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Application of AI Controller for Doubly Fed Induction Generator based Wind Energy Conversion System

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ABSTRACT: The wind energy conversion (WEC) is in increasing need as the power demand from generation side is not sufficient. Distribution side generation increases in rural areas due to high loss in transmission. So wind energy conversion system with doubly fed induction generator (DFIG) plays important role in energy production. The control of DFIG uses PI controller where the robustness is less in this research artificial intelligence (AI) based PI is introduced to make the DFIG system robust. MATALB is used for performance analysis.

KEYWORDS: Active Power; DFIG; Fuzzy Logic; Membership Functions; Reactive Power; Rule Base; WECS

I.INTRODUCTION

With the ongoing development in the field of science and technology there is a remarkable increase in the use of high power electric devices. Almost the whole world seems to have shifted to the use of electric machines, hence causing an increase in the demand of electric energy. Electricity can be produced using different techniques. Broadly speaking we have non-renewable and renewable resources of energy. Most of the non-renewable resources are not environment friendly unlike the renewable resources which have many advantages over non-renewable ones.The renewable energy resources are the main focus of research nowadays. There are basically two main renewablesi.e. wind and solar. A lot of research has been done on solar systems and it still continues on. Likewise there is a need to work on wind energy generation systems and many issues need to be addressed in this area. This is the main motive of our research on wind energy systems.

This study is mainly focused on improving the operation of doubly fed induction generator (DFIG) based wind energyconversion system (WECS) in such a way that the system can withstand and track desired power even if any of the machine parameters gets disturbed because of the environmental issues like temperature, moisture etc. Moreover, it also contributes towards the quick response of the system to certain changes in parameters. There are two objectives that are successfully tackled using an Artificial-Intelligence based controller in comparisonwith a conventional PI controller. First is the perfect tracking of power references during normal operation of the machine and second is to maintain this improved tracking even if there is any change in machine parameters leading towards the enhanced robustness of the system.

Magedi et al [2] gives a comparison between the horizontal axis wind turbines, or HAWTS, and the vertical axis wind turbines, or VAWTS. The two types of wind turbines are used for different purposes. Several models of both types are presented from previous research. J.Soltaniet al [4] a robust nonlinear controller is presented for doubly-fed induction machine (DFIM) drives. The nonlinear controller is designed based on combination of Sliding-Mode (SM) and Adaptive-Back stepping control techniques. Using the fifth order model of DFIM in a stator d, q axis reference frames with stator currents and rotor fluxes as state variables, a SM controller is designed in order to follow a linear reference model.

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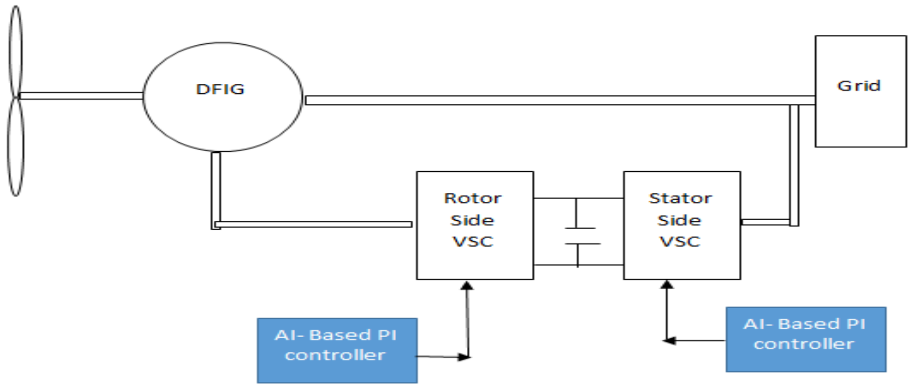

Figure-1DFIG Based WECS

In this study the configuration that is used for mathematical modeling and control purposes is the DFIG based WECS [1] as given in above figure-1. It is clear in the figure that the stator is directly connected to the grid and rotor is fed via a back to back voltage source power converter. As the stator is directly connected to the power grid so it is supplied with a constant voltage and constant frequency while the rotor is connected to the grid via power converters. So it can be supplied with variable voltage and frequency according to the requirement as shown in figure-1.

Sergei Peresadaet al [5] discuss a new indirect stator flux field-oriented output feedback control for doubly fed induction machine is presented. It assures global exponential torque tracking and stabilization of the stator-side power factor at unity level, provided that electric machine physical constraints are satisfied. Based on the inner torque control system, a speed tracking controller, with load torque compensation is designed using passivity approach. Applications of fuzzy logic (FL) to power electronics and drives are on the rise. Gilbert C, D et al [6] discusses some representative applications of FL in the area, preceded by an interpretative review of fuzzy logic controller (FLC) theory. A discussion on design and implementation aspects is presented, that also considers the interaction of neural networks and fuzzy logic techniques. A. G. Ram et al [7] proposed fuzzy adaptive PI control algorithm is designed for non-linear level process to improve the control performance better than the conventional PI controller.

The conventional PI controller works well only if the mathematical model of the system could be computed. Hence it is difficult to implement the conventional PI controller for variable as well as complicated systems. But fuzzy logic control does not require any precise mathematical model and works good for complex applications also.L. Zhanget al [8] A grid-connected wind power generation scheme using a doubly-fed induction generator (DFIG) in conjunction with a direct AC-AC matrix power converter is proposed. The analysis employs a stator flux vector control algorithm and a space vector modulated matrix converter to control the generator rotor current. The system enables optimal speed tracking for maximum energy capture from the wind and high performance active and reactive power regulation. The paper discusses the operating principles of this power generation scheme.
This paper is organized as follows: section-II contains mathematical Model, section-III contains controller design, section-IV contains simulation results and section-V contains conclusion and Reference's.

II.SYSTEM MODEL AND ASSUMPTIONS

The power extraction by the rotor blades from the wind is based on the principle of aerodynamics. As the air strikes thewind turbine rotor blades the power extracted depends upon the size, shape and speed of wind etc. The relation betweenspeed of wind and Kinetic Energy is given as below:

The global scheme for a grid-connected wind turbine system is given in Fig. 2.

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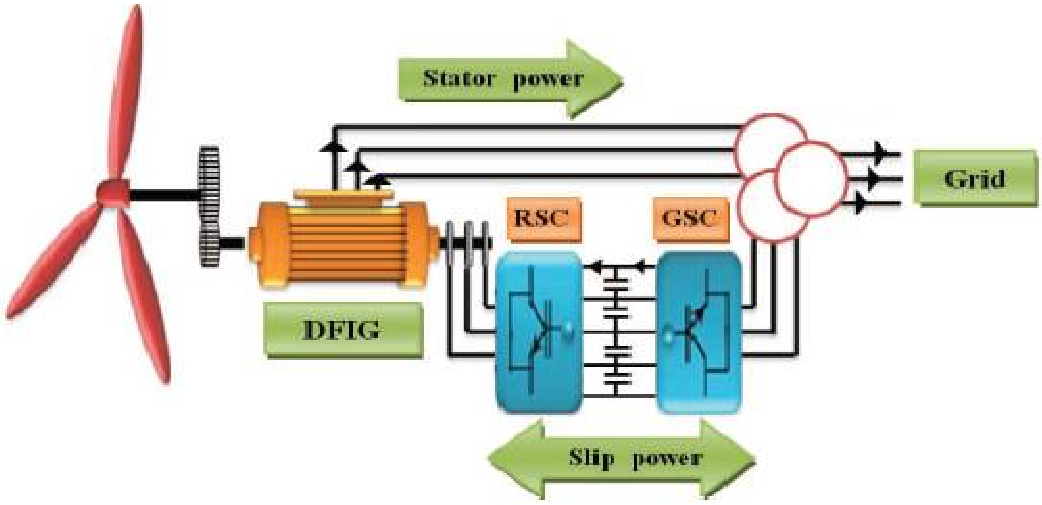

Figure.2. Configuration of DFIG- wind turbine system.

A. Wind turbine model

There is only a fraction of the wind power that can be extracted by the turbine, it is called the aerodynamic power of the turbine and denoted by Pt. Its expression is given as:

$$P_t = T_t.\omega_t = \frac{1}{2}\pi\rho R_{balde}^2 v_w^3 C_p(\lambda_{TSR}, \beta) \qquad (1)$$

whereTt is the turbine torque and Wt is the shaft speed turbine side. vw is the wind speed and Rbalde is the radius of blades.The efficiency coefficient CP(λTSR,β) is a function of the blade angle called the pitch angle, denoted by β , and the tip speed ratio (TSR) denoted by λTSR, the TSR is given as:

$$\lambda tsr = \frac{Rblade\, Wt}{Vw} (2)$$

The efficiency coefficient is approximated by using a nonlinear function, because it gives more accurate results and it is faster in simulation :

$$C_p(\lambda_{TSR}, \beta) = 0.2101\left(\frac{116}{\lambda_i} - 0.4\beta - 5\right)e^{\frac{-12.5}{\lambda_i}}$$

$$\frac{1}{\lambda_i} = \left[\left(\frac{1}{\lambda_{TSR} + 0.08\beta}\right) - \left(\frac{0.035}{\beta^3 + 1}\right)\right] \qquad (3,4)$$

B. Drive train model

Some authors consider two-mass models [6]. Our problem is oriented to the power control analysis. Hence the typical one-mass model appears sufficient [7].

$$\frac{d}{dt}\omega_m = \frac{1}{J_{eq}}(T_m - T_{em} - f_{eq}\omega_m) \qquad (5)$$

The turbine is coupled to the generator shaft through a gearbox. The gear ratio *G* is chosen to set the generator shaft speed within the required speed range . By neglecting the shaft losses, the mechanical torque (T_m) and shaft speed referred to the generator side of the gearbox are given by:

$$Tm = \frac{Tt}{G} \quad Wm = Wt\, G \qquad (6)$$

B. Induction generator model

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Assuming that the stator and rotor windings are sinusoidal and symmetrical, the model in the synchronous reference d-q coordinate is expressed as [2,3]:

$$\begin{cases} \frac{d}{dt}\varphi_{sd} = V_{sd} - R_s i_{sd} + \omega_s \varphi_{sq} \\ \frac{d}{dt}\varphi_{sq} = V_{sq} - R_s i_{sq} - \omega_s \varphi_{sd} \\ \frac{d}{dt}\varphi_{rd} = V_{rd} - R_r i_{rd} + (\omega_s - \omega_e)\varphi_{rq} \\ \frac{d}{dt}\varphi_{rq} = V_{rq} - R_r i_{rq} - (\omega_s - \omega_e)\varphi_{rd} \end{cases} \quad (7)$$

The stator and rotor flux can be expressed as:

$$\begin{cases} \varphi_{sd} = L_s i_{sd} + M i_{rd} \\ \varphi_{sq} = L_s i_{sq} + M i_{rq} \\ \varphi_{rd} = L_r i_{rd} + M i_{sd} \\ \varphi_{rq} = L_r i_{rq} + M i_{sq} \end{cases} \quad (8)$$

where R_s, R_r, $L_s$and $L_r$are respectively the resistances and inductances of the stator and rotor windings, M is the mutual inductance. V_{sd}, V_{sq}, V_{rd}, V_{rq}, i_{sd}, i_{sq}, i_{rd}, i_{rq}, y_{sd}, y_{sq}, $y_{rd}$and y_{rq} are the direct and quadratic components of the space phasors of the stator and rotor voltages, currents and flux respectively. $W_e=PW_m$is the electrical generator speed.

The electromagnetic torque (T_{em}) can be expressed as:

$$T_{em} = \frac{p}{2}\frac{M}{\sigma L_s L_r}(\varphi_{rd}\varphi_{sq} - \varphi_{rq}\varphi_{sd}) \quad (9)$$

The stator active and reactive power yields:

$$P_s = V_{sd} i_{sd} + V_{sq} i_{sq} \quad (10.a)$$

$$Q_s = V_{sq} i_{sd} - V_{sd} i_{sq} \quad (10.b)$$

The above mentioned ***dq-model*** is used to design the controller to improve the operation of DFIG.

III. Controller Design

This section covers the complete details about the mathematical model used in the controller design process. It also describes details for the selections of reference frame orientation in order to obtain decouple control of active and reactive power of DFIG. The doubly fed induction generator is very popular in wind energy conversion systems because it provides variable speed operation and the power converters used in this system enables control of stator active and reactive power by controlling the currents of the rotor.

Wind energy conversion system is not very simple to control it easily because if we closely monitor the mathematical equations then one can notice that firstly these equations are cross coupled differential equations and to solve these equations is really very difficult task. So for controller design purposes these differential equations are not directly used instead vector control theory is used to design a controller for induction machine. So for making the model of the machine simple usually different reference frames are used to transform the three phase quantities to two phase dc quantities, so that, controller can be designed efficiently.

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By taking into account the equations involving stator active P_s and reactive powers Q_s and taking the Laplace of V_{dr} and V_{qr} equations, We get the following transfer function to controlthe rotor current to get required stator active and reactivepower:

$$G(s)=\frac{LmVs/LrLs\sigma}{s+LsLr/LrLs\sigma} \quad (11)$$

Where
$$\sigma = 1 - \frac{Lm*Lm}{Lr\ Ls} \quad (12)$$

And when using PI controller, suitable values of K_p and K_i, we can get the desired results. See Result section for simulation results.

The results of PI controller based system show that for certain variation in machine parameters the PI controller cannot perfectly tracks the desired power references because for every parameter value change there must be some mechanism to update the PI gains K_p and K_i according to the requirement. So in this thesis an intelligent controller is designed using fuzzy systems and the method of gain scheduling is used to update the values of K_p and K_i continuously according to the situation i.e. the fuzzy controller acts as a supervisory controller which updates the gain values for PI controller [12] used as first level controller in this case.

IV. RESULT AND DISCUSSION

The simulation is done by changing different parameters of the machine . The parameter that are changed while checking system response are rotor resistance Rr, rotor inductance Lr, stator inductance Ls, Mutual inductance Lm. Machine Parameters are: Vs= 398/ 690V, Rs= 0.012Ω, Rr= 0.021Ω, Ls= 0.0137H, Lr= 0.0136H, Lm= 0.0135H
Matlab Simulink model for stator active power is given below:

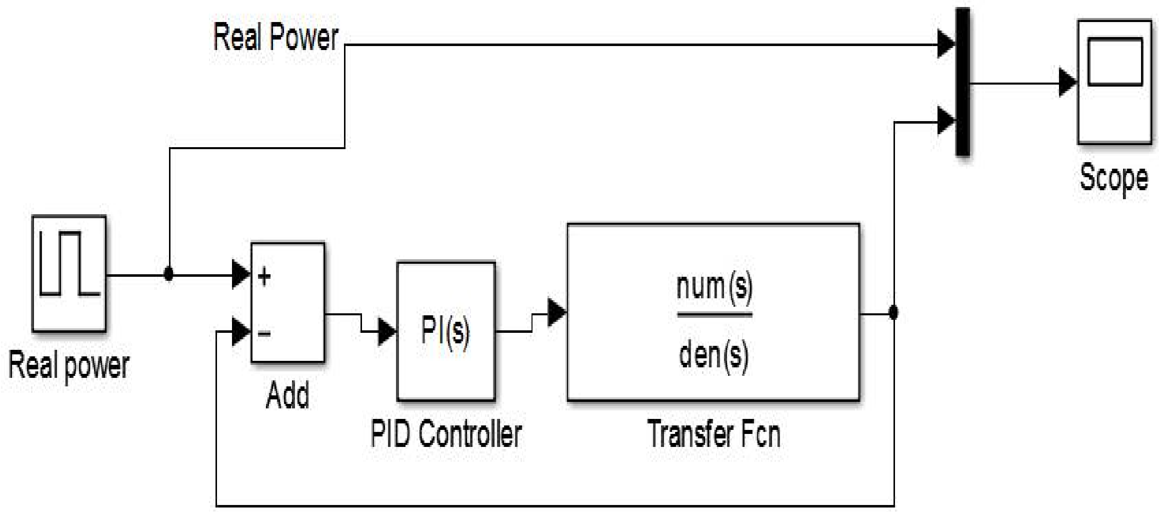

Figure-3 Simulink Modal Of Stator Active Power

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Matlab Simulink model for stator reactive power is given below:

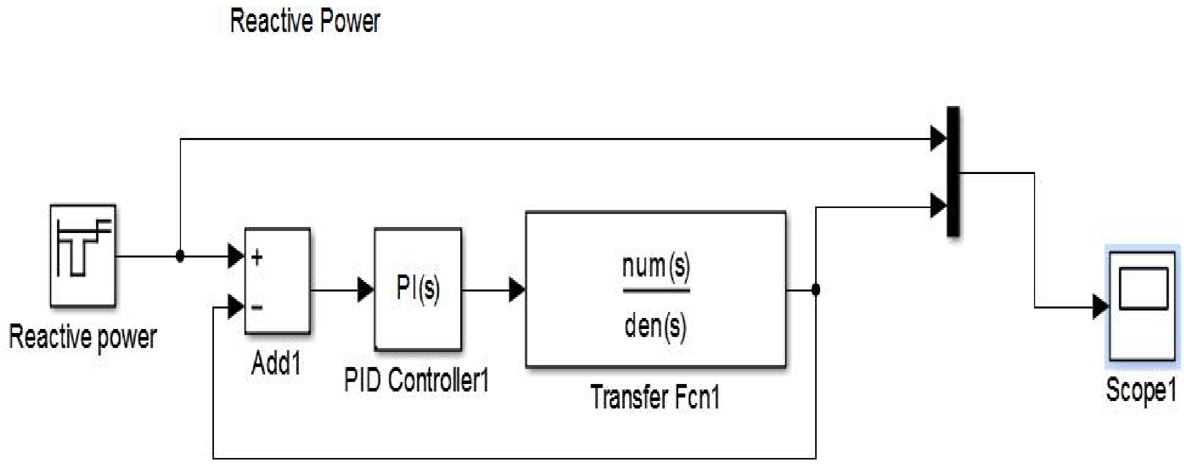

Figure-4 Simulink Modal Of Stator Reactive Power

By varying different parameters of machine the responses of both the controller are given in diagrams given. Fig-5,6shows the response when varying rotor resistance Rr, Figure-7,8 shows the response when varying stator inductance Ls, Figure-9,10 shows response when varying rotor inductance Lr and represents the system response when varying all the parameters simultaneously. These results show that the system with conventional PI controller having fixed values of gains Kp and Ki, it is not possible to perfectly track the stator active and reactive power references when varying different parameters of the machines. The system with a fuzzy controller acting as a supervisory controller for online tuning of PI controller gains enhanced the system's reference tracking capability, hence improving robustness of the system.

Real and Reactive Power response with respect to time with variation in different parameters shown below

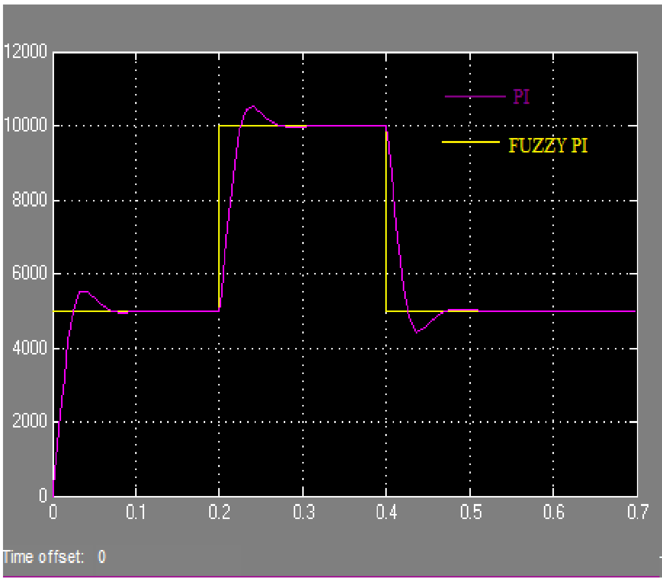

Figure-5 Stator Active power with Rr variation.

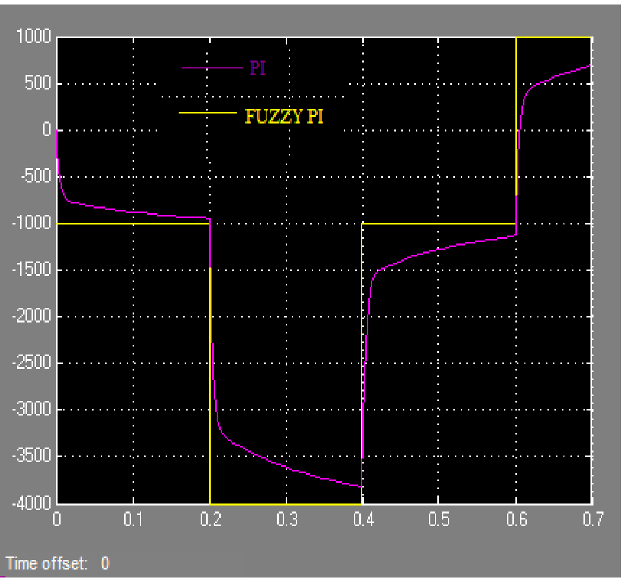

Figure-6 Stator Reactive Power with Rr variation.

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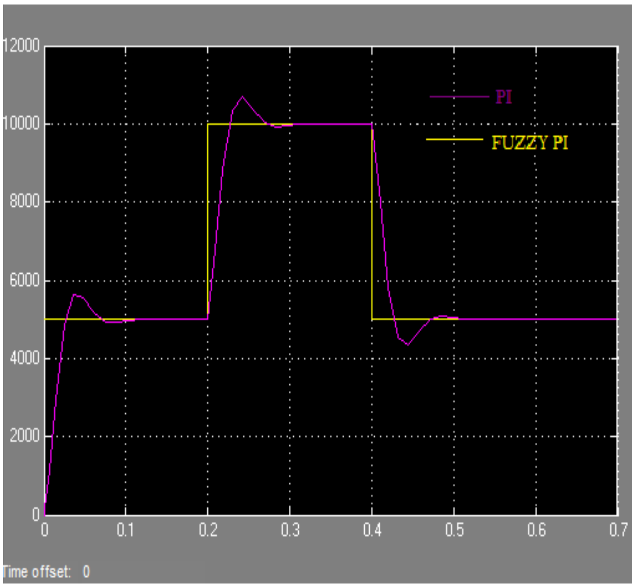

Figure-7 Stator Active power with Lr variation.

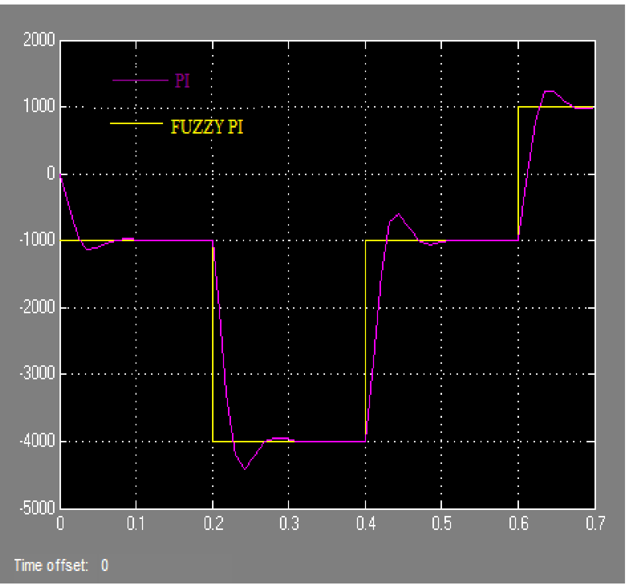

Figure-8 Stator Active power with Lr variation.

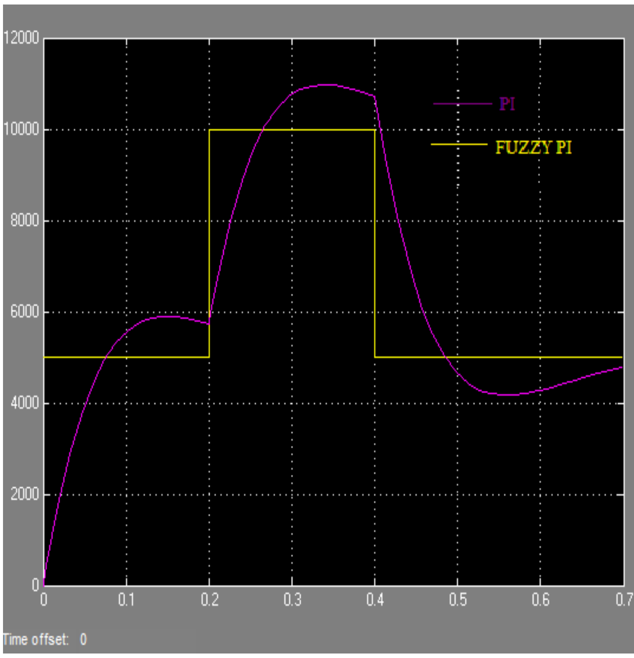

Figure-9 Stator Active power with Rr,Ls,Lr,Lmvariation.

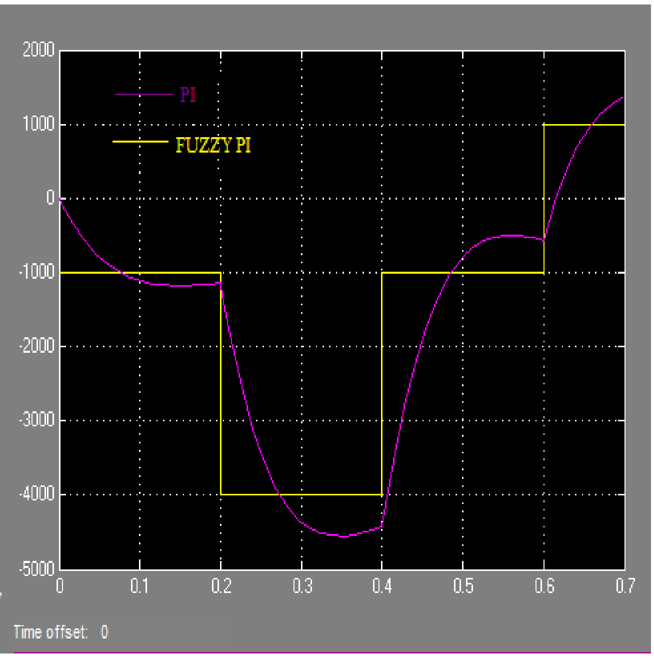

Figure-10 Stator Active power with Rr,Ls,Lr,LmVariation

The Simulation results are obtained by varying various parameters of DFIG like stator and rotor parameters and the application of Artificial intelligency is used to controll the stator active and reactive power in the given system.

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V. CONCLUSION

The wind energy conversion system is a combination of aerodynamic, mechanical and electrical portions reflecting its complex nature in order to control it. Moreover, its mathematical model involves cross differential equations and analysis with these equations is difficult so vector control technique proves good for simplification of mathematical model facilitating intelligent controller design process for decouple control of active and reactive power. The intelligent controller based on fuzzy logic improved the reference tracking by online tuning of PI controller gains. So instead of only using a PI controller it is better to have an intelligent controller so that the system can cater for expected variation in machine parameters.

REFERENCES

[1] Rubyna K. Brenden, WajeehHallaj, Ganesh Subramanian, Sony Katoch, "Wind Energy Roadmap" PICMET 2009 Proceedings, August 2-6, Portland, Oregon USA © 2009 PICMET

[2] MagediMoh. M. Saad ,NorzelawatiAsmuin, "Comparison of Horizontal Axis Wind Turbines and Vertical Axis Wind Turbines" IOSRJournal of Engineering (IOSRJEN) Vol. 04, Issue 08 (August. 2014)

[3] Aiman NOUH, Faisal MOHAMED, "Wind Energy Conversion Systems; Classifications and Trends in Application" The fifthInternational Renewable Energy Congress IREC © 2014

[4] J. Soltani, A. FarrokhPayam, "A Robust Adaptive SlidingMode Controller for Slip Power Recovery Induction Machine Drives," *IEEE Trans. Power Electronics and Motion Control Conference, vol.3*, pp. 3-8, 2006.

[5] Sergei Peresada, Andrea Tilli and, Alberto Tonielli, "Indirect Stator Flux-Oriented Output Feedback Control of a Doubly FedInduction Machine," *IEEE Trans. Control Systems Technology, vol.11*, pp.875-888, Nov 2003.

[6] Gilbert C, D. Sousa and, B. K. Bose, "Fuzzy logic applicationsto power electronics and drives - an overview," *Proceedings of IECON 1995*, Nov 1995, pp.57-62.

[7] A. G. Ram, S. and A. Lincoln, "Fuzzy adaptive PI controller for single input single output non-linear system," *ARPN Journal ofEngineering and Applied, Sciences. Vol. 7, NO.10,* pp. 1273 – 1280, 2012.

[8] L. Zhang, C. Watthansarn and W. Shehered: "A matrix converter excited doubly-fed induction machine as a wind power generator," *IEEE Trans.Power Electronics and Variable SpeedDrives, vol. 2, pp 532 - 537,* 06 August 2002.

[9] F. Poitiers, M. Machmoum, R. Le Daeufi and M.E. aim, "Control of a doubly-fed induction generator for wind energyconversion systems," *IEEE Trans .Renewable Energy, Vol. 3, N°. 3, pp.373-378, December 2001*.

[10] T.J.Porcyk and E.H.Mamdani, "A linguistic self-organizingprocess controller," *Automatica, vol.15, pp.15-30, 1979*.

[11] M. Machmoum, F. Poitiers, C. Darengosse and A. Queric, "Dynamic Performances of a Doubly-fed Induction Machine for a Variable-speed Wind Energy Generation," IEEE Trans. Power System Technology, vol. 4, pp. 2431-2436, Dec. 2002.

[12] A. G. Ram, S. and A. Lincoln, "Fuzzy adaptive PI controller for single input single output non-linear system," ARPN Journal of Engineering and Applied, Sciences. VOL. 7, NO.10, pp. 1273 –1280, 2012.

[13] M. Machmoum, F. Poitiers, C. Darengosse and A. Queric,"Dynamic Performances of a Doubly-fed Induction Machine for a Variable-speed Wind Energy Generation," IEEE Trans. Power System Technology, vol. 4, pp. 2431-2436, Dec. 2002.