STATCOM Design for Voltage Control using Synchronous Vector PI Controller

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***Abstract*— The objective of this paper is to improve Voltage profile of the system by controlling reactive power using a synchronous vector PI controller. Voltage in a power system is mainly affected by reactive loads and faults. This paper proposes modeling of a STATCOM (STATic+ COMpensator) with a synchronous vector PI controller under a nonlinear load. The prototype has been programmed in MATLAB/SIMULINK environment which has been tested on a standard IEEE 14 bus system. It has been observed that after installing STATCOM the voltages of the buses are found to be within the acceptable limits.**

Keywords*— *FACTS, Reactive power, PI vector controller, STATCOM, Voltage control.

I. INTRODUCTION

After deregulation of the electricity market, the electrical utilities have been trying to improve the efficiency of the power system networks. One of the most concerned problems today is voltage swell or sag [1]. The voltage sag/swell magnitude is ranged from half cycle to one minute. System voltage is directly proportional to the reactive power of the system. Thus whenever there is a disturbance in the reactive power of the system, the system voltage profile gets disturbed. Moreover increased penetration of renewable energy sources such as wind and solar power plants is also disturbing the reactive power of the system. As for instance the solar power plant is employing a great number of semiconductor devices to convert the solar energy into electrical energy [2-3], the wind power plant is also absorbing great VARs during its running condition [3-4]. So all these problems are having a great impact on reliable and secure power supply which is very important in the world of Globalization and Privatization of electrical systems. New approaches have been coming up for power system operation and control for congestion management[5-6], reliable operation and counteracting of various dynamic disturbances[7] such as transmission lines switching, loss of generation, short-circuits and load rejection. To counteract these problems, the power industries are shifting towards large deployment of FACTS devices [8]. The FACTS technology has the principal role of enhancing controllability and power transfer capability in power system. This technology enables the loading of transmission line closer to its thermal limit. FACTS devices can also be effectively used for power flow control, load sharing along parallel feeders, voltage regulation, and enhancement of transient stability and mitigation of system oscillations [9]. Over the period of time various FACTS technologies were developed [10]. With respect to FACTS equipment, voltage sourced converter (VSC) technology, which utilizes self-commutated technique such as GTOs, GCTs and IGBTs has been successfully applied in a number of installations world-wide for static synchronous Compensator [11-12], unified power flow controllers [13] and back to back dc ties [14].

Amongst the FACTS devices, STATCOM is the most preferred device in the power industries for voltage and reactive power compensation [15]. Analogous to a synchronous condenser, STATCOM is operated as a shunt connected static VAR compensator whose capacitive and inductive output current can be controlled independent of ac system voltage. The converters used in STATCOM can be either voltage source or current source converters but voltage source converters are more economical [16] due to the high conduction losses in switches of current source converters .The shunt connection of STATCOM to the Grid is shown in Fig.1

STATCOM provides the following advantages:

- Quick response to system disturbance.
- Smooth voltage control over a wide range of operating conditions.
- Damping of power oscillations.
- Transient stability improvement.
- Alsop control of active power possible(with a DC energy source).
- No Sub Synchronous Resonance.
- Less space required due to availability in modules.

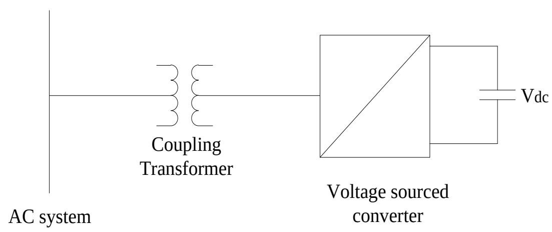

Fig 1: Connection of a STATCOM to ac system

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 05, May-2016

The ideal V-I characteristic of a STATCOM is shown in Fig. 2. STATCOM can be used both for leading VARs and lagging VARs compensation.

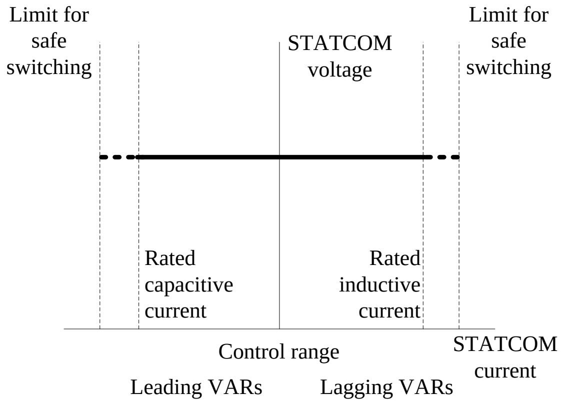

Figure 2: Ideal V-I characteristic of STATCOM

By implementing various hybrid converters the ideal characteristic can be made drooping as per the requirement for VAR compensation [17]. One of such modified drooping characteristic is shown in Fig.3.

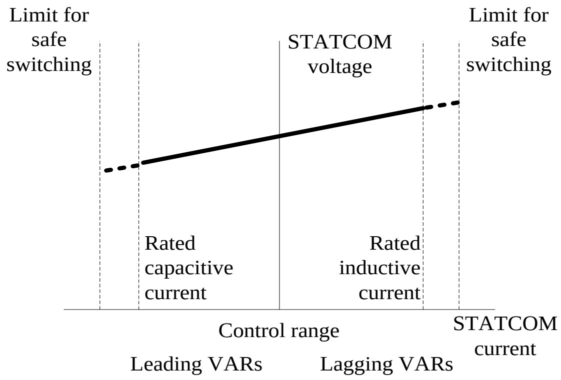

Figure 3: Drooping V-I characteristic of STATCOM

II. MATHEMATICAL MODELLING OF THE SYSTEM

A. Modelling of STATCOM

The methodology proposed in this paper as with reference to [17], under the method of linearization. In fig 4. the equivalent model of the STATCOM being connected to the AC supply has been shown.

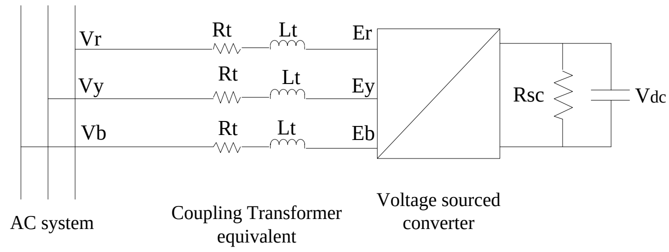

Figure 4: Equivalent Diagram of a STATCOM

TABLE I
NOMENCLATURE

Symbol	Description
V_r, V_y, V_b	Line voltages
R_t	Equivalent resistance of the coupling transformer
L_t	Equivalent inductance of the coupling transformer
w_s	System Frequency
E_r , E_y , E_b	Voltages available in the STATCOM output
R_{SC}	Switching loses equivalent resistance
V_{DC}	Voltage available across the capacitor
C	Capacitance across the converter
θ_s	Phase angle
V_s	R.M.S phase voltage
α	Firing angle
k	Factor relating V_{dc} and V_s

The ac KVL equations for the circuit can be expressed in matrix form,

$$\begin{bmatrix} \frac{di_r}{dt} \\ \frac{di_y}{dt} \\ \frac{di_b}{dt} \end{bmatrix} = \frac{-R_t}{L_t}\begin{bmatrix} i_r \\ i_y \\ i_b \end{bmatrix} + \frac{1}{L_t}\begin{bmatrix} E_r - V_r \\ E_y - V_y \\ E_b - V_b \end{bmatrix} \quad (1)$$

The AC system phase voltage and the output of the STATCOM (neglecting harmonics) is given by (2) & (3) respectively,

$$V_r = \sqrt{2}V_s \sin(w_s t + \theta_s) \quad (2)$$

$$V_r = kV_{DC} \sin(w_s t + \alpha) \quad (3)$$

The above system is now transformed to a synchronous reference frame (on p.u. basis),

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 05, May-2016

$$\begin{bmatrix} \frac{di_d}{dt} \\ \frac{di_q}{dt} \\ \frac{dV_{DC}}{dt} \end{bmatrix} = [A_s]*\begin{bmatrix} i_d \\ i_q \\ V_{DC} \end{bmatrix} - \frac{w_s}{L_t}\begin{bmatrix} V_s\cos\theta_s \\ V_s\sin\theta_s \\ 0 \end{bmatrix} \quad (4)$$

where,

$$A_s = \begin{bmatrix} \frac{-R_t w_s}{L_t} & w_s & \frac{kw_s\cos(\alpha+\theta_s)}{L_t} \\ -w_s & \frac{-R_t w_s}{L_t} & \frac{kw_s\sin(\alpha+\theta_s)}{L_t} \\ -M_k\cos(\alpha+\theta_s) & -M_k\sin(\alpha+\theta_s) & \frac{-Cw_s}{L_t} \end{bmatrix} \quad (5)$$

and

$$M_k = 1.5*k*w_s*C \quad (6)$$

The injected active power and reactive power at the bus connected to the STATCOM are given by,

$$P = V_s*\left(\cos\theta_s i_d + \sin\theta_s i_q\right) \quad (7)$$

$$Q = V_s*\left(\sin\theta_s i_d - \cos\theta_s i_q\right) \quad (8)$$

The characteristic equation of the linearized system of (4) is given by,

$$s^3 + s^2\left(\frac{2R_t w_s}{L_t} + \frac{w_s C}{R_{SC}}\right) + s\left\{\frac{R_t w_s}{L_t}\left(\frac{R_t w_s}{L_t} + \frac{2w_s C}{R_{SC}}\right) + w_s^2 + \frac{3k^2 w_s^2 C}{2L_t}\right\}$$
$$+\left\{\frac{w_s^3 C}{R_{SC}}\left(1+\frac{R_t^2}{L_t^2}\right) + \frac{3k^2 w_s^3 C R_t}{2L_t^2}\right\} = 0 \quad (9)$$

Now with reference to [18], the per unit values of ***R_t = 0.01, L_t=0.15, C=0.88, R_{sc} =100/K, K=4/π, w_s=377*** are taken and the characteristic equation (9) has been solved for the Eigen values in MATLAB.These parameters yield the following Eigen values for the Linearized system,

s=-3.8 & s=-25.35±j147

These values show that the STATCOM is highly overdamped and also has a high frequency of oscillations. Now in steady state (4) has been solved.

$$[A_s]*\begin{bmatrix} i_d \\ i_q \\ V_{dc} \end{bmatrix} = \frac{w_s}{L_t}\begin{bmatrix} V_s\cos\theta_s \\ V_s\sin\theta_s \\ 0 \end{bmatrix} \quad (10)$$

$$\begin{bmatrix} i_d \\ i_q \\ V_{dc} \end{bmatrix} = \frac{w_s}{L_t}*[A_s^{-1}]*\begin{bmatrix} V_s\cos\theta_s \\ V_s\sin\theta_s \\ 0 \end{bmatrix} \quad (11)$$

B. Modeling of Control scheme

Various current control schemes for three phase voltage source PWM converters have been explained in [20]. Out of these schemes the Synchronous vector controller (PI) been implemented in this paper. The schematic diagram of this scheme is shown in Fig 5. The synchronous vector PI controller is used when the phase or amplitude errors are needed to be completely eliminated. It employs two PI controllers of current vector components in a rotating synchronous frame (d-q) [21]. This controller has been used as the control scheme in this paper as this scheme eliminates the errors completely and also operates satisfactorily in high frequency system. The only disadvantage of this controller is that its dynamic properties are inferior to that of other non-linear controllers.

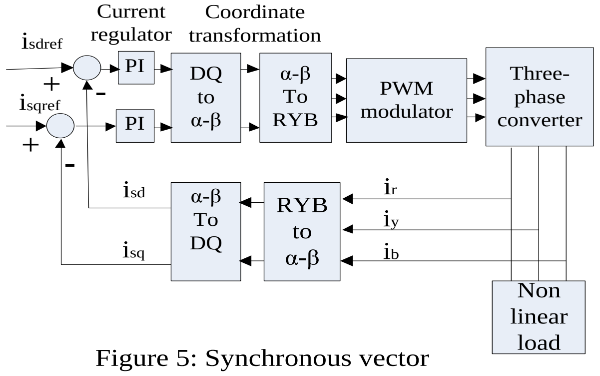

Figure 5: Synchronous vector Controller (PI) Scheme

III. IMPLEMENTATION

The design of STATCOM with Synchronous Vector PI controller, presented in Fig. 4, has been implemented on a standard IEEE 14 bus system (Fig. 6) using MATLAB. Table II represents the data of IEEE 14 bus system [22].

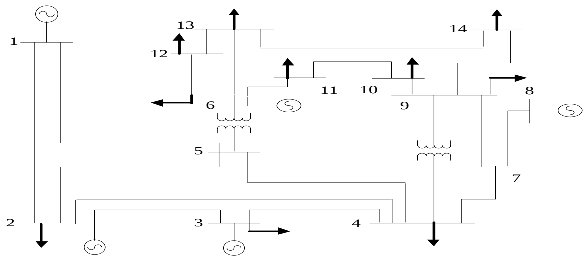

Figure 6: Standard IEEE 14 bus system

TABLE II
BUS DATA OF 14-BUS SYSTEM

Bus	Voltage	Angle	P_{Gi}	Q_{Gi}	P_{Li}	Q_{Li}
1	1.0600	0.00	188.86	-9.90	188.86	0.00
2	1.0450	-4.05	40.00	34.63	21.70	12.70
3	1.0100	-11.17	0.00	23.90	94.20	19.00
4	1.0202	-8.237	0.00	0.00	47.80	-3.90
5	1.0232	-6.915	0.00	0.00	7.60	1.60
6	1.0700	-10.32	20.00	15.838	11.20	7.50
7	1.0528	-9.397	0.00	0.00	0.00	0.00
8	1.0900	-7.638	20.00	23.311	0.00	0.00
9	1.0356	-11.16	0.00	0.00	29.50	16.60
10	1.0341	-11.30	0.00	0.00	9.00	5.80
11	1.0482	-10.94	0.00	0.00	3.50	1.80
12	1.0537	-11.20	0.00	0.00	6.10	1.60
13	1.0473	-11.27	0.00	0.00	13.50	5.80
14	1.0225	-12.23	0.00	0.00	14.90	5.00

IV. RESULTS

Load flow analysis is performed initially to identify bus voltages which are out of the tolerance level (5%). The results of load flow analysis in steady state show that the voltages in buses 9 and 13 violate the tolerance level. Hence the modeled STATCOM is connected to these buses to bring the voltage level within tolerance limit.

Table III shows the load flow analysis of 14-bus system. It can be observed from Fig. 7 that the voltage profile is going out of the tolerance level in bus 9 and 13.

Table IV shows the load flow analysis of 14-bus system with STATCOM been connected at buses 9and 13 respectively. It is evident from Fig. 8, that the voltage profile has been improved considerably. Thus it can be concluded that STATCOM results in improvement of voltage profile by controlling the reactive power.

TABLE III
RESULTS OF LOAD FLOW WITHOUT STATCOM

Bus	Voltages	Angle
1	1.0400	0.0000
2	1.0430	-5.3543
3	1.0196	-7.5308
4	1.0104	-9.2841
5	1.0100	-14.1738
6	1.0392	-14.0644
7	1.0020	-12.8649
8	1.0100	-11.0581
9	***0.9335***	***-16.5031***
10	1.0145	-15.6550
11	0.9991	-16.3007
12	0.9944	-16.9077
13	***0.9428***	***-17.8067***
14	1.0132	-16.0084

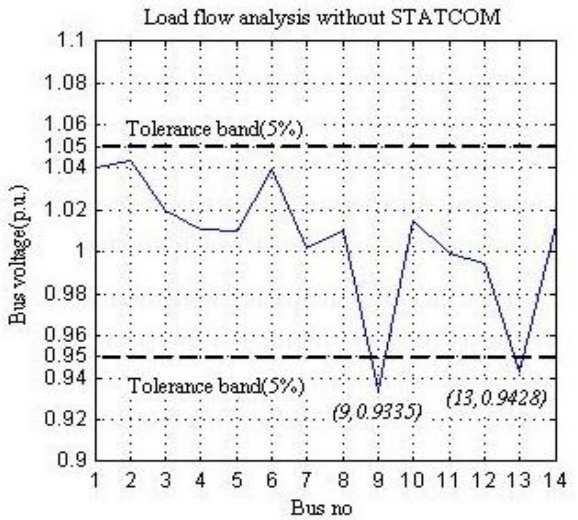

Figure 7: Graph of load flow studies without STATCOM

TABLE IV
RESULTS OF LOAD FLOW WITH STATCOM

Bus	Voltages	Angle
1	1.0400	0.0000
2	1.0430	-5.3543
3	1.0200	-7.5318
4	1.0108	-9.2848
5	1.0190	-14.1692
6	1.0402	-14.0508
7	1.0023	-12.8655
8	1.0100	-11.8168
9	***1.0000***	***-16.7794***
10	1.0240	-15.7112
11	1.0091	-11.7434
12	1.0076	-17.0359
13	***1.0000***	***-18.0205***
14	1.0330	-15.0935

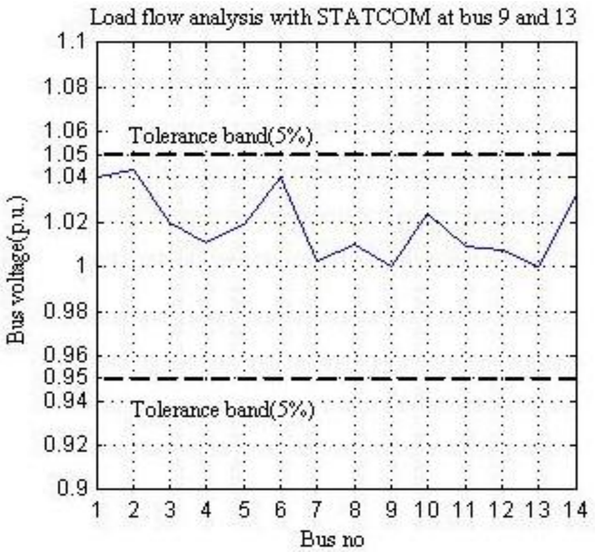

Figure 7: Graph of load flow studies with STATCOM

V. CONCLUSION

This paper illustrates the design of a STATCOM model using a synchronous vector PI control technique to meet the voltage dip problem. The results obtained and the analyses are the justifications of the design.

The present work can be extended to incorporate the following sectors:

a) Conduction loss calculation of the switches.
b) Harmonic analysis and appropriate filter design.
c) Operation during various fault conditions.
d) Optimization of the capacitance value.
e) Dynamic performance.

New trends in the current control techniques have come up such as hysteresis controller neural networks and fuzzy-logic based controllers. These controllers can also be implemented on the model discussed above.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 05, May-2016

REFERENCES

[1] St.John, A.N. ; San Diego Gas & Electr., CA, USA,"Survey of recent voltage sag papers from around the world." Industrial and Commercial Power Systems Technical Conference, 1993, p.p. 52-54.

[2] Anto, R. ; Dept. of Electr. & Electron. Eng., Mar Bacellious Christian Coll. of Eng., Kottayam, India ; Jose, J.,"Performance analysis of a 100kw solar photovoltaic power plant." 2014 IEEE Annual International Conference..

[3] Mueller, D. ; Camm, E.H.,"Power quality standards for utility wind and solar power plants." Transmission and Distribution Conference and Exposition (T&D), 2012 IEEE PES.

[4] Badrzadeh, B. Gupta, M. ; Singh, N. ; Petersson, A. ; Max, L. ; Hogdahl, M.,"Power system harmonic analysis in wind power plants — Part I: Study methodology and techniques" Industry Applications Society Annual Meeting (IAS), 2012 IEEE..

[5] Muneender, E. ; Dept. of Electr. Eng., Nat. Inst. of Technol., Warangal, India ; Kumar, D.M.V.," Optimal rescheduling of real and reactive powers of generators for zonal congestion management based on FDR PSO." Transmission & Distribution Conference & Exposition: Asia and Pacific, 2009.

[6] Chong, B. Zhang, X.-P. ; Yao, L. ; Godfrey, K.R. ; Bazargan, M.,"Congestion Management of Electricity Markets Using FACTS Controllers." Power Engineering Society General Meeting, 2007. IEEE.

[7] Allaf, B.A. ; Saudi Electr. Co., Jeddah, Saudi Arabia ; Elkhatib, A.A,"Power system dynamics during disturbances." GCC Conference & Exhibition, 2009 5th IEEE.

[8] Gotham, D.J. ; State Utility Forecasting Group, Purdue Univ., West Lafayette, IN, USA ; Heydt, G.T,"Power flow control and power flow studies for systems with FACTS devices." Power Systems, IEEE Transactions1998.

[9] Paserba, J.J. "How FACTS Controllers Benefit AC Transmission Systems-phases of power system studies." Power Systems Conference and Exposition, 2009, p.p. 1-4.

[10] Edris, A,"FACTS technology development: an update", IEEE Volume: 20, Issue: 3 DOI:10.1109/39.825623 Publication Year: 2000 , Page(s): 4-9.

[11] Reed, G.;Paserba, J.; croasdaile, T.; Westover, R.; Jochi, S. "SDG& E Talega STATCOM project-system analysis, design, and configuration." Transmission and Distribution Conference and Exhibition 2002, vol. 2, p.p. 1393-1398.

[12] S. mori, k. matsuno, T. hasegawa, S. ohnishi, M. Takena, M. selo, S. murakami, F. ishiguro, "Development of a large static VAR generator using self-commutated inverters for improving power system stability." IEEE transaction on power systems, vol. 8, No. 1, February, 1993, pp.371-377.

[13] B.A. Renz, A.J.F. Keri, A.S. Mehraban, J.P. Kessinger, C.D. Schauder, L.Gyugyi, L.J. Kovalsky, A.A. Edris, "World's First Unified Power Flow Controller on the AEP System," CIGRE Paper 14-107, Paris Session, 1998.

[14] H. Suzuki, M. Takeda, G. Reed, "Application of Voltage Source Converter Technology to a Back-to-Back DC Link," Presented at the Panel Session on FACTS Controllers: Applications and Operational Experience, Proceedings of the IEEE PES Summer Power Meeting, Edmonton, Alberta, July 1999.

[15] Suja, K.R. ; Noorul Islam Univ., Kumaracoil, India ; Raglend, I.J.,"Power quality improvement in grid connected wind energy system using STATCOM." Computing, Electronics and Electrical Technologies (ICCEET), 2012 International Conference.

[16] Azmi, S.A. ; Dept. of Electron. & Electr. Eng., Univ. of Strathclyde, Glasgow, UK ; Ahmed, K.H. ; Finney, S.J. ; Williams, B.W.," Comparative analysis between voltage and current source inverters in grid-connected application." Renewable Power Generation (RPG 2011), IET Conference 2011.

[17] El Moursi, M. ; Masdar Inst., Abu Dhabi, United Arab Emirates ; Alobaidli, K.A. ; Zeineldin, H.H.,"Ahybrid STATCOM for economical system installation with proven dynamic and transient response."PowerTech (POWERTECH), 2013 IEEE Grenoble.

[18] Rao, P.; Crow, M.L.; Zhiping Yang "STATCOM control for power system voltage control applications", IEEE transactions on Power Delivery 2000, vol. 15, page(s): 1311-1317.

[19] C. Schauder and H. Mehta, "Vector analysis and control of advanced static VAR compensators," IEE Proceedings, 1993, vol. 140.

[20] "Current Control Techniques for Three-Phase Voltage –Source PWM Converters: A Survey", by Marian P. Kazmierkowski, Fellow, IEEE, and Luigi Malesani, Fellow, IEEE.

[21] M. P. Kazmierkowski and H. Tunia, "Automatic Control of Converter-Fed Drives. "Amsterdam, The Netherlands: Elsevier, 1994.

[22] Choudhury, N.B.D; Kakoti, R.K., "Identification of transmission loss in trading of power using tracing of power", 2012 9th international conference on ECTI-CON.