FUZZY LOGIC CONTROL OF VARIABLE SPEED INDUCTION MACHINE WIND GENERATION SYSTEM

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Abstract-**This paper presents the use of fuzzy logic control (FLC) of a variable speed induction machine wind generation system. The generation system uses three fuzzy logic controllers (FLC's), first fuzzy logic controller tracks the generator speed with wind velocity to extract maximum power. Second fuzzy logic controller programs the machine flux for light load efficiency improvement. Third fuzzy logic controller provides robust speed control against wind vortex and turbine oscillatory torque. By selecting appropriate fuzzy rules are designed to tune the parameters of conventional PI controller, the performance of the wind generation system has improved significantly compare to conventional PI controller. The performance of the wind generation system evaluated through the toolbox simulink of matlab.**

Keywords- ***Aerodynamic turbine, squirrel cage induction machine, double sided pulse width modulation (PWM) converter system, fuzzy logic control.***

I. INTRODUCTION

Wind energy conversion schemes generally use a self-excited induction generator on account of its simplicity, ruggedness, and ease of implementation and low cost [1]. Due to the intermittent and stochastic nature of wind energy, this system (WECS) is generally used with some form of energy backup to provide continuous supply of electrical power in the case of autonomous systems However, for utility interactive operation, direct interfacing the WECS to a utility gives rise to problems of voltage fluctuations, flickering and generation of sub harmonics associated with the pulsating torque of the induction generator. Hence, to overcome these difficulties an asynchronous (AC–DC–AC) link is used to interconnect the WES to the utility. Generally, the asynchronous link consists of a phase-controlled rectifier and a line-commutated inverter as shown in Fig. 1.

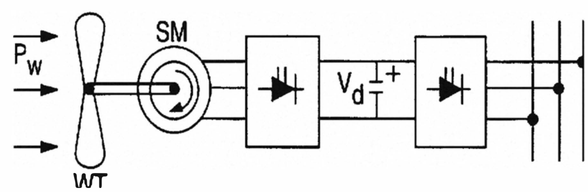

Fig.1. wind energy converter system.

The use of FLC significantly changes the control approach compared with that of conventional control approaches. A conventional controller adjusts the system control parameters on the basis of an accurate mathematical model of the process dynamics. In the case of a fuzzy rules-based expert system, it is a logical model of the human behavior of the process operator (linguistic information).Also FLC usually leads to better results than those of the conventional controllers, in terms of response time, settling time and robustness [2]. The FLC is designed on a hypothetical basis of step variation of wind speed, and then tested on real on-site data. The effectiveness and robustness of the fuzzy logic controller is demonstrated by computer simulation.

II. SYSTEM DESCRIPTION

Figure 2 is a block diagram of the power circuit and the fuzzy logic based control of the wind generation system. The wind turbine is coupled to the squirrel cage type induction generator through a speed-up gear box (not shown). The variable frequency variable voltage power generated by the machine is rectified to direct current (dc) by an IGBT(Insulated gate bipolar transistor) SPWM(space pulse width modulation) bridge rectifier that also supplies lagging excitation current to the machine [3]. The dc link power is inverted to alternating current (ac) through an IGBT SPWM inverter and fed to a utility grid at a unity power factor. The line power factor can further be controlled by means of active VAR compensator. The generator speed is controlled by indirect vector control with torque control in its inner loop. The line side converter is also vector controlled, using direct vector control and synchronous current control in the inner loop. The output line power P_o is controlled to control the dc link voltage V_d. since an increase of the line power causes a decrease of dc link voltage this causes a decrease of dc link voltage, the voltage loop error polarity has been inverted. The insertion of filter inductance L_s creates some coupling effect which is eliminated by a decouple in the synchronous current control loop. The system uses three fuzzy controllers(FLC-1,FLC-2 and FLC-3). Neglecting losses, the line power output of the system as a function of generator speed at different wind velocity is explained in Figure 3. For a certain wind velocity, if generator speed is increased, output power first increases, reaches a maximum value, and then decreases.It is desirable that, for any wind velocity, the system should always operate at the maximum power point where the turbine aerodynamic efficiency is maximum. Since wind velocity is an unknown parameter, the speed of the generator can be modified by on-line search until the maximum power point is attained[4].

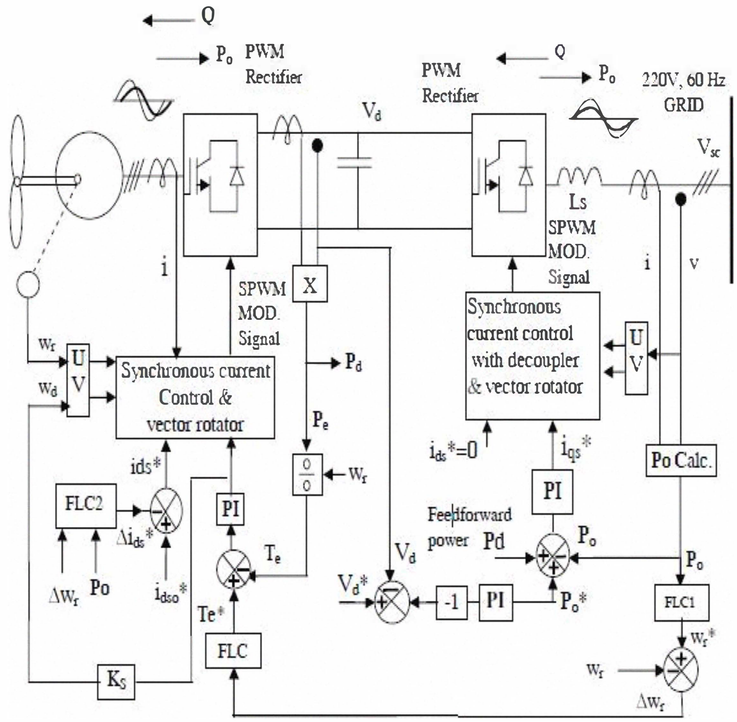

Figure.2: Fuzzy logic based control block diagram of wind generation system.

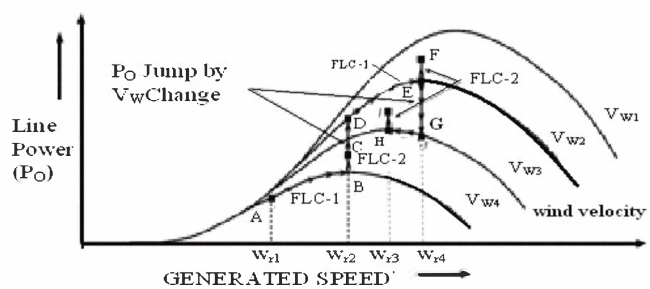

Figure.3: FLC-1 and FLC-2 operation indicating maximization of power

A. Turbine model

There are two types of turbines: vertical and horizontal type. [5] A vertical type turbine need not be oriented with respect to wind direction because the shaft is vertical, the transmission and generator can be mounted at ground level allowing easier servicing and a lighter weight, lower cost tower. It is therefore preferred for high power output.

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***B. Variable speed with squirrel cage induction generator*:** A few manufacturers have produced variable-speed wind turbines with squirrel cage induction generators with a converter carrying the full power. Compared to the doubly-fed induction generator this system has the following advantages, the generator is cheaper, the generator has no brushes, the system is often used as a standard industrial drive.

III. FUZZY LOGIC CONTROLLERS

The Wind generation system consists three numbers of fuzzy logic controllers [6].

A.FLC-1(Generator speed tracking controller):

In this paper, the above block diagram of FLC-1 was simulated using triangular membership function and the centroid method was used for defuzzification. The membership functions for all the variables are asymmetrical [7],[8] because they gives more sensitivity as the variables approaches zero value. A typical rule of FLC-1 can be read as follows: "If ΔP_o is PM (positive medium) AND $L\Delta\omega_r^*$ is P (positive) , THEN $\Delta\omega_r^*$ is PM(positive medium)."

A(i).Membership functions of FLC-1:

Input(1):

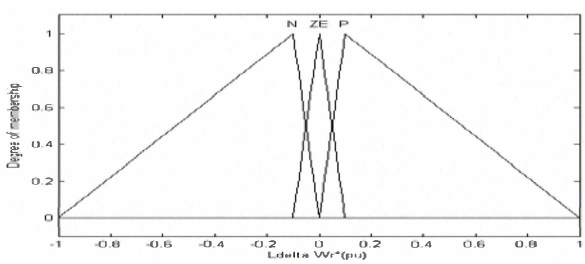

Fig.4(a): LdeltaW$_r^*$(p.u)-degree of membership

Input(2):

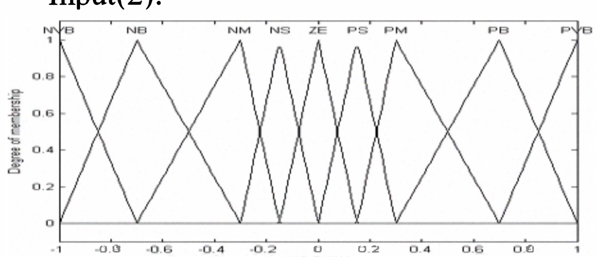

Fig.4(b):delta P_O(p.u)-degree of member ship

Output:

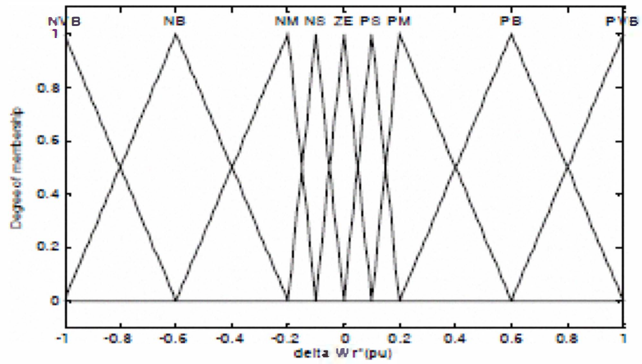

Fig.4(c):delta W_r (p.u)-degree of membership

Fig.4(a),(b)&(c) membership functions of FLC-1

Table (1):

A(ii).Rule matrix for FLC-1[7] is given below

$L\Delta\omega_r^*$ / ΔP_0	P	ZE	N
NVB	NVB	NVB	PVB
NB	NB	NVB	PB
NM	NM	NB	PM
NS	NS	NM	PS
ZE	ZE	ZE	ZE
PS	PS	PM	NS
PM	PM	PB	NM
PB	PB	PVB	NB
PVB	PVB	PVB	NVB

B. FLC-2 (Generator flux programming controller):

The function of FLC-2 is to program the machine rotor flux for light load efficiency improvement.

B(i).Membership functions of FLC-2:

Input(1)

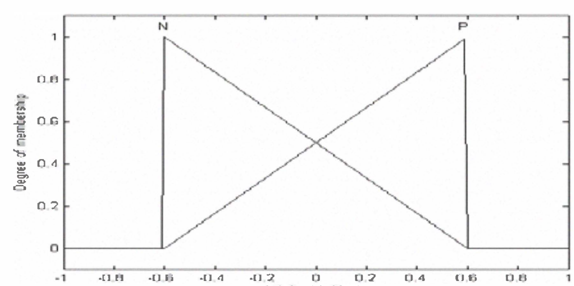

Fig.5(a): Ldelta i_{ds}^*(p.u)-degree of membership Function

Input(2)

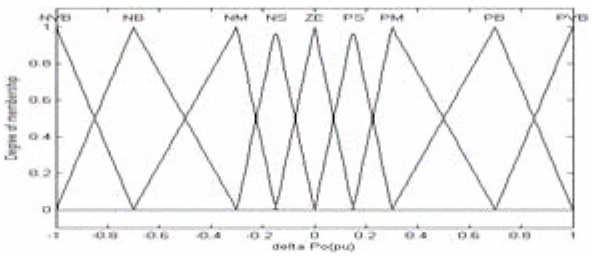

Fig.5(b): delta $P_o(k)$(p.u)-degree of membership function

Output

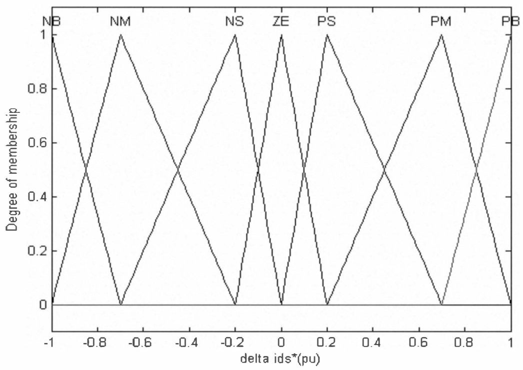

Fig.5(c): delta i_{ds}^{*}(p.u)-degree of membership function

Fig.5(a),(b)&(c) membership functions of FLC-2

Table(2):

B(ii)Rule matrix for FLC-2 is given below

LΔi_{ds}*(pu) ΔP_{0}(k)	N	P
PB	NM	PM
PM	NS	PS
PS	NS	PS
NS	PS	NS
NM	PM	NM
NB	PB	NB

C.FLC-3 (Closed loop generator speed controller):

C(i).Membership functions of FLC-3:

Input(1)

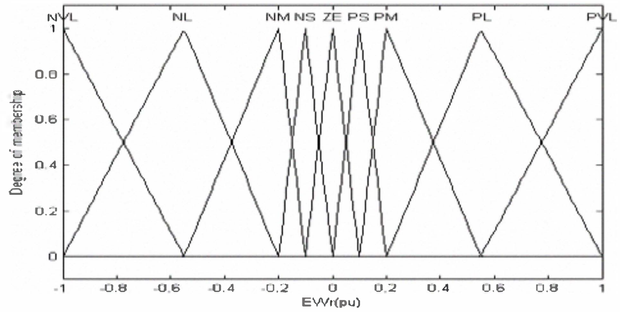

Fig.6(a): EW_r(p.u)-degree of membership function

Input(2)

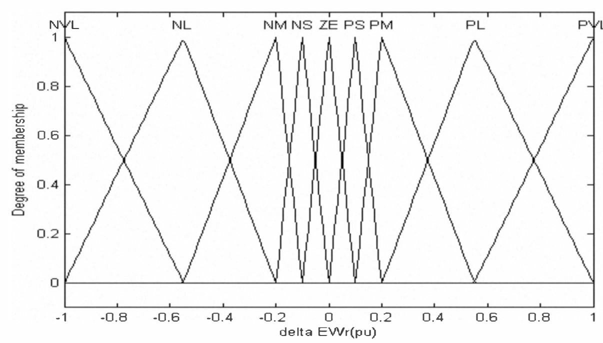

Fig.6(b):deltaE W_r(p.u)-degree of membership Function

0utput

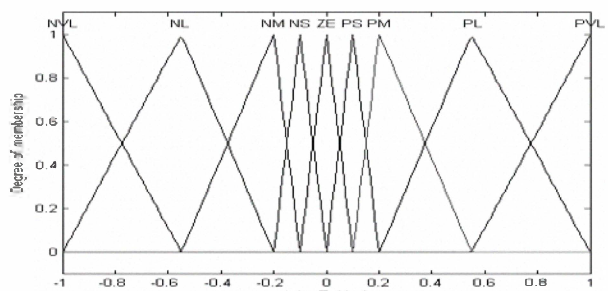

Fig.6(c):delta T_e^{*}(p.u)-degree of membership function

Fig.6(a),(b)&(c) membership functions of FLC-3

Table(3):

C(ii).Rule matrix for FLC-2 is given below

$E\omega_r$ (pu) / $\Delta E\omega r$ (pu)	NVL	NL	NM	NS	ZE	PS	PM	PL	PVL
NVL					NVL	NL	NM	NS	ZE
NL					NL	NM	NS	ZE	PS
NM				NL	NM	NS	ZE	PS	PM
NS			NL	NM	NS	ZE	PS	PM	PL
ZE		NL	NM	NS	ZE	PS	PM	PL	
PS	NL	NM	NS	ZE	PS	PM	PL		
PM	NM	NS	ZE	PS	PM	PL			
PL	NS	ZE	PS	PM	PL				
PVL	ZE	PS	PM	PL	PVL				

MACHINE PARAMETERS

3 phase, 10 hp, 460 V_{rms}, 7.6A, 2 poles, 1760 r.p.m, R_s=0.6837Ω, R_r=0.451Ω, L_{1s}=4.152 mH, L_{1r}=4.152 mH, L_m= 0.1486h

TURBINE PARAMETERS

3.5KW, Tower=99.95m,11.1-22.2 r.p.m

η_{GEAR}=5.2, A=0.015, B=0.03, C=0.015

IV. MATLAB SIMULINK BLOCK DIAGRAMS OF WIND ENERGY CONVERSION SYSTEM:

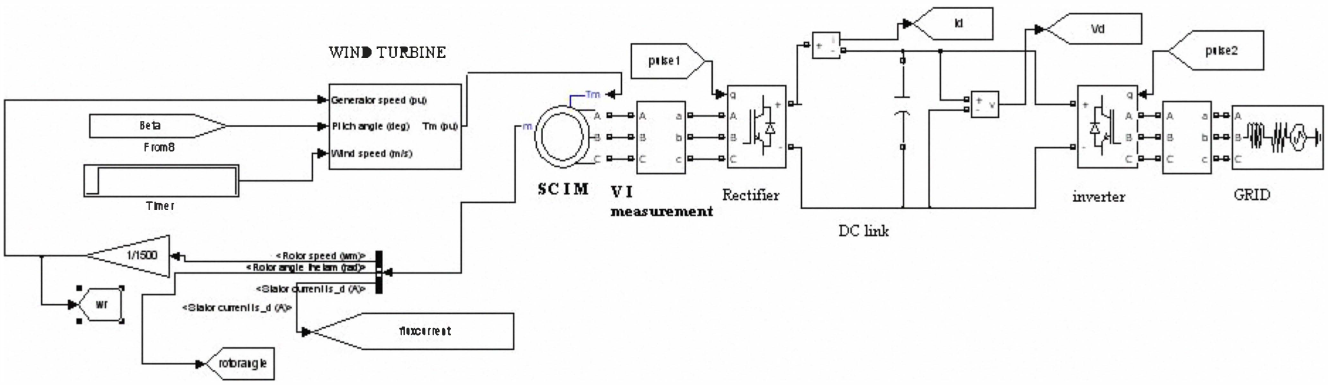

Fig.7 Represents Wind energy conversion system

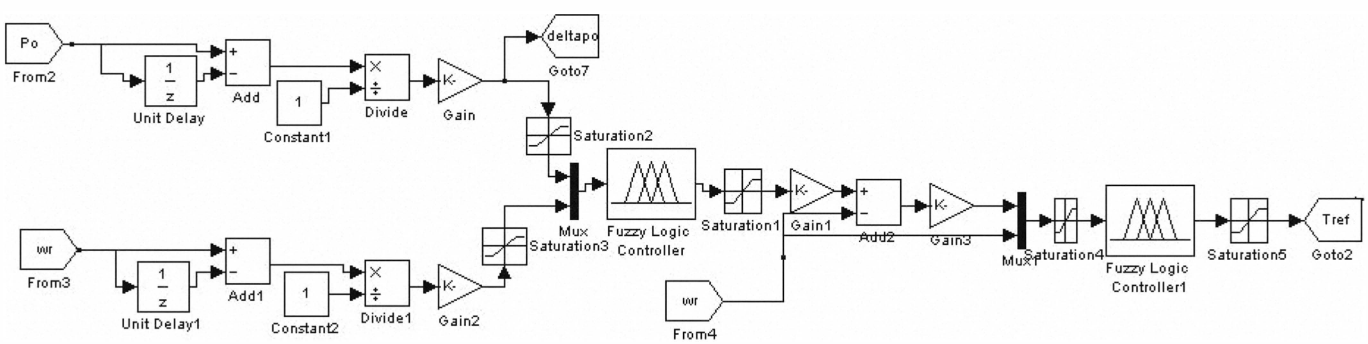

Fig.8FLC-1 is Generator speed tracking controller and FLC-2 is Generator flux programming controller

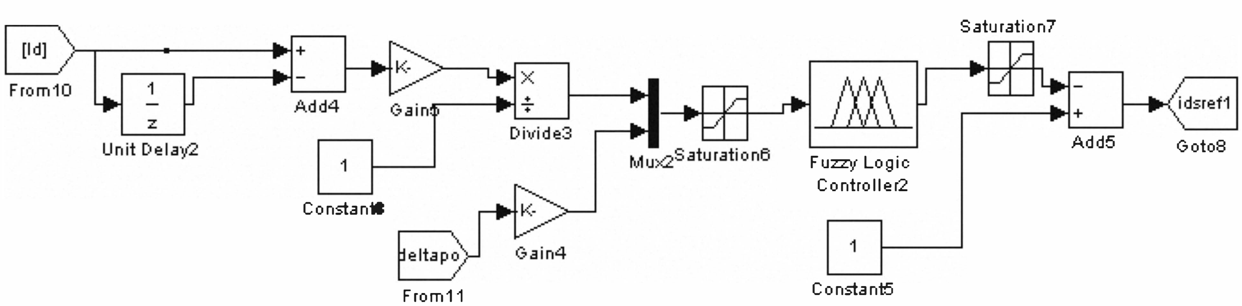

Fig.9. Closed loop generator speed controller with FLC-3

V. TIME DOMAIN CLOSED LOOP SIMULATION RESULTS

1. Wind velocity

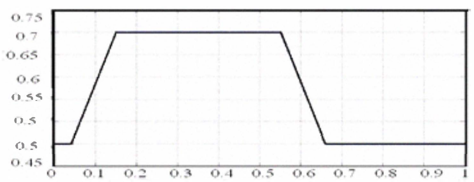

Fig.10. Wind velocitry-time(in sec)

2. Flux current

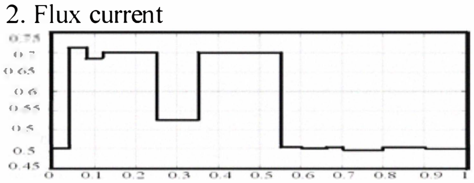

Fig.11.Flux current-time(in sec)

3 .Generator speed

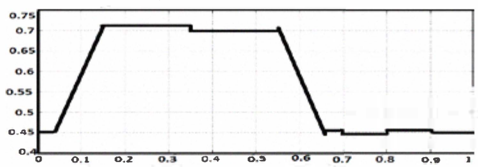

Fig.12.Generator speed-time(in sec)

4. Output power

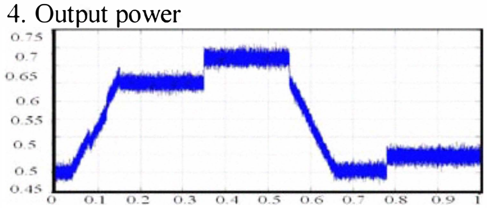

Fig.13.Output power-time (in sec)

V(a). COMMENTS

Fig.10. has been taken as the input for obtaining closed loop response of the wind generation system. In Fig.11, Fig.12 and Fig.13 the outputs are observed with respect to change in wind velocity.

Fuzzy logic controller-1: FLC-1 will track the generator speed with the change in wind velocity to extract maximum power .So as the wind velocity increases, generator speed is also increased by FLC-1.As a result of which the corresponding line output power is also increased during the interval FLC-1 is active by assuming a lossless system.

Fuzzy logic controller-2: FLC-2 will reduce the generator rotor flux component of current i.e., i_{ds}.The core loss of machine decreases but on the other hand torque component of current i_{qs} is increased , which in turn increases the copper loss of the machine. However, the total system loss i.e machine and converter loss decreases , resulting in an increase of total generated or output power P_o. That's why in fig.13 the output power P_o is increased by FLC-2 by means of ΔP_o , i.e change in output power.

Fuzzy logic controller-3: The turbine is modeled with aerodynamic torque(T_m) and turbine oscillatory torque (T_{OSC}) and some turbulence has also been added with the wind velocity to verify the robustness of FLC-3.

VI. CONCLUSION

The fuzzy logic-tracking controller is designed to control the firing angle of the inverter. Simulation results for above cases proved the robustness, fast response, and exact maximum power tracking capabilities of the designed FLC.

The second fuzzy controller FLC-2 programs the machine flux by an on line search so as to optimize the machine converter efficiency.

If it is compared with PI controller , system efficiency is high.

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