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Implementation of Intelligent Algorithms for Pitch Angle and Output Power Control of Dfig Wind Turbine System.

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Abstract: The blade pitch angle is the vital part of wind energy system in getting desired output power. PID controller with the modified gains is considered as flexible and is administered for the regulation of blade pitch angle of turbine in this paper because of its lucidity, intermittent in its functionality and with easy usage in control system. FLC has powerful approach for collecting wind turbine response over PI controller where the speed and generator output power acting as input control variables for FLC with which these variables are evenly responsible to maintain proper aerodynamic power and its speed at rated value without any disturbance in output power and at gust speeds, the intelligent algorithms are been implemented to control the pitch angle upon adjusting the angle between the chord line of blades by adopting to new learning techniques as per the data collected. ANFIS had both the features of ANN and Fuzzy Logic Controllers by using Particle Swarm Optimization which gives the better response over the typical PI controller. This paper gives the information of supremacy of FOPID controller with PSO tuning over the other existing controllers. The dominance of the proposed method is made evident with the simulation results using 9MW WTS using MATLAB Simulink.

Index Terms: PI controller, FLC, ANFIS, PSO, FOPID controller, pitch angle.

I. INTRODUCTION

In recent years due to increase in energy deficit and need to provide sustainable energy there is an enormous increase in installation of wind farms throughout the world for generating clean power. As a result the share of wind energy in total electrical power generation was increasing playing a vital role as energy sources in power grids. The variable speed variable pitch wind systems generally operate in two regions as per the direction of wind speed. In the light load region where the wind speed is smaller than the fixed speed the governance of the turbine is excellent extracting maximum energy from wind turbine. Under full load region, where wind speed is beyond the fixed speed the generator output power is restricted to rated value conflicting maintenance of pitch angle for regulation of output power at light load region.

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The control of blade pitch angle is salient in achieving desired power[1] which is done by using different control techniques among which PID controller is dominant[2,3].The gains of the controller can be controlled either by human knowledge or by implementation of various control techniques or union of both.

The nonlinear characteristics are produced on top of WTS by using Linear Quadratic Gaussian mechanism due to this the performance is bounded and it is not affordable as an automatic optimizer [4,5].The FLC had a great feature of using the rotor speed as a function of wind speed[6] having concurrence and contrary to the changing of parameters even in case of noise signals. The Neuro fuzzy controllers are being implanted to control the pitch angle by gathering the demands like reducing deviations and giving the maximum output energy. The principle advantage of these intelligent controllers is their ability to learn new techniques and adjusting themselves as per situation choosing the efficient membership functions to find the best location of output power and rotor speed of generator. ANFIS controllers are designed using minimal membership functions for achieving the rated rotor speed of DFIG. The tuning of FOPID controller with PSO is also carried in this paper and the results are compared with different controllers for establishing a better analysis[7,8].

II. THEORITICAL ANALYSIS

A. Modelling of Wind Turbine System.

The extraction of wind energy from kinetic energy contained in air can be explained by considering the two different sections in Wind turbine model [9].The below given are its corresponding relations [10],

$$\frac{dw_r}{dt} = \frac{1}{2H_r}(T_E + T_{sh}) \quad (1)$$

$$\frac{dw_t}{dt} = \frac{1}{2H_T}(T_M - T_{sh}) \quad (2)$$

$$\frac{d\beta}{dt} = W_b(W_t - W_r) \quad (3)$$

Where T_E and T_M are electromagnetic and turbine torques respectively. T_{sh} is shaft torque.W_r and W_t are the angular frequency of the rotor and turbine. H_R and H_T are rotor and turbine inertia constants respectively. β is shaft twist angle[11].The mechanical torque of turbine is given as,

$$T_M = \frac{0.5\rho\pi R^2 C_p V_w^3}{S_b W_t} \quad (4)$$

Where ρ is density of air, R is radius of the blade is in meters, V_w is wind speed in m/sec , S_b is nominal power,

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C_p is the power coefficient of Wind Turbine System.

$$C_p = 0.22\left(\frac{116}{\lambda_i} - 0.4\beta_p - 5\right)e^{\frac{-12.5}{\lambda_i}} \qquad (5)$$

β_p is the pitch angle and λ_i is given by,

$$\lambda_i = 1/\left(\frac{1}{\lambda+0.08\beta_p} - \frac{0.035}{\beta_p^3+1}\right) \qquad (6)$$

λ = blade tip speed to wind speed, $\lambda = \frac{Rw_t}{V_w}$.on controlling λ, the MPPT is achieved and is expressed by considering derivative of C_p i.e eqn(5) the λ can be found with extreme points C_p.

$$\lambda_{opt} = \left(\frac{1}{\frac{14.28+0.4\beta_p}{116} + \frac{0.035}{\beta_p^3+1}}\right) - 0.8\beta_p \quad (7)$$

III. EXISTING METHODS OF PITCH ANGLE CONTROL

A.PI CONTROLLER:

The general pitch angle control mechanism of WTS is composed of ordinary PI controller to limit the rotor speed and output power of generator. The functional block diagram of PI controller in WTS is given in figure1. The K value of this controller is set usually to 1.

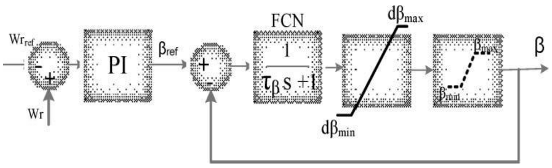

Fig1: Block diagram of PI controller.

B.FUZZY LOGIC CONTROLLER:
The fuzzy logic controller is designed by human experience using a set of empirical rules for controlling the pitch angle whose block diagram is given as below in figure2 using a membership functions of mamdani interface as shown in figure3 which is a three input controller with inputs as Δp, δΔp and w_r. The numerical errors are converted into linguistic variables by FLC control mechanism which are termed as, Positive Small(PS), Positive Medium(PM), Positive Big(PB), Very Negative(VN), Medium Negative(MN), Slightly Negative(SLN), Zero(ZE), Slightly Positive(SLP), Medium Positive(MP), Very Positive(VP). Which are expressed in table1.Δp and δΔp are calculated by the following equations[12].

$$\Delta p(i) = P_g(i) - P_{ref}(i)Z$$
$$\delta(\Delta p) = \Delta p(i) - \Delta p(i-1)$$

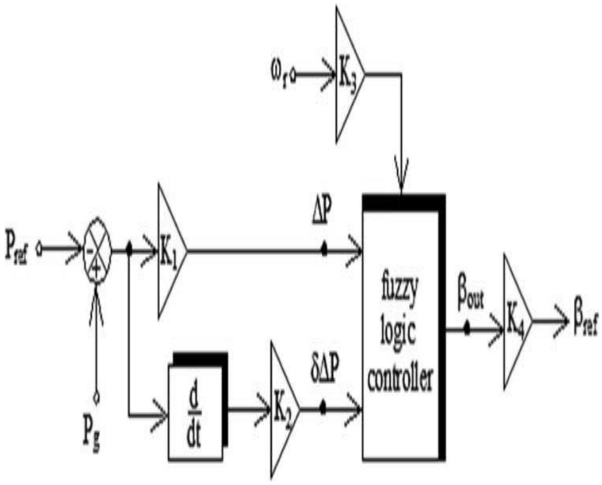

Fig2: Functional diagram of FLC.

Table 1. Fuzzy rules.

ω_r		PS					PM					PB				
Δp		VN	SLN	ZE	SLP	VP	VN	SLN	ZE	SLP	VP	VN	SLN	ZE	SLP	VP
$\delta\Delta p$	VN	VN	VN	VN	VN	MN	SLN	SLN	SLN	MP	MP	SLP	SLP	MP	MP	VP
	SLN	VN	VN	VN	MN	MN	SLN	SLN	ZE	MP	MP	SLP	SLP	MP	MP	VP
	ZE	VN	VN	MN	SLN	SLN	SLN	ZE	ZE	MP	MP	SLP	MP	MP	VP	VP
	SLP	VN	MN	MN	SLN	SLN	SLN	ZE	ZE	MP	SLP	MP	MP	VP	VP	VP
	VP	MN	MN	SLN	MN	SLN	ZE	ZE	SLP	SLP	SLP	MP	MP	VP	VP	VP

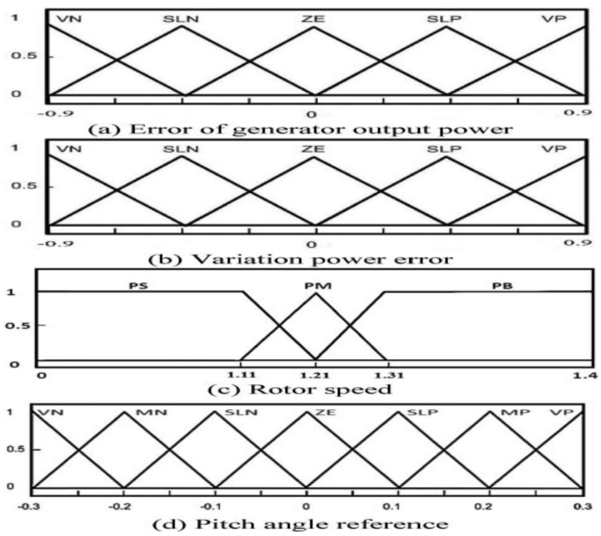

Fig3:fuzzy membership functions.

C.ANFIS CONTROLLER (ANFIS1& ANFIS2):

The ANFIS Controllers Are Used In This Paper Comprising Of Two Modules. ANFIS1 Is Basic Intelligent Controller Whereas ANFIS2 Refers To Usage Of PSO Technique For Tuning Of ANFIS

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Table 2. Generator and grid parameters.

Parameters	Values
Nominal. power	9 MW
Grid voltage and frequency	575 V–60 Hz
Infinitive bus-voltage	120 kv
Nom. dc bus voltage	1200 V
DC-bus capacitor	0.06 F
Grid gains [Kp Ki]	[1.25 300]
Rotor gains [Kp Ki]	[1 100]
Line length	20 km

Table 3. Parameters of wind turbine.

Rated power	9 MW
Rated wind speed	12 m/s
Max. pitch angle	40 deg
Max. rated of pitch angle	2 deg/s
Cut-in speed	5 m/s
Cut-out speed	24 m/s

Which holds both the features of ANN and fuzzy involving collection of neural data by training and testing as given in figure4, to achieve a best solution over group of solutions.

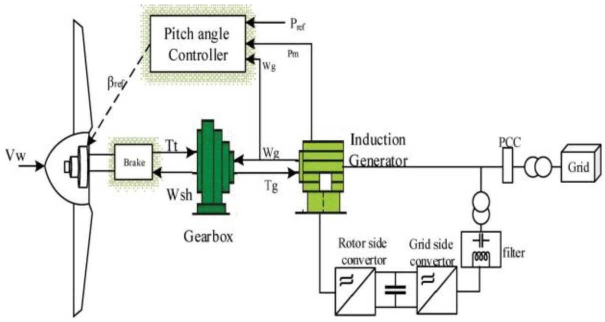

Fig4: Control block diagram of pitch angle controller .

Its function is carried out in five different layers[13] as given in figure5 each of which had its unique function as, first layer deals with the calculation of degree of membership function. Second layer is associated to calculate the firing power of each rule, third layer is responsible for calculating the firing power rule with respect to the ith node which is expressed as,

$$\overline{Wi} = \frac{Wi}{\sum Wj}$$

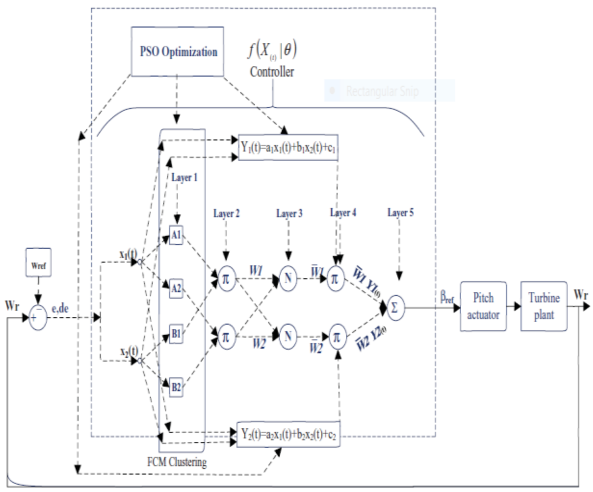

Fig5: mechanism involved in ANFIS controller.

The output of this is fed into fourth layer to evaluate the parameters by considering the condition parts of the rules. Final layer gives the output of all the given signals by multiplying with their corresponding weights.

IV. PROPOSED FOPID CONTROLLER WITH PSO

In recent years FOPID controllers have attained greater importance because of their dynamic behaviour over the traditional PID controllers. These controllers are capable of handling nonlinear characteristics to reduce error content in the system. The tuning of these intelligent controllers can be carried out based on analytical or numerical optimization techniques. In this paper the tuning of FOPID is done with PSO so as to reduce the total time taken and further with better solution upon choosing suitable fitness function. The conventional PID controllers have three terms K_p , K_i, $and\ K_d$ whereas it had the two additional parameters λ and μ which can be adjusted as per requirement. The differential operators $D_t^{-\lambda}, D_t^{-\mu}$ are notated as,

$$aD_t^{\alpha} = \begin{cases} \dfrac{d^{\alpha}}{dt} & \alpha > 0 \\ 1 & \alpha = 0 \\ \displaystyle\int_0^t (d\tau)^{-\alpha} & \alpha < 0 \end{cases}$$

The transfer function is given as,

$$G_c(s) = \frac{Y(s)}{E(s)} = K_p + \frac{K_i}{s^{\lambda}} + K_d s^{\mu}.$$

The block diagram of FOPID is given in figure6.

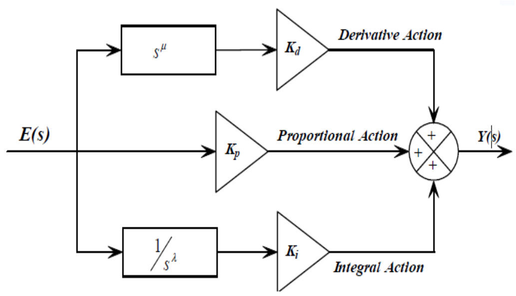

fig6:Block diagram of FOPID controller.

For an ideal controller λ=μ=1 where these may range with different values for the controller to make it vigorous which could be achieved either by improving the derivative power or by mitigating the integrator power terms respectively[14].The optimization algorithms generally depends on population size and fitness function which are iteratively modified until a termination criterion. The application of FOPID in this paper gives the better result over the conventional techniques with the fitness function given as,

$$F = 1 - (e^{-\gamma M_p} * e^{-\gamma e_{ss}} * e^{-\gamma T_s} * e^{-\gamma T_r}).$$

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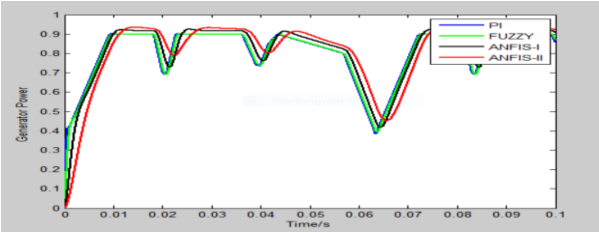
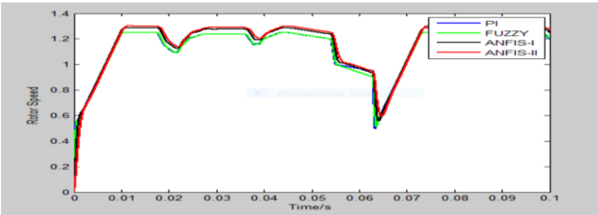
Where F is fitness function, M_p is peak overshoot, e_{ss} is steady state error, T_s is settling time, T_r is rise time, γ is scaling factor.

V. SIMULATION RESULTS

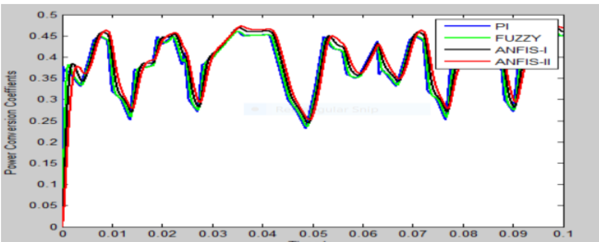
The simulation results of various parameters of DFIG WTS with PSO tuning are given as follows on setting the values as K_1=10e^{-6}, K2=10e^{-2}, K3=1, K4=100. Tables 4 and 5 shows optimized parameters of ANFIS controllers.



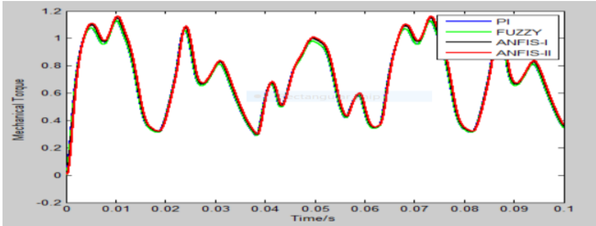
(a)Output power of generator.



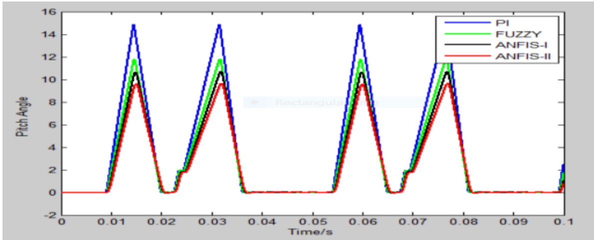
(b)Speed of rotor.



(c)power conversion coefficients.



(d) Mechanical Torque.



(e)Pitch Angle.

Figure7: simulation results of existing PI fuzzy and ANFIS controllers.

Table 4. Optimized parameters in ANFIS 1.

	σ		C		OUTPUT		
Params/MF	IN1	IN2	IN1	IN2	A	B	C
MF1	0.02729	0.5459	−0.019	8.9e-5	741.9	0.00053	−0.00024
MF2	0.09085	0.01446	−0.5155	0.5711	592.1	0.0054	−0.0006
MF3	0.04229	0.04069	−0.1769	0.003697	465.2	−0.00066	−0.0013
MF4	0.03165	0.07162	0.03603	4.433e-5	200	−0.00011	0.00034

Table 5. Optimized parameters in ANFIS 2.

	σ			C			OUTPUT			
Params/MF	IN1	IN2	IN3	IN1	IN2	IN3	A	B	C	D
MF1	0.02907	0.03475	0.01337	−0.05654	0.0081	1.199	41.05	−1.205	27.38	−50.58
MF2	0.02929	0.04231	0.02975	0.00303	−0.0010	0.7985	−68.85	5.229	340.2	−522.9
MF3	0.00922	0.02597	0.0175	0.00354	−0.00663	1.186	79.28	−11.97	112.1	−132.2
MF4	0.09269	0.04689	0.03637	−0.2349	0.03638	0.68	15.32	6.915	−21.04	12.74

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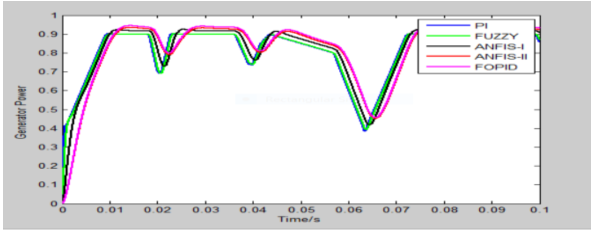
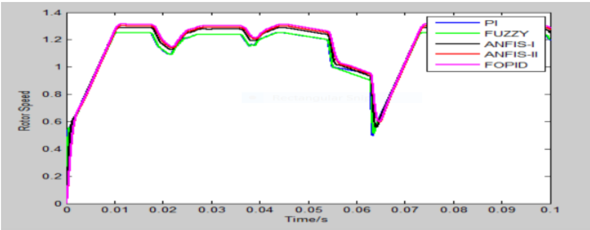
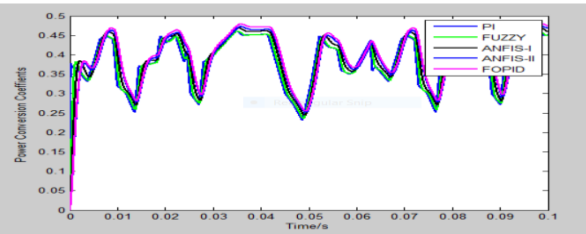


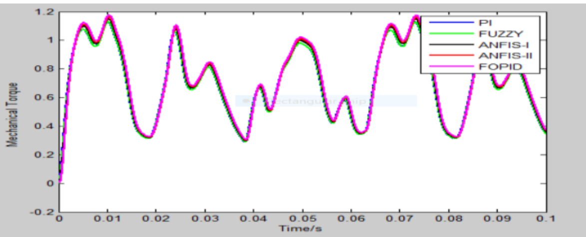
(a) Output of generator.



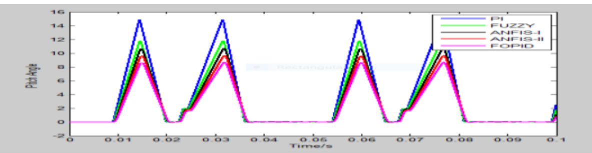
(b) Speed of rotor.



(c) Power conversion coefficients.



(d) Mechanical torque.



(e) Pitch angle.

Figure8: simulation results of the proposed controllers using PSO.

VI. CONCLUSION

Thus, in this paper the use of various controllers ranging from PI, Fuzzy, ANFIS and FOPID controllers are employed in this paper one having the superiority over the other by simulating in the MATLAB environment.

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