Interval Type-2 Fuzzy Pitch Angle Controllers (IT2FPACs) for Small Scale Horizontal Axis Wind Turbines

Ali Musyafa', Dwi Aftika, Bambang L. Widjiantoro

***Abstract*— Wind energy is one of the renewable energy sources need to be explored and developed. Wind speed varied wind turbine rotational speed resulted in ever-changing. Production of electricity generated depends on the position angle of the wind turbine blade. To ensure the power production of wind turbines, wind turbine blade position is controlled by Interval Type II Fuzzy Controllers. The results of the controlled system in the form of a round shaft turbine able to work at its optimum. The test results showed that at set point control system 10 pulse per second (pps), has a maximum overshot time 50 %, error steady state (ess), 16.3 %; set point 20 pps, have a maximum overshoot time 35 %, error steady-state 12.65 %; set point 30 pps, have a maximum overshoot time 26.7 %, error steady state 10.4 % and set point 40 pps. Have a maximum overshoot time 12.5 %, error steady state 5 %. The best system response is the response of wind turbine pitch angle controller with set point 40 pps, it has the smallest overshoot and minimum error steady state.**

***Index Term*— Blade, Pitch angle, Wind Turbine, Interval Type-II Fuzzy Controllers.**

I. Introduction

Indonesia is an archipelago country with a long coastline fourth largest in the world with a length of 95 181 km. Sumer Indonesian coast has the potential of wind power is great . But the fact that a large wind energy potential has not been exploited into a useful source of alternative energy. Wind energy potential in Indonesia is 73 GW with optimum installed capacity of 25 MW, while the installation currently installed approximately 0.6 MW. The low utilization of wind energy in Indonesia, also have an impact on developing the company's wind turbine technology in Indonesia.

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Indicators limitations of wind turbine technology development in Indonesia can be seen in the use of the conventional wind turbine without any means of control mode. Turbine rotational speed is too low will affect the rotation generator produced so it cannot work optimally. However, the wind speed is too tight will result in the working range of the turbine exceeds the threshold round job, resulting in employment exceeds the capacity of the generator so that the effect on the age of the generator.

In this research paper is designed Blade Wind Turbine Pitch Angle Control Fuzzy Logic Based Interval Type II ". It is expected to be able to optimize the work of the wind turbine receives wind speed variations. This control system has been used to control the tilt angle of the blade (pitch angle). By Changing the angle of the blade it will significantly alter the aerodynamics of the blade. The aerodynamic changes then will change the change amount of wind power that is captured [1].

Fuzzy logic Control Type II (FLC-type II) method is an improvement of the method of fuzzy type 1. Fuzzy membership function in type 1 is very simple, so that the membership functions IT2FPACs corrected by giving a certain interval. Expected to make use of this control mode can result in optimization of wind turbine blade pitch angle for each variation of wind velocity received. Issues to be raised in this research journals is how design Angle Blade Wind Turbine Pitch Angle Control Fuzzy Logic Based Interval Type II , thus providing optimal results in the rotation of wind turbine blade [2].

II. Materials and Methods

Wind turbines with electrical and mechanical configurations will produce different power different, but the theory of aerodynamic blade remains the same [4-5]. Wind has kinetic energy because it contains the mass and velocity. Wind turbines capture the kinetic energy and turn it into energy rotor rotation.

Figure 1 is described as a water foil exposed to the wind from the front W, it will produce a lift force vector (FL) and drag (FD) with a resultant (FT). Style lift and the drag force changes directly by the shape of the blade geometry, wind speed and direction to the main line of the blade. As a result of changes in the lift and drag force, the angular velocity and torque shaft will change as well [3-6].

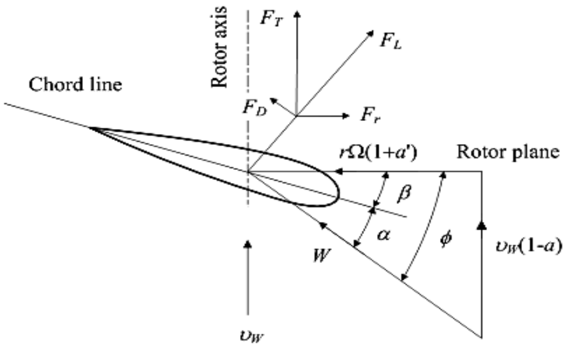

Fig 1. Vector force on the turbine blade [1]

Tilt angle control system is one of the mechanisms that control the wind turbine works by controlling the aerodynamics of the blade through the blade to control the tilt angle of the wind direction (angle of attack) as shown in Figure 1. [1] Changes the blade angle will affect the angular velocity (RPM) of the shaft due to changes in the amount of power received by the blast of wind blades that are converted to shaft rotational speed. Mechanical power that can be generated at the wind turbine wind speed v, windswept cross-sectional area A satisfies the equation.

$$P = \frac{1}{2} \rho_{air} \, C_p(\lambda,\theta) \, A_r \, V_w^3 \qquad (1)$$

In actual conditions depends on the density of air humidity and air temperature. Mechanical efficiency depends on the power coefficient. Wind turbine power coefficient is a function of tip speed ratio and tilt angle. Tip speed ratio (TSR) is defined as the ratio of the linear speed of the rotor and the wind speed, the angular speed of the blade is then TSR is defined [1]

$$\lambda = \frac{\omega}{v} R \qquad (2)$$

By substitution into equation 2 obtained persamaan1 power wind turbines

$$P_{turbine} = \frac{1}{2} \, C_p(\lambda,\theta) \, \rho_{air} \, A_r \, V_w^3 \qquad (3)$$

In theory, the value Cp will never be greater than 59.3% [6]. This was stated by Albert Betz, a German physicist. The theory is known as the Betz Limit. At this time, modern wind turbines have a value that ranges between 35-45%. Type 2 Fuzzy Logic Fuzzy Logic is a development of type 1. At type - 1 fuzzy logic knowledge base is often used to build the uncertain rules. There are three reasons why uncertainty rules can occur namely:

The word is used as the antecedents and consequents of rules can have different meanings to different people.

- Consequents obtained from polling a group of experts will often differ on the same rule because the experts do not necessarily all agree on the rules.
- Training data that contain a lot of noise. [4]
- Fuzzy logic membership function type 1 cannot directly handle rule uncertainties. Antecedent or consequent membership functions Fuzzy Logic type 2 is capable of handling uncertainty rules.

The concept of uncertainty of the type - 2 fuzzy sets was introduced by Zadeh, the development of the concept of ordinary fuzzy sets. Levels in type - 2 fuzzy set can be a subset of membership in the primary, secondary and membership in the subset. Same with type 1 Fuzzy Logic, Fuzzy Logic type 2 also includes membership faction, Fuzzy Inference System, and defuzzyfication [3].

Membership Function, Interval type-2 fuzzy logic has similarities with type-1 fuzzy logic is the fusilier, rule base, inference engine, and output processor. Output processor, including the type reducer and defuzzifier produces output fuzzy sets of type-1 or a number. But the difference lies in the process of finding the centric of interval type-2 fuzzy sets made by Upper Membership Function (UMF) and Lower Membership Function (LMF). Membership functions in an interval type 2 fuzzy logic is set as the region called the Uncertainty Footprint which is limited to 2 type 1 fuzzy logic membership functions UMF and LMF. Membership function fuzzy logic type II can be seen in Fig. 2.

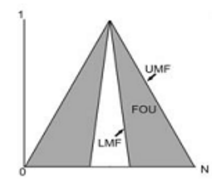

Fig 2. Footprint of Certainty [3]

Operations on Interval Type-2 Fuzzy sets is similar to the Type-1 Fuzzy sets, only on Interval Type-2 Fuzzy System, the operation is performed on the two intervals, above (UMF) and lower (LMF) at once. Operations on type-2 membership function can be seen in Figure 3.

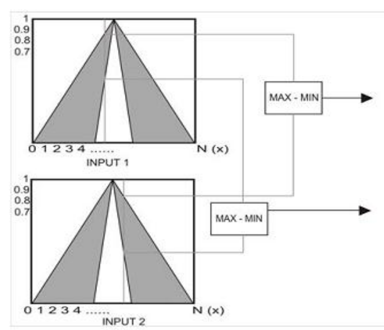

Fig 3. Operations on Type-2 Membership Function [3]

Fuzzy Interference System, Fuzzy Inference System in Type-2 is similar to the Fuzzy Inference System in Type-1, using the same steps. Fuzzy Operating System Inference can be seen in Figure 4.

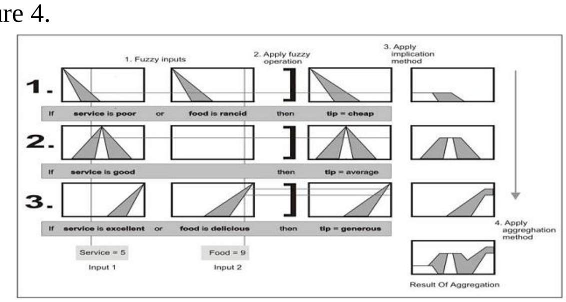

Fig 4. Fuzzy Inference in Type-2 System [3]

III. Results and Discussion

Design of Blade Pitch Angle Control Prototype Wind Turbine using Type II Fuzzy Logic Control referred on turbines have a diameter = 200 cm and has 3 main blades. Turbines are designed Horizontal Axis Wind Turbine. The wind turbine will be equipped with a speed sensor Rotary Encoder integrated with ATMEGA 16 as an indicator of the speed of the wind turbine. The wind turbine has a weight of 1297 grams for each blade. As the actuator servo motor driving the blade used with a maximum torque of 6 kg.cm.

Design of Control Algorithm using Fuzzy Interval Type 2; the algorithm prepared using type 2 fuzzy interval logic. Logic that there would be compiled in C language so that it can be used in microcontroller ATEMEGA 16. Algorithm is designed to have two membership functions of input and output membership functions of type 1 Takagi Sugeno. The membership functions for each input and output, as shown in Figure 5-6.

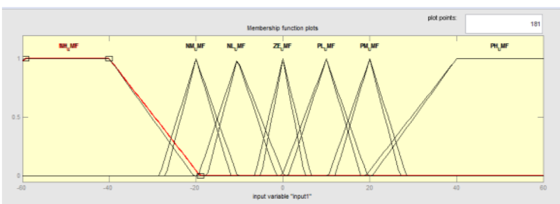

Fig 5. Input of membership function error

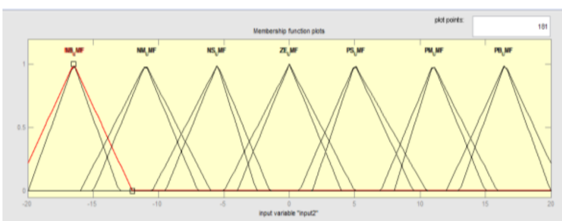

Fig 6. Input of membership function delta error

Fig 7. Membership function of output system

Based on computational software used, method of Takagi-Sugeno with a constant output value does not consider the form of input membership functions. However, only the limitations which are used. System comparison of two input used is the maximum. If the input data is located at the intersection of the retrieved value is the maximum value, so that the boundary region is the intersection of two intersecting straight line function. [5]

Limitation of input error,
NH_UMF: [-102.5 -60 -40 -19]
NH_LMF: [-103 -59.7 -40 -20.5]
NM_UMF: [-28.5 -20 -10.5]
NM_LMF: [-27 -20 -12]
NL_UMF: [-19.5 -10.5 0.25]
NL_LMF : [-17.5 -10.5 -1.5]
ZE_UMF : [-6.5 0 6.5]
ZE_LMF : [-5 -0 5]
PL_UMF : [-0.25 10 19.5]
PL_LMF : [1.25 10 18]
PM_UMF: [10.5 20 28.5]
PM_LMF: [12 20 27]
PH_UMF: [19 40 60 109]
PH_LMF : [20.5 40 60 109]

Limitation of input delta error,
NB_UMF: [-21 -16.5 -12]
NB_LMF: [-20 -16.5 -13]
NM_UMF: [-16 -11 -6]
NM_LMF: [-15 -11 -7]
NS_UMF: [-10.5 -5.5 -1.5]
NS_LMF : [-9.5 -5.5 -2.5]
ZE_UMF : [-4.98 0 4.97]
ZE_LMF : [-5 0 5]
PS_UMF : [-4 0 4]
PS_LMF : [0.75 5 10.5]
PM_UMF: [1.75 5 9.5]
PM_LMF: [7 11 15]
PB_UMF : [12 16.5 21]
PB_LMF : [13 16.5 20]
Output of pitch angle*:* 0, 5, 10, 15, 20, 25, 30, 35, 40, 45.

Limitation of membership functions are made narrower, so that the output value more accurately. However, the resulting smallest resolution is 50. At the output value range 0-50 wind turbines rotating at a low speed. However, for the output value of 10-200, the wind turbine is at its maximum speed. As for the output value of 250-450, tend to slow down the speed of the wind turbine, it is used as an action to reduce the rotational speed of the wind turbine.

The design of the rule base of the fuzzy type 2 is no different from the fuzzy rule base design usual. Rule base fuzzy logic or rules represent the relationship between the input-output. Rule base is constructed based on the data that has been retrieved previously.

TABLE I
RULE BASE OF TYPE –II FUZZY LOGIC CONTROL

DE/E	NH	NM	NL	ZE	PL	PM	PH
NB	45	45	40	15	15	15	15
NM	45	45	40	10	10	10	15
NS	40	35	20	5	10	10	10
ZE	40	35	20	5	10	10	10
PS	35	20	15	5	10	10	10
PM	30	15	10	10	5	5	5
PB	30	15	10	10	5	5	5

Control Algorithms Using Simulation Software Computing, Simulation aims to acquire the suitability of existing control logic with the characteristics of wind turbines that have been made . Simulation is also useful to avoid errors as small as possible during the process of collecting data on the actual plan. Testing was conducted to determine the control algorithm that controls functioning properly made or not. Data retrieval, the data for the parameters are taken large wind turbine blade pitch angle of wind turbine wheel, and the response to a given control plan.

The response in the form of PPS (pulse per second) when rotating wind turbine with a given amount of step-in parameters. Interface Hardware and Software; Programming the controller use the programming language that is used based language C. Thus, an algorithm that has been converted into a compiled C language, so it can be put into microcontroller. The monitoring system using Visual Basic is useful to study the response of the control system has been created. To view monitoring system that has been created, it can be seen in Figure 8. [8-9].

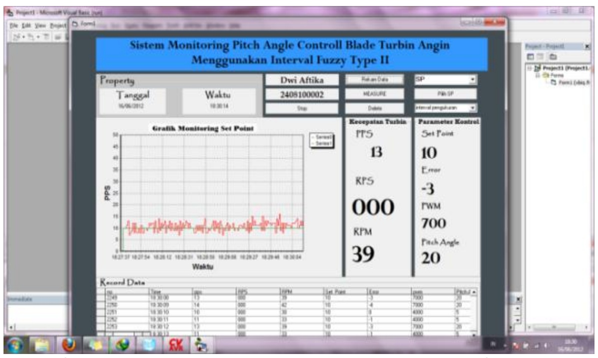

Fig 8. Interface monitoring system controls the pitch angle of the wind turbine

Qualitative Analysis Response System Wind Turbine Pitch Angle Control using Fuzzy Interval Type II The qualitative analysis is done by comparing the control parameters such as maximum overshoot and steady state error. This analysis can be known with reliability and quality control system for responding to a given set point. In figure 9 shown response time of the system is given set point 10 pps. [8-9]

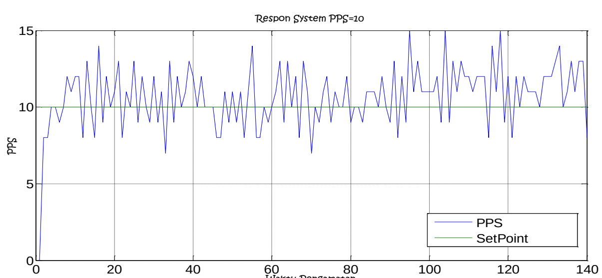

Fig 9. System response with set point = 10 pps.

When set point sytem 10 pps, the response in fluctuates between 7-15 pps. The system has a maximum overshoot of 15 pps. From the calculation of the standard deviation values obtained for the response of the system by 1.99 pps. For the value of the average system response to set point 10 for 10.84, and has a steady state error of 1.63. The quality certainly does not meet the given error tolerance if taken by 5% tolerance. Response graph drawing system shown in Figure 10. Below is the system response when given standard deviation of 20 pps.

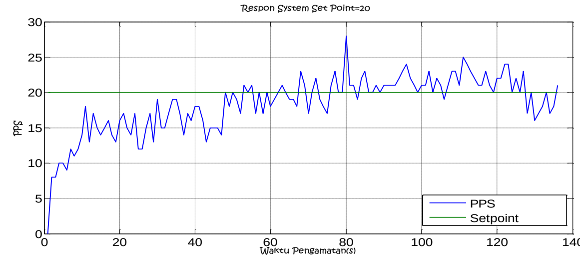

Fig 10. System response with a set point of 20 pps

When given set point of 20 pps, the response system fluctuates between 27-17 pps with a maximum overshoot of 27 pps. From the calculation of the standard deviation values obtained for the response of the system by 2.1 pps. The value of the average response time of the system for 20 steady state set point of 20.6 and has a steady state error of 2.53. From the magnitude of the resulting error, it certainly does not meet the quality of a given error tolerance if taken by 5% tolerance. As for the response of the system to the set point value of 30 pps can be seen in Figure 11.

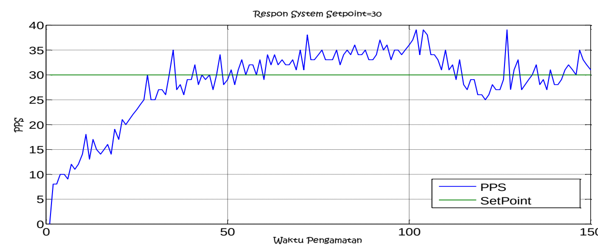

Fig 11. System response to a set point of 30 pps.

When given set point of 30 pps, the response system fluctuates between 38-27 pps with a maximum overshoot of 38 pps. From the calculation of the standard deviation values obtained for the response of the system by 3.32 pps. The value of the average response time of the system for 30 steady state set point of 31.9, and had an average steady-state error of 3.13 pps. If the terms of the magnitude of the error is generated, it certainly does not meet the quality of a given error tolerance if taken tolerance of 5% (5 % of the set point value of 1.5).

Standard deviation of the system response relationship with the average response of the system, the control system can be said to be still under the standard deviation. Thus the controller is designed using type 2 fuzzy interval algorithm has a relatively good performance to be applied because of the range of responses were in the range of standard deviations below the system response. For the highest set point value in the data retrieval is 40 pps. Response system for high- speed turns out to have a response that is relatively stable compared with the previously given set point, Fig. 12. [10].

The system has a maximum overshoot of 45 pps. From the calculation of the standard deviation values obtained for the response time of the system reached 1.83 pps. For the average value of the system's response to a set point of 41.64 pps 40 and has a steady state error of 2.0 pps. For set point 40 pps, the control system meets the steady-state error tolerance of 5% (5% of 40 pps for 2 pps).[11-12]

Similarly, when seen from the standard deviation of the system response relationship with the average response of the system, it can be said control system is still below the standard deviation. Thus for a relatively high speed in this case 40 pps.

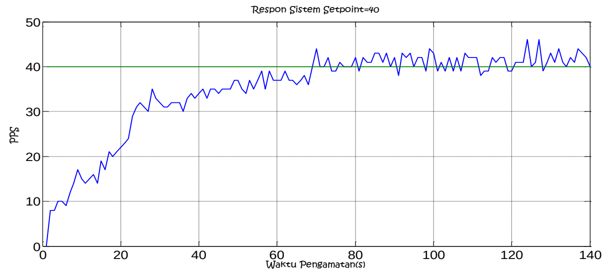

Fig 12. System response with set point = 40 pps.

Four variations of set point that has been given, the general response of the system control algorithms pitch angle of wind turbine using fuzzy type II can be seen in Table 2.

TABLE II
RESPONSE OF TYPE-II FUZZY LOGIC CONTROL

Step-in (pps)	Max. Overshoot	Settling Time (s)	Error Steady state	Std. Dev.	ITAE
10	50%	10,84	16,3%	1,99	31.460
20	35%	20,6	12,65%	2,10	58.380
30	26.7%	31,9	10,4%	3,32	105.420
40	12.5%	41.64	5%	1,83	129.780

From Table II it can be seen that the control system of wind turbine pitch angle using interval type II fuzzy stable when given the relatively high set point (30-40 pps). Testing set point tracking is done by providing a set point value between (20-30) pps. and then headed back down to 20 pps. Lass stable algorithm for sudden changes in set point. So it can be said that the time it takes the wind turbine to achieve a given set point changes are relatively long. For more details, can be seen in Figure 13.

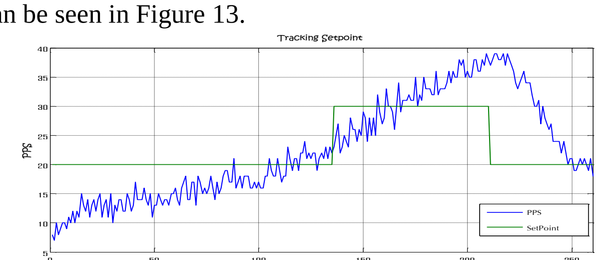

Fig 13. System response tracking set point

Figure 14. Shown that the control system of wind turbine pitch angle fuzzy type 2 is less suitable to be applied to models with type tracking control set point. That is because the longer the fuzzy algorithm is used, the longer the system (wind turbine) to adjust the given set point. The system experienced a steady wind turbine for set point 20 at t = 80 seconds. When the set point is raised to 30 pps. the wind turbine is able to adjust the set point. After reaching the desired set point 30 pps., wind turbines round raised nearly 40 pps. For set point is lowered to 20 pps. Affect pps. decrease towards the desired set point and occurs suddenly. Time to steady the set point to the required 30 to 20 pps. Towards the 50 second. The best response control system for wind turbine pitch angle. For comparison the parameters will be seen by the maximum overshoot, standard deviation, steady state error and the value of ITEA.

Steady state error control system of wind turbine pitch angle is always below 10 % for all set point. Maximum overshoot control system below 5 %. ITAE of pitch angle control system with the smallest value of interval fuzzy type II has a good response = 31460. Time Absolute Error (ITAE) counted during the observation process for t = 140s. It is used to determine the absolute number of errors the system responds to the resulting set point. [10-13]

IV. CONCLUSION

Based on qualitative analysis that has been done, at 10 pps. Set point control system has a maximum overshoot time by 50%, 16.3% steady state error; 20 pps. have a maximum set point overshoot time 35%, 12.65% steady-state error; 30 pps. have a maximum set point overshoot time 26.7%, 10.4% steady state error; whereas for 40 pps. Have a maximum set point overshoot time 12.5%, 5% steady state error. Based on quantitative analysis has been carried out, the control system at the set point 10, 20, 30, 40 pps. respectively have ITAE of 31460, 58 380, 105 420, and 129 780. Based on the response of the system provided for each set point, the control system used is suitable for the high set point value in this case 40 pps.

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