



IMPLEMENTING FUZZY CONTROLLER FOR WIND TURBINE CONTROL FOR ALL WIND SPEEDS --WITH REDUCED FUZZY RULE SET

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ABSTRACT

To extract maximum power, at below rated speed of wind, the speed of the generator rotor is adjusted for maximum power extraction. But for higher wind speed, however the output power is monitored and controlled at rated power by pitch angle adjustments. In this paper attempt has been made to design and implement a fuzzy controller, which is applicable for both below rated wind speed region as well as above that. It is proposed and shown that how framing control rules using only the desired extremity conditions helps attaining the desired result with a reduced rule set, making it easy for further fine tuning too.

INTRODUCTION

Renewable energy is the key to future global sustainability, and many endeavors are being made to harvest renewable energy in an efficient and profitable manner. Wind energy systems being one of the simplest and cleanest forms of renewable energy conversion system lot of research has been done to increase the efficiency and controllability of the system.

The following are the major energy conversion steps for a wind turbine:

- Aerodynamic System: The wind energy is converted into kinetic energy of blades to drive the generators. **Betz's** law states that, no turbine can capture more than 16/27 (59.3%) of the kinetic energy in wind. **Betz's** coefficient is equal to 16/27 (0.593). Most of the wind turbines can achieve a peak of 75% to 80% of the **Betz limit**
- Mechanical System :The gear train assembly is used to match the turbine blade speed with that of the generator speed
- And Electrical Conversion: It is at this stage that the mechanical energy is converted into electrical form. As the frequency of the wind generated electricity thus produced is not steady, ac-dc-ac converters are used to make the power grid compatible.

In the conversion process energy is lost at every stage. The maximum energy is lost in the first stage.

Total energy thus produced by the wind conversion system is less than the total wind power flowing into the turbine blades.

The term **Power Coefficient** (C_p) is used for the ratio of actual electric **power** produced by a **wind turbine** with respect to the total **wind power** flowing into the **turbine** blades at specific **wind** speed .This term represents the overall efficiency of the entire wind power system, and can be expressed as[1]:

$$C_p = (0.44 - 0.0167\beta) \sin \left| \frac{\pi(\lambda - 3)}{15 - 0.3\beta} \right| - 0.00184(\lambda - 3)\beta \quad (1)$$

Where $\lambda = \text{Tip speed ratio} = \frac{\text{Tangential speed of the tip of a blade}}{\text{actual speed of the wind}(v)} = \frac{\omega R}{v}$



as ω is the rotor rotational speed in radians/second, and R is the rotor radius in meters and v is in meter per second thus Tip speed [2] of the blade is $=\omega R$ and β = **Blade pitch** refers to turning the angle of attack of the turbine blades into or out of the wind to control the absorption of power.

To extract maximum power, at below rated speed of wind, the speed of the generator rotor is adjusted [3] for maximum power extraction. But for higher wind speed however the output power is monitored and controlled at rated power by pitch angle adjustments. In this paper attempt has been made to design and implement a fuzzy controller, which is applicable for both below rated wind speed as well as above that. It is proposed and shown that how framing control rules using only the desired extremity conditions results attaining the desired result with reduced number of rules, making it easy for the controller fine tuning too.

From equation 1, it can be inferred that for higher value of C_p i.e higher energy conversion ratio, value of β should be small for a given value of λ .

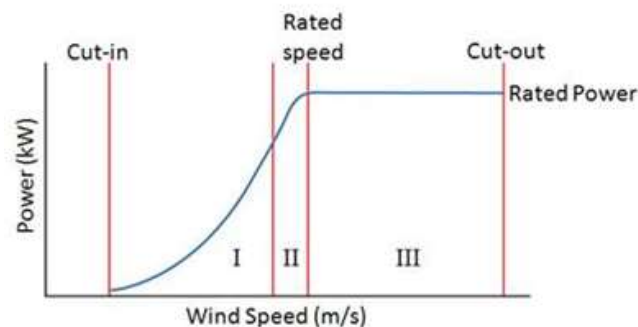


Fig 1. Typical power versus wind speed characteristics of a wind turbine

The optimum tip speed ratio for maximum power extraction from the wind striking its blades depends on the configuration as well as the number of blades of the given turbine. Fewer the number of blades higher should be the optimum tip speed ratio.

To extract maximum power, at below rated speed of wind, the speed of the generator rotor is adjusted to obtain the optimal tip speed ratio. When wind speed is very low, pitch angle is kept very small generally 3° . But for higher wind speed however the power is monitored and controlled at rated power by pitch angle adjustments.

Both for below rated and above rated wind speed region, the fuzzy logic rule base follow the same logic. Based on experiences fuzzy relations are built through fuzzy reasoning and decision.

FUZZY LOGIC CONTROLLER SIMULATION

From control point of view the two important factors of wind turbine energy transfer system are the generator speed for below rated wind speed region and the pitch control system for above rated wind speed region. Two dimensional fuzzy controller with error and rate of error as inputs are implemented. For below rated wind speed, input error is generator speed error and the output is control signal for controlling generator speed [4]. Above rated wind speed region, for input error monitoring of power is done and the output is controlling signal for the pitch angle.

Control rules are written using expert knowledge accumulated through experience. Advantage of fuzzy controller is that one does not require the exact mathematical model of the system. Fuzzy conditional statements are formed using fuzzy control rules. In this paper attempt has been made to implement the fuzzy controller using minimum rule base. For implementing it one requires to identify only the extremity conditions.



For example : if the error magnitude is too high in negative(NB) direction and also the rate of change of error value in negative direction is too sharp(NB), the rotor's stator voltage has to be increased too rapidly(PB) to counteract this effect .

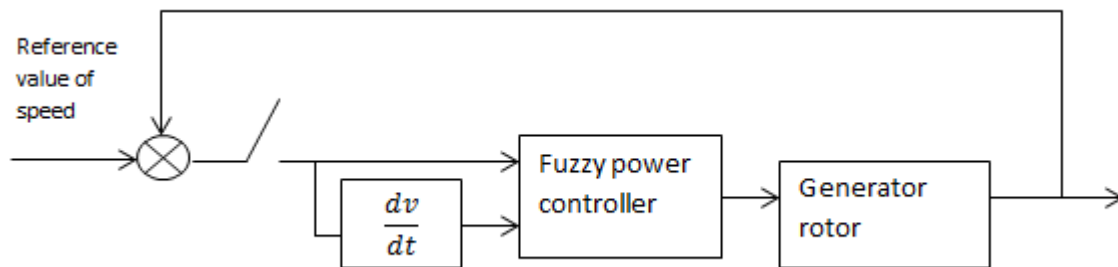


Fig 2. Block diagram of control system for low wind speed

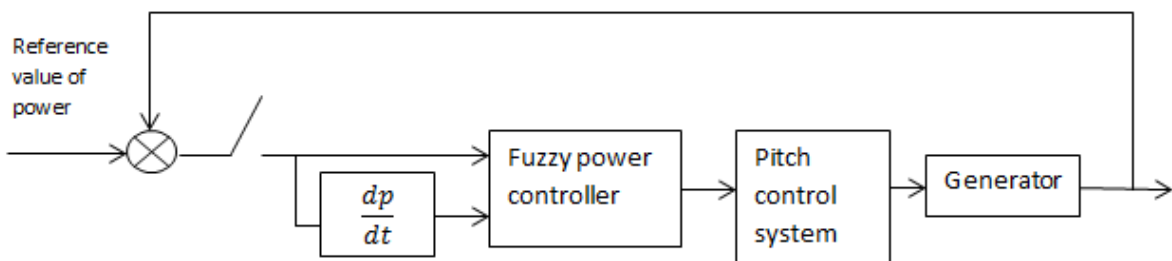


Fig 3. Block diagram of control system for higher than the rated wind speed

Using the extremity conditions following set of rule base are written

1. If (error is NB) or (rate of change of error is NB) then (output is PB)
2. If (error is NM) or (rate of change of error is NM) then (output is PM)
3. If (error is Z) and (rate of change of error is Z) then (output is Z)
4. If (error is PM) or (rate of change of error is PM) then (output is NM)
5. If (error is PB) or (rate of change of error is PB) then (output is NB)
6. If (error is NB) and (rate of change of error is PB) then (output is Z)
7. If (error is PB) and (rate of change of error is NB) then (output is Z)

Where all parameter values are normalized in the range of -1 to 1, and PB signifies positive big, PM positive medium, Z stands for zero, NM negative medium and NB negative big

EXPERIMENTAL SIMULATION

The control system was implemented using Gaussian membership function.
Membership function plot

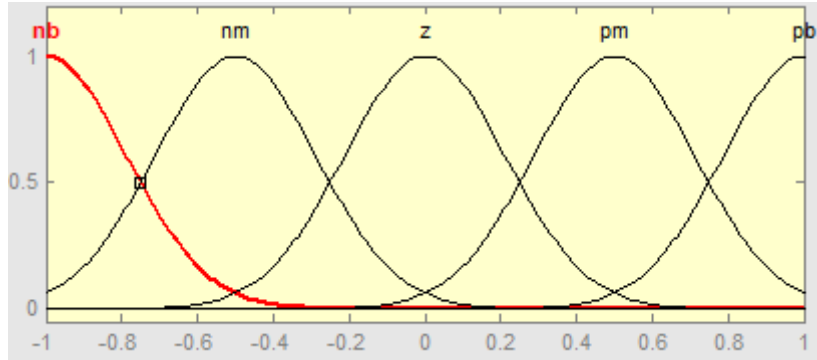


Fig 4. The Membership function of error and rate of change of error

Under different wind speed, simulation result shows the output power as below:

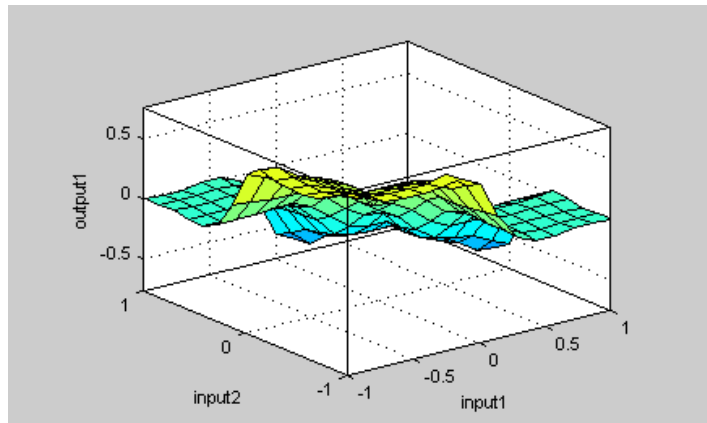


Fig 5. The surface view of control rule

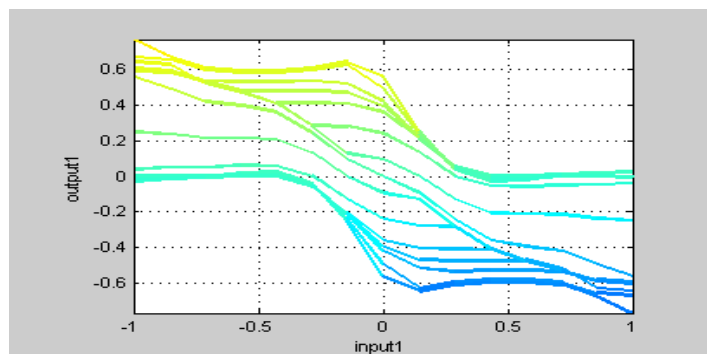


Fig 6. Error versus Output plots

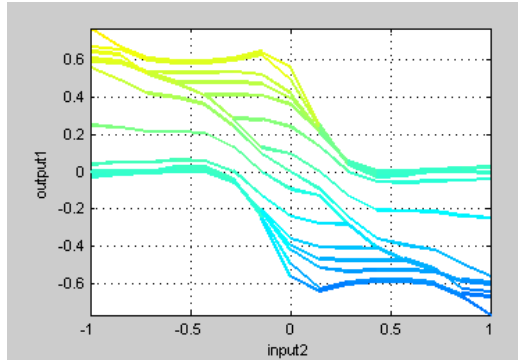


Fig 7. Rate of change of error versus Output plots

Modifying the rules a bit i.e rule number 2 and 4 as follows:

- 2. If (error is NM) or (rate of change of error is NM) then (output is 0.5 PM)
- 4. If (error is PM) or (rate of change of error is PM) then (output is 0.5 NM)

Following improved results are obtained:

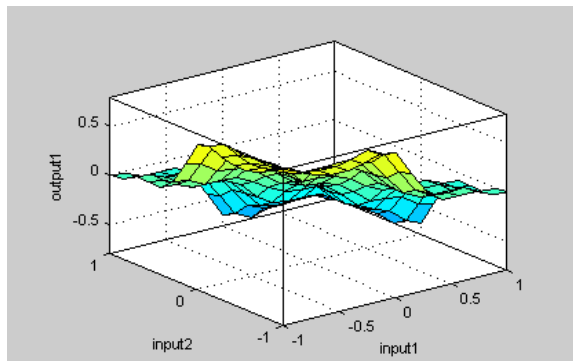


Fig 8.The surface view of control rule

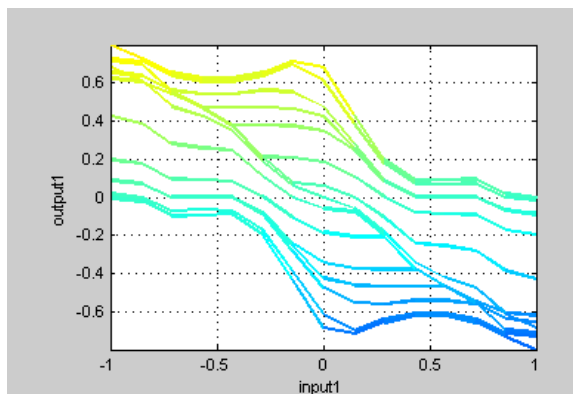


Fig 9. Error versus Output plots

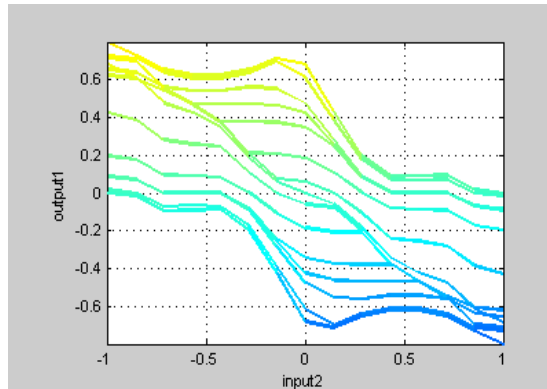


Fig 10. Rate of change of error verses Output plots

RESULT AND CONCLUSION

The plots for error verses output as well as plot for rate of change of error verses output , shows that the desired control action could be implemented using lesser number of rules considering only the extremity cases., thus making it easy for it's fine tuning too.

As the membership function selected for each input variable was five, the total number of fuzzy control rules forming the rule matrix to be written are $(5 \times 5 = 25)$ twenty five. At times it becomes difficult to decide the output variable value for each input parameter combination. As seen from figure 5 and 6, the output variation could be satisfactorily implemented using extremity conditions, using lesser number of rules.

FUTURE SCOPE

This method can be tested for different membership functions and the result compared for further improvement of the control strategy

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