International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2013): 4.438

Damping of Power and Enhancement of Stability for a Large Offshore Windfarm Using a Rectifier Current Regulator

Santhosh Kumar.T[1], Jagadeswari.G[2]

Department of Power System Engineering, Valliammai Engineering College, Chennai, India

Abstract: ***This paper describes the anlalysis, dynamic modelling and control of power in an induction generator driven by variable speed offshore wind turbine. The generated power is available to the grid via a HVDC link. A control scheme based on PID controller has been developed at the converter stations in order to control the power flow in the HVDC link. The power developed by the generator and power flow across the converter and inverter stations with PID and without PID Rectifier current regulator has been analysed. The eigen value analysis has been performed to check the stability of the entire system.***

Keywords: High voltage direct current(HVDC)link, induction generator(IG),Eigen value analysis.

1. Introduction

Due to the environmental issues it is very important to generate power in an efficient way. As an option, generation of power using wind energy is a rapidly growing high technology on a worldwide basis. The integration of generated power by the offshore wind turbine to the power system and its operation poses a challenge. Because of the nature of the wind, the output power produced by the wind turbine will also be fluctuating in nature. This will definitely affect the interconnected grids and lessen the lifespan of the neighbouring stations. Hence it is necessary to control the power generated by the wind energy system. Furthermore when the power transmitted through the HVAC lines it poses severe limitation line length, uncontrolled power flow, over/low voltage during lightly/overloaded conditions, stability problem, fault isolation etc. To overcome the above mentioned problems, this paper proposes the control of power using HVDC link. The PID based regulator is developed across the rectifier side to generate the firing pulse for the semiconducting devices. The potential development in the HVDC technology overcome the technical challenges faced by HVAC system and also effectively controls the generated power[4]. The control statergy of DFIG based wind farm connected to the HVDC link using a conventional converter stations has been investigated[5]. The control system for a large offshore windfarm with a line commutated HVDC provides high performance control of ac grid has been be proposed in [6]. Two different control schemes has been developed to enhance the damping for the electromechanical mode of the system [8].

This paper presents the damping of power oscillations by controlling the firing angles of theconverters and also steady state eigen value analysis has to check the stability of the proposed system.

2. Proposed System Modelling

The 80MW induction generator which is aggregated by forty 2 MW induction generator driven by offshore wind turbine together. The generated output power is connected to the HVDC link through step up transformer with an impedance of $R_{t1} + jX_{t1}$. The HVDC links consists of a front-end converter (rectifier) station, a T-equivalent transmission line and a back-end converter (inverter) station that delivers the power to the grid through step down transformer of impedance $R_l + jX_l$.The proposed system model is shown in fig1.

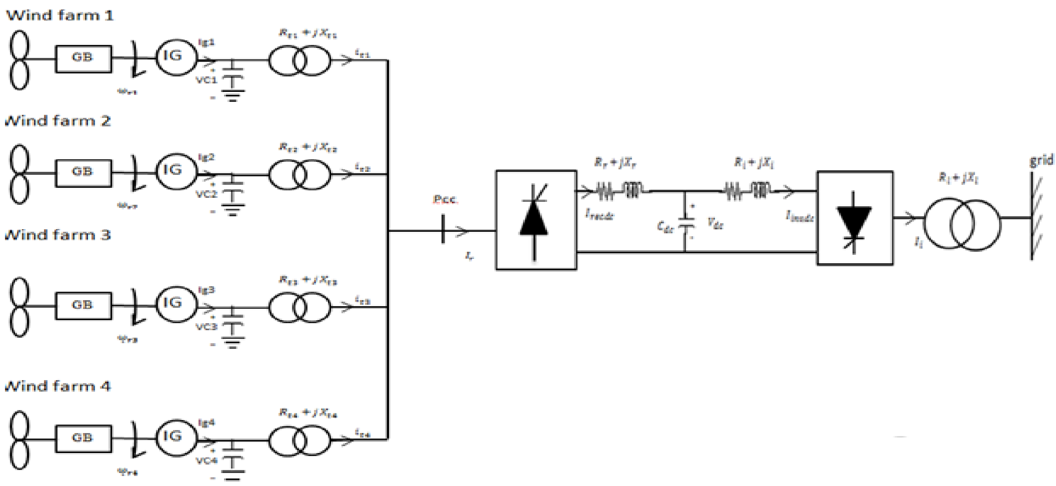

Figure 1: Proposed System

A. Wind Turbine Modelling

The extracted power by the wind turbine is given by,

$$P_m = \frac{1}{2}\acute{\rho} C_p A V_w^3 \quad (1)$$

where P_m is the mechanical power produced in W, A is the swept area of the blade in m^2, V_w is the wind velocity in m/s, $\acute{\rho}$ is the air density, and C_p is the power coefficient which is a function of the blade pitch angle θ and it is represented as

$$C_p(\lambda,\theta) = C_1\left(\frac{C_2}{\Lambda} - C_3\theta - C_4\theta^x - C_5\right)e^{\frac{-C_6}{\Lambda}} \quad (2)$$

$$\frac{1}{\Lambda} = \frac{1}{\lambda+0.08\theta} - \frac{0.035}{\theta^3+1} \quad (3)$$

the tip speed ratio λ defined as

$$\lambda = \frac{\omega R}{U_w} \quad (4)$$

where, ω is the rotational speed of rotor in rad/sec, R is the radius of blade in m, θ is the pitch angle in degrees, C_1 to C_6 and x are constants.

The mechanical equation for the two-inertia reduced-order wind turbine model is given by [1]-[3],

$$2H_H\, p(\omega_H) = T_M - D_{HG}\omega_H - K_{HG}\theta_{HG} \quad (5)$$

$$2H_G\, p(\omega_G) = -T_e + D_{HG}\omega_G + K_{HG}\theta_{HG} \quad (6)$$

$$p(\theta_{HG}) = \omega_b(\omega_H - \omega_G) \quad (7)$$

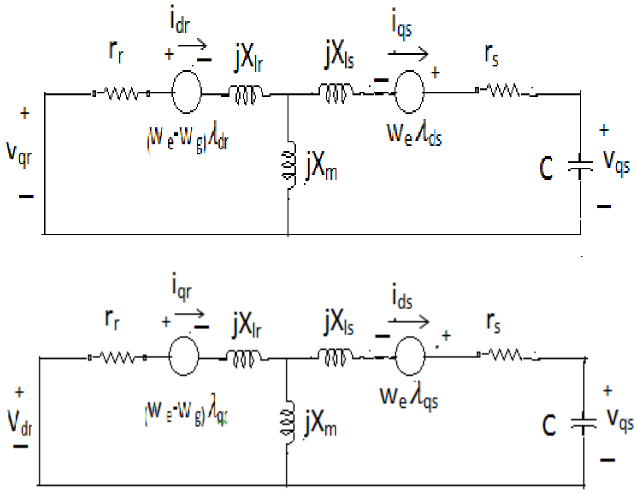

Figure 3: d-q axes representation of induction generator

$$p(i_{dr}) = [-(r_r/D) * i_{dr} - (x_m * r_s)/(D * x_{ss})i_{ds} + (\omega_e - D) * \omega_g D)i_{qs} - (x_m/(D * x_{ss})) * v_{ds}]\omega_b \quad (8)$$

$$p(i_{ds}) = [-(r_r/x_m * D) * i_{dr} - (([1+Y] * r_s)/x_{ss}) * i_{ds} - (\omega_g/(x_m * Y)) * i_{qr} + (\omega_e + (Y * \omega_g)) * i_{qr} + ((1+Y * x_{ss})/X_{ss}) * v_{qs}]\omega_b \quad (9)$$

$$p(i_{qr}) = [(D\omega - \omega_e) * i_{dr} - (x_m * \omega_g) * i_{ds} - (r_r/D) * i_{qr} - ((x_m * r_s)/Dx_{ss})) * i_{qs} + (x_m/(D * X_{ss})) * v_{ds}]\omega_b \quad (10)$$

$$p(i_{qs}) = [((\omega_g/x_m) * Y) * i_{dr} - (\omega_e + (Y * \omega_g)) * i_{ds} - (r_r/x_m) * i_{qr} - ((1+Y) * r_s/x_{ss}) * i_{qs} - (1+Y * x_{ss})/x_{ss}) * v_{qs}]\omega_b \quad (11)$$

$$Y = \frac{x_m^2}{D * x_{ss}},\ D = x_{rr} - \frac{x_m^2}{x_{ss}}$$

where ω_b is the p.u electrical base speed, ω_s is the p.u synchronous speed, v_{qs} *and* v_{ds} is the p.u q-axis and d-axis voltage of stator, v_{qr} *and* v_{dr} is the p.u q-axis and d-axis voltage of rotor, i_{qs} *and* i_{ds} is the p.u q-axis and d-axis current of stator, i_{qr} *and* i_{dr} is the p.u q-axis and d-axis current of rotor, X_m is the p.u mutual inductances, x_{rr} & x_{ss} are the p.u self reactance of the stator and the rotor, R_r is the p.u rotor resistances.

where H_H & H_G are the p.u inertia of the hub and induction generator, D_{HG}, K_{HG}, θ_{HG} are the p.u mechanical damping coefficient, spring constant and rotor angle difference between hub and induction generator, ω_H & ω_G are the p.u angular velocity of the hub and generator, T_e is the p.u electromagnetic torque of induction generator, T_M is the p.u mechanical input torque. The two mass model of the wind turbine is shown in fig2

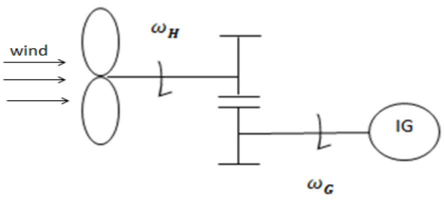

Figure 2: Two mass reduced order wind turbine model

B. Induction Generator Model

The d-q axes representation of induction generator is shown in fig3. The linearised differential equation of induction generator for stability analysis in state variable form are represented by the following equations.

C. Excitation Capacitor Bank Model

The state variable representation of excitation capacitor bank model is given by,

$$p(v_{qs}) = (w_b * i_{qc}/c) + (\omega_e * \omega_b * v_{qs}) \quad (11)$$

$$p(v_{ds}) = (w_b * i_{dc}/c) - (\omega_e * \omega_b * v_{qs}) \quad (12)$$

where i_{qc}, i_{dc} are the p.u qaxis and d-axis excitation capacitor currents, v_{qs}, v_{ds} are the p.u q-axis and d-axis stator voltages, ω_e, ω_b p.u base and synchronous angular speed.

D. Modelling of HVDC Link

The representation of HVDC link model is shown in fig 5. The p.u voltage current equation of the HVDC link represented in state variable form is shown below.

$$p(i_{REC,DC}) = -\frac{R_r}{L_r} i_{REC,DC} + \frac{1}{L_r} V_{REC,DC} - \frac{1}{L_i} v_L \quad (13)$$

$$p(i_{INV,DC}) = -\frac{R_i}{L_i} i_{INV,DC} + \frac{1}{L_i} v_{INV,DC} - \frac{1}{L_i} v_L \quad (14)$$

$$p(v_L) = \frac{1}{C_L} i_{REC,DC} - \frac{1}{C_L} i_{INV,DC} \quad (15)$$

where $i_{REC,DC}$ & $i_{INV,DC}$ are the rectifier and the inverter current in HVDC link, $v_{REC,DC}$ & $v_{INV,DC}$ are the rectifier and inverter voltage in HVDC link.

E. Converter Model

The voltage developed across the rectifier and inverter can be written as

ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2013): 4.438

$$v_{REC,DC} = v_{dor} \cos \alpha - \frac{3\sqrt{2}}{\Pi} x_{cr}\, i_{REC,DC} \quad (16)$$

$$v_{INV,DC} = v_{dor} \cos \Upsilon - \frac{3\sqrt{2}}{\Pi} x_{ci}\, i_{INV,DC} \quad (17)$$

where x_{cr} & x_{ci} are the commutation reactance, α is the delay angle of the c rectifier, ϒ is the extinction angle of the inverter.

F. Power Grid Model

The p.u voltage-current equation of the output of the inverter terminal is given by

$$p(i_{ql}) = [v_{q,inv} - v_{q,grid} - R_l i_{ql} - \omega_e x_l i_{dl}]\omega_b / x_l \quad (18)$$

$$p(i_{dl}) = [v_{d,inv} - v_{d,grid} - R_l i_{dl} + \omega_e x_l i_{ql}]\omega_b / x_l \quad (19)$$

where, i_{ql} & i_{dl} are the p.u q-axis and d-axis line currents, $v_{q,inv}$ & $v_{d,inv}$ are the p.u q-axis and d-axis voltages of the inverter, $v_{q,grid}$, $v_{d,grid}$ are the p.u q-axis and d-axis grid voltages, x_l p.u. leakage reactance.

G. Modelling Of Pid Based Rectifier Current Regulator And Inverter Current Regulator

The design of PID based rectifier current regulator is shown Fig 4 below. This regulator generates the firing angle that triggers the semiconducting devices.The p.u equation of PID based rectifier current regulator and inverter current regulator is given by,

$$p(\alpha_r) = \left(\frac{K_r}{T_r}\right)\left(I_{ref} - I_r + I_c\right) - \left(\frac{1}{T_r}\right)\alpha_r \quad (20)$$

$$p(\gamma_i) = \left(\frac{K_i}{T_i}\right)\left(I_{ref} - I_i\right) - \left(\frac{1}{T_i}\right)\gamma_i \quad (21)$$

Where I_c is the generated control signal by PID regulator. The block diagram of the current regulator is shown in Fig 7.

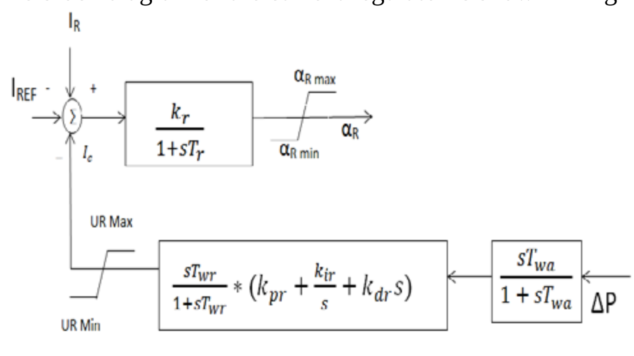

Figure 4: Block Diagram of PID Rectifier Current Regulator

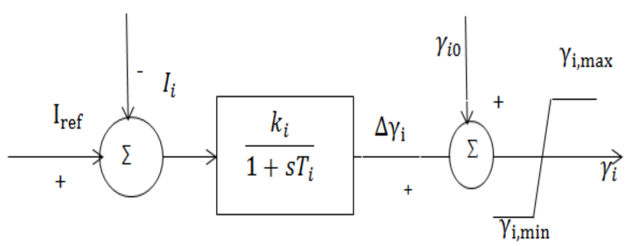

Figure 5: Block Diagram of Inverter Current regulator

3. State Space Modelling

The equations that described before are used to develop the state space model. The state space representation of the proposed system is given by

pX=AX+BU+VW(22)
Y=CX+DU(23)

X=[$i_{ds}\, i_{dr}\, i_{qs}\, i_{qr}\ \omega_{\boldsymbol{H}}\omega_{\boldsymbol{G}}\, \theta_{HG}\ v_{qs}\ v_{ds}\ i_{dl}\ i_{ql}\, i_{REC,DC}\ i_{INV,DC}\ v_L\ \alpha_r\, \gamma_i$]
A=[k1 k2 k3 k4 0 0 0 0 L1 0 0 0 0 0 0 0
k5 k6 k7 k8 0 0 0 L1 0 0 0 0 0 0 0 0
k9 k10 k11 k12 0 0 0 0 L2 0 0 0 0 0 0 0
k13 k14 k15 k16 0 0 0 L2 0 0 0 0 0 0 0 0
0 0 0 0 k17 k18 0 0 0 0 0 0 0 0 0 0
0 0 0 0 k19 0 k20 0 0 0 0 0 0 0 0 0
0 0 0 0 0 k21 k22 0 0 0 00 0 0 00
0 0 0 0 0 0 0 0 k23 0 0 0 0 0 0 0
0 0 0 0 0 0 0 k24 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 k25 k26 0 0 0 0 0
0 0 0 0 0 0 0 0 0 k27 k25 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 h1 0 h2 0 0
0 0 0 0 0 0 0 0 0 0 0 0 h3 h4 0 0
0 0 0 0 0 0 0 0 0 0 0 h5 h6 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 k28 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 k29]

k1=$\dfrac{r_s * \omega_b * \left(1 + \left(x_m * \frac{x_m}{D} * x_{ss}\right)\right)}{x_{ss}}$;

k2=$(\omega_e * x_{ss}) + (\frac{\omega_g * x_m * x_m}{D})) * (\omega_b / x_{ss})$;

k3=-$(r_r * \omega_b * x_m)$/(D*x_{ss})

k4=$((\omega_e * x_m * \left(\left(\frac{x_{rr}}{D}\right) + (Y - 1) - \left(\omega_g * x_{rr} * \frac{x_m}{D}\right)\right) * (\omega_b / x_{ss})$;

k5=-$((\omega_g * x_m * x_m$/D)+$(\omega_e * x_{ss}) * \omega_b)/x_{ss}$;

k6=(1+(Y*$r_s * \omega_b)/x_{ss}$);

k7=$(\omega_g * x_{rr} * \omega_b * x_m)$/(D*$x_{ss}$);

k8=-$(r_r * \omega_b * x_m)$/(D*x_{ss});

k9=-$(r_s * \omega_b * x_m)$/(D*x_{ss});

k10=$-r_r * \omega_b * x_m$;

k11=$-r_r * \omega_b / D$;

k12=$((\omega_e * (x_{rr} + Y)) - (\omega_{g*} x_{rr})) * \omega_b)/D)$;

k13=$-\omega_g * \omega_b * x_m$;

k15=$\frac{(\omega_{g*} x_{rr}) - (\omega_e * D)}{D} * \omega_b$;

k16=$-r_r * \omega_b$;

k17=$-\frac{P_m + D_{hgw}}{2 * h_h}$;k18=$-\frac{k_{hg}}{2 * h_g}$;

k19=ω_b; k20=-ω_b; k21=$\frac{D_{hgw}}{2 * h_g}$;

k22=-k18; L1=$\left(1 + \frac{x_m^2}{D}\right) * \frac{\omega_b}{x_{ss}}$; L2=$-\frac{x_m * \omega_b}{D * x_{ss}}$;

k23=-$\omega_e * \omega_b$;

k24=$\omega_e * \omega_b$;k25=$\frac{-r_l \omega_b}{x_l}$;k26=-k23;k27=k23;

k28= $-1/t_r$; k29= $-1/t_i$;h1=$-\frac{R_r}{L_r}$;h2= -$\frac{1}{L_i}$; h3=$-\frac{R_i}{L_i}$;

h4=$-\frac{1}{L_i}$;h5=$\frac{1}{C_l}$; h6=$-\frac{1}{C_l}$;

Where X is the state vector, Y is the output vector, W is the disturbance input and U is the compensated input. A,B, C, p are constant matrices. The state vector X is obtained by considering the state equations of induction generator, wind turbine, excitation capacitor bank model, HVDC link model and power grid model. The state space modelling of single induction generator connected to the HVDC link is shown above.

From the state space model the eigen values analysis under various wind speed with PID rectifier current regulator and without PID rectifier current regulatorare obtained.

4. Simulation Results

The eigen values analysis(shown in table 1) has been made to ensure the stability of the system with PID RCR and damping of power at the converters(shown in table 2) has been achieved via MATLAB coding.

TABLE 1: Eigen values when wind speed=4m/s and 6 m/s

Wind speed =4m/s	Wind speed=6m/s
-0.0000 + 0.0006i	-0.0000 + 0.0006i
-0.0000 - 0.0006i	-0.0000 - 0.0006i
-0.0051	-0.0077
-0.0044 + 1.0329i	-0.0044 + 1.0329i
-0.0044 - 1.0329i	-0.0044 - 1.0329i
-0.0012 + 1.0781i	-0.0012 + 1.0781i
-0.0012 - 1.0781i	-0.0012 - 1.0781i
-1.5458	-1.5458
-0.0123	-0.0123
-0.0003 + 0.6060i	-0.0003 + 0.6060i
-0.0003 - 0.6060i	-0.0003 - 0.6060i
-0.0011 + 0.5608i	-0.0011 + 0.5608i
-0.0011 - 0.5608i	-0.0011 - 0.5608i
-0.0174	-0.0174
-0.0000 + 0.0006i	-0.0000 + 0.0006i
-0.0000	-0.0000 - 0.0006i
- 0.0006i	-0.0001
-0.0001	-0.0002
-0.0002	-.0002

Table 2: Power at the converter stations with PID RCR and without PID RCR

Controller / Converter	WITH PID RCR	WITHOUT PID RCR
RECTIFIER SIDE	P=238Mw Q=110MVA	P=184Mw Q=118MVA
INVERTER SIDE	P=184Mw Q=24MVA	P=184Mw Q=143MVA

5. Conclusion

An approach for carrying out the power flow analysis of an HVDC link has been presented. The damping of power is achieved by controlling the firing pulse generation using PID controllers. The proposed system also maintains the stability by addition of PID RCR.

APPENDIX

1) Single IG of the Wind farm

$v_{base} = 690v, S_{base} = 2MW, f_{base} = 50\ HZ,$

$r_s = 0.00488\ p.u, x_{ss} = 0.09241\ p.u,$

$r_r = 0.00549\ p.u, x_{rr} = 0.09955\ p.u,$

$x_m = 3.9527\ p.u,$

2) CAPACITOR BANK

$x_c = 0.375\ p.u, r_t = 0.01\ p.u, x_t = 0.04\ p.u,$

[13]

$r_l = 0.02\ p.u, x_l = 0.08\ p.u,$

3) HVDC LINE PARAMETERS

$R_r = 0.05\ p.up.u, X_r = 0.2\ p.u,$

$R_i = 0.05\ p.u, X_i = 0.2\ p.u, T_r = 0.1\ s,$

$T_i = 0.1s, k_r = 1\ p.u, k_i = 1$

References

[1] C.J. Trudnowski, A. Gentile, J. M. Khan, “Fixed speed wind generator and wind park modelling for transient stability studies,” IEEE Trans. Power Syst., vol. 19, no. 4,pp. 1911-1917,Nov.2004.

[2] S. M. Muyeen, M. H. Ali, R. Takahashi, T. Murata,Y. Tomaki, A. Sakahara, and E. Sasano, “Transient stability analysis of wind generator system with consideration of multi-mass shaft model,” in Prac. Int. Conf. Power Electron. Drives Syst., vol.1,pp. 511-516 Jan 2006.

[3] P. Cartwright, L. Holdsworth, J. B. Ekanayake, and N. Jenkins, “coordinated voltage control statergy for a DFIG based wind fam,” Proc. Inst. Electr. Eng. Gener.Transmiss. Distib.,vol.151, no.4,pp.495-502,Jul 2004.

[4] N. M. Kirby, M. J.Luckett, and L. Xu, “HVDC transmission for large offshore wind farms,” AC-DC Power Trans., no.485, pp.162-168, Nov.2001.

[5] K. R. Padiyar and N. Prabhu, “Modelling control design and analysis of VSC based HVDC transmission system,” in Proc. IEEE 2004 Int Conf. Power System Technology, Nov. 2004, vol. 1,pp.774-779.

[6] D. Xiang, L. Ran, J. R. Bumpy, P. J. Tavner, and S.Yang, “Coordinated control of an HVDC link and Dfog in large offshore windfarms,” IEEE Trans.Power Del.,vol. 21, no. 1,pp. 463-470, Jan. 2006.

[7] S. V. Bozhko, G. Asher, R. Li, J.Clare, and G. M. Asher, “control of DFIG based wind farm grid with line commutated HVDC connection ”IEEE Trans. Energy onvers., vol. 22, no.1,pp. 37-43, Mar.2007.

[8] L. Wang, “A comparative study of damping schemes on damping generator oscillations,” IEEE Trans. Power Syst., vol. 8.no.2, pp.613-619, may1993.

[9] L.wang, S,-J.Mau, and C.-C.Chuko, “Suppression of common torsional Imodeinteractions using shunt reactor controllers,” IEEE Trans. Energy Convers., vol. 8, no. 3,pp. 539-545, Sep. 1993.

[10] Y.-Y. Hsu and L. Wang, “Damping of parallel ac-dc power system PID power system stabilizers and rectifier current regulators,” IEE Proc., vol. 136, pt. C, pp. 76-86, Mar.1989.

[11] A. H. M. A.Rahim and I. M. El-Amin, “Stabilization of high voltage AC/DC power ,system., I. Evaluation of control startergies,”IEEE Trans. Power syst., vol. PWRS-1, no. 11, pp. 128-136,Nov 1986.

[12] A. H. M. A. Rahim ,I. M. El. Amin, “Stabilization of high voltage AC-DC power system I Evaluation of control startergies,”IEEETrans PAS, vol 104,pp 3084-3091, March 1985.