission Systems. Piscataway, NJ: IEEE Press, 2002.

[9] Y. Liang and C. O. Nwankpa, “A new type of STATCOM based on cascading voltage-source inverter with phase-shifted unipolar SPWM,”IEEE Trans. Ind. Appl., vol. 35, no. 5, pp. 1118–1123, Sep./Oct. 1999.

[10] C. A. C. Cavaliere, E. H. Watanabe, and M. Aredes, “Multi-pulse STATCOM operation under unbalance voltages,”in Proc. IEEE Power Engineering Society Winter Meeting, vol. 1, Jan. 2002, pp. 27–31.

[11] A. H. Norouzi and A. M. Sharaf, “An auxiliary regulator for the SSSC transient enhancement,” in Proc. IEEE 35th North Amer. Power Symp., Rolla, MO, Oct. 2003.

[12] Q. Yu, P. Li, and Wenhua, “Overview of STATCOM technologies,” in Proc. IEEE Int. Conf. Electric Utility Deregulation, Restricting, Power Technologies, Hong Kong, Apr. 2004, pp. 647–652.

[13] B. Singh, S. S. Murthy, and S. Gupta, “Analysis and design of STATCOM-based voltage regulator for self-excited induction generators,”IEEE Trans. Energy Convers., vol. 19, no. 4, pp. 783–790, Dec. 2004.

[14] NEW CONTROL STRATEGY OF TWO-LEVEL 12-PULSE VSCS BASED STATCOM USING HYBRID FUZZY-PI CONTROLLER K. Venkata Srinivas, Bhim Singh, Ambrish Chandra and Kamal-Al-Haddad, Indian Institute of Technology Delhi.

[15] F. Liu, S. Mei, Q. Lu, Y. Ni, F. F. Wu, and A. Yokoyama, “The non-linear internal control of STATCOM: Theory and application,” Elect.Power Energy Syst., vol. 25, pp. 421–430, 2003.

[16] C. Schauder and H. Mehta, “Vector analysis and control of advanced static VAR compensators,”Proc. Inst. Elect. Eng. Gen, Transm, Dis-trib., vol. 140, no. 4, pp. 299–306, Jul. 1993.

[17] P. W. Lehn and M. R. Iravani, “Experimental evaluation of STATCOM closed-loop dynamics,”IEEE Trans. Power Del., vol. 13, no. 4, pp. 1378–1384, Oct. 1998.

[18] P. Rao et al., “STATCOM control for power system voltage control applications, ”IEEE Trans. Power Del., vol. 15, no. 4, pp. 1311–1317,Oct. 2000.

[19] L. Donget al., “A reconfigurable FACTS system for university labo-ratories,”IEEE Trans. Power Syst., vol. 19, no. 1, pp. 120–128, Feb.2004.

[20] Y. Cheng, C. Qian, and M. L. Crow, “A comparison of diode-clamped and cascaded multilevel converters for a STATCOM with energy storage, ”IEEE Trans. Ind. Electron., vol. 53, no. 5, pp. 1512–1521,Oct. 2006.

[21] M. S. El-Moursi and A. M. Sharaf, “Novel controllers for the 48-PulseVSC STATCOM and SSSC for voltage regulation and reactive power compensation, ”IEEE Trans. Power Syst., vol. 20, no. 4, pp. 1985–1997,Nov. 2005.

[21] M. Saeedifard, H. Nikkhajoei, and R. Iravani, “A space vector mod-ulated STATCOM based on a three-level neutral point clamped con-verter,”IEEE Trans. Power Del., vol. 22, no. 2, pp. 1029–1039, Apr.2007.

[21] N. Hatano and T. Ise, “Control scheme of cascaded H-bridge STATCOM using zero-sequence voltage and negative-sequence cur-rent, ”IEEE Trans. Power Del., vol. 25, no. 2, pp. 543–550, Apr. 2010.

[22] R. Sternberger and D. Jovcic, “Analytical modeling of a square-wave-controlled cascaded multilevel STATCOM,”IEEE Trans. Power Del.,vol. 24, no. 4, pp. 2261–2269, Oct. 2009.

[23] Yan, “*Introduction to fuzzy systems*”, Electronic Technology Directions proceedings, pp: 94-103, Adelaide, May 1995.

[24] Young-Hua Song, “*Applications of fuzzy logic in power system. I. General introduction to fuzzy logic”,* Power engineering Journal, Vol.11, No 5, pp: 219-222, Oct 1997.

[25] Sivanaandam. S.N, *“Introduction to Fuzzy Logic using MATLAB”,* Springer Berlin Heidelberg New York.

[26] Ross J. Timothy, “*Fuzzy Logic With Engineering Applications*”, Second Edition, John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO198SQ, England.

[27] Ghafouri.A, *“Fuzzy Controlled STATCOM for improving the Power System Transient Stability.”* 39th North America Power Symposium, 2007, Las Cruces, NM, pp: 212-216, Dec 2007.

[28] An. Luo, “*Fuzzy-PI Based Direct Output Voltage Control Strategy for the STATCOM used in Utility distribution system”,* IEEE Transactions on Industrial Electronics, Vol 56, No 7, pp 240-241, July 2009.

.

Thenepalli Murali Mohan was born in 1975. He completed B. Tech degree from S. V. University, Tirupati in 1999 and completed M. Tech degree from IIT Madras in 2001. He has 12 years of teaching experience both at under and post Graduate levels. Currently he is working towards his doctoral degree. His research interest includes renewable energy sources.

Zeyauddin Sk Md received his B.Tech and M.Tech degrees from JNTU KAKINDA, INDIA in 2011 and 2013 respectively. His area of interest includes Renewable Energy Systems, Fuzzy and Genetic algorithms.