

Active and Reactive Power control operation of DFIG for Wind Power Generation Using Fuzzy Logic

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Abstract: The output power of the present wind turbine is continuously increasing. Due to this Double fed Induction generators are gaining more attention especially in the field of wind power generation due to many advantages and rapid development in both power electronics and control strategies. Vector Control of doubly fed induction generator for variable speed wind power generation is used widely now days. The Control scheme used is stator flux oriented control for rotor side converter control and grid voltage vector control for grid side converter control for the control of active and reactive powers of the DFIG under variable speed operation. The scheme implemented uses Conventional PI controllers as well as Fuzzy logic controllers for the rotor side converter control to control active and reactive power and optimize the power generation from the DFIG.

Here the design of a doubly fed induction generator (DFIG), using back-to-back PWM converters in the rotor circuit has been described. A vector-control scheme results in independent control of active and reactive powers, while ensuring sinusoidal supply currents. The scheme provides a wide speed-range operation from sub synchronous to super-synchronous modes.

Index Terms: windpower generation, fuzzylogic, DFIG

I. Introduction:

Wind power technology dates back many centuries. These are historical claims that wind machines which harness the power of the wind date back beyond the time of the ancient Egyptians. In the late part of 13th century. The typical European wind mills had been development took place [1]. At the end of the 20th century there were more than 60,000 windmills in Europe. India is not that much concerned with wind power generation

In this entire concept of paper, we shown wind power generation under changing in wind speed by using PI controller, PI combination of fuzzy logic controller [1,2], with its comparison performance. Here the power converters are designed such so in partial scale. In this concept we can see the two main converters those are rotor side converter (RSC) and grid side converter (GSC). The major working of the converters is the improvement of active and reactive power with the reference values.

II. Wind Turbine Modelling:

Various models of wind turbines we came across. They have different purposes and therefore, treat different features of the wind turbine system and they span. In fact, all the aspects relevant to such a device. mechanical engineers are most concerned with the safe and economical dimension of the whole wind turbine will make the task simpler [3]. general purpose models concerned with electrical properties of wind turbines are widely used. here we have power coefficient (C_p), the functions of the tip speed ratio (λ) and also depending upon theta

$$\lambda = \frac{R\omega}{V} \quad (1) \quad P = \frac{1}{2} C_p(\lambda) \rho A \left(\frac{R}{\lambda}\right)^3 \omega^3 \quad (2) \quad T_{turbine} = \frac{1}{2} \rho A C_p V / \lambda \quad (3)$$

The above represents tip speed ratio, mechanical power and T turbine respectively. [2]

III. Modelling Of Double Fed Induction Generator:

In a common used model, for induction generator converting power from the wind to serve the electrical grid in which stator of the wound rotor. Induction machine is connected to the low voltage balanced 3-phase grid and the rotor is fed pulse width modulation converters(PWM)[2], converters back-to-back with common DC-link. Grid side converter control, the power flow between the DC-bus and the AC-side and allows the system to be operated in the sub-synchronous region to super synchronous speed. The proper rotor excitation is provided by the machine side power converter; also it provides active and reactive power control on the stator and the rotor sides respectively by employing vector control.

In the stator flux oriented reference frame, a reactive power can be controlled by controlling the D-axis rotor current [3]. In stator flux oriented control, both stator and rotor quantities are transformed to a special reference frame that rotates at an angular frequency identical to the stator flux linkage space to deal with machine dynamic behavior in case rotor and the stator quantities were referred to natural reference frame in model the following equations are DFIG modeling equations which is given by the equation number.

The components of electromagnetic torque and per-unit model equation of generator in motor as follows

$$T_{em} = \frac{3}{2} * \frac{P}{2} * \frac{L_m}{L_s} (\lambda_{sQ} * I_{rD} - \lambda_{sD} * I_{rQ}) \quad (4)$$

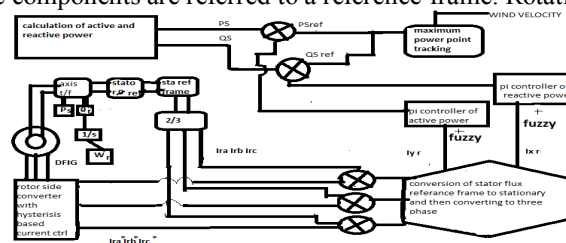
$$\frac{d}{dt} \left(\frac{\omega_r}{\omega_b} \right) = \frac{1}{2H} * \left\{ T_{mech} - T_{em} - K_D \left(\frac{\omega_r}{\omega_b} \right) \right\} \quad (5)$$

IV. Controlling Of Rotor Side:

In the rotor side converter torque can be controlled by the desired speed. Rotor current components are required to be controlled under balanced grid voltage condition. In addition to independently controlling the average dc components of the active and reactive power.

$$\begin{aligned} \frac{d}{dt} (I_{sD}) &= \left\{ R_s L_r I_{sD} - L_m (L_r \omega_r \sin \theta_r + R_r \cos \theta_r) I_{r\alpha} - L_r V_{sD} + L_m \cos \theta_r V_{r\alpha} - L_m \sin \theta_r V_{r\beta} \right\} / (L_m^2 - L_s L_r) \\ \frac{d}{dt} (I_{sQ}) &= \left\{ L_m^2 \omega_r I_{sD} + L_m (L_r \omega_r \cos \theta_r - R_r \sin \theta_r) I_{r\alpha} - L_r V_{sQ} + L_m \sin \theta_r V_{r\alpha} + L_m \cos \theta_r V_{r\beta} \right. \\ &\quad \left. + R_s L_r I_{sQ} - L_m (L_r \omega_r \sin \theta_r + R_r \cos \theta_r) I_{r\beta} \right\} / (L_m^2 - L_s L_r) \\ \frac{d}{dt} (I_{r\alpha}) &= \left\{ -L_m (L_s \omega_r \sin \theta_r + R_s \cos \theta_r) I_{sD} + R_r L_s I_{r\alpha} + L_m \cos \theta_r V_{sD} + L_m \sin \theta_r V_{sQ} - L_s V_{r\alpha} \right. \\ &\quad \left. + L_m^2 \omega_r I_{r\beta} + L_m (L_s \omega_r \cos \theta_r - R_s \sin \theta_r) I_{sQ} \right\} / (L_m^2 - L_s L_r) \\ \frac{d}{dt} (I_{r\beta}) &= \left\{ L_m (R_s \sin \theta_r - L_s \omega_r \cos \theta_r) I_{sD} + R_r L_s I_{r\beta} + L_m \cos \theta_r V_{sQ} - L_m \sin \theta_r V_{sD} - L_s V_{r\beta} \right. \\ &\quad \left. - L_m^2 \omega_r I_{r\alpha} - L_m (R_s \cos \theta_r + L_s \omega_r \sin \theta_r) I_{sQ} \right\} / (L_m^2 - L_s L_r) \end{aligned} \quad (6)$$

In the present scheme, the inverter output voltage is controlled, [4] while its frequency is held constant at 50Hz. here the stator side current and voltage components are referred to stationary reference frame, while the rotor side current and voltage components are referred to a reference frame. Rotating at rotor electrical speed.



ROTOR SIDE CONVERTER (RSC)

Here the stator flux oriented frame current variations of the rotor can show effect in the variations of the stator current. Primarily we set the reference values and such that we stimulate to track that reference value using PI controller, and PI with fuzzy. Below equations can be clearly understand us active and reactive power in stator flux oriented reference frame [3]

$$P_s = - \left(\frac{3}{2} \right) * |V_s| * L_m / L_s * I_{ry} \quad (7)$$

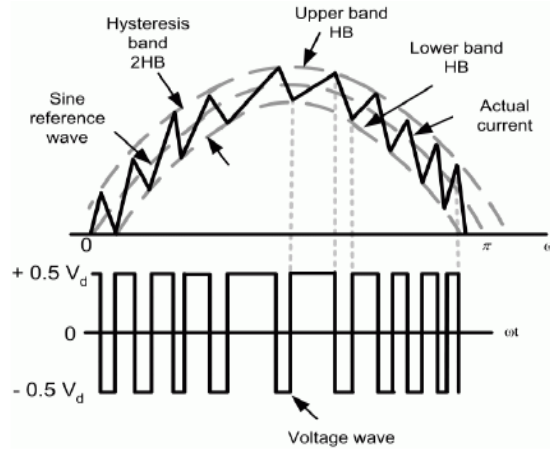
$$Q_s = \left(\frac{3}{2} \right) * |V_s| * L_m / L_s (I_{ms} - I_{rx}) \quad (8)$$

The output power from the active and reactive power is then transformed to stationary reference frame. Two axes are then transformed to a-b-c frame of reference for rotor current components have to be changed using rotor angle position. [6]

V. Hysterisis Band Current Control Pwm Technique:

It is basically an instantaneous feedback current control method of PWM where the actual current continually tracks the command current with in the hysteresis band[5] .In this control circuit generates the sine reference current wave of desired magnitude and frequency ,and it is from +0.5Vd to -0.5Vd. And the current starts to decay. The equations for pe-phase voltages are given below:

Compared with the actual phase current wave .As the current exceeds a prescribed hysteresis band, the upper switch in the half bridge is turned off Current crosses the lower switch is turned off and the upper switch is turned on. A lock out time td is provided at each transition to prevent a shoot throughfault. The actual current wave is thus forced to track the sine reference wave with in the hysteresis band by back and forth switching of the upper and the lower switches. The inverter then essentially becomes a current source with peak to peak current ripple, which is controlled with in the hysteresis band irrespective of Vd fluctuation.



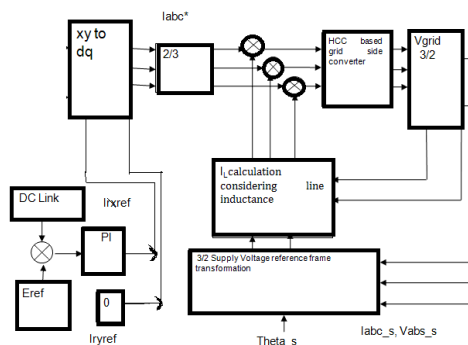
PRINCIPLE OF HYSTERISIS BASED PWM CURRENT CONTROL TECHNIQUE

$$\begin{aligned}
 v_{cn} &= \frac{2}{3}v_{c0} - \frac{1}{3}v_{a0} - \frac{1}{3}v_{b0} & v_{an} &= \frac{2}{3}v_{a0} - \frac{1}{3}v_{b0} - \frac{1}{3}v_{c0} \\
 v_{bn} &= \frac{2}{3}v_{b0} - \frac{1}{3}v_{a0} - \frac{1}{3}v_{c0} & &
 \end{aligned}
 \tag{9}$$

Here Vcn, Vbn and Van are between +0.5Vd to -0.5Vd upper switch will be ON and lower switch will be ON respectively [4].

VI. Grid Side Converter Control:

Grid –side converter of the DFIG used plays the role of the boost rectifier at the sub-synchronous speed and maintains a constant DC-link voltage at the full speed range of operation .under un-balanced grid voltage conditions its behavior can be depicted in the D-Q reference frame.



BLOCK DIAGRAM OF THE VOLTAGE VECTOR ORIENTED VECTOR CONTROL SCHEME FOR GRID SIDE CONVERTER CONTROL

$$P_{grid} = \left(\frac{3}{2}\right) * (V_x * I_x + V_y * I_y) = \left(\frac{3}{2}\right) * (V_x * I_x) \quad (10)$$

$$Q_{grid} = \left(\frac{3}{2}\right) * (V_y * I_x - V_x * I_y) = \left(\frac{3}{2}\right) * (V_x * I_y) \quad (11)$$

The scheme uses real axis aligned with the supply phasor voltage .Ix,Iy has to be found from the above.

VII. Dc-Link Voltage Modelling:

Dc-link voltage can be modeled with the following equations [4]

$$P_{ac_grid_conv} = \frac{3}{2} * (I_x * V_{conv_x} + I_y * V_{conv_y}) \quad (12)$$

$$P_{ac_rotor_conv} = \frac{3}{2} * (I_{rx} * V_{rx} + I_{ry} * V_{ry}) \quad (13)$$

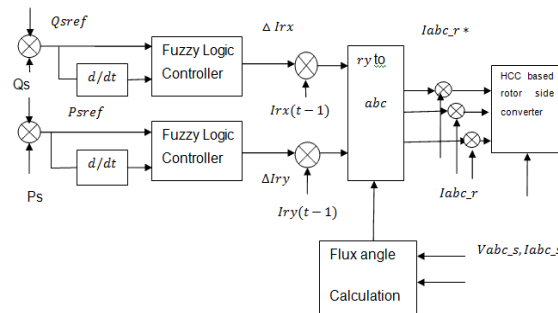
Dc-link power can be evaluated by

$$P_d = P_{ac_grid} - P_{ac_rotor} = V_d * I_d \quad (14)$$

$$V_d = \frac{1}{C} * \int I_d dt \quad (15)$$

Here c-----dc link capacitor capacitance.

VIII. Design Of Fuzzy Logic Controller:



The inputs of fuzzy logic controller are error in active, reactive, and rate of change in active and reactive power error. Here different types of membership function which is helpful for smooth variation, the type of membership function available is triangular membership function. Original rules can be expanded into five meta rules [3].

For simplification of unification design fuzzy control can be using implementation through computer which most possible under critics.

ΔIry				ΔE(P,Q)			
	NB	NM	NS	Z	PS	PB	
NB	NVB	NVB	NVB	NB	NM	Z	
NM	NVB	NVB	NB	NM	NS	PS	
NS	NVB	NB	NM	NS	Z	PM	
Z	NB	NM	NS	Z	PS	PB	
PS	NM	NS	Z	PS	PM	PVB	
PB	Z	PS	PM	PB	PVB	PVB	

ACTIVE AND REACTIVE POWER RULE BASE OF FUZZY CONTROLLER

The universe of error $e(k) = Psref(k) - Ps(k)$ (16)

From above we can calculate emax, emin changes,

$$\Delta u_{max} = u_{max} - u_{min}$$

$$\Delta u_{min} = u_{min} - u_{max} \quad (17)$$

The output of the defuzzified can be get by the fuzzy logic algorithm, however tuning of the active and reactive currents can be achieved by tuning of the output scaling factors ,by changing the scaling factors we can get P,Q reaches the reference values closely.

IX. Results And Its Comparision:

Here the scheme responses shown in figure. The results are shown with PI controller, PI with fuzzy controller and comparisonwith its response with active and reactive power with different inputs such as ramp, constant and step [6] .the rotor current also shows some distortion. The below responses are compared with step and ramp inputs ,which convey as follows with of those inputs ,the scheme also works well in both sub-synchronous and super synchronous mode. The additional fuzzy controller improves the performance of DFIG as compared to that of using PI tuned.

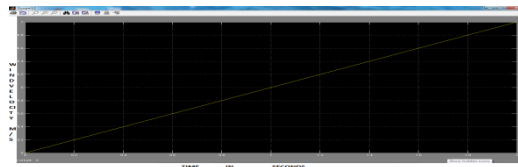


Figure 1 X-axis shows the time in sec (2),y-axis shows wind input speed 0f from 5-7m/s(ramp)

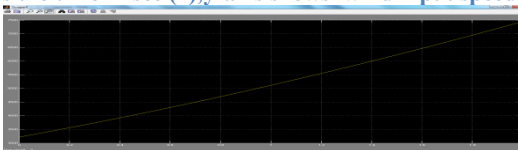


Figure 2 X-axis - time in sec (2) y-axis -reference active power to track(3000-7500W) (ramp)

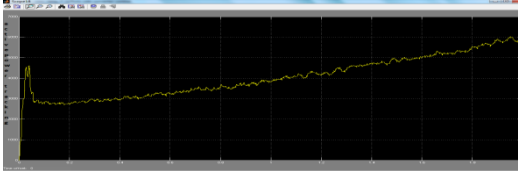


Figure 3 x-axis time in sec(2),y-axis-active power tracking(3000-7500w) using pi controller(ramp)

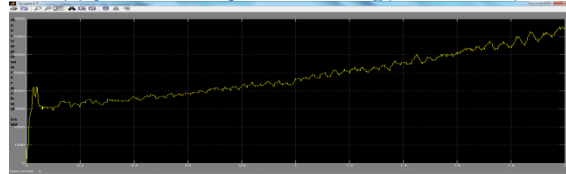


Figure 3 x-axis -time in sec(2) ,y-axis-active power tracking(3000-7500w) using fuzzy +pi controller (ramp)

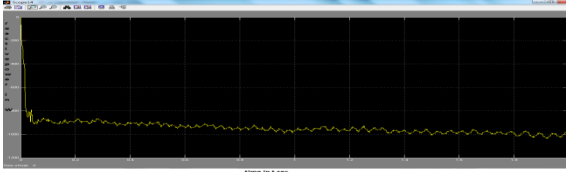


Figure 4 x-axis –time in sec(2),y-axis-reactive power tracking (0 to 1200w) using pi controller(ramp)

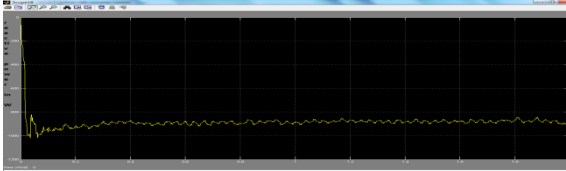


Figure 5 x-axis –time in sec(2),y-axis- reactive power tracking(0to1200w) using pi +fuzzy controller(ramp)

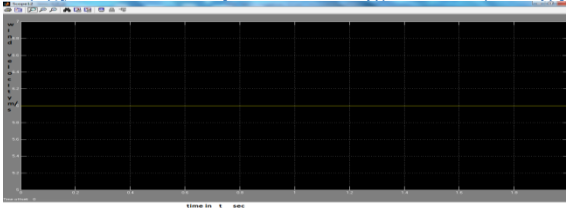


Figure 6 x-axis-time in sec(2),y-axis- wind input speed of 6m/s (constant)

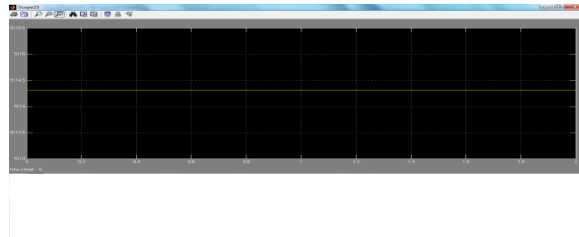


Figure 7 x-axis-time in sec(2),y-axis-reference active power (constant)

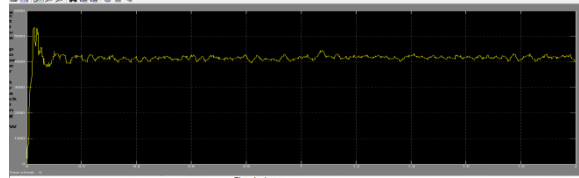


Figure 8 x-axis time in sec(2),y-axis-active power tracking (0 -6000w) using pi(constant)

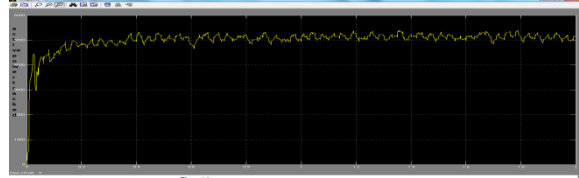


Figure 9 x-axis time in sec (2),y-axis –active power tracking(0-6000w) using fuzzy +pi controller (constant)

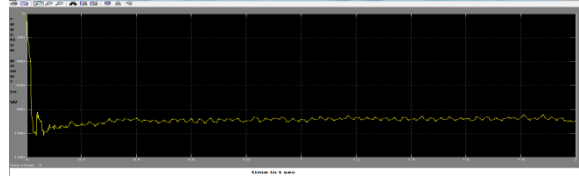


Figure 10 x-axis time in sec(2),y-axis –reactive power tracking using pi controller(constant)b/w (0 to 1500w)

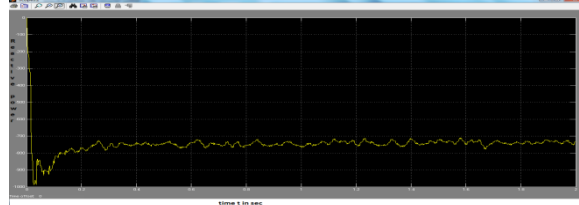


Figure 11 x-axis time in sec(2),y-axis-reactive power tracking using fuzzy +pi controller(constant)b/w (0 to 1000w)(constant)

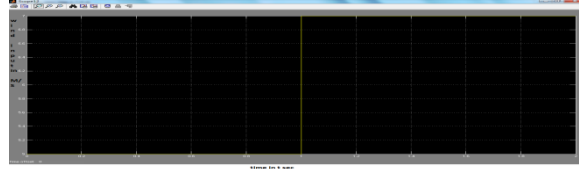


Figure 12 x-axis time in sec(2),y-axis-wind input speed 5-7m/s (step)

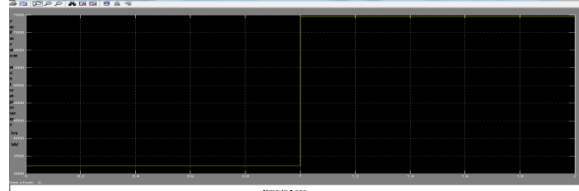


Figure 13 x-axis time in sec(2),y-axis –reference active power to track (3000 to 7500w) (step)

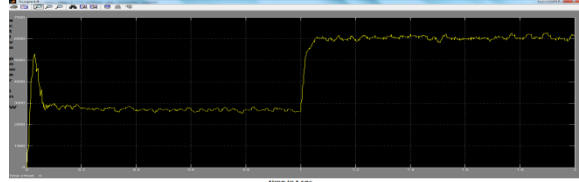


Figure 14 x-axis –time in sec(2),y-axis-active power tracking using pi controller(step)

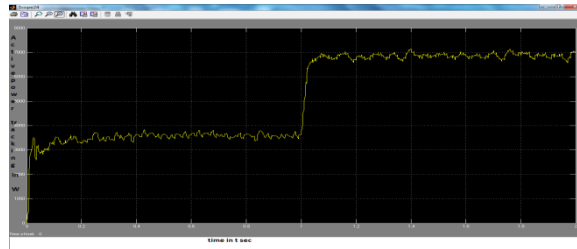


Figure 15 x-axis-time in sec(2),y-axis-active power tracking using fuzzy+pi controller(step)

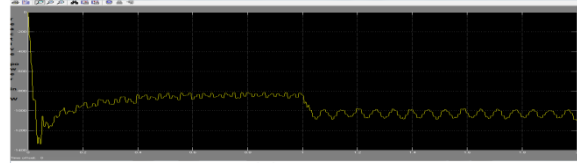


Figure 16 x-axis –time in sec(2),y-axis-reactive power tracking using pi controller(0 to 1400w) (step)

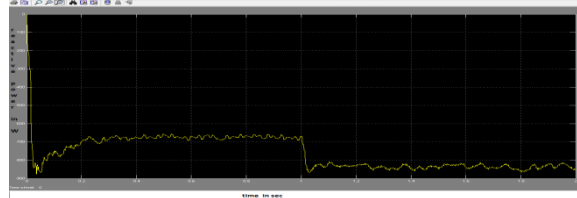
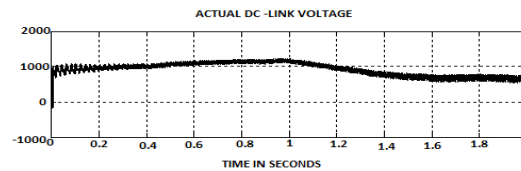
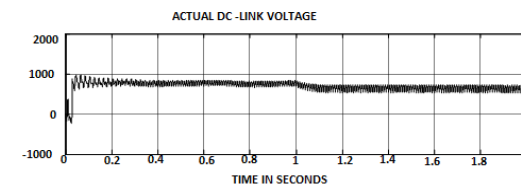


Figure 17 x-axis time in sec(2),y-axis –reactive power tracking using pi+fuzzy controller b/w(0 to 900w)(step)

Here , we can see that the active and reactive power improvement in the fuzzy+PI controller ,than with alone PI controller.The improvement of active and reactive power is depicted in theabove case with constant , ramp and step input.



RESPONSE WITH PI CONTROLLER(DC-LINK VOLTAGE)STEP



RESPONSE WITH FUZZY PI CONTROLLER (DC -LINK VOLTAGE)STEP

X. Conclusion:

Here, we have seen the comparison results with PI-controller, fuzzy tuned PI and controllers with different inputs. We can conclude that the active and reactive power tracking is increasing sequentially with the above controlling procedures in respective manner. The DC-link voltage tries to stable at constant value using controllers which is better in case of fuzzy tuned PI, when compared to alone PI controller.DFIG performance can be improved by fuzzy tuned PI-controller. Equations are modelled for active and reactive power control of fuzzy logic .

APPENDIX:

Rating of wind turbine:

Power $p = 7.5\text{kw}$

Radius $r = 3.24\text{m}$

Rated rotational speed = 296 rpm

Inertia $I = 7.5\text{kgm}^2$

Gear box ratio = 3

Damping co-efficient, $K_d = 0.01\text{nm/rad}$

Wound rotor induction machine:

Power $p = 7.5\text{kw}$

Stator voltage $V_s = 415\text{v}$

Rotor voltage $V_r = 440\text{v}$

Rated stator current = 19A

Rated rotor current = 11A

$P = 6$.

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