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# Optimal Control of Variable Speed Wind Turbines Using Adaptive Fuzzy Controller

**Vidya G H[1], Ashok Kusagur[2]**

[1]Visvesvaraya Technological University, University of BDT College of Engineering, Dental College Road, Davanagere-577004, India

[21]Visvesvaraya Technological University, University of BDT College of Engineering, Dental College Road, Davanagere-577004, India

**Abstract:** ***In order to maximize energy capturing in wind turbines, the wind turbine generator needs to tune the speed of the wind turbine according to the wind. Conventional controllers have low efficiency to obtain the better dynamic quality and robustness. In this paper, an adaptive fuzzy controller on the variable speed wind turbines was proposed and it was compared with PID and Fuzzy controllers. The use of adaptive fuzzy controller causes the system does not have any steady-state error at all moments of time, the response rate is better than PID and fuzzy controller as obtained from the simulated results in Matlab/Simulink .***

**Keywords:** Variable speed wind turbines, Fuzzy controller, Blade Pitch control, PID controller, Adaptive controller.

## 1. Introduction

As energy demands around the world increased, the need for a renewable energy sources that will not harm the environment was also been increased. Wind energy is the fastest-growing renewable energy source. Compared however with fossil fuel based power systems, wind energy is considered to be a low power quality unreliable source with low conversion efficiency. Therefore, the main goal is to develop effective and efficient renewable energy systems and to achieve minimization of the cost and maintenance of the corresponding installation at the same time.

According to the forecasts, it is expected that by 2050 global demand for energy grows up to 3 times. At least 15 to 20 percent of global energy demand will be met directly by new and renewable energy sources [1]. In the year 2011, compared to the end of 2009, the rapid growth of 50.532% can be seen in the volume of energy intake (MW) of wind turbines in the world that the current leaders of the movement are advanced industrial countries [2]. In principle, a wind energy conversion system (WECS) is a physical system that has three primary components. The first one is rotor connected to blades. As wind goes through blades, it makes the rotor rotate and therefore creates mechanical power. The second one is a transmission that transfer power from the rotor to generator. The last one is electric generator that converts mechanical power to electric power.

The variable-speed, variable-pitch wind turbine systems typically have two operating regions according to the wind speed. In the partial-load region where the wind speed is lower than the rated-wind speed, the turbine speed is controlled at the optimal value so that the maximum energy is extracted from the wind turbine. In the full-load region where the wind speed exceeds its rated value, the generator output power is limited at the rated value by controlling the pitch angle since the capacity of the generator and converter are limited . On the contrary, the pitch regulation can be used for output power smoothening at the partial-load region. One of the factors which cause tensions and amortization in wind turbines is fluctuations and high overshoot. Because the axis of the wind turbine generator is coupled with the generator shaft, the speed fluctuations will transfer to the generator so the amortization of generator and wind turbine will increase. For this reason, preventive care and maintenance for the turbines increases. Due to the high cost of wind turbines and setting up them in difficult access regions, such a large depreciation will involve high costs, which shows the importance of the speed control of wind turbines. If you do not control the wind turbine fluctuations, fluctuations in electrical frequency can be seen in the induction generators, so with less money, the speed of the wind turbine can be controlled to a large extent.

## 2. Variable Pitch Wind Turbine Model

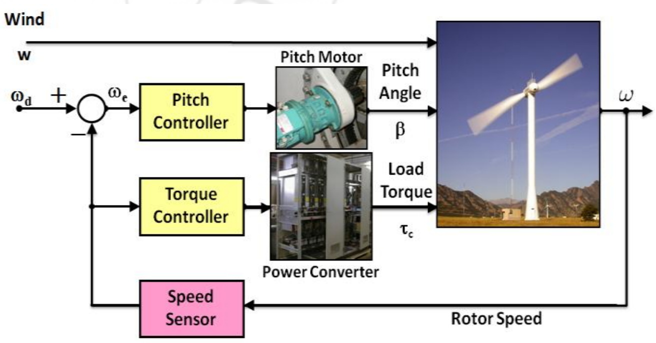


**Figure 1:** Basic Control loops of wind turbine

The main dynamics of the variable speed wind turbine are obtained by the following mathematical model:

$$J_t\omega_t = T_w - T_m \quad (1)$$

$$J_t = \rho_a \bullet I \quad (2)$$

Where $J_t$ is the moment of inertia of the turbine rotor , I is the moment of inertia, $\rho_a$ is regional density of the rotor axis, which obtained by multiplying the length in the bulk density Wt is Angular velocity of turbine axis, Tm is the necessary mechanical torque to turn the generator, and it is obtained by the equation:

$$T_m = \frac{\rho ARC_T V_W^2}{2} \quad (3)$$

Where ρ is air density, A is the area swept by the blades and CT is torque coefficient, which obtained by the following equation CT = Cp / λ where λ is the ratio of the velocity of at the tip of the blades and it is the ratio of the angular velocity of the rotor to the linear wind speed at the tip of the blades.

The wind turbine is determined by the power coefficient curve (Cp) as a function of the speed of the blade tip λ and pitch angle (β or θ). The output power of the turbine is given by the following equation

$$P_m = C_P(\lambda, \beta)\frac{\rho A}{2}V^3 wind \quad (4)$$

Pm =Mechanical output power of the turbine (W)
Cp=Performance coefficient of the turbine
ρ=Air density (kg/m3), A=Turbine swept area (m2), Vwind=Wind speed (m/s)
λ=Tip speed ratio of the rotor blade
β=Blade pitch angle (deg)

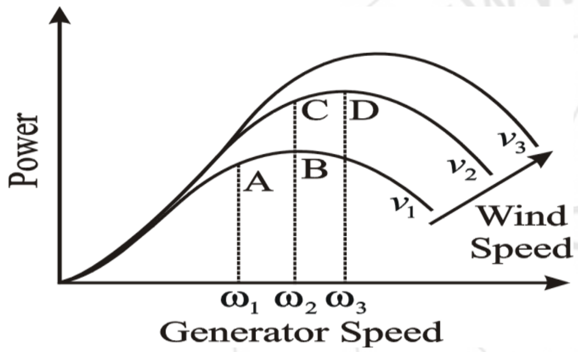


**Figure 2:** Power curves for wind turbines

### 2.1 Pitch control in wind turbines

The pitch function gives full control over the mechanical power and the most common method is used for the variable speed wind turbines. At wind speeds below the rated power of the generator, the pitch angle is at its maximum though it can be lower to help the turbine accelerate faster. Above the rated wind speed, the pitch angle is controlled to keep the generator power at rated power by reducing the angle of blades. Normally, pitch control is used to limit the aerodynamic power captured from the wind. In low wind speeds, the wind turbine should simply try to produce as much power as possible, so there is no need to pitch the blades. For wind speeds above the rated value, the pitch control scheme is responsible for limiting the output power. Normally blade pitch setting should be adjusted to 5 to 10 deg depending upon the wind speed and the design of turbines. Primarily pitch will be at 0 deg, then 45 deg is maximum point, the 90 deg is the pitch rate when turbine stops.

## 3. Simulation of Linear Model of Wind Turbine Using PID & Adaptive Fuzzy Controllers

### 3.1 PID Controller

PID control strategies are used to maximize the efficiency of wind energy conversion based on the control of power electronic circuits. Particularly, in thyristor rectifier controlled by the firing angle alpha is placed between the wind generator and a resistive load. The controller is an integrator that simply calculates the integration of the error between the reference maximum power, which is derived according to the wind rotor angular speed changes and the actual output power which is measured from the load voltage and current

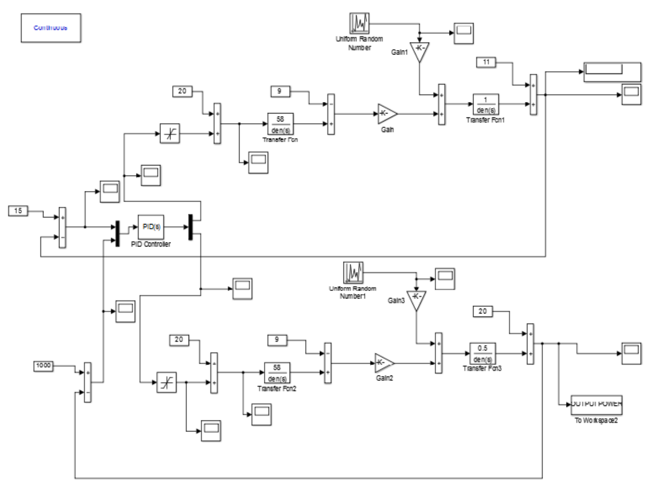

**Figure 3:** Block diagram of PID controller in Matlab

### 3.2 Adaptive Fuzzy logic controller

Fuzzy logic control is one of the most powerful control methods based on fuzzy set theory and associated techniques. The fuzzy logic algorithm is suitable for wind turbine control with complex nonlinear models and parameters variation. Basic structure of the fuzzy logic controller consists of three important stages: Fuzzification, Decision Making Unit and Defuzzification Unit. The inputs of the Fuzzification are selected as error and rate of change of error and the output is the pitch angle reference. Two variables were defined as fuzzy input: error and error change. The output of the fuzzy controller is output1.The universe of inputs and outputs are partitioned into 3 fuzzy sets,N(negative),Z(zero),P(positive).The Mamdani is used as rule base and fuzzy inference system. Defuzzification method is centroid,here set of nine rules are written . First, input are fuzzified using input membership functions, then based on rule bases and inference system ,outputs are produced and finally the fuzzy outputs are defuzzified and applied to the main control system.

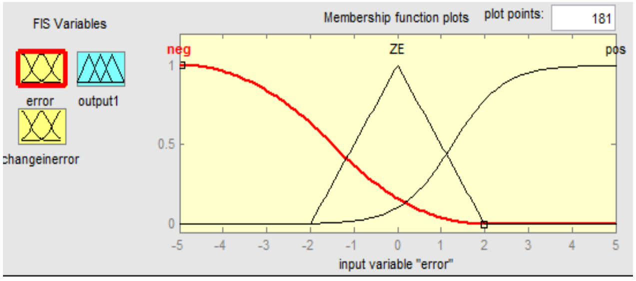


**Figure 4:** Membership function editor window

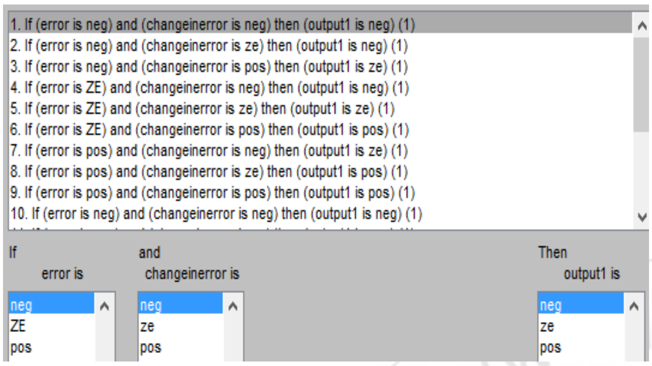


**Figure 5:** Rules in rule editor window

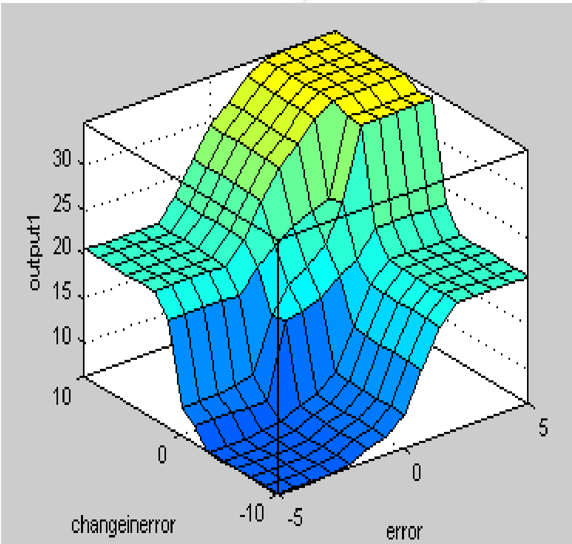


**Figure 6:** surface viewer in FIS Editor

Basically, fuzzy systems are knowledge-based systems and the heart of a fuzzy system is a knowledge base that is made up of if-then fuzzy rules. Adaptive fuzzy controller is a stochastic global search method that capable of locating high performance areas in complex domains without experiencing the difficulties associated with high dimensionality.

The traditional PID controller is determining online in various operating conditions, then the control signal is calculated and applied to the system. Considering the different working conditions, the control signal is calculated directly based on knowledge-based fuzzy inference engine and applied to the system.

Coefficients of PID controllers are adjusted at the beginning of the process and they are fixed during it. In systems with variable dynamics, constant coefficients do not lead to satisfactory results so the comparative method is necessary to adjust the controller's coefficients. The fuzzy controller is a right choice to adjust the online PID. In fuzzy adaptive controller, the creation of the fuzzy controller is online, in other words, simultaneously with the operation of the system, the fuzzy controller is modified so that optimal control process goes.

Adaptive fuzzy control theory was applied to wind turbine pitch control, through the stator voltage control at low speed and the blade pitch angle control at high speed the generators works in the best condition. By comparison with the traditional controller this method can accelerate system response speed, improve the accuracy and improve variable pitch wind turbine control effect.

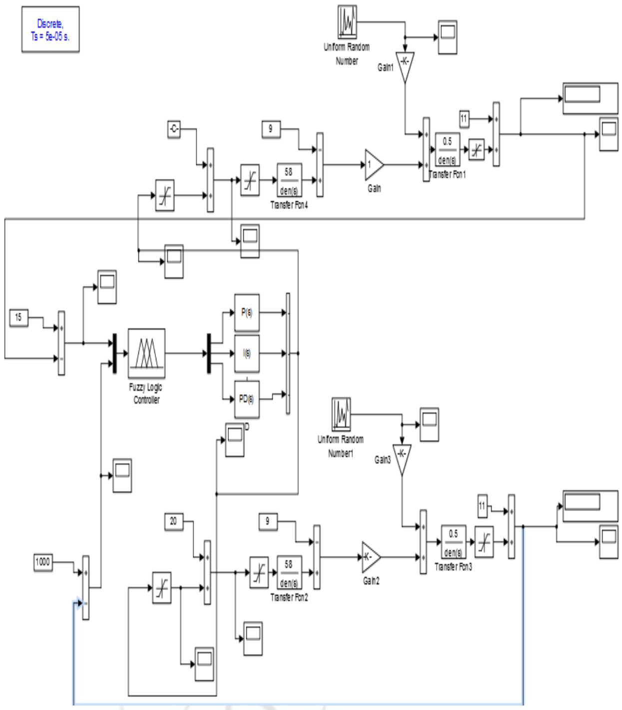

**Figure 7:** Block diagram of Adaptive fuzzy controller in Matlab

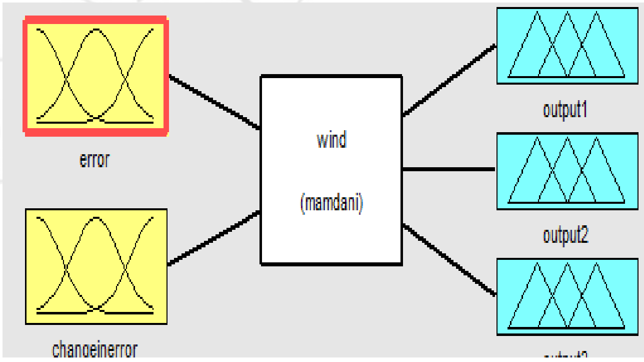


**Figure 8:** Simulink block diagram of adaptive fuzzy controller

Number citations consecutively in square brackets [1]. The sentence punctuation follows the brackets [2]. Multiple references [2], [3] are each numbered with separate brackets [1]–[3]. Please note that the references at the end of this document are in the preferred referencing style. Please ensure that the provided references are complete with all the details and also cited inside the manuscript (example: page numbers, year of publication, publisher's name etc.).

## 4. Results and Discussion

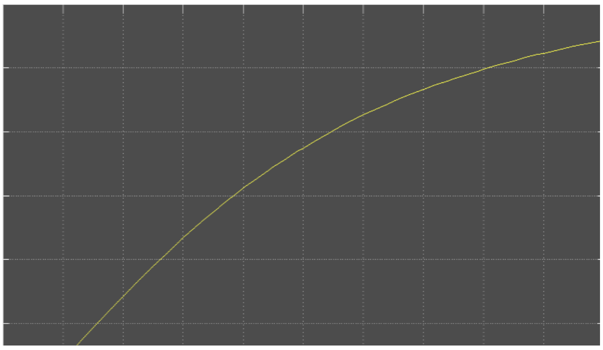

**Figure 9:** Plot of Rotor speed v/s time of PID

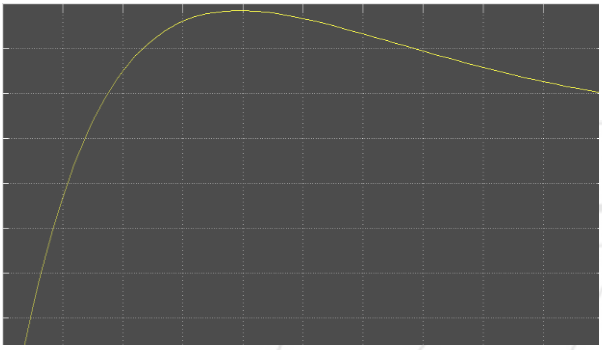

**Figure 10:** Plot of Output power v/s time of PID

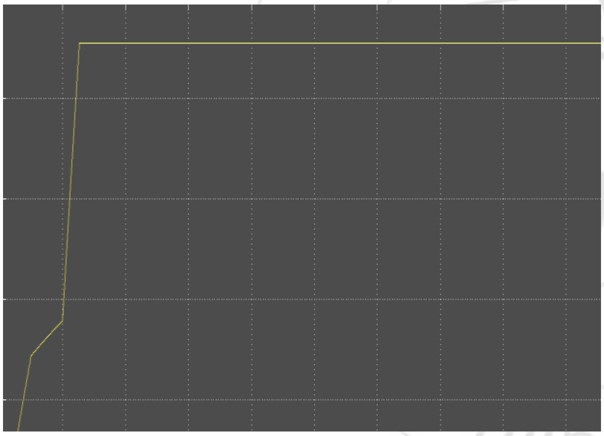

**Figure 11:** Rotor speed v/s time Adaptive fuzzy controller

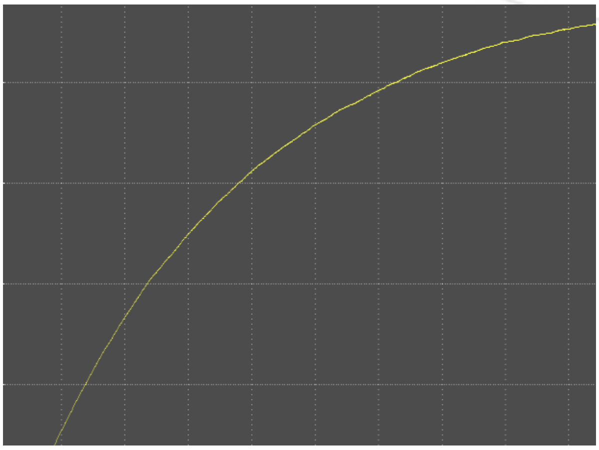

**Figure 12:** Rotor speed v/s time Adaptive fuzzy controller

As specified in the figure, the use of PID controller will be led to high overshoot in speed and also fluctuations are observed around the stable speed. The fuzzy controller is used to control the speed and power of the wind turbine. The advantage of this controller is the absence of overshoot in speed curve, power and reducing the fluctuation range after reaching steady state. Compared to the PID controller, the settling time is a little more and fuzzy adaptive PID controller provides good performance and effective response for the system. The use of fuzzy adaptive PID controller causes that the system does not have any steady-state error and in all the time of speed, the response is better than PID and fuzzy controllers.

## 5. Conclusion

In this paper, Adaptive fuzzy control theory was applied to wind turbine pitch control, and compared with the traditional controllers, so that this method can accelerate system response speed, improve the accuracy and improve variable pitch wind turbine control effect. Fuzzy and Adaptive fuzzy PID controllers have a less overshoot compared to the PID controller and also fluctuations in wind turbine rotor speed in them is less than PID controller. In the adaptive fuzzy PID controller compared to the PID and fuzzy controllers, the settling and rise time is less so better response in transient and stable state and also a good and effective performance for system response will be provided

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