Fuzzy predictive control of Variable Speed Wind Turbines Using Fuzzy Techniques

D. Jyothirmayi [1], P. Navyasri[2], N.Sudhakar[3],A.Madhubabu[4] ,S.Anil[5] ,K.Saranya[6]

[1,2,3,4,5,6] IV B tech student, RSR engineering college Dept of EEE ,R.S.R engineering college ,Kadanuthala
[6] Assistant Professor ,Dept of EEE ,R.S.R engineering college ,Kadanuthala, Bogole (M) ,SPSR Nellore (Dst) A.P state, India.

Abstract - *In this paper, a fuzzy logic controller is proposed to fulfill the objective of maximum power extraction based on a two mass model. One of the typical problems is that the effective wind speed cannot be measured directly due to the high disturbance of the wind speed and the high cost of sensors. Three algorithms are used to estimate the effective wind speed by solving power balance equations. The estimated wind speed is used to determine the optimal speed reference for generator control system. The control performance of the fuzzy logic controller is verified in the whole system Simulation results are presented to illustrate the effectiveness and robustness against parameter variations of the proposed control design.*

***Key Words*: Wind Power generation ,MPPT, LQR, Fuzzy systems, Filtering algorithms**

1. INTRODUCTION

DURING the last decades, the demand of clean and renewable energy sources has been growing intensively due to environment issues. Among the renewable energy sources, such as wind turbines, Photovoltaic and fuel cells, are expected Owing to the rapid progress in wind turbine technology and its economic and safety properties, wind power is considered as one of the most promising cleaner and renewable sources among these renewable energy sources [1]–[3]. One of the most prominent problems of wind energy extraction is its low efficiency. Therefore, under the partial loaded operation condition, how to increase the power extraction becomes of high importance. A widely used control method is maximum power point tracking (MPPT) control [4]–[8]. This control strategy aims to adjust the rotor speed according to the variations of wind speed, in order to maintain the tip speed ratio at its optimal value, which equivalently realizes MPPT. The principle obstacle of the MPPT control design is the unavailability of the wind speed. First, wind speed is a highly disturbed value which cannot be easily measured using simple and portable measuring device. Second, since the blade is a non-particle rigid body, the measured wind speed only represents a single point in the blade which is not applicative to other parts. Third, the implementation of physical sensors will increase system complexity, cost, space and reduce system reliability [9]. According to [10], the sensors failure and the consequent control failures take up more than 40% of failures. As a result, many research endeavors have been focused on the wind speed estimation problem [11] such as power balance estimator method [12], Kalman filter (KF)-based estimator [13]–[15], disturbance accommodating control (DAC) [16], unknown input observer (UIO) [17] and the immersion and invariance (I&I) estimator [18]. In this paper, three algorithms are used to estimate the effective wind speed by solving power balance equations. The estimated wind speed is used to determine the optimal speed reference for generator control system. Several model based control approaches have been studied for the wind turbine system, such as linear-quadratic regulator (LQR), pole-placement and PID, which provides convenience to implement such controllers in practical applications [3], [19].

Sliding mode techniques have been widely used to control the wind turbine systems [21], [22]. Especially, higher order sliding mode algorithms have better performance as compared to classical sliding mode controllers because their output is continuous and does not require any low pass filters [23]–[25]. However, such methods require accurate mathematical models of wind turbine system, which are difficult to obtain.

In this paper, fuzzy logic control method is adopted [5]. Fuzzy logic is a part of artificial intelligence which approximates the imprecise reasoning process in human mind and largely enhanced the expert system technology. Fuzzy logic control is based on the fuzzy if-then linguistic rules and has the inherent robustness to uncertainties [27], [28].

2. WIND SYSTEM

A wind turbine is a device that converts the wind's kinetic energy into electrical power.

Wind turbines are manufactured in a wide range of vertical and horizontal axis types. The smallest turbines are used for applications such as battery charging for auxiliary power for boats or caravans or to power traffic warning signs. Slightly larger turbines can be used for making contributions to a domestic power supply while selling unused power back to the utility supplier via the electrical grid. Arrays of large turbines, known as wind farms, are becoming an increasingly important source of intermittent renewable energy and are used by many countries as part of a strategy to reduce their reliance on fossil fuel.

A quantitative measure of the wind energy available at any location is called the Wind Power Density(WPD). It is a calculation of the mean annual power available per square meter of swept area of a turbine, and is tabulated for different heights above ground. Calculation of wind power density includes the effect of wind velocity and air density.

Wind turbines can rotate about either a horizontal or a vertical axis, the former being both older and more common. They can also include blades (transparent or not) or be bladeless. Vertical designs produce less power and are less common.

3. WIND TURBINE MODELING

Wind turbine system consists of four major parts,i.e., wind turbine blades, gearbox and shaft, generator, and power converters. The wind energy is captured through turbine blades and converted into mechanical torque. The generator transforms the mechanical torque into electricity, which is conveyed into the grid after been adjusted by the power converters. This paper focuses on the modeling of the mechanical and aerodynamic parts, which considers comprehensive dimensions, such as gearbox and shafts stiffness, viscous resistance, loading effect, losses, etc. A two-mass model is adopted in this paper which is suitable for control design. Fig. 1 shows the structural model of such transmission system [20].

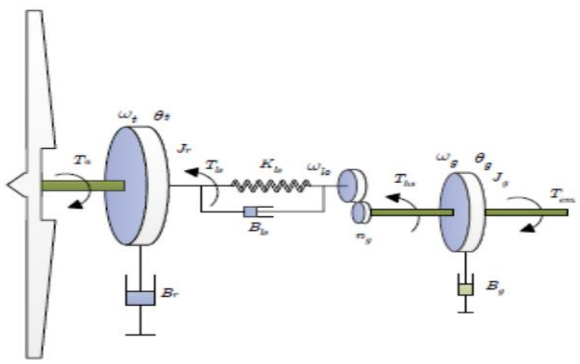

Fig1- Two-Mass Drive Train Model.

The rotator and low-speed shaft is modeled by a rotational moment of inertia Jr, two viscous damper with damping constant Br and Bls respectively and a spring which represents shaft stiffness Kls. The generator and high-speed shaft is modeled by a rotational moment of inertia Jg, and a viscous damper with damping constant Bg. The gearbox is modeled by a gearbox ratio ng, which is supposed to be perfectly stiff.

4. FUZZY LOGIC CONTROL

Fuzzy logic is a part of artificial intelligence which approximates the imprecise reasoning process in human mind and largely enhanced the expert system technology. The fuzzy controller consists of four parts: fuzzification, fuzzy rule base, inference engine and defuzzification [4], [27],[30]. Fuzzy logic control is based on the fuzzy if-then linguistic rules and has the inherent robustness to uncertainties [27], [28]. Compared to classical control methods, fuzzy logic based controller can effectively avoid the requirement of precise model of the control system. The block diagram of MPPT control system is shown in Fig.2(a). In the block diagram, the ω_{topt} and i_{qopt} are the reference value of rotor speed and generator current respectively, while the ω_t and i_q are the measurement value derived from the wind turbine system.

The block diagram of MPPT control system is shown in Fig.2(a). In the block diagram, the ω_{topt} and i_{qopt} are the reference value of rotor speed and generator current respectively, while the ω t and iq are the measurement value derived from the wind turbine system.

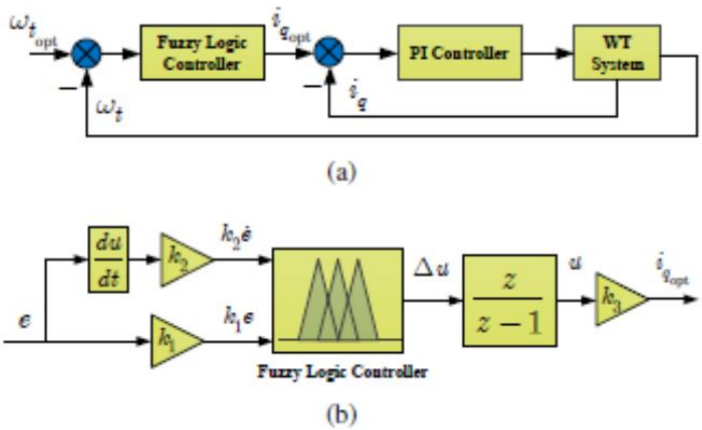

Fig2- (a) MPPT Control System With Fuzzy Logic Controller
(b) Structure Of Fuzzy Logic Controller

4.1 DESIGNING OF FUZZY SYSTEM:

Inorder to create a Fuzzy system for the model we have to follow the given procedure.

1.Open the MATLAB File.

2.Enter Fuzzy in the matlab window.

3.Fuzzy toolbox will open.

4.Open file in the tool box.

5.Select Mandani model

6.Now open edit option and add required variables from input and output.

7.Now open input and draw the membership functions for the required range.

8.After drawing the membership functions now write down the rules for the system.

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 05 Issue: 03 | Mar-2018 www.irjet.net p-ISSN: 2395-0072

9.Now SAVE the system with the nameXX.fis.

10.After saving the system now export it to the matlab model.

In the case of fuzzification process for this system we have taken two inputs input 1 is actual value of the error e ,input 2 is change of the error ė and output 1 isΔu .For these inputs we have taken the triangular membership functions from the range -6 to 6.For the outputs we have taken the triangular membership function for thr range -7 to 7.For these member ship functions we have taken the rule base sytem in 7X8 format .it means that totally we have created 56 rules. For the defuzzification method we use the centroid method.

For these inputs and output the linguistic terms are shown in table 1.

TABLE-1: Fuzzy linguistic terms

e	fuzzy set:	{NB,NM,NS,NO,PO,PS,PM,PB}
$\dot{e}$	fuzzy set:	{NB,NM,NS,ZO,PS,PM,PB}
Δu	fuzzy set:	{NB,NM,NS,ZO,PS,PM,PB}

The linguistic terms “NB”, “NM”, “NS”, “ZO”,“PS”, “PM”, “NB” mean “negative big”, “negative medium”, “negative small”, “zero”, “positive small”, “positive medium”, “positive big”, respectively. The “NO” and “PO” mean “negative zero” and “positive zero” respectively to improve control precision as the variables approach zero. The universes of discourse of the error e, the change of the error ė and the output Δu are firstly determined by the range of predicted actual values. These universes of discourse can be adjusted on the basis of the controller performance by the scaling factors as shown in Fig. 2(a).

Particularly, the triangle membership functions of all the three signals have no overlap in order to simplify the controller. The membership functions should not be set to zero at the neighborhood of original to preclude output dead zone.

The parameters of the membership function should be slightly adjusted in order to improve the controller’s performance. To fulfill the control objective that the measurement value ωt track the optimal reference rotor speed ωtopt , the following fifty-six fuzzy inference rules are adopted as illustrated in Table 2. In this fuzzy logic controller, the inference method used is minimum and the defuzzication used is based on the center of gravity method.

TABLE-2: FUZZY RULES

$\dot{e}$ \ e	NB	NM	NS	NO	PO	PS	PM	PB
NB	PB	PB	PM	PM	PM	PS	ZO	ZO
NM	PB	PB	PM	PM	PM	PS	ZO	ZO
NS	PB	PB	PM	PS	PS	ZO	NM	NM
ZO	PB	PB	PM	ZO	ZO	NM	NB	NB
PS	PM	PM	ZO	NS	NS	NM	NB	HH
PM	ZO	ZO	NS	NM	NM	NM	NB	NB
PB	ZO	ZO	NS	NM	NM	NM	NB	NB

The fuzzy editor system and the surface viewer is shown in the figure3 and 4.

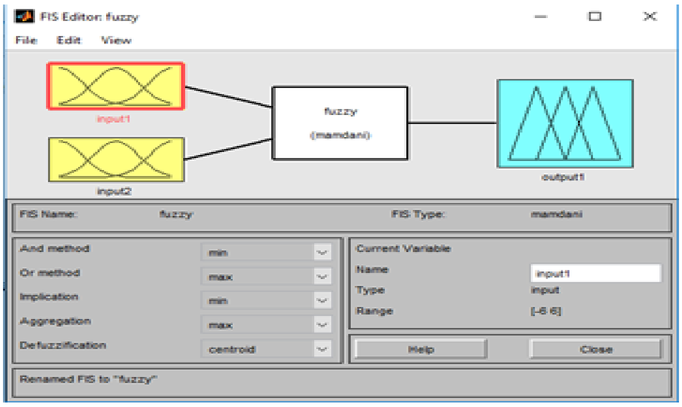

Fig3- FIS editor system

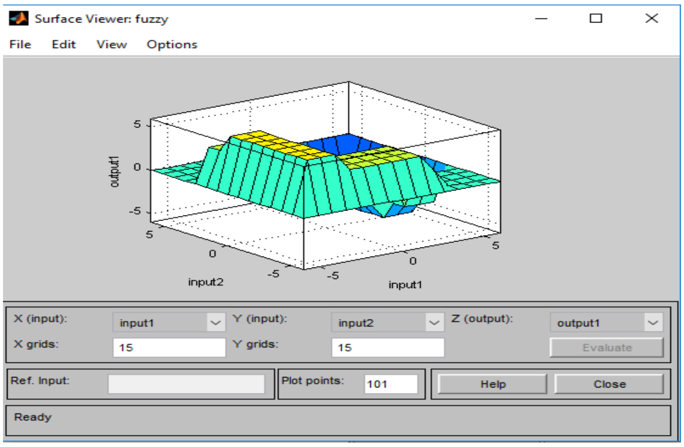

Fig4-Surface viewer of fuzzy system

4.2 Advantages of fuzzy logic controllers

1. FLC controllers do not need an accurate mathematical model it can work with imprecise inputs.
2.More robust.
3.Faster adjustment time.
4. High adaptability of fuzzy controller to nonlinear system.
5. The steady-state error of fuzzy logic control is minor.

5. SIMULNK DIAGRAM

Simulink model For Wind Turbine Using Fuzzy Logic Controller Is Shown Below:

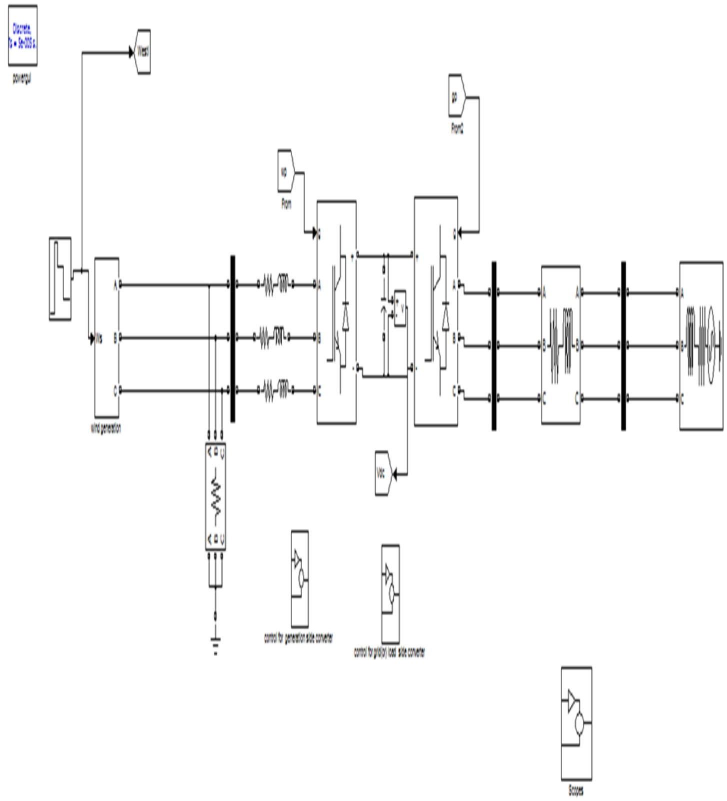

Fig4-Wind turbine using FLC

6. RESULTS:

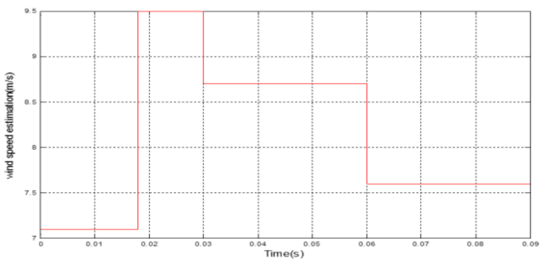

Fig5- Wind Speed Estimation Of FLC Control

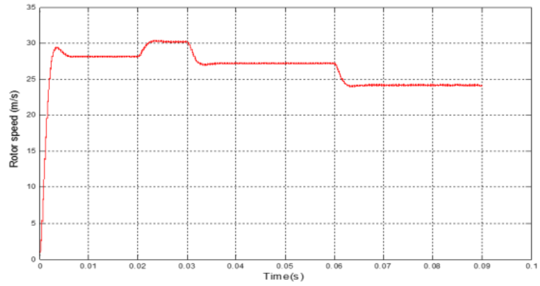

Fig6- Optimal Rotor Speed Tracking Of FLC Control

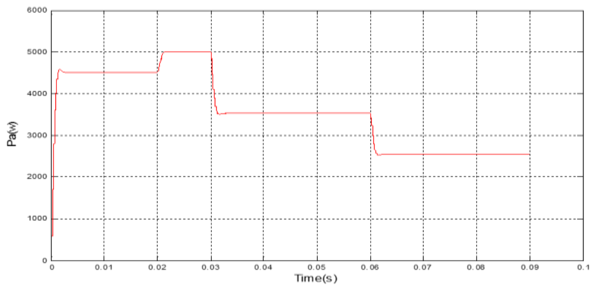

Fig7- Turbine Power Capture Of FLC Controller

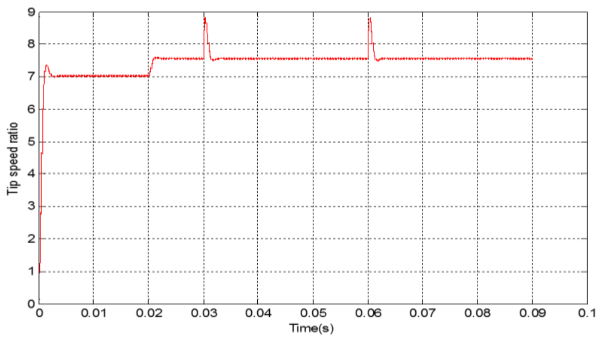

Fig8- Actual Tip Speed Ratio Of FLC Controller

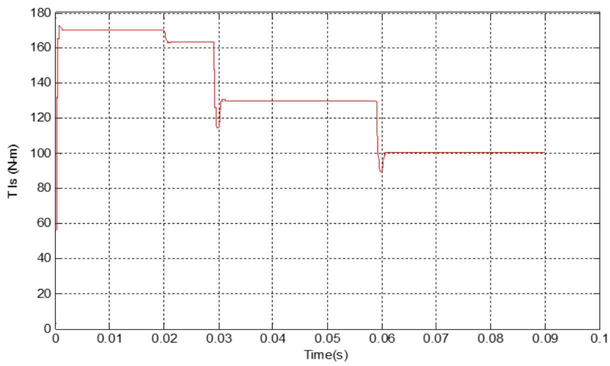

Fig9- Low Speed Shaft Torque Of FLC Controller

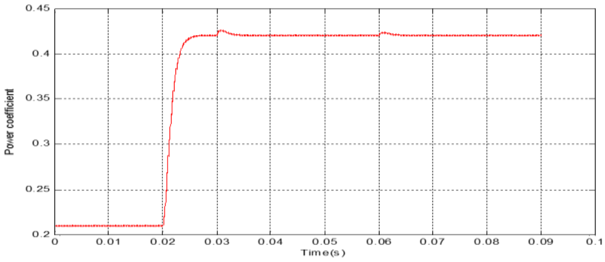

Fig10- Actual Power Coefficient Of FLC Control

CONCLUSION

This paper has proposed a fuzzy logic controller for maximum wind power extraction based on a two-mass model. The value of wind speed has been estimated from the available variables, i.e. the generator speed and turbine torque using three numerical algorithms. The estimated value has been used for sensor-less control design based on fuzzy logic algorithm. The effectiveness and superiority of the proposed estimation and control approaches have been demonstrated by simulation results, as compared to PI controller with its gains well-tuned.

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