Pitch Angle Controller Design on the Wind Turbine with Permanent Magnet Synchronous Generator (PMSG) Base on Firefly Algorithms (FA)

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***Abstrak*: This paper explains about Fire fly Algorithm method (FA) as parameter tuning of Proportional Integral Derivative (PID) controller. PID is used to control wind turbine speed with pitch angle controller. FA method is used in tuning the control speed on wind turbine with Permanent Magnet Synchronous Generator (PMSG). When wind speed is low in under the average value, speed control have to be able to maintain a level speed. Then it will give maximum output, so the turbine efficiency will be rise. Pitch angle setting is required in conditions of wind speed above the desired. Little change of pitch angle can influence power output. Pitch angle control is one of the way to adapt aerodynamic torque in wind turbine when wind speed is above on speed value and some other variable controls. From the experiments of the test, the results of the running programs show that tuning the system using the method of FA obtained the most optimal power output and stable compared to the Ziegler-Nichols method and the PID Controller.**

Keyword – Firefly Algorithm, pitch angle, Wind Turbine

I. INTRODUCTION

The increase in the number of people making electrical energy requirements will increase. The electricity supply to the consumers also affects the increasing electrical load. The impact when the power supply increases so the output power is issued by the generator will also increase. If the generator output power increases, demand for fuel will increase and will result in expenses would be expensive. [1]

The power plant operating general in Indonesia dominated by plants whose primary energy comes from coal. It needs special attention and the previously anticipated, remember that coal is classified as non-renewable materials. One concern that must be done is to encourage the practitioners and academics to assess the potential of other power plant sources of renewable energy, e.g. sunlight, geothermal, or wind potential. Power wind of power plants are power plants which have the main advantage due to the nature of the material is renewable, this means the exploitation of this energy source will not make the wind resources is reduced.

This paper will be discussing wind turbine with Permanent Magnet Synchronous Generator (PMSG). PMSG is synchronic generator which has permanent magnet. This PMSG will be combined with turbine, in order that it produces electric energy. PMSG has less optimal efficiency to produce electric power. This matter is influenced from wind speed, pitch angle, etc. Therefore, turbine needs to be controlled to produce optimal electric power [1].

While the control which used is PID controller to control pitch angle. Like in the previous research about "Modeling of a Variable Speed Wind Turbine with a Permanent Magnet synchronous Generator" [2]. And another research about "Pitch Angle Controllers With Imperialist Competitive Algorithm" (ICA).[1]

This paper consists of introduction, Permanent Magnet Synchronous Generator (PMSG), wind turbine model, PID Controller Ziegler-Nichols, Firefly Algorithm (FA)

II. WIND TURBINE

To determine the mass ($\dot{m}$) flow rate in the field of the rotor, where cross section area is just wiper area from rotor (A)
Mass flow rate is as follows:

$$\dot{m} = \rho A v b \quad (1)$$

If the assumption is made that the wind speed through rotor machine just speed average upwind and downwind. So that can be written as follows:

$$P_b = \frac{1}{2} Pa \left(\frac{v+vd}{2}\right) (v^2 - vd^2) \quad (2)$$

To keep it constant simple algebra, can be defined ratio downstream to upstream, wind speed will be λ :

$$\lambda = \left(\frac{\mathrm{vd}}{\mathrm{v}}\right) \quad (3)$$

Substitutions (2) into (3) give:

$$\mathrm{P_b} = \frac{1}{2} \rho \mathrm{A} \left(\frac{\mathrm{v} + \lambda \mathrm{v}}{2}\right) (\mathrm{v}^2 - \lambda^2 \mathrm{v}^2)$$
$$= \frac{1}{2} \rho \mathrm{A} \mathrm{v}^3 \left[\frac{1}{2} (1 + \lambda)(1 - \lambda^2)\right] \quad (4)$$

Equation (4) shows that power extracted from the wind is same with the upstream wind power multiplied by the quantity in parenthesis. Therefore, the quantity in the parenthesis is a fraction of the wind power extracted by the turbine blades: it is rotor efficiency and called as Cp.

Rotor efficiency =

$$C_p = \frac{1}{2}(1 + \lambda)(1 - \lambda^2) \quad (5)$$

So that basic connection to the power derived from the rotor becomes:

$$P_b = \frac{1}{2}\rho A v^3 . C_P \quad (6)$$

To determine the maximum rotor efficiency, can be taken from the derivative (5) associated with λ and set it equal to zero:

$$\frac{dC_p}{d\lambda} = \frac{1}{2}[(1 + \lambda)(-2\lambda) + (1 - \lambda^2)] = 0$$
$$= \frac{1}{2}[(1 + \lambda)(-2\lambda) + (1 + \lambda)(1 - \lambda)]$$
$$= \frac{1}{2}(1 + \lambda)(1 - 3\lambda) = 0 \quad (7)$$

Which has solution.

$$\lambda = \frac{vd}{v} = \frac{1}{3} \quad (8)$$

The other word, blade efficiency would be maximized if the wind slow down to a third of the upstream speed without disturbance. If change λ = 1/3 into the equation for the rotor efficiency (5), it is found that the maximum theoretical efficiency of the blade is:

Maximum rotor efficiency

$$= \frac{1}{2}\left(1 + \frac{1}{3}\right)\left(1 - \frac{1}{3^2}\right) = \frac{16}{27}$$
$$= 0.593 = 59.3\%$$

That the maximum theoretical efficiency of the rotor is 59,3%, It is called efficiency betz or betz law [3]

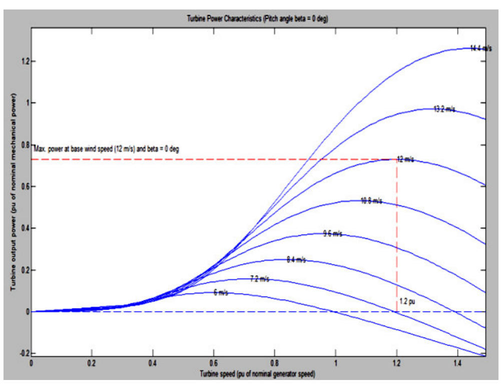


Fig1. Wind turbine characteristic

Operation district of wind turbine has three different points:

1. Cut in wind speed: the lowest wind speed where wind turbine starts to generate electric power.
2. Rated wind speed: wind speed when wind turbine to generate electric power, which is usually maximum power from the wind turbine.
3. Cut-out wind speed : wind speed which can shut and switch off wind turbine, to be protected from mechanical damage.[4]

1) Wind turbine operation mode

There are three modes to control variable speed pitch in wind turbine. Selections of the operating mode depend on the available wind speed and the amount of power is required to supply the load. Three modes:

1. Maximum power point tracking: this mode is used to convert the maximum power from wind, when the low wind speed will follow the value of the power coefficient. Converted mechanical power is :
$$P_m = \frac{1}{2}\rho A C_{p\_max} V^3 \quad (9)$$
2. Blade pitch control: this mode is used when wind speed outside from average value, in this situation the electromagnetic torque is not enough to control the rotor speed, so that generator will overload. To avoid this problem, conversion of the wind turbine power have to be limited and it is done with reduce the power coefficient (Cp) from wind turbine. The power coefficient can be manipulated with varying the blade pitch angle (β)
3. Power regulation: with the increasing number of wind power enter to system, in the operation of the wind turbine is impossible to keep in order that the power result will be constant. Therefore, controlling the voltage and frequency required, so that the product of electric power agree with load demand.[5]

2) *Permanent Magnet Synchronous Generator* (PMSG)

Synchronous Generator with Permanent Magnet (PMSG) can be modeled with equation park transformation. The equation based on the stator current and voltages, such as equation 10,11.

$$v_{sd} = R_s\, i_d + \frac{d\lambda_d}{dt} - \omega_e\, \lambda_d \quad (10)$$

$$v_{sq} = R_s\, i_q + \frac{d\lambda_q}{dt} - \omega_e\, \lambda_q \quad (11)$$

Where :

v_{sd} dan v_{sq} = stator voltage
i_d dan i_q = stator current
R_s = stator coil resistance

Flux at stator can be written as equation 12, 13.

$$\lambda_d = L_{sd} i_d + \lambda_m \quad (12)$$
$$\lambda_q = L_{sq} i_q \quad (13)$$

Where

λ_m = nucleus magnetic flux
L_{sd}dan L_{sq} = stator coil inductance

Torque electric from PMSG can be written as equation 14.

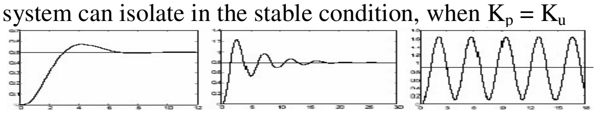
$$T_e = \frac{3}{2}p\ [\lambda_m i_q - (L_{sq} - L_{sd}) i_q\, i_d\,] \quad (14)$$

Where P is amount of pair of pole PMSG.[7]

III. TUNING PID CONTROLLER

A. PID_Ziegler Nichols

PID Control is the system of the combination control between proportional control, integral, and derivative. In this method, reasoning is done in closed prop where input reference is step function (Step). The controlling in this method is just proportional controlling. Kp, is increased from 0 until critical value K_p, so in order to obtain continuous output oscillates with the same amplitude. The critical value Kp called as ultimate gain. The response generated outputs at 3 strengthening proportional conditions are shown on Fig 2. The system can isolate in the stable condition, when $K_p = K_u$



(a) Value Kp = 1. (b) Value Kp : 1< Kp < Ku. (c) Value Kp = Ku.

Fig 2. Output Characteristic of a System With add of Kp.

The values of Period ultimate (Tu) is obtained after system output reach continuous isolated condition. The value of the basic period (Tu) and strengthening basic (Ku) used to determine constants controllers according to the empirical constants Ziegler-Nichols.[5][6]

B. Firefly Algorithm (FA)

Firefly Algorithm is one of algorithms in the Artificial intelligence field. There are two matters and very important in the Firefly Algorithm, that is light intensity and attractive function.

1. Attractive firefly

The level of the Light intensity on the firefly (x) can be seen as : $I(x) = f(x)$ (15)

I value is the level of light intensity on the firefly (x) which is comparable to the solution of the function of problem will be searched *f(x).*

$$\beta(r) = \beta_0 * e(\gamma r^m). \quad (m \geq 1) \quad (16)$$

Attractive β has the relative value, because light intensity have to be seen and assessed by other fireflies. So, the results of assessment will different depend on distance between a firefly and other firefly r ij. Besides, light intensity will go down, because it is absorbed by media, for example air γ [8][9]

2. Distance between firefly

Distance between firefly i and j in the location x, xi and xj can be determined when doing the laying down of point where this firefly is spread randomly in diagram Cartesians with formula :

$$r_{ij} = \sqrt{(x_i - x_j)}^{\,2} + (y_i + y_j) \quad (17)$$

3. The movement of firefly

The movement of the firefly (i) moves to the best light intensity level. It can be seen the following equation:

$$x_i = x_i + \beta_0 * exp(-\gamma r^2{}_{ij}) * (x_j - x_i) + \alpha * (rand - \tfrac{1}{2}) \quad (18)$$

Where the first variable (xi) shows the first position of firefly in the location (x), then the second equation which is consist of variable β_0 = 1.0 This variable is the value of the first attractive firefly, variable (exp) exponential numeral, variable γ = 1.0 is value of the rate of absorption in the firefly around area is air and the last (r ij) is separation variable in the first distance between firefly i and j [9]

IV. DISCUSSION AND ANALYSIS

Wind turbine system has input generator speed, pitch angle, and wind speed. Turbine parameter = Nominal mechanical output power = 200 (w), base power of the electrical generator = 200 /0,9 (VA) base wind speed = 0,73 (PV), base rotation speed = 1.2 (PU) pitch angle beta = 0 (deg), and this pitch angle will be controlled by controller. This PMSG is given stator phase resistance Rs = 0.0018 (ohm), Armature inductance = 0.000835 (H), voltage constant = 400 (V-peak L-L /krpm), Torque constant = 3,308 (N.m/A-peak). In this phase three load active power P is 110(w), nominal phase-to-phase voltage Vn = 400 (Vrms), and nominal frequency fn = 50 (Hz). Design controller can be seen in this Fig 3.

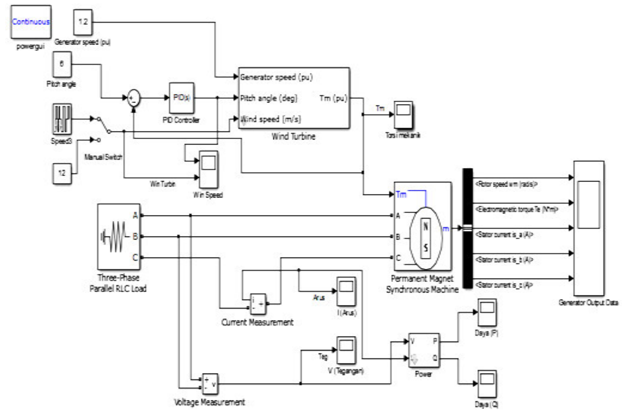


Fig 3. Wind Turbine System

The simulation result from wind turbine uncontrolled, PID, PID Conventional (Ziegler-Nichols) and PID_FA can be seen on this Figs 4,5,6 ,7, 8, 9 and 10. With the value of the base period in the turbine, Tu = 3, and basic strengthening Ku = 12 used to determine constants Ziegler-Nichols Kp = 3 Ku/5 = 7.2, Ki = Tu/2 = 0.6 and Kd = 3 Tu / 25 = 0.144. While the result of the wind turbine with PID controller which in tuning uses FA obtained value K_p = 8.14, K_i = 4.52, K_d = 0.12.

The simulation result can be seen on the table 4.1

	Uncontrolled	PID	PID_ZA	PID_FA
K_p	-	1	7.2	8.14
K_i	-	1	0.6	4.52
K_d	-	0	0.144	0.12

On the input Wind Speed for uncontrolled model, PID, PID_ZN and PID_FA in the Wind Turbine system are all made equal. Can be Shown in the Fig 4.

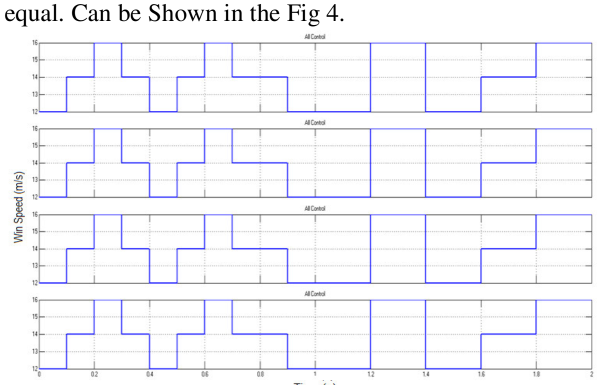


Fig 4. Input Wind Speed

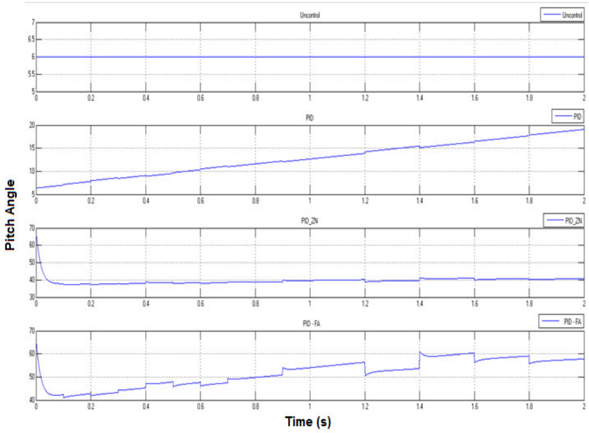


Fig 5. Result of Pitch Angle Simulations

From the result of running obtained the value pitch angle in uncontrolled = 6 (deg) and unchanged although the wind speed change. On the PID pitch angle value = 6.4 – 19.1 (deg), pitch angle PID_ZN = 40 – 40.6 (deg) and pitch angle PID_FA = 44 – 59 (deg).

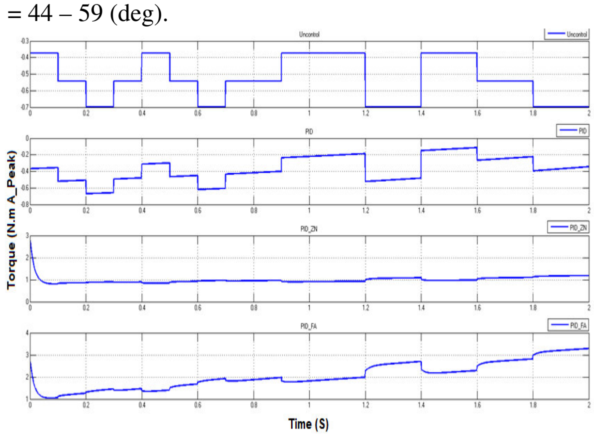


Fig 6. Result of torque mechanical simulation (Tm)

From the result of running program obtained the value of torque in uncontrolled = - 0.7 – (-0.38) Nm A_Peak. On the torque of PID = – 0.62 – (-0.2) Nm A_Peak, torque PID_ZN = 0.8 – 1.2 Nm A_Peak and torque PID_FA = 1.04 –3.28 Nm A_Peak.

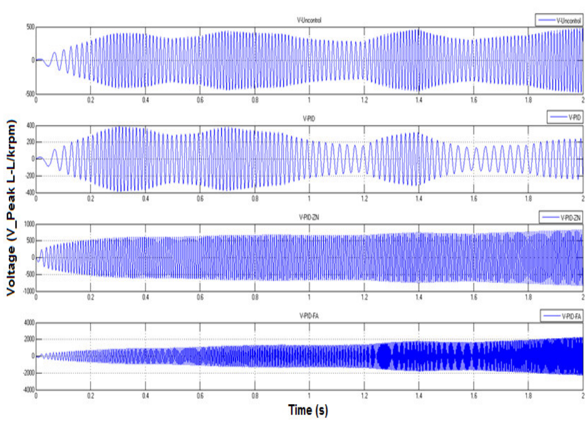


Fig 7. Result of Voltage simulation (V)

From the result of running program obtained the value of Voltage in uncontrolled = 380 V_Peak L-L/krpm. Voltage of PID = 276 V_Peak L-L/krpm, Voltage PID_ZN = 680 V_Peak L-L/krpm and Voltage PID_FA = 1400 V_Peak L-L/krpm

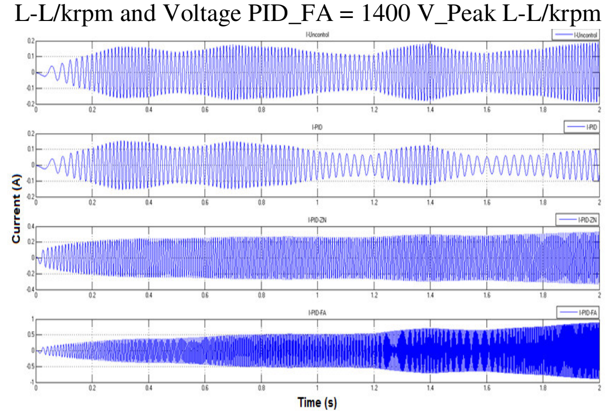


Fig 8. Result of current simulation (I)

From the result of running program obtained the value of Current in uncontrolled = 0.15 A. Current of PID = 0.105 A, Current PID_ZN = 0.3 A and Current PID_FA = 0.8A

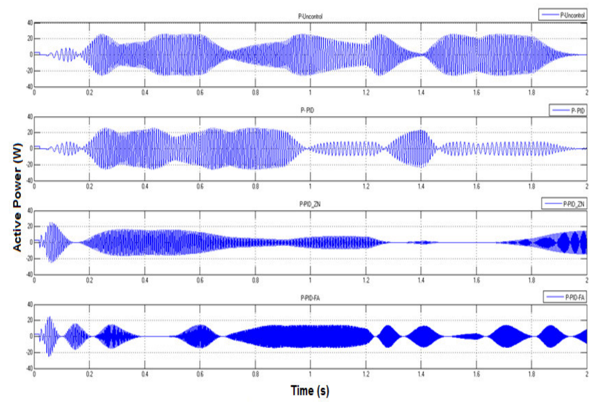


Fig 9. Result of Active Power simulation (W)

From the result of running program obtained the value of Active Power in uncontrolled = 0 – 9 (W). Active Power of PID = 0 – 9 (W), Active Power PID_ZN = 0-25 (W) and Active Power PID_FA = 16 – 25 (W)

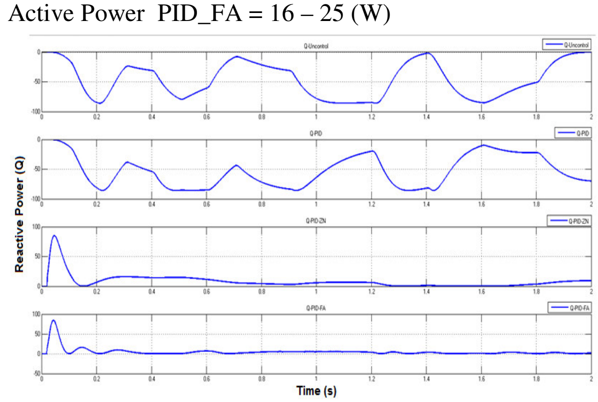


Fig 10. Result of Reactive Power simulation (Q)

From the result of running program obtained the value of Reactive Power in uncontrolled = -86 – 0 (Var). Reactive Power of PID = -86 - 0 (W), Reactive Power PID_ZN = 0-85 (Var) and Reactive Power PID_FA = 0-85 (Var)

V. CONCLUSION

Form the results of simulation program, can be concluded:

1. On the wind turbine system in uncontrolled obtained value torque, voltage, current and power not optimal.
2. On the wind turbine system with PID controller obtained value torque, voltage, current and power less optimal.
3. On the wind turbine system with PID controller Ziegler-Nichols obtained value torque, voltage, current and power more optimal.
4. On the wind turbine system with PID controller which in tuning used FA obtained value torque, voltage, current and power very optimal and stable.

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