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Modeling and Controlling of an Coordinated Power Control Grid Connected Hybrid System with Wind, PV and Fuel Cell Sources

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Abstract: Among the Renewable sources wind PV fuel cell are become popular for generating of electrical energy to meet the load demand due to their abidance availability and easy to generate electric power .Multiple dg sources are selected to increase the stability of the system to meet the energy demand ,the hybrid system is designed using wind, PV fuel cell and MPPT control techniques are implement to increase the demand and the controller is designed for the power flow controller from generation to load. Result is tacked with MPPT and without MPPT techniques and the results are compared with these two models .Compare to the individual sources hybrid system is having more advantage to meet the energy demand. Power electronic interfacing technologies is used to interconnect all the renewable energy sources and the dc link capacitor is used for the maintaining constant voltage in generating side .PI controller techniques are used for tuning the power flow controller .entire system is modeled using the Matlab simulation tool.

Keywords: *Hybrid Energy System, Wind Turbine, Solar Array, fuel cell, Grid Interface*

1. Introduction

Now a days the energy demand is increase in all the fields ,the country development is measured by the energy utilized .in order to meet the energy demand generation has to increase but due to the reduction in the non-renewable energy sources research has find out the alternative energy sources such as non-renewable energy sources ,in order to overcome the losses occur in the generation side and the losses in the transmission lines generation is done in the distributions side known as distributed generation this area is become popular dur to the deregulation of power system. With this type of sources the environment factors also reduced .among the renewable energy sources wind, PV, fuel cell are become more prominent due to the easily power generation and free availability. But this sources are depend upon the weather conditions and the internal parameters of fuel stack and PV arrays ,so continuous power generation is not possible in order to meet the load demand the system is made hybrid for the continuous generation and power generated is stored in some cases ,with the help of the battery system for the continuous power supplying to the load .

2. System Description

The system consists of a wind system (i.e) wind, pv and fuel cell generating sources. Wind system consists of the wind turbine blades along with the direct driven Permanent magnet synchronous generator (PMSG). Permanent magnet synchronous generator has advantage over another generator like PMSG has property of self-excitation allows PMSG operate at high power factor and high efficiency .the system does not require slip rings and an additional power supply for the excitation of magnetic field system. Energy drawn from this wind system is directly connected to uncontrolled AC/DC rectifier and it is connected to common dc link as shown in the below circuit diagram. PV cell is designed and it is converted in the PV modules and arrays by connecting number of PV cells in series and parallel power generated from the PV sources is connected to the dc link voltage as shown in the diagram. Fuel is designed and it is converted into fuel stack and the power from the fuel stack is inter connected to the dc link capacitor along with other sources .grid interface is done with help of the voltage source inverter (VSI)with the pi control technique the controlling of power flow to grid is also done by VSI .

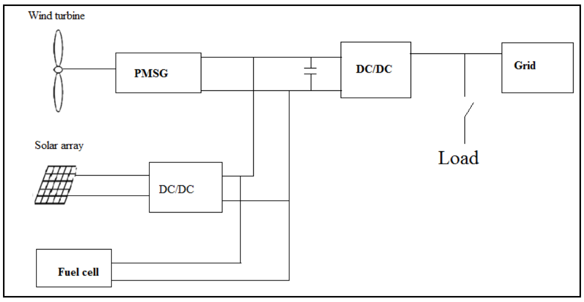

Figure 1 *Block diagram of grid connected wind/pv system.*

Power electronic interface technology is used for connecting hybrid system to the grid. The power converter is used for the power flow control from source to load \and the reactive power compensation to minimum value

3. Modeling of Wind Turbine

The wind turbine (WT) system converts wind energy to mechanical energy. A model of the WT is necessary to evaluate the torque and power production for a given wind speed and to study the effect of wind speed variations on the produced torque. The torque and power produced by the WT within the interval [V_{min}, V_{max}], where V_{min} is minimum wind speed and V_{max} is maximum wind speed, are functions of the blade radius R, air pressure, wind speed and coefficients C_q and C_p [4]. The power available in the wind can be calculated by the equation1.

$$P_m = C_p(\lambda,\beta)\frac{\rho A V_{wind}^3}{2} \quad (1)$$

Where P_m = power in watts, ρ= air density, A= rotor swept area, V_w= wind speed in m/sec Cp known as the power coefficient of rotor the effective area of rotor blade ,wind speed ,and wind flow condition determine the power absorption from wind turbine. Where λ is the tip speed, V_{wind} is the wind speed, R is the radius of turbine blades and β is the blade pitch angle [1][3].

Torque of the turbine T is given by equation 2.

$$T = \frac{P_m}{\omega_m} \quad (2)$$

$$\lambda = \frac{R*\omega}{V_{wind}} \quad (3)$$

The performance coefficient $C_p(\lambda, \beta)$, which depends on tip speed ratio λ and blade pitch angle β, determines the amount of wind energy that can be captured by the wind turbine system. A nonlinear model describes $C_p(\lambda, \beta)$ as in equation4.[]12

$$C_p(\lambda,\beta) = C_1\left(\frac{C_2}{\lambda_i} - C_3\beta + C_4\right)e^{\frac{C_5}{\lambda_i}} + C_6 \quad (4)$$

Where, C_1=0.5176, C_2=116, C_3=0.4, C_4=5, C_5=21and C_6=0.0068.λ_i is expressed in terms of λ and β as in equation 4

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \quad (5)$$

Table 1: *.parameters of wind system*

S.no	Name	Rating
1	V_{rated}	12m/sec
2	Pole pair	10
3	Stator resistance	2.875Ω
4	Ld	8.5e-3
5	Lq	8.5e-3
6	Inertia	0.8e-3

4. Modeling of PV Array

The equivalent circuit of a PV cell is shown in Fig. 1. I-V characteristic of the ideal PV cells can be expressed mathematically by equation 7 and 8 [3-6].

$$I = I_{pv} - I_o\left\{\exp\left(\frac{q(V+IR_s)}{AKT}\right) - 1\right\} - \frac{V+IR_s}{R_p} \quad (6)$$

$$I_o = \frac{I_{sc} + K_I d_t}{\exp\left((V_{oc} + K_v d_t)/aV_t\right) - 1} \quad (7)$$

where $I_{pv,}$ is the photo voltaic current generated by incident light, I_o diode current, I_{sc} is the reverse saturation or leakage current of the diode, q is the electron charge [1.60217646 x 10^{-19} C], k is the Boltzmann constant [1.3806503 x 10^{-23} J/K], T is the temperature of the p-n junction [K], a is the diode ideality constant.

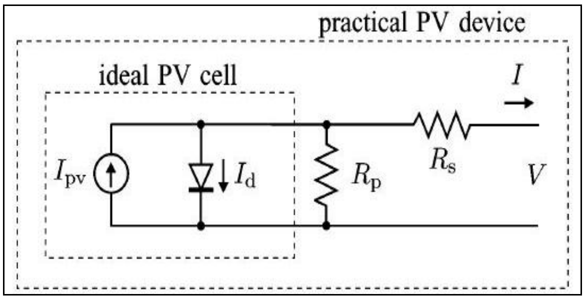

Figure 2 *Equivalent circuit of a PV cell [3]*

Practical photovoltaic arrays consist of several connected photovoltaic cells and the basic equation 6 of the elementary photovoltaic cell is modified to equation 7 in order to make it suitable to practical photovoltaic arrays. Rs is the equivalent series resistance of the array and R_p is the equivalent parallel resistance. The value of R_s and R_p are extracted in an iterative manner. The value of R_s is incremented starting from an initial value .By incrementing the value of R_s corresponding R_p is obtained [1].

$$R_p = \frac{V_{mp}\left(V_{mp} + I_{mp}R_s\right)}{V_{mp}I_{mp} - V_{mp}I_o\exp\left(\frac{q\left(V_{mp}+I_{mp}R_s\right)}{AKTN_s}\right) + V_{mp}I_o - P_{max}} \quad (8)$$

The initial value of series resistance is zero and shunt resistance is given by

$$R_{p\min} = \frac{V_{mp}}{I_{sc} - I_{mp}} - \frac{V_{oc} - V_{mp}}{I_{mp}} \quad (9)$$

The value of A that best fits the experimental data specified by the manufacturer is chosen arbitrarily and the value of it varies between 1 and 2.

Once the value of R_s and R_p are determined the equation of I_{ph} is improved.

$$I_{ph} = \frac{R_p + R_s}{R_p} I_{scn} \quad (10)$$

Temperature and irradiance dependence the open circuit voltage and circuit current, and light generated current .The light generated current depend on temperature and irradiance is

$$I_{ph} = \left(I_{phn} + K_I d_t\right)\frac{G}{G_n} \tag{11}$$

I_{phn} is the photovoltaic current at STC, dt is difference between the operating temperature and temperature as STC, G_n is irradiance .The effect of temperature and irradiance on short circuit current and effect of temperature on open circuit voltage is given by

$$I_{sc} = \left(I_{sc} + K_I d_t\right)\frac{G}{G_n} \tag{12}$$

$$V_{oc} = \left(V_{ocn} + K_v d_t\right) \tag{13}$$

The effect of irradiance on open circuit voltage is obtained by substituting the values of I_{sc}, I_{ph} in equation of OCC and solving open circuit voltage. d_t=T-$T_{n.}$

Parameters of the KVT200GT solar array at 25^0c,1000W/m^2 is taken for calculating the initial values.

Table 2: *Parameters of PV system*

Parameter	Value and units
I_{mp}	7.61 A
V_{mp}	26.3 V
P_{max}	200.143 W
V_{oc}	32.9 V
K_v	-0.1230 V/K
K_I	0.0032 A/K
Ns	54
I_o	9.825×10^{-8} A
I_{pv}	8.214 A
R_p	415.405Ω
R_S	0.221Ω

5. Modeling of the Fuel Cell

The fuel system is designed by using the basic equations and it is converted into the fuel stack the output voltage of single fuel cell is calculate by using the Nernst and Ohinc and con equations[11]

Output voltage of a single cell is

$$V_{FC} = E_{Nernst} - V_{act} - V_{ohmic} - V_{con} \tag{14}$$

Thermodynamic potential of the cell

$$E_{Nernst} = 1.229 - 0.85 * 10^{-3}(T - 298.15) + (4.31 * 10^{-5}) * T(\log(P_{H2}) + (\log(P_{O2}) \tag{15}$$

Voltage drop due to the activation of anode and cathode

$$V_{act} = -[\xi_1 + \xi_2 T + \xi_3 T * \log(CO_2) + \xi_4 T * \log(i_{FC}) \tag{16}$$

Where,

ξ = parametric coefficients for each cell model

$$CO_2 = \frac{P_{O2}}{(5.08 * 10^6 * e^{-498\pi})} \tag{17}$$

Ohmic voltage drop

$$V_{ohmic} = i_{FC}(R_m + R_c) \tag{18}$$

Where,

$$R_m = \frac{\rho_m * l}{A}$$

$$\rho_m = \frac{181.6\left[1 + 0.03\left(\frac{i_{FC}}{A}\right) + 0.062\left(\frac{T}{303}\right)^2\left(\frac{i_{FC}}{A}\right)^{2.5}\right]}{\left[\psi - 0.634 - 3\left(\frac{i_{FC}}{A}\right)\right] * e^{\left[4.18\left(\frac{T-303}{T}\right)\right]}} \tag{19}$$

A = cell active area (cm^2), l = thickness of the membrane (cm), ρ_m = specific resistivity of the membrane for the electron flow.Voltage drop resulting from the reduction in concentration of the reactance gases

$$V_{con} = -B * log\left[1 - \frac{J}{J_{max}}\right] \tag{20}$$

Where, B = parametric coefficient , actual current density, $J = \frac{i_{FC}}{A}$,maximum current density, $J_{max} = \frac{i_{max}}{A}$

Table 3: *Parameters of fuel cell*

S.no	Parameter	Value	Parameter	Value
1	T	343K	Ξ1	-0.948
2	A	50.6cm2	Ξ2	
3	L	178um	ξ 3	7.610e-5
4	Ph2	1atm	Ξ4	1.93e-5
5	Po2	1atm	Ψ	23
6	B	0.016	Jmax	1500A/cm2
7	Rc	0.0003Ω	jn	1.2ma/cm2

6. Integration of Wind and Photovoltaic Fuel Cell Hybrid Energy Systems to the Grid through PI Controller

The hybrid system is interconnected to the grid and it is operated in the grid connected mode with help of power electronic converter pi control technique is used for the inverter. The value of DC link voltage is given by [4]

$$0.612 m_a V_{dc} \geq \sqrt{\left(V_{acc}^2\right) + 3\left(\omega L_f I_{ac}\right)^2} \tag{21}$$

PQ control technique is used for the grid interface inverter. In PQ control, the real and reactive powers exchanged with the grid are the variables controlled by the inverter. In order to have a faster response it has been chosen to decouple active and reactive power channels the inverter. The dynamic model of this converter in rotating frame is calculated by [11]

$$u_d = e_d - R_{id} - \omega L_{id} - L\frac{d_{id}}{d_t} \tag{22}$$

$$u_q = e_q - R_{iq} - \omega L_{iq} - L\frac{d_{iq}}{d_t} \quad (23)$$

Where id is the direct current component (i_d) and reactive power the quadrature current component (i_q). To control the active power through the inverter, the DC link voltage is measured and compared to DC link reference voltage. The DC link voltage error is used to generate d axis current reference through a PI controller. This d-axis current reference is compared with actual d-axis current. To control the reactive power flow, reference q-axis current is compared with actual q-axis current. The control voltages for the three phases VSI are generated based on the errors in d axis and q axis currents through PI controllers. The active and reactive synchronous power is calculated by

$$P = \frac{3}{2}\left[V_{gd}I_d + V_{gq}I_q\right] \quad (24)$$

The equation 16 shows the active power of grid side inverter and this is controlled with the pi controllers.

$$Q = \frac{3}{2}\left[VqI_d - V_{gd}I_q\right] \quad (25)$$

The equation 17shows the reactive power of grid side inverter and this is controlled with the pi controller .and the value is zero that we can see from the above equation as the i_q value we are taking as zero in the VSI inverter [4].

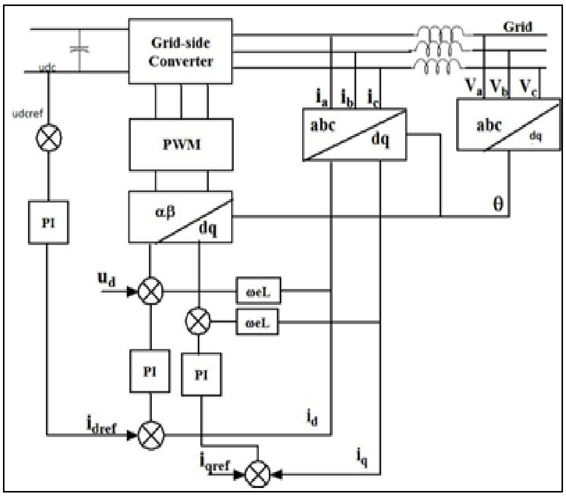

***Figure 3** Block diagram of AC-shunted grid-connected hybrid PV/wind energy system [11].*

7. Results and Discussions

The hybrid system is modeled and simulated is tested for different conditions like hybrid system without using the MPPT technique and with using of the MPPT technique. Fig. 4show dc link voltage of Wind energy system and PV energy system and the fuel cell respectively maintained at the reference value, It is seen that the dc link voltage is maintained constant at the reference voltage by the controllers.

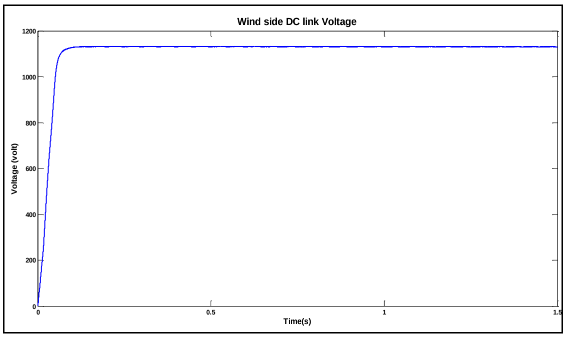

***Figure 4** DC link voltage of wind energy system*

Fig. 5 shows active power supplied by the wind energy system, PV energy system, and the fuel cell i.e the hybrid system load power and the power supplied by the grid.

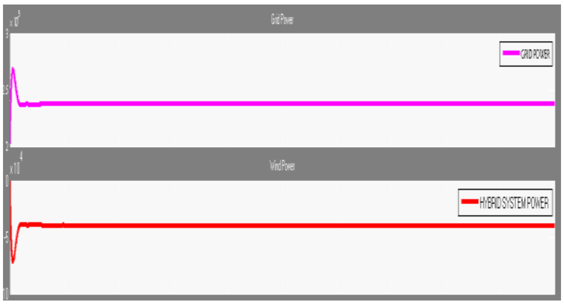

***Figure 5** Active power*

Figure5 shows the active power balance i.e power demand by the load and the power supplied by the hybrid system and the power supplied by the grid.

***Figure 6** Reactive power*

Figure6 shows the reactive power balance i.e power demand by the load and the power supplied by the hybrid system and the power supplied by the grid. It is also observed that the reactive power of wind energy system and PV energy system is constant at zero which is controlled by PQ controllers with zero reactive power reference. The required reactive power of load is supplied by the grid.

***Table 4:** Active power of system without using mppt*

S. No	Real power of load	Real power of grid	Real power of hybrid system
1	*125e3*	*4e4*	*2,4e5*

***Table 5:** Reactive power of system without using mppt*

S. No	Real power of load	Real power of grid	Real power of hybrid system
1	*1.86e5*	*3.4e5*	*1.3e4*

Case ii:

As the demand is not met by the generation to improve the generation the MPPT control techniques are implemented and the flow chart for the algorithm is given below

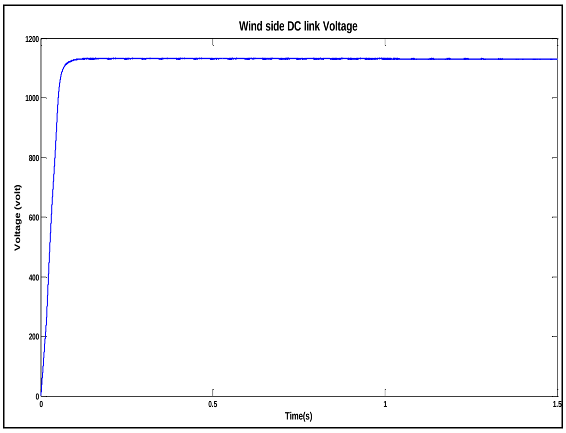

***Figure 7** DC link voltage of wind energy system with MPPT*

As there is no change is in the input parameters there is no change in the dc link voltage it is maintain constant without any alteration.

Flow chart:

For The MPPT Technique

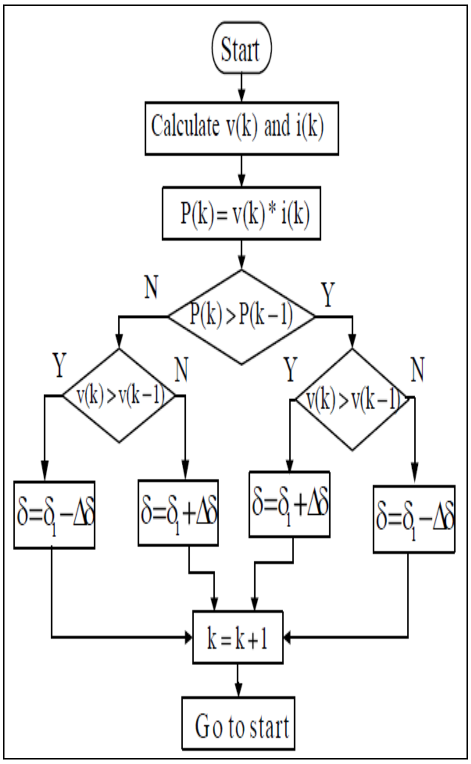

***Figure 8** Active power when change in load is simulated*

Figure8 shows the active power balance i.e power demand by the load and the power supplied by the hybrid system and the power supplied by the grid with the using of the MPPT control algorithm.

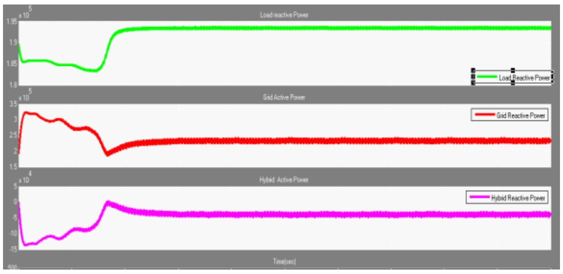

***Figure 9** Reactive power when change in load is simulated*

Figure9 shows the reactive power balance i.e power demand by the load and the power supplied by the hybrid system and the power supplied by the grid. It is also observed that the reactive power of wind energy system and PV energy system is constant at zero which is controlled by PQ controllers with zero reactive power reference. The required reactive power of load is supplied by the grid.

***Table 6:** Active power of system with using MPPT*

S. No	Real power of load	Real power of grid	Real power of hybrid system
1	*125e3*	*1.9e5*	*1.2e5*

***Table 7:** Reactive power of system with using MPPT*

S. No	Real power of load	Real power of grid	Real power of hybrid system
1	*1.95e5*	*1.94e5*	*-0.1e4*

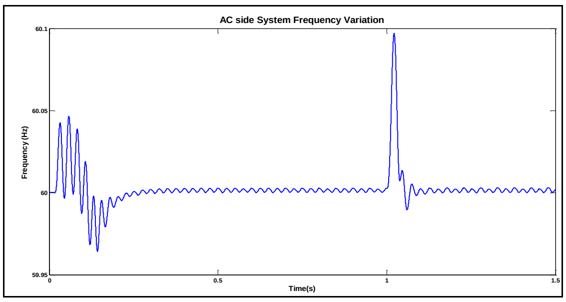

***Figure 10** System frequency when there is no change in input parameters and change load parameters*

7. Conclusions

Modeling of wind turbine coupled with PMSG and photovoltaic energy system and the fuel cell is developed using MATLAB. The models of wind and photovoltaic energy system and the fuel cell are integrated with the grid through pi controller inverter grid-connection scheme. PQ control strategy is used to control pi inverter, it observed from the results the generation is improved form case one to cse2i.e with and without using MPPT control technique the demand can meet without improving form the generation parameters or fuel stack and PV modules but it can be improve by implementing the control technique in the system.so the economically the system is improved. It is possible to have a good response of grid-connected hybrid energy system.

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References

[1] Frede Blaabjerg, Zhe Chen and Soeren Baekhoej Kjaer, "Power Electronics as Efficient Interface in Dispersed Power Generation Systems" *IEEE Transactions on Power Electronics,* Vol. 19, No.5, pp 1184-1194, 2004.

[2] Alejandro Rolan. Alvaro Luna. Gerardo Vazquez and Gustavo Azevedo., "Modeling of a Variable Speed Wind Turbine with a Permanent Magnet Synchronous Generator", *IEEE International Symposiumon Industrial Electronics.*Marcelo,2009.

[3] M. G. Villalva. J. R. Gazoli. E and Ruppert F, "Modeling and Circuit-Based Simulation of Photovoltaic Arrays," *Proceedings of power electronics conference COBEP'09*, Brazil, pp.1088-1094, 2006.

[4] Jitendra Kasera, Ankit Chaplot and Jai Kumar Maherchandani, "Modeling and Simulation of Wind-PV Hybrid Power System using Matlab/Simulink," *Proceedings of Students Conference on Electrical, Electronics and Computer Science, SCEECS'12*, pp1-4, 2012.

[5] K. T. Tan, P. L. So, Y. C. Chu. and K. H. Kwan, " Modeling, Control and Simulation of a Photovoltaic Power System for Grid-connected and Stand-alone Applications," *Proceedings of IPEC,IPEC'10*, pp608-613, 2010.

[6] Fei Ding, Peng Li, Bibin Huang, Fei Gao, Chengdi Ding and Chengshan Wang, " Modeling and Simulation of Grid-connected Hybrid Photovoltaic/Battery Distributed Generation System," *Proceedings of International Conference on Electricity Distribution, CICED'10*, China, pp1-10, 2010

[7] Yaow-Ming Chen, Chung-Sheng Cheng and Hsu-Chin Wu, "Grid-Connected Hybrid PV/Wind Power Generation System with Improved DC Bus Voltage Regulation Strategy," *Proceedings of 21st annual applied power electronics conference and exposition APEC'06*, ,pp.1088-1094, 2006.

[8] B. M Hasaneen and Adel A. Elbaset Mohammed, " Design and Simulation of DC/DC Boost Converter," *Proceedings of 12th international middle east Power system conference, mepcon'08,* pp 335-340, 2008.

[9] V. Galdi, A. Piccolo and P. Siano, " Dynamic Performances and Control of Dispersed Generators Connected through Inverter," *Proceedings of international conference on modeling, control and automation and international conference on intelligent agents, web technologies and internet commerce*, vol1, p1060-1065, 2005.

[10] Kiam Heong Ang, Gregory Chong and Yun Li, "PID Control System Analysis, Design, and Technology," *IEEE Transactions on Control Systems Technology*, vol. 13, no. 4, pp559-576, 2005.

[11] Joan R, Alvaro L. Frede B,Pedro R, "Control of Power Converters in AC Microgrids." *IEEE Transactions on Power Electronics,* vol. 27, no. 11, pp 4734-4749, 2012.

[12] Shun Yang, Lida Zhang, (2013)"Modeling and Control of the PMSG Wind Generation System with a Novel Controller" Third International Conference on Intelligent System Design and Engineering Applications (ISDEA), pp.946-949, 16-18 Jan. 2013.

[13] Jayalakshmi N.S Gaonkar D.N. Kumar K.S.K (2012) "Dynamic Modeling and Performance Analysis of Grid connected PMSG based variable speed wind turbines with simple power conditioning system," 2012 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES), pp.1-5, 16-19 Dec. 2012.

[14] Seul-Ki Kim, Eung-Sang Kim, Jong-Bo Ahn "Modeling and Control of a Grid-connected Wind/PVHybrid Generation System," Transmission pp.1202-1207, 21-24 May 2006.